QUANTITATIVE AND QUALITATIVE OBSERVATIONS ON FISH FOODS IN WADDELL CREEK LAGOON[1]

P. R. Needham

U. S. Bureau of Fisheries, Stanford University, California

Abstract

Seasonal studies of bottom foods were made in Waddell Creek Lagoon in 1932, 1933, and 1934. Quantitative samples were taken both with an Ekman dredge and a square-foot box. The numbers of organisms per square meter and pounds of food per acre are based on recalculations of results obtained from the unit areas sampled.

The most abundant bottom populations by weight were found in March, and the least in November. Dominant animals were three crustaceans: two amphipods, *Gammarus confervicolis* and *Corophium spinicorne*, and one isopod, *Exosphaeroma oregonensis*. These are brackish water forms and almost completely replace typical fresh-water forms in the inter-tidal areas in Waddell Lagoon. Steelhead trout were found to eat large numbers of *Gammarus*, considerably less of *Exosphaeroma*, while no *Corophium* were found in the stomachs examined. A summary of results is given at the end of the paper.

Description of Waddell Creek

The food studies herein reported were undertaken as a regular part of the program of the California Trout Investigations from 1932 to 1934. Detailed studies of the life history and habits of coastal-stream steelhead trout and silver salmon had been conducted in Waddell Creek, Santa Cruz County, California, since 1932. General observations suggested that lagoons of coastal streams served as good natural rearing ponds for young steelhead trout and silver salmon prior to their migrations into salt water. In fact, lagoons of coastal streams were considered to furnish such excellent nursery and feeding grounds for young trout and salmon that in 1932 the California Division of Fish and Game closed certain lagoons to angling in the summer months to afford greater protection to seaward migrants. More detailed observations seemed desirable to determine the seasonal availability of each major lagoon food, the contribution of each food item by weight compared to numbers of individuals, and the contribution of the various organisms to the diet of trout.[2] A two-way fish counting weir was constructed across Waddell Creek in 1933 about 1.5 miles above its mouth and well above the upper limits of tidewater. The weir furnished the means of counting all upstream migrants and a proportion of downstream migrating salmon and trout. References made in this

[1]published with permission of the Commissioner of Fisheries.

[2]The help of Mr. Francis Sumner, Mr. Elden H. Vestal, and of Mr. Leo Shapovalov in this work is gratefully acknowledged. Thanks are also given to the California Division of Fish and Game and to Emeritus Dean of Engineering, Professor Theodore Hoover of Stanford University, who supplied excellent field laboratory and living quarters on Waddell Creek; to Stanford University for laboratory and library facilities furnished on the Stanford Campus. The help of W.P.A. Project No. 10,533 is also acknowledged.

REPRINTED FROM VOLUME 69 (1939) TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY, INVESTMENT BUILDING, WASHINGTON, D. C. 1940.
Printed in U. S. A.

paper to the movements of those fishes are based on observations made at this weir which was described by Taft (1934 and 1936).

From its upper reaches in the Santa Cruz Mountains, Waddell Creek flows about 15 miles southwest into the Pacific Ocean at a point 22 miles north of Santa Cruz, California. Like other coastal streams, Waddell Creek is subject to extreme seasonal fluctuations. In the dry season of early fall the flow may diminish to as low as 200 gallons per minute (0.45 cubic feet per second), while during the rainy season in late winter and early spring a flow of 224,400 gallons per minute (500 cubic feet per second) is not unusual. The interaction of stream flow, ocean tides, and storms have produced a sandy beach, or bar, which extends for over 3,000 feet across the mouth of the creek where it enters the ocean.

Lagoons offer a highly unstable environment for fish-food organisms. High tide, or waves during storms, may raise the height of the sand bar across the outlet, thereby increasing the depth and size of the lagoon by impounding more water. Conversely, floods often cut down the height of the bar at the ocean so that the normally quiet water of the lagoon is replaced by a swiftly flowing stream. Swift water does but little harm to lagoon populations in the wider, broader lagoon areas. In narrow places, however, washing occurs, and collections taken in such places contained but few animals.

The point of entrance of the water into the ocean often changes. The water usually enters the ocean at the south end of the bar. In a single season, depending upon conditions, it may break through the bar at several different points, each being closed in turn by wave or tidal action. Floods pouring into the lagoon from the stream above usually make the initial break in the bar. The mouth of the lagoon usually does not remain closed more than three or four weeks at a time.

High tides may reverse the normal direction of flow. Thus, aquatic conditions in the lagoon will vary seasonally from pure fresh-water through typical brackish-water lagoon conditions, to nearly pure sea-water conditions. Lagoons contain rather amazing amounts of food when these hazardous life conditions are considered.

The bottom of the lagoon is composed mostly of sand. Some gravel usually is present, as are scattered masses of vegetable and animal debris dropped out by flood waters. Superficially, lagoon bottoms have a barren appearance but this impression is soon dispelled by sampling.

Lagoon Temperatures and Fauna

Fifteen air-temperature readings taken in March and April, 1934, during the course of the bottom sampling operations averaged 57.2°F. Minimum and maximum temperatures were 45°F. to 61.5°F., respectively. Fifteen water-temperature readings, taken at the same time, average 57.5°F. and they ranged between 52°F. minimum and 61.2°F. maximum. On June 30, 1933, a temperature of 74.5°F. was recorded

NOTES ON THE ECOLOGY OF THE MIDGE FAUNA (DIPTERA: TENDIPEDIDAE) OF HUNT CREEK, MONTMORENCY COUNTY, MICHIGAN

La Verne L. Curry[1]
Central Michigan College of Education, Mount Pleasant, Michigan

Although invertebrate organisms inhabiting trout streams have long been recognized as important items of fish food, little is known regarding the genera and species of the true nematocerous midges. In the past, reports covering investigations on Michigan trout streams listed many immature forms of insects identified to genus and species. However, when considering the Tendipedidae (= Chironomidae), the family usually was divided into groups and the individual forms listed numerically. This method was employed because of insufficient knowledge of the taxonomy within the group, especially of immature stages.

During the summer of 1952 a preliminary investigation of the family was conducted along Hunt Creek (T.29 N., R.2.E., Sections 25, 34, 35, 36) Montmorency County, Michigan. The work was undertaken to determine the specific midge fauna of the stream in the vicinity of Hunt Creek Experiment Station, to collect information regarding the morphology and life history of the various species collected, and if possible to obtain data regarding the ecological relationships existing between the various members of the fauna and the stream bottom as determined by the plant associations of the adjacent stream valley.

The portion of stream studied was approximately two miles long and flowed in a general northeasterly direction through state-owned land. The terrain within this section (roughly three square miles) was such that four distinct ecological situations were recognized. They were: beaver dam impoundments; highlands; black spruce-white cedar-tamarack swamp; and sedge-meadow (marsh).

Description of Areas Studied

Hunt Creek holds a unique place among Michigan's smaller trout streams in that the brook trout (*Salvelinus fontinalis fontinalis*) is able to maintain a fairly large population within its waters. The stream is essentially spring-fed, and is not generally subject to flooding unless a beaver dam washes out, or an excessively heavy rain occurs. The stream receives comparatively little runoff water.

Due to the origin of the water within the stream, its temperature remains cold in summer, dropping into the low fifties at night even during the hottest part of the summer. During the winter the stream remains open throughout a major portion of its length in the experimental area. The beaver ponds and portions of Section "A" (Fig. 1) freeze over in winter. Throughout the area trout display a slow growth rate as compared to those from such streams as the Pigeon and north branch of the Au Sable.

The soil of the "highlands" is composed of morainic materials, sand and gravel, while that of the drainage basin is in general thin, light, and poor.

The portion of Hunt Creek flowing within the area of state-owned land has been divided into sections to facilitate the study of creel-census reports. The sections are designated as "Z," "A," "B," "C," and "D" starting at the downstream portion of the controlled area and extending upstream toward the headwaters (Fig. 1). Concrete weirs containing self-cleaning rotary screens have been installed in the stream at the junction of Sections "C" and "D," and at the lower limits of Section "Z". The weirs enable the staff at the station to study the migratory habits of the trout within the stream.

Portions of the stream investigated have been described by Leonard (1940, 1942a, b), Shetter and Leonard (1943), and Shetter, Clark, and Hazzard (1949). For convenience a summary of the four ecological areas is given from these researches. The botton deposits recorded during this investigation are based on Roelof's (1944) classification of lake muds.

The beaver impoundments located in Section "D" (Fig. 1) occurred in the upper reaches of the stream and were bordered by two types of vegetation. The ponds proper were located in the center of a wide sedge-meadow rimmed with a sparse growth of aspen on the higher ground. The ponds were open and had no discernible current even where the stream had narrowed to a width of several feet. Toward the headwaters of the stream the meadow narrowed abruptly and was replaced by a white cedar-tamarack swamp. The bottom deposit of the standing waters within these areas was mainly muck and detritus. Sta-

[1] Contribution from Michigan Institute for Fisheries Research.

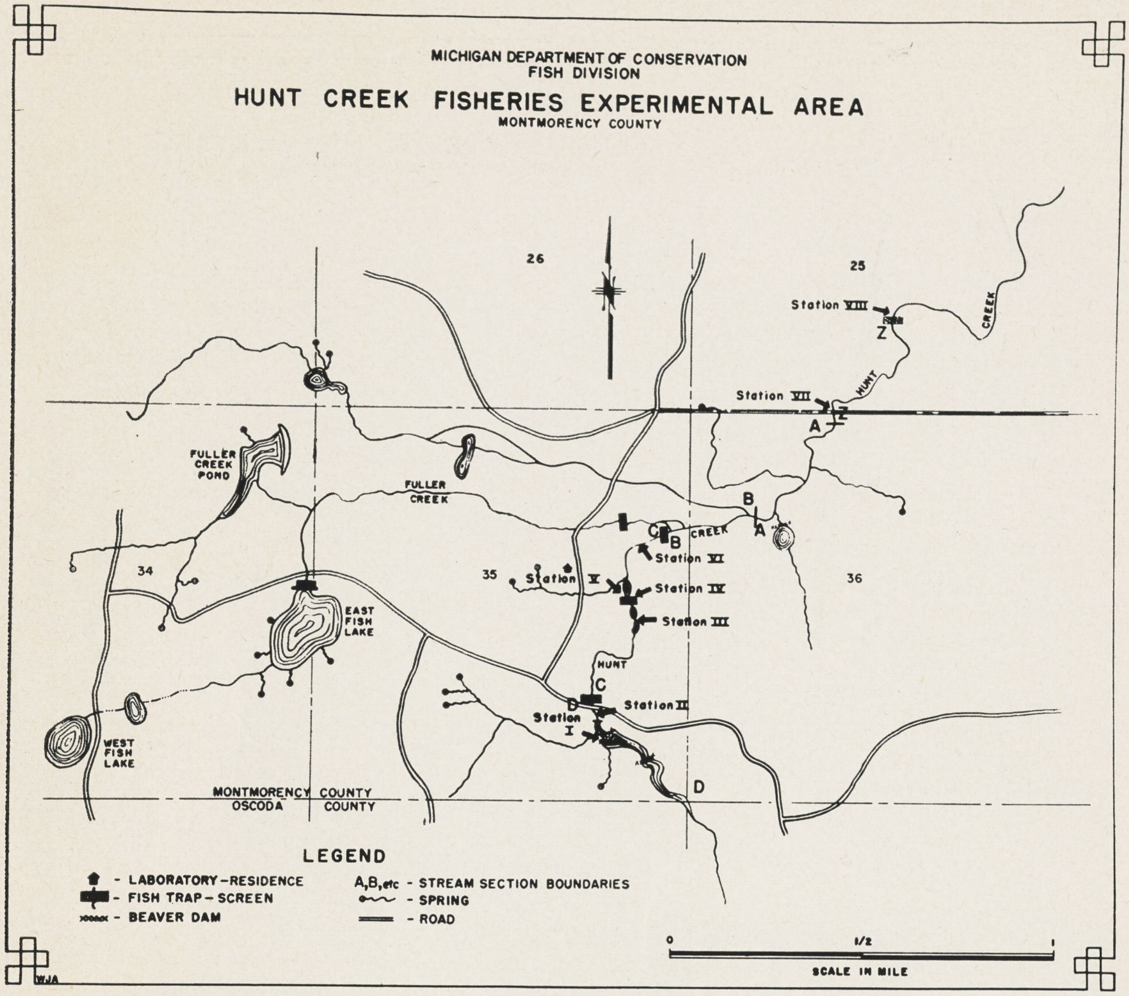


FIG. 1. Map of Hunt Creek experimental area.

tion 1 was established in a pool at the foot of the largest beaver dam (Fig. 1). The dam was approximately 75 feet long and impounded the water above the dam to a depth of about five feet above the water in the stream below. The stream directly below the dam ranged from 15-20 feet in width, narrowing rapidly downstream to about 10 feet. The pool in which Station 1 was established was about 4 feet deep, but, while collections were being made at this site during the fall, the beaver constructed a new dam downstream and increased the depth of water to almost 5 feet.

Station 2 was also established in Section "D" (Fig. 1) directly below an old wooden bulkhead constructed by the CCC as a stream-improvement structure. The stream at this point was typical of that found in the "highlands," being about six feet wide with a swift current and flowing over a clay ledge. Immediately downstream a riffle was formed by rubble and gravel.

The fall of the stream between the C-D and A-Z boundries (Fig. 1) has been estimated to be approximately 25 feet. This gradient imparted a current of 1.5-2.5 feet per second in the upper reaches of Section C. Below Station 2 the stream followed a narrow channel between high, sandy banks supporting a growth of aspen, birch, and balm-of-Gilead. The bottom throughout this area was mainly fine and medium gravel.

Deflectors have been established for stream improvement along the course of the stream (Shetter, Clark, and Hazzard 1949). They were constructed of logs and rough lumber and secured into the bank and stream bottom by piling. Behind these stream improvement devices the bottom differed considerably, being formed of silt and detritus. This change was especially evident where the stream flowed through the marsh and cedar swamp.

The portion of the stream designated as Sec-

EXTRACT FROM PROGRESSIVE FISH CULTURIST
Vol. 18, No. 1, Jan. 1956

A DRAG-TYPE RIFFLE-BOTTOM SAMPLER

Robert L. Usinger and Paul R. Needham
University of California
Berkeley, California

IN THE COURSE OF WORK performed for the California State Water Pollution Control Board in 1953 and 1954, it became necessary to develop a new type of stream-bottom sampler. As this piece of apparatus may be of interest to limnologists and others concerned with stream-bottom sampling, it seems desirable to publish a description of it at this time.

The most serious objection to such sampling devices as those reported by Needham (1928), Surber (1937), Wilding (1940), and Hess (1941), is that their use is restricted to water of depths less than an arm's length. The drag-type sampler (figure 1) was therefore designed to take samples from riffles at any depth. The new sampler is similar in principle to certain marine dredges, but it is much smaller and is adapted in various ways to stream conditions. It was devised in consultation with Dr. G. Dallas Hanna and was made in the instrument shop of the California Academy of Sciences.

Description of the Sampler

The drag-type sampler consists of a rectangular iron box, which operates on either side, with bars on the open face to exclude large rocks and trash. The tines, which dig into the rock and gravel of the bottom, serve the same purpose as the fingers of operators of the shallow-water-type samplers. The current sweeps the organisms into a net, just as in those samplers.

The net bag is removable and can be opened by means of a zipper to take out organisms. The net bag may be made of any strong material. In our tests nylon net or 24-mesh silk bolting cloth was used. Mesh of the latter size is about as fine as can be safely used. The net must permit a good flow of water and at the same time retain minute organisms such as midge larvae and pupae, simuliids, or others. A canvas sleeve is provided to protect the net. Care should be taken at all times to see that the protective skirt covers the net.

Discussion

The new sampler, like others referred to here, will not work in still or very slowly moving water. Sampling can be done from the middle of a riffle, from a prominence on shore, or even from a bridge above a stream. Difficulty was encountered in sampling from high bridges, but this may be overcome by adjusting weights on the sampler and weighting the line several feet in front of the sampler.

Several difficulties have arisen in using the new sampler. One disadvantage is that it will not take satisfactory samples in mud or sand and will not work on bed rock. Another disadvantage is that the net, although protected by a canvas sleeve, tears easily under the rough treatment to which it is inevitably subjected. Sand grains tend to interfere with the action of the zipper, and for this reason it must be rinsed thoroughly after each use. Care must be taken to avoid catching the net with the zipper. In large streams it is not possible to wade very far from the shore because of the depth and swiftness of the water. The only alternative is to take the samples in suitable shallow riffle areas where bottom materials are small enough to permit the tines of the sampler to penetrate and stir up the stones as it is pulled upstream. Obviously, the drag-type sampler--or any sampler, for that matter--cannot be used in stream bottoms where large boulders compose the substrate. The term "large" here refers to stones or boulders larger than a football. Still larger boulders can often be used as platforms from which to pull the sampler.

The type of riffle bottom in which the drag-type sampler works most efficiently is composed of stones smaller than grapefruit with coarse and fine gravel filling the interspaces. In preliminary tests it has been found that the drag-type sampler, when pulled over 10 feet of bottom, takes organisms in numbers and proportions roughly similar to those taken by the square-foot Surber Sampler.

Sampling Technique

The operator drops the sampler into the current, open end upstream, holding it by the bridle and attached rope. If the current is sufficiently swift, it will aid the operator by carrying the sampler downstream in preparation for pulling it the required distance. If the sampling is performed from a bridge and the current is swift, the sampler may not settle properly on the bottom. In this event, the extra weights provided should be fastened to the sampler.

The sampler should always be pulled parallel to and against the direction of flow. Samples cannot be taken with the drag-type sampler crosswise of the current or at right angles to the direction of flow. When the pull is completed, the sampler is lifted from the water with the bridle and placed on some solid object in preparation for removal of the materials collected. The zipper is then opened, the net is turned inside out, and the contents are dumped into a bucket. The resulting sample contains the usual sand, gravel, leaves, and fine stones. The inverted net end is swirled in the solution to dislodge

(Drawing courtesy of the authors)

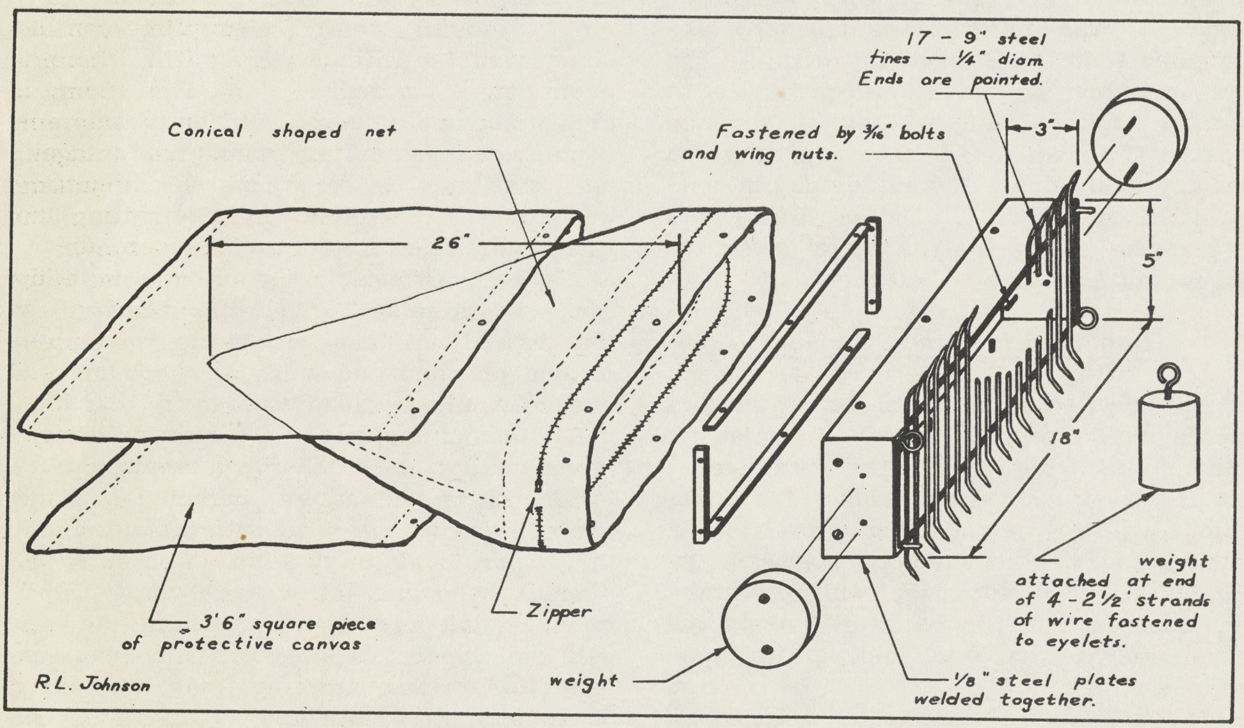


FIGURE 1.--Details of the drag-type sampler.

H I L G A R D I A

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOL. 24 APRIL, 1956 No. 14

VARIABILITY IN THE MACROFAUNA OF A SINGLE RIFFLE IN PROSSER CREEK, CALIFORNIA, AS INDICATED BY THE SURBER SAMPLER[1]

PAUL R. NEEDHAM[2] and ROBERT L. USINGER[3]

INTRODUCTION

In 1954, the authors designed a plan for a periodic biological sampling program of the macrofauna of streams for the California State Water Pollution Control Board.[4] In the course of this study and after review of all pertinent literature dealing with the subject of stream-bottom sampling in its qualitative and quantitative aspects, it became obvious that no thorough study had yet been made of the normal variability expected in a single riffle. This held true for both weights and numbers of each major group of organisms present and also for total wet weight of all animals in the individual samples. Accordingly, it was decided that field tests would be conducted to fill this gap in our knowledge of stream ecology. For the purposes of the test it was decided to use the Surber Square Foot Sampler (Surber, 1936).[5] This sampler has had the widest use of any of the many types devised.

The Surber sampler is used under a great variety of conditions and for various purposes at the present time. For example, it is used to determine stream productivity as a basis for stocking policies for game fish; it is used to study the foods available to trout and other fishes; and it is used as a means of revealing pollution in streams. However, in none of these cases has it been determined whether or not the method yields results which are statistically significant.

The advantages of the Surber sampler are that it is small, light, easy to carry, and secures samples from a definite area of stream bottom. Its chief disadvantages are: 1) it can be used only in depths up to arms' length; 2) it can be used only in running water; and 3) it permits many organisms to escape in swift water because of back currents at the mouth of the net. In addition, the operator finds it difficult to avoid getting organisms from out-

[1] Received for publication June 2, 1955.
[2] Professor of Zoölogy-Fisheries, University of California, Berkeley.
[3] Professor of Entomology and Entomologist in the Experiment Station, Berkeley.
[4] The statistical data from which much of the material presented here was derived are now on file at the office of the State Water Pollution Control Board, Sacramento, California.
[5] See "Literature Cited" for citations, referred to in the text by author and date.

side the square foot frame, since there is no barrier and rocks are almost always disturbed in an effort to set the square frame firmly and evenly on the bottom.

Other types of quantitative samplers are the square foot box sampler (Needham, 1928) the circular square foot sampler (Hess, 1941), dragtype sampler (Usinger and Needham, 1956), and the Ekman (1911) and Peterson (1911) dredges. The latter two types are often used in deep water and soft bottoms. The Peterson is also especially useful for sampling in weed beds.

Still another square foot sampler is the "basket" tray (Wene and Wickliff, 1940). It is a very simple device, but is practical only as a research tool for evaluating the efficiency of other samplers. A square foot of quarter-inch mesh screen with wire-stiffened, upturned margins and small side handles is buried in the bottom of a stream in such a way that the normal stream bottom is restored practically to its original state. This is much easier to do in an intermittent stream when the bed is dry, but is possible in a perennial stream. After a period of time the tray is lifted, and with it the square foot of bottom with all associated organisms.

In spite of its limitations, the Surber sampler was chosen for the Prosser Creek test because it has been used so widely in stream survey work.

Description of the Test

The place selected for the test was a broad and relatively uniform riffle on Prosser Creek near Truckee, California, about one eighth of a mile upstream from the bridge on State Route 89. The riffle was roughly 30 feet wide, and the test area was arbitrarily limited to 100 feet of stream. The bottom was relatively homogeneous, consisting of small gravel and rubble that ranged from particles the size of a pea to stones as large as a grapefruit, intermixed with fine gravel and sand; large rubble was lacking.

The cross-sectional area varied considerably from one side of the stream to the other. On the south side (column 1, fig. 3) the stream bottom "feathered" very gradually to zero depth. On the opposite or north side of the stream where the samples in column 10 were taken, the bank was much steeper, falling away to the deepest and fastest current within a short distance, as shown in figure 1.

Within the sample area 10 vertical columns and 10 horizontal rows were laid out (fig. 1). The resulting checkerboard was then set up as a Latin Square experimental design so that 100 samples could be taken with no one of the five men sampling more than twice in a single column or row. Sampling was started at the downstream row of the riffle in order to avoid disturbance to upstream areas. A stake was driven into the stream bed immediately after taking each sample to mark precisely the point sampled. Two full days were required to take the 100 samples, each man securing 10 samples a day. Ideally, the 100 samples should have been taken simultaneously but this obviously was not possible. The sampling technique is illustrated in figure 2.

The field test was conducted on July 1 and 2, 1953. Both days were sunny with no overcast. The air temperature ranged from 66° to 79° F during the test. Water temperatures ranged from 48° F at 10:00 a.m., July 1, to 58° F at 4:40 p.m., July 2. The pH was 7.1 throughout the test. Shade was not a

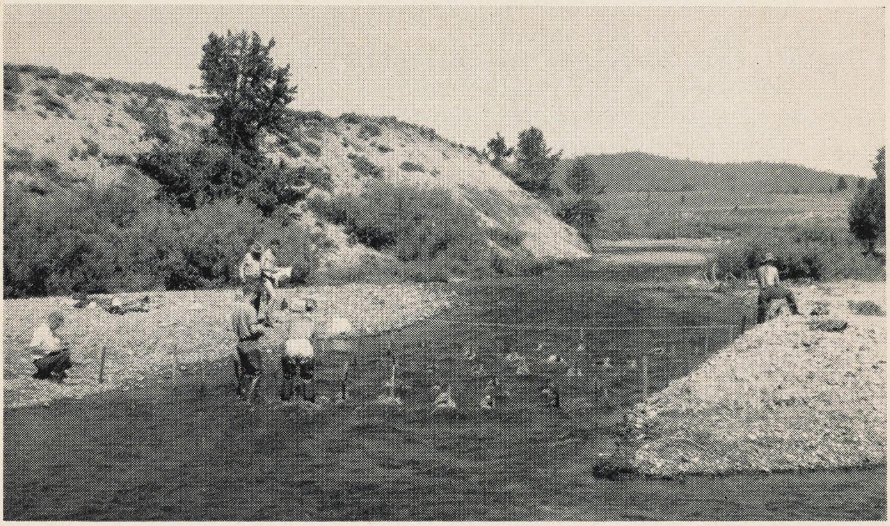


Fig. 1. General view of the test area on Prosser Creek near Truckee, California.

Fig. 2. Sampling technique, using the Surber square foot bottom sampler.

factor since the riffle was fully exposed to the sun's rays without bank vegetation adjacent to the area sampled.

The 100 preserved samples were picked, weighed, counted, and identified in 3 months immediately following the field test. Picking was done with forceps in a white enamel pan. Wet weights were taken by straining off the alcohol, jarring the specimens onto blotting paper, and weighing after 1 minute of drying. Specimens were then sorted according to taxonomic groups —down to the generic level for insects—and counted as they were placed in vials, 1 vial for each genus.

TABLE 1

COMPARISON OF STREAM WIDTHS MEASURED AT ROWS 1, 5, and 10 AT 10:25 A.M. AND 4:40 P.M. ON JULY 2, 1953

Row number	A.M., width in		P.M., width in		Inches increase
	Feet	Inches	Feet	Inches	
1	29	4	30	2	10
5	26	6	27	9	15
10	24	0	24	9	9

Diurnal Fluctuations in Width

Because of alternate freezing and melting of snow at the head of the Prosser Creek basin, the flow increased slightly in the afternoon of each of the 2 sampling days. This is illustrated by comparing morning and afternoon stream width at rows 1, 5, and 10 (table 1). Width increases ranged from 9 to 15 inches at rows 10 and 5, respectively. The greater increase at row 5 can be attributed to the lower gradient of the south bank at that point in the sampling area.

Depths in the Sampling Area

Increased afternoon flows, of course, caused parallel diurnal fluctuations in both depth and current speed. Slight increases in depth are more difficult to detect than increments of width because of the great variability in taking depth measurements. Suffice it to say here that on the gentle sloping south bank (column 1), depths at each of the 10 rows sampled ranged from 2.5 inches to 8.0 inches with an average of 3.0 inches (fig. 3). Because of insufficient current to wash organisms into the bag of the Surber sampler, it was impossible to sample in shallower water. This would have been undesirable, too, for the additional reason that data obtained by sampling areas intermittently flooded and exposed each day would not be comparable to those from permanently watered, deeper areas. The maximum depth recorded for the 100 samples was 17.0 inches. A profile of the stream bed for each column is presented in figure 3.

Current Speeds

Current speeds measured with a Gurley current meter varied from 0.7 of a foot per second at the side of the riffle to 5.27 feet per second in column 6 near the middle of the riffle at the end of the day when, as pointed out above, peak flows occurred (fig. 3).

The rate of flow was also determined by floating a chip down the center of the riffle over the 60 feet of linear distance between rows 1 and 10 and timing it with a stop watch. At 11:10 a.m., on July 2, the rate by the latter method gave a velocity of 5.5 feet per second from the average of 10 tests. At 3:05 p.m. on the same day, a velocity of 5.3 feet per second was determined, or 0.2 feet per second less than that obtained in the morning.

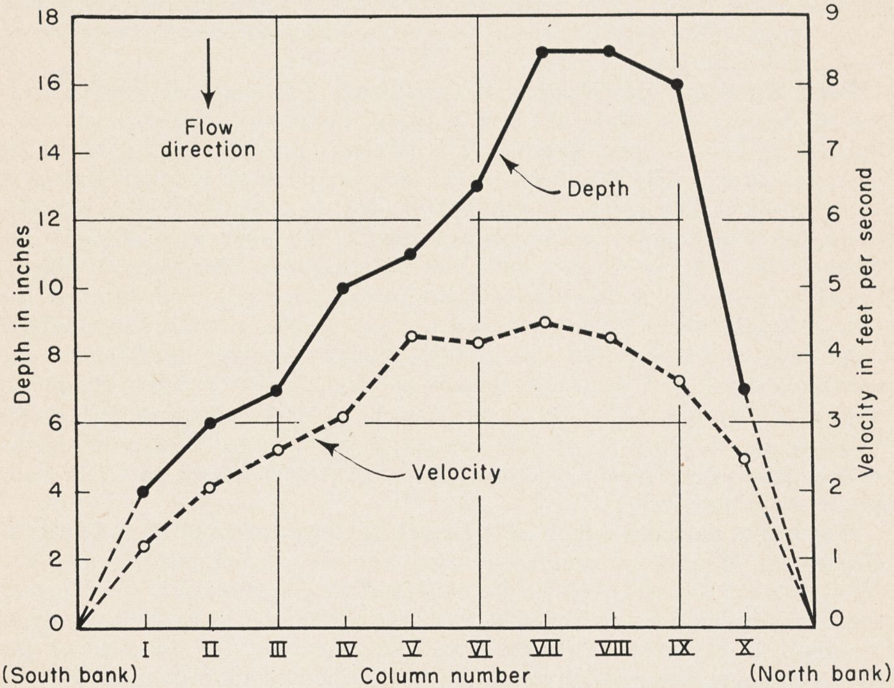


Fig. 3. Water depths and velocities, Prosser Creek, California, recorded across Row 10, July 2, 1953, between 9:45 and 10:45 a.m.

Questions to be Answered

As an aid in interpreting previous stream-sampling data and as a guide to future sampling, an attempt was made to find answers to the following basic questions about a single relatively uniform riffle:

1. How many samples are necessary to give statistically significant (95 per cent level) figures on the total number and weight of organisms present?
2. How many samples must be taken to insure getting at least one of each of the groups of organisms present in a single riffle?
3. How much individual variation is there between persons taking the samples?
4. What correlations, if any, exist between types of organisms and the ecological factors of width, depth, speed of current, and type of bottom?

Results

Data on wet weights in grams, total numbers of organisms, depths, and persons who took the samples are given in table 2. The initials of operators stand for Weidlein, Usinger, Jones, Brock, and Helm. Table 2 also shows the Latin Square design with vertical columns and horizontal rows. The direction of flow is from row 1 to row 10. Samples were numbered consecutively from 1 to 100 as taken, beginning with the lower lefthand corner and proceeding across to the lower righthand corner, then back to the left side in row 9 and across to the right, *et cetera.* (See table 3 for detailed counts according to numbered samples.)

Total Numbers and Weights of Organisms. The statistical analyses revealed that for the whole test, 194 samples would be required to give significant figures on total weights of organisms, and 73 samples would be necessary to give significant figures on total numbers at a 95 per cent level of significance. The greater variability of weights of the individual samples compared with numbers is further indicated by the coefficients of variation. These were 0.78 for weights and 0.56 for numbers. Obviously no fishery biologist, ecologist, or other investigator would have either the time or the energy to take 194 or 73 samples from any given riffle. We then can conclude from these data that purely quantitative routine sampling in streams to determine weights and numerical data is impractical. Wet weights ranged in variation from a low of 0.015 gram (sample no. 8) to a high of 2.31 grams (sample no. 95) with an overall average of 0.575 gram. Total numbers in each sample varied from 2 (sample no. 8) to 198 (sample no. 44). The average number was 75.7.

Number of Samples Required to Insure Representation of Each Group of Organisms. While total weights of organisms showed tremendous variation, the frequency of occurrence of the abundant or common kinds or groups of organisms was much less variable. For this reason and because weighing of a sample is far more laborious than counting, only the numbers of the common genera were used in the course of the detailed analysis of the Prosser Creek results. Total counts for each genus (or higher group) in each sample are given in table 3. For purposes of this analysis, groups of organisms which were represented by very low densities were excluded. A list of the common groups is given in table 4, together with the approximate number of samples required to insure getting at least 1 representative of each group.

The groups for which small numbers of samples are required, all belonging to the Plecoptera, Ephemeroptera, Trichoptera, and Diptera, were represented by large numbers of organisms and were therefore appropriate for statistical analysis. Of these, only the Plecoptera genera *Isogenus, Isoperla,* and *Alloperla* followed a Poisson distribution. The lack of fit of the other groups merely requires that the binomial distribution be applied. In table 4 a collective figure is given for the whole order after the genera contained in the order.

Sample calculations are given below for both Poisson (*Alloperla*) and binomial (*Brachycentrus*) distributions. In both cases it is assumed that there was complete independence of samples.

TABLE 2
LATIN SQUARE DESIGN OF THE PROSSER CREEK TEST*

Rows	Columns									
	I	II	III	IV	V	VI	VII	VIII	IX	X
1	.34 82 3″ W	.94 135 8″ U	1.10 163 12″ J	.49 63 12.5″ B	2.31 163 11″ H	.36 65 14.5″ W	.60 57 14″ U	.48 74 6″ J	.22 53 9.5″ B	.46 84 9″ H
2	.42 114 4″ U	.20 41 6″ J	.41 44 8″ B	1.36 141 10″ H	.51 54 13.5″ W	.35 42 14″ U	1.10 140 13″ J	.48 57 11.5″ B	1.01 144 11″ H	.11 29 10″ W
3	.34 64 4″ J	.43 58 7″ B	.81 115 12″ H	1.44 156 13″ W	.37 53 14″ U	.39 31 17″ J	.20 33 15″ B	.60 74 12″ H	.22 33 13″ W	.16 37 7″ U
4	.20 95 3.5″ B	.67 95 8.5″ H	1.51 168 14″ W	.48 61 14″ U	.37 45 17″ J	.59 55 16.5″ B	1.05 132 15.5″ H	.24 34 14″ W	.25 52 9″ U	.21 45 7.5″ J
5	.44 76 3.5″ H	.41 75 9.5″ W	.67 72 14″ U	.74 89 14″ J	.64 80 15″ B	1.23 110 15.5″ H	1.13 92 16″ W	.31 60 13″ U	.37 66 10″ J	.37 59 6.5″ B
6	.36 81 8″ W	1.19 139 7″ U	.41 62 11″ J	1.12 146 10″ B	.87 100 18″ H	1.32 135 14″ W	.71 58 15″ U	.42 49 15″ J	.06 18 9.5″ B	.29 53 7″ H
7	.57 119 3″ U	.52 78 6.5″ J	.58 73 8″ B	1.8 198 12″ H	.86 93 14″ W	.47 56 14″ U	.26 32 16.5″ J	.09 24 14.5″ B	.22 47 13″ H	.23 52 8.5″ W
8	.46 128 3.5″ J	.91 131 6″ B	1.17 188 10″ H	.85 84 13″ W	1.16 95 12″ U	.50 42 15.5″ J	.15 23 20″ B	.35 47 20″ H	.15 31 15″ W	.24 54 6″ U
9	.37 72 3.5″ B	.64 129 6.5″ H	1.07 124 9.0″ W	.72 89 11.0″ U	.31 32 14″ J	.72 69 14″ B	.94 75 16″ H	.20 29 16″ W	.065 12 11″ U	.20 43 6″ J
10	.30 70 2.5″ H	1.09 73 3.5″ W	.36 73 6.0″ U	.90 87 9.0″ J	.19 27 10.0″ B	.65 94 13.0″ H	.08 17. 17.5″ W	.015 2 18.0″ U	.16 28 17.0″ J	.16 28 9.5″ B

S. Bank — N. Bank

Direction of Flow ↓

* In each square from top to bottom is given, in order, the wet weight in grams of organisms, the number of organisms, depth, and initial of the person who took the sample.

TABLE 3
ORIGINAL DATA ARRANGED ACCORDING TO SEQUENCES OF SAMPLES IN THE LATIN SQUARE EXPERIMENTAL DESIGN

Genera (or higher groups)	Sample																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Nematodes	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
Oligochaetes	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..
Hydracarina	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1
Alloperla	4	4	1	..	1	3	..	..	1	1	2	1	2	2	..	2	2	..	..	4	8	..	2
Isogenus	1	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	1	..	..	..	..	..	5
Nemoura	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
Isoperla	1	..	..	1	..	1	..	..	..	..	1	..	..	..	..	..	2	..	..	1	3	..	..
Arcynopteryx	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Baetis	..	2	2	3	1	6	2	..	2	2	..	9	3	5	2	3	2	..	..	4	6	5	4
Ameletus	3	..	1	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	4	..	..
Cinygmula	25	15	20	13	4	5	..	..	1	11	19	37	20	13	3	1	1	1	3	11	25	18	37
Rhithrogena	..	3	5	5	2	36	1	..	2	..	1	6	3	10	3	14	27	4	3	6	1	1	4
Iron	..	6	9	11	3	7	6	..	15	1	6	4	6	6	3	1	9	..	1	3	16	6	12
Ephemerella	16	17	16	8	3	11	1	1	1	5	19	38	25	9	4	5	9	4	1	8	13	23	43
Paraleptophlebia	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Sericostoma	1	..	..	..	..	..	1	1	..	..	..	..	..	1	..	..	..	1	..	..	1	..	..
Glossosoma	..	3	9	44	9	13	..	..	..	..	2	7	28	22	7	33	12	14	1	..	..	53	32
Hydropsyche	2	3	3	..	..	..	..	..	..	..	..	7	2	..	..	..	..	..	..	1	3	..	3
Brachycentrus	1	2	4	..	1	1	2	..	1	..	..	4	9	..	..	..	1	..	..	1	..	2	6
Lepidostoma	12	2	..	1	..	2	..	..	..	2	8	4	10	2	1	1	2	..	..	1	17	3	14
Rhyacophila	..	..	..	..	..	..	..	..	..	..	..	..	2	1	2	..	..	..	..	..	2	2	2
Neophylax	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..
Limnephilus	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
Limnephilidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dytiscidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Helophorus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Elmus	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..	1	..	..	..	1	2	..
Psephenidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Simuliidae	..	1	1	1	1	5	3	..	1	2	..	1	2	3	..	..	3	2	1	1	1	2	6
Heleidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	..	..
Chironomidae	..	6	1	..	..	..	..	..	2	..	3	3	5	8	4	6	2	2	1	1	10	9	13
Limnophila	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..
Erioptera	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..
Hexatoma	2	4	..	..	..	..	..	..	..	..	7	1	1	..	1	1	..	..	..	..	10	1	..
Eriocera	..	2	..	..	..	..	..	..	..	..	1	..	3	2	..	..	..	..	..	..	..	..	..
Blepharoceridae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Antocha	..	1	..	..	..	..	..	..	..	..	..	..	..	1	..	1	1	..	..	..	..	..	..
Tabanidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Tipulidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Nostoc Chironomidae	..	..	..	..	..	..	..	..	..	..	..	4	..	..	..	..	..	..	..	..	..	..	5
Pericoma	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dolichopodidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..
Rhagionidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cyclorrhapha	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Numbers

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
..	..	2	..	..	..	..	1	1	..	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	1	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	2	..	..	1	1	3	..	..	1	2	..	1	..	2	5	..	3	1	..	1	..	..	3	..	4
..	..	..	1	..	..	1	..	..	1	..	1	..	..	1	..	..	1	..	1	..	1	..	..	1	..	..
..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1	..	..	..	..	..	1	..	1	..
..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3	2	1	2	..	3	8	3	3	1	3	1	1	..	..	2	4	2	2	..	2	3	1	1	2	..	4
..	..	..	..	..	..	..	2	1	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
4	4	1	2	12	4	..	25	12	12	30	1	2	..	4	8	18	15	29	12	5	4	1	1	1	2	8
2	9	8	9	23	10	18	..	..	..	5	9	6	6	6	9	3	2	2	1	5	26	5	15	11	6	6
6	21	9	2	1	3	3	6	6	2	10	7	15	2	..	2	5	6	9	3	13	12	8	9	3	4	15
12	12	6	1	5	5	10	34	16	10	25	7	8	1	2	12	6	24	26	14	10	15	7	4	3	..	9
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..
..	..	..	2	..	..	1	..	..	..	..	1	..	..	1	2	1	..	..	..	1	..	..	..	..	..	..
48	35	7	2	1	..	..	1	19	40	106	50	18	15	4	1	..	2	54	26	84	20	94	17	17	..	..
..	1	..	..	..	..	3	3	5	..	..	..	..	..	..	..	3	2	5	..	..	2	1	..	..	..	2
..	1	..	..	1	2	2	12	2	1	1	..	1	..	1	1	2	4	8	2	2	1	..	..	..	1	2
..	..	..	..	..	..	1	3	8	..	..	..	..	..	..	1	3	9	6	3	3	4	..	1	1	..	1
..	..	..	..	..	..	..	..	..	2	1	..	..	..	..	..	..	..	2	..	1	..	3	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	..	..	..	..	..	1	..	..	..	..
..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	1	..	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3	3	2	..	1	..	1	..	..	2	3	6	3	3	5	2	..	..	..	..	5	..	4	3	2	2	..
..	..	..	..	..	..	..	10	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1	..	..	..	..
5	3	2	1	...	1	4	10	2	1	7	5	1	3	..	3	1	3	6	3	8	7	5	5	4	1	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	4	1	..	..	..	..	..	..	..	..	7	3	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1	..	1	..	..	..	1	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	1	3	1	1	..	1	..	1
..	..	..	..	1	..	..	..	..	..	..	..	1	..	..	..	..	1	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	1	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	2	..	..	1	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE 3
(Concluded)

Genera or higher groups)	Sample																					
	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
Nematodes	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..
Oligochaetes	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Hydracarina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
Alloperla	3	1	..	1	3	3	2	1	2	2	5	..	4	1	2	1	3	1	1	2	6	1	2
Isogenus	..	..	..	..	..	..	..	1	1	..	..	1	..	1	..	..	1	..	..	1	..	..	2
Nemoura	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Isoperla	..	..	..	..	..	..	..	1	..	..	2	1	..	..	..	..	..	..	2	2	..	..	..
Arcynopteryx	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Baetis	..	..	1	1	2	2	1	3	6	2	..	2	6	3	..	..	4	2	3	1	..	1	..
Ameletus	17	..	..	..	..	1	..	..	..	..	4	..	..	..	..	..	..	..	..	..	..	..	..
Cinygmula	8	17	3	3	5	5	2	4	6	9	..	11	10	3	1	1	16	4	9	9	10	12	19
Rhithrogena	..	..	1	2	9	17	12	5	12	4	..	..	7	9	7	6	25	5	17	7	..	3	7
Iron	1	4	..	2	5	18	3	..	3	16	2	2	19	6	1	1	19	3	4	6	3	..	2
Ephemerella	3	10	9	3	12	8	5	11	17	7	9	33	21	5	2	..	9	7	4	7	10	8	26
Paraleptophlebia	1	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	1	..
Sericostoma	2	..	..	2	..	1	.	2	..	1	3	..	..	..	..	1	..	1	..	..	1	..	2
Glossosoma	..	21	47	56	28	42	54	3	3	..	1	33	74	17	30	39	37	7	1	..	1	19	34
Hydropsyche	..	1	..	..	1	..	..	..	1	..	..	2	1	..	..	1	1	..	..	3	1	..	2
Brachycentrus	..	3	..	1	2	..	..	4	..	1	..	1	..	2	..	..	1	..	1	1	2	6	..
Lepidostoma	12	1	2	3	1	1	..	10	..	2	9	1	4	..	..	..	1	..	1	2	8	3	7
Rhyacophila	..	..	1	..	1	1	..	1	..	..	..	..	2	1	..	..	1	..	..	..	1	..	..
Neophylax	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Limnephilus	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Limnephilidae	..	1	..	..	..	..	..	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..
Dytiscidae	..	..	..	..	1	..	..	..	..	..	2	..	..	1	..	..	..	..	..	..	..	..	..
Helophorus	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
Elmus	..	..	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Psephenidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Simuliidae	..	1	1	3	2	4	3	8	7	5	1	..	5	3	..	2	5	..	6	1	..	1	3
Heleidae	2	1	..	..	..	..	..	..	..	2	8	..	..	..	..	..	..	..	..	..	..	..	..
Chironomidae	17	10	5	12	1	5	9	2	6	6	21	5	7	2	3	3	8	3	3	3	13	1	7
Limnophila	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Erioptera	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Hexatoma	5	4	1	..	..	..	..	..	..	..	15	1	2	..	..	..	..	..	..	..	4	1	..
Eriocera	2	..	..	..	..	..	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..
Blepharoceridae	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	..	..	..	..	..
Antocha	..	..	..	..	1	..	..	..	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..
Tabanidae	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..
Tipulidae	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..
Nostoc Chironomidae	..	..	..	..	5	..	..	1	..	..	6	..	..	6	..	..	..	1	..	..	..	1	..
Pericoma	..	..	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..
Dolichopodidae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rhagionidae	..	..	..	..	..	..	..	1	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..
Cyclorrhapha	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Numbers

74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4	1	..	2	3	2	5	6	4	..	..	2	1	..	..	..	1	4	3	3	1	..	1	..	..	3	4
..	..	..	..	2	..	..	3	1	1	..	..	..	..	..	1	..	..	2	..	..	..	..	..	..	..	2
..	..	..	..	1	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	2	1	..	..	1	..	..	1	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
7	5	2	1	12	1	2	3	1	1	2	4	1	4	1	4	..	1	2	..	2	4	3	1	4	..	4
1	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
8	5	..	2	12	3	7	28	10	6	7	3	1	2	4	9	3	25	22	13	..	10	..	2	1	9	24
18	10	6	5	10	7	5	..	1	6	5	11	14	5	20	5	7	..	4	4	6	34	14	5	10	17	11
11	4	..	5	7	3	7	9	..	6	29	4	4	33	3	7	3	8	21	26	7	33	10	13	8	3	8
21	7	1	..	3	3	4	20	7	6	15	7	6	16	3	20	6	7	15	27	5	10	5	7	8	14	14
..	..	..	..	1	..	..	..	1	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..
1	..	..	..	2	1	..	2	..	..	..	2	1	..	1	1	..	..	1	1	2	2	..	1	..	..	1
47	9	16	7	10	5	1	2	8	13	59	15	4	59	18	8	..	5	45	22	27	55	7	18	14	1	..
1	..	..	..	4	1	..	1	..	1	1	..	..	1	..	..	..	..	2	2	2	..	..	..	1	1	1
7	..	..	..	..	..	..	1	3	..	2	..	..	1	..	3	..	7	3	4	2	3	1	..	10	..	6
7	1	1	1	2	..	1	8	3	3	3	1	2	4	2	6	..	10	7	2	..	3	..	..	..	1	3
..	1	1	..	..	..	..	..	..	..	1	1	..	2	..	2	..	..	1	2	1	..	..	..	1	..	2
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	1	..	1	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
6	..	..	4	1	3	2	1	..	..	6	2	1	3	1	71	5	2	1	48	1	1	19	3	5	3	2
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..
11	9	3	5	3	2	2	27	1	..	7	..	4	3	4	6	2	6	3	7	4	4	3	4	9	..	2
..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..	1	..	..	1	..	..	1	..
..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	1	..	..	2	..	..	..	..	..	..	1	..	1	1	1	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1	..	..	..	..	1	..	..	..	..	..	..	3	4	..	..	..	..	2	..	1	..	..	..	..	..	..
2	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	1	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..

Alloperla (Assume a Poisson distribution with n independent trials.)

λ = mean number of organisms per sample

$\hat{\lambda}$ = observed mean = 1.54

P (the probability that all n cells will be empty) =

$$e^{-n\hat{\lambda}} \leq .05$$

$$n \geq \frac{\log_\epsilon .05}{-\hat{\lambda}} = \frac{-2.99573}{-1.54}$$

$$= 1.95$$

$$\text{or } n = 2$$

Brachycentrus (Assume a binomial distribution, i.e., n independent samples each with the same probability (p) of having at least one representative in it.)

$\hat{p}$ (observed proportion of samples with at least one) = .58

$1 - \hat{p}$ = (proportion of samples without *Brachycentrus*) = .42

P (the probability that all n cells will be empty) =

$$(1 - \hat{p})^n \leq .05$$

$$n \geq \frac{\log_\epsilon .05}{\log_\epsilon (1 - \hat{p})} = \frac{-2.99573}{-.86750}$$

$$= 3.45$$

$$\text{or } n = 4$$

From the figures in table 4 it is clear that 2 or 3 samples would be sufficient to insure (at the 95 per cent level of significance) that at least 1 representative of each of the commonest genera of bottom-dwelling insects would be present. At the ordinal level the required number of samples drops to 1 or 2. In general the numbers for individual columns fall within the above ranges but some are higher and some lower.

Personal Bias in Sampling. Data from four of the five samplers showed no significant differences. The fifth person showed a consistent bias which amounted to the equivalent of sampling 1.57 times the area covered by the other samplers. Presumably he did not follow directions, but consistently included rocks outside of the square foot outlined by the frame of the Surber sampler. The fact that four persons obtained such parallel results indicates that it is not necessary to have the same man take every sample. On the other hand, the deviation by one sampler clearly demonstrates the necessity for adequate training in sampling techniques. A correction factor was used to reduce both weights and numbers to the corresponding norm obtained by the other four samplers.

Row and Column Effects. Analysis of the data on total numbers and weights revealed no significant row effects. The differences between row means could be attributable to chance variation. Column effects, however, were highly significant. Even when depth and velocity effects were taken out to a first approximation (linear or a grouping) there still remained significant differences between column means. The biological reasons for the cross-sectional distribution of various genera presented in figures 4 to 22 are not known. One explanation might be that most aquatic organisms (note *Rhithrogena,* figure 10, and *Glossosoma,* figure 14, for striking exceptions) find conditions more to their liking in shallow water, where the velocity of flow is slower and general living conditions less rigorous, than in deeper, faster water. Needham (1928), in discussing the distribution of bottom foods in terms of stream width, found a general decrease of 11.9 per cent by weight from shorelines to midchannels of streams over 18 feet wide. Leger (1910) indicated a decrease of 50 per cent in food organisms from the shoreline to midchannels of streams over 5 meters wide. The latter work was done in the streams of southern France.

Correlation Between Types of Organisms, Depth, and Velocity. Striking correlations were found with depth and speed of current. Depth and velocity followed a similar pattern, being lowest in column 1, building up gradually to a peak in columns 7 and 8, and dropping off rapidly to column 10.

TABLE 4

NUMBER OF SAMPLES REQUIRED TO BE REASONABLY SURE (95 PER CENT) THAT AT LEAST ONE OF A GROUP OF ORGANISMS IS PRESENT

Organisms	Number samples required
Alloperla	2 – 3
Isogenus	10 – 15
Isoperla	12 – 17
PLECOPTERA	2
Baetis	2 – 3
Cinygmula	2
Rhithrogena	2
Iron	2
Ephemerella	2
EPHEMEROPTERA	1 – 2
Glossosoma	2 – 3
Hydropsyche	6 – 9
Brachycentrus	4 – 5
Lepidostoma	3 – 4
Rhyacophila	9 – 13
TRICHOPTERA	1
Simuliidae	3
Chironomidae	2
DIPTERA	1

Rhithrogena (fig. 10) followed this pattern exactly, indicating a definite preference for deep, fast-flowing water. On the other hand, *Alloperla* (fig. 4), *Isoperla* (fig. 6), *Cinygmula* (fig. 9), *Ephemerella* (fig. 12), *Hydropsyche* (fig. 15), *Rhyacophila* (fig. 18), *Brachycentrus* (fig. 16), and *Lepidostoma* (fig. 17) showed almost exactly opposite patterns with higher numbers in the shallower, slower water and lower numbers in the deep, swift waters of columns 6 and 7. The remaining genera did not show consistent trends in their distributional patterns.

Members of the order *Trichoptera* present a special problem in quantitative sampling of stream beds because some genera are free living whereas others are case-bearers. The question here is how many samples would be required for an investigator to be reasonably sure of getting at least 1 of the case-bearing forms as compared with the number required to get at least 1 of the free-living larvae? The figures for the Prosser Creek test are: 2 samples for the case-bearers and 6 to 13 samples for the free-living forms.

Conclusions

The Prosser Creek test showed conclusively that an excessive number of samples would be required to provide significant data on total weights and total numbers of bottom organisms. As noted above, the figure for total numbers was 73, and this was for a single, relatively uniform riffle. Such a conclusion is not surprising, although the figure is higher than most limnologists would have guessed. These results indicate that existing data on stream productivity must be used with caution. However, they also show that only 2 square foot samples are necessary to be reasonably certain of obtaining representatives of the principal groups of organisms present. This is important in connection with stream-pollution surveys, where the total spectrum of groups of organisms is more significant than total weights or numbers (Patrick, 1949).

Summary

1. Using the Latin Square experimental design, 100 bottom samples of macrofauna were taken in a single riffle in Prosser Creek near Truckee, Nevada County, California, with the Surber Square Foot Sampler, on July 1 and 2, 1953.

2. The samples were preserved in 70 per cent alcohol in the field, after which the organisms were sorted from the trash, and total wet weights of each determined. Sorting and counting were carried to the generic level where possible.

3. Actual wet weights varied from a low of 0.015 gram to a high of 2.31 grams and averaged 0.575 gram of organisms. Numbers varied from 2 to 198 and averaged 75.7 per sample.

4. Statistical analyses of the data revealed that 194 samples would be required to give significant figures (95 per cent level of confidence) as to total wet weight of organisms, and 73 samples would be necessary to give significant figures as to total numbers. The coefficients of variation were 0.78 for weights and 0.56 for numbers.

5. It was found that 2 or 3 samples of the commonest genera of *Plecoptera, Ephemeroptera, Trichoptera,* and *Diptera* would be sufficient to insure that at least 1 representative of each would be present.

6. Consistent results were obtained by four of the five persons who took the 100 samples; therefore, with proper training, it is unnecessary to have the same man take every sample.

7. No correlation was found with type of bottom but striking correlations were observed with depth and speed of current.

8. The bulk of genera of aquatic insects indicated a definite preference for shallower, slower water although some, such as the beautifully streamlined *Rhithrogena,* preferred the deepest, swiftest water.

Acknowledgments

The Prosser Creek test was financed by the California State Water Pollution Control Board through the California Department of Fish and Game. Mr. Vinton Bacon of the former agency and Mr. Robert Paul of the latter, were especially helpful in all phases of the program. For aid in taking the test samples in Prosser Creek and in sorting and identifying the organisms, we wish to thank Mr. Elbert Brock, Mr. Albert C. Jones, Mr. Donald Weidlein, and Mr. Lawrence Helm. Mr. Richard Gard assisted in statistical analyses of the data. We are especially indebted to Dr. Evelyn Fix of the Statistical Laboratory of the University of California for her labors on helping design the Prosser Creek test and for her quantitative analysis of the data. Mr. Charles Warren, now Assistant Professor of Fishery Biology at Oregon State College, also gave help in setting up the statistical design for the Prosser Creek test.

LITERATURE CITED

Ekman, S.
1911. Neue Apparate zur Qualitativen and Quantitativen Erforschung der Bodenfauna der Seen. Internatl. Rev. Hydrobiol. 7:164–204.

Hess, A. D.
1941. New limnological sampling equipment. Limnological Society of America, Special Publication no. 6, 5 pp.

Leger, L.
1910. Principes de la Methods Rationelle du Peuplement des Cours d'eau a Salmonides. Travaux du Laboratoire de Pisciculture de L'Université de Grenoble, Fascicle 1, p. 531.

Needham, P. R.
1928. A quantitative study of the fish food supply in selected areas. A Biological Survey of the Oswego River System, N. Y State Cons. Dept. Suppl. to 17th. Ann. Rpt. (1927), pp. 192–206.

Patrick, Ruth
1949. A proposed biological measure of stream conditions, based on a survey of the Conestoga Basin, Lancaster County, Pennsylvania. Acad. Nat. Sci. Phila. Proc. 100:283–341.

Peterson, C. G. J.
1911. Valuation of the sea. I. Danish Biol. Sta. Rpt. I, vol. 20:1–76.

Surber, Eugene W.
1936. Rainbow trout and bottom fauna production in one mile of stream. Amer. Fisheries Soc. Trans. 66:193–202.

Usinger, R. L., and P. R. Needham
1956. A drag-type riffle bottom sampler. *The Progressive Fish-Culturist,* U. S. Fish and Wildlife Service, Washington, D.C., 18:42–44.

Wene, G., and E. L. Wickliff
1940. "Basket" method of bottom sampling. Canadian Ent. 72:131–35.

4m-2,'56(B3222)MH

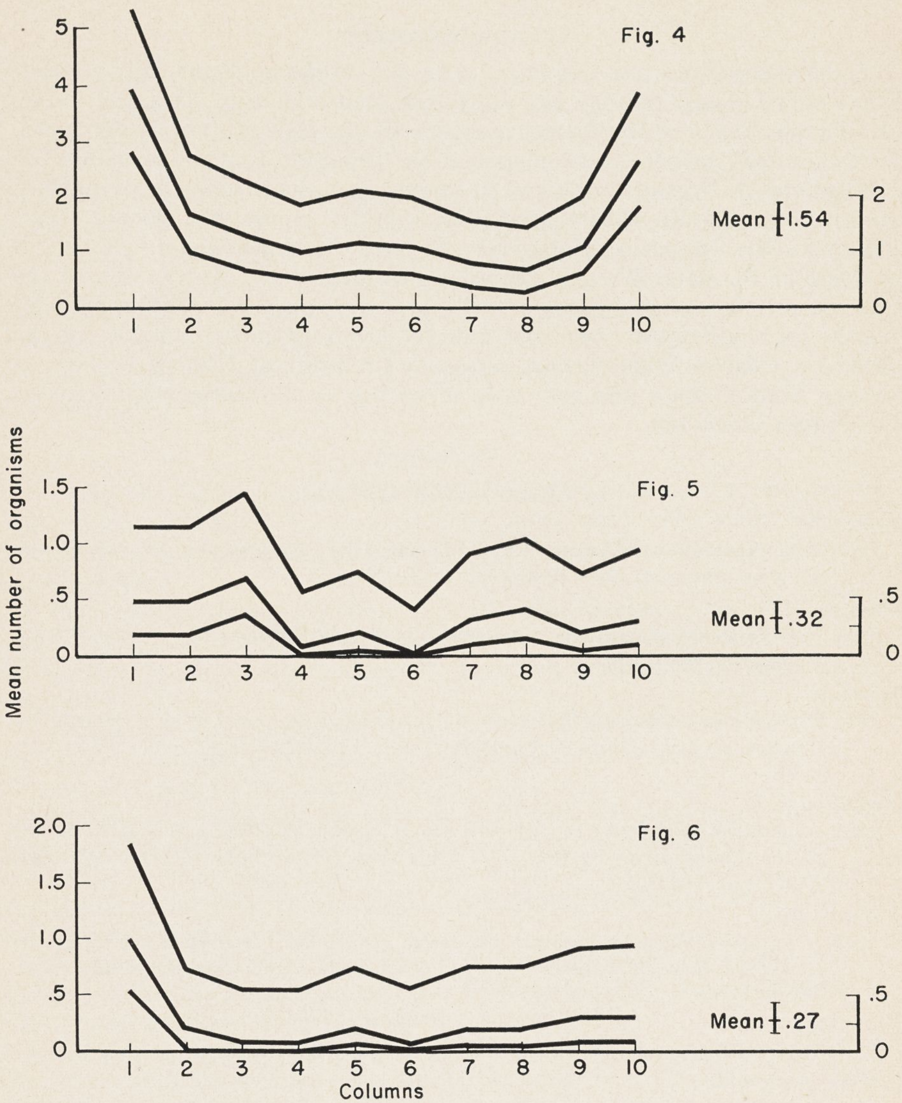


Fig. 4. *Alloperla,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 5. *Isogenus,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 6. *Isoperla,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

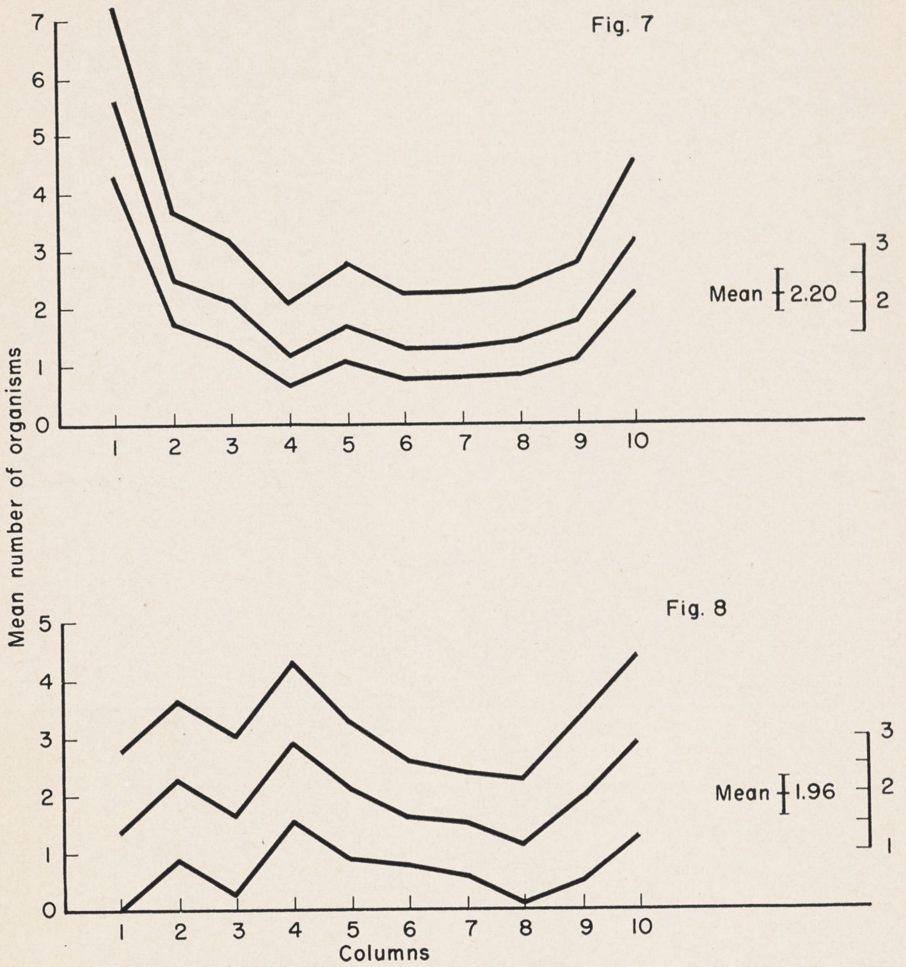


Fig. 7. *Plecoptera,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 8. *Baetis,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

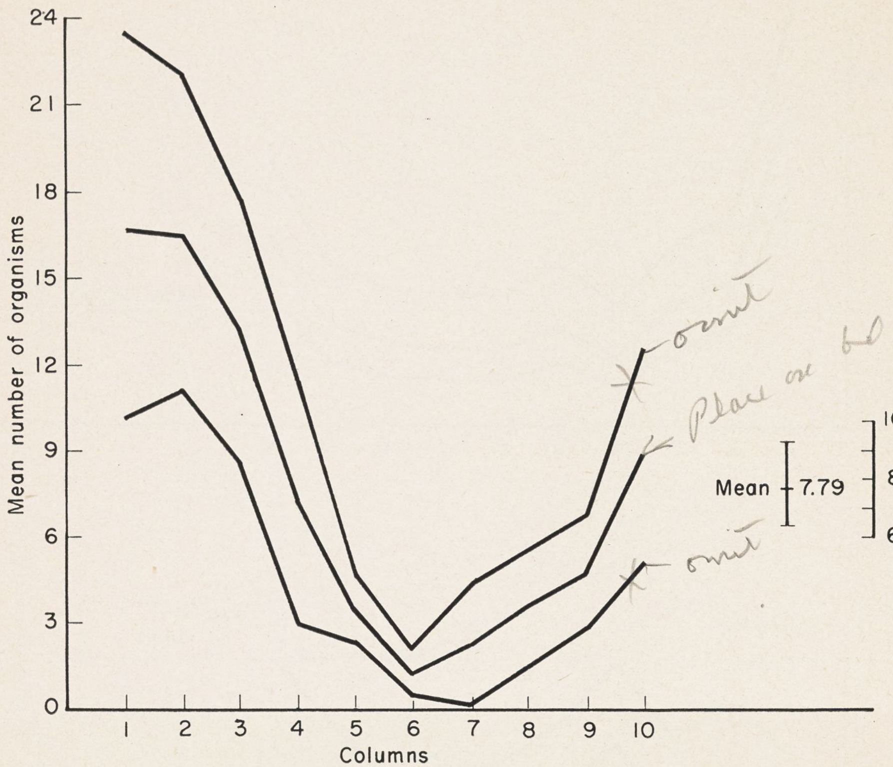


Fig. 9. *Cinygmula,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

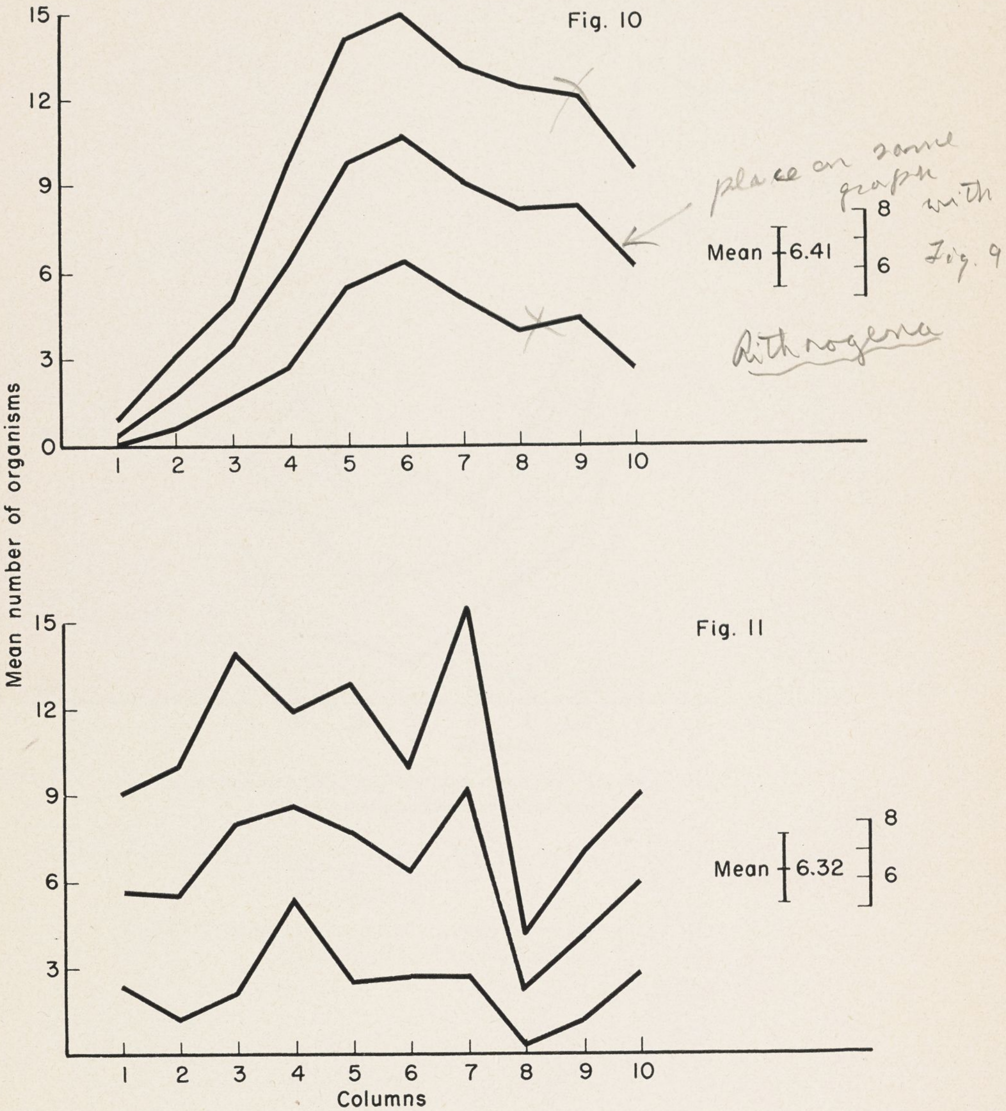


Fig. 10. *Rhithrogena,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 11. *Iron,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

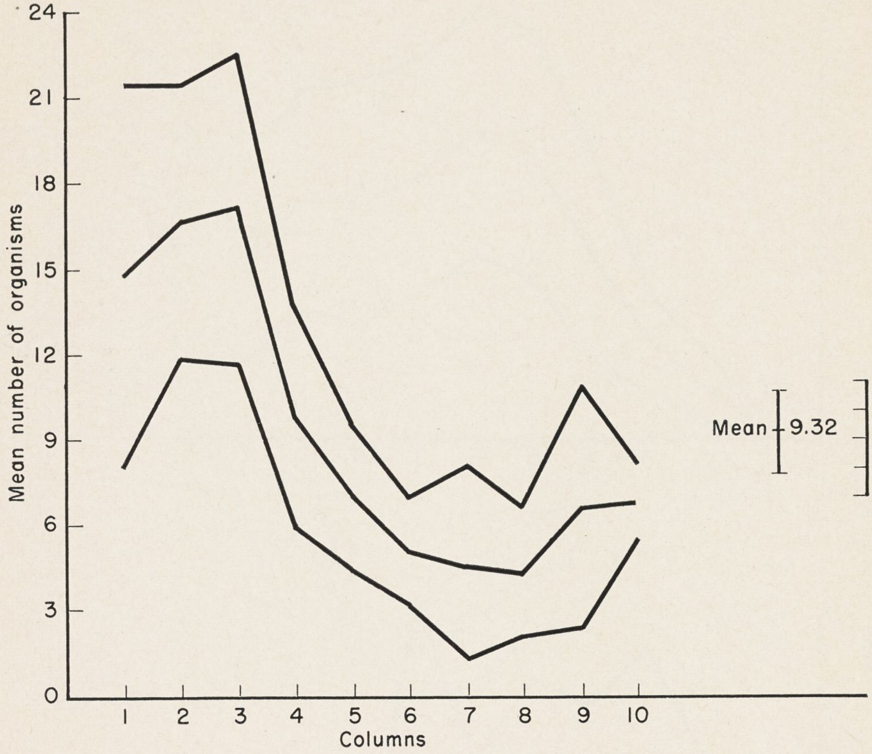


Fig. 12. *Ephemerella*, mean numbers per unit area and upper and lower 95 per cent confidence limits.

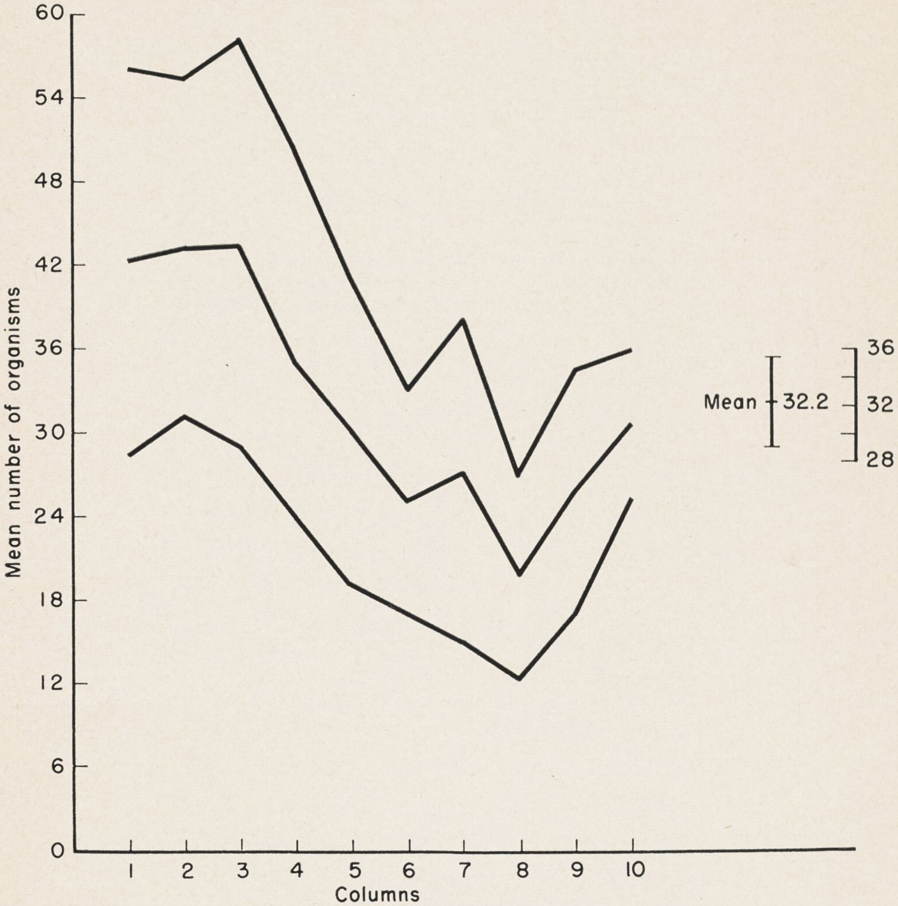


Fig. 13. *Ephemeroptera,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

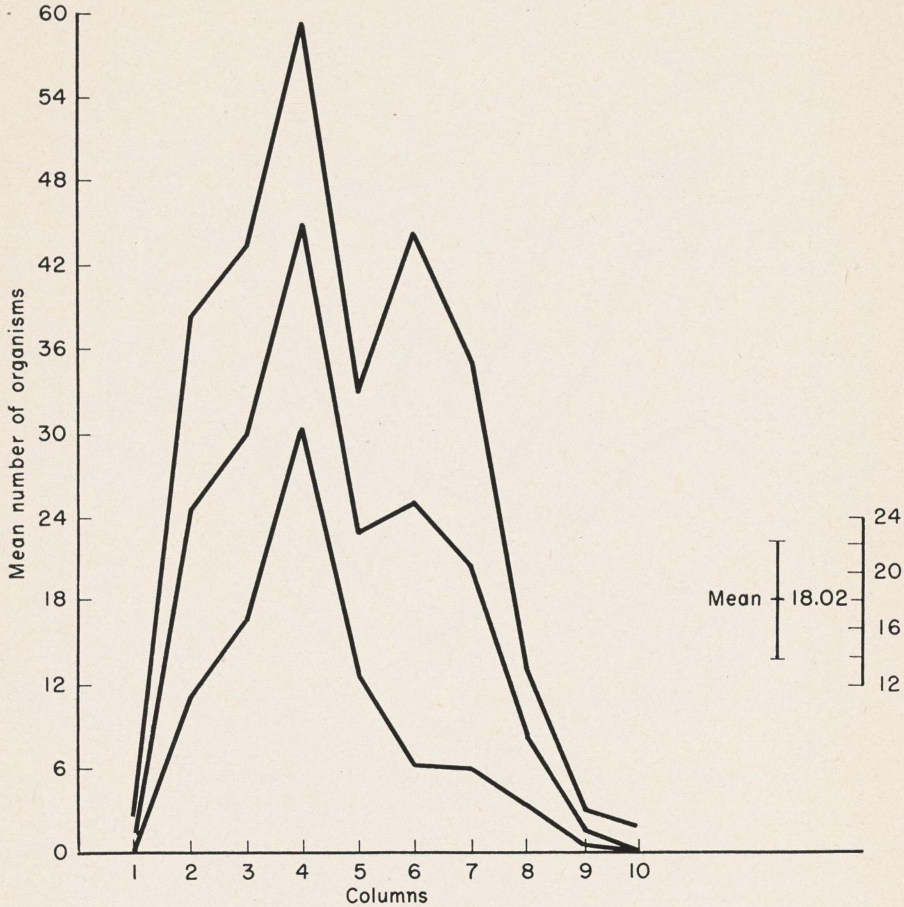


Fig. 14. *Glossosoma,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

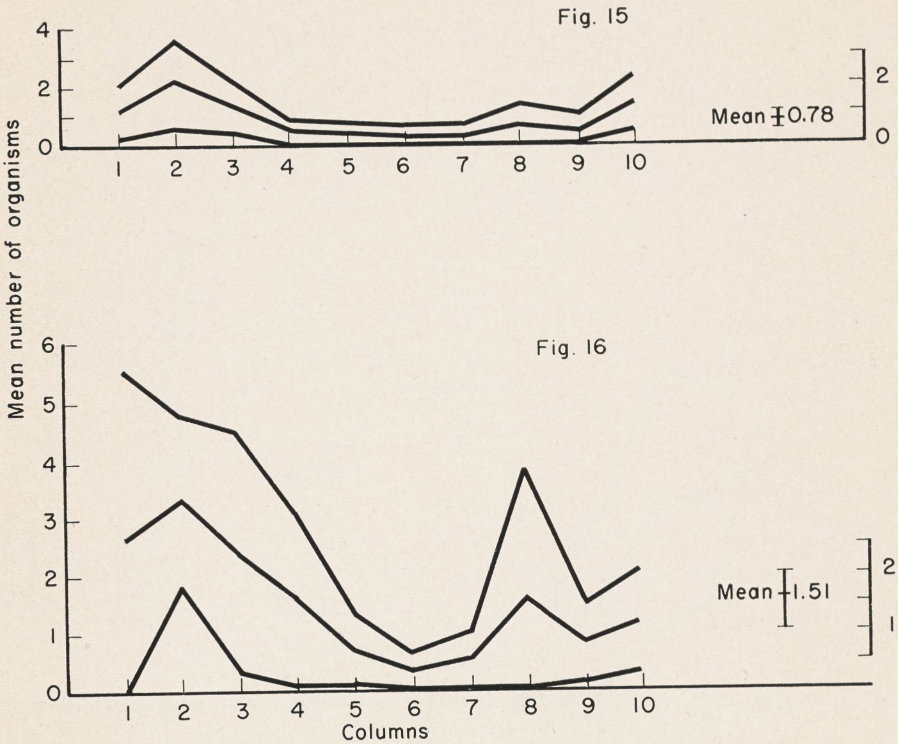


Fig. 15. *Hydropsyche,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 16. *Brachycentrus,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

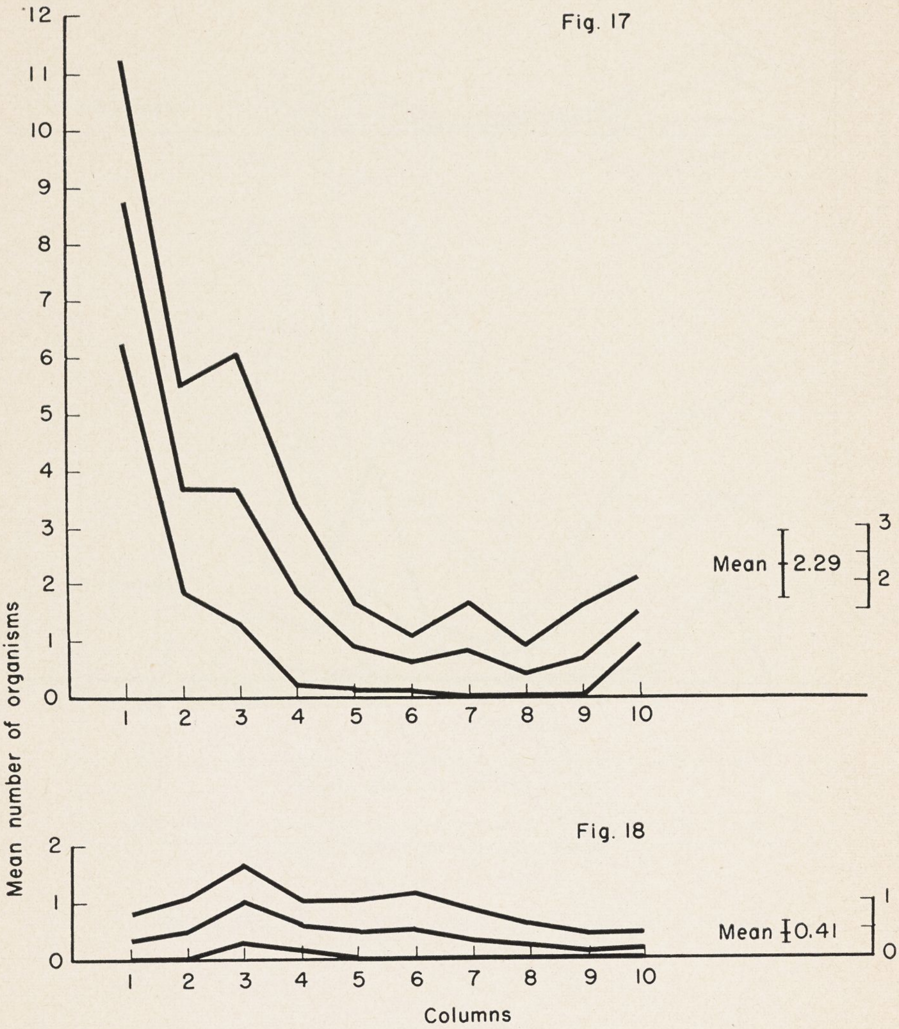


Fig. 17. *Lepidostoma,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 18. *Rhyacophila,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

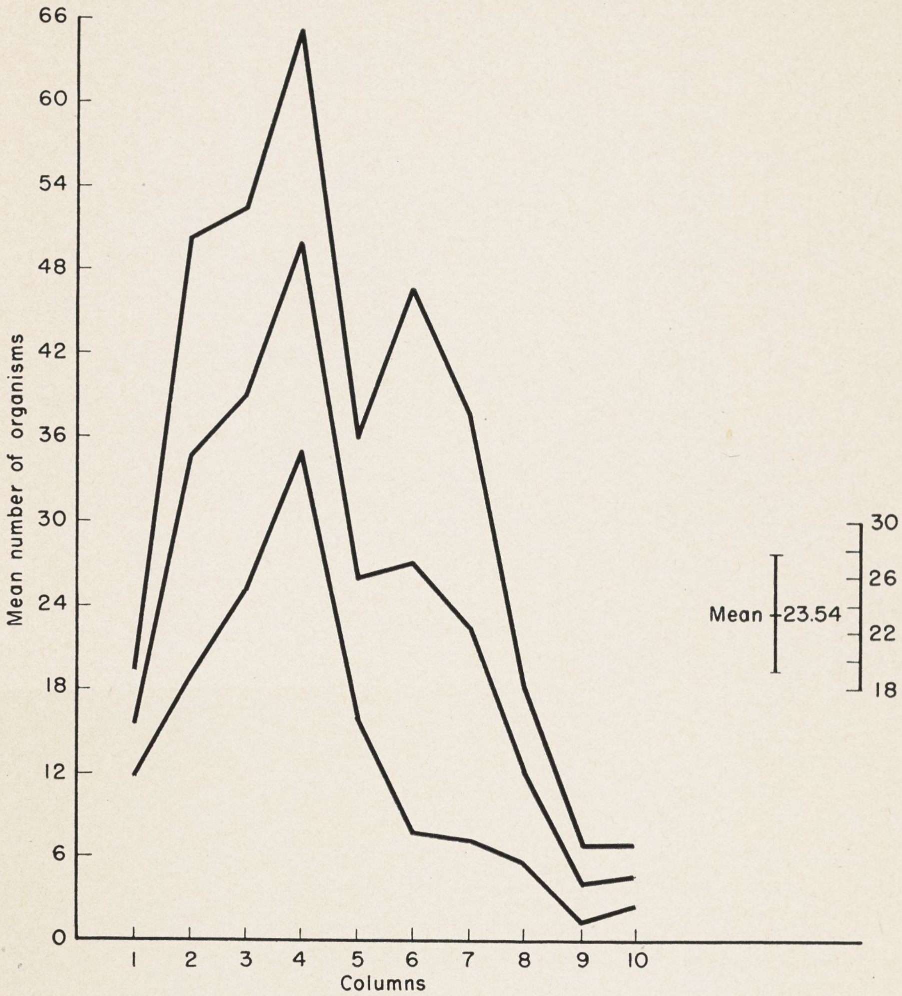


Fig. 19. *Trichoptera,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

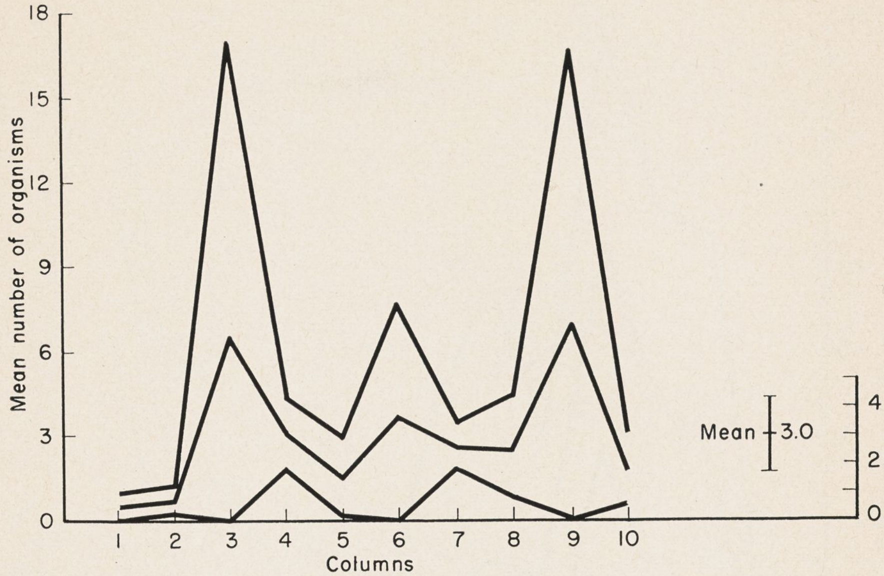


Fig. 20. *Simuliidae,* mean numbers per unit area and upper and lower 95 per cent confidence limits.

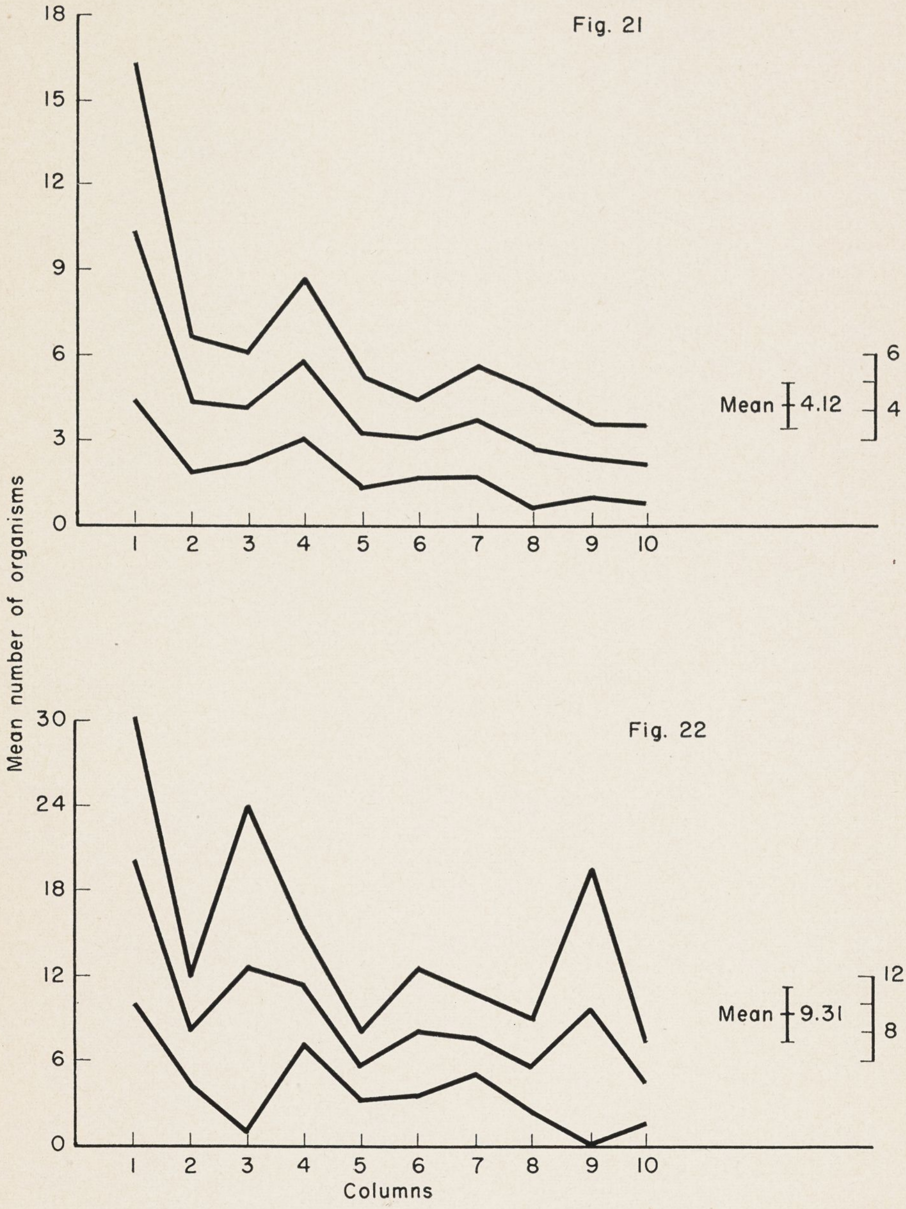


Fig. 21. *Chironomidae*, mean numbers per unit area and upper and lower 95 per cent confidence limits.

Fig. 22. *Diptera*, mean numbers per unit area and upper and lower 95 per cent confidence limits.

The Small Stream as a Laboratory Project: *Bottom Fauna*[1]

ANDREAS A. PALOUMPIS and KENNETH D. CARLANDER
Department of Zoology and Entomology
Iowa State College, Ames

A. *Introduction*

A small stream located near the school can serve effectively as a "laboratory" in the study of the biological sciences. Most schools have one or more small streams within relatively easy access.

Students can usually recognize more quickly the adaptations which aquatic animals have than the adaptations of the more familiar terrestrial animals. Study of aquatic animals is thus a particularly effective method of teaching ecology or the relationship of animals to their environment. The study of a small stream can assist the instructor in teaching about animal communities, soil erosion and pollution.

It is not possible to deal with all phases of stream life in one article, and therefore, this article discusses only the animals that live in or on the bottom of a stream.

B. *Material and Methods*

Very little special equipment is needed to study the bottom fauna of streams. Many of the organisms may be collected and observed by merely picking up stones from the stream bottom. A pair of forceps is of great help in picking animals from the rocks because many of the animals are small and flattened against the rock surface or in crevices where they cannot be picked out with the fingers. The animals can then be placed into a pan, glass jar, or aquarium for observation. Closer examination under a hand lens or the lower power of a microscope is often desirable. An hour's collection from the stream bottom can easily provide material for three or four hours' profitable study in the laboratory.

More can be learned about the relationship of the aquatic animals to their environment if quantitative methods of collection are used. Then the numbers and kinds of organisms on one type of stream bottom can be compared with the numbers and kinds on another stream bottom. Or the life in pools can be compared with that on riffle areas. The "productivity" of areas can be evaluated. Equipment for quantitative collection can be very easily accumulated and made.

The important feature in quantitative collections is the capture of all organisms from a measured area of bottom. A simple, efficient sampler can be made with a section of stove pipe. The stove pipe is pressed into the stream bottom thereby measuring the area. The sand, mud and water inside the stove pipe are then dipped out with a tin can or cup and placed in a pan so that the bottom organisms can be picked out. Only the top 3 inches of the stream bottom need to be taken since few organisms burrow that far. The mud and fine sand can be separated from the rest of the sample before picking the organisms by sifting the sample in a box with fine screen on the bottom. Brass screen with 30 meshes to the inch is usually used in research investigations. A larger mesh, such as copper window screen, will catch the larger animals and permit more rapid examination of the sample.

Quantitative sampling of rocky bottoms is more difficult. A satisfactory sampler can be made from two metal frames, each one foot square, hinged so that they are at right angles to each other. The vertical frame has a bag net of 000 XXX bolting silk or of fine mesh nylon netting. Canvas or muslin is stretched on each side across the angle formed by the two frames to prevent organisms from washing out rather than through the net. The sampler is placed with one frame marking off one square foot of stream bottom and with the other frame and net on the downstream edge.

[1]From Project 38 of Iowa Cooperative Fisheries Research Unit sponsored by the Iowa State Conservation Commission and the Industrial Science Research Institute of Iowa State College.

Reprinted from *The American Biology Teacher,* Vol. 18, No. 5, May, 1956.

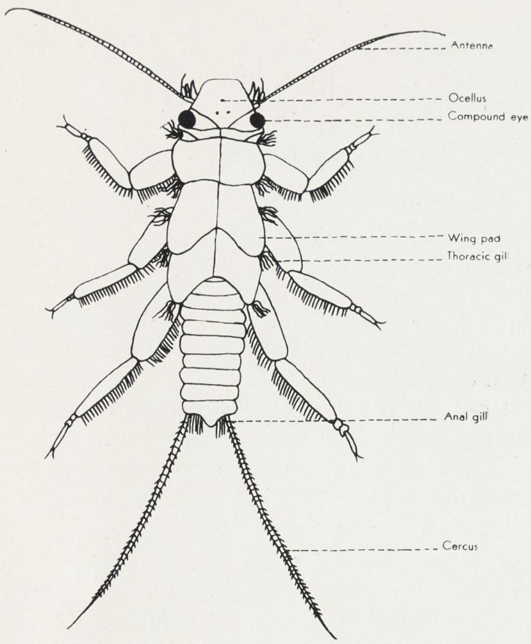


FIGURE 1. Generalized stonefly nymph. (Modified from Pennak, 1953).

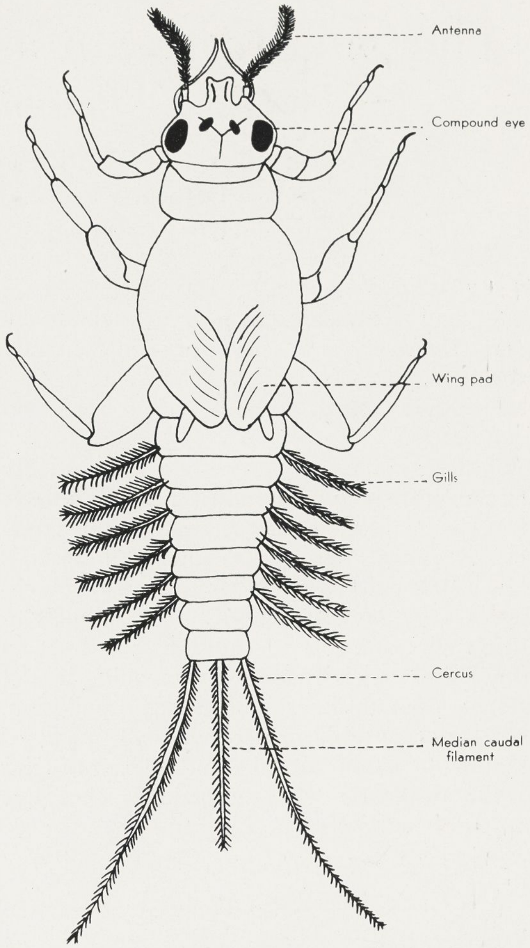


FIGURE 2. Generalized mayfly nymph. (Modified from Burks, 1953).

The rocks within the sample area are then scrubbed (an ordinary kitchen scrub brush works well) under water so that the organisms wash into the net. The other materials within the sampling area are also stirred up to a depth of three inches. This sampler can be used only in shallow, flowing water, but it picks up many forms which might otherwise be missed.

If many quantitative samples are collected for comparative studies, the screened materials or the picked organisms may be placed in jars and preserved with 1 part of concentrated formalin to 9 parts of water.

At least three types of analysis are desirable in comparing the fauna of different areas. First, the various kinds of organisms in each habitat should be listed. Second, the number of organisms of each kind per square foot-sample should be determined. Some habitats have only a few species of animals but large numbers of individuals. Since the organisms vary greatly in size, a third analysis is necessary if the "productivity" of areas is to be compared. A simple method is to determine the volume of the organisms found per square foot sample. A graduate is half-filled with water and the volume of the water recorded. The organisms from a sample are then placed on a paper towel for about one minute and then dropped into the graduate. The increased volume in the graduate is equal to the volume of the organisms. A graduated centrifuge tube gives more accurate measurements than a larger graduated cylinder if the total volume of the organisms is small.

In trout stream investigations, less than 1 cubic centimeter of organisms per square foot sample is taken to represent an unproductive area. Over 2 cubic centimeters per square foot usually means good production of trout food.

C. *Principal Bottom Organisms and their Habitat Preference*

The types of organisms which inhabit stream bottoms are many and varied and not all forms will be found in any one habitat type.

Mr. Klein [1957]

Fishery Leaflet No. 53
October 15, 1957

Subject: Management (T)

AN EXPERIMENTAL PLANT OF THE SMALL CRUSTACEAN MYSIS

By: W. D. Klein

In 1951 Dr. R. W. Pennak, of the Biology Department at Colorado University, suggested that the importation of Mysis was feasible and would probably improve the food chain for trout in some of the deeper Colorado Mountain lakes where good oxygen conditions prevailed at all depths. Since the possibilities of improving environmental conditions for trout in lakes of the type mentioned are extremely limited, it was deemed advisable to take advantage of the possibilities of improving the food chain for trout by importing Mysis on an experimental basis.

Mysis are large plancters that reach a length of about 3/4 of an inch. They are known to be an important source of food for lake trout in particular and likely would be fed upon by other species of trout and kokanee. The Mysis exhibit extensive daily vertical migrations. At dusk they migrate into the surface waters and at dawn the animals move into a narrow layer of water just above the lake bottom.

With the cooperation of the Minnesota Department of Conservation Mysis were obtained from Clearwater lake in Northeastern Minnesota and planted in lower Twin Lake near Leadville on October 3, 1957.

If the plant is successful it will likely be several years before Mysis become sufficiently abundant in Twin Lake to be detected. They will probably be detected in trout stomachs before becoming abundant enough to collect by sampling devices.

####### #######

Kentucky Fish Bull. #47, 1967.

- Desirability of threadfin Dorosoma petenense as forage and/or competitor / supressor of gizzard shad, D. cepedianum well documented:

· Henley, J. P. (1967) - 2 citations listed for 1967 - Ky. Fish Bull. 28 (L. Cumberland) & #46 - Buckhorn Res.

(see also L. Shasta - salmonid forage) - But eastern Kentucky winters too severe for threadfin survival & annual spring stocking now standard mgt. practice

see Miller's biblio.

- Introduced car body reefs - attractors - those fishing over these reefs had double the success of average angler.

- Goldeye, in Canada mooneye bull. -

- McAllan. T. A. F. S. 1968 · 97 : 300-305 good silversides -

- Swedish brown trout -
feeding - lake spawning - relat. w/ char.

Nilsson, N.-A. and G. Andersson. 1967. Food and growth of an allopatric brown trout in northern Sweden. Inst. Freshw. Res. Drottningholm, Rept. 47: 118-127: • Introduced brown trout consume small planktonic crustaceans. - flesh turns redder as trout grows. ^ Most lakes w/ char & trout - char eat mostly small planktonic crustaceans.
^p. 126: "It is tempting to speculate that both the plankton-feeding and the lake-spawning habits in some allopatric trout pop. may be due to the absence of competition from other fish species, such as char."

Aass, Per, 1969. Crustacea, especially Lepidurus arcticus Pallas, as brown trout food in Norwegian mountain reservoirs. Inst. Freshw. Res. Drottningholm Rept. 49: 183-201

(fm. Arctic waters) - Cladoceran feeding pop. of brown trout introduced into subarctic reservoirs in 1968.

- Arctic brown trout in reservoirs feed heavily on Lepidurus arcticus (suborder Euphyllopoda)

- Char & whitefish exploit cladoceran pop. in lakes better than trout (trout usually stunt) - Try out brown trout from L. Jolstervatn which may be cladoceran adapted feeders (+ spawn in lake itself p. 199) - several lakes stocked -

– Alewives — Mysis

Lindenberg, John G. 1970.
(Asst. Aquat. Biol)

Landlocked alewives in Congamond Lake. Mass. Wildl. Jan.-Feb. 1970: 14-15.

– In Congamond Lakes (series[2] of 3): – Apr. 1966 – 6000 alewives from Swartswood Lakes. N.J. stocked. Resident pop. of brown trout, L.M. bass, pickerel. – Alewives have reproduced and large pop. now in lake. – alewives found in pickerel stomachs and pickerel growth rate is rapid – no info on bass & trout.

– Mysis – Sweden:

Fürst, M. 1967. Successful introduction of glacial relicts as argument in a discussion of postglacial history. Inst. Freshw. Res. Drottningholm Rept. 47: 113-117. Some lakes only 6½ m. deep hold Mysis.

– In Kootenay L. – J. Fish. Res. Bd. Can. 21 (1964) (5): 1325-27

Profiles and Biology of Western European Streams as Related to Fish Management[1]

MARCEL HUET
Director, Belgian Waters and Forests Research Station and Lecturer at the University of Louvain

ABSTRACT

In the running waters of temperate Western Europe there are four main biological zones, each of which is characterized by a distinctive fish fauna. These are designated; (1) trout, (2) grayling, (3) barbel, and (4) bream zones. They are related basically to longitudinal section (slope of the stream bed) and to the cross section of the stream and its valley. The physical and biological characteristics of these zones are discussed together with the concepts "slope-rule" and "slope-graph", which express these relationships, and which have proven useful for evaluating and comparing running waters and for estimating fisheries potentials of streams from topographic information.

INTRODUCTION

In Western Europe, as elsewhere in the world, standing fresh waters, such as lakes, ponds, and marshes, have been the subject of many researches; but there has been much less study of running waters. The present paper deals with the streams of western Europe and, for the most part, summarizes information gathered by the author concerning them.

In these streams it has long been recognized that there are four main—and usually quite distinct—biological zones each of which has a characteristic fish fauna with a diagnostic or "key" species of fish. Principal emphasis in the present paper is on the relationships between the biological zones of the streams and the physical nature of the water course; especially its cross and longitudinal sections. These relationships have been of great use in fish management in Western European streams and undoubtedly have potential use elsewhere.

FISH FAUNAL ZONES IN STREAMS

The usual sequence of the fish faunal zones from headwaters to mouth of Western European streams is: (1) trout (*Salmo trutta*) zone, (2) grayling (*Thymallus thymallus*) zone, (3) barbel (*Barbus barbus*) zone, and (4) bream (*Abramis brama*) zone. In the two lower zones, which are characterized by cyprinids (Zones 3 and 4), the barbel and associated fishes are most common in those waters with moderate current and flow (Zone 3). The bream and associated smaller cyprinids are usually fishes of quieter waters (Zone 4)—somewhat as is the golden shiner (*Notemigonus chrysoleucas*) in North America.

The zonation evident in the fish fauna is mostly the result of stream gradient which affects both water temperature and rapidity of current. There are, however, many other characteristics of streams which are related to stream gradient and which, directly or indirectly, affect fish: such characteristics as the physical nature of the stream bottom (especially soils), composition of the aquatic flora and abundance of aquatic plants, and the composition and size of the populations of bottom-dwelling invertebrate animals (bottom fauna). The effect of stream gradient and current upon distribution of fish in streams has been noted both in Europe by Leger (1945) and in North America by Trautman (1942).

[1]Address at the 88th Annual Meeting of the American Fisheries Society at Philadelphia, September 1958.

Reprinted from Volume 88 (1959), Transactions of the American Fisheries Society.
Published 1959. Printed in U.S.A.

The four icthyological zones occurring in European streams really represent two faunistic regions: an upper salmonid region of cooler waters (trout and grayling zones) and a lower cyprinid region of warmer waters (barbel and bream zones). However, from the point of view of stream gradient and rapidity of current the trout, grayling, and barbel zones can be grouped, for they are all zones of rapidly flowing waters that are characterized by rheophilic fishes. In contrast, the bream zone is of waters with little or slow movement and the fishes associated with the bream in this lower zone are predominantly limnophilic. Faunistic relationships and the principal species of fish in the four zones are shown in Table 1.

The physical characteristics of the four stream zones are as follows:

Trout Zone

Waters of the trout zone are cool brooks, creeks, and rivers with steep gradient and rapid, sometimes even torrential, flow. The water is always well oxygenated. Summer water temperatures rarely exceeds 64°F. The stream bottom is most often rock, boulders, or pebbles but is sometimes gravelly or sandy. The water varies considerably in depth but is often quite shallow. Stream width is also quite variable. Along with the brown trout, which dominates the fish population, are the sculpin (*Cottus gobio*) and the minnow (*Phoxinus phoxinus*). The physical characteristics of the trout zone differ somewhat in high mountains, mountains of moderate height, foothills, and coastal plains; but the water is always cool and well oxygenated. A typical stream of the Trout Zone is shown in Figure 1.

Grayling Zone

The grayling zone is characteristic of rivers and larger streams (Figure 2) that have rather rapidly flowing water. Gradient is generally less than in trout waters and the riffles and

TABLE 1.—*Occurence and relative abundance of principal fishes in gradient zones of running waters of temperate western Europe* [Relative abundance of kinds of fishes is indicated by the number of asterisks]

Stream zone	Trout	Grayling	Barbel	Bream
Fish fauna	Salmonid[1] fauna	Mixed fauna, salmonids[1] predominating	Mixed fauna, cyprinids predominating	Cyprinid fauna, with predators
	***Trout	***Trout and grayling	*Trout and grayling	
		**Running water cyprinids[2]	***Running water cyprinids[2]	*Running water cyprinids[2]
		*Accompanying cyprinids[3]	**Accompanying cyprinids[3]	***Accompanying cyprinids[3]
		*Accompanying predators[5]	**Accompanying predators[5]	***Accompanying predators[5]
			*Still-water cyprinids[4]	***Still-water cyprinids[4]

[1]Salmonids—Brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*).
[2]Running water cyprinids—Barbel (*Barbus barbus*), chub (*Squalius cephalus*), hotu (*Chondrostoma nasus*).
[3]Accompanying cyprinids—Roach (*Gardonus rutilus*), rudd (*Scardinius erythrophtalmus*), dace (*Leuciscus leuciscus*).
[4]Still-water cyprinids—Carp (*Cyprinus carpio*), tench (*Tinca tinca*), bream (*Abramis brama*).
[5]Accompanying predators—Pike (*Esox lucius*), perch (*Perca fluviatilis*), eel (*Anguilla vulgaris*).

IOWA STATE COLLEGE JOURNAL OF SCIENCE
Vol. 33 No. 3 February 15, 1959 pp. 395-419

PRODUCTION OF BOTTOM FAUNA IN THE PROVO RIVER, UTAH[1]

Arden R. Gaufin[2]

Department of Zoology and Entomology
Iowa State College, Ames

INTRODUCTION

Life is precarious in mountain streams and a fine degree of fitness is necessary for those plants and animals found there. Constantly changing from day to day, from month to month, and from season to season, stream conditions offer a highly unstable and complicated environment. Man has further accentuated the instability of this environment by his various activities. The seasons often bring sudden changes in volume and velocity of water that wipe out whole aquatic populations in a short time. The specialized conditions restrict the number of animal and plant species very markedly. Indeed, in our best trout waters—clear, cold, mountain streams, the larger aquatic plants, upon which many aquatic invertebrates depend for their livelihood, are practically eliminated by the current. The biota is further limited to species that are either strong swimmers or have special structural adaptations for clinging.

A striking feature of mountain streams is the rapid and abrupt change of habitats. In a small area may be found all the extremes from a vertical to a horizontal flow of water; from shallow, placid stretches to deep, stone-lined pools. Animals and plants assemble in small communities or biotic islands, often separated by barren areas kept uninhabited by the severity of the current.

The Provo River is a typical mountain stream of the Intermountain region and is well known for its trout fishing. Field investigations on this river were initiated by the writer on September 15, 1946 and continued to May 28, 1949.

The general purpose of this study was to obtain a quantitative and qualitative measure of the stream bottom invertebrates of the river as potential sources of food for the trout populations present. Another objective was to learn something about the life histories, habits, and adaptations of the invertebrate inhabitatns of the stream. Various physical, chemical, and biotic factors which influence the productivity of a river were measured. Finally, since very few investigations have

---

[1] Part of a thesis filed in partial fulfillment of the requirements for the degree of Ph.D. at Iowa State College. This project was sponsored by the Research Committee of the University of Utah and the Utah Fish and Game Department.

[2] Now Associate Professor of Zoology, University of Utah, Salt Lake City, Utah.

dealt with conditions existing in streams during the winter season, special attention was given to the determination of the ecological changes occurring during that time of the year.

METHODS

In order to select sampling stations which would be representative of the different sections of the stream the author spent the first ten months of study conducting seasonal reconnaissance surveys of the entire river. Information concerning the geology and topography of the drainage basin was gathered. Collections of fauna and flora were made from as many different habitats as could be found. Changes in water level and course brought about by the multiple uses of the river for irrigation, power, and recreation were determined.

In making qualitative collections of the fauna in the stream a Needham hand screen sampler was found to be most useful. Hand picking of nymphs and larvae from rocks, debris, and vegetation was also used effectively on many occasions. Adults were picked from bridges, rocks, and buildings or by sweeping the vegetation. The specimens collected were preserved in vials of 80% ethyl alcohol and were later identified to genus or species.

Following this reconnaissance phase of the project, nine major stations were selected in typical average sections of the stream from the headwaters to its mouth. Chemical, physical, and biological data and samples were taken at each station on a weekly basis from June to September, 1947. Sampling and collecting of data were conducted on a monthly basis during the following twenty-one months of the study.

The direction of flow and the stream gradient were determined by use of a surveyor's transit and stadia rod. The approximate altitude at each station was obtained by reference to United States Geological Survey maps of the region. Average widths and depths were determined by actual measurements and by reference to stream bottom profiles and staff gauges which were constructed at the beginning of the project. Stream velocities were measured by timing the passage of floats over one hundred foot sections at each station. The volume of flow was determined by using the formula given by Embody (1927). The turbidity and color of the water were obtained by means of a United States Geological Survey turbidity rod and glass color disk outfit. Air and water temperatures were measured by standardized chemical thermometers.

All water samples for chemical analysis were taken below the stream's surface with a 1.5 liter Kemmerer water bottle. Hydrogen ion concentrations were determined colorimetrically with a La Motte set, using cresol red or bromthymol blue as indicators. The unmodified Winkler method as outlined in Standard Methods of Water Analysis (1947) was used for the determination of dissolved oxygen. Free carbon dioxide values were obtained by titrating 100 cc. samples of water with N/44 sodium hydroxide using phenolphthalein as an indicator. Phenolphthalein and methyl orange alkalinities were obtained by titrating a 100 cc. sample of water against N/50 sulfuric acid using phenolphthalein and methyl orange as indicators. The electrolytic content of the water was determined by means of a Leeds and Northrop Soil Meter connected to

Habitat and Associated Fauna of Four Species of Fish in Ontario Streams[1, 2]

By J. C. Hallam[3]

Department of Zoology, University of Toronto,
and Fisheries Research Board of Canada
Biological Station, London, Ont.

ABSTRACT

Four species of fish found in Ontario streams can be divided into two distinct groups on the basis of habitat and associated fauna. *Salvelinus fontinalis* (Mitchill) and *Cottus bairdi* Girard are found associated in cool source waters whereas *Ambloplites rupestris* (Rafinesque) and *Micropterus dolomieui* Lacépède occur together in warmer downstream waters. The latter group has more associated species of fish than the former. Some invertebrates such as certain stonefly and mayfly nymphs occur frequently with fish of one group and rarely with fish of the other group. They may be useful as indicators of waters likely to be inhabited by or suitable for the species of fish with which they are frequently associated.

CONTENTS

INTRODUCTION

Sources of Data

Each summer since 1946 the Department of Planning and Development of the Province of Ontario has surveyed rivers in southern Ontario. Data from these surveys, on which the author worked in the summers of 1950, 1951, and 1952, were made available for this study. Data for Wilmot Creek, similar to that for the above surveys, were collected under the auspices of National Research Council of Canada.

Description of Watersheds. All the rivers and streams examined are in southern Ontario and drain into the Great Lakes except for the South Nation River which is a tributary of the Ottawa River.

The Ganaraska, Humber, Don, Wilmot, Mimico and Etobicoke are small watersheds bounded on the north by either the Niagara cuesta or moraines of the interlobate series or, in the case of the Humber, by both. The Humber River thus derives water from both sources. The Ganaraska and Don Rivers and Wilmot Creek originate in the interlobate moraines. Mimico Creek and Etobicoke Creek

[1]Received for publication March 5, 1958.
[2]Based on a thesis submitted to the University of Toronto in partial fulfillment of the requirements for the degree of Master of Arts.
[3]Author's present address: 1472 Bishop St., Apt. 2, Montreal, Quebec.

J. Fish. Res. Bd. Canada, **16**(2), 1959.
Printed in Canada.

do not tap these main source areas but arise as drainage of the till plain. All these rivers and creeks enter Lake Ontario at intervals which extend over about 80 miles of the north shore in the Toronto region.

The Nith and adjacent Thames watersheds are similar to one another in some respects. Although part of the source of the Thames River is in till plains and moraines and that of the Nith River in clay plains, the upper ends of both tend to dry up in summer. Many of their upper waters are now drainage ditches and the land drained is agricultural and relatively low in contour.

The Speed and Saugeen Rivers flow southwestward on the inclined limestone plain to the west of the Niagara cuesta. That portion of the Saugeen surveyed originates from sources in this limestone and in the gravel moraines and kames of the horseshoe series in the vicinity. It flows mainly in the spillways of the antecedent glacial streams. The Speed, which drains the Guelph drumlin fields, also flows in old spillways. A large proportion of these two watersheds is forested.

The Ausable River flows westward into the southern end of Lake Huron. Most of its small headwater streams are now drainage ditches and the river is characterized by heavy spring floods and low summer flow.

The Moira and Napanee river flow into the northeastern end of Lake Ontario. Both have their headwaters in the region of Precambrian rocks of the Canadian Shield and their lower course and southern tributaries of Paleozoic limestone.

The South Nation River is the only one surveyed which does not drain into the Great Lakes. Its highest source area is located on a limestone plain northeast of the eastern end of Lake Ontario and from this it flows northeastward across a flat plain to the Ottawa River. Much of the South Nation dries up completely or to standing pools in late summer of dry years. Its gradient of only 2.5 feet per mile on the average, contrasts with that of the Saugeen, 9.5 feet per mile, and of the Speed, 20.0 feet per mile.

The Holland River flows north into Lake Simcoe. It is notable for its sandy source areas and its meandering downstream section in the Holland Marsh.

STREAM SURVEYS. Since most of the data presented in this study were selected from data collected on surveys by the Department of Planning and Development a short discussion of the purpose and methods of the surveys will be given.

The purpose of the surveys, as stated in the reports of the Department, was "to make a preliminary examination of the waters of the drainage basins and to classify them as to their present suitability for fish and secondly to make recommendations for possible improvements."

Prior to each summer's field work, places were selected in the watershed to be visited by the field crew. These "stations", located usually where a road crossed the river or stream, were as close as one half mile on small tributaries and as far apart as three or four miles on large rivers. Stations were also located above and below settlements on streams.

Information relating to conditions of the stream, both of the water and terrain, along with biological data, was recorded for each station.

Aquatic organisms were sampled as follows: fish were generally caught by one person using a six-foot seine although in large rivers other methods such as

[1959]
J-stor

Reprinted from LIMNOLOGY AND OCEANOGRAPHY
Vol. 4, No. 3, July, 1959
Printed in U.S.A.

Chlorophyll and Productivity in a Mountain River[1]

WILLIAM J. McCONNELL

Institute of Marine Science, The University of Texas, Port Aransas, Texas

AND

WILLIAM F. SIGLER

Department of Wildlife Management, Utah State University, Logan, Utah

ABSTRACT

Chlorophyll was sampled on the shallow, rocky, canyon section of Logan River—a swift, clear, calcareous mountain river in the Middle Rocky Mountains of northern Utah. Chlorophyll extractions were made by immersing entire rocks supporting algae in acetone. The average quantity of chlorophyll per m^2 of bottom of the canyon section of Logan River was 0.30 grams. Downstream supplementary stations supported 3 to 4 times as much chlorophyll as the canyon section. No significant difference existed between means of chlorophyll samples in fall and late winter and between the upstream and downstream portions of the canyon section.

Annual gross primary production equal to about 1.2 kg per m^2 was estimated from the relation of chlorophyll to photosynthesis in light and dark jar experiments. A standing crop of 25 grams of dry plant biomass per m^2 was determined from the chlorophyll dry weight ratio of samples of the community. Average standing crops (dry wt.) of insects and fish were 5 and 1.6 per cent, respectively, of the producer biomass or average standing crop of algae.

Production of chlorophyll on artificial substrata (concrete rocks) showed no close relationship with either insolation or water movement within the range of values encountered in the Logan River.

INTRODUCTION

Investigation of primary production in streams and rivers has lagged behind similar investigations in marine and lacustrine environments. Recently, however, Odum (1956) has demonstrated methods that allow the estimation of productivity of most moving waters. Odum's method, unfortunately, is not satisfactory for determination of productivity in shallow, very rapid rivers as typified by Logan River. In this kind of environment the diurnal pulse in dissolved oxygen is caused primarily by changes in the saturation value related to diurnal temperature changes rather than by accumulation and depletion of photosynthetic oxygen. The investigation herein reported was primarily an exploration of a method possibly applicable to measurement of primary productivity under the foregoing conditions. The relationship of photosynthesis to chlorophyll content in planktonic algae (Edmondson 1955, Ryther 1956b) suggested this exploration.

In addition to the measurement of productivity, the relation of chlorophyll to standing crop of algae and the effects of diffusion and insolation on chlorophyll distribution were investigated.

The importance of current photosynthesis in rapid rivers is, perhaps, greater than it is in other aquatic habitats. Attrition due to water currents is a constant process which removes primary food material and carries it away from the site of production. Brief measurements of pseudo-plankton or stream drift suggest that a large percentage of the net product of photosynthesis is lost downstream. Nowhere on the bed of Logan River is there evidence of important conservation of organic matter in the form of muck or plant detritus. Although quantities of leaves fall into the river, terrestrial

[1] Based on a thesis presented by the first author to the Department of Wildlife Management of Utah State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

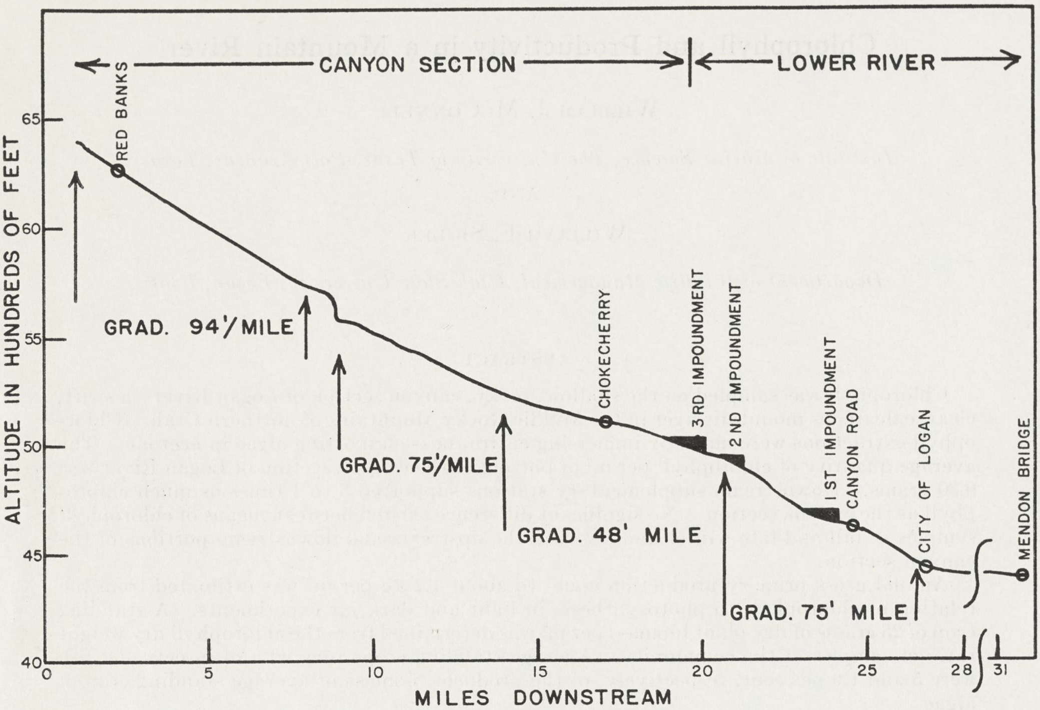


Fig. 1. Profile of Logan River showing gradients, stations, and sections referred to in the text.

contributions are actually unimportant. Little of the imported plant material reaching the canyon section of Logan River is arrested in downstream transport until it reaches the 3rd impoundment (Fig. 1).

The food habits of the dominant fishes of Logan River indicate a complete dependence on aquatic insect larvae (Fleener 1951, Zarbock 1951, Sigler 1951). Although the food of many North American stream insects has not been intensively investigated, work on the food habits of closely allied insects from British streams shows that algae are an important food of the herbivorous types (Badcock 1949, Jones 1949, 1950).

Provision of the basic grant (E-1435C) by the National Institutes of Health of the United States Public Health Service made the research possible. William J. Clark cooperated closely in the collection of most of the physical and chemical data. Dr. Francis Drouet identified reference collections of algae which were the basis for identifications in routine algal collections. We also thank the people at Utah State University and elsewhere who provided valuable suggestions and criticisms.

MATERIALS AND METHODS

Chlorophyll was extracted by soaking rocks supporting algae in acetone. Bleaching of the chlorophyll solution during extraction was minimized by the use of closely covered containers and extraction at low temperatures. The magnitude of errors introduced by bleaching, incomplete extraction, turbidity of extracts and varying water content of extracts was assessed by supplementary experiments. Appropriate corrections were made (McConnell 1958).

Optical density of acetone chlorophyll extracts was measured at 664 mμ with a Bausch and Lomb "Spectronic 20." The chlorophyll *a* equivalent to these optical densities was determined by reference to the relationship between optical density at 664 mμ and the 3 wavelength determination prescribed by Richards with Thompson (1952). This relation proved to be very constant (Fig. 2).

R. Behnke
1960
London, Salmon, & Trout Assn

THE SALMON AND TROUT ASSOCIATION

London Conference, 1960

FLY LIFE

by T. T. Macan

I HAVE been asked to talk about Fly Life and take the liberty of interpreting this to cover all invertebrates, because all affect fish directly or indirectly. Invertebrates have two functions in the eyes of fishermen:—

(1) They serve as models for the flies wherewith he catches fish;

(2) They serve as food for fish.

The first subject is better left to anglers and I shall confine myself to the second.

We wish, then, to understand the complex interaction of many species with each other and with chemical and physical factors which produces a crop for fish to feed on.

The first thing to find out about any piece of water is what occurs in it, in other words to produce a species list. Generally to a lay audience one must labour the point that two species which look exactly the same except perhaps to a specialist may behave differently and must therefore be distinguished, but to fly-fishermen this is not necessary. On the other hand I find that not all anglers are aware how many different species may be numerous in quite a small piece of water.

No one will attempt to compile a list without at the same time gaining some idea of the numbers of the various species and if next, by weighing each species at different sizes, he can answer the question how much? as well as as the question how many? he is beginning to get information of value to the fisherman. When he can go a stage further and state not merely how much there is today or was at the beginning of the fishing season or on the day his summer vacation ended but how much is produced in the course of a year, he will be in a position to talk hard business. The first step in any investigation of total annual production is study of life histories; two species may be equally abundant on a certain date but, if one has three generations in a single year and the other a single generation in three years, their contributions to the fishes' upkeep will be greatly different. Some are absent for long periods of the year. A final important query is where? and, when I come to it, I want to talk about the populations in different kinds of plants in one fishpond.

This is the path along which the fisherman would like to see the biologist plodding his weary way and my intention is now to examine how far he has got. I hope your verdict will not be that he has left the world to darkness.

Lists of Species

Laymen are often surprised to learn that this first fence is still impassable at places. The naming of species started with Linnaeus some 200 years ago and reached its peak in the last century. In this one it has gradually fallen out of fashion and I may remark that scientists are as much slaves to fashion as any lady buying an Ascot hat. Although there are some that have not been revised for a long time and others that have never been studied well, there is no group of animals that has never been studied, but this is true only of adults, and in several groups the immature stages, which are often the ones that concern the freshwater biologist, have never been described. In 1938 Dr. H. B. N. Hynes started to work on the nymphs of stoneflies at Wray Castle and a little later I started to do the same for the Ephemeroptera. It took us both about twenty years to complete the task. Nobody has done the same for the caddis larvae, though Dr. N. E. Hickin has described about a quarter of the British species. Our inability to put names to these hinders all kinds of research.

It is, therefore, not possible to complete the first stage of an investigation of any piece of water and give a full list of the species in it, and even incomplete lists are few. I have listed such as there are in a review that should appear next year (Macan 1961), and shall make no further observation except to comment that stony streams have been the most popular pieces of freshwater for study and that the absence of any survey of a chalk river is striking. The nearest approach to it is Berg's (1948) painstaking study of the Susaa in Denmark.

Life Histories

It always surprises me that, when I talk to people from the south, they refer to scarcity of food in winter and abundance in summer, which is the reverse of what we are familiar with in the north, as fig. 13 in Hynes' (1960) recent book on pollution shows particularly well. This observation serves to illustrate how little we know about life histories and how important it is that we should know more. It is something of an endless quest, for life histories of many species vary from place to place according to temperature and other conditions and must be studied separately in each.

Fig. 1 shows the life history of *Heptagenia lateralis* (Ephemeroptera), which is a typical winter species of a type that predominates in the northern waters with which I am familiar. Eggs start to hatch in the autumn, there is growth then and in early spring though little at the coldest time of year, and the adults emerge in early summer. The high temperatures of mid and late summer are evidently unfavourable to this species which can, however, tolerate them in the egg stage. I deduce this both from direct field observation and from a comparison of my findings (Macan 1957) with those of Dr. Janet Harker (1952) who worked on a stream that was a few degrees colder than mine. In it *Heptagenia* adults continued to appear for

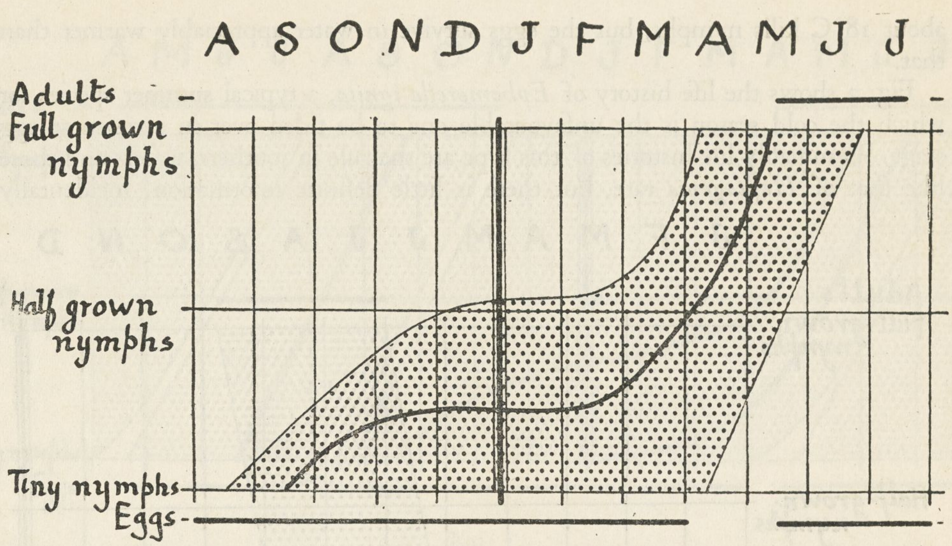


Fig. 1

Life history of *Heptagenia lateralis*. The fine line bounding the dotted area on the left-hand side indicates the size of the largest specimen. The fine line on the right-hand side indicates the size of the smallest specimen, and the thick line in the middle indicates the size of the majority of specimens at any time. It will be noted that, though the egg-laying period is not longer than two months, from mid-May to mid-July, some eggs are still unhatched at the beginning of the following April.

longer and the eggs hatched sooner, with the result that nymphs of two successive years, always separated by a month or two in my stream, occurred together.

The field observations showed that *Heptagenia lateralis* was abundant in some parts of small stony streams but scarce or absent in others. A correlation with temperature seemed likely and, by a happy coincidence, 1959, with its record-breaking fine summer, was the year chosen for the testing of this hypothesis. Maximum and minimum thermometers were placed at various points and read at suitable intervals. In the warmest stream, the outflow from a tarn, the temperature reached 28°C, in the coldest it did not exceed 16°C. In all the places where the temperature was 18°C or below, *Heptagenia* was abundant; in warmer waters it was scarce or absent, except in one stretch that was close to a densely populated cold one. Correlation between temperature and range is therefore good but one anomaly is the abundance of the species in Windermere, whose surface waters may exceed 20°C. However, there is a difference between small streams and large lakes whose significance in the present connexion is difficult to doubt; streams reach in May a maximum little below the highest of the summer, but Windermere is comparatively cool in that month and warms up steadily throughout the summer. Evidently a temperature of about 18°C kills nymphs, but the eggs survive in water appreciably warmer than that.

Fig. 2 shows the life history of *Ephemerella ignita*, a typical summer species for which the cold season is the unfavourable one to be tided over in a resistant egg stage. Presumably life histories of this type are the rule in southern waters and those like that of *Heptagenia* rare, but there is little definite information. Incidentally

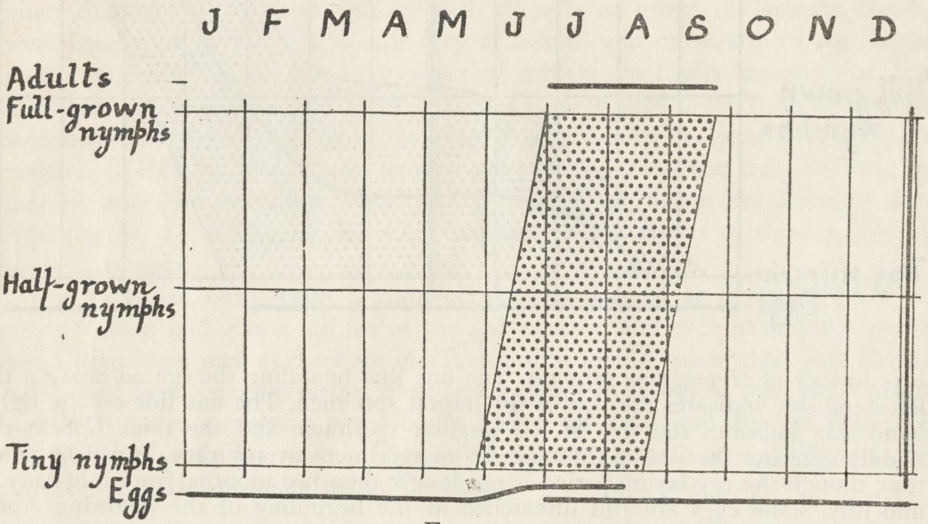


FIG. 2

Life history of *Ephemerella ignita.*

Ephemerella nymphs are to be found over a much longer period in southern waters, but whether this is due to an increase in the number of generations in the year or to a longer period during which the eggs hatch is not known. It has been established in other groups that the number of generations increases with decreasing latitude.

Fig. 3 shows the life history of *Baetis rhodani,* which has a long over-wintering generation and a shorter summer generation. In fact there is some overlap between the two which has been omitted for the sake of simplicity. Working in Austria, Dr. Gertrud Pleskot (1958) finds a gap of about two months between the two generations and she believes this due to temperature unfavourably high to all stages but the egg.

Some life-histories are much less easy to work out. *Gammarus pulex*, for example, starts to breed at the beginning of the year and continues to breed until October. Hynes (1955) has worked out that a female can produce nine broods in this time and he has also calculated the total progeny possible. An animal of this kind is obviously of great value in a stream that has been depopulated by a calamity, for it

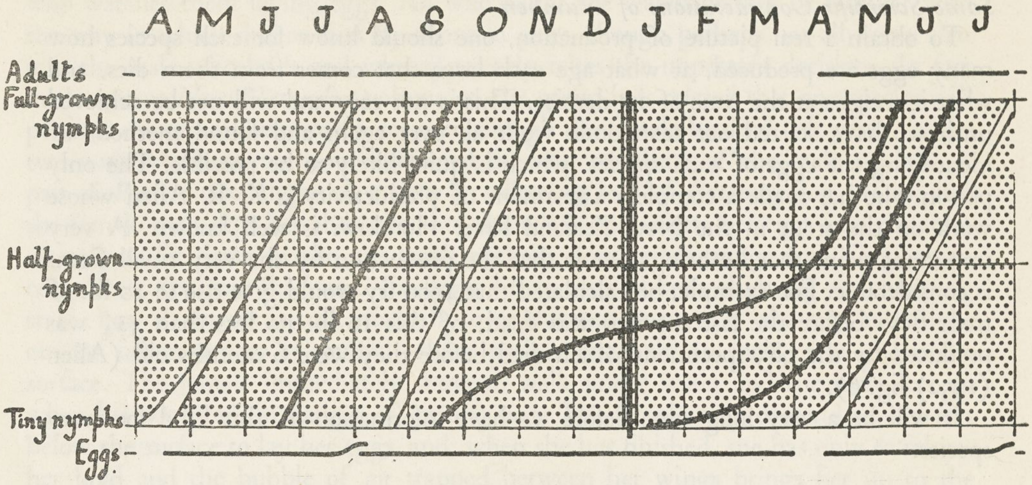


FIG. 3

Life history of *Baetis rhodani*. The eggs laid by the adults of the summer generation are hatching from late August to early April, but the hatching reaches peaks of intensity in autumn and again in January, which is why two thick lines are shown for the overwintering nymphs.

will re-establish itself sooner than a species which takes one or more years to complete a generation.

Some Practical Considerations of Numbers

Some years ago a forceful member of the committee of an angling club that had a reservoir told me how he had persuaded the others that what was required to improve the fishing was more snails. Accordingly a few thousand were purchased and introduced. The number no doubt sounded impressive in committee, but I calculated that it represented no more than the normal population of 15 square yards, which was a good deal less than one thousandth of the total area of the reservoir. I doubted if the money had been well spent.

According to the figures quoted by Berg (1948) there are 30 million *Gammarus* in a mile of the Susaa and 600 million invertebrate animals altogether, not counting those that can be seen only with a microscope. I mention these figures because I think that they may be of interest to anyone who is contemplating adding invertebrates to a river to improve the food for fish; he may be doing little more than the equivalent of paying a lot of money for a bucket of water to pour into a stream whose flow is not as copious as desired.

Some Scientific Considerations of Numbers

To obtain a real picture of production, one should know for each species how many eggs are produced, at what age each larva that comes from them dies, and what it weighs at the time of its demise. This is not easy and will not be achieved until we have started our taxonomic work all over again and found methods of identifying the eggs of each species, which is quite likely to be possible. The only person who has made a complete assessment of productivity is K. R. Allen whose work on the trout in the New Zealand River Horokiwi is well known. A very important point that he brings out is that the production by the very small forms is considerable. For example, he calculated that 1000 fry would give rise to 10 lb. of trout flesh before the last survivor was dead; of this 10 lb. no less than 3¾ was produced by the 985 specimens which died before they were 6 months old (Allen (1952) fig. 6).

It will be a very long time before we have information of this kind for every species.

Occurence of Animals in different parts of a Tarn

One of the commonest questions that fishermen ask is what type of weed harbours most invertebrates, and it is clearly a point of great importance. It is not a problem that has attracted the attention of scientists but I have been gaining some relevant figures in a Lake District tarn or fishpond during the last few years. For zoological purposes the vegetation can be divided into four types:

(1) Emergent—mainly Sedge (*Carex*).
(2) Floating-leaved—entirely Floating Pond Weed (*Potamogeton natans*).
(3) Sward—thick *Littorella uniflora* in the shallow water.
(4) Milfoil (*Myriophyllum*) all over the deeper parts of the tarn. The greatest depth is about 9 feet and the total area about an acre.

I shall consider first the range of certain species that are much commoner in some parts of the tarn than in others and then the total number of animals. *Holocentropus dubius*, a caddis whose larva makes no case but spins a net, is much more numerous in the milfoil than anywhere else. *Cloeon dipterum* is found in shallow water, whereas *Cloeon simile* occurs mainly in the milfoil in the deep water. I think that both these species are known to fishermen as Lake Olives when they reach the flying stage. Two small dragon-flies, one bright red and known as *Pyrrhosoma*, the other bright blue and known as *Enallagma*, are, in the nymph stage, among the commonest animals in the tarn. *Pyrrhosoma* is confined to shallow water, but *Enallagma* occurs in the milfoil out in the middle as well and is very scarce in the sedge. Various species of water beetles and water bugs are confined to the shallow water.

I have no idea why the caddis-fly or the two Ephemeroptera are distributed as they are, but the occurrence of the dragonflies can be explained at once by anyone who watches them laying eggs. All who haunt the waterside will be familiar with the way in which dragon-flies fly about in pairs, though perhaps not all know that it is the male who leads and who apparently takes the important decisions. In fact in the recent *New Naturalist* volume on the group it is related that one species will perform the typical oviposition act even though the female be dead. However, in the two with which we are now concerned the responsibilities of the male are less. A pair of *Pyrrhosoma* alight on a stem or a floating leaf of *Potamogeton natans*, and the female then dips her abdomen into the water and inserts her eggs into the stem or stalk as far down as she can reach without getting her wings wet. Oviposition completed, the pair fly away. *Enallagma* may also be seen alighting on emerging stems but, if the air is still, many fly over the middle parts of the tarn and alight on the inflorescences of milfoil which project but half an inch or so above the surface. The female immediately starts to walk under water and the male lets go when his wings are in danger of getting wet. The female may descend several feet below the surface to lay her eggs, and, when she has finished, she has only to release her hold and the bubble of air trapped between her wings brings her up to the surface in a flash. No part of the tarn is inaccessible to the egg-laying *Enallagma,* whereas *Pyrrhosoma* is confined to these regions where emergent or floating-leaved plants grow, and apparently the nymphs move little from the place where they hatch. This is in strong contrast to the behaviour of the green dragon-fly, *Lestes,* which lays its eggs in the same way as *Pyrrhosoma* but whose nymphs spread all over the tarn soon after emergence.

The water-beetles and water-bugs must come to the surface periodically, for they obtain oxygen from a bubble of air carried on the body. A long journey would expose them to the attacks of predators and it may be supposed that it is to avoid this danger that they frequent shallow water.

Evidently behaviour is an important factor determining where species occur. *Gammarus pulex*, the freshwater shrimp, also illustrates this point. It is scarce in the tarn except in one corner where the bottom is stony. Obviously there can be nothing unfavourable about the water and it is not easy to imagine how food supply can differ significantly under stones and among plants. The most plausible explanation is that plants fail to provide something, probably cover of a particular kind, which *Gammarus* seeks and accordingly it moves out of them to continue the search elsewhere.

Incidentally it is common practice to cut floating pond-weed during the summer in Lake District tarns, which results in the removal of great numbers of eggs of *Pyrrhosoma.*

The average number of specimens in different plants, shown below, is based on 7 visits to the tarn in 1956, 9 in 1957, 4 in 1958 and 3 in 1959. On each visit collections were made from about twelve different stations but, for various reasons, not all are included here.

	Littorella			*Carex*			*Pot. natans*	*Myriophyllum*	
Total animals	355	318	272	210	203	200	174	79	95
Ephemeroptera	159	147	106	109	88	62	54	17	21
Dragon-flies	98	102	116	24	25	44	27	18	25

Each figure represents the average number of animals at a different station in the plants named, and it will be noted that there is rather little variation; the last station in *Littorella* yielded less than the other two, but this was probably because the plants formed a less thick cover there at the start of the investigation.

What really matters, as was emphasized at the start, is not total numbers but total weight produced in a year and these figures, which include 29 species, must be examined very carefully before they are used to compare the productivity of the four kinds of plant. Such examination reveals that there is no species of animal which has a life history distinctly different from that of all the rest and which preponderates in one kind of plant, nor any animal which, distinctly heavier than all others, abounds in some plants but not all.

Pyrrhosoma takes three years to complete development in *Carex* and two years in *Littorella* and, since it is one of the commonest species, this will lower the value of the *Carex* figures in relation to those of the other plants. Apart from this, close familiarity with all the species involved leads me to believe that, when specimens have been weighed, annual productivity in the four plants will be found not to differ greatly from the figures quoted above. They stand roughly in the proportion 4:3:2:1; in other words there are four times as many animals in *Littorella* as there are in *Myriophyllum*. This is a finding which calls for examination. *Myriophyllum* and *Potamogeton natans* die down to some extent in winter and offer less cover then, which may be why they hold smaller populations. *Carex* and *Littorella* do not change greatly from one year's end to another. *Littorella* probably offers a bigger surface area than *Carex* and therefore more pasturage for the herbivores, which, as far as we know, feed mainly on the algae growing on the surfaces of higher plants and inanimate objects. In fact the stems are always coated with algae and it looks as if the amount available is much greater than the amount consumed, but, until more is known about which species of algae are eaten, nothing can be stated with confidence. Probably because it provides better vantage points, there are in the *Littorella* also more carnivores, mainly dragon-fly nymphs, creatures that do not pursue their prey but lie in wait until it comes within reach. There is a big open space between *Carex* plants and in this one may imagine that a large population of water-fleas, the main food of the dragon-flies, can move about with only an occasional specimen swimming near enough to a stem to get caught and eaten. The leaves of *Littorella* are close together and anything swimming among them must come within range of a lurking predator much more often. The structure of the substratum created by different species of plant may well prove to be one of the important factors determining the number of animals to be found in a given volume of it. Not only does this need investigating but also the question, one of great practical importance, of how much of the invertebrate food in it fish are able to get out of any one kind of plant.

It is not easy to determine exactly what limits the size of a population but there are four factors which call for discussion against the background of what has just been written. A poor population may be due to the following:

(1) Too few eggs are laid. This is a commonly advanced explanation; for example, it is frequently stated that a poor hatch of Mayfly is due to wet and windy conditions having interfered with oviposition two or three years previously. This may well be true but nobody, as far as I know, has ever proved it. A female *Ephemera* can lay some 2,500 eggs, possibly more, and therefore only a few females could provide all the nymphs that quite a big stretch of river could support. Very often these simple and apparently obvious correlations in biology prove complex when they are examined carefully. It is indeed possible that a particularly good year for eggs would lead to a poor crop of adults because the resulting larvae were so numerous that nearly all died of starvation.

(2) There is not enough to eat. Fundamentally food must be the cause of different rates of production; it would be optimistic to expect one of our mountain tarns draining poor and rocky fell-side to yield as great a weight of fish as the same volume of water in a river draining the lush pastures of Hampshire, for example. All the same, our postbag at the Freshwater Biological Association reveals that such optimists do exist. However a fundamentally productive piece of water does not always produce a good crop of fish. In the first place water-plants, especially algae, are not all equally palatable or nutritious and some are distasteful or actually poisonous to animals. This important field has been studied rather thoroughly in recent years in Russia and the International Association of Limnology hopes shortly to publish an account of the work in one of the western European languages. Herbivores are often small and it is well established that, if fish are to grow well, there must be food of ever-increasing size available to them as they get larger. This means that they are often feeding extensively on other carnivores and here is another link in the chain which may be a weak one. Carnivores may be scarce if, as suggested above when dragon-flies were being discussed, vantage points from which prey can be secured are few.

(3) Too many are eaten. A vantage point for a small predator must also serve to protect it from a larger one. Many aquarists will have had the experience of bringing in a sample of pond fauna that was evidently existing in a state of balance and of seeing one carnivore, a large beetle larva or dragon-fly nymph, eat everything else in a day or two when the catch was placed in an aquarium. The dragon-fly nymph must spend its days in weed because it is not a good swimmer, but the beetle larva is and it can hunt in open water. The fact that no species has ever adapted itself to existence in the middle of big lakes where there is generally a rich supply of plankton to feed on is perhaps because it would be so vulnerable to fish.

(4) Territory. I do not know whether freshwater invertebrates ever establish territories, but fish certainly do. Kalleberg (1958), working at the famous Swedish station at Drottningholm, observed young trout in a large tank and noted that each one established a territory from which it chased intruders with ferocity. The size of the territories depended on the configuration of the bottom; if it was flat and regular, the fish would not tolerate a neighbour within a distance that excited no reaction if there was a large stone or other irregularity between them. As the fish grew larger, they increased the size of the territory and the weaker ones were pushed out and probably perished. The population of trout in a stony stream, therefore, depends above all on the configuration of the bottom. This is a point not only relevant to the present discussion but of some practical importance to those concerned with stocking. Kalleberg records that the fish rarely hunted for their food but waited under the lee of a stone for objects washed down by the current. The territorial and feeding behaviour changed completely when the current speed fell below a certain level.

We are beginning to be able to perceive dimly the conditions that will give best fish growth under natural conditions. There is a nice balance between a number of interacting factors. Basically the nutrient supply entering the system must influence the output, but the relation between the two is rarely direct. Efficient utilization depends on a certain combination of species in a certain proportion and this is a product of the behaviour of each one and its reactions to other species and to the inanimate and vegetable background. Ideally from the human point of view each link in the food chain should be able to keep the numbers of the one below at a level where it neither overcrops nor undercrops the food available to it. We know remarkably little about this system and how far reality is from the ideal.

The biologist whose object is to produce game fish has an additional problem unknown to other scientists whose task is to make two blades of grass or two pounds of flesh grow where one grew before. The fisherman wants not only plenty of well grown specimens but fish that will rise to take food at the surface. It is easy to imagine, and there may well be actual examples, a place where there is so much to eat at the bottom that no fish ever bother to feed at the top, and replete monsters stare up with cynical amusement at the biped animals who cast little objects on to the water with so much unrewarded doggedness.

REFERENCES

Allen, K. R. (1952). A New Zealand trout stream: some facts and figures. *New Zealand Marine Dept. Fish. Bull.* 10A.

Berg, K. (1948). Biological studies on the River Susaa. *Folia limnol. scand.* No. 4, pp. 318.

Harker, J. E. (1952). A study of the life cycles and growth-rates of four species of mayflies. *Proc. R. ent. Soc. Lond.* A. **27**, 77–85.

Hynes, H. B. N. (1955). The reproductive cycle of some British freshwater Gammaridae. *J. Anim. Ecol.* **24**, 352–387.

Hynes, H. B. N. (1960). *Biology of polluted waters.* Liverpool University Press.

Kalleberg, H. (1958). Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *S. trutta* L.). *Rep. Inst. Freshw. Res. Drottning.* **39**, 55–98.

Macan, T. T. (1957). The life histories and migrations of the Ephemeroptera in a stony stream. *Trans. Soc. Brit. Ent.* **12**, 129–156.

Macan, T. T. (1961). A review of running water studies. *Verh. int. Ver. Limnol.* **14**.

Pleskot, G. (1958). Die Periodizität einiger Ephemeropteren der Schwechat. *Wasser und Abwasser* 1958. 1–32.

MADE AND PRINTED IN GREAT BRITAIN

WILDLIFE MONOGRAPHS

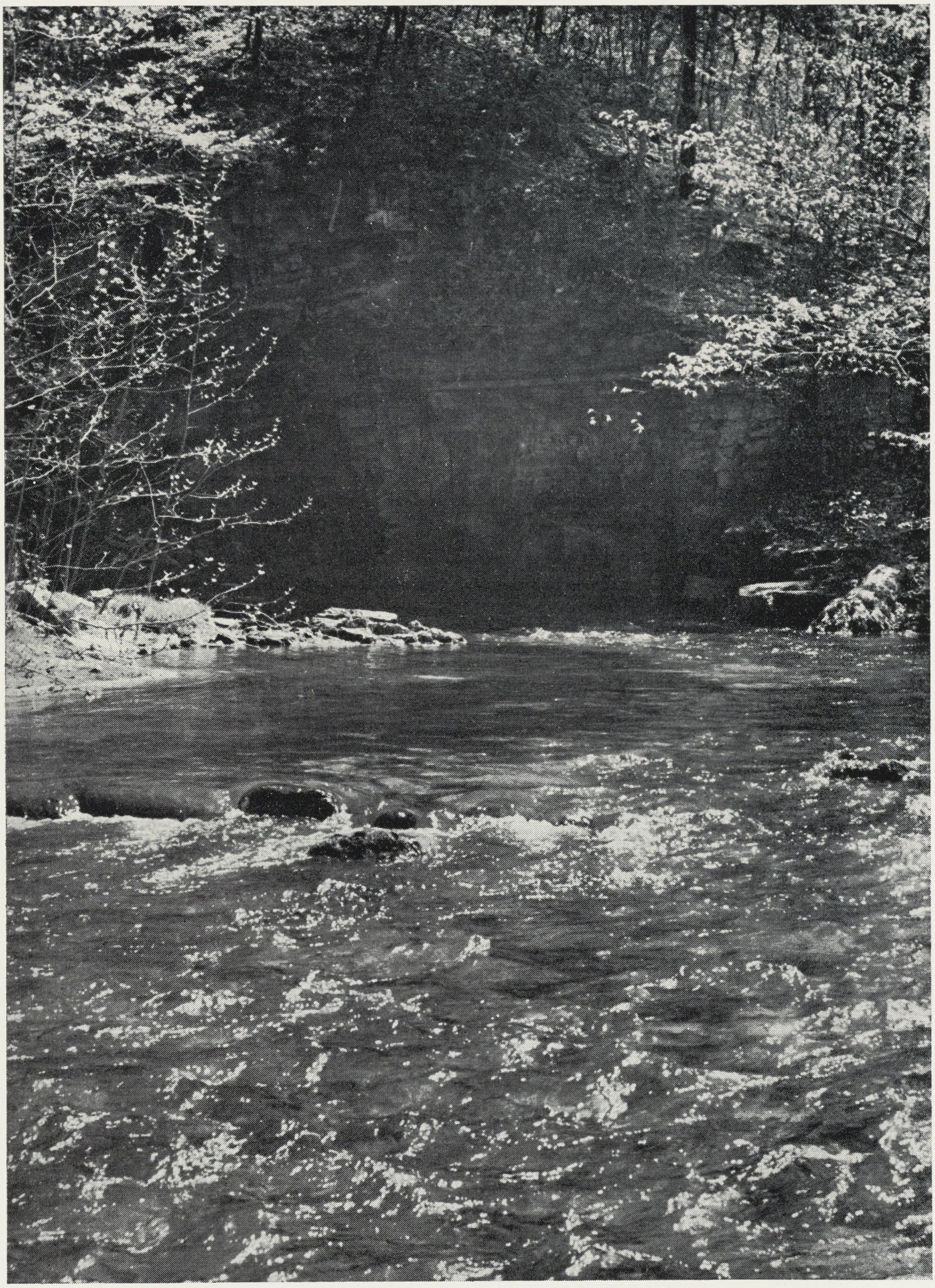
A Publication of the Wildlife Society

THE ECOLOGY OF A SPRING STREAM DOE RUN, MEADE COUNTY, KENTUCKY

by

W. L. MINCKLEY

SEPTEMBER 1963 NO. 11



FRONTISPIECE. Spring source of Doe Run, Meade County, Ky., April 24, 1960. Photograph by Charles B. Stone.

THE ECOLOGY OF A SPRING STREAM DOE RUN, MEADE COUNTY, KENTUCKY[1]

W. L. Minckley[2]

Department of Biology, University of Louisville, Louisville 8, Kentucky

CONTENTS

---

[1] Contribution on No. 64 (New Series) from the Department of Biology, University of Louisville, Louisville 8, Kentucky.

[2] Present Address: Department of Zoology, Arizona State University, Tempe, Arizona.

INTRODUCTION

In recent years an increasing amount of research has been directed toward the ecology of flowing waters, mainly because of their importance in the disposal of industrial and domestic wastes. Much of the research on streams in North America has been oriented toward various aspects of pollution control, the search for indices of pollution (both biological and physicochemical), and toward the management of streams for sport or commercial fisheries. However, many problems that now confuse findings of applied research may be solved only after accumulation of basic data.

This paper concerns an unpolluted spring stream, somewhat modified by man, and is an attempt to describe and analyze its physical, chemical, and biological characteristics. Investigations of Doe Run, Meade County, Ky., were begun in February 1959, and were intensified November 1, 1959. A year of study was completed before the downstream half of the creek was prepared for impoundment, and intensive sampling ended on July 9, 1961, when impoundment was effected.

ACKNOWLEDGMENTS

This report is based on research performed under Contract No. AT-(40-1)-2595 between the U. S. Atomic Energy Commission and the University of Louisville, with Louis A. Krumholz as principal investigator. It is a revision of parts of a dissertation submitted to the graduate faculty of the University of Louisville in partial fulfillment of requirements for the degree of Doctor of Philosophy.

Many persons assisted in the various phases of study and I am grateful to all of them. Special mention should be made of my fellow students, both graduate and undergraduate, who gave their time and energy freely in the field and in the laboratory. The landowners along Doe Run are to be given special consideration and thanks. The Kentucky Department of Fish and Wildlife Resources granted the necessary permits for collection of vertebrates from the area. Louis A. Krumholz, University of Louisville, was available at all times for discussion of problems that arose in the course of study, and his ideas and suggestions were major factors in completion of this report. Jane S. Davis, Virginia Institute of Marine Science, prepared most of the figures.

Many persons assisted in identification of invertebrates from Doe Run: Gerald A. Cole, Arizona State University, and E. L. Bousfield, National Museum of Canada, identified malacostracans; William E. Ricker, Fisheries Research Board of Canada, Plecoptera; Herbert H. Ross, Illinois Natural History Survey, Trichoptera; Lewis Berner, University of Florida, Ephemeroptera; and Stuart E. Neff, Virginia Polytechnic Institute, Diptera. Assistance in identification of algae and higher plants was provided by Arland T. Hotchkiss and Donald R. Tindall, University of Louisville.

This paper is dedicated to my wife, Barbara, who assisted in many ways in its completion, and who deserves special recognition.

DESCRIPTION OF THE STUDY AREA

Geographic, Geologic, and Historic Information

The main spring of Doe Run (Front.) lies about 3 miles east and 0.4 mile north of Ekron, Ky., in eastern Meade County, 37° 56′ N and 86° 07′ W (Fig. 1). The creek flows north–northeast and is 9.7 miles long, although the distance from source to mouth by airline is only 5 miles. Doe Run enters the Ohio River about 3.5 miles east of Brandenburg, Ky.

The stream is located on a belt of Mississippian limestones that exhibit extensive karst topography and extend from central Indiana through Kentucky and into central Tennessee (Swinnerton, 1942). In Kentucky, this well-defined topographic area is called the Pennyroyal and is considered a major physiographic region of the state (Sauer, 1927).

The uplands into which Doe Run has deeply incised lie approximately 680 feet

A Survey of the Bottom Fauna of Streams in the Scottish Highlands

Part I
Composition of the Fauna

by

N. C. Morgan & Henry J. Egglishaw

Agricultural Scientific Services, East Craigs, Edinburgh and Freshwater Fisheries Laboratory, Pitlochry, Perthshire

Introduction

As part of the studies being carried out on the biology of the Atlantic salmon at the Freshwater Fisheries Laboratory, Pitlochry, it is intended to investigate the feeding of juvenile salmon in the Scottish Highlands. Before commencing these feeding studies it was considered necessary to study the invertebrate fauna of streams within this area and the variation in the quantity and quality of the bottom fauna between different streams. Since there is little published information on the fauna of streams in the Highlands it was decided to carry out a survey of streams north of the Highland Boundary Fault. Having done this a stream typical of the area could be chosen for detailed feeding studies and streams with exceptionally rich or poor faunas selected for comparison.

The main aims were to determine the composition of the bottom fauna and the distribution of the different species and, if possible, to relate the findings to the physical and chemical conditions of the stream, the geology of its watershed, or its geographical position. This paper deals with the composition and distribution of the fauna and a second paper dealing with the influence on the fauna of the factors mentioned above will be published later.

Received July 9, 1963.

As it is known that the composition of a stream fauna changes as the nature of the stream changes along its course, the choice lay between sampling a small number of streams at a large number of stations along their courses or sampling many more streams at only one station. In view of the aims of the work the latter plan was adopted, a restriction on the choice of sampling sites being that all were within the 'salmonid region' (ILLIES, 1952). All told, bottom fauna samples were taken from 103 streams and the collections from 50 of these streams and the stream in which the sampling techniques were tested have been analysed in detail.

The streams were selected to give a wide geographical coverage of the area and each was sampled at a point above which it was considered to have flowed over only one particular rock type. The geological information was obtained from the Geological Maps and Memoirs prepared by the Ordnance Survey. As some parts of the area have not been surveyed in great detail and the scale of the maps was small, it is possible that intrusions of different rocks occurred of which the authors were not aware.

In a somewhat ambitious study of this sort, by a small team of workers, it is clear that the number of times which the streams are sampled must be kept to a minimum. The work of MACAN (1957a) and HYNES (1961) indicates that the minimum number of times in a year that streams in Britain can be sampled in order to collect all the major species occurring is twice. Accordingly, the streams were sampled in February-March 1960 to obtain the spring emerging insects at their largest before they emerged as adults, and again in July 1960 to obtain the summer emerging insects at their largest.

By sampling all the streams in a reasonably short period of time and in the same year it is hoped that annual fluctuations and most short-term fluctuations in the bottom fauna, due to variations in climatic conditions, have been avoided.

No similar survey of streams has been made in the British Isles although detailed work has been carried out on the fauna of individual streams (HYNES, 1961 gives references).

METHODS

To keep the sampling period as short as possible the collecting technique employed had to be rapid yet, at the same time, accurate within the requirements of the survey. It was not necessary to obtain absolute values of the quantity of the bottom fauna in a stream, even if this were possible, as long as the differences between catches were directly proportional to the differences between streams.

The technique had also to be one which could be used on a wide variety of substrates as the stream beds would vary from silt to boulders. Various techniques were examined and comments on these are given below.

A shovel-net sampler, similar to that described by MACAN (1958) was found to work satisfactorily only where the stones of the stream bottom were not more than about 6 in. (15 cm) across and where the packing of the stones and gravel was sufficiently loose to allow the shovel-net to be driven through the bottom. The frame of the net had an external width of 14 in. (35.5 cm) and the use of a larger net was impractical as the apparatus would be too unwieldy. The shovel-net was found to be of limited use in Highland streams where a considerable proportion of the bottom is usually composed of large stones or bedrock.

The shovel-net was also employed as a Surber sampler (SURBER, 1936) by setting it on the downstream side of a wooden frame with raised sides which surrounded 1 ft^2 of the bottom. The stones from this area were hand-picked into a bucket and the remaining sand and gravel thoroughly disturbed so that the fauna and lighter debris were washed into the shovel-net by the current. The stones were scrubbed with a nail brush, in a bowl of water, and the washings filtered through a net and preserved with the contents of the shovel-net. The scope of the method was greater since it could be used on a wider variety of substrates. However, it involved too much time and labour for it to be of practical value in carrying out a stream survey on the scale envisaged, each sample taking about three-quarters of an hour to collect. Furthermore, NEEDHAM and USINGER (1956), using a square foot Surber sampler, found that 73 samples were required to give an estimate of the total number of organisms in a single riffle significant at the 95% level of confidence but that two or three samples were sufficient to ensure that at least one representative of each of the commonest genera was present. This should be possible from a less time-consuming method.

Tests were also carried out using NEILL'S sampler (NEILL, 1938) but it was found that this could only be used effectively on a very limited range of types of bottom.

All the above techniques probably underestimate the fauna of the area sampled. It was shown, using dyes, that not all the water flowing over the sampling area passed through the collecting nets so that a proportion of the fauna would probably be missed. Since much time was taken up in separating the animals from the other organic and mineral material taken with the samples, it was practical to sacrifice some accuracy for a technique which would be more rapid and versatile.

HYNES (1961) used a triangular handnet, which was held vertically against the stream bed, to collect the animals whilst the area of the stream bed immediately upstream was vigorously stirred by the collector. Each sample consisted of ten such operations. HYNES (personal communication) has also used a similar technique whereby a standard number of kicks are given in front of the net to provide the sample.

This latter method was tested in January 1960 at Allt Leathan (stream number 51), a moorland stream running off the northern slopes of Schiehallion, Perthshire. A handnet was used which consisted of a pyramid-shaped net, 30 cm deep, made of grit gauze, 12 meshes per cm, which was attached to a square frame with 24 cm sides. This net was held against the downstream side of the area to be sampled and the substrate disturbed with the investigator's boot. A given number of kicks were made in an upstream direction for a distance of about 18 inches (46 cm), each kick digging deeper into the substrate. The stream current carried a proportion of the debris and animals which were disturbed into the net, and a pause was made between each kick for this to take place.

Table I shows the results obtained on 25th January, 1960, for six standard kick-samples, three kicks being made for each sample. They were taken in a fairly uniform stretch of the stream where the bottom consisted of angular and rounded-angular stones up to 8 in. (20 cm) in diameter compacted in gravel and sand. With the exception of sample V the catches showed good agreement for a method which was only expected to be quasi-quantitative. *Brachyptera risi* nymphs and *Simulium* spp. larvae show a tendency to clump so that variation in the catches of these is to be expected.

In order to decide upon the number of kicks which should be given, a series of six-kick samples were taken at Allt Leathan and the net emptied after every second kick so that each sample was the sum of three pairs of kicks at the one site. Of the total catch at each site, 51—87% was taken in the first two kicks, 9—36% in the second two kicks and 4—15% in the third two kicks. The only species to occur in the last pair of kicks of any sample and not in the first and second pairs were *Esolus parellelopipedus* (two larvae in one sample) and *Latelmis volkmari* (one larva in each of two others). These helmid larvae presumably burrow further into the substrate than the other animals and are not of importance as fish food. It was therefore decided that four kicks at each site would be adequate. More kicks would give very few more animals but would increase the amount of debris from which they would have to be separated.

This method of sampling can be used on a wide variety of substrates, from sand up to stones 18 inches (45 cm) to 2 feet (60 cm) across, amongst weed and even on bedrock using the boot as a scraper. The method is rapid and the whole process of selecting a site, taking the sample, bottling, labelling and making a description of the substrate sampled takes about 10 minutes.

TABLE I

The catches from Allt Leathan, January 1960, using the kick-sampling method.

	SAMPLE NUMBER					
	I	II	III	IV	V	VI
PLECOPTERA						
Amphinemura sulcicollis (STEPH.)	7	26	4	13	3	19
Protonemura praecox (MORT.)	7	2	5	4	0	1
Leuctra inermis KEMPNY	6	20	13	14	3	5
Leuctra hippopus (KEMPNY)	0	4	5	2	1	1
Leuctra spp.	0	1	1	0	0	0
Brachyptera risi (MORT.)	12	0	0	3	0	4
Isoperla grammatica (PODA)	1	2	0	1	0	1
EPHEMEROPTERA						
Rhithrogena spp.	8	18	7	15	3	9
Ecdyonurus spp.	0	0	8	7	4	3
Baetis rhodani (PICT.)	22	10	12	15	4	17
Baetis pumilus (BURM.)	1	3	4	1	4	4
Baetis spp.	1	10	3	1	1	0
TRICHOPTERA	3	1	3	3	0	2
DIPTERA						
Simulium spp.	19	0	0	1	0	2
Chironomidae	3	1	3	2	1	1
OTHER spp. of invertebrates	2	3	2	1	0	2
Total	92	101	70	83	24	71

In view of the versatility, speed and good replication of results it was decided to use this technique for the collections during the stream survey. Three four-kick-samples were taken in each stream, one in a pool, one in a run and a third in a position where conditions were intermediate between those at the other two sampling sites. Some streams are far more variable in physical characteristics than others but by distributing the sampling points in this way there is a good chance of catching all the common species even in the most variable streams.

Regular collections of bottom fauna organisms were made from Allt Leathan, once a month, from February 1949 to May 1951 (unpublished data) using a tray technique, similar to that employed by MOON (1935) in Windermere, supplemented by handnet collections. Also shovel-net and cylinder samples were taken in June and September 1959. The quality of the fauna as shown by these other methods may be compared with that obtained during the stream survey on 25th January and 29th June 1960. A total of 55 species were distinguished from all the collections taken at the stream and of these 45 were recorded during the stream survey. Only the Plecoptera and Ephemeroptera were determined to species in all the collections and, of these, 11 out of 15 species of Plecoptera and 7 out of 8 species of Ephemeroptera were recorded during the present stream survey. One species of mayfly, *Heptagenia lateralis*, which had not been recorded previously, was taken in the kick-samples. All the commoner species in the stream were well represented in the kick-samples.

A total of four shovel-net samples, sampling one square foot each and a cylinder sample, covering about this area, were taken on 30th June, 1959 and three standard kick-samples were taken from the same region on 29th June, 1960. Comparison of the qualitative composition of the catches in each year showed that 39 species were taken in 1959 and 33 species in 1960 of which 27 were common to both years. The same species were recorded as being the most abundant by all the methods used. Thus the advantage gained by sampling more streams, using the kick-sample technique, far outweighs the advantage of the slightly higher number of species obtained by using much more laborious and perhaps more accurate methods for a smaller number of streams. The habitats within the same stream are generally so variable that a strictly quantitative method would have little value over a quasi-quantitative method unless an extremely large number of samples were taken.

The kick-samples in Allt Leathan caught one-fifth to one-tenth of the number of animals caught in shovel-net samples, covering one square foot, taken at the same time of year. These results, however, are not strictly comparable as the shovel-net had half the mesh size of the kick-sample nets and thus caught many more small nymphs and larvae. Deducting the nymphs under 2 mm and the larvae of *Corynoneura* spp., which were not caught satisfactorily by the kick-sample nets, each kick-sample caught one-third to one-fifth of the number of animals caught by the shovel-nets.

Formalin was added to the kick-samples in the field and they were sorted later in the laboratory. Small portions at a time of the sample were examined, in white photographic trays, using x2 head-magnifiers until all the animals had been removed from the debris.

Complete identification to species was only attempted for the Platyhelminthes, Hirudinea, Isopoda, Amphipoda, Plecoptera, Ephemeroptera, Coleoptera and Gastropoda. Many animals within the other major taxa could not be identified further than family.

After the animals had been counted and identified the total wet weight of the animals in each sample was determined to the nearest milligram. Before weighing, the preserving fluid was drained off the sample and the surface moisture removed from the animals by spreading and rolling them on a filter paper with a fine brush.

Clinging forms such as *Ancylastrum fluviatile* and Hydroptilidae, which can attach themselves tightly to stones, were not always collected by the kick-sampling technique. The kick-sample collections were therefore supplemented by picking stones from the stream and scrubbing them with a nail-brush in a bucket of water. These washings were then sieved through a 100 mesh net (39 meshes per cm). They were preserved and sorted in the same manner as the kick-samples, but complete counts were not carried out, the samples being scanned under a microscope and only the presence of a species being recorded.

It might also be expected that the stony-cased caddis would not be sampled properly by a technique which depends on flow to wash the animals into the net and, indeed, a large proportion of the caddis caught were caseless forms. However, SPRULES (1947), using an emergence cage to trap insects, found that the most abundant caddis in streams in Algonquin Park, Ontario were caseless forms.

A short description of each stream at the site where it was sampled is given in Appendix 1. In the spring a sample of water was taken from each stream for chemical analysis. The full results of these analyses will be published elsewhere by HOLDEN, but the chemical richness of the water, as given by total cation concentration (i.e. the sum of the amounts of calcium, sodium, magnesium and potassium ions) expressed in micro-equivalents per litre, is given in Appendix 2.

The chemical composition of the water of a stream may be considerably different during spates from that under normal conditions. It was fortunate that during the spring of 1960 few streams were in spate when they were visited but, where they were, further samples for analysis were taken later under more normal conditions.

THE COMBINED FAUNA OF THE STREAMS

In order to give an overall picture of the stream fauna of the area covered by the survey both the spring and summer kick-sample catches from fifty streams were summed. These streams occurred on the five major kinds of rock covered by the survey and comprised 16 on schist, 13 on granite and 7 each on basalt, limestone and sandstone. The composition of the fauna is shown in Table II. Unless indicated otherwise the insects mentioned are nymphs or larvae and this procedure will be adopted throughout this paper. Only the numbers of the most important groups and species are expressed as percentages of the total fauna. The presence of a species in the stone-scrubbings was sufficient for it to be included in the column headed 'Occ.' even though the species was not collected in the kick-samples from that stream.

Although included in the totals of Table II the following insects which did not occur in more than one stream have not been mentioned by name: *Brachyptera putata* (Newm.), *Leptophlebia marginata* (L.) and *Ochthebius impressicolis* Cast. adult in the spring, and *Taeniopteryx nebulosa* (L.), *Ephemera danica* Müll., *Centroptilum pennulatum* Etn., *Procloeon rufulum* (Müll), *Goera* sp., Lepidostomatinae, Sericostomatidae, *Brychius elevatus* Py. adult, Haliplidae, *Oreodytes septentrionalis* Gyll. adult, *Limnebius truncatellus* Thumb. adult, *Dryops* sp. adult and *Thaumalea* sp. in the summer.

A minimum number of 131 species were differentiated, although for the Hydrozoa, Rhabdocoela, Nematoda, Oligochaeta, Ostracoda, Diptera and Hydracarina the authors were unable to identify the representatives to specific level. Of these 131 species, 94 occurred in the spring and 118 in the summer samples.

The slight differences in the intensity and clarity of the pattern on the abdominal terga of *Baetis scambus* Etn. and *B. bioculatus* (L.) mentioned by Macan (1950) indicated that our specimens entered under *B. scambus/bioculatus* (L.) in Table II and Appendix 2 probably belonged to the former species. The larvae entered as *Hydropsyche* (?) *fulvipes* are almost certainly *H. fulvipes* but these cannot be distinguished from *H. saxonica* McLach with certainty. Miss R. M. Badcock, who confirmed the identification, points out, however, that *H. saxonica* is very rare and that she has not come across it in Scotland during quite extensive collecting, her only two records coming from the south of England. The possibility of *H. saxonica* occurring in the Highlands cannot, however, be ruled out as it does occur in small stony streams. It is also likely that the *Polycentropus* spp. are all *P. flavomaculatus* (Pictet). Over 99% of the larvae entered under Tanypodinae were *Ablabesmyia* spp. Similarly Humphries & Frost (1937) in their survey of the River Liffey found that the Tanypodinae were dominated by *Ablabesmyia* spp.

The spring fauna

The fauna of each of the fifty streams surveyed appears in the tables in Appendix 2. Details of the composition of the fauna in the spring and summer are given. Information on the variation of a species from one stream to another, its distribution and its frequency of occurrence can be extracted from these. The streams are grouped according to the type of rock upon which they were situated and, within each group, are arranged in ascending order of chemical richness. A total of 10,430 animals was collected from these streams in the spring. Twelve streams had a total of between 9 and 100 animals in the three samples, 18 had 101—200, seven had 201—300, six had 301—400, six had 401—500 and one 638.

The spring fauna (Table II) was composed mainly of Plecoptera nymphs (33.1% of total fauna), Ephemeroptera nymphs (31.8%) and Diptera (20.2%). The remaining 14.9% of the fauna was made up of several orders, of which Trichoptera, Coleoptera and Oligochaeta were the most important.

The ephemeropteran *Baetis rhodani* was the most abundant and widespread animal collected in the spring. It formed 15.5.% of the total fauna and occurred in 47 of the 50 streams. This species and *Rhithrogena* sp. formed three-quarters of the mayfly catch. The second most abundant and widespread animal in the spring was the plecopteran *Leuctra inermis* (11.2% of the fauna and present in 43 streams) which made up one-third of the stoneflies. *Amphinemura sulcicollis* and *Brachyptera risi* were other important stoneflies. Although *Chloroperla torrentium* and *Isoperla grammatica* each amounted to only 2.3% of the fauna they were both very widespread occurring in at least 38 of the streams. The mayfly *Baetis pumilus* was also widely distributed.

Two more species of stoneflies, *Leuctra hippopus* and *Protonemura meyeri* each formed 1% or more of the spring fauna. Fourteen other species of stoneflies and nine of mayflies occurred much less frequently. The categories 'Other Plecoptera' and 'Other Ephemeroptera' include four *Brachyptera putata* and four *Leptophlebia marginata* respectively.

The Diptera were mainly the larvae of *Simulium* (10.3%) and of Chironomidae (8.8%), both taxa containing several species. The samples from all but two of the streams contained larvae of these two groups. There were representatives of six other families of Diptera present but all told they accounted for only 1.1% of the total fauna.

Nearly all of the Coleoptera (3.3%) were larvae or adults of four species of the family Helmidae, *Helmis maugei*, *Esolus parallelopipedus*, *Limnius tuberculatus*, and *Latelmis volkmari*.

The Trichoptera formed 5.2% of the fauna and were represented by eight families of which the caseless caddises belonging to the Hydropsychidae and Polycentropidae accounted for more than half of the Trichopteran fauna. Although hydroptilid larvae were present in the kick-samples from ten streams, they also occurred among the stone-scrubbings from another nine streams. The chironomid *Corynoneura* occurred in the kick-samples from two streams and the stone-scrubbings from another ten, and the freshwater limpet *Ancylastrum fluviatile* was caught in the kick-samples from five streams and the stone-scrubbings from another eight. These were the only animals which were found in any appreciable amount in the stone-scrubbings and not in the kick-samples. No species of Ephemeroptera was found in the stone-scrubbings and not in the kick-samples, and four species of Plecoptera each occurred once in the stone-scrubbings when they were not in the kick-samples.

The entire oligochaete fauna (3.4%) was not identified but representatives which were examined by Dr. R. O. Brinkhurst were identified as *Nais elinguis*, *Ophidonais serpentina*, *Lumbriculus variegatus*, *Stylodrilus heringianus* and *Rhyacodrilus coccineus*. The Platyhelminthes (1.6%) were represented by the two species *Polycelis felina* and *Crenobia alpina*. Several Mollusca (0.4%) the amphipod *Gammarus pulex* (0.6%) and a small number of nematodes, leeches, ostracods and mites completed the spring fauna.

The summer fauna

A total of 32,306 animals were caught from the 50 streams in the summer, the total catches in individual burns ranging from 64 to 2943. Stream number 19 had almost dried out when sampled in July and it was possible to take only two sets of kick-samples instead of three. In the overall total the lack of one kick-sample is insignificant. The catches from each stream are tabulated in Appendix 2.

The most abundant groups were Diptera (39% of the fauna) Ephemeroptera (23%) and Oligochaeta (16%). Platyhelminthes, Amphipoda, Plecoptera, Trichoptera and Coleoptera together formed 20% of the fauna and the other ten groups represented formed only 2% of the fauna.

The Chironomidae were the most abundant group of the Diptera forming 32% of the fauna. These were chiefly Orthocladiinae although a third of the chironomid catch belonged to the Tanytarsini. The carnivorous Tanypodinae formed only 5% of the total Chironomidae. The free-living larvae of the Tanypodinae would be expected to be more easily dislodged and caught using the kick-sample technique than larvae belonging to other groups of the Chironomidae, which suggests that the true proportion of Tanypodinae may be even less in Highland streams. Humphries & Frost (1937) found that Tanypodinae formed a very small proportion of the Chironomidae in moss. The large proportion of Orthocladiinae in the summer samples agrees with the findings of other workers (Humphries & Frost, 1937; Frost, 1942; Hynes, 1961) but the large proportion of Tanytarsini is interesting as, over the whole year, Hynes (1961) found that they were nowhere important in the Afon Hirnant, which was similar in characteristics to many of the streams sampled. The only other Diptera to occur frequently were *Simulium* spp. and *Dicranota* spp. The former tend to clump together in places where stream conditions suit their method of feeding, so that very high numbers were recorded from a few burns where a sample happened to have been taken at a point where *Simulium* spp. were aggregated. They were, however, widely distributed and the summing of the collections from a large number of streams must give a good estimate of their relative abundance in salmon and trout streams in the Scottish Highlands.

Of the Ephemeroptera, *Baetis* spp. were by far the most abundant, forming 18.3% of the fauna. Of all the animals which it was possible to identify to species *B. rhodani* was the most abundant and second most widespread. The *Baetis* nymphs under 3 mm in length could not be identified to species with certainty and are grouped as *Baetis* spp. If these are apportioned to species in the same proportion as those which could be identified specifically the number of *B. rhodani* would be more than doubled. *B. scambus/bioculatus* which was absent from the spring fauna was the second most abundant species of Baetis. *Ephemerella ignita*, which was also absent in the spring, was an important species in the summer. It is interesting that Hynes recorded such a small proprtion of *Baetis* spp. in July using a similar technique and particularly that the number of small nymphs was so low as shown by his silk-net and moss samples (Hynes, 1961, Fig. 2), when over half the *Baetis* spp. caught in the summer samples, during this survey, were under 3 mm long. On the other hand *Ephemerella ignita* was far more abundant in his July samples, being the most abundant animals in the stramin net samples.

Ninety per cent of the Oligochaeta were Naididae and the remaining 10% consisted of Lumbricidae, Enchytraeidae, Tubificidae and Lumbriculidae. Representative samples were identified by Dr. R. O. Brinkhurst as *Nais elingius*, *N. pseudobtusa*, *Ophidonais serpentina*, *Stylaria lacustris*, *Eiseniella* (?) *tetraedra*, *Lumbriculus variegatus*, *Aulodrilus pluriseta* and *Rhyacodrilus coccineus*.

Two species of Platyhelminthes were recorded and the small number which could not be identified, very probably belonged to these species. Although *Polycelis felina* occurred in far fewer streams than *Crenobia alpina* the total number caught was much higher, due to exceptionally large numbers in two streams where it formed

10.9% and 11.5% of the fauna.

The Plecoptera formed only 5% of the summer fauna and *Leuctra fusca* was the most abundant stonefly forming two-thirds of the stonefly catch. This species was recorded from more streams than any other single species. The stoneflies, shown as *Protonemura* spp. in Table II were all under 2 mm in length and were probably nearly all *P. meyeri* in which case this species would be the second most abundant.

Nearly two-thirds of the caddis flies were caseless forms. No species occurred in more than half of the streams sampled and only five taxa; *Hydropsyche instabilis*, *Polycentropus* spp., *Wormaldia* spp., *Rhyacophila dorsalis* and hydroptilids were caught in more than 15 streams. The Hydroptilidae were probably all *Hydroptila* spp. but because many larvae of this family have not yet been described this cannot be stated with certainty.

The Coleoptera were chiefly Helmidae. *Helmis maugei* (3.8% of fauna) was the most abundant species occurring in 32 streams although the most widespread species was *Latelmis volkmari* (0.9% of fauna) which occurred in 36 streams.

Although the Hydracarina formed a very low proportion of the total fauna they were widely distributed. Mollusca were recorded from less than half the streams. *Ancylastrum fluviatile* was the most widespread, occurring in 16 streams, but larger numbers of *Hydrobia jenkinsi* and *Limnaea peregra* were caught although they were far less widespread. In four streams *Ancylastrum fluviatile* was recorded from the stone-scrubbings only, but the number of occurrences based on kick-samples alone is still higher than those for *Hydrobia* and *Limnaea*. Smaller catches of *A. fluviatile* may have been taken because it adhers tightly to stones and is not nearly so easily dislodged as *H. jenkinsi* and *L. peregra*.

Comparison of the spring and summer faunas

The total number of animals caught in the 50 streams was three times greater in the summer than in the spring and this was accompanied by a small increase in the minimum number of species recorded (from 94 to 118). Although there were some changes in the qualitative composition of the catch many species were common to both the spring and summer samples and most of these were caught in larger numbers in the summer than in the spring. The total catch increased from spring to summer in 44 streams, becoming more than double in 31 of them, it decreased in four streams and remained about the same (within 10%) in two streams. This general

Table II

The combined catch from fifty streams for spring and summer

Organism	Spring No.	Spring %	Spring Occ.	Summer No.	Summer %	Summer Occ.
Hydra sp.	0			36		
RHABDOCOELIDA	0			1		
PLATYHELMINTHES						
Polycelis felina (Dalyell)	36		12	330	1.0	12
Crenobia alpina (Dana)	136	1.3	23	190	0.6	28
Platyhelminthes indet.				6		
NEMATODA	2			18		
OLIGOCHAETA						
Naididae	57	0.5		4589	14.2	
Other oligochaeta	302	2.9		518	1.6	
HIRUDINEA						
Glossiphonia complanata (L.)	2		2	1		1
Helobdella stagnalis (L.)	4		2	4		2
Erpobdella octoculata (L.)	6		1	3		1
OSTRACODA	6			24		
MALACOSTRACA						
Asellus aquaticus L.	0			8		1
Gammarus pulex (L.)	64	0.6	5	322	1.0	11
G. duebeni Lillj.	0			2		1
PLECOPTERA						
Brachyptera risi	476	4.6	38	0		
Amphinemura sulcicollis	861	8.3	42	4		3
Nemurella picteti Klapalek	1		1	24		5
Nemoura erratica Claassen	3		2	0		
N. cinerea (Retzius)	2		2	0		
N. cambrica (Steph.)	32		9	0		
Protonemura meyeri (Pict.)	106	1.0	26	61		14
P. praecox	14		8	9	0.6	1
Protonemura sp.	0			127		26
Leuctra inermis	1164	11.2	43	0		
L. hippopus	153	1.5	29	0		
L. nigra (Olivier)	8		4	3		3
L. fusca (L.)	2		1	1105	3.4	49
L. moselyi Mort.	1		1	18		7
Leuctra spp.	11			24		
Capnia bifrons (Newm.)	2		2	0		
Diura bicaudata (L.)	0			2		2
Perlodes microcephala Pict.	8		8	10		8
Dinocras cephalotes (Curt.)	39		9	91	0.3	19
Perla bipunctata Pict.	27		11	40		11
Chloroperla torrentium (Pict.)	245	2.3	40	19		10
C. tripunctata (Scop.)	43		19	28		11
Isoperla grammatica	243	2.3	38	14		8
Other Plecoptera	7			23		
EPHEMEROPTERA						
Paraleptophlebia submarginata (Steph.)	5		2	7		5
Ephemerella ignita (Poda)	0			1021	3.1	40
Caenis rivulorum Etn.	15		7	114	0.4	14
Baetis scambus/bioculatus	0			507	1.6	32
B. vernus/tenax	0			107	0.3	6
B. rhodani	1619	15.5	47	1804	5.6	45
B. pumilus	262	2.5	34	280	0.9	24
B. niger (L.)	5		3	10		4
Baetis spp.	317	3.1		3200	9.9	
Centroptilum luteolum (Müll.)	14		5	39		5
Ameletus inopinatus Etn.	4		3	0		
Rhithrogena sp.	902	8.6	41	39		11
Heptagenia sulphurea (Müll.)	2		2	1		1
H. lateralis (Curt.)	12		3	17		3
Heptagenia spp.	23			3		
Ecdyonurus venosus (Fabr.)	52		20	7		5
E. torrentis Kimmins	8	1.0	5	81	0.8	21
Ecdyonurus spp.	41			168		
Ecdyonuridae indet.	29			36		
Other Ephemeroptera	5			6		
MEGALOPTERA						
Sialis fuliginosa Pict.	0			4		2
TRICHOPTERA						
Limnephilidae	75			249		15
Silo spp.	23			12		5
Lepidostomatinae	25		9	0		
Hydropsyche instabilis Curt.	27			110		20
H. (?) *fulvipes* Curt.	28		7	10	0.7	4
H. angustipennis Curt.	0			1		1
Hydropsyche spp.	88		29	91		
Plectrocnemia sp.	2		1	19		11
Polycentropus sp.	43			141	0.4	24
Polycentropidae	104			52		
Philopotamus montanus (Donovan)	4			87	0.3	11
Wormaldia sp.	1		1	161	0.5	20
Philopotamidae	2			4		
Rhyacophila dorsalis Curt.	21		11	44		21
R. obliterata McLachlan	0			18		9
R. munda McLachlan	0			3		3
Rhyacophila spp.	14			75		
Glossosoma boltoni Curt.	8		4	3		3
G. vernale Pict.	0			8		4
Agapetus sp.	14			1		1
Glossosomatinae	4			2		
Hydroptilidae l p	41		19	159	0.5	24
Oxyethira spp.	13		4	28		12
Other Trichoptera l	4			25		
Trichoptera p	3			17		
COLEOPTERA						
Oreodytes rivalis Gyll. l a	0			216	0.7	12
Platambus maculatus (L.) a	0			2		2
Dytiscidae l	0			14		
Hydraena gracilis Germar a	11		8	94	0.3	22
Helophorus brevipalpis Bedel a	0			22		5
Helodes sp. l	6		4	16		12
Helmis maugei Bedel l a	118	1.1	20	1227	3.8	32
Esolus parallelopipedus Müll. l a	70	0.7	16	594	1.8	31
Limnius tuberculatus Müll. l a	68	0.7	13	175	0.5	23
Riolus cupreus Müll. l a	0			14		6
Latelmis volkmari Panzer l a	60	0.6	21	282	0.9	36
Other Coleoptera l p a	9			7		
DIPTERA						
Dicranota spp.	63	0.6	24	324	1.0	39
Other Tipulidae	10			27		
Pericoma sp.	7		5	35		7
Dixa sp.	1			15		6
Tanypodinae	70	0.7	20	511	1.6	46
Corynoneura spp.	5		12	156	0.5	42
Tanytarsini	128	1.2	26	3223	10.0	49
Other Chironomidae	700	6.7	48	6154	19.1	50
Chironomidae p	12			279		
Atrichopogon p	0			4		4
Ceratopogonidae l p	1			22		
Simulium spp. l p	1076	10.3	48	1786	5.5	45
Hemerodromia sp.	3			23		10
Clinocerinae	27		20	88	0.3	32
Limnophora l p	1			23		7
Other Diptera l	3			12		
Other Insecta l	0			4		
HYDRACARINA	16		10	298	0.9	40
MOLLUSCA						
Hydrobia jenkinsi Smith	7		1	74		2
Limnaea peregra (Müll.)	12		7	79		7
Ancylastrum fluviatile (Müll.)	17		13	64		16
Planorbis sp.	2		2	0		
Other Gastropoda	1			3		
Pisidium sp.	4		4	14		5
TOTAL	10.430			32,306		

l = larvae, p = pupae, a = adults. Occ. = The number of streams in which a species occurred.

increase in numbers, from spring to summer, agrees with the findings of FROST (1942), who found that, for the moss fauna of the River Liffey, it was chiefly due to an increase in the number of Orthocladiinae. HYNES (1961, Table II) found that for stramin net (6 threads per cm) samples, taken in a similar manner to the method used in this survey, the total number of animals caught in February-March was about the same or higher than the numbers caught in July for the Afon Hirnant. His records for fine-mesh silk samples and moss samples however, indicated larger numbers of animals in July owing to these methods catching much smaller animals which are present in larger numbers in July. The smaller mesh size used for the kick-samples taken in the present survey (12 threads per cm) possibly accounts for the difference in the results when using a similar collecting technique. On the other hand several workers in America have found higher densities of animals in stony streams and rivers in the spring than in the summer (NEEDHAM, 1934; MACIOLEK & NEEDHAM, 1951; ARMITAGE, 1958; GAUFIN, 1959).

TABLE III

Comparison of the spring and summer catches

	Spring		Summer	
	catch	% of fauna	catch	% of fauna
Hydrazoa			36	0.1
Rhabdocoelida			1	
Platyhelminthes	172	1.6	526	1.6
Nematoda	2		18	0.1
Oligochaeta	359	3.4	5107	15.8
Hirudinea	12	0.1	8	
Ostracoda	6	0.1	24	0.1
Asellus aquaticus			8	
Gammarus spp.	64	0.6	324	1.0
Plecoptera	3448	33.1	1602	5.0
Ephemeroptera	3315	31.8	7447	23.1
Sialis sp.			4	
Trichoptera	544	5.2	1320	4.1
Coleoptera	342	3.3	2663	8.2
Tipulidae	73	0.7	351	1.1
Chironomidae	915	8.8	10323	32.0
Simulium spp.	1076	10.3	1786	5.5
Other Diptera	43	0.4	222	0.7
Other Insecta			4	
Hydracarina	16	0.2	298	0.9
Mollusca	43	0.4	234	0.7
Total	10430		32306	
Total weight in mg	23289		32028	

Overall the Plecoptera and Ephemeroptera dominated the fauna numerically in the spring and the Ephemeroptera and Chironomidae predominated in the summer (Tables II and III). The Oligochaeta, Coleoptera and Chironomidae increased greatly in number between the spring and summer to become important components of the fauna. The proportion of Hydracarina in the fauna also increased in the summer. The numbers of Plecoptera decreased by half and formed only a twentieth of the fauna in the summer compared with a third of the total in the spring. The numbers of Ephemeroptera and *Simulium* spp. increased but not proportionately with the total catch whereas the Platyhelminthes, Trichoptera and Tipulidae were present in about the same proportions in spring and summer.

The increase in the number of Oligochaeta in the summer was chiefly due to a striking increase in the numbers of Naididae, probably owing to the worms belonging to this family being able to reproduce rapidly asexually. PERCIVAL & WHITEHEAD (1929) and HYNES (1961) also found the Naididae were at a minimum in the colder months, HYNES specifying January to March. *Polycelis felina* and *Gammarus pulex* were other permanent members of thefauna which increased considerably in numbers in the summer.

It is noteworthy that the most abundant stoneflies in spring and summer, *Lecutra inermis* and *L. fusca* respectively, occur at the same density. HYNES (1941) records that all the *Leuctra* spp. are herbivorous with a very uniform diet and he found both *L. inermis* and *L. fusca* up to the sources of stony streams at 2,000 ft, usually among the stones and gravel. This would suggest that the two species are complementary and occupy the same ecological niche at different times of year and thus the numbers of each caught might be expected to be similar. The Plecoptera are predominantly a spring-emerging group and consequently the number of species caught declined from 21 in the spring to 15 in the summer. HYNES (1961) found that the eggs of three species of stonefly had delayed hatching periods. These were *Brachyptera risi*, with no nymphs from May to September, *Nemoura cinerea* with no nymphs from June to October and *Perlodes microcephala* with no nymphs from May to July inclusive. Neither of the former two species occurred in the summer samples (Table II) but *Perlodes microcephala* occurred in eight streams in July suggesting that the hatching period of the egg is not so long as suspected by HYNES. The absence of nymphs of *Nemoura erratica* and *N. cambrica* in the summer may also be related to delayed hatching of the egg and this is probably also true for *Capnia bifrons*, as *Capnia* spp. are typical cold water forms which grow during the winter months.

The number of mayflies caught doubled from spring to summer and this was accompanied by a small increase in the number of species from 13 to 17. *Baetis rhodani* and *B. pumilus*, which were the only common species to be caught in spring and summer in similar numbers, at an identifiable size, are the only common mayfly species present which are known to be bivoltine, (MACAN, 1957b). The numbers of the larger nymphs of these species caught by MACAN were also similar in February-March and July. *Rhithrogena* sp. was the second most abundant mayfly in the spring. HARKER (1952) and MACAN (1957b) showed that *R. semicolorata* was univoltine, emerging in May and June. MACAN (1957b) and HYNES (1961) found small nymphs first appearing in August whereas HARKER found them in July. Small nymphs were found in eleven of the Highland streams sampled in July. These streams were scattered over the whole area sampled which suggests, because the temperature of streams in the Western Highlands is generally higher than that of streams in the central or eastern Highlands, that no special temperature conditions were regulating their early appearance. The other common species in the summer samples, *Baetis scambus/bioculatus*, *B. vernus/tenax* and *Ephemerella ignita* did not occur in the spring samples. *E. ignita* is known to be a summer emerging species (BUTCHER, LONGWELL & PENTELOW, 1937; MACAN 1957b; PLESKOT, 1958; HYNES, 1961) and the appearance of *Baetis scambus/bioculatus* and *B. vernus/tenax* in the summer samples only, suggests that these are also summer species with a long over-wintering period in the egg stage. This agrees with the findings of HYNES (1961) for the Afon Hirnant where *B. scambus* and *B. tenax* grow concurrently with the second generation of *B. rhodani*.

Twenty species of Trichoptera were caught in the summer and fourteen in the spring. The commoner species increased in numbers from spring to summer. HYNES (1961) found that *Hydropsyche instabilis* is univoltine and the largest larvae occurred in the Afon Hirnant from June to August. The greater number of *H. instabilis* recorded in the summer in Table II is probably due to their larger size at this time of year as many of the small larvae recorded as *Hydropsyche* spp. in the spring were probably this species. Similarly the number of the larvae of *Polycentropus* sp. was greater in the summer than in the spring and many of these larvae were probably recorded as Polycentropidae in the spring. If the Polycentropidae and *Polycentropus* sp. are summed in each set of samples there is little change from spring to summer. *Hydropsyche* (?)*fulvipes* was less abundant than *H. instabilis* but the slightly higher numbers and occurrences in the spring compared with summer suggest that this species may emerge earlier in the year than *H. instabilis*.

The catches of *Wormaldia* sp. and *Philopotamus montanus* suggest that they are summer growing species with a long period in the egg stage. However, ILLIES (1952) caught adult *P. montanus* from April to August.

The big increase in the number of Coleoptera from spring to summer was accompanied by an increase in the number of species caught from seven to seventeen. At both times of year the Helmidae were by far the most important group, *Helmis maugei* being the most abundant species. ILLIES (1952) found that, in streams where they both occurred, *Hydraena gracilis* adults were always far more abundant than *Helmis maugei* but this was not true of the Highland streams studied. In the River Wharfe, PERCIVAL & WHITEHEAD (1930) found members of the Helmidae to be the most common Coleoptera and caught them in the following order of abundance; *Helmis maugei* (44% of the Coleoptera caught), *Limnius tuberculatus* (24%), *Esolus parallelopipedus* (13%), *Riolus cupreus* (9%) and *Latelmis volkmari* (6%). Frost (1942) found that *Limnius tuberculatus* was the predominant beetle forming 98.5% of the Coleoptera at Ballysmuttan but HYNES (1961) found a similar situation to that found in Highland streams with *Helmis maugei* as the most important beetle, with *Esolus parallelopipedus* as the next most abundant helmid and *Limnius tuberculatus* scarce. *Latelmis volkmari* appears to be on the whole, more important in streams in the Scottish highlands than in most

TABLE IV

The total number of larval and adult helmid beetles caught in spring and summer

	Larvae		Adults	
	Spring	Summer	Spring	Summer
Helmis maugei	110	1095	8	132
Esolus parallelopipedus	65	403	5	191
Latelmis volkmari	53	236	7	46
Limnius tuberculatus	48	93	20	82

streams studied previously. The relative numbers of larvae and adults of the four most abundant Helmidae are shown in Table IV. The numbers of *Helmis maugei*, *Esolus parallelopipedus*, and *Latelmis volkmari* show a distinct increase from spring to summer and this is also true for *Limnius tuberculatus*, although the increase is smaller. FROST (1942), examined the moss fauna, found maximum numbers of *L. tuberculatus* larvae in July and small numbers in February-March whereas adults were more abundant in February-March than in July.

The only other beetle to be caught in large numbers during the present survey was *Oreodytes rivalis* and both adults and larvae occurred in the summer samples only, suggesting that they are in the pupal stage at the time of the spring sampling. BALFOUR-BROWNE (1940) found larvae in July and August.

The big increase in the number of Diptera caught in the summer was chiefly due to the Chironomidae which increased eleven times in numbers. All the taxonomic groups of Chironomidae which could be separated, showed an increase in numbers. HUMPHRIES & FROST (1937) found that the Orthocladiinae were present in maximum numbers in July-August and November-February in the River Liffey. Their March catches were considerably lower but the difference between them and the July catches was not as great as that found in the present survey. Although the Tanytarsini were well represented in the Liffey, Humphries and Frost did not separate them when dealing with seasonal fluctuations. It is thus not known whether or not they showed any great increase between spring and summer comparable with that found in Highland streams. HYNES (1961) caught many more Tanypodinae in July than in February-March.

Dicranota spp. larvae were also more numerous in the summer samples but *Simulium* spp. larvae increased only slightly. HYNES caught much larger numbers of the latter in his stramin net samples in July than in February-March and FROST (1942) had similar results for the River Liffey at Straffan, although at Ballysmuttan, where *Simulium* spp. were far less abundant, the catches were similar in spring and summer.

Both the Hydracarina and the Mollusca increased considerably in numbers from spring to July, probably due to the hatching of eggs laid in early summer, but both groups still formed less than 1% of the fauna.

Predatory animals, including salmon and trout, become very active between February and July and consume greater quantities of food in the summer. The reproductive rate of the bottom fauna in general is such that, even with this reduction due to predation, the number of organisms in the streams still increases by three times. At the same time as this increase there is a much greater development of algae, at the higher temperatures and light intensities of the longer summer days, providing a basis for the support of larger numbers of herbivores.

THE WEIGHT OF ANIMALS CAUGHT

The total weight of organisms caught in the summer was greater than that for those caught in the spring but whereas the number of animals caught increased by 3.1 times from spring to summer the total weight increased by only 1.4 times (Table III). Thus the average weight of one animal was 2.2 mg in the spring and 1.0 mg in the summer for the bottom fauna caught by a mesh size of 30 threads to an inch (12/cm). This is due to a summer increase in the number of small species and earlier stages of animals in the fauna, in particular to the increase in Naididae and *Baetis* spp. under 3 mm long, and Chironomidae. By number these formed 12.4% of the fauna in spring and 56.1% in summer. The relationships between such changes in the size of organisms and the growth, food and feeding behaviour of salmon fry and parr are at present being studied.

Of a total number of 49 streams for which both spring and summer weights are available, the total weight of organisms in the samples increased from spring to summer in 27 streams compared with an increase in numbers in 44. This is of course related to the decline in average weight of the individual members of the fauna. The total weight decreased between spring and summer in 13 streams and remained about the same (within 10%) in nine.

The effect of mild pollution

Although sampling sites were selected to avoid any effect by pollution, three streams were included which, during the course of sampling, were discovered to be mildly polluted with organic matter and household refuse. These were streams 30, 45 and 47.

In stream 30, which flowed over basalt, a reddish-brown silt covered the whole bottom and contaminated a thick coating of algae that was present on most of the stones. In the spring the stonefly fauna was sparse; *Amphinemura sulcicollis*, *Leuctra inermis*, *L. hippopus*, *Chloroperla torrentium*, *C. tripunctata* and *Isoperla grammatica* being absent and *Brachyptera risi* rare. There were no Platyhelminthes or Trichoptera and only one ecdyonurid was taken in the samples. In the summer collection there were no Platyhelminthes and only two ecdyonurid nymphs and two trichopteran larvae.

Stream 30, moreover, was the only one examined containing *Asellus aquaticus* and *Erpobdella octoculata* and was one of the two streams containing *Sialis fuliginosa*. *Glossiphonia complanata* was also present; this leech occurred in only two other streams.

A decrease in the total number of larvae and species of Plecoptera, Ephemeroptera and Trichoptera to leave a fauna poor in these orders but including leeches, *Asellus* and *Sialis* is a typical change caused by mild organic pollution (Pentelow et al. 1938; Hynes 1960).

In stream 45, which was on sandstone, the stones and gravel were lying on, but not embedded in, sand and were covered with a thin layer of fine, dark grey silt. Many of the stones were covered by moss. The samples taken were rich in animals in both spring and summer. In summer it was the richest stream by number and the second richest by weight of animals.

The spring samples were very poor in Plecoptera and in Ephemeroptera, *Baetis rhodani* and Ecdyonuridae being absent. The samples contained no Coleoptera and only two Trichoptera larvae. The Oligochaeta and Chironomidae components were, however, the richest of all the spring samples and the leech *Helobdella stagnalis* was present. There were no Ecdyonuridae or *Baetis rhodani* in the summer samples although the mayfly *Ephemerella ignita* was plentiful. As in the spring, the summer fauna was very poor in Trichoptera and Coleoptera but was again rich in Oligochaeta, chiefly Naididae, and *Helobdella stagnalis* was present.

This stream yielded the second highest catch of *Crenobia alpina* in the spring and by far the highest in the summer. MACAN (1961) reports that *Polycelis felina* increased greatly in numbers in a small stream following overloading of a septic tank which discharged into the stream. He suggests this was possibly because of increased supplies of small food derived from the septic tank. The *C. alpina* in stream 45 may have benefited in a similar manner from the mild organic pollution.

The large numbers of Naididae, and probably also Chironomidae in the spring were most probably due to the large amount of moss in the burn, as this was found to be the most productive habitat for these animals by PERCIVAL & WHITEHEAD (1929). The Naididae feed on the large amount of silt and fine organic material, which is entrapped by the moss and it is probably this that made this habitat so rich, as moss in streams free of silt contains far fewer Naididae.

In stream 47, which flowed over sandstone, the stones and gravel were partially embedded in sand and in the pools there was a thin layer of brown silt. Both the spring and summer samples were comparatively poor in number and weight of animals.

The only stoneflies present in the spring fauna were *Brachyptera risi*, which was fairly plentiful, and *Lecutra hippopus*, and the only mayfly present was *Baetis pumilus*. Oligochaeta and Trichoptera were absent. In the summer samples there were no Ephemeroptera, the Trichoptera were poorly represented but the Coleoptera and Diptera were present in normal quantities.

The presence of *Brachyptera risi* in all three streams suggests that this species is more tolerant of mild pollution than most stoneflies.

The pollution occurring in the three streams described was caused chiefly by domestic refuse and sewage. Severe pollution owing to industrial or agricultural wastes is unlikely to occur in the Scottish Highlands as there is little heavy industry and the farming is chiefly sheep farming. Pollution from domestic sources is not severe because of the sparseness of the population.

NOTES ON THE DISTRIBUTION OF THE MALACOSTRACA AND PLECOPTERA

Information on the abundance and distribution of the freshwater invertebrates collected in the present survey is given in Table II and Appendix 2. Here attention is drawn only to the instances of increased range that have been revealed by the survey. The region covered by the present survey included vice, counties 109 Caithness, 108 Sutherland W., 107 Sutherland E., 106 Ross E., 105 Ross W., 97 Westerness, 96 Easterness, 95 Elgin, 94 Banff, 93 Aberdeen N., 92 Aberdeen S., 90 Forfar, 89 Perth N., 88 Mid Perth and 98 Main Argyll (BALFOUR-BROWNE, 1931).

Gammarus pulex. Large numbers of this species were found in an unnamed burn in the Black Isle, (Ross E., v.c. 106). This stream, which was not included in those examined in detail, was rich chemically (2425μe total cations per 1) and flowed over sandstone. This record extends the known northern limits of distribution of this species in the British Isles (HYNES, MACAN & WILLIAMS 1960).

Gammarus duebeni. A brackish water species on the mainland of Scotland (HYNES 1954, HYNES et al. 1960) was present in stream 42 (Sutherland W., v.c. 108). The sampling site was within 80 m of the estuary.

Asellus aquaticus. The presence of *A. aquaticus* in stream 30 extends the known distribution of this species (HYNES et. al. 1960) into Argyll (v.c. 98).

Owing to taxonomic work on the Plecoptera, chiefly by HYNES (1941, 1958) the nymphs of all the 34 known British species have been described and this group is therefore one of the best known of all the groups of freshwater invertebrates in Britain. The stonefly nymphs examined in the present survey, except for a few very young ones, could be identified to species. HYNES (1958) gives maps showing the distribution of Plecoptera in Britain on a vice-county basis and the records below are additions to those of HYNES.

Species	New V.C. Records	Remarks
Taeniopteryx nebulosa	93	
Brachyptera putata	97	
B. risi	93, 95, 97, 98, 109	Present throughout the Highland area.

Protonemura praecox	89, 94, 97, 98, 107	
P. meyeri	95, 97, 107, 109	Not yet recorded from 93 and 106.
Amphinemura sulcicollis	95, 97, 98	
Nemoura cinerea	109	
N. cambrica	94, 95, 98	Not yet recorded from the most northerly part of Scotland (105, 107, 108, 109) an area from which 12 streams were examined and could well be absent from here.
N. erratica	89, 109	
Leuctra inermis	95, 97, 98, 107, 109	Present throughout the Highlands.
L. hippopus	97	Not yet recorded from 93 and 95.
L. nigra	98, 109	
L. fusca	94, 95, 97, 105, 106, 107, 108	Present throughout the Highlands.
L. moselyi	89, 90, 94, 98, 105, 106	
Capnia bifrons	98	
Perlodes microcephala	94, 95, 98, 105, 106, 107, 109	Not recorded from 91, 93, 97.
Diura bicaudata	98, 105	
Isoperla grammatica	93, 95, 97, 98	Present throughout the Highlands.
Dinocras cephalotes	97, 98, 106	Not yet recorded from 91 and 95.
Perla bipunctata	89, 95, 97, 98, 106	Present throughout the Highlands.
Chloroperla torrentium	94, 97, 98, 107	Present throughout the Highlands.
C. tripunctata	89, 95, 97, 98, 105, 107, 108	Not yet recorded from 91, 96, 106 and 109.

Acknowledgements

We are indebted to Mr. D. W. Mackay for his assistance in all phases of the stream survey. We are grateful to Mr. A. V. Holden and Mr. L. A. Caines for carrying out the water analyses.

We wish to thank the following for their help with the identification of the groups named: Miss R. M. Badcock (Hydropsychidae), Dr. R. O. Brinkhurst (Oligochaeta), Dr. J. Balfour-Browne (Coleoptera), Dr. P. Freeman (Diptera), Dr. H. B. N. Hynes (Plecoptera), Dr. T. T. Macan (Ephemeroptera), Dr. K. H. Mann (Hirudinea) and Dr. T. B. Reynoldson (Platyhelminthes). Thanks are also due to Dr. Hynes and Dr. Macan for useful discussions on methods of carrying out the survey. We are grateful to Mr. J. H. S.

Blaxter of the Marine Laboratory, Aberdeen, for translating the summary into German, and Dr. G. Hempel of Germany for checking it.

Summary

1. A survey of fifty streams in the Highlands of Scotland was carried out in 1960 to determine the distribution and composition of the bottom fauna.
2. Each stream was sampled in February-March, to obtain the spring emerging insects at their largest, and again in July, to obtain the summer emerging ones, by means of kick-samples using a handnet to collect the fauna.
3. A short description of each stream is given in Appendix 1 and the composition of the catches of bottom fauna from each stream is given in the tables in Appendix 2.
4. A total of 10,430 animals was collected from the streams in the spring. At this time the catches were composed mainly of stonefly nymphs (33% of total fauna) mayfly nymphs (32%) and Diptera (20%). The mayfly *Baetis rhodani* was the most abundant and widespread animal collected, accounting for 15.5% of the total fauna and occurring in 47 of the 50 streams; the second most abundant and widespread animal was the stonefly *Leuctra inermis* (11.2% of the fauna and present in 43 streams). Four other species of stonefly (*Amphinemura sulcicollis*, *Brachyptera risi*, *Chloroperla torrentium*, *Isoperla grammatica*) and two other mayflies (*Rhithrogena* sp., *Baetis pumilus*) were also important and widespread. The Diptera were mainly *Simulium* spp. (10.3%) and Chironomidae (8.8%). The samples from all but two of the streams contained larvae of these two groups.
5. The total summer catch from the streams was 32,306 animals. The chief groups were Diptera, mainly Chironomidae (39% of total fauna), mayfly nymphs (23%) and Oligochaeta (16%). The most abundant and widespread species were the mayflies *Baetis rhodani* (5.6% of total fauna and present in 45 streams) and *Ephemerella ignita* (3.1% and present in 40 streams) and the stonefly *Leuctra fusca* (3.4% and present in 49 streams).
6. A minimum number of 94 species of bottom fauna occurred in the spring samples and 118 in the summer samples. Altogether 131 species were recorded during the survey.
7. Whereas the total number of animals caught increased by 3.1 times from spring to summer the total weight increased by only 1.4 times. The average weight of one animal was 2.2 mg in the

spring and 1.0 mg in the summer for the bottom fauna caught by a net of mesh size 12 threads per cm.

8. Although sampling sites were selected to avoid any effect of pollution, three streams were included which, during the course of sampling were discovered to be mildly polluted with organic matter and household refuse. Important differences in their fauna resulting from this pollution are described.
9. The survey has shown that many species of Plecoptera have a much wider distribution in Scotland than was previously known.

Zusammenfassung

1. Im Jahre 1960 wurden im Schottischen Hochland 50 Bäche auf Verbreitung und Zusammensetzung ihrer Bodenfauna untersucht.
2. Die Proben eines jeden Baches ("kick"-Proben) wurden im Februar-März genommen, um die Frühjahrsschlüpfer zu erhalten (wenn sie am grössten sind) und wieder im Juli, um die Sommerschlüpfer zu bekommen. Zur Probennahme wurde ein Kescher verwendet.
3. Eine kurze Beschreibung eines jeden Baches wird in Anhang 1 gegeben und die Zusammensetzung der Fänge der Bodenfauna in den Tabellen in Anhang 2.
4. 10430 Tiere wurden im Frühjahr in den Bächen gesammelt. Zu dieser Zeit enthielten die Fänge hauptsächlich Plecoptera – Nymphen (33% der Gesamtfauna), Ephemeriden–Nymphen (32%) und Dipteren (20%). Die Ephemeride *Baetis rhodani* (15,5% der Gesamtfauna) war das häufigste Tier und kam in 47 von 50 Bächen vor. Am zweithäufigsten war die Steinfliege *Leuctra inermis* (11,2% und anwesend in 43 Bächen). Vier andere Arten von Plecoptera (*Amphinemura sulcicollis*, *Brachyptera risi*, *Chloroperla torrentium*, *Isoperla grammatica*) und zwei andere Ephemeriden (*Rhithrogena* sp., *Baetis pumilus*) waren ebenso wichtig und weit verbreitet. Von den Dipteren waren es hauptsächlich *Simulium* spp. (10,3%) und Chironomiden (8,8%). Zwei Bäche ausgenommen enthielten alle anderen Larven dieser beiden Gruppen.
5. Die Gesamtsumme des Sommerfanges beträgt 32306 Tiere. Die Hauptgruppen bilden Dipteren, hauptsächlich Chironomiden (39% der Gesamtfauna), Ephemeriden – Nymphen (23%) und Oligochaeten (16%). Am häufigsten und weitesten verbreitet waren die Eintagsfliege *Baetis rhodani* (5,6% der Gesamtfauna und anwesend in 45 Bächen) und *Ephemerella ignita* (3,1% und anwesend in 40 Bächen) und die Steinfliege *Leuctra fusca* (3,4% und anwesend in 49 Bächen).

6. Mindestens 94 Bodentierarten waren in den Frühjahrfängen, 118 Arten in den Sommerfängen enthalten. Insgesamt wurden 131 Arten festgestellt.
7. Während die Gesamtindividuenzahl in den Fängen vom Frühjahr zum Sommer auf das 3,1 fache stieg, nahm das Gesamtgewicht nur um das 1,4 fache zu. Das mittlere Individualgewicht betrug im Frühjahr 2,2 mg, in Sommer 1,0 mg (Maschweite des verwendeten Netzes: 12 Fäden/cm).
8. Die Probenplätze waren so gewählt, dass nach Möglichkeit kein Einfluss des Abwassers zu befürchten war. Es ergab sich jedoch während der Untersuchungen, dass drei der Bäche verunreinigt waren durch organische Substanzen und häusliche Abwässer. Deutliche Unterschiede in der Bodenfauna, hervorgerufen durch diese Verunreinigung, werden beschrieben.
9. Die Untersuchung hat gezeigt, dass viele Plecopteren – Arten in Schottland viel weiter verbreitet sind, als bisher bekannt war.

APPENDIX 1 – *THE STREAMS SAMPLED*

Information about each of the streams at the place where the samples were taken is given in the following order:
(a) Number and name
(b) Map reference (Ordnance Survey national grid reference system)
(c) Height above sea level
(d) Vice-county
(e) Dates on which sampled
(f) Type of rock over which the stream flowed
(g) General characteristics of the surroundings
(h) Gradient (classified as gentle, moderate or steep)
(i) Rate of flow (estimated as 1 = slight, 2 = gentle, 3 = moderate, 4 = fast, and 5 = torrential)
(j) Width of the stream bed
(k) Maximum depth
(l) Structure of the stream bed, expressed in tenths, in the following order – bedrock, boulders over 30 cm, stones 30 cm down to 5 cm, gravel less than 5 cm, sand. Thus for stream number 43, Fincastle Burn, Bottom 02611 means that the substrate consisted of 2/10th boulders, 6/10th stones, 1/10th gravel and 1/10th sand. Where silt was present this is mentioned.
(m) Amounts of moss and algae on the stones in summer (graded as 0+ = present in a very small amount, 1 = thin covering, 2 = medium, 3 = thick. Intermediate amounts are shown by a plus or minus sign after the figure).

1. River Etive. 27/264548. 260 m. Main Argyll. 12 Feb. and 7 July. Granite. Flat grass and heather moor. Gradient gentle. Flow 2—3. Width 14 m. Max. depth 0.7 m. Bottom 12520. Moss 1—, Algae 2.
2. Allt Brander. 27/050284. 200 m. Main Argyll. 9 Feb. and 4 July. Granite. Grass and heather moor with very few trees. Gradient steep. Flow 4—5. Width 0.5—5 m. Max. depth 0.5 m. Bottom 05410. Moss 0, Algae 0+.

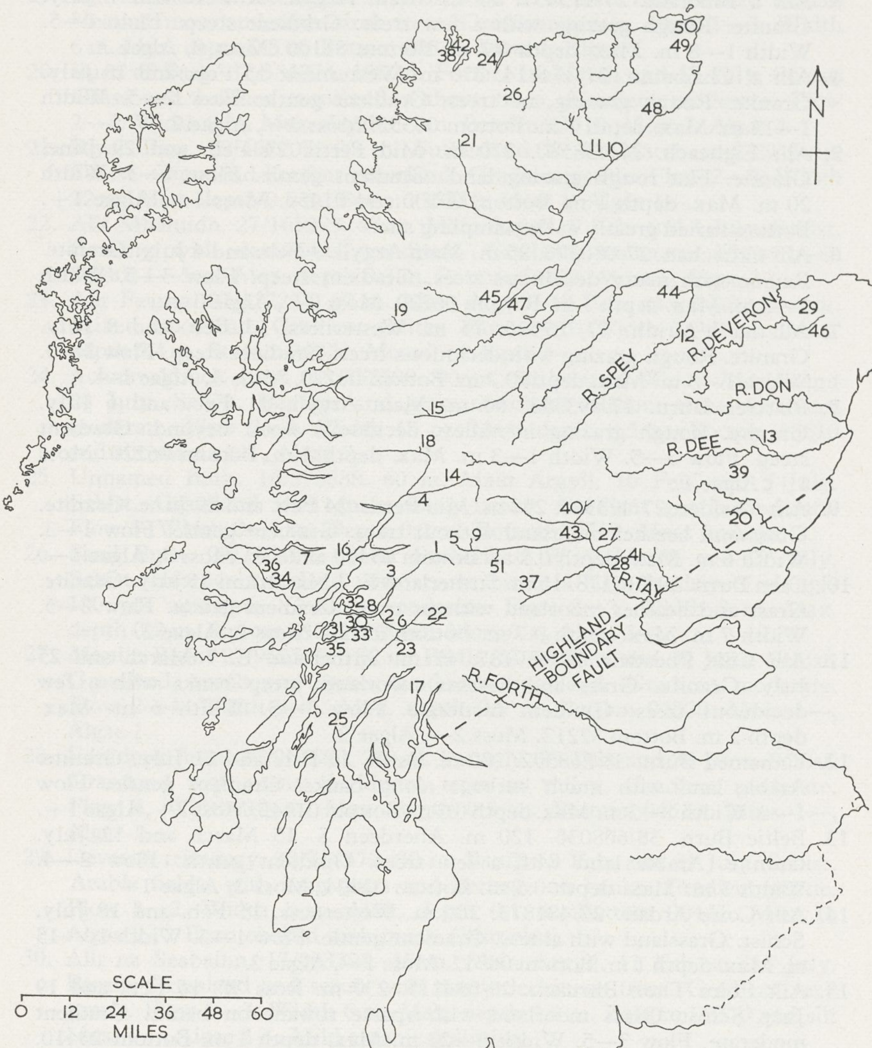


Fig. 1. Map of Scotland showing the position of streams included in the survey. The numbers given are those used in Appendix 1.

3. Allt a Bhiorain. 27/113457. 15 m. Main Argyll. 12 Feb. and 7 July. Granite. Rough grazing with a few trees. Gradient steep. Flow 1—5. Width 1—8 m. Max. depth 0.7 m. Bottom 81100. Moss 0, Algae 2.
4. Allt a' Chaioninn. 27/374814. 270 m. Westerness. 15 Feb. and 18 July. Granite. Rough grazing, no trees. Gradient gentle. Flow 2—5. Width 1—12 m. Max. depth 1 m. Bottom 00352. Moss 1—, Algae 2.
5. Allt Eigheach. 27/438580. 270 m. Mid Perth. 24 Feb. and 29 June. Granite. Flat rough grazing land. Gradient gentle. Flow 1—3. Width 20 m. Max. depth 1 m. Bottom 90100 and 01450. Moss 1+, Algae 1+. Bottom varied greatly at the sampling site.
6. Allt Cruachan. 27/080270. 25 m. Main Argyll. 9 Feb. and 4 July. Granite. Ravine with many deciduous trees. Gradient steep. Flow 3—5. Width 2—8 m. Max. depth 1 m. Bottom 06220. Moss 0+, Algae 0+.
7. Allt na h'Airidh. 17/787596. 75 m. Westerness. 13 Feb. and 8 July. Granite. Rough grazing with deciduous trees. Gradient steep. Flow 2—3. Width 1—3 m. Max. depth 0.7 m. Bottom 06220. Moss 3, Algae 1—.
8. Blarcree Burn. 17/993353. 60 m. Main Argyll. 11 Feb. and 6 July. Granite. Rough grazing in valley, deciduous wood beyond. Gradient steep. Flow 3—5. Width 1—3 m. Max. depth 2 m. Bottom 06220. Moss 1+, Algae 1.
9. Allt Chalder. 27/473580. 290 m. Mid Perth. 24 Feb. and 29 June. Granite. Grass and heather moorland without trees. Gradient gentle. Flow 1—3. Width 8 m. Max. depth 0.5 m. Bottom 05410 and silt. Moss 3, Algae 1—.
10. Caen Burn. 39/015178. 15 m. Sutherland E. 7 March and 25 July. Granite. Grass and heather moorland without trees. Gradient gentle. Flow 2—5. Width 7 m. Max. depth 0.7 m. Bottom 03520. Moss 2, Algae 2.
11. Allt Cille Pheadair. 29/989187. 45 m. Sutherland E. 7 March and 25 July. Granite. Grass and heather moorland, steep banks with a few deciduous trees. Gradient moderate. Flow 1—5. Width 6 m. Max. depth 2 m. Bottom 32212. Moss 2—, Algae 2.
12. Unnamed Burn. 38/268392. 200 m. Banff. 26 Feb. and 21 July. Granite. Arable land with much herbage along banks. Gradient gentle. Flow 1—3. Width 1—3 m. Max. depth 0.3 m. Bottom 01342. Moss 2+, Algae 1+.
13. Beltie Burn. 38/608036. 120 m. Aberdeen S. 15 March and 12 July. Granite. Arable land with a few trees. Gradient gentle. Flow 2—4. Width 3 m. Max. depth 0.5 m. Bottom 02404. Moss 2, Algae 1+.
14. Allt Coire Ardair. 27/481873. 260 m. Westerness. 15 Feb. and 18 July. Schist. Grassland with alders. Gradient gentle. Flow 1—3. Width 10—15 m. Max. depth 1 m. Bottom 00712. Moss 1—, Algae 2.
15. Allt Coire Tholl Bhruach. 28/054115. 230 m. Ross W. 16 Feb. and 19 July. Schist. Grass moorland with sparse rowans on banks. Gradient moderate. Flow 3—5. Width 8—20 m. Max. depth 1 m. Bottom 23410. Moss 1+, Algae 1.
16 Carnoch River. 17/885604. 90 m. Westerness. 13 Feb. and 8 July. Schist. Grass and heather moorland, no trees. Gradient gentle. Flow 1—3. Width 10 m. Max. depth 0.7 m. Bottom 02620. Moss 1, Algae 3.
17. Glinne Mhoir. 27/210063. 150 m. Main Argyll. 10 Feb. and 5 July. Schist. A steep-sided valley with grass and other herbage, banks fringed with birch. Gradient moderate-steep. Flow 3—5. Width 5—10 m. Max. depth 0.8 m. Bottom 61210. Moss 0+, Algae 1—.
18. Allt Dubh. 28/243030. 110 m. Westerness. 15 Feb. and 18 July. Schist. Grassland and heather with some deciduous trees. Gradient moderate. Flow 1—5. Width 9 m. Max. depth 0.5 m. Bottom 42310. Moss 1—, Algae 1+.

19. Allt Duchairidh. 28/122587. 170 m. Ross E. 17 Feb. and 19 July. Schist. Heather moorland with birch trees. Gradient gentle. Flow 1—3. Width 6 m. Max. depth 0.5 m. Bottom 02530. Moss 1, Algae 2.
20. Burn of Beag. 37/534774. 180 m. Forfar. 16 March and 13 July. Schist. Grass and heather moorland without trees. Gradient moderate. Flow 2—4. Width 2 m. Max. depth 0.4 m. Bottom 23410. Moss 2, Algae 2.
21. River Fiag. 29/467205. 90 m. Sutherland E. 11 March and 29 July. Schist. Grass and heather moorland. Gradient gentle. Flow 2—5. Width 22 m. Max. depth 0.5 m. Bottom 13510. Moss 1, Algae 1+.
22. Allt Mhaluidh. 27/165273. 45 m. Main Argyll. 9 Feb. and 4 July. Schist. Grazing with deciduous woodland. Gradient moderate. Flow 1—3. Width 1—5 m. Max. depth 0.3 m. Bottom 51121. Moss 1, Algae 0+.
23. Allt Fearna. 27/112234. 60 m. Main Argyll. 10 Feb. and 4 July. Schist. Mixed woodland. Gradient gentle. Flow 2—3. Width 7—10 m. Max. depth 0.4 m. Bottom 00820. Moss 0+, Algae 2—.
24. Achnavoldrach Burn. 29/555588. 90 m. Sutherland W. 10 March and 28 July. Schist. Heather and grass moorland without trees. Gradient moderate. Flow 2—4. Width 18 m. Max. depth 0.5 m. Bottom 03610 and silt. Moss 0+, Algae 2.
25. Unnamed Burn. 16/878888. 60 m. Main Argyll. 10 Feb. and 5 July. Schist. Grassland with gorse along banks. Gradient gentle-moderate. Flow 3. Width 2—3 m. Depth 0.2 m. Bottom 20710. Moss 0, Algae 2.
26. Skail Burn. 29/716479. 60 m. Sutherland W. 9 March and 27 July. Schist. Heather moorland with sparse birch, a large landsip of shingle 100 yds upstream. Gradient moderate. Flow 2—3. Width 3 m. Max. depth 0.2 m. Bottom 03520 and silt. Moss 0+, Algae 2—.
27. Moulin Burn. 27/945595. 180 m. Perth N. 29 Feb. and 30 June. Schist. Grassland, scrub and some deciduous woodland. Gradient moderate. Flow 2—4. Width 3 m. Max. depth 0.5 m. Bottom 03520. Moss 1—, Algae 1.
28. Edradour Burn. 27/961580. 200 m. Perth N. 29 Feb. and 30 June. Schist. Grassland with many deciduous trees in valley. Gradient moderate. Flow 3. Width 10 m. Max. depth 0.3 m. Bottom 04510. Moss 1—, Algae 1—.
29. Deveron tributary. 38/718572. 30 m. Banff. 19 Feb. and 21 July. Schist. Arable fields, with long grass and herbage on banks. Gradient gentle. Flow 1—2. Width 1 m. Max. depth 0.1 m. Bottom 00442. Moss 0, Algae 2+. Burn choked with musk. (Mimulus).
30. Allt na Seabaihn. 17/983321. 45 m. Main Argyll. 11 Feb. and 6 July. Basalt. Grassland and scrub with many deciduous trees. Gradient very gentle. Flow 1—3. Width 6 m. Max. depth 0.3 m. Bottom 00370 and silt Moss 1—, Algae 2+. Mild organic pollution.
31. River Lonan. 17/943276. 70 m. Main Argyll. 11 Feb. and 6 July. Basalt. Grassland with a few deciduous trees. Gradient gentle. Flow 0—4. Width 6 m. Max. depth 0.5 m. Bottom 01810. Moss 3, Algae 3.
32. Abhain Achnacree. 17/930363. 15 m. Main Argyll. 11 Feb. and 6 July. Basalt. Grassland with open scrub. Gradient gentle. Flow 0—2. Width 6 m. Max. depth 0.3 m. Bottom 01720. Moss 0, Algae 2+. Burn almost dried out in summer.
33. Unnamed Burn. 17/995296. 60 m. Main Argyll. 11 Feb. and 6 July. Basalt. Grassland with many alders. Gradient gentle. Flow 1—3. Width 4 m. Max. depth 0.7 m. Bottom 01630. Moss 0, Algae 2.
34. Savary River. 17/640458. 15 m. Westerness. 12 Feb. and 7 July. Basalt.

Grassland with deciduous trees along banks. Gradient gentle. Flow 1—3. Width 12 m. Max. depth 1 m. Bottom 00523. Moss 0, Algae 2.

35. River Gallain. 17/848190. 70 m. Main Argyll. 10 Feb. and 5 July. Basalt. Grassland with wooded valley. Gradient gentle-moderate. Flow 2—3. Width 7 m. Max. depth 0.5 m. Bottom 22420. Moss 2—, Algae 2.
36. Killundine River. 17/581501. 30 m. Westerness. 12 Feb. and 7 July. Basalt. Grass and deciduous woodland. Gradient gentle. Flow 1—3. Width 7 m. Max. depth 0.5 m. Bottom 02530. Moss 0, Algae 1—.
37. Allt Tir Artair. 27/595353. 200 m. Mid-Perth. 4 March and 2 Aug. Limestone. Grassland with deciduous trees. Gradient steep. Flow 3—6. Width 8 m. Max. depth 0.5 m. Bottom 43300. Moss 0+, Algae 0+.
38. Bealoch Mor. 29/373627. 15 m. Sutherland W. 10 March and 28 July. Limestone. Grass and heather moorland with a few gorse bushes. Gradient gentle. Flow 1—3. Width 6 m. Max. depth 0.4 m. Bottom 02611. Moss 0+, Algae 2—.
39. Burn of Birse. 37/556969. 120 m. Aberdeen S. 14 March and 11 July. Limestone. Grassland with a few deciduous trees and scrub in stream valley. Gradient gentle. Flow 1—2. Width 3 m. Max. depth 0.3 m. Bottom 01315. Moss 3, Algae 1—.
40. Fender Burn. 27/904688. 350 m. Perth N. 8 Feb. and 28 June. Limestone. Grassland. Gradient moderate. Flow 3. Width 4—7 m. Max. depth 0.5 m. Bottom 01810. Moss 0, Algae 1+.
41. Allt Menach. 37/097595. 260 m. Perth N. 2 March and 11 July. Limestone. Grassland with many deciduous trees on banks. Gradient gentle. Flow 1—3. Width 5 m. Max. depth 0.5 m. Moss 2, Algae 2.
42. Allt Acnaidh. 29/383649. 30 m. Sutherland W. 10 March and 28 July. Limestone. Grazing land without trees. Gradient moderate. Flow 2—4. Width 6 m. Max. depth 0.2 m. Bottom 03421 and silt. Moss 0+, Algae 2—.
43. Fincastle Burn. 27/875614. 210 m. Mid Perth. 8 Feb. and 1 Aug. Limestone. Grazing with sparse alders. Gradient gentle-moderate. Flow 1—3. Width 1—2 m. Max. depth 0.5 m. Bottom 02611. Moss 2+, Algae 2—.
44. Red Burn. 38/295571. 90 m. Elgin. 19 Feb. and 20 July. Sandstone. Overhanging herbage, sparse alders and coniferous trees. Gradient gentle. Flow 0—3. Width 2 m. Max. depth 0.7 m. Bottom 00631 and silt. Moss 0, Algae 1.
45. River Peffery. 28/505594. 15 m. Ross E. 17 Feb. and 19 July. Sandstone. Grassland with mixed herbage and scrub, many deciduous trees. Gradient gentle. Flow. 3. Width 5 m. Max. depth 0.5 m. Bottom 00820 and silt. Moss 3, Algae 2—. Mildly polluted.
46. Idoch Water. 38/770493. 60 m. Aberdeen N. 19 Feb. and 21 July. Sandstone. Grassland with herbage, scrub and a few deciduous trees. Gradient gentle. Flow 3—4. Width 6 m. Max. depth 0.4 m. Bottom 00721 and silt. Moss 1—, Algae 2+.
47. Unnamed Burn. 28/605605. 30 m. Ross E. 18 Feb. and 20 July. Sandstone. Steep-sided valley with rhododendrons and many deciduous trees. Gradient gentle. Flow 1—3, Width 3 m. Max. depth 0.1 m. Bottom 01612 and silt. Moss 1, Algae 0+. Mildly polluted.
48. Latheron Wheel. 39/184331. 30 m. Caithness. 8 March and 26 July. Sandstone. Grass, scrub and deciduous trees. Gradient gentle. Flow 1—4. Width 5 m. Max. depth 0.5 m. Bottom 02521. Moss 2, Algae 1+.
49. Gill Burn. 39/367677. 15 m. Caithness. 8 March and 26 July. Sandstone. Grassland and herbage. Gradient gentle. Flow 1—3. Width 3 m. Max. depth 0.5 m. Bottom 02710 and silt. Moss 3—, Algae 2—.

APPENDIX 2a THE SPRING FAUNA OF THE INDIVIDUAL STREAMS

Organism	GRANITE												
Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Polycelis felina	-	-	-	-	-	-	-	-	-	2	10	-	-
Crenobia alpina	-	3	-	-	-	1	-	2	-	-	5	-	1
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	-	-	-	-	-	-	-	1	-	5	24	4	10
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Cammarus pulex	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachyptera risi	-	-	-	1	1	-	41	30	-	2	6	6	5
							34	13		1	2	1	3
Amphinemura sulcicollis	1	-	4	1	7	-	24	4	6	21	31	60	2
							20	2	5	6	8	9	1
Nemoura erratica	-	-	-	-	-	-	-	-	-	-	-	-	-
N. cinerea	-	-	-	-	-	-	-	-	-	-	-	-	-
N. cambrica	-	-	-	-	-	-	1	-	-	-	-	1	-
Protonemura meyeri	-	-	-	-	-	-	15	1	3	3	38	4	1
P. praecox	-	-	-	-	-	-	-	-	-	-	1	6	-
Leuctra inermis	-	6	-	4	44	1	2	16	-	48	105	185	5
							2	7		13	27	29	3
L. hippopus	-	-	-	-	-	3	1	3	2	2	3	30	2
L. nigra	-	-	-	-	-	-	-	-	-	-	-	-	-
Leuctra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Capnia bifrons	-	-	-	-	-	-	-	-	-	-	-	-	-
Perlodes microcephala	1	-	-	-	-	-	-	-	-	1	-	-	1
Dinocras cephalotes	-	-	-	-	-	-	-	-	1	-	-	-	-
Perla bipunctata	-	-	-	-	-	-	-	2	1	-	-	-	-
Chloroperla torrentium	4	-	-	-	5	-	2	-	5	21	4	12	2
C. tripunctata	-	-	-	-	-	1	-	4	-	-	1	1	-
Isoperla grammatica	3	-	-	1	5	-	2	9	5	5	19	45	6
Other Plecoptera	-	-	-	-	-	-	-	-	4	-	-	-	-
Caenis rivulorum	-	-	-	-	-	-	-	-	2	-	-	-	-
Baetis rhodani	2	-	11	6	7	2	11	57	11	110	3	90	12
							9	25	9	30	1	14	8
B. pumilus	-	-	-	3	-	-	2	4	6	3	-	20	2
B. niger	-	-	-	-	-	-	-	-	-	-	-	-	-
Baetis spp. small	-	-	1	-	-	-	-	1	-	3	3	-	3
Certroptilum luteolum	-	-	-	-	-	-	-	-	-	-	-	2	-
Ameletus inopinatus	-	-	-	-	-	-	1	-	-	-	-	-	-
Rhithrogena sp.	-	-	1	2	3	-	3	25	1	28	12	13	25
							3	11	1	8	3	2	16
Heptagenia spp.	-	-	-	-	-	-	-	1	-	-	-	-	-
Ecdyonurus venosus	-	-	-	-	1	-	-	-	-	1	-	4	1
E. torrentis	-	-	-	1	-	-	-	-	-	-	-	-	-
Ecdyonurus spp.	-	-	-	1	-	-	-	-	2	-	-	-	-
Ecdyonuridae	-	-	-	-	-	-	-	1	-	1	-	-	-
Other Ephemeroptera	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnephilidae	-	-	-	-	-	-	-	1	-	-	1	1	9
Lepidostomatinae	-	-	-	-	-	-	-	-	-	1	1	6	1
Silo sp.	-	-	-	-	-	-	-	-	-	-	-	-	11
Hydropsyche instabilis	-	-	-	-	-	-	-	1	-	3	6	-	-
H. fulvipes	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsyche spp.	1	1	-	1	-	-	-	-	-	3	2	2	+
Plectrocnemia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Polycentropus sp.	-	-	-	-	-	-	-	-	-	-	3	6	-
Polycentropidae	-	-	-	-	1	-	-	-	-	4	10	26	4
Philopotamus montanus	-	-	-	-	-	-	-	-	-	-	-	-	-
Wormaldia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Philopotamidae	-	-	-	-	-	-	-	1	-	-	-	-	-
Rhyacophila dorsalis	1	-	-	-	1	-	-	-	-	1	-	2	4
Rhyacophila sp.	-	-	-	-	-	-	-	-	-	2	-	1	-
Glossosoma boltoni	-	-	-	-	-	-	-	-	-	-	-	-	2
Agapetus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydroptilidae	1	-	-	-	-	-	-	-	+	14	2	-	-
Oxyethira sp.	-	-	-	-	-	-	-	-	-	5	1	-	-
Other Trichoptera l p	-	-	-	-	1	-	-	-	-	2	1	1	-
Hydraena gracilis a	-	-	-	-	-	-	-	-	-	-	-	1	-
Helodes sp. l	-	-	-	-	-	-	-	-	-	-	-	2	-
Helmis maugei l	-	-	-	-	-	-	-	+	-	-	-	7	27
H. maugei a	-	-	-	-	-	-	-	-	-	-	-	-	+
Esolus parallelopipedus l	-	-	-	-	-	-	-	-	-	3	1	1	4
E. parallelopipedus a	-	-	-	-	-	-	-	-	-	-	-	-	1
Limnius tuberculatus l	1	-	-	-	-	-	-	-	2	4	15	-	-
L. tuberculatus a	-	-	-	-	1	-	-	-	-	2	-	-	-
Latelmis volkmari l	-	-	-	-	1	-	-	-	-	-	-	-	2
L. volkmari a	-	-	-	-	-	-	-	-	-	1	-	-	-
Other Coleoptera l a	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicranota spp.	-	-	-	-	-	-	-	1	1	-	2	3	2
Other Tipulidae	-	-	-	-	-	-	-	-	-	2	-	2	-
Tanypodinae	-	-	-	-	-	-	-	-	+	3	4	27	-
Corynoneura spp.	-	-	1	-	-	-	-	-	-	-	-	-	-
Tanytarsini	-	-	-	-	-	-	-	1	1	1	7	8	6
Other Chironomidae	4	+	31	-	1	1	2	1	7	38	11	46	3
Chironomides pupae	-	-	-	-	-	-	-	-	-	-	-	-	-
Simulium spp. l	1	2	6	36	15	-	13	57	56	22	51	9	1
							11	25	48	6	13	1	1
Clinocerinae	-	-	-	-	-	-	-	-	1	-	1	-	-
Other Diptera l p	-	-	-	-	-	-	-	-	-	-	1	-	-
Hydracarina	-	-	-	-	-	-	-	-	-	1	1	-	3
Limnaea peregra	-	-	-	-	-	-	-	-	-	-	-	-	-
Ancylastrum fluviatile	-	-	-	-	-	-	-	-	-	+	-	4	+
Other Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium	-	-	-	-	-	-	-	-	-	1	-	-	-
TOTAL	20	12	55	57	54	9	120	224	117	368	384	638	159
Weight in mg.	197	13	32	56	160	11	195	361	234	753	762	961	295
Min. number of species	11	7	6	10	14	6	14	22	21	30	31	33	35
Total cations in μ e/l.	224	262	292	300	306	322	365	375	412	718	771	787	1005

Organism	SCHIST															
Stream Number	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Polycelis felina	--	-	-	-	-	-	-	-	1	1	-	2	-	-	-	-
Crenobia alpina	3	-	-	-	2	-	-	-	-	1	-	1	-	4	-	15
Nematoda	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Oligochaeta	1	1	4	-	1	2	-	4	-	4	-	4	-	8	-	8
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Cammarus pulex	-	-	-	-	-	-	-	-	-	1	-	42	-	7	-	-
Brachyptera risi	2	2	3	19	21	9	29	-	2	1	-	1	10	34	18	-
				15	18		10		2	1			7	11	7	
Amphinemura sulcicollis	14	-	2	6	3	2	32	7	5	9	-	2	20	36	88	73
				5	3		11	5	4	7			15	12	32	16
Nemoura erratica	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-
N. cinerea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N. cambrica	-	-	+	1	-	-	-	-	-	-	-	4	-	-	5	16
Protonemura meyeri	-	-	-	-	1	-	2	-	1	1	-	1	-	1	4	6
P. praecox	-	-	-	-	2	-	1	-	-	1	-	-	2	1	-	-
Leuctra inermis	7	6	9	17	-	13	121	5	19	14	1	32	14	54	18	73
				14			42	4	16	10		11	10	18	7	16
L. hippopus	2	-	-	-	-	-	2	5	1	-	1	2	3	5	3	48
L. nigra	-	-	-	-	-	2	-	-	-	-	-	4	-	1	-	-
Leuctra sp.	-	-	-	-	-	3	-	-	1	-	-	-	-	-	-	-
Capnia bifrons	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Perlodes microcephala	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinocras cephalotes	-	-	-	-	-	1	8	-	-	-	-	-	-	8	-	-
Perla bipunctata	2	-	-	-	-	5	-	-	-	-	-	5	-	-	3	-
Chloroperla torrentium	3	4	2	1	1	2	4	13	1	-	5	5	2	11	1	8
C. tripunctata	-	1	1	-	1	-	-	-	3	6	-	-	-	2	-	-
Isoperla grammatica	2	3	-	2	3	-	9	6	-	1	1	1	-	4	4	38
Other Plecoptera	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	1
Caenis rivulorum	-	-	-	-	-	-	-	1	-	3	-	-	-	-	2	-
Baetis rhodani	11	22	34	27	45	10	7	31	44	24	22	30	32	33	13	2
				22	39		2	22	37	17		10	24	11	5	
B. pumilus	1	3	-	1	4	-	11	-	12	71	-	5	-	4	6	28
B. niger	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	-
Baetis spp. small	-	6	12	8	14	3	19	4	2	12	2	69	9	9	3	-
Certroptilum luteolum	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Ameletus inopinatus	-	2	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Rhithrogena sp.	3	25	-	3	6	2	8	21	14	13	3	35	12	27	36	54
				2	5		3	15	12	10		11	9	9	13	12
Heptagenia spp.	-	-	-	-	-	-	-	1	-	-	11	-	3	-	-	-
Ecdyonurus venosus	3	-	-	-	3	-	8	-	5	-	-	2	-	2	2	-
E. torrentis	-	-	-	-	-	-	-	2	1	-	-	-	-	-	1	-
Ecdyonurus spp.	-	1	-	-	1	-	5	4	-	3	-	2	-	-	2	-
Ecdyonuridae	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-	-
Other Ephemeroptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnephilidae	-	-	-	-	-	-	1	-	-	-	-	-	-	2	2	39
Lepidostomatinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silo sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Hydropsyche instabilis	-	-	-	1	-	-	-	5	-	2	-	2	-	-	1	-
H. fulvipes	-	-	-	-	1	-	-	-	-	-	-	-	-	-	7	-
Hydropsyche spp.	-	-	-	-	-	-	4	-	5	-	7	2	-	-	1	-
Plectrocnemia sp.	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
Polycentropus sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Polycentropidae	-	-	-	-	-	-	-	2	-	-	1	1	-	-	-	1
Philopotamus montanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Wormaldia sp.	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Philopotamidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Rhyacophila sp.	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-
Glossosoma boltoni	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
Agapetus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Hydroptilidae	+	-	+	-	1	+	1	2	-	+	-	+	+	-	-	-
Oxyethira sp.	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Trichoptera l p	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Hydraena gracilis a	-	-	-	-	-	-	-	-	-	2	-	-	-	2	-	-
Helodes sp. l	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-
Helmis maugei l	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-
H. maugei a	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
Esolus parallelopipedus l	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
E. parallelopipedus a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnius tuberculatus l	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-
L. tuberculatus a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Latelmis volkmari l	-	-	-	-	-	-	1	2	-	2	-	2	-	1	-	-
L. volkmari a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Coleoptera l a	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	1
Dicranota spp.	3	-	-	-	-	3	2	-	-	3	-	8	-	2	-	7
Other Tipulidae	-	-	-	2	-	-	-	1	-	-	-	-	-	-	+	-
Tanypodinae	-	-	+	-	-	-	1	-	-	-	-	-	-	-	-	1
Corynoneura spp.	-	-	-	-	-	-	+	-	-	+	-	-	+	+	-	-
Tanytarsini	-	-	+	-	-	1	2	4	-	-	-	-	1	11	-	1
Other Chironomidae	3	1	12	7	5	3	1	10	3	7	17	4	-	11	11	14
Chironomides pupae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simulium spp. l	9	1	2	27	1	8	10	2	1	8	1	20	19	15	40	18
				22	1		4	1	1	6		7	14	5	14	4
Clinocerinae	-	1	-	1	-	-	1	-	-	-	-	3	-	1	2	1
Other Diptera l p	-	-	-	-	-	-	-	-	1	-	-	-	-	2	1	1
Hydracarina	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnaea peregra	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Ancylastrum fluviatile	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Other Gastropoda	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Pisidium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
TOTAL	70	80	85	124	116	69	288	139	120	139	67	306	136	308	277	466
Weight in mg.	254	265	69	129	307	90	790	434	243	280	118	748	214	998	625	1240
Min. number of species	18	15	16	15	17	15	25	21	17	30	11	32	20	35	26	29
Total cations in μ e/l.	266	279	303	362	374	424	425	450	660	725	756	851	1041	1138	1394	1662

Organism	BASALT							LIMESTONE							SANDSTONE							
Stream Number	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Polycelis felina	-	1	-	-	-	2	-	-	-	10	-	-	-	-	3	1	1	2	-	-	-	-
Crenobia alpina	-	-	8	-	4	3	3	-	12	1	1	-	1	1	1	54	8	1	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Oligochaeta	10	9	1	1	2	7	-	4	8	8	-	2	3	2	-	139	55	-	13	4	10	-
Hirudinea	7	-	-	-	-	-	-	-	-	1	-	-	-	-	-	3	+	-	-	-	1	-
Ostracoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Cammarus pulex	-	-	-	-	-	-	-	3	-	-	-	-	-	11	-	-	-	-	-	-	-	-
Brachyptera risi	+	3	11	129	-	3	4	9	1	5	13	6	2	4	6	4	-	31	2	-	-	10
		2	5	26		1	2	2		2	7	4	1	2	2	1						
Amphinemura sulcicollis	-	14	3	7	4	22	12	88	19	20	10	18	20	3	55	-	-	-	78	27	-	66
		7	1	1	2	6	6	21	7	8	5	10	12	2	14				17	7		
Nemoura erratica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N. cinerea	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
N. cambrica	-	1	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-
Protonemura meyeri	-	1	-	-	2	-	1	5	-	3	-	4	1	4	2	-	-	-	1	-	-	13
P. praecox	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leuctra inermis	-	2	3	40	26	24	12	52	13	15	24	20	16	11	38	1	-	-	34	40	14	74
		1	1	8	13	7	6	13	5	6	13	12	10	6	10				7	11	12	
L. hippopus	-	11	2	1	-	1	-	2	-	13	1	1	-	1	-	-	-	1	1	-	-	7
L. nigra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Leuctra sp.	-	-	1	-	-	2	1	-	-	1	-	-	-	-	-	1	-	-	-	4	-	-
Capnia bifrons	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Perlodes microcephala	-	-	-	1	-	-	-	-	1	-	-	1	-	-	1	-	-	-	-	1	-	-
Dinocras cephalotes	-	-	-	-	-	-	-	11	-	-	1	4	-	-	-	-	-	-	5	-	-	2
Perla bipunctata	-	-	-	1	3	3	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	2
Chloroperla torrentium	4	4	12	3	2	4	-	4	6	13	1	2	3	4	39	3	5	-	13	9	-	-
C. tripunctata	-	1	1	6	2	5	3	-	1	-	-	-	-	1	2	-	-	-	-	-	-	-
Isoperla grammatica	-	9	-	3	-	1	2	5	2	8	8	8	1	7	2	-	1	-	5	7	-	3
Other Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caenis rivulorum	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	4	-	-	-
Baetis rhodani	12	49	12	118	24	150	45	98	60	7	62	32	54	31	19	-	11	-	67	51	8	37
	8	24	18	24	12	43	24	24	23	3	34	19	32	17	5		9		14	14	7	
B. pumilus	2	10	-	30	3	24	7	11	3	7	4	3	2	12	-	-	-	2	12	8	-	8
B. niger	-	-	-	-	-	-	-	-	-	- -	-	-	-	-	-	-	-	-	-	1	-	-
Baetis spp. small	-	20	-	4	-	7	5	12	-	2	1	4	1	6	9	1	-	-	33	28	1	16
Certroptilum luteolum	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	-
Ameletus inopinatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhithrogena sp.	1	7	-	70	15	34	27	43	5	7	16	14	6	52	168	-	-	-	35	27	-	68
	1	3	14	8	5	14	14	10	2	3	9	8	4	28	41				8	7		
Heptagenia spp.	-	-	-	-	-	-	-	-	3	-	8	-	10	-	-	-	-	-	-	-	-	-
Ecdyonurus venosus	-	7	-	-	-	3	2	1	-	-	1	1	-	1	-	-	-	-	3	1	-	-
E. torrentis	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus spp.	-	9	-	3	-	-	-	1	-	-	-	-	-	1	1	-	-	-	4	2	-	10
Ecdyonuridae	-	-	-	-	2	4	1	8	-	-	5	-	-	1	-	-	-	-	3	-	-	1
Other Ephemeroptera	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	4	-
Limnephilidae	-	-	-	-	-	-	-	-	-	-	-	-	2	8	4	1	1	-	-	3	-	-
Lepidostomatinae	-	-	-	-	-	-	-	1	-	4	-	-	-	-	-	1	-	-	-	1	9	-
Silo sp.	-	-	-	-	-	4	-	-	-	3	4	-	-	+	-	-	-	-	-	-	-	-
Hydropsyche instabilis	-	3	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-
H. fulvipes	-	7	-	-	-	5	1	-	-	-	-	4	-	-	-	-	-	-	3	-	-	-
Hydropsyche spp.	-	3	-	-	1	4	2	-	9	1	1	15	1	2	1	-	-	-	17	3	-	3
Plectrocnemia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polycentropus sp.	-	7	-	-	-	-	-	-	-	4	-	-	-	-	1	-	+	-	5	16	-	-
Polycentropidae	-	-	-	2	-	-	1	-	4	28	-	-	-	-	5	-	-	-	2	-	12	-
Philopotamus montanus	-	-	-	-	+	+	-	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-
Wormaldia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Philopotamidae	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	-	-	-	-	-	-	3	1	1	-	-	-	-	2	-	-	-	2	3	-	1
Rhyacophila sp.	-	-	-	-	-	-	-	-	-	1	1	+	-	+	3	-	2	-	1	1	-	-
Glossosoma boltoni	-	-	-	-	+	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Agapetus sp.	-	-	-	+	+	+	-	-	-	1	-	-	-	8	-	-	-	-	-	-	-	-
Hydroptilidae	-	-	-	-	2	+	-	1	8	-	-	+	+	-	-	-	-	-	9	+	-	3
Oxyethira sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Other Trichoptera l p	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	2	1	-	1
Hydraena gracilis a	-	-	-	1	-	-	-	-	-	1	-	-	-	-	2	-	-	-	1	1	-	-
Helodes sp. l	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Helmis maugei l	-	-	-	-	-	-	-	-	1	21	+	5	-	2	1	-	3	1	1	37	1	-
H. maugei a	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	3	-	-
Esolus parallelopipedus l	-	3	1	-	2	2	-	-	12	12	-	-	5	1	-	-	-	1	10	6	-	-
E. parallelopipedus a	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	1	-	3
Limnius tuberculatus l	1	1	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	+	18	-	-
L. tuberculatus a	-	1	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	+	14	-	-
Latelmis volkmari l	1	-	-	2	1	-	-	2	2	8	-	-	-	-	-	-	1	1	1	6	17	-
L. volkmari a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	3	-
Other Coleoptera l a	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Dicranota spp.	-	1	-	2	3	3	-	1	2	4	1	-	-	-	-	1	-	-	1	5	2	1
Other Tipulidae	-	+	-	-	-	+	-	-	-	-	-	-	-	-	1	-	-	1	1	-	-	1
Tanypodinae	2	4	1	-	-	2	-	2	2	8	-	1	-	-	-	2	2	-	7	+	1	-
Corynoneura spp.	-	-	-	-	-	-	+	+	+	-	-	-	+	-	-	-	-	-	4	+	+	-
Tanytarsini	1	-	-	1	1	4	-	-	5	4	-	-	2	-	5	2	1	-	28	24	6	1
Other Chironomidae	14	13	32	10	8	5	21	12	70	8	+	1	37	3	4	137	5	4	49	5	8	20
Chironomides pupae	1	+	3	-	2	-	-	-	-	-	-	-	-	-	1	2	2	-	1	-	-	-
Simulium spp. l	106	2	123	52	88	16	33	32	1	1	20	15	-	7	29	73	12	8	4	2	1	25
	66	1	56	11	44	5	18	8			11	9		4	7	17	10		1		1	
Clinocerinae	-	+	-	-	1	1	2	1	1	-	1	-	+	1	1	6	-	-	-	-	-	3
Other Diptera l p	-	-	1	-	-	1	-	-	1	1	-	-	-	-	-	3	-	-	1	2	-	-
Hydracarina	+	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	+	7	1
Limnaea peregra	-	-	2	-	-	-	-	-	-	5	-	-	-	-	-	2	2	-	+	+	-	-
Ancylastrum fluviatile	-	-	1	-	+	-	-	-	-	+	-	+	-	+	-	+	8	-	+	1	3	-
Other Gastropoda	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	1	1
Pisidium	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
TOTAL	161	205	219	490	199	346	188	413	259	242	185	168	169	187	408	439	127	54	469	377	118	383
Weight in mg.	208	648	552	779	419	607	455	1590	528	450	270	360	383	401	1083	631	635	104	1186	1015	151	
Min. number of species	21	28	16	22	25	30	20	25	30	32	22	27	21	27	26	24	21	12	37	41	21	
Total cations in μ e/l.	719	730	798	800	801	1058	1061	415	1138	1150	1366	1444	1659	1785	1383	1636	1770	1857	2059	2736	3608	

APPENDIX 2b THE SUMMER FAUNA OF THE INDIVIDUAL STREAMS

GRANITE

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Organism													
Hydra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Polycelis felina	-	-	-	-	-	-	-	-	-	120	107	-	-
Crenobia alpina	1	13	-	1	-	7	-	1	-	-	3	7	4
Platyhelminthes indet.	2	-	-	-	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	2	-	-	-	2
Naididae	49	91	49	178	20	16	16	39	20	13	84	141	70
Other Oligochaeta	2	-	-	-	2	1	5	-	6	3	20	8	5
Hirudinae	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Asellus aquaticus	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammarus pulex	-	-	-	-	-	-	-	-	-	-	-	-	-
G. duebeni	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphinemura sulcicollis	-	-	-	-	-	-	-	-	-	-	-	-	-
Nemurella picteti	-	-	-	-	-	-	-	-	-	-	-	-	-
Protonemura meyeri	-	-	-	-	-	-	3	-	-	3	-	12	-
Protonemura sp.	-	-	-	1	-	-	1	-	-	-	-	3	-
Leuctra nigra	-	-	-	-	-	-	-	-	-	-	-	-	-
L. fusca	8	1	9	7	9	2	7	17	3	27	20	47	28
	3.3	0.6	2.8	2.5	4.3	0.2	4.2	7.7	1.6	2.6	2.0	3.0	3.3
L. moselyi	-	-	-	-	-	-	-	-	-	-	-	1	-
Leuctra spp.	-	-	-	1	-	-	-	1	-	-	1	4	-
Diura bicaudata	-	1	-	-	-	-	-	-	-	-	-	-	-
Perlodes microcephala	-	-	-	-	-	-	-	-	-	-	-	1	2
Dinocras cephalotes	-	-	-	1	-	-	-	-	1	7	7	-	1
Perla bipunctata	-	-	-	-	-	-	-	3	-	-	-	-	-
Chloroperla torrentium	-	-	-	-	1	-	-	-	-	-	-	3	-
C. tripunctata	-	-	-	-	-	-	5	-	-	-	-	1	1
Isoperla grammatica	1	-	-	-	-	-	2	-	-	-	-	3	1
Other Plecoptera	-	-	-	-	1	-	-	9	1	1	4	3	-
Paraleptophlebia submarginata	-	-	-	-	-	-	-	-	1	-	-	-	-
Ephemerella ignita	15	-	2	6	9	-	2	7	10	6	3	200	35
	6.1		0.6	2.1	4.3		-1.2	3.2	5.3	0.6	0.3	13	4.1
Caenis rivulorum	2	-	1	1	-	-	-	-	13	1	5	-	-
Baetis scambus/bioculatus	63	-	18	1	11	-	-	-	-	14	-	61	16
	26		5.6	0.4	5.2					1.3		3.9	1.9
B. vernus/tenax	-	20	-	-	-	9	-	-	-	-	-	1	-
		11				1.0						0.1	
B. rhodani	14	-	43	8	2	23	61	24	4	16	7	70	43
	5.7		1.3	2.8	1.0	2.6	36	11	2.1	1.5	0.7	4.5	5.0
B. pumilus	-	-	-	3	-	-	-	-	1	20	5	9	-
				1.1					0.5	1.9	0.5	0.6	
B. niger	-	-	-	-	-	-	-	-	-	-	-	5	-
Baetis spp.	5	4	28	21	11	49	16	18	26	14	8	99	29
	2.0	2.2	8.6	7.4	5.2	555	9.5	8.1	1.4	1.3	0.8	6.3	3.4
Centroptilum luteolum	-	-	-	-	-	-	-	-	-	-	-	20	-
Rhithrogena sp.	-	-	-	-	-	-	-	1	-	1	-	-	-
Heptagenia lateralis	-	-	-	-	-	-	-	-	-	-	-	1	-
Heptagenia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus venosus	-	-	-	-	-	-	-	-	-	-	-	-	-
E. torrentis	-	-	-	-	-	-	-	-	-	1	-	3	1
Ecdyonurus sp.	-	-	-	-	-	-	-	-	-	-	-	25	2
Ecdyonuridae	-	-	-	-	-	-	-	-	-	-	-	3	1
Other Ephemeroptera	-	-	-	-	-	-	-	-	-	-	-	-	-
Sialis fuliginosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnephilidae	-	-	-	-	-	-	-	-	-	9	2	5	13
Silo sp.	-	-	-	-	-	-	-	-	-	-	-	-	4
Hydropsyche instabilis	3	12	1	-	1	-	-	-	1	18	20	-	-
H. (?) fulvipes	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsyche spp.	1	2	-	-	-	-	-	-	-	3	-	-	-
Plectrocnemia sp.	-	1	-	-	-	-	1	-	-	-	-	2	-
Polycentropus sp.	-	1	7	-	1	-	-	-	-	10	4	21	-
Polycentropidae	-	-	-	-	-	-	-	-	-	5	7	23	-
Philopotamus montanus	-	-	-	-	-	-	-	-	-	68	-	-	-
Wormaldia sp.	-	3	3	-	-	2	-	-	-	55	16	-	-
Philopotamidae	-	-	-	-	-	-	-	-	-	4	-	-	-
Rhyacophila dorsalis	1	3	-	-	1	6	1	-	2	-	1	5	1
R. obliterata	-	-	-	-	-	3	-	-	-	-	-	-	-
R. munda	-	-	-	-	-	-	-	-	-	1	-	-	-
Rhyacophila spp.	2	-	-	-	1	4	1	1	-	-	-	6	4
Glossosoma boltoni	-	-	-	-	-	-	-	-	-	-	-	-	-
G. vernale	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydroptilidae l p	3	-	12	-	-	-	-	-	+	20	4	-	-
Oxyethira ap.	-	-	-	-	-	-	-	-	-	1	3	-	-
Other Trichoptera l p	-	-	-	2	-	-	-	-	-	7	-	-	2
Oreodytes rivalis l	-	-	-	-	2	-	-	-	-	+	-	14	9
a	-	-	-	-	11	-	-	-	-	-	-	36	2
Dytiscidae l	-	-	-	-	-	-	-	-	-	1	1	-	-
Hydraena gracilis a	-	-	-	-	-	1	-	1	-	-	11	5	4
Helophorus brevipalpis a	-	-	-	-	-	-	-	-	-	-	-	-	1
Helodes sp. l	-	-	-	-	-	-	1	1	-	-	1	-	-
Helmis maugei l	-	-	-	-	1	-	9	-	-	10	3	301	181
					0.5		5.4			1.0	0.3	19	21
a	-	-	-	-	-	-	-	-	-	2	19	25	5
Esolus parallelopipidus l	-	-	-	-	-	-	-	-	-	10	7	2	26
										1.0		0.1	3.0
a	-	-	-	-	-	-	-	-	-	3	4	-	14
Limnius tuberculatus l	-	-	1	-	2	-	1	-	1	8	8	-	-
a	1	-	1	1	5	-	-	-	1	2	41	-	-
Riolus cupreus l a	-	-	-	-	-	-	-	1	-	-	-	-	-
Latelmis volkmari l	6	-	-	2	10	-	4	-	-	-	-	3	9
	2.5			0.7	5.0		2.4					0.2	1.0
a	1	-	-	-	4	-	-	-	1	-	2	-	-
Other Coleoptera l a	-	-	-	-	-	-	-	1	-	-	-	2	-
Dicranota spp.	-	-	-	1	2	5	1	5	1	4	1	16	24
				0.4	1.0	0.6	0.6	2.3	0.5	0.4	0.1	1.0	2.8
Other Tipulidae	1	-	-	-	2	-	-	-	-	1	-	1	1
Pericoma sp.	-	-	-	-	-	-	-	-	-	-	11	1	-
Dixa sp.	-	-	-	-	-	-	-	-	-	-	-	1	-
Tanypodinae	-	10	5	1	2	1	3	14	7	24	66	16	-
		5.6	1.5	0.4	1.0	0.1	1.8	6.3	3.7	3.5	6.7	1.0	
Corynoneura	4	+	+	+	-	+	1	15	2	2	1	2	-
							0.6	6.8	1.1	0.2	0.1	0.1	
Tanytarsini	3	1	1	4	4	1	-	1	2	301	134	47	177
	1.2	0.6	0.3	1.4	1.9	0.1		0.4	1.1	29	14	4.5	21
Other Chironomidae	35	4	136	20	86	21	19	47	74	173	314	218	61
	14	2.2	42	7.1	41	2.4	11	21	39	17	32	14	7.1
Chironomidae p	-	3	3	8	1	3	2	9	1	11	7	7	5
Atrichopogon sp. p	-	-	-	-	-	-	—	-	-	1	-	-	-
Ceratopogonidae l p	-	-	-	-	1	-	-	1	-	1	-	-	1
Simulium spp. l p	21	10	-	13	1	733	3	2	2	21	2	36	14
	8.6	5.6		4.6	0.5	82	1.8	1.0	1.0	2.0	0.2	2.3	1.6
Hemerodromia sp.	-	-	-	-	-	-	-	-	-	3	2	-	2
Clinocerinae	-	-	3	1	+	-	-	-	+	1	-	5	2
Limnophora sp. l p	-	-	-	-	-	-	-	-	-	2	4	-	-
Other Diptera l	-	+	-	-	-	-	-	1	-	-	-	2	-
Other Insecta l	-	-	-	-	-	-	-	1	-	-	-	-	-
Hydracarina	-	-	-	-	7	1	3	1	4	4	5	22	56
					3.3	0.1	1.8	0.5	2.1	0.4	0.5	1.4	6.5
Hydrobia jenkinsi	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnaea peregra	-	-	-	-	-	-	-	-	-	-	-	-	-
Ancylastrum fluviatile	-	-	-	-	-	-	-	-	-	3	3	8	-
Other Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	244	180	323	282	210	890	168	222	189	1046	978	1563	860
Weight in mg.	231	376	172	78	147	793	229	139	148	2145	836	1519	805
Min. no. of species	20	15	16	21	23	19	20	25	25	41	35	43	33

SCHIST

Stream Number	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Organism																
Hydra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polycelis felina	-	-	-	-	-	-	-	-	2	10	-	5	-	-	-	-
Crenobia alpina	-	4	-	-	5	1	5	-	1	-	-	-	-	3	2	17
Platyhelminthes indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	2	-	-	-	1	6	-	-	-	-
Naididae	63	12	-	6	4	17	42	54	7	2	264	67	15	33	76	-
Other Oligochaeta	3	4	1	2	-	8	6	10	2	7	-	147	-	3	5	14
Hirudinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Asellus aquaticus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Gammarus pulex	-	-	-	-	-	-	-	-	1	5	-	70	-	5	-	-
									0.5	2.2		13		0.5		
G. duebeni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphinemura sulcicollis	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1
Nemurella picteti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Protonemura meyeri	3	1	-	-	2	-	-	-	1	-	-	-	-	1	1	-
Protonemura sp.	-	3	-	-	-	-	-	-	-	3	2	-	5	-	3	7
Leuctra nigra	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-
L. fusca	7	5	2	6	11	58	14	5	16	19	6	18	33	82	41	1
	3.3	1.2	3.1	5.0	6.9	27	6.4	2.1	8.3	8.7	1.2	3.2	15	8.9	5.2	0.1
L. moselyi	-	1	-	1	-	-	1	-	-	-	-	-	-	12	-	2
Leuctra spp.	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	2
Diura bicaudata	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Perlodes microcephala	-	-	-	-	-	1	-	2	-	-	1	-	-	1	-	-
Dinocras cephalotes	-	2	-	-	5	1	12	-	-	-	-	2	-	3	4	-
Perla bipunctata	4	-	-	-	2	1	-	-	4	-	-	3	-	-	-	-
Chloroperla torrentium	1	-	-	-	1	1	-	-	-	-	-	-	-	2	-	5
C. tripunctata	-	-	-	1	-	-	-	-	-	2	-	-	2	1	-	-
Isoperla grammatica	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Plecoptera	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1
Paraleptophlebia submarginata	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-
Ephemerella ignita	2	9	-	25	1	-	28	2	5	2	-	27	-	38	15	19
	1.0	2.1		21	0.6		7.3	0.8	2.6	0.9		4.8		4.1	1.9	2.0
Caenis rivulorum	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	-
Baetis scambus/bioculatus	1	15	-	24	6	8	6	1	9	-	6	60	2	45	4	-
	0.5	3.6		2.0	3.8	3.8	1.6	0.4	4.7		1.2	11	0.9	4.9	0.5	
B. vernus/tenax	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	53
		4.0														5.5
B. rhodani	22	27	2	17	26	13	26	2	10	15	25	8	4	64	28	128
	10	6.4	3.1	14	16	6.2	6.8	0.8	5.2	6.8	5.1	1.4	1.8	6.9	3.5	13
B. pumilus	-	-	-	-	-	1	1	-	2	4	-	4	3	1	7	1
						0.5	0.3		1.0	1.8		0.7	1.3	0.1	0.9	0.1
B. niger	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Baetis spp.	5	34	4	5	35	1	21	8	11	23	18	59	2	105	223	165
	2.4	8.1	6.3	4.2	22	0.5	5.5	3.3	5.7	1.0	3.5	1.0	0.9	11	28	17
Centroptilum luteolum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhithrogena sp.	-	7	-	-	-	1	-	-	-	-	-	-	-	1	-	-
Heptagenia lateralis	-	-	-	-	-	-	+	-	-	-	-	-	-	16	-	-
Heptagenia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus venosus	-	-	1	-	-	2	-	1	2	22	-	-	-	-	-	-
E. torrentis	-	-	-	-	-	-	-	1	2	2	-	7	1	-	1	-
Ecdyonurus sp.	-	-	-	1	1	-	7	-	7	4	-	13	-	7	2	-
Ecdyonuridae	-	-	1	-	-	1	-	1	-	-	-	-	1	-	8	-
Other Ephemeroptera	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Sialis fuliginosa	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
Limnephilidae	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	171
Silo sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsyche instabilis	-	1	-	-	-	-	1	6	-	3	2	1	-	-	1	-
H. (?) fulvipes	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Hydropsyche spp.	-	-	-	-	-	-	-	-	-	-	2	-	-	-	2	-
Plectrocnemia sp.	-	1	-	-	-	1	-	-	-	-	-	5	-	-	-	1
Polycentropus sp.	-	1	-	-	-	-	-	7	-	-	9	-	8	-	-	-
Polycentropidae	-	-	-	-	-	-	1	1	-	-	-	1	-	-	-	-
Philopotamus montanus	1	-	-	-	-	-	1	-	-	-	-	-	5	1	-	-
Wormaldia sp.	1	-	5	-	-	-	-	4	+	4	-	3	3	-	-	-
Philopotamidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	1
R. obliterata	-	3	-	-	-	-	-	-	-	-	-	-	1	-	-	4
R. munda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila spp.	-	4	-	-	-	-	1	1	-	5	2	1	1	3	3	2
Glossosoma boltoni	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
G. vernale	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-
Hydroptilidae l p	-	2	-	-	-	3	+	-	-	-	8	1	52	-	+	-
Oxyethira ap.	-	-	-	-	-	1	-	3	-	-	10	1	3	-	-	-
Other Trichoptera l p	-	-	-	-	-	+	-	-	1	1	-	-	-	3	1	-
Oreodytes rivalis l	-	-	-	-	-	-	-	-	-	-	-	-	-	28	-	-
a	-	-	-	-	-	-	5	-	1	-	-	-	-	28	3	-
Dytiscidae l	+	-	-	-	-	1	4	-	-	-	-	-	-	-	-	-
Hydraena gracilis a	-	2	-	-	1	-	-	-	6	8	-	-	-	2	1	-
Helophorus brevipalpis a	-	-	-	-	-	-	-	-	—	-	-	-	-	+	-	19
Helodes sp. l	-	1	-	-	-	-	-	-	-	3	-	1	-	+	1	-
Helmis maugei l	-	12	-	-	1	3	61	-	-	1	-	1	-	1	-	3
		2.8			0.6		16			0.5		0.2		0.1		0.3
a	-	4	-	-	-	-	9	-	-	-	-	-	-	2	-	3
Esolus parallelopipidus l	1	-	-	1	-	8	2	-	1	2	-	-	-	-	3	-
	0.5			0.8		3.8	0.5		0.5	0.9				0.4	0.4	
a	-	-	-	-	-	-	3	-	9	4	-	-	-	1	4	-
Limnius tuberculatus l	-	-	-	-	-	-	-	7	-	-	2	-	3	2	-	-
a	-	-	-	-	1	-	-	3	-	-	1	3	-	-	-	-
Riolus cupreus l a	-	-	-	-	-	—	-	-	+	-	-	6	-	-	-	-
Latelmis volkmari l	-	-	-	1	-	1	3	4	3	-	-	-	-	-	-	-
				0.8		0.5	0.8	1.7	1.6							
a	-	-	-	-	-	-	-	-	-	1	1	2	-	-	-	-
Other Coleoptera l a	-	-	-	-	-	-	1	-	-	-	2	-	-	-	-	-
Dicranota spp.	4	4	1	2	2	2	-	-	11	1	-	6	-	13	2	17
	2.0	1.0	1.6	2.0	1.2	2.0			5.7	0.5		1.1		1.4	0.3	1.8
Other Tipulidae	3	-	-	-	-	2	1	-	-	-	-	1	1	1	-	-
Pericoma sp.	-	-	-	-	-	-	-	-	—	-	-	-	-	-	-	1
Dixa sp.	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Tanypodinae	-	+	-	2	3	2	17	3	5	6	11	5	10	79	10	1
				1.7	1.9	0.9	4.4	1.3	2.6	2.7	2.2	0.9	4.5	8.5	1.3	0.1
Corynoneura	1	1	+	1	1	2	+	1	7	6	7	-	+	1	3	2
	0.5	0.2		1.0	0.6	0.9		0.5	3.6	2.7	1.3			0.1	0.4	0.2
Tanytarsini	8	20	6	-	18	19	15	36	5	2	33	4	36	128	16	41
	3.8	4.7	9.4		11	9.0	3.9	15	2.6	0.9	6.6	0.7	16	14	2.0	4.2
Other Chironomidae	58	23	32	14	15	42	69	61	36	60	78	14	15	146	297	54
	28	5.5	50	12	9.4	20	18	25	19	27	14	2.5	6.7	18	38	5.6
Chironomidae p	10	1	2	3	-	5	11	7	1	1	2	2	16	20	4	-
Atrichopogon sp. p	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae l p	-	1	-	-	-	-	-	-	-	1	-	2	-	-	1	-
Simulium spp. l p	7	195	3	5	11	-	2	2	16	2	2	1	5	29	13	210
	3.3	46	4.7	4.2	6.9		6.5	0.8	8.3	0.9	0.4	0.2	2.2	3.1	1.6	22
Hemerodromia sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	4	-	-
Clinocerinae	2	2	+	3	-	2	1	1	1	-	2	1	-	6	1	1
Limnophora sp. l p	-	-	-	-	-	-	-	-	-	-	-	2	—	-	-	-
Other Diptera l	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Other Insecta l	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydracarina	-	1	2	-	3	1	5	2	4	-	-	5	1	2	1	5
		0.2	3.1		1.4	0.5	1.3	0.8	2.1			0.9	0.5	0.2	0.1	0.5
Hydrobia jenkinsi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnaea peregra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ancylastrum fluviatile	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Other Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	209	422	64	120	160	211	385	239	193	219	500	567	220	925	789	965
Weight in mg.	258	599	113	136	227	307	419	355	165	337	208	728	248	1210	706	1677
Min. no. of species	22	32	13	17	24	30	32	25	31	31	22	37	23	37	30	28

BASALT

Stream Number	30	31	32	33	34	35	36
Organism							
Hydra sp.	5	-	-	-	-	-	-
Polycelis felina	-	25	-	2	-	1	1
Crenobia alpina	-	-	8	2	10	-	4
Platyhelminthes indet.	-	-	-	-	-	-	-
Nematoda	+	-	-	-	-	-	-
Naididae	123	27	222	6	24	8	2
Other Oligochaeta	15	7	1	6	2	10	3
Hirudinae	3	-	-	-	-	-	-
Ostracoda	-	1	-	-	-	-	-
Asellus aquaticus	8	-	-	-	-	-	-
Gammarus pulex	3	4	-	5	-	-	-
	0.7	0.4		0.9			
G. duebeni	-	-	-	-	-	-	-
Amphinemura sulcicollis	-	-	-	-	-	-	-
Nemurella picteti	8	-	-	2	-	-	-
Protonemura meyeri	1	-	-	-	-	-	-
Protonemura sp.	1	-	-	6	8	-	-
Leuctra nigra	-	-	-	-	-	-	-
L. fusca	36	59	25	52	5	25	16
	8.8	6.3	2.4	9.4	1.0	6.5	3.4
L. moselyi	-	-	-	-	-	-	-
Leuctra spp.	2	-	-	-	-	2	-
Diura bicaudata	-	-	-	-	-	-	-
Perlodes microcephala	-	-	-	1	-	-	-
Dinocras cephalotes	-	-	-	-	1	-	-
Perla bipunctata	-	-	-	3	1	1	1
Chloroperla torrentium	-	+	-	-	-	-	-
C. tripunctata	1	-	-	9	-	1	-
Isoperla grammatica	-	-	-	-	-	4	-
Other Plecoptera	-	-	1	-	-	3	1
Paraleptophlebia submarginata	-	-	-	-	-	-	-
Ephemerella ignita	5	38	-	9	6	13	2
	1.2	4.1		1.6	1.2	3.4	0.4
Caenis rivulorum	-	-	-	-	9	1	27
Baetis scambus/bioculatus	3	21	-	-	-	-	1
	0.7	2.3		0.2			0.2
B. vernus/tenax	-	-	-	-	-	-	-
B. rhodani	21	48	26	26	24	18	6
	5.1	5.2	2.5	4.7	5.0	4.7	1.3
B. pumilus	4	-	3	53	5	24	-
	1.0		0.3	9.5	1.0	6.3	
B. niger	-	1	-	-	-	-	-
Baetis spp.	17	94	63	64	105	27	194
	4.1	10	6.0	11	22	7.0	41
Centroptilum luteolum	-	1	-	-	-	-	-
Rhithrogena sp.	-	-	-	2	2	-	-
Heptagenia lateralis	-	-	-	-	-	-	-
Heptagenia sp.	-	-	-	-	-	-	-
Ecdyonurus venosus	-	2	-	-	-	-	-
E. torrentis	+	+	-	-	-	2	-
Ecdyonurus sp.	1	7	-	6	-	10	-
Ecdyonuridae	-	2	-	-	3	-	-
Other Ephemeroptera	-	-	-	-	-	-	-
Sialis fuliginosa	2	-	-	-	-	-	-
Limnephilidae	-	-	-	-	-	-	-
Silo sp.	-	-	-	-	-	-	-
Hydropsyche instabilis	-	1	-	-	-	2	-
H. (?) fulvipes	-	-	-	1	-	2	5
Hydropsyche spp.	1	64	-	1	-	1	-
Plectrocnemia sp.	-	-	-	-	-	1	-
Polycentropus sp.	-	16	2	5	1	2	1
Polycentropidae	-	2	-	-	-	1	-
Philopotamus montanus	-	-	1	1	1	-	-
Wormaldia sp.	-	-	-	6	2	-	1
Philopotamidae	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	3	2	4	-	1	2
R. obliterata	-	-	-	1	-	-	-
R. munda	-	-	-	-	-	-	-
Rhyacophila spp.	1	2	-	6	2	1	-
Glossosoma boltoni	-	-	-	-	1	-	1
G. vernale	-	-	-	-	2	2	-
Hydroptilidae l p	-	5	-	+	-	1	-
Oxyethira ap.	-	-	-	-	-	-	-
Other Trichoptera l p	-	-	-	3	1	3	4
Oreodytes rivalis l	-	-	-	-	-	-	-
a	-	-	-	-	-	-	-
Dytiscidae l	-	-	-	-	-	-	+
Hydraena gracilis a	1	2	1	16	1	-	7
Helophorus brevipalpis a	-	-	-	-	-	-	-
Helodes sp. l	-	-	1	-	-	-	-
Helmis maugei l	5	1	-	1	8	1	-
	1.2	0.1		0.2	1.7	0.3	
a	-	-	-	-	1	-	-
Esolus parallelopipidus l	1	-	1	9	16	3	8
	0.2		0.1	1.9	3.3	0.8	1.7
a	-	1	2	9	14	-	3
Limnius tuberculatus l	3	6	-	-	-	-	-
a	-	4	-	-	-	-	-
Riolus cupreus l a	-	-	-	-	+	-	-
Latelmis volkmari l	3	5	2	5	1	1	-
	0.7	0.5	0.2	0.9	0.2	0.3	
a	-	1	-	1	1	-	1
Other Coleoptera l a	-	-	-	-	-	-	-
Dicranota spp.	-	6	1	16	7	20	3
		0.6	0.1	3.0	1.4	5.2	0.6
Other Tipulidae	-	+	-	-	-	1	-
Pericoma sp.	-	-	-	-	-	-	-
Dixa sp.	-	-	-	-	-	-	-
Tanypodinae	4	5	14	16	12	8	9
	1.0	0.5	1.3	2.9	2.5	2.1	1.9
Corynoneura	2	15	43	15	2	1	13
	0.5	1.6	4.1	2.7	0.4	0.2	2.7
Tanytarsini	37	8	8	18	5	11	2
	9.0	0.9	0.8	3.2	1.0	2.3	0.4
Other Chironomidae	58	299	593	145	51	159	161
	14	32	56	26	31	41	34
Chironomidae p	1	14	12	5	4	4	2
Atrichopogon sp. p	1	-	-	-	-	-	-
Ceratopogonidae l p	-	-	1	-	-	-	-
Simulium spp. l p	5	110	10	13	36	6	3
	1.2	11.8	0.9	2.3	7.4	1.6	0.6
Hemerodromia sp.	-	-	-	-	-	-	-
Clinocerinae	-	2	12	3	-	-	-
Limnophora sp. l p	-	-	-	-	-	-	-
Other Diptera l	-	-	-	-	-	1	-
Other Insecta l	-	-	-	-	-	-	-
Hydracarina	24	9	-	-	5	2	2
	5.9	1.0			1.0	0.5	0.4
Hydrobia jenkinsi	-	-	-	-	-	-	-
Limnaea peregra	-	-	-	-	-	-	-
Ancylastrum fluviatile	-	2	1	-	6	+	+
Other Gastropoda	-	-	-	-	-	-	-
Pisidium spp.	-	7	-	-	-	-	-
Total	411	926	1056	555	484	384	476
Weight in mg.	303	657	-	443	357	626	455
Min. no. of species	33	35	23	35	31	31	28

LIMESTONE

Stream Number	37	38	39	40	41	42	43
Organism							
Hydra sp.	-	-	-	-	-	-	-
Polycelis felina	-	-	7	-	-	-	10
Crenobia alpina	-	2	4	-	-	-	46
Platyhelminthes indet.	-	-	2	-	-	-	-
Nematoda	-	1	2	-	-	-	-
Naididae	9	2	63	11	14	5	179
Other Oligochaeta	2	40	6	-	5	5	9
Hirudinae	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	-
Asellus aquaticus	-	-	-	-	-	-	-
Gammarus pulex	7	-	4	-	1	-	217
	2.4		0.3		0.2		7.8
G. duebeni	-	-	-	-	-	2	-
Amphinemura sulcicollis	-	-	-	-	-	-	-
Nemurella picteti	-	-	-	-	-	2	-
Protonemura meyeri	-	1	-	-	3	-	6
Protonemura sp.	-	-	10	-	-	-	68
Leuctra nigra	1	-	-	-	-	-	-
L. fusca	28	8	62	9	12	8	41
	9.8	2.1	5.2	3.6	2.8	6.5	1.5
L. moselyi	-	-	-	-	-	-	-
Leuctra spp.	-	1	2	-	-	-	3
Diura bicaudata	-	-	-	-	-	-	-
Perlodes microcephala	-	-	1	-	-	-	-
Dinocras cephalotes	8	-	5	11	3	-	12
Perla bipunctata	-	-	-	4	4	-	-
Chloroperla torrentium	-	-	1	-	-	-	-
C. tripunctata	-	-	-	-	-	-	-
Isoperla grammatica	-	-	-	-	-	-	1
Other Plecoptera	-	-	-	-	-	-	-
Paraleptophlebia submarginata	-	1	-	-	-	-	-
Ephemerella ignita	1	6	76	7	37	-	28
	0.3	1.6	6.4	2.8	8.5		1.0
Caenis rivulorum	-	-	-	6	-	-	-
Baetis scambus/bioculatus	-	-	12	10	1	-	34
			1.0	4.0	0.2		1.2
B. vernus/tenax	-	-	-	-	-	-	-
B. rhodani	37	36	36	5	69	-	281
	13	9.4	3.0	2.0	16		10
B. pumilus	-	2	16	-	-	-	49
		0.5	1.3				1.8
B. niger	-	-	-	-	-	-	-
Baetis spp.	38	20	52	4	57	3	732
	13	5.2	4.4	1.6	13	2.4	26
Centroptilum luteolum	-	1	-	-	-	-	-
Rhithrogena sp.	-	1	-	-	-	-	1
Heptagenia lateralis	-	-	-	-	-	-	-
Heptagenia sp.	-	1	-	-	-	-	-
Ecdyonurus venosus	-	-	-	1	-	-	-
E. torrentis	3	3	1	3	2	-	2
Ecdyonurus sp.	3	-	-	7	-	-	10
Ecdyonuridae	2	-	-	1	1	-	5
Other Ephemeroptera	3	-	-	-	-	-	-
Sialis fuliginosa	-	-	-	-	-	-	-
Limnephilidae	2	2	25	-	1	-	-
Silo sp.	1	-	-	-	3	-	3
Hydropsyche instabilis	-	22	11	-	-	-	2
H. (?) fulvipes	-	-	-	-	-	-	-
Hydropsyche spp.	-	-	-	-	-	-	2
Plectrocnemia sp.	-	-	-	-	-	-	-
Polycentropus sp.	3	3	1	-	-	2	-
Polycentropidae	1	-	-	-	-	-	-
Philopotamus montanus	-	6	-	-	1	-	-
Wormaldia sp.	-	-	20	14	15	-	-
Philopotamidae	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	-	-	-	1	-	2
R. obliterata	-	-	-	-	1	-	3
R. munda	-	-	2	-	-	-	-
Rhyacophila spp.	-	-	1	1	4	-	9
Glossosoma boltoni	-	-	-	-	-	-	-
G. vernale	-	-	-	-	-	-	-
Hydroptilidae l p	+	6	+	2	+	36	-
Oxyethira ap.	-	2	1	1	-	1	-
Other Trichoptera l p	1	1	5	-	-	-	2
Oreodytes rivalis l	-	-	4	3	-	-	7
a	-	-	-	1	-	-	2
Dytiscidae l	-	-	-	-	+	-	-
Hydraena gracilis a	-	1	5	-	-	-	6
Helophorus brevipalpis a	-	-	-	-	-	-	1
Helodes sp. l	-	-	1	-	-	1	4
Helmis maugei l	2	-	89	24	19	-	176
	0.7		7.8	9.7	4.4		6.3
a	-	1	4	4	7	-	10
Esolus parallelopipidus l	-	17	47	10	7	10	89
		4.4	3.9	4.0	1.6	5.1	3.2
a	-	8	17	19	8	2	19
Limnius tuberculatus l	-	7	-	-	-	2	-
a	-	2	-	-	-	-	-
Riolus cupreus l a	-	-	-	-	6	-	-
Latelmis volkmari l	2	9	25	-	10	9	10
	0.7	2.3	2.1		2.3	7.3	0.4
a	-	-	1	3	2	1	2
Other Coleoptera l a	-	-	-	-	-	-	-
Dicranota spp.	-	1	39	-	7	-	20
		0.3	3.3		1.6		0.7
Other Tipulidae	-	2	2	-	-	-	1
Pericoma sp.	—	-	1	-	-	-	-
Dixa sp.	-	-	4	-	-	-	3
Tanypodinae	10	1	21	5	7	3	10
	3.5	0.3	1.8	2.0	1.6	2.4	0.4
Corynoneura	+	-	1	-	+	+	1
			0.1				0.0
Tanytarsini	33	8	70	22	15	5	98
	11	2.1	5.9	8.9	3.4	4.0	3.5
Other Chironomidae	21	140	344	49	89	21	467
	7.3	37	29	20	20	17	17
Chironomidae p	3	3	16	5	4	+	8
Atrichopogon sp. p	-	-	1	-	-	-	-
Ceratopogonidae l p	-	2	-	-	-	-	-
Simulium spp. l p	65	5	23	3	14	1	58
	23	1.3	1.9	1.2	3.2	0.8	2.1
Hemerodromia sp.	-	-	2	-	2	-	-
Clinocerinae	1	-	4	-	-	3	4
Limnophora sp. l p	-	-	-	-	-	-	3
Other Diptera l	-	-	-	-	-	-	-
Other Insecta l	-	-	3	-	-	-	-
Hydracarina	1	5	5	6	3	2	23
	0.3	1.3	0.4	2.4	0.7	1.6	0.8
Hydrobia jenkinsi	-	-	-	-	-	-	-
Limnaea peregra	-	3	30	-	-	-	-
Ancylastrum fluviatile	-	-	3	-	-	-	-
Other Gastropoda	-	-	-	-	-	-	-
Pisidium spp.	-	-	-	-	-	-	-
Total	287	383	1190	247	435	124	2775
Weight in mg.	412	564	1614	216	641	83	2251
Min. no. of species	23	34	45	22	31	20	38

SANDSTONE

Stream Number	44	45	46	47	48	49	50	51
Organism								
Hydra sp.	18	18	13	-	-	-	-	-
Polycelis felina	35	-	-	6	-	-	-	-
Crenobia alpina	4	23	8	1	2	-	-	-
Platyhelminthes indet.	2	-	-	-	-	-	-	-
Nematoda	-	-	1	-	-	1	-	-
Naididae	102	2131	76	24	11	82	20	3
Other Oligochaeta	4	94	4	13	10	2	16	3
Hirudinae	-	3	2	-	-	-	-	-
Ostracoda	-	-	5	1	2	5	3	-
Asellus aquaticus	-	-	-	-	-	-	-	-
Gammarus pulex	-	-	-	-	-	-	-	-
G. duebeni	-	-	-	-	-	-	-	-
Amphinemura sulcicollis	-	-	-	-	-	-	-	-
Nemurella picteti	5	-	-	-	-	-	-	-
Protonemura meyeri	23	-	-	-	-	-	-	-
Protonemura sp.	1	-	-	-	-	3	-	1
Leuctra nigra	-	-	-	1	-	-	-	-
L. fusca	80	36	-	4	19	2	69	21
	5.3	1.2		1.3	2.5	0.1	9.7	7.2
L. moselyi	-	-	-	-	-	-	-	2
Leuctra spp.	2	-	-	-	-	-	-	2
Diura bicaudata	-	-	-	-	-	-	-	-
Perlodes microcephala	-	-	-	-	-	-	-	-
Dinocras cephalotes	-	-	-	-	5	-	-	3
Perla bipunctata	4	-	-	-	-	-	-	3
Chloroperla torrentium	4	-	-	-	-	-	-	-
C. tripunctata	4	-	-	-	-	-	-	-
Isoperla grammatica	1	-	-	-	-	-	-	-
Other Plecoptera	-	-	2	-	-	4	-	-
Paraleptophlebia submarginata	-	-	-	-	-	3	-	-
Ephemerella ignita	10	215	82	-	17	1	-	9
	0.7	7.3	16		2.2			3.1
Caenis rivulorum	-	-	-	-	65	-	-	-
Baetis scambus/bioculatus	9	-	20	-	13	-	11	10
	0.6		4.0		1.7		1.5	3.4
B. vernus/tenax	-	7	-	-	-	-	-	-
B. rhodani	205	-	52	-	104	-	78	7
	13		10		14		11	2.7
B. pumilus	14	-	-	-	48	-	-	1
	0.9				6.3			0.3
B. niger	3	-	-	-	-	-	-	-
Baetis spp.	427	23	11	-	164	-	58	42
	28	0.8	2.2		22		8.2	14
Centroptilum luteolum	12	-	-	-	-	5	-	-
Rhithrogena sp.	16	-	-	-	6	-	-	2
Heptagenia lateralis	-	-	-	-	-	-	-	1
Heptagenia sp.	-	-	-	-	-	-	-	-
Ecdyonurus venosus	-	-	-	-	-	-	-	-
E. torrentis	26	-	-	-	11	-	8	1
Ecdyonurus sp.	43	-	-	-	9	-	1	15
Ecdyonuridae	-	-	-	-	5	1	-	-
Other Ephemeroptera	-	-	1	-	-	-	2	-
Sialis fuliginosa	-	-	-	-	-	-	-	-
Limnephilidae	10	2	-	2	-	-	3	-
Silo sp.	-	-	-	-	-	-	-	-
Hydropsyche instabilis	-	-	-	-	1	-	-	-
H. (?) fulvipes	-	-	-	-	-	-	-	1
Hydropsyche spp.	-	-	-	-	9	3	-	1
Plectrocnemia sp.	-	-	-	4	-	-	1	1
Polycentropus sp.	4	-	-	-	11	20	1	-
Polycentropidae	2	-	-	1	2	1	5	-
Philopotamus montanus	-	-	-	-	1	-	-	-
Wormaldia sp.	2	-	-	-	-	-	-	13
Philopotamidae	-	-	-	-	-	-	-	-
Rhyacophila dorsalis	-	-	-	-	1	-	3	1
R. obliterata	1	-	-	-	-	-	-	-
R. munda	-	-	-	1	-	-	-	-
Rhyacophila spp.	3	1	-	-	-	-	2	1
Glossosoma boltoni	-	-	-	-	-	-	-	1
G. vernale	-	-	-	-	-	-	-	-
Hydroptilidae l p	-	-	-	-	1	-	1	+
Oxyethira ap.	-	-	-	-	1	-	-	-
Other Trichoptera l p	7	-	-	-	1	1	-	6
Oreodytes rivalis l	16	-	-	-	-	-	-	-
a	44	-	-	-	-	-	-	-
Dytiscidae l	-	-	-	1	1	3	-	-
Hydraena gracilis a	7	-	-	-	5	-	-	-
Helophorus brevipalpis a	-	1	-	-	-	-	-	1
Helodes sp. l	-	-	-	4	-	-	-	-
Helmis maugei l	14	1	16	12	33	81	24	-
	0.9	0.0	3.2	4.0	4.3	3.2	3.2	
a	-	-	-	4	-	1	31	-
Esolus parallelopipidus l	47	-	1	10	52	12	-	16
	3.1		0.2	3.3	6.9	0.5		5.5
a	20	-	-	3	20	3	-	1
Limnius tuberculatus l	-	-	3	1	-	26	10	-
a	-	-	-	-	1	8	7	-
Riolus cupreus l a	-	-	-	-	-	1	-	-
Latelmis volkmari l	8	3	3	2	9	2	84	6
	0.5		0.6	0.7	1.2	0.1	12	2.1
a	5	-	1	-	1	1	13	3
Other Coleoptera l a	1	2	-	-	-	-	-	-
Dicranota spp.	13	5	1	11	2	9	38	9
	0.9	0.2	0.2	3.7	0.3	0.4	5.4	3.1
Other Tipulidae	4	1	-	1	-	-	-	-
Pericoma sp.	3	12	-	6	-	-	-	-
Dixa sp.	6	-	-	-	-	-	-	-
Tanypodinae	20	6	+	17	15	14	1	3
	1.3	0.2		5.7	2.0	0.6	0.2	1.0
Corynoneura	2	-	-	+	+	1	-	+
	0.1					0.0		
Tanytarsini	53	44	66	23	22	1509	103	-
	3.5	1.5	13	7.7	2.8	60	14	
Other Chironomidae	140	224	47	138	44	627	16	77
	9.2	7.6	9.4	46	5.8	25	2.3	26
Chironomidae p	6	16	6	2	8	25	-	8
Atrichopogon sp. p	-	-	-	-	-	-	-	-
Ceratopogonidae l p	-	2	3	3	-	2	-	3
Simulium spp. l p	23	48	-	-	2	-	-	8
	1.5	1.6			0.3			2.7
Hemerodromia sp.	2	-	4	-	1	-	-	-
Clinocerinae	9	3	+	-	5	7	-	1
Limnophora sp. l p	-	-	-	-	1	7	-	-
Other Diptera l	-	2	1	2	-	-	1	-
Other Insecta l	-	-	-	-	-	-	-	-
Hydracarina	13	4	23	2	4	9	21	4
	0.4	0.1	4.6	0.7	0.5	0.4	3.0	1.3
Hydrobia jenkinsi	-	-	17	-	-	-	57	-
Limnaea peregra	-	17	3	-	8	1	9	-
Ancylastrum fluviatile	-	1	28	-	3	6	8	-
Other Gastropoda	-	-	-	-	-	2	1	-
Pisidium spp.	-	1	-	1	-	3	2	-
Total	1521	2943	502	300	759	2491	709	292
Weight in mg.	1207	2061	834	362	939	600	1356	519
Min. no. of species	43	29	31	26	39	29	27	31

50. Unnamed Burn. 39/384723. 45 m. Caithness. 8 March and 26 July. Sandstone. Arable, with grass and herbage on banks. Gradient gentle. Flow 2—4. Width 1 m. Max. depth 0.3 m. Bottom 10621. Moss 0, Algae 2.
51. Allt Leathan. 27/569721. 350 m. Mid Perth. 25 Jan. and 29 June. Quartzite-schist. Heather moor with sparse alder. Gradient gentle. Flow 1—3. Width 2 m. Max. depth 0.5 m. Bottom 00910. Moss 0, Algae 2—.

APPENDIX 2 – THE FAUNA OF THE INDIVIDUAL STREAMS

The composition of the catches of animals from each stream for spring and summer is given in the tables that comprise this appendix. Each table also includes the total catch by number and by weight and the minimum number of species found in each stream. The plus (+) sign indicates that, although the species was not found in the kick-samples, it was present in the stone-scrubbings. The proportion of the total catch that the main species and some other taxa comprise is given as a percentage in italics. These percentages are not calculated when the catch from a stream does not exceed 100 animals.

The chemical richness of each stream, as total cations in micro-equivalents per litre, is given, in the table of the spring fauna.

Both tables include animals that were identified further than the category in which they appear. These are listed below.

a. The table of the spring fauna:

The Hirudinea are *Glossiphonia complanata* 1 in stream 30, 1 in 50; *Helobdella stagnalis* 1 in 39, 3 in 45 and *Erpobdella octoculata* 6 in burn 30. *Gammarus duebeni* 1 in stream 42. *Leuctra* spp. include *L. fusca* 2 in 49 and *L. moselyi* 1 in 45. The 'Other Plecoptera' include *Brachyptera putata* 4 in 9; *Chloroperla* spp. 3 in 23 and *Nemurella picteti* 1 in 29. *Heptagenia* spp. include *H. sulphurea* 1 in 21, 1 in 8 and *H. lateralis* 1 in 38, 10 in 42, 1 in 26. The 'Other Ephemeroptera' include *Leptophlebia marginata* 1 in 48, 4 in 49 and *Paraleptophlebia submarginata* 4 in 50. The 'Other Coleoptera' include *Ochthebius impressicollis* 1 adult in 41. Among the 'Other Diptera' are *Pericoma* spp. larvae, 1 in 22, 1 in 27, 3 in 45, 1 in 48, 1 in 32; *Dixa* sp. 1 larva in 27; Ceratopogonidae 1 larva in 35; *Hemerodromia* spp. larvae 1 in 38, 2 in 49 and *Limnophora* sp. 1 larva in 39. The 'Other Gastropoda' include *Planorbis albus* Müll. 1 in 23, 1 in 30 and *Hydrobia jenkinsi* 7 in 46.

b. The table of the summer fauna:

One member of the Rhabdocoelida was found in 30 and included in the total count for the stream.

The Hirudinea were *Helobdella stagnalis* 3 in 45, 1 in 46; *Erpobdella octoculata* 3 in 30 and *Glossiphonia complanata* 1 in 46. 'Other Plecoptera' include *Taeniopteryx nebulosa* 1 in 46 and *Protonemura praecox* 9 in 8. 'Other Ephemeroptera' include *Ephemera danica* 1 in 46; *Centroptilum pennulatum* 3 in 37; *Procloeon rufulum* 2 in 50 and *Heptagenia sulphurea* 1 in 21 and also present in 9. The 'Other Trichoptera' included *Goera* sp. 1 in 13; Lepidostomatinae 1 in 37; Sericostomatidae 4 in 10; *Hydropsyche angustipennis* 1 in 48; *Agapetus* sp. 1 in 23 and Glossosomatinae 1 in 43, 1 in 22. The 'Other Coleoptera' include *Brychius elevatus* 1 adult in 45, *Oreodytes septentrionalis* 1 adult in 44, *Limnebius truncatellus* 1 adult in 12, *Dryops* sp. 1 adult in 8, *Platambus maculatus* 1 adult in 24, 1 in 12. The following *Simulium* spp. pupae were identified: – *S. latipes* Meig. in 43, 29 and 12, *S. ornatum* Meig. in 45, *S. latipes* or *costatum* Friederichs in 48 and 31, *S. variegatum* Meig. in 34 and 17, and *S. nölleri* Friederichs in 34.

References

ARMITAGE, K. B., - 1958 - Ecology of the riffle insects of the Firehole River, Wyoming. *Ecology*, 39, 571—80.

BALFOUR-BROWNE, F., - 1931 - A plea for uniformity in the method of recording insect captures. *Ent. mon. Mag.* 67: 183—193.

BALFOUR-BROWNE, F., - 1940 - British Water Beetles, Vol. 1. London, 375 pp.

BUTCHER, R. W., LONGWELL, J. & PENTELOW, F. T. K., - 1937 - Survey of the River Tees, III. The non-tidal reaches. Chemical and Biological. *Tech. Pap. Wat. Pollut. Res. Lond.*, 6, 187 pp.

FROST, W. E., - 1942 - River Liffey Survey IV – The fauna of the submerged mosses in an acid and an alkaline water. *Proc. R. Irish Acad.* B, 47: 239—269.

GAUFIN, A. R., - 1959 - Production of bottom fauna in the Provo River, Utah. *Iowa. St. Coll. J. Sci.* 33: 395—419.

HARKER, J. E., - 1952 - A study of the life cycles and growth rates of four species of mayflies. *Proc. R. ent. Soc. Lond. A*, 27: 77—85.

HUMPHRIES, C. F. & FROST, W. E., - 1937 - River Liffey Survey. The Chironomid fauna of the submerged mosses. *Proc. R. Irish Acad. B*, 43: 161—8.

HYNES, H. B. N., - 1941 - The taxonomy and ecology of the nymphs of British Plecoptera with notes on the adults and eggs. *Trans. R. ent. Soc. Lond.* 91: 459—557.

HYNES, H. B. N., - 1954 - The ecology of *Gammarus duebeni* Lilljeborg and its occurrence in fresh water in Western Britain. *J. Anim. Ecol.* 23, 38—84.

HYNES, H. B. N., - 1958 - A key to the adults and nymphs of British stoneflies. *Sci. Pub. Freshwat. biol. Ass.* 17, 86 pp.

HYNES, H. B. N., - 1960 - The biology of Polluted Waters. Liverpool. 202 pp.

HYNES, H. B. N. - 1961 - The invertebrate fauna of a Welsh mountain stream. *Arch. Hydrobiol.* 57: 344—388.

HYNES, H. B. N., MACAN, T. T. & WILLIAMS, W. D., - 1960 - A key to the British species of Crustacea: Malacostraca occurring in fresh water. *Sci. Pub. Freshwat. biol. Ass.* 19, 36 pp.

ILLIES, J., - 1952 - Die Mölle. Faunistisch-ökologische Untersuchungen an einem Forellenbach im Lipper Bergland. *Arch. Hydrobiol.* 46: 424—612.

MACAN, T. T., - 1950 - Descriptions of some nymphs of the British species of the genus *Baetis* (Ephem.). *Trans. Soc. Brit. Ent.* 10: 143—66.

MACAN, T. T., - 1957a - The Ephemeroptera of a stony stream. *J. Anim. Ecol.* 26: 317—42.

MACAN, T. T., - 1957b - The life histories and migration of the Ephemeroptera of a stony stream. *Trans. Soc. Brit. Ent.* 12: 129—56.

MACAN, T. T., - 1958 - Methods of sampling the bottom fauna in stony streams. *Mitt. int. Ver. Limnol.* 8: 21 pp.

MACAN, T. T., - 1961 - in 29th Annual Report of Freshwater Biological Association.

MACIOLEK, J. A. & NEEDHAM, P. R., - 1951 - Ecological effects of winter conditions on trout and trout foods in Convict Creek, California. *Trans. Amer. Fish. Soc.* 81: 202—217.

MOON, H. P., - 1935 - Methods and apparatus suitable for an investigation of the littoral region of oligotrophic lakes. *Int. Rev. Hydrobiol.*, 32: 319—33.

NEEDHAM, P. R., - 1934 - Quantitative studies of stream bottom foods. *Trans. Amer. Fish. Soc.*, 64: 238—247.

NEEDHAM, P. R. & USINGER, R. L., - 1956 - Variability in the macrofauna of a single riffle in Prosser Creek, California, as indicated by the Surber sampler. *Hilgardia*, 24: 283—409.

NEILL, R. M., - 1938 - The food and feeding of the brown trout (*Salmo trutta* L.) in relation to the organic environment. *Trans. roy. Soc. Edinb.* 59: 481—520.

PENTELOW, F. T. K., BUTCHER, R. W. & GRINDLEY, J., - 1938 - An investigation of the effects of milk wastes on the Bristol Avon. *Fish. Invest. Lond.*, Ser.1, 4 (1), 80 pp.

PERCIVAL, E. & WHITEHEAD, H., - 1929 - A quantitative study of the fauna of some types of stream bed. *J. Ecol.* 17: 282—314.

PERCIVAL, E. & WHITEHEAD, H., - 1930 - Biological survey of the River Wharfe. 2. Report on the invertebrate fauna. *J. Ecol.* 18: 286—302.

PLESKOT, G., - 1958 - Die Periodizität einiger Ephemeropteren der Schwechat. *Wasser und Abwasser* 1958: 1—32.

SPRULES, W. M., - 1947 - An ecological investigation of stream insects in Algonquin Park, Ontario. *Univ. Toronto Stud., Biol. Ser.* 56. *Publ. Ont. Fish. Res. Lab.*, 69: 1—45.

SURBER, E. W., - 1936 - Rainbow trout and bottom fauna production in one mile of stream. *Trans. Amer. Fish. Soc.*, 66: 193—202.

Parasitology (1964), **54**, 263–272
With 2 text-figures
Printed in Great Britain

A comparison between the helminth burdens of male and female brown trout, *Salmo trutta* L., from a natural population in the River Teify, West Wales

By J. D. THOMAS
University of Ghana, Legon, Accra, Ghana

(*Received* 27 *October* 1962—*Revised* 9 *November* 1963)

INTRODUCTION

Differences in the parasitic burdens of male and female hosts have been discussed by von Brand (1952), Haley (1958), Dobson (1961*a*, *b* 1962), Lees (1962), Dudzinski & Mykytowycz (1963), Hickman (1960), Leigh (1960), Neafie & Haley (1962), Berry (1962), Schad (1962) and Nelson, Heisch & Furlong (1962). The only previous reference to differences of this nature in male and female fish appears to be that of Leigh (1960). The purpose of this paper is to compare the susceptibilities of male and female trout, *Salmo trutta* L. to helminth parasites and to consider the role of host resistance in the two sexes. This was made possible by analyses of data from investigations by Thomas (1958*a*, *b*, 1962, 1964) into the ecology of brown trout and their helminth parasites.

MATERIALS AND METHODS

The number of trout on which the present analysis is based is given in Table 1. These were caught over a period of 12 months in the River Teify, West Wales, at two stations, one in the bog area near Tregaron and the other 4 miles downstream

Table 1. *The number of brown trout* (Salmo trutta *L.*) *examined for helminth parasites*

Age group ...	1 year old		2 years old		3 years old		4 years old +	
Months	Female	Male	Female	Male	Female	Male	Female	Male
Jan.–Mar.	—	—	32	32	51	31	36	27
Apr.–Sept.	45	45	55	59	39	17	26	23
Oct.–Dec.	90	84	57	54	43	31	11	16

near Pont Llanio. All the trout were measured, weighed, sexed, examined for food and parasites and their ages determined as previously described (Thomas, 1962, 1964). The volume of food was estimated by eye using a points scheme; e.g. a quarter full stomach would be given four points, a full stomach sixteen points and a distended stomach a higher number of points in proportion to the volume of food present (Thomas, 1962). An arbitrary criterion was given for age and all the trout captured after 31 December were deemed to have completed a year's growth. Trout in the 1+, 2+, 3+ and 4+ age groups were termed 1, 2, 3 and 4 years old and over respectively.

The incidence and intensity of infestation of male and female fish with parasites have been expressed as the percentage number of infested fish and the mean number of parasites per fish respectively. Differences between percentage infestations were tested by means of the χ^2 test and the differences between the mean number of parasites by means of 'Student's' t test. Before the latter could be used it was necessary to transform the data using the formula $Y = 100.\log(1+x)$ as recommended by Bishop & Margolis (1955) as the distribution of all the parasites tends to conform to the negative binomial distribution.

RESULTS

Although twelve species of helminths were found in the brown trout only six, namely *Discocotyle sagittata* (Leuckart), *Phyllodistomum simile* Nybelin, *Crepidostomum metoecus* (Braun), *Crepidostomum farionis* (Müller), *Dacnitis truttae* (Fabricius) and *Neoechinorhynchus rutili* (Müller) occurred commonly and have been selected for the present comparisons. The writer is indebted to Mr S. Prudhoe, British Museum (Nat. Hist.) for identifying the acanthocephalan *N. rutili* and for advising on the nomenclature of *D. truttae*. According to Yamaguti (1961), however, the genus *Dacnitis* is a synonym of *Cucullanus* and *C. globosus* Zeder, 1800, is a synonym of *C. truttae* Fabricius. Of the trematodes, *D. sagittata* occurs in the gills, *P. simile* in the urinary bladder, *Crepidostomum metoecus* in the intestine chiefly the pyloric caeca region and *C. farionis* mainly in the post-pyloric caeca region. The nematode *D. truttae* occurs chiefly in the pyloric caeca region, whereas *N. rutili* is found mainly in the post-pyloric caeca region.

Fig. 1. gives the incidence and intensity of infestation separately for male and female trout at three different periods. The periods chosen were October to December when sexually mature brown trout were spawning, January to March when they were wintering and recovering from the effects of spawning and from April to September the period of maximum growth. The gonads of sexually mature trout develop rapidly during the months of August to October. Less than 5% of the trout in their second year became sexually mature compared with more than 50% of those in their third year. All the trout of 4 years and over had fully developed gonads. Fig. 1 shows that both the incidences and intensities of infestation tend to follow the same trend, but the latter is a more sensitive index of change as it gives a direct measure of population density.

A comparison between the levels of infestation in male and female trout is complicated by changes due to the season and age of the host. These aspects are discussed more fully by Thomas (1958*a*, *b*, 1964), but a summary of the findings will be given here. Although all six parasites undergo population oscillations over the period of investigation only the two species of *Crepidostomum* show seasonal changes which are statistically significant. Both show a decrease in population density during the summer months but these seasonal effects are not, however, evident in all age groups in Fig. 1 because the figures are compounded from several monthly figures. The changes in infestation with the age of the host are quite marked and with the exception of *N. rutili* there is a tendency for both the intensity and incidence of infestation to increase with the age of the host.

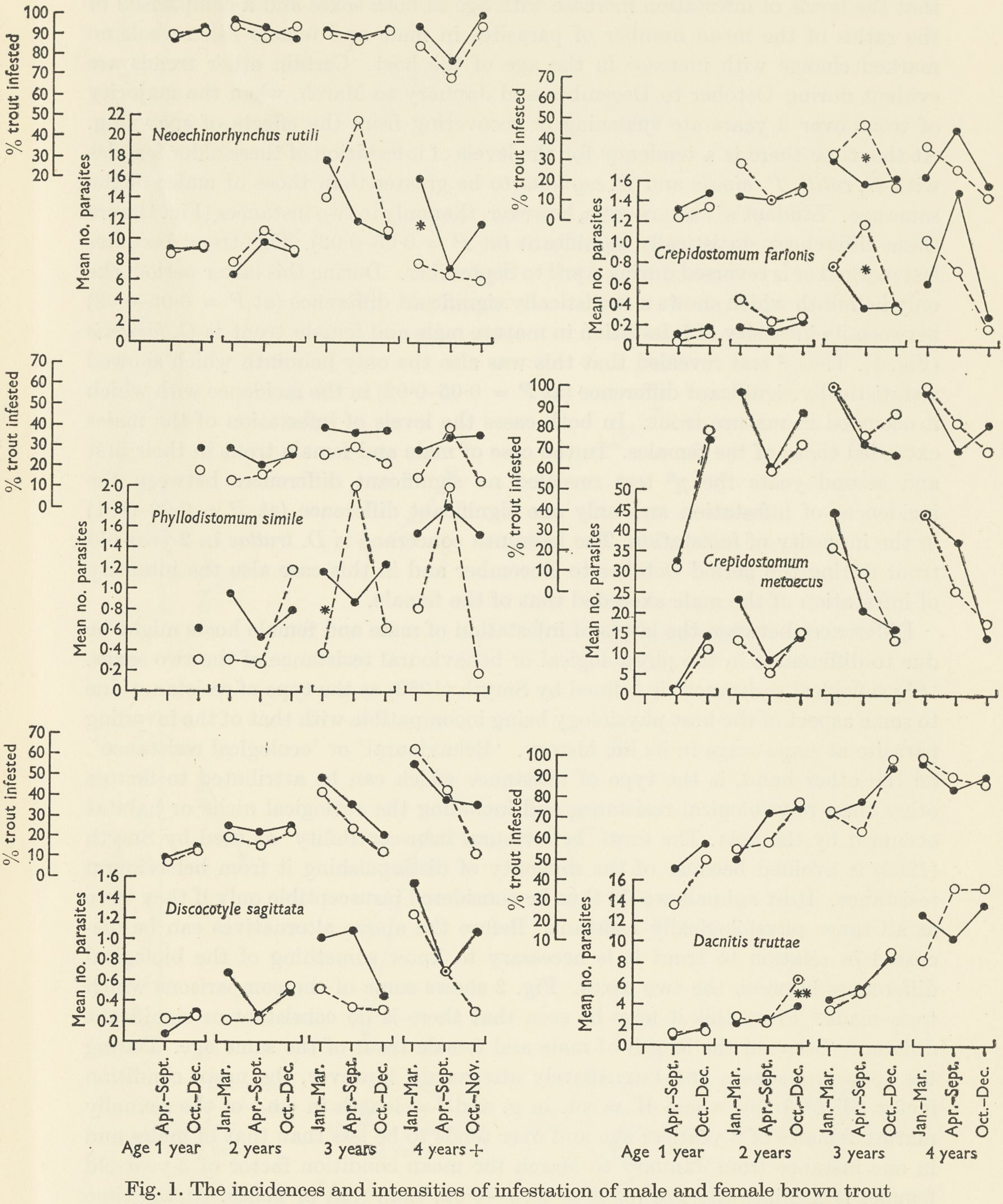


Fig. 1. The incidences and intensities of infestation of male and female brown trout of different ages with helminth parasites. ●—●, Female trout; ○- - -○, male trout. * $P=0{\cdot}05$—$0{\cdot}02$; ** $P=0{\cdot}02$—$0{\cdot}01$.

There is a tendency for the differences between the levels of infestation in male and female trout to be appreciably greater in the case of trout of 3 years of age and over than in younger trout (Fig. 1). This apparent trend is partly due to the fact that the levels of infestation increase with age in both sexes and a comparison of the ratios of the mean number of parasites in male and female fish reveals no marked change with increase in the age of the host. Certain other trends are evident during October to December and January to March, when the majority of trout over 3 years are spawning or recovering from the effects of spawning. At this time there is a tendency for the levels of infestation of these older females with *N. rutili*, *P. simile* and *D. sagittata* to be greater than those of males of the same age. 'Student's' *t* test reveals, however, that only in two instances (Fig. 1) were these differences statistically significant (at $P = 0{\cdot}05$–$0{\cdot}02$). This trend becomes less marked or is reversed during April to September. During this latter period, the only helminth which shows a statistically significant difference (at $P = 0{\cdot}05$–$0{\cdot}02$) between its intensity of infestation in mature male and female trout is *C. farionis* (Fig. 1). The χ^2 test revealed that this was also the only helminth which showed a statistically significant difference (at $P = 0{\cdot}05$–$0{\cdot}02$) in the incidence with which it occurred in mature trout. In both cases the levels of infestation of the males exceeded those of the females. In the case of male and female trout in their first and second years the χ^2 test revealed no significant differences between the incidences of infestation and only one significant difference (at $P = 0{\cdot}02$–$0{\cdot}01$) in the intensity of infestation. The helminth concerned is *D. truttae* in 2-year-old trout during the period October to December and in this case also the intensity of infestation of the male exceeded that of the female.

Differences between the levels of infestation of male and female hosts might be due to differences in the physiological or behavioural resistance of the two sexes. 'Physiological resistance' is defined by Smyth (1962) as the type of resistance due to some aspect of the host physiology being incompatible with that of the invading parasite at some stage in its life history. 'Behavioural' or 'ecological resistance', on the other hand, is the type of resistance which can be attributed to factors other than physiological resistance and including the ecological niche or habitat occupied by the host. The term 'behavioural insusceptibility' as used by Smyth (1962) is avoided because of the difficulty of distinguishing it from behavioural resistance. Host animals would thus be considered insusceptible only if they were at all times physiologically resistant. Before the above alternatives can be discussed in relation to trout it is necessary to know something of the biological differences between the two sexes. Fig. 2 shows some of the comparisons which were made. From this it may be seen that there is no consistent or significant difference between the length of male and female trout of the same age. During the spawning season and immediately afterwards, however, the mean condition factor ($W/L^3 . 1000$; where W = wt. in g. and l = length in cm.) of the sexually mature females of 3 years of age and over tends to be less than that of males and in one instance from January to March the mean condition factor of 3-year-old females is significantly less (at $P = 0{\cdot}05 - 0{\cdot}02$) than that of males. At the time of spawning also the 3-year-old females had significantly less food ($P = 0{\cdot}05 -$

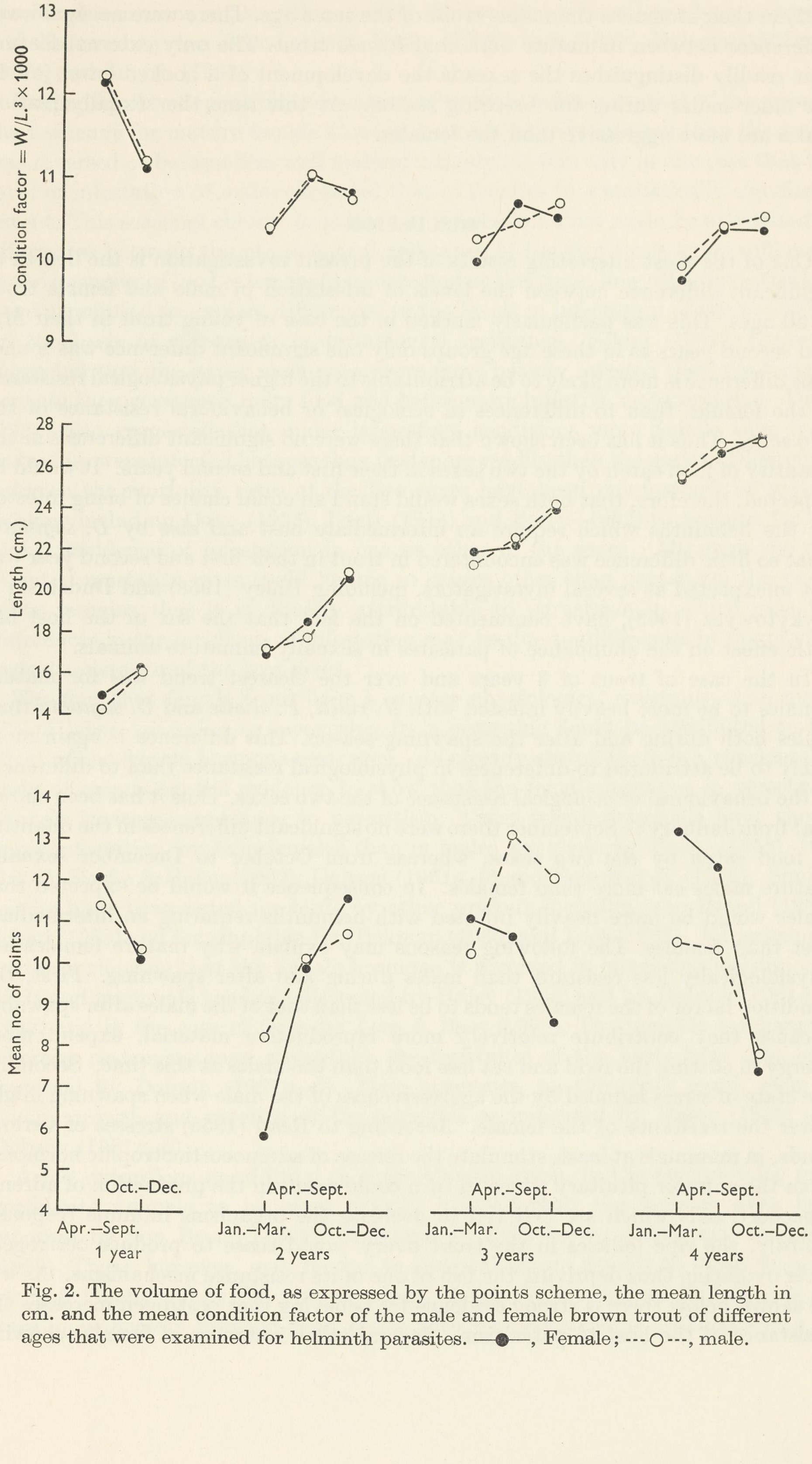


Fig. 2. The volume of food, as expressed by the points scheme, the mean length in cm. and the mean condition factor of the male and female brown trout of different ages that were examined for helminth parasites. —●—, Female; ---○---, male.

0·02) in their stomachs than male trout of the same age. There were no significant differences between immature male and female trout. The only external feature that readily distinguishes the sexes is the development of a hooked lower jaw in the older males during the breeding season. At this time the sexually mature males are more aggressive than the females.

DISCUSSION

One of the most interesting results of the present investigation is the dearth of significant difference between the levels of infestation in male and female trout of all ages. This was particularly marked in the case of young trout in their first and second years as in these age groups only one significant difference was found. This difference is more likely to be attributable to the higher physiological resistance of the females than to differences in ecological or behavioural resistance of the two sexes. Thus it has been shown that there were no significant differences in the quantity of food eaten by the two sexes in their first and second years. It would be expected, therefore, that both sexes would stand an equal chance of being infested by the helminths which require an intermediate host and also by *D. sagittata*. That so little difference was encountered in trout in their first and second year was not unexpected as several investigators, including Haley (1958) and Dudzinski & Mykytowycz (1963), have commented on the fact that the sex of the host has little effect on the abundance of parasites in sexually immature animals.

In the case of trout of 3 years and over the clearest trend was for mature females to be more heavily infested with *N. rutili*, *P. simile* and *D. sagittata* than males both during and after the spawning season. This difference is again more likely to be attributed to differences in physiological resistance than to differences in the behavioural or ecological resistance of the two sexes. Thus it has been shown that from January to September there were no significant differences in the quantity of food eaten by the two sexes, whereas from October to December sexually mature males eat more than females. In consequence it would be expected that males would be more heavily infested with helminths requiring an intermediate host than females. The following reasons may explain why mature females are physiologically less resistant than males during and after spawning. First, the condition factor of the females tends to be less than that of the males after spawning because they contribute relatively more reproductive material, expend more energy in cutting the redd and eat less food than the males at this time. Secondly, the state of stress induced by the aggressiveness of the male when spawning might lower the resistance of the female. According to Read (1958) stresses of various kinds, in mammals at least, stimulate the release of adrenocorticotrophic hormones from the anterior pituitary which in turn could result in the production of adrenal glucocorticoids which are believed to decrease the organisms immune response. Thirdly, the ripe follicles in the trout ovary would cease to produce oestrogens after ovulating thus depriving the fish of one of its resistance mechanisms. As will be shown below there is strong evidence for believing that oestrogen increases the resistance of the host to parasitism. Several other instances of females showing decreased resistance to parasitism during the breeding season have been reported and discussed by von Brand (1952), Haley (1958), Bull (1959), Dobson (1961*a*, *b*, 1962), and Smyth (1962).

During April to September, the season of growth and maturation of the gonads, the tendency for mature female trout to be more heavily infested than the males was reversed or became less well marked although it was only in one case that the level of infestation of males exceeded that of females to a statistically significant extent. This seasonal change in pattern of infestation must again be attributed to differences between the physiological resistance of the two sexes as no difference in the quantity of food eaten could be detected at this time. Few other investigators have attempted to explain differences in the levels of infestation of the two sexes on the basis of differences in behavioural resistance. Schad (1962), however, suggested that the larger male geese were more heavily infested than the females because they consumed more food and hence more infestive metacercariae. Duke (1933) also suggested that under laboratory conditions more female than male tsetse flies were infected because they feed more readily than the males. Differences between the mortality rates of the two sexes have been put forward by several workers including Duke (1933), Burtt (1946) and Berry (1962) to account for the higher incidence of infestation in one or other of the sexes. Although the differential mortality rates could be due to causes other than parasitism the possibility remains that it is directly attributable to parasitism in which case the differences in the incidence of infestation may be due to differences in the physiological resistance of the two sexes.

The fact that female trout have a greater physiological resistance than males except when spawning or recovering from spawning could be attributed to the effect of the female hormone oestrogen. As already stated there is a considerable body of circumstantial evidence to show that the female hormone in vertebrate animals increases resistance to parasitism. Cases where mammals have shown lower infestation levels in females than in males are given by Haley (1958), Bull (1959), Neafie & Haley (1962), Dobson (1961*a*, *b*) and Nelson *et al.* (1962). Similar results have been noted for birds by other workers including von Brand (1952), Schad (1962) and for amphibia by Hickman (1960) and Lees (1962). Experimental evidence showing that the female hormone is involved in increasing resistance in birds and mammals has been discussed by Haley (1958) and by Dobson (1961*a*, *b*, 1962) and in the case of frogs by Lees & Bass (1960). The possible mechanisms whereby oestrogens may strengthen the resistance of the hosts have also been reviewed by Dobson (1961*a*, *b*). Male hormones, on the other hand, seem to favour growth and survival of the parasites as indicated by Haley (1958) and Dobson (1961*a*, *b*).

A few exceptions in addition to those already given, to the tendency for male vertebrate animals to be more heavily infested than the females have been reported by von Brand (1952), Dudzinski & Mykytowycz (1963) and by Leigh (1960). These, however, may be due to seasonal effects similar to those reported by Bull (1959) and in the present paper. Leigh (1960) showed that female gar were more heavily infested than males with metacercariae of *Odhneriotrema* sp.

but did not give information regarding the age of the hosts or the state of the gonads. In the invertebrates the relationship of parasites to the sex of the host often differs from that generally found in vertebrates. Thus papers cited by von Brand (1952) indicate that female insects are sometimes more heavily infested than males, although von Brand (1952) and Ashcroft (1959) have also reported the converse. The observations on crustacea are also conflicting (von Brand, 1952). In the case of molluscs Berry (1962) found that females of *Littorina saxatilis* are consistently more frequently infected with trematode larvae than the males. These differences between vertebrates and invertebrates may be due to differences in their physiology. There is little evidence of gonadal hormones being active in insects, and although they have been demonstrated in the crustacea (Prosser & Brown, 1961) there is little likelihood of their being identical in their action to those of vertebrates.

Three reasons may be advanced to explain why so few differences were found in the levels of infestation in mature male and female trout: first the interplay of various ecological factors affecting the population density of the parasites including those causing seasonal oscillations, might obscure the effects due to the sex of the host; secondly the seasonal reversals of the infestation patterns of the two sexes are self cancelling; and thirdly the difference between the physiological resistance of male and female trout is of a low order. Lees (1962) has demonstrated that the parasites which show the most striking differences between their incidence in male and female frogs are those which obtain their nourishment directly from the blood or tissues of the host. Yet in the present investigation even parasites which fall into this category, namely, *D. sagittata*, *P. simile* and *N. rutili* show few significant differences between the levels with which they infest the two sexes. It is possible that the female hormones of fishes are less potent than those of higher vertebrates in promoting resistance to parasitism. According to Hoar (1957), although androgens and oestrogens have been demonstrated in fishes, the true identity of the steroids has not been established and the results of experiments with sex hormones in fish are not always those which one would expect on the basis of mammalian physiology. In view of the scarcity of knowledge regarding the relationship of sex to parasitism in fishes more field and laboratory observations are desirable.

SUMMARY

1. Nine hundred and five brown trout were collected from the River Teify, West Wales, over a period of 12 months and their helminth infestations are considered in relation to the age and sex of the host and season.

2. Only one statistically significant difference could be detected between levels of infestation in male and female trout of 1 and 2 years of age.

3. When trout of 3 years of age and over were spawning or recovering from the effects of spawning there is a tendency for sexually mature females to be more heavily infested with some parasites than the males. During the season of growth and maturation of the gonads this trend was reversed or became less marked. In the case of fish that were not spent or spawning the statistically significant differences showed the males to be more heavily infested than the females.

4. The possible reasons for these variations are discussed with particular reference to the roles of 'physiological' and 'behavioural' or ecological resistance'.

REFERENCES

ASHCROFT, M. T. (1959). The sex ratio of infected flies found in transmission experiments with *Glossina morsitans* and *Trypanosoma rhodesiense* and *T. brucei*. *Trans. R. Soc. trop. Med. Hyg.* **53**, 394–9.

BERRY, A. J. (1962). The occurrence of a trematode larva in a population of *Littorina saxatilis* (Olivi). *Parasitology*, **52**, 237–40.

BISHOP, Y. M. & MARGOLIS, L. (1955). A statistical examination of *Anisakis* larvae (Nematoda) in herring (*Clupea pallasi*) of the British Columbia Coast. *J. Fish Res. Bd. Can.* **12**, 571–92.

BRAND, T. VON (1952). *Chemical Physiology of Endoparasitic Animals*. New York: Academic Press, Inc.

BULL, P. C. (1959). A seasonal sex difference in the infestation of rabbits with the nematode *Trichostrongylus retortaeformis* (Zeder, 1800). *Nature, Lond.*, **184**, 281–2.

BURTT, E. (1946). The sex-ratio of infected flies found in transmission experiments with *Glossina morsitans* and *Trypanosoma rhodesiense*. *Ann. trop. Med. Parasit.* **40**, 74–9.

DOBSON, C. (1961*a*). Certain aspects of the host-parasite relationship of *Nematospiroides dubius* (Baylis). I. Resistance of male and female mice to experimental infections. *Parasitology*, **51**, 173–9.

DOBSON, C. (1961*b*). Certain aspects of the host-parasite relationship of *Nematospiroides dubius* (Baylis). II. The effects of sex on experimental infections in the rat (an abnormal host). *Parasitology*, **51**, 499–510.

DOBSON, C. (1962). Certain aspects of the host parasite relationship of *Nematospiroides dubius* (Baylis). V. Host specificity. *Parasitology*, **52**, 41–8.

DUDZINSKI, M. L. & MYKYTOWYCZ, R. (1963). Relationship between sex and age of rabbits, *Oryctolagus cuniculus* (L.) and infection with Nematodes *Trichostrongylus retortaeformis* and *Graphidium strigosum*. *J. Parasit.* **49**, 55–9.

DUKE, H. L. (1933). Relative susceptibility of the sexes of *Glossina* to infection with Trypanosomes. *Ann. trop. Med. Parasit.* **27**, 355–6.

HALEY, A. J. (1958). Sex difference in the resistance of hamsters to infection with the rat nematode, *Nippostrongylus muris*. *Exp. Parasit.* **7**, 338–48.

HICKMAN, J. L. (1960). Cestodes of some Tasmanian Anura. *Ann. Mag. nat. Hist.* **3**, 1–23.

HOAR, W. S. (1957). Endocrine organs. In Brown, M.E. (ed.): *The Physiology of Fishes*, vol. I, pp. 245–85. New York: Academic Press, Inc.

LEES, E. (1962). The incidence of helminth parasites in a particular frog population. *Parasitology*, **52**, 95–102.

LEES, E. & BASS, L. (1960). Sex hormones as a possible factor influencing the level of parasitization in frogs. *Nature, Lond.*, **188**, 1207–8. Correspondence.

LEIGH, W. H. (1960). The Florida Spotted Gar, as the intermediate host for *Odhneriotrema incommodum* (Leidy, 1856) from *Alligator mississippiensis*, Abstract, *J. Parasit.* **46**, (5, Sect. 2), 16.

NEAFIE, R. C. & HALEY, A. J. (1962). Sex difference in resistance of the mouse *Mus musculus* to infection with the rat nematode, *Nippostrongylus brasiliensis* (Travassos, 1914). *J. Parasit.* **48**, 151.

NELSON, G. S., HEISCH, R. B. & FURLONG, M. (1962). Studies on filariasis in East Africa. II. Filarial infections in man, animals and mosquitoes on the Kenya coast. *Trans. R. Soc. trop. Med. Hyg.* **56**, 202–17.

PROSSER, C. L. & BROWN, F. A. (1961). *Comparative Animal Physiology*: Philadelphia: Saunders.

READ, C. P. (1958). Status of behavioural and physiological resistance. *Rice Inst. Pamphl.* **45**, 36–54.

SCHAD, G. A. (1962). Helminth parasitism in a flock of domestic geese introduced to arctic summer conditions in Canada. *Canad. J. Zool.* **40**, 1–4.

SMYTH, J. D. (1962). *Introduction to Animal Parasitology*. London: The English Universities Press.

Thomas, J. D. (1958*a*). Studies on the structure, life history and ecology of the trematode *Phyllodistomum simile* Nybelin 1926 (Gorgoderidae: Gorgoderinae) from the urinary bladder of brown trout *Salmo trutta* L. *Proc. zool. Soc. Lond.* **130**, 397–435.

Thomas, J. D. (1958*b*). Studies on *Crepidostomum metoecus* (Braun) and *C. farionis* (Müller), parasitic in *Salmo trutta* L. and *S. salar* L. in Britain. *Parasitology*, **48**, 336–52.

Thomas, J. D. (1962). The food and growth of brown trout (*Salmo trutta* L.) and its feeding relationships with the salmon parr (*Salmo salar* L.) and the eel (*Anguilla anguilla* (L.)) in the River Teify, West Wales. *J. Anim. Ecol.* **31**, 175–205.

Thomas, J. D. (1964). Studies on the growth of brown trout (*Salmo trutta* L.) from four contrasting habitats. *Proc. zool. Soc. Lond.* **142**, 1–51.

Yamaguti, S. (1961). *Systema Helminthum*, Vol. 3. *Nematodes*. Parts 1 and 2. London: Interscience Publishers, Ltd.

THE DISTRIBUTIONAL RELATIONSHIP BETWEEN THE BOTTOM FAUNA AND PLANT DETRITUS IN STREAMS

By H. J. EGGLISHAW

Freshwater Fisheries Laboratory, Pitlochry, Perthshire

INTRODUCTION

The problem of what factors determine the distribution of invertebrate animals within stream habitats has received little attention. Percival & Whitehead (1929) studied the variation of the bottom fauna from different types of stream bed, and from moss and other plant substrates. Harker (1953) found that at the time of emergence the distribution of nymphs of three species of mayfly was associated with the relative (and not absolute) depth of water. Other workers (Hynes 1941; Macan 1957) have suggested factors which may affect the distribution of particular groups of bottom living organisms. The effect of water velocity on the distribution of particular species has been studied under laboratory conditions by Ambühl (1959) and Bournaud (1963). In general, however, few attempts have been made to measure the physical or biological factors influencing the distribution of the bottom fauna of streams.

From an examination of the literature on the food of the stream bottom fauna (*e.g.* Hynes 1941; Jones 1949, 1950, 1958; Slack 1936) and from the relative abundance of the various species found by the writer in a year's regular sampling of a stream riffle (the Shelligan Burn) it is apparent that most of the stream organisms feed on plant detritus or on the microflora associated with it. A riffle is a shallow stretch in a stream where the water flows swiftly. It might be expected that the quantitative distribution of the bottom fauna of a riffle would be related to that of the plant detritus present there. Yet in Macan's reviews (1961, 1962) of recent work on the ecology of aquatic insects and factors affecting animals in streams there is no mention of any study of plant detritus as an ecological factor.

The present paper is intended to show the importance of plant detritus in determining the distribution of many bottom fauna animals in stream riffles. Experimental evidence is given suggesting that the similarity in the distribution pattern of the bottom organisms and plant detritus is not due solely to the operation of physical factors and that the animals aggregate in plant detritus probably for food.

The term 'plant detritus' is used in its widest sense to include all kinds of disintegrating plant material.

Some preliminary results of this work have already been reported (Report in the Fisheries of Scotland for 1962, Appendix VI, p. 114, London, H.M.S.O.).

METHODS

The main observations and field experimental work were made on the Shelligan Burn, a tributary of the River Almond, in Perthshire (Nat. Grid ref. 951290). Before reaching the sampling area, which is among agricultural land and rough pasture, the Shelligan Burn flows over heather moorland. Data were collected in two ways: from series of monthly samples from the bed of a riffle and from the aggregation of animals in trays, containing plant detritus, placed in the bed of the stream.

The samples were collected within a 50 m length of a riffle 4 m wide. The bottom of the riffle consists of stones up to about 0·3 m in diameter lying on stones embedded in gravel and sand. The depth of most of the riffle is between 12 and 25 cm under normal water conditions but reaches 45 cm in a few places.

The technique used for taking the samples was that previously used in carrying out a survey of the bottom fauna of streams (Morgan & Egglishaw 1964; Egglishaw & Morgan 1964). It depends on allowing the water current to wash animals from a disturbed substrate into a handnet held on the downstream side of the sampling site. The substrate is disturbed by the investigator 'kicking' into the stream bed in a standard fashion, in an upstream direction. Each sample consists of four 'kicks' at the same site, each kick digging deeper into the stream bed. The handnet used is pyramid-shaped and of grit gauze having 12 meshes/cm. This is attached to a square frame with 24 cm sides. As the current washes the animals into the net a certain amount of plant detritus and inorganic matter is caught at the same time. Each sample thus consists of the animals, plant detritus, sand and fine gravel occurring together at the same site. The plant detritus is usually fragments of leaves, stems and seed cases of land plants with occasional small pieces of algae and moss.

Each sample was taken in a depth of water up to about 20 cm and at a site where the stones were 8–25 cm in diameter. The current speed over all sites was the same as far as could be observed. Slow speeds were avoided as the current had to be fast enough to wash the plant material and bottom fauna quickly into the net. Care was taken to avoid sampling sites where there was moss growing on the stones as the community of animals living in moss is different from that found among stones where there is little moss.

Ten samples were taken each month from March 1962 to April 1963. Some samples taken before March 1962 from other riffles of the Shelligan Burn are included in the results.

Samples were preserved with formalin in the field. In the laboratory the animals were separated from the plant and inorganic matter, the volumes of which were measured by displacement of water, after excess preservative had been drained off through a sieve.

As the samples were taken by two workers there might have been differences caused by variations in technique. From the Shelligan Burn one worker collected 14 776 animals and the second worker 13 754 animals, each worker having taken fifty samples. From other streams the two workers taking seventy-five samples each collected 5294 animals and 4970 animals respectively. These figures suggest that errors due to variations between individual's sampling techniques were not large.

Since each sample was taken in the same way, the areas of the substrate sampled varied only slightly. The range in the amounts of plant detritus taken in a series of samples was often from 1 or 2 ml to over 15 or 20 ml. Therefore, as would be expected, the plant detritus is unevenly distributed over the substratum of a riffle, some sites accumulating much more plant detritus than others.

This paper is not concerned with the physical factors that determine the distribution of plant detritus in stream riffles but with the relationship between the distribution and the bottom fauna present.

A Survey of the Bottom Fauna of Streams in the Scottish Highlands

Part II. The relationship of the fauna to the chemical and geological conditions

by

Henry J. Egglishaw
Freshwater Fisheries Laboratory, Pitlochry, Perthshire

&

N. C. Morgan
Agricultural Scientific Services, East Craigs Edinburgh[1])

Introduction

A survey of the bottom fauna of 52 streams in the Scottish Highlands was carried out in 1960, samples being taken from the 'salmonid region' (Illies, 1952) of each stream, in both spring and summer. The survey extended over the Highland area of the mainland and included the main geological strata. Details concerning the streams sampled, the composition of the bottom fauna and the distribution of species have already been published (Morgan & Egglishaw, 1965). The present paper relates the amount and composition of the bottom fauna to the chemical richness (i.e. the ionic concentration) of the streams and to the geology of their substrates.

Although the sampling sites were selected to avoid polluted conditions three streams (one on basalt and two on sandstone) were included which were found to be mildly polluted with organic matter and household refuse. The bottom fauna of these streams was markedly different from the fauna of the other streams (Morgan & Egglishaw, l.c.). The three streams have been excluded from the

[1]) Formerly of Freshwater Fisheries Laboratory, Pitlochry, Perthshire.

Received May 15th 1964.

present analysis of the relationship of the bottom fauna to chemical and geological conditions.

In the following account the reference numbers given for streams are those used in the brief descriptions of the streams given in MORGAN & EGGLISHAW (l.c.).

All the streams included in the survey were chosen so that upstream from the sampling site each flowed over only one kind of rock as far as could be discerned from the Geological Maps prepared by the Ordnance Survey. Of the 49 unpolluted streams examined, 16 occurred on schist and 13 on granite, the two commonest rock types in Highland Scotland; six were on basalt, seven on limestone and five on sandstone, the other important types of rock. There was also one stream flowing over gneiss and one over quartzite.

When the survey was planned, the geology of the substrate was used as the basis for the selection of streams to be studied, because this seemed likely to have a controlling effect on the fauna of the streams. The geology of a region influences the surface texture and size of the component parts of the substrate of a stream, the nature of the surrounding land and thus the rate of flow of the water. Further, since the kinds of rock over which the streams flow have different constituents of various solubilities they may affect the chemistry of the water to different degrees. There are, of course, many other factors such as surroundings, local agricultural practices and amount and composition of the rain which can greatly modify the chemical composition of the stream water.

The chemical analysis of water samples taken during the survey showed there was great variation in the total cationic concentration from stream to stream (MORGAN & EGGLISHAW, 1965, Appendix 2a). An account of the results of the chemical analyses of the water samples is being published by HOLDEN. Here it is necessary to give details of the chemistry of the stream waters, only in so far as they might indicate possible correlations with the amount and kind of bottom fauna present.

The ranges of the total cation concentration (as micro-equivalents/l) and certain ions and pH of the samples from streams occurring on each kind of rock are given in Table I. Only on granite and schist were there streams with water having less than 400 micro-equivalents of total cations/l and these streams have been classified separately.

The extensive range of the total cation concentration/l of samples from the streams on sandstone is due to three streams which had a high concentration of sodium (644, 1140 and 1705 μ eNa^{+}/l), presumably because of their proximity to the sea.

TABLE I

The range in certain chemical properties of water samples from streams on different types of rock.

	Number of streams	Total cations	Ca^{++}	Mg^{++}	HCO_3^-	pH
Granite	8	224– 375	40– 95	50–100	26– 100	6.12–6.75
	5	412–1005	138– 361	74–210	100– 296	6.60–7.23
Schist	5	266– 374	56– 115	53– 89	54– 136	6.22–6.75
	11	424–1662	84– 936	29–364	20– 828	5.98–7.40
Basalt	6	730–1061	180– 476	171–315	330– 644	7.13–7.50
Limestone	7	415–1785	195–1457	44–502	100–1108	6.48–7.82
Sandstone	5	1383–3608	656–1063	206–790	328–1232	7.12–7.61

THE RELATIONSHIP BETWEEN THE STANDING STOCK OF BOTTOM FAUNA AND THE CHEMICAL RICHNESS OF THE STREAMS

The mean catches of bottom fauna from streams of five ranges of total cation concentration are given in Table II.

Since *Simulium* spp. larvae feed by extracting particles from the current (SMART, 1944) the factors affecting their distribution in a stream are very different from those affecting the distribution of the majority of bottom fauna organisms, which feed on the food present at a site (EGGLISHAW 1964). *Simulium* spp. can occur at very high densities where conditions suit their method of feeding, and high numbers were recorded from a few streams where a sample was taken at a site where the larvae were aggregated. In the table *Simulium* spp. have not been included in the mean catches of bottom fauna and their numbers have been given separately.

In waters having a concentration of less than 400 μe of total cations/l the bottom fauna was severely limited in amount. The samples from streams with water containing between 401 and 800 μe of total cations/l contained a significantly higher mean number and weight of animals in spring and in summer than samples from streams in the lowest category of chemical richness. With increasing total cation concentration above 800 μe/l the mean catches and weights of bottom fauna showed no significant increase in the spring, and although there was an increase in summer, the increase is of doubtful significance for the numbers of animals, and for the weight of the catches it is non-significant. The values suggest a possible non-linear relationship between the amount of bottom fauna and the chemical richness of the streams. From streams with a total cation concentration of above 400 μe/l there was a wide range in the amount of

TABLE II

The catch of bottom fauna from streams of different concentrations of cations

	I	II	III	IV	V	
Total cations μe/l	224–400	401–800	801–1200	1201–1600	over 1600	
Ca^{++}	40–115	94–394	186– 667	656–1067	492–1457	
HCO_3^-	26–136	20–404	204– 748	328–1076	340–1232	
No. of streams	13	14[1])	9	4	7	
Spring fauna						
mean catch	66	234	217	234	267	$66 < 234$ $t = 3.546$, $P < .01$
mean *Simulium* spp.	13	27	22	26	6	
mean wt. (mg) of catches[2])	158	588	524	585	716	$158 < 588$ $t = 3.712$, $P < .01$
mean wt. per animal[2])	2.00	2.25	2.19	2.25	2.62	
Summer fauna						
mean catch	185	539	596	735	1151	$185 < 539$ $t = 2.958$, $P < .01$
						$539 < 1151$ $t = 1.909$, $P = .1–.05$
mean *Simulium* spp.	23[3])	21	14	13	39	
mean wt. of catches[2])	226[3])	611	734	693	1106	$226 < 611$ $t = 2.208$ $P = .05–.02$
						$611 < 1106$ $t = 1.687$ $P = .2–.1$
mean wt. per animal[2])	1.09	1.09	1.20	0.93	0.93	

[1]) 13 streams in summer, one (no. 32) having dried up.
[2]) including *Simulium* spp.
[3]) excluding one stream (no. 6) from which there was caught a large number (733, 82% of the bottom fauna) of *Simulium* spp.

Table III

The spring fauna of chemically poor and richer streams on granite and on schist

	GRANITE				SCHIST			
	Poor streams (8)		Richer streams (4)		Poor streams (5)		Richer streams (7)	
	mean catch	%	mean catch	%	mean catch	%	mean catch	%
PLATYHELMINTHES	1	2	5	1	1	1	3	1
OLIGOCHAETA	+		11	3	1	1	3	1
Gammarus pulex (L.)	—		—		—		7	3
PLECOPTERA	26	49	171	47	29	33	103	46
Brachyptera risi (Mort)	9		5		9		9	
Amphinemura sulcicollis (Steph.)	5		29		5		33	
Protonemura meyeri (Pict)	2		12		+		2	
Leuctra inermis Kempny	4		86		8		29	
L. hippopus (Kempny)	1		9		+		9	
Chloroperla torrentium (Pict.)	1		10		2		5	
Isoperla grammatica (Poda)	3		19		2		7	
EPHEMEROPTERA	18	34	84	23	47	54	76	34
Baetis rhodani (Pict)	12		54		28		22	
Rhithrogena sp.	4		20		7		26	
TRICHOPTERA	1	2	34	9	1	1	13	6
Polycentropidae	+		13		—		2	
COLEOPTERA	+		18	5	+		3	1
CHIRONOMIDAE	5	9	39	10	6	7	11	5
OTHER DIPTERA	+		3	1	1	1	4	2
HYDRACARINA	—		1		+		—	
MOLLUSCA	—		1		—		+	
mean total catch	53		366		87		225	
	53 <366 t=5.00, P <.01				87 <225 t=2.43, P=.05–.02			
mean *Simulium* spp.	16		21		8		17	
mean wt. (mg) of catches	128		693		205		603	
mean minimum no. of species	11		32		16		26	
	11 <32 t=7.29, P <.01				16 <26 t=2.67, P=.05–.02			

	Granite poor streams	Granite richer streams	Schist poor streams	Schist richer streams
Taxa occurring only in the class under which they appear with the number of streams in which they were found.	3 spp. each occurred in one stream only	*Polycelis felina* 2 *Protonemura praecox* 2 Lepidostomatinae 4 *Oxyethira* sp. 2 *Esolus parallelopipedus* 4 Other Tipulidae 2 Tanypodinae 3 Hydracarina 3 *Ancylastrum fluviatile* 3 7 spp. each occurred in only one stream	3 spp. each occurred in only one stream	*Polycelis felina* 2 *Gammarus pulex* 3 *Nemoura erratica* 2 *Leuctra nigra* 2 *Caenis rivulorum* 2 *Baetis niger* 2 *Heptagenia* sp. 2 Limnephilidae 3 *Hydraena gracilis* 2 *Helodes* sp. 2 *Latelmis volkmari* 3 *Corynoneura* sp. 3 19 spp. each occurred in one stream only

+ = present but less than 0.5.

Table IV

The summer fauna of chemically poor and richer streams on granite and on schist

	GRANITE				SCHIST			
	Poor streams (8) mean catch	%	Richer streams (4) mean catch	%	Poor streams (5) mean catch	%	Richer streams (7) mean catch	%
PLATYHELMINTHES	3	1	60	5	2	1	5	1
OLIGOCHAETA	59	27	86	8	19	13	90	16
AMPHIPODA	—		—		—		11	2
PLECOPTERA	11	5	45	4	13	9	39	7
Leuctra fusca (L.)	8		31		6		29	
EPHEMEROPTERA	62	29	181	17	58	38	175	31
Baetis rhodani	22		34		19		39	
TRICHOPTERA	10	5	86	8	4	3	47	8
COLEOPTERA	9	4	193	18	5	3	20	4
TIPULIDAE	2	1	12	1	3	2	6	1
CHIRONOMIDAE	59	27	394	36	44	29	157	28
HYDRACARINA	2	1	22	2	1	1	2	
MOLLUSCA	—		4		—		—	
mean total catch	217		1094		151		560	
	217 <1094 t=8.34 p <.01				151 <560 t=3.28, p <.01			
mean *Simulium* spp.	7[1])		18		7[2])		37	
mean wt. (mg) of catches	196[1])		1329		184[2])		731	
mean minimum no. of species	20		38		22		30	
	20 <38, t=7.70, P <.01				22 <30 t=2.10, P=.1–.05			
Taxa occurring only in the class under which they appear with the number of streams in which they were found	4 spp. each occurred in only one stream.		*Polycelis felina* 2 *Perlodes microcephala* 2 *Ecdyonurus torrentis* 3 Limnephilidae 4 *Oxyethira* sp. 2 Dytiscidae 1. 2 *Pericoma* sp. 2 *Hemerodromia* sp. 3 *Limnophora* sp. 2 *Ancylastrum fluviatile* 3 14 spp. each occurred in only one stream.		3 spp. each occurred in only one stream		*Polycelis felina* 2 Nematoda 2 *Gammarus pulex* 3 *Perlodes microcephala* 2 *Caenis rivulorum* 2 *Baetis pumilus* 6 *Oxyethira* sp. 3 *Oreodytes rivalis* 2 *Helophorus brevipalpis* 2 14 spp. each occurred in only one stream.	

[1]) excluding one stream (no. 6), having 733 *Simulium* spp.
[2]) excluding one stream (no. 15) having 195 *Simulium* spp.

bottom fauna caught, both poor (< 180 animals less *Simulium* spp. in spring, and < 330 animals less *Simulium* spp. in summer) and rich faunas being found, (see MORGAN & EGGLISHAW, 1965, Appendix 2) whereas in streams with a total cation concentration below 400 μe/l the fauna was always poor.

REYNOLDSON (1958) has shown that the calcium content of lake waters is an important factor in determining the size of triclad populations. As the calcium content of lakes increases the number of species and their abundance generally increases. REYNOLDSON (l.c.) pointed out that there are groups of lakes at the lowest calcium levels which support relatively smaller triclad populations than would be expected if the relationship between triclad numbers and calcium was linear. From REYNOLDSON's regression diagrams these lowest levels correspond with the lower levels of calcium found in the stream survey (i.e. less than about 200 μe Ca^{++}/l).

STREAMS ON GRANITE AND SCHIST

Granite and schist were the only types of rock having streams with water containing less than 400 μe of total cations/l. In Tables III and IV the fauna of these chemically poor streams is contrasted with that of the richer streams, having over 700 μe total cations/l on the same type of rock.

There was little difference between the range of altitudes at which the chemically poor streams were sampled and the range at which the chemically richer streams were sampled. The sites of the chemically poor streams were from 15 m to 270 m altitude with six of the 13 sites below 110 m and the sites in the chemically richer streams were from 15 m to 200 m with seven of the 11 sites below 110 m.

The two chemically richest streams on granite and the richest on schist were running through arable land at the sampling area and fertiliser leaching from this land may have contributed to the chemical richness of the streams. None of the chemically poor streams ran through arable land.

Tables III and IV show that in both spring and summer the chemically richer streams, have, with but few exceptions, a greater mean number of all groups and main species of animals than the poor streams, many of the differences being of the order of five times and more. The differences between the mean total catches are very significant.

The variety of animals is also much greater in the samples from the chemically richer streams than in those from the chemically poor ones, three of the four increases in the number of species present being significant. The increase in the fourth case is of doubtful significance. In the lower part of Tables III and IV there are listed the animals which occurred in only one of the two classes of stream. Only those species or other taxa that were present in at least two streams of the class are entered by name.

It should be emphasised that although there were many species occurring in the samples from the chemically richer streams only, their numbers were usually few and they comprised only a small proportion of the total animals collected. This can be seen from figures given in Table V.

The summed samples from the eleven chemically richer streams contained 11,341 animals less *Simulium* spp. and the summed samples from the chemically poor streams contained 3,347 animals less *Simulium* spp. Of the difference of 7,994 animals between the two classes of streams only 963 animals or 12% were of species or other taxa not present in the samples from the chemically poor streams.

Polycelis felina (Dalyell) was the only animal identified to species present in the chemically richer streams on granite and schist, in both spring and summer which did not occur in the chemically poor streams.

It might be argued that the lower standing stock of bottom fauna in chemically poor streams is possibly due to these streams having a steeper gradient, and consequently a quicker flow, than the chemically richer streams. It might be expected that a steep gradient would greatly affect the amount of stream fauna particularly during and after spates and that the higher rate of flow would exceed the limits of tolerance of many species to this factor. During the stream survey the gradient of each stream at the sampling area was classed as gentle, moderate or steep.

The gradient of five (all on granite) of the thirteen chemically poor streams was steep and the gradient of five (three on granite, two on schist) was gentle. The streams on a steep gradient had a mean catch of 68 animals less *Simulium* spp. in spring and 207 in summer and those on a gentle gradient had a mean catch of 45 animals less *Simulium* spp. in spring and 193 in summer, which suggests that a steep gradient has not restricted the standing stock of bottom fauna in these streams. The composition of the bottom fauna of the streams on the two gradients was similar, less than 3% of the total catch belonging to species or other taxa that were present in streams of only one or other of the categories.

TABLE V

The proportion of animals which occurred in the chemically poor streams only or in the richer streams only, on granite and schist

	GRANITE				SCHIST			
	Poor streams		Richer streams		Poor streams		Richer streams	
Number of streams	8		4		5		7	
	spring	summer	spring	summer	spring	summer	spring	summer
Total number of animals less. *Simulium* spp. from these streams	421	1737	1466	4374	435	754	1578	3923
Simulium spp.	130	783	83	73	40	221	121	262
Total number of animals in species which occurred in only one class of stream	3	6	111	417	5	3	178	257
As a percentage of total less *Simulium* spp.	0.7	0.3	7.6	9.5	1.1	0.4	11.3	6.6

THE BOTTOM FAUNA OF STREAMS ON DIFFERENT GEOLOGICAL SUBSTRATES

The mean catch of bottom fauna from streams on each type of rock is given in Table VI. As several streams on granite and schist were poor chemically and such streams have been shown carlier to have less bottom fauna than chemically richer streams, it is to be expected that the mean catches from streams on granite and schist would be lower than those for the other types of rock. The granite and schist formations whilst containing the streams with the least dense bottom fauna, 11 of the 12 poorest in spring and 15 of the poorest 17 in summer, also had some streams rich in bottom fauna.

The streams on basalt had less variation in the quantity of bottom fauna than the streams on the other types of rock. This is probably because the streams on basalt were in the same region (Argyll) and were more similar with regard to stratigraphy, climate and che-

TABLE VI

The catch of bottom fauna from streams on different kinds of rock

	Granite (13)	Schist (16)	Basalt (6)[1]	Limestone (7)	Sandstone (5)
Mean catch of animals less *Simulium* spp.					
in spring	150	162	222	222	290
in summer	484	356	531	749	1191

[1]) 5 in summer.

mistry of water than streams on the other formations which were not so geographically restricted.

To discover if the geological substrate had any appreciable effect on the quality and amount of bottom fauna in streams other than through affecting the chemistry of the water, streams on the same kind of rock and containing a concentration of more than 400 μe of total cations/l were grouped and the mean catches of the chief taxa calculated. This analysis appears in Table VII where the spring fauna is dealt with fully and the three common species that occurred only in the summer have been included.

Table VII shows that the amount and composition of the bottom fauna from streams having a concentration of more than 400 μe of total cations/l but on different rocks is very similar. Even the large differences in the mean number of particular species or groups are not significant, and are shown at the bottom of the table to be due to peculiarities in the catches from individual streams.

The gastropod molluscs were more abundant in the streams on sandstone than in streams on the other rocks. In the summer samples there was a mean of 29 grastropod molluscs from the streams on sandstone. This catch was significantly greater than the catch from the streams on schist ($29 > O$, $P < .01$). Their greater abundance in streams on sandstone compared with streams on limestone ($29 > 5$) and basalt ($29 > 1.4$) was of doubtful significance ($P = .1$—$.05$) and compared with those on granite ($29 > 2.8$) was not significant.

Large numbers of *Pisidium* sp. (68 in the spring samples and 24 in the summer ones) forming 28% and 7% of the fauna in spring and summer were collected from a stream in North West Sutherland which flowed over gneiss. The highest number collected from any other stream was seven (stream no. 31). The stream on gneiss was also the only one from which the caddis *Chimarrha marginata* (*L.*) was recorded.

Summary

1. A survey of the bottom fauna of 52 streams in the Scottish Highlands was carried out in 1960. The survey included streams on granite (13), schist (16), basalt (6), limestone (7) and sandstone (5).
2. The bottom fauna was much poorer in amount in streams having a concentration of less than 400 μe of total cations/l than in streams having 401—800 μe of total cations/l. In the spring, streams having a concentration of more than 800 μe of total cations/l were not richer in number of animals than streams with 401—800 μe of total cations/l, and although in the summer the mean number of animals in the streams with more than 800 μe/l was greater than

Table VII

The bottom fauna of streams on different rocks and having a concentration of over 400 μe of total cations/1.

	Granite	Schist	Basalt	Limestone	Sandstone
Number of streams	5	11	6[1])	7	5
SPRING FAUNA					
PLATYHELMINTHES	4	2	3	4	3
OLIGOCHAETA	9	3	3	4	16[2])
PLECOPTERA					
Brachyptera risi	4	9	25[3])	6	2
Amphinemura sulcicollis	24	25	10	25	32
Protonemura meyeri	10[4])	1	1	2	1
Leuctra inermis	69[5])	33	18	22	25
L. hippopus	8	7	3	3	+
Chloroperla torrentium	9	5	4	5	11
Isoperla grammatica	16[6])	6	3	6	3
EPHEMEROPTERA					
Baetis rhodani	45	23	66	49	31
B. pumilus (Burm.)	6	7	12	6	5
Baetis spp. total	53	41	85	59	52
Rhithrogena sp.	16	20	25	20	46
TRICHOPTERA	27	10	7	18	20
Hydropsychidae	3	3	4	5	5
Polycentropidae	9	1	2	5	7
COLEOPTERA	15	3	2	12	26[7])
DIPTERA					
Tanypodinae	7	+	1	2	2
Tanytarsini	5	2	1	2	13
Other Chironomidae	21	7	15	19	14
MOLLUSCA	1	+	+	1	5
Mean total catch less *Simulium* spp.	309	198	222	222	290
Mean weight (mg) of catches	601	525	577	569	814
SUMMER FAUNA					
Leuctra fusca	25	27	31	24	34
Ephemerella ignita (Poda)	51[8])	12	14	22	22
Baetis scambus/bioculatus	20	13	5	8	11
MOLLUSCA-GASTROPODA	3	0	1	5	29
Mean total catch less *Simulium* spp.	910	447	565	749	1191
Mean weight (mg) of catches	1091	578	508	826	987

[1]) Five streams in summer [2]) 55 from stream no. 46 [3]) 129 from stream no. 33
[4]) 38 from stream no. 11 [5]) 185 from stream no. 12 [6]) 45 from stream no. 12
[7]) 87 from stream no. 49 [8]) 200 from stream no. 12

the mean number in streams in the 401—800 μe/l range the increase was of doubtful significance.

3. Granite and schist were the only types of rock having streams with water containing less than 400 μe of total cations/l. The bottom fauna of these chemically poor streams is compared with the fauna from the richer streams (700—1662 μe of total cations/l) on the same rock types. The summed samples from eleven chemically richer streams contained 11,341 animals and the summed samples from the chemically poor streams contained 3,347 animals. Of the difference of 7,995 animals only 963 or 12% were of species or other taxa not present in the samples from the chemically poor streams.
4. The amount and composition of the bottom fauna from streams on different types of rock and having a concentration of over 400 μe of total cations/l was very similar.

Zusammenfassung

1. Die in 52 Bächen des Schottischen Hochlands befindliche Bodenfauna wurde im Jahre 1960 untersucht, wobei Bäche, die auf Granit (13), Schiefer (16) Basalt (6), Kalkstein (7) und Sandstein (5) flossen, in Betracht gezogen wurden.
2. In Bächen mit einer Gesamtkationenkonzentration von weniger als 400 μe/l kamen viel geringere Mengen Bodenfauna vor, als in Bächen mit 401—800 μe Gesamtkationen/l. Im Frühling waren die Bäche mit mehr als 800 μe Gesamtkationen/l zahlenmässig nicht reicher an Tieren, als diejenigen mit 401—800 μe Gesamtkationen/l. Obgleich im Sommer die Durchschnittszahl der in Bächen mit mehr als 800 μe/l vorhandenen Tiere grösser war, als die Durchschnittszahl bei Bächen mit 401—800 μe/l, liess sich dennoch diese Zunahme als von zweifelhafter Bedeutung betrachten.
3. Ausschliesslich beim Granit und beim Schiefer kamen Bäche mit einem Gesamtkationeninhalt im Wasser von weniger als 400 μe/l vor. Die Bodenfauna dieser chemische armen Bäche wird mit der Fauna aus den reicheren Bächen (700—1662 μe Gesamtkationen/l) verglichen, die über dieselben Steinarten fliessen. Die Gesamtproben aus elf chemisch reicheren Bächen enthielten 11.341 Tiere, während diejenigen aus den chemisch armen Bächen 3.347 Tiere ergaben, d.h., 7.994 Stück weniger, wovon nur 963, d.h., 12%, zu Arten oder anderen systematischen Gruppen gehörten, die in den aus den chemische ärmeren Bächen entnommenen Proben nicht vertreten waren.
4. Sowohl die Anzahl als auch die Zusammensetzung der Boden-

fauna aus Bächen, die über verschiedene Steinarten flossen und eine Gesamtkationenkonzentration von mehr als 400 μe/l aufwiesen, waren sehr ähnlich.

Acknowledgments

We wish to acknowledge the assistance given by Mr. D. W. Mackay throughout this work. We are grateful to Mr. A. V. Holden and Mr L. A. Caines for chemical analyses of the stream waters.

References

Egglishaw, H. J. - 1964 - The distributional relationship between the bottom fauna and plant detritus in streams. *J. Anim. Ecol.* 33, 463—476.

Illies, J. - 1952 - Die Mölle. Faunistisch-ökologische Untersuchungen an einem Forellenbach in Lipper Bergland. *Arch. Hydrobiol.* 46: 424—612.

Morgan, N. C. & Egglishaw, H. J. - 1965 - A survey of the bottom fauna of streams in the Scottish Highlands. Part 1. Composition of the fauna. *Hydrobiologia* 25: 181—211.

Reynoldson, T. B. - 1958 - The quantitative ecology of lake-dwelling triclads in Northern Britain. *Oikos*, 9, 94—138.

Smart, J. - 1944 - The British Simulidae. Sci. Pub. Freshwat. Biol. Ass. 9, 51 pp.

REPRINT FROM
Calif. Fish and Game, 51 (1) : 48–51. 1965.

INTRODUCTION OF THE OPOSSUM SHRIMP (*MYSIS RELICTA* LOVEN) INTO CALIFORNIA AND NEVADA[1]

JACK D. LINN
Inland Fisheries Branch
California Department of Fish and Game

and

TED C. FRANTZ
Nevada Fish and Game Commission
Reno, Nevada

In 1963 and 1964, 182,300 live opossum shrimp were introduced into four lakes in California and Nevada (Lake Tahoe, Lower Echo Lake, Huntington Lake, and Blue Lake). These had been collected at Upper Waterton Lake, Canada, and Green Lake, Wisconsin. It is hoped they will become established locally, and provide forage for trout.

Opossum shrimp were introduced into Lake Tahoe and three other lakes in California and Nevada in the autumns of 1963 and 1964. The Tahoe introduction was made primarily to provide forage for juvenile lake trout (*Salvelinus namaycush*). The need was made apparent by Dingell-Johnson Project California F-21-R and Nevada F-15-R, ''Lake Tahoe Fisheries Study,'' supported by Federal Aid to Fish Restoration funds (unpublished data). The other releases were made to increase the chances of establishing the shrimp locally, and to test their trout-forage potential in coldwater fluctuating reservoirs.

Studies elsewhere (Larkin, 1948; Hacker, 1956; and Rawson, 1961) had shown that *M. relicta* is very important in the diet of juvenile lake trout and in the diet of various coregonids, the chief forage fishes of adult lake trout. In one Wisconsin lake, in a year when *M. relicta* was especially abundant, survival of young stocked lake trout increased three times (Threinen, 1962). Lake Tahoe does not have a similar invertebrate, and the diet of juvenile lake trout consists largely of cladocerans.

The opossum shrimp is one of four freshwater North American species of the order Mysidacea (Vincent, 1958). It inhabits cold, deep lakes in Northeastern United States, Canada, and Northern Europe. It exists in certain eutrophic lakes of Europe also. It reaches a length of about 30 mm and has a life span of approximately 2 years (Pennak, 1953). The female has about 40 eggs per clutch and keeps them in a brood pouch during development. Young remain in the brood pouch 1 to 3 months until they are about 4 mm long. As a rule, reproduction takes place from October through May. However, in some lakes reproduction

[1] Submitted for publication November 1964. This work was performed as part of Dingell-Johnson Project California F-21-R and Nevada F-15-R, "Lake Tahoe Fisheries Study," supported by Federal Aid to Fish Restoration funds.

may occur throughout the year (Larkin, 1948). Sexual maturity is reached at 1 or 2 years. They eat zooplankton, phytoplankton, and detritus.

Distribution patterns and migratory habits of *M. relicta* were described by Beeton (1960) for Lakes Huron and Michigan and by Larkin (1948) for Great Slave Lake. They are found immediately above the bottom during the day, but small mysids stay farther off the bottom than large ones. Distance above the bottom increases with increasing depth (1.8 meters in depths less than 91 meters compared to 7 meters at a depth of 152 meters). They are found at all depths in Great Slave Lake (maximum of 614 meters) including depths less than 10 meters where low light intensity prevails. *M. relicta* is negatively phototrophic, migrating to the surface at sunset and descending at dawn. Although migrations are initiated and controlled by light penetration, thermal conditions, either absolute or gradient values, may cause modifications. Maximum temperature and minimum oxygen concentrations tolerated have been listed as 14° C. and 4 cc per liter. However, *M. relicta* has been collected in both warmer waters and waters of lower dissolved oxygen.

COLLECTION AND TRANSPORTATION

In September of 1963 and 1964, biologists from California and Nevada introduced about 182,300 live opossum shrimp into various waters of both states. These were collected from Upper Waterton Lake, Waterton Lakes National Park, Alberta, Canada. About 165,300 were planted in Lake Tahoe in the 2 years, 15,000 were released in 1963 into Lower Echo Lake, El Dorado County, California, and 2,000 were planted in 1964 in Blue Lake, Humboldt County, Nevada. These figures do not include an additional 20,000 *M. relicta* from Green Lake, Wisconsin, which were planted in Huntington Lake, Fresno County, California, in November 1963. The 1963 and 1964 Tahoe releases were made over depths ranging from 45 to 1,200 feet. Release localities were Emerald Bay and off Bijou, Upper Truckee River, Cascade Creek, Rubicon Point, Homewood, Dollar Point, Incline Creek, Logan Shoals and Cave Rock.

M. relicta proved surprisingly easy to collect and transport. They were taken with a tow net measuring 5 by 1½ by 12 feet. It was attached to a tubular steel frame with runners that keep it 6 inches off the bottom (Figure 1). Two sizes of bobbinet were used: 4 meshes per inch for the body, and 16 meshes per inch for the cod end. Opossum shrimp were captured at depths from 40 to 140 feet. Tows varied from 3 to 20 minutes duration, with 5 minutes being the most efficient. Longer tows picked up too much mud, which suffocated the shrimp. As many as 5,000 opossum shrimp were caught per tow.

At Waterton a survival test was conducted with 40 *M. relicta* in a 5-gallon can of Tahoe water. Two controls were set up using Waterton Lake water in one can and hatchery water in the other. All cans were aerated and bathed in a circular hatchery pond at 52° F. After initial high survival, opossum shrimp in the Tahoe water died after 48 hours. There was 85 percent survival in a later test by holding them in a 50:50 mixture of Waterton and Tahoe water for one-half hour before putting them in Tahoe water. This procedure was followed to temper the opossum shrimp before releasing them in Tahoe. Some shrimp were

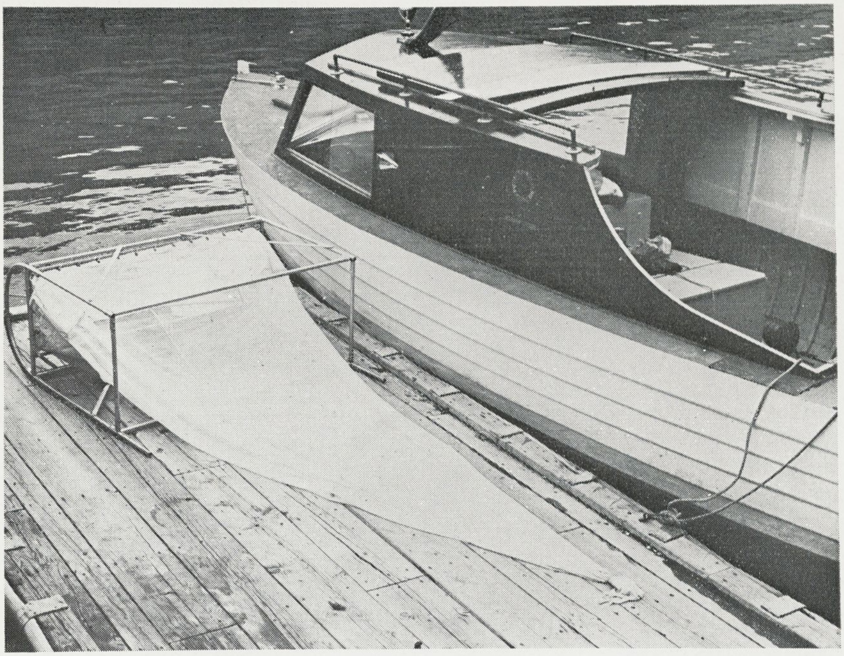


FIGURE 1. Trawl net used for capturing opossum shrimp at Waterton Lake, Canada. *Photo by Ted C. Frantz.*

placed directly in Tahoe water in September 1963, and one remained alive for 6 months. The aquarium was in subdued light, aerated, and held at 42°F. The water was not changed or filtered.

Opossum shrimp were transferred from the tow net to a large tub and then separated from as much extraneous material and foreign organisms as possible and placed in 5-gallon cans. They were held in a pond at Waterton Park Hatchery in perforated wooden boxes lined with plastic screen. Survival was good at densities as high as 1,000 per gallon. As time permitted and prior to loading into containers for final transportation all obvious unwanted organisms were removed. The last cleaning took place during the tempering process prior to release.

Shipments were flown to Lake Tahoe from Cutbank, Montana, in lots of approximately 50,000 each. Shrimp were transported in lots of 3,000 in 5-gallon aluminum milk cans which were iced and aerated in transit, or in lots of 1,000 in 5-gallon plastic containers ("cubitainers") in cartons. These were half filled with water and ice, the air replaced with oxygen, and then sealed. The shrimp fared well in both types during the 10-hour trip ($5\frac{1}{2}$-hours in air transit).

Shrimp from Wisconsin were shipped in 10, 5-gallon cubitainers, each loaded with 2,000 shrimp. The same shipping procedures as above were used. They were flown from Oshkosh to San Francisco and then were taken by car to Huntington Lake. About 10 percent died during the 30-hour trip.

In 1964, the feasibility of transporting large numbers of shrimp in a one-half-ton pickup with canopy was tested. Cubitainers were used and the same procedures were followed as above except different densities were tried. Two cubitainers were filled with 2,000 shrimp, one with 2,500, and the rest with 1,000 shrimp. The bed of the truck was lined with 1 inch of styrofoam and the cubitainers covered with 3 inches of fiberglass insulation. The water temperature in the containers was 39°F. At approximately the half-way point in the return trip, the cubitainers were unsealed to be re-iced and re-oxygenated. Temperatures ranged from 42° to 47°F. Addition of more ice lowered the temperatures to 39°F., and for the balance of the trip temperatures did not rise above 45°F.

At the end of the 36-hour trip, losses in the containers carrying 1,000 averaged about 10 percent and containers carrying 2,000 and 2,500 suffered about 20 percent mortality.

ACKNOWLEDGMENTS

We are indebted to personnel of the Canadian Department of Northern Affairs and National Resources, National Parks Branch, for the use of their facilities and the fine cooperation and courtesy shown us through all phases of the project. Particularly valuable assistance was provided by Fred C. Browning, Ken Goble, Art Colbeck, and Clanch Shatuck. We also thank Vernon A. Hacker, Wisconsin Department of Conservation, who collected the shrimp from Green Lake and shipped them to California. Al Reese and Carrol Faist, California Department of Fish and Game, flew the shrimp from Montana to Lake Tahoe. Jack Hanson, California Department of Fish and Game, supervised the 1964 collections. Sebastian Coli, Nevada Fish and Game Commission, provided assistance in the field.

REFERENCES

Beeton, Alfred M. 1960. The vertical migration of *Mysis relicta* in Lakes Huron and Michigan. Fish. Res. Bd. Canada, Jour., 17(4) : 517–539.

Hacker, Vernon A. 1956. Biology and management of lake trout in Green Lake, Wisconsin. Amer. Fish. Soc., Trans., 86(1) : 71–83.

Larkin, P. A. 1948. *Pontoporeia* and *Mysis* in Athabaska, Great Bear, and Great Slave lakes. Fish. Res. Bd. Canada, Bull., (77) : 1–33.

Pennak, Robert W. 1953. Fresh-water invertebrates of the United States. New York, The Ronald Press Co., 769 p.

Rawson, D. S. 1961. The lake trout of Lac la Ronge, Saskatchewan. Fish. Res. Bd. Canada, Jour., 18(3) : 423–462.

Threinen, C. W. 1962. What's new in fish management. Wisconsin Cons. Bull., 27(2) : 14.

Vincent, Robert E. 1958. *Mysis* on the menu. New York Cons., 13(2) : 10 p.

41069—800 3-65 275

REPRINT FROM
Calif. Fish and Game, 51 (4) : 270–275. 1965.

INTRODUCTION OF THE BONNEVILLE CISCO *(PROSOPIUM GEMMIFERUM* SNYDER) INTO LAKE TAHOE, CALIFORNIA AND NEVADA[1]

TED C. FRANTZ
Nevada Fish and Game Commission, Reno, Nevada, and

ALMO J. CORDONE
Inland Fisheries Branch, California Department of Fish and Game

Bonneville cisco were introduced into Lake Tahoe in 1964 to improve the food supply for lake trout and possibly other species of trout. Few forage fishes occur naturally in Tahoe's deep water areas during summer, and we expect the Bonneville cisco to fill this gap. This cisco is a small, active, plankton feeder, widely distributed and abundant in its native habitat. It lacks parasites, spawns on lakeshores, and prefers colder waters the year around. At Bear Lake, Utah-Idaho, it provides an important dipnet sport fishery.

BASIS FOR INTRODUCTION

Bonneville cisco were introduced into Lake Tahoe in January 1964 as a forage fish for lake trout, *Salvelinus namaycush,* after studies showed that lake trout lacked forage during the summer (Lake Tahoe Fisheries Study, unpublished data).

During the summer, lake trout inhabit depths from 100 to 500 feet. An important forage fish, the Piute sculpin, *Cottus beldingii,* is most abundant then at depths less than 100 feet, with smaller numbers found down to 300 feet, and very few deeper. Other forage fishes such as the tui chub, *Siphateles bicolor,* Lahontan redside, *Richardsonius egregius,* and Tahoe sucker, *Catostomus tahoensis,* favor shallow, warmer waters from mid-May through October. At this time, lake trout under 15 inches fork length eat plankton primarily, followed by sculpin. By frequency of occurrence, these remain the most important food items in fish up to 20 inches long.

A literature survey and correspondence with other fisheries workers showed that rapid lake trout growth is associated with abundant forage fish populations (Martin, 1952; Cuerrier, 1954; McCaig and Mullan, 1960). In the Great Lakes and large, deep Canadian lakes, ciscos (although of the genus *Coregonus*) are the most abundant forage fishes and often comprise the bulk of lake trout diets (Rawson, 1961). Bonneville cisco may prove to be a better forage fish than ciscos found in these lakes because they are smaller and have an extremely low incidence of parasitism. This species, like others in the cisco-whitefish complex, seeks colder waters the year around. Seasonal movements, except for spawning migrations, correspond to those of lake trout. However, they are also abundant in the open water or limnetic zone.

---

[1] Submitted for publication December 1964. This work was performed as part of Dingell-Johnson Project Nevada F-15-R and California F-21-R, "Lake Tahoe Fisheries Study," supported by Federal Aid to Fish Restoration funds.

Snyder (1919) and later Perry (1943) discussed their potential as a forage fish for trout.

An abundant cisco population may, at least during their winter inshore spawning migration, supplement the food supply of rainbow trout, *Salmo gairdnerii,* and brown trout, *Salmo trutta.* Apart from the mid-May through October period, we believe existing Tahoe forage fishes remain relatively dormant close to the cover of rocks and submerged aquatic plants. The cisco moves widely during the colder months and thus should be more available.

The vast limnetic zone of Tahoe is devoid of fish life except for relatively few rainbow trout and a small population of kokanee salmon, *Oncorhynchus nerka.* This area supports unusually low densities of zooplankton, but the plankton that is present occurs commonly to 300 feet and in lesser numbers to 500 feet. Rainbow now feed mostly on surface insects. With the cisco as forage, a trophy rainbow fishery may develop.

One potential problem is that cisco might compete with lake trout for food and space, especially with small trout. We believe this risk is minimal, since the studies mentioned earlier showed that lake trout do well in the presence of abundant forage.

Another potential drawback is that Bonneville cisco may not become established in Lake Tahoe because of habitat differences between Tahoe and Bear Lake, Utah-Idaho, their native habitat. Both waters are cold and have dissolved oxygen suitable for trout at all depths and seasons. But Tahoe is extremely oligotrophic (McGauhey *et al,* 1963), while Bear Lake is only moderately so (McConnell *et al,* 1957). Bear Lake is also considerably smaller and shallower than Tahoe (maximum depth of 208 feet compared to 1,645 feet).

THE BONNEVILLE CISCO

The cisco is one of three whitefishes endemic to Bear Lake (Snyder, 1919). It is found nowhere else and this is the first attempted extension of its range.

The cisco is small, slender and typically whitefish-like in appearance except for a distinctly long and sharply pointed snout (Figure 1). The sides are bright and silvery except during the spawning season when they develop longitudinal gold and bronze bars. One of the smallest North American coregonids, it attains a maximum total length of under 8.5 inches. Growth is relatively rapid the first 3 years and then abruptly levels off. According to Perry (1943), total length in inches at the end of each year of life approximates 2.1, 4.1, 5.7, 6.5, 7.0, and 7.2, and a 10-year-old cisco may be only 7.7 inches long. However, Bangerter (1964) found that fish from 3 to 7 years old in the dip-net fishery had average total lengths of 6.5, 7.1, 7.5, 7.8, and 8.1 inches. Perry (1943) believed genetic rather than environmental factors controlled growth rate.

Cisco feed almost entirely on plankton with heavy year-round reliance on the copepod *Epischura* except during spring, when the cladocerans, *Bosmina* and *Chydorus,* and the copepod, *Cyclops,* increase in importance (Perry, 1943). Along with the rotifer *Conochilus, Epis-*

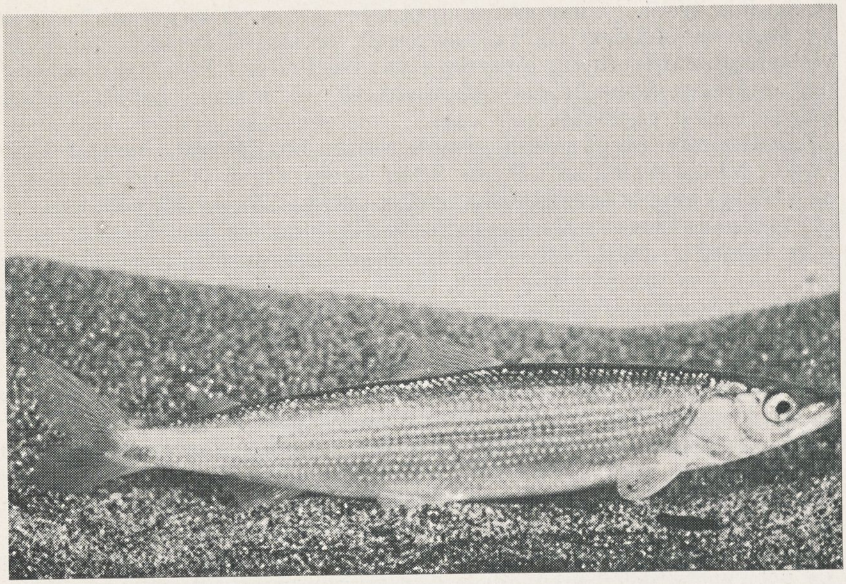


FIGURE 1. Bonneville cisco. Photograph by Ted C. Frantz.

chura is the most abundant and widely distributed zooplankter in Bear Lake (Perry, 1943; McConnell *et al*, 1957). During the spawning run, cisco feed heavily on their own eggs (Bangerter, 1962). Sigler (1962) states, "Bottom dwelling invertebrates are taken more commonly by the cisco in the winter months when the ciscos are in close to shore."

Unlike other species of cisco and whitefish, this form has an extremely low incidence of parasitism (Perry, 1943).

Numerically the Bonneville cisco is the most abundant species in Bear Lake (Sigler, 1962). This was determined by gill nets set in open water (Perry, 1943) and on the bottom (Loo, 1960; Hassler, 1960). Distribution has been correlated with depth, temperature, and zooplankton abundance. Loo (1960) believed temperature exerted the controlling influence while Sigler and Miller (1963) stated that food was probably the prime factor. The most dense cisco concentrations are found along the steep east shore (Loo, 1960). Perry (1943) found cisco widely distributed throughout Bear Lake except during the summer when they remained in and below the thermocline and seemed to prefer temperatures less than 59° F. Using bottom gill nets, McConnell *et al* (1957) reported cisco numbers increased with depth. However, Loo (1960) and Hassler (1960) found cisco most concentrated at 50 and 100 feet, with lesser numbers at 150 feet; they reported a similar distribution for lake trout.

Food habit studies of Bear Lake game fishes have been few and the samples small. Smart (1958) examined 28 lake trout stomachs and found, "Sculpin were in the majority of stomachs except during December and January when cisco was more common. This was due to the inshore spawning schools of cisco which made them more available to the lake trout." Cisco and sculpin were the most important foods in 24 cutthroat *(Salmo clarkii)* stomachs, while 67 rainbow stomachs yielded primarily surface insects. Examination of additional cutthroat and rainbow stomachs showed about the same food habits picture (McConnell *et al,* 1957).

Cisco spawn along a rocky 2-mile section on the east shore of Bear Lake between North and South Eden creeks which is adjacent to the only steep slope in the lake (Bangerter, 1962, 1963, and 1964). Spawning generally covers a 2-week period in January but sometimes extends into February. During the past five spawning seasons (1961–1965) an ice cover was present only once. Eggs are dispersed over a rock and rubble substrate in shallow water, sometimes less than a foot deep. The maximum spawning depth has not been established. The sex ratio on the spawning ground has averaged from 2.4 to 6.4 males per female with daily ratios often exceeding 10 to 1. The sex ratio at other times of the year is close to 1 to 1. The cisco matures in either the 2nd or 3rd year of life. Five- and 6-year-old fish dominate the spawning runs followed by 4– and 7–year–olds. Water temperatures during spawning and egg incubation range from 32 to 39° F, but are usually 34 or 35° F. Ten female cisco were spawned and averaged 1,301 eggs each.

Despite severe winter conditions, a very popular and productive dip-net sport fishery takes place during the spawning period. Sportsmen harvested 159,292 fish in 1962, 118,728 in 1963, and 106,863 in 1964 (Bangerter 1962, 1963, 1964). Fishing is good with or without an ice cover. Cisco are considered a delicacy and some fishermen traveled over 400 miles round trip to get them.

COLLECTION AND TRANSPORTATION

Lightweight, 18-inch diameter circular dip nets with $\frac{1}{2}$-inch stretched mesh and 10-foot aluminum handles were efficient collecting tools. Most cisco were collected between 7 and 10 AM. They were placed in holding pens in the lake and were later transferred in 5-gallon containers to two, 1,000-gallon (700-gallon carrying capacity) fish-planting trucks. Although the fish tanks and pipes were insulated, lake water (33° F) introduced into the units froze in the pump system unless motors were operated or preheated with warmer water.

The two trucks hauled 3,500 and 5,000 cisco. The trips took 24 and 27 hours, respectively. Each utilized combination spray and oxygen aeration. Temperatures were maintained between 42 and 50° F.

Part of each load was released over rubble substrate at Cave Rock on the east side of the lake and part at Pebble Beach on the west side where the substrate is similar to the spawning area at Bear Lake.

Approximately 4,600 males and 900 females were released alive. Mortality was 41 percent for the first load and 31 percent for the second. Of the dead fish, 55 percent were females and 45 percent males. A check of dead females revealed that only 6 percent were spent. In January 1962, experimental hauling from Bear Lake to Battle Mountain, Nevada, resulted in only 13 percent mortality. Hours in transport and fish per gallon of water on this haul were similar to the first 1964 load. The higher 1964 mortality probably centered around netting and loading techniques at Bear Lake. Losses could be substantially reduced by decreasing the time interval from capture to placement in the tank, by eliminating overcrowding in holding pens and 5-gallon buckets, and by maintaining tank temperatures during loading similar to lake temperatures. In the planting tank, losses probably can be reduced by decreasing water agitation and carrying less than five fish per gallon of water.

About 45,000 eggs were taken and fertilized from angler-caught fish. They were placed in two, 1-gallon "thermos" jugs and transported by truck at temperatures ranging from 32.5 to 42° F for a period of 22 to 27 hours.

Approximately 5,000 eggs were placed in hatchery incubator trays. Some hatched but none of the fry lived longer than 23 days. An estimated 40,000 eggs were dispersed through a syringe held under water in two rocky areas at Lake Tahoe: off Rocky Point on the northwest shore, and south of Sand Harbor on the east shore. The eggs were distributed over depths from 6 inches to 3 feet. Success of development is unknown.

Some green eggs were put in cheesecloth sacks and placed in Lake Tahoe under rocks in about 12 inches of water. Thirty-one days later several eggs had reached the eyed-stage. Some eggs were alive after 45 days but survival was low. Loss of sacks ended the test before any eggs hatched. During this period, water temperatures varied from 36 to 50° F.

ACKNOWLEDGMENTS

We are indebted to the Utah State Department of Fish and Game for their cooperation in obtaining Bonneville cisco from Bear Lake. Particular appreciation is extended to Arnold Bangerter, Utah Fishery Biologist, for his sincere interest, cooperation, and long hours in the field which made this venture successful. We thank personnel of Nevada's Washoe Rearing Station who handled the actual transportation. The editorial assistance of H. K. Chadwick, California Inland Fisheries Research Supervisor, is gratefully acknowledged.

LITERATURE CITED

Bangerter, Arnold. 1962. Bear Lake Bonneville cisco investigations, 1962. Utah State Dept. Fish and Game, 7 p. (mimeo).

——— 1963. Bear Lake Bonneville cisco investigations, 1963. Utah State Dept. Fish and Game, 14 p. (mimeo).

——— 1964. Bear Lake Bonneville cisco investigations, 1964. Utah State Dept. Fish and Game, 15 p. (mimeo).

Cuerrier, Jean-Paul. 1954. The history of Lake Minnewanka with reference to the reaction of lake trout to artificial changes in environment. Canad. Fish Cult., (15) :1–9.

Hassler, Thomas J. 1960. Relationship of certain environmental factors of benthic fish densities in Bear Lake, Idaho-Utah. Utah State Univ. Lib., M.S. Thesis, 38 p.

Loo, Stanley K. Y. 1960. Distribution and movements of some fishes in Bear Lake, Utah-Idaho, 1958–59. Utah State Univ. Lib., M.S. Thesis, 40 pp.

Martin, Nigel V. 1952. A study of the lake trout, *Salvelinus namaycush*, in two Algonquin Park, Ontario, lakes. Amer. Fish. Soc., Trans., **81** (1951) :111–137.

McCaig, Robert S., and James W. Mullen. 1960. Growth of eight species of fishes in Quabbin Reservoir, Massachusetts, in relation to age of reservoir and introduction of smelt. Amer. Fish. Soc., Trans., **89** (1) : 27–31.

McConnell, William J., William J. Clark, and William F. Sigler. 1957. Bear Lake, its fish and fishing. Utah St. Dept. Fish and Game, Idaho Dept. Fish and Game, Wildl. Mangt. Dept. Utah St. Agric. Coll., 76 p.

McGauhey, P. H., Rolf Eliassen, Gerhard Rohlich, Harvey F. Ludwig, and Erman A. Pearson. 1963. Comprehensive study on protection of water resources of Lake Tahoe Basin through controlled waste disposal. Prepared for Lake Tahoe Area Council, Engineering-Science, Inc., 157 p.

Perry, L. Edward. 1943. Biology and economic significance of the peaknose cisco of Bear Lake, Idaho and Utah. Univ. of Mich., Ph.D. Dissertation, 229 p.

Rawson, D. S. 1961. The lake trout of Lac la Ronge, Saskatchewan. Fish. Res. Bd. Canada, Jour., **18**(3) : 423–462.

Sigler, William F. 1962. Bear Lake and its future. Twenty-sixth faculty honor lecture, The Faculty Assoc., Utah St. Univ., 22 p.

Sigler, William F., and Robert Rush Miller. 1963. Fishes of Utah. Utah St. Dept. Fish and Game, Salt Lake City, Utah, 203 p.

Smart, Earl W. 1958. An ecological study of the bottom fauna of Bear Lake, Idaho and Utah. Utah St. Univ. Lib., Ph.D. Dissertation, 88 p.

Snyder, John O. 1919. Three new whitefishes from Bear Lake, Idaho and Utah, U.S. Bur. Fish., Bull., (36) : 3–9.

o

printed in CALIFORNIA OFFICE OF STATE PRINTING
57648—800 10-65 325

REPRINT FROM
Calif. Fish and Game, 53(3) :209–210, 1967.

FINAL INTRODUCTIONS OF THE BONNEVILLE CISCO (*PROSOPIUM GEMMIFERUM* SNYDER) INTO LAKE TAHOE, CALIFORNIA AND NEVADA

In January of 1964, 1965, and 1966, spawning Bonneville cisco were collected from Bear Lake, Utah-Idaho, and transported to Lake Tahoe. Reasons for the introduction, a description of the cisco, and details of the 1964 program were presented by Frantz and Cordone (1965). In all, 15,888 cisco were released over the three years (Table 1).

TABLE 1
Bonneville Cisco Planted in Lake Tahoe

Year	Number collected and transported	Transportation loss	Released alive
1964	8,500	3,000	5,500
1965	7,906	2,614	5,292
1966	5,100	4	5,096
Totals	**21,506**	**5,618**	**15,888**

Losses during transportation were reduced to an insignificant level in 1966, following high losses in 1964 and 1965. This reduction was attributed to more careful handling, maintaining temperatures in the tank between 34 and 40 instead of between 42 and 50°F., and reducing the concentration of fish in the tank from between 4.7 and 7.1 to about 3.5 per gallon.

In addition to the ripe adults, an estimated 250,000 eggs were artificially taken and fertilized at Bear Lake during the three collection years. About 205,000 were released directly into shallow rocky areas in Lake Tahoe. The remainder were held at Nevada's Verdi Fish Hatchery, and those that survived were released later as eyed eggs (25,000) and alevins (3,000).

We wish to acknowledge the wholehearted support of the Utah State Department of Fish and Game and the Idaho Fish and Game Department. The assistance of Arnold Bangerter, Utah Fishery Biologist, was especially valuable.

LITERATURE CITED

Frantz, Ted C., and Almo J. Cordone. 1965. Introduction of the Bonneville cisco (*Prosopium gemmiferum* Snyder) into Lake Tahoe, California and Nevada. Calif. Fish and Game, **51** (4) : 270–275.

—*Ted C. Frantz, Nevada Fish and Game Commission, Reno, Nevada and Almo J. Cordone, Inland Fisheries Branch, California Department of Fish and Game, September 1966.*

75026—800 6-67 425

REPRINT FROM
Calif. Fish and Game, 52(3) :220. 1966.

THE FINAL INTRODUCTION OF THE OPOSSUM SHRIMP (*MYSIS RELICTA* LOVEN) INTO CALIFORNIA AND NEVADA

The final introduction of the freshwater opossum shrimp into California and Nevada was made in September 1965. This and earlier introductions (Linn and Frantz, 1965) totaled 442,000 shrimp (Table 1). These introductions were made to improve the food supply for trout (Linn and Frantz, 1965).

TABLE 1

Summary of Introductions of *Mysis relicta* into California and Nevada in 1963, 1964, and 1965

Lake	Location	Surface area (acres)	Maximum depth (feet)	Total number shrimp planted
Lake Tahoe	California and Nevada	123,300	1,645	333,000
Fallen Leaf Lake	El Dorado County, California	1,410	1,100	30,000
Lower Echo Lake	El Dorado County, California	338	150	27,000
Donner Lake	Nevada County, California	960	200	26,000
Huntington Lake	Fresno County, California	1,441	150	20,000
Blue Lake	Humboldt County, Nevada	11	48	4,000
Island Lake	Elko County, Nevada	7½	22	2,000
Total				**442,000**

LITERATURE CITED

Linn, Jack D., and Ted C. Frantz. 1965. Introduction of the opossum shrimp (*Mysis relicta* Loven) into California and Nevada. Calif. Fish and Game, 51(1) : 48–51.

—*Jack A. Hanson, Inland Fisheries Branch, California Department of Fish and Game, November 1965.*

o

printed in CALIFORNIA OFFICE OF STATE PRINTING
71509—800 5-66 325

ENERGY TRANSFORMATIONS BY A POPULATION OF FISH IN THE RIVER THAMES

By K. H. MANN

Department of Zoology, The University, Reading

Early investigations of fish populations were primarily concerned with describing the species present, their feeding habits and their rates of growth. With the development of techniques for estimating the sizes of populations, attention became focused on the weight of fish present in a given habitat and interesting comparisons were made between populations and between habitats from this point of view. More recently biologists have come to realize that biomass data alone are not a sufficient basis for predicting the yield of a fishery and efforts have been made to assess rates of production. The interaction between biomass, production and degree of exploitation of populations has proved a fruitful field of study for fishery biologists. From this and related fields of ecological thought it has become clear that a full understanding of the production potential of a population cannot be obtained without a knowledge of its intake of energy and materials as food.

A study of the fish of the River Thames at Reading has been in progress since 1958 and has passed through each of the stages mentioned above. The early work was undertaken by Williams (1963, 1965) and this paper attempts to carry his work one stage further by producing an estimate of the energy consumption of the fish populations. In a preliminary account (Mann 1964) the energy transformations by the two most abundant species were calculated very approximately. No attempt was made to estimate the energy requirements of the fish not vulnerable to the net and no justification was given for the methods of calculation used. In this paper these deficiencies are remedied.

CHOICE OF METHODS

Previous studies of the quantitative relationships between fish and their food are of three kinds: those in which attention has been concentrated on the biomass of the food material and the fish, those in which the turnover of inorganic materials such as nitrogen has been studied and those concerned with energy transformations. Studies of the first type were made by Surber (1935) and Pentelow (1939) who fed fish with *Gammarus*, Brown (1946) who fed trout with a mixture of minced meat and liver, and Johnson (1960) who fed pike with live minnows. In each case two parameters were determined: the maintenance ration, i.e. the food required to maintain the fish without gain or loss in weight, and the efficiency of food utilization for growth, i.e. the ratio between food consumed above the maintenance ration and the corresponding gain in weight. This type of study has been used as the basis for calculation of the food uptake of populations of fish in nature. Allen (1951) and Horton (1961) used Pentelow's data and Johnson (1960) extrapolated his own results to obtain an estimate of the food consumption of a population of pike in Windermere.

Gerking's work (1952, 1953, 1954, 1955a, b, 1962) is an example of a study of the turnover of nitrogen in fish. The results were converted to protein equivalent, and two parameters were determined: firstly the protein required to replace that broken down 'during the normal course of living', i.e. the maintenance requirement, and secondly the ratio between protein consumed and protein retained, i.e. the efficiency of protein utilization for growth. Gerking calculated the protein turnover of a population of bluegill sunfish in a lake in Indiana, using the results of laboratory studies of these two variables.

Winberg (1956) first drew attention to the possibility of studying the bioenergetics of fish populations. The methods he discussed are those used in studying the nutrition of domestic animals (Maynard & Loosli 1956), and the basic principles have since been carefully and critically expounded by Slobodkin (1960). Winberg was mainly concerned with calculating the food requirements of fish reared in ponds. To what extent can his method be applied to the study of populations in nature? The grave disadvantage of earlier work is that determinations of the relationship between food consumption and growth, whether the emphasis is on biomass or on nitrogen, are tedious and difficult. It is well known that the rate of metabolism of a poikilothermous animal is dependent on body weight, the temperature of the environment, and the time of year, yet in none of the studies listed above was it possible to explore this relationship to the full. Inevitably there were approximations. Both Allen (1951) and Horton (1961) assigned a constant value to the efficiency of food utilization during growth, in spite of the fact that Pentelow's values show a very wide variation indeed. Gerking (1962) showed that Allen's approximations led him to overestimate the food consumption of the trout in the Horokiwi stream by at least two to three times. Gerking (1955a) studied thoroughly the relationship between food consumed and food retained at various levels of feeding, but only over a limited range of temperatures and body sizes. He confined his calculations of food turnover to a 5 month period from May to September.

Winberg's method does not suffer from the limitations of the earlier work. It is based on the assumption that the energy content of the food equals the sum of the energy contents of the material lost in egestion and excretion, the material retained in growth and the material broken down in metabolism. The first two of these quantities are open to direct measurement and the third, metabolism, may be determined indirectly in a respirometer. The assumption is a sound one, and the main question for further discussion is whether a reasonable estimate of energy metabolized in nature can be obtained by the indirect methods of respirometry. Winberg's argument may be summarized as follows. It is generally accepted that the resting metabolic rates of animals are related to body weight by the equation

$$Q = a\, w^k$$

where Q is rate of metabolism, w is the body weight and a and k are constants for the species. There is abundant evidence from the literature that the value of k for fish is never very far from 0·8 (extremes, 0·71 and 0·81) but that the value of a varies over a considerable range, the value for Salmonidae being about 2½ times that for Cyprinidontiformes. From published data Winberg showed that, in general, the metabolic rate of fish at various temperatures follows the curve of Krogh (1916). Thus, given a suitable value for a it is possible to predict the resting metabolic rate of a fish at any combination of body size and temperature.

A fish in a natural habitat is not continually in a state of rest and it is necessary to add to the figure for resting metabolism a figure for activity in the environment. Brody, Procter & Ashworth (1934) found that the metabolism of active domestic cattle was twice the resting rate. Other workers on domestic animals have found it to be 45%, 50% or 75% above the resting level. Winberg proposed that the metabolic rate of fish in nature

AKADEMIYA NAUK SSSR
(Academy of Sciences of the USSR),
MINISTERSTVO RYBNOGO KHOZYAISTVA SSSR
(Ministry of Fisheries of the USSR),
IKHTIOLOGICHESKAYA KOMISSIYA (Commission of Ichthyology).

THE ACCLIMATIZATION OF FISH AND INVERTEBRATES IN USSR WATER BODIES
(Akklimatizatsiya ryb i bespozvonochnykh v vodoemakh SSSR)

Editors: A. F. Karpevich, Chief editor; L. S. Berdichevskii, S. I. Doroshev, A. I. Isaev, N. I. Kozhin, N. K. Lukonina

"Nauka" Publishing House, Moskva, 1968, 272 pp, price 1r. 21 kop.

One of the most important tasks to be achieved by modern ichthyology is raising fish production in water bodies. Of all the measures directed to this purpose, one of the most important is research and practical works for the acclimatization of fish and invertebrates in the country's water bodies.

This collection contains various materials, which were reported at the All-Union Conference of Acclimatization, 1965. These materials constitute a review of the investigations carried out over several years by several institutes of scientific research, dealing with problems of the acclimatization of water creatures.

The book is aimed at ichthyologists, hydrobiologists and fishery workers.

PREFACE

Serious problems have arisen during the last decade for specialists of fishery biology and commercial fisheries. The rapid development of several branches of the national economy related to utilization of the country's water resources — the regulation of flow in big rivers and the building of hydro developments in them, the diverting of an important part of the river flow for irrigation, the pollution of water bodies by industrial and household sewage — have changed and deteriorated the hydrological and biological regime of water bodies and worsened the living conditions of commercial fishes and their forage organisms.

The processes occurring in the water bodies of the fishing industry have led to the intensification of hydrobiological and ichthyological research.

The present aims of the science and practice of fishing are as follows: despite the new changes and the deteriorating conditions in water bodies, fish reserves should not only be prevented from diminishing, but a considerable increase of fish productivity must be brought about, together with a radical improvement of the qualitative composition of commercial and feeding fauna, as well as the growth of the reserve and catch of commercial fish. This requires a vast combination of scientific measures, the most important of which are: fish breeding, acclimatization, fishing regulations, and systems for the improvement of fishing conditions.

The steps leading to the acclimatization of fish and forage organisms should be emphasized. Many well-known examples show a successful acclimatization of aquatic animals.

Thus, the diadromous Atlantic herring has been implanted off the American shores of the Pacific ocean. Salmon have been brought over from the northern regions of the Atlantic and Pacific oceans into the Southern Hemisphere, the waters of New Zealand and South America. The Pacific Ocean oyster has been acclimatized off the Australian shores.

In the USSR too, acclimatization has been successfully achieved. The Black Sea mullet has been acclimatized with success in the Caspian Sea. Similar results have been attained in the same sea with the Azov nereis worm and the syndesmia mollusk, which have adapted well and have spread over almost the whole sea, where they constitute the basic food of the common and stellate sturgeon.

In the various water bodies of the USSR, we observe the successful acclimatization of many valuable fish species, such as whitefish, carp and others. Lake Balkhash is a classical example of the radical improvement which has been effected in the composition of the commercial ichthyofauna and of the rise in the productivity of a water body.

In recent years, acclimatization works have been carried out on a large scale, and the positive results are becoming increasingly evident. We feel obliged, however, to emphasize the fact that the acclimatization of fish and forage organisms does not alone solve all the problems inherent in the rise of fish productivity and the improvement of quality in water bodies.

This book is a collection of reports delivered at the All-Union Scientific Conference on Problems of Acclimatization, held in Rostov, in December 1965.

The collection includes more than 40 articles which explain the results of investigations conducted and the practical steps taken during the last 15 years in the field of acclimatization of fish and invertebrates, in all the country's water bodies and in each one of them separately. It also contains the text of the resolution adopted during this conference.

This collection will decidedly be of use to a large circle of scientific and practical workers.

The Editors

TABLE OF CONTENTS

* [GLAVRYBVOD – Glavnoe Upravlenie Rybookhrany i Rybovodstva (Main Administration for Fish Breeding and Conservation).]

[1968]

CALIFORNIA VECTOR VIEWS

Vol. 15 No. 7 July 1968

THE POTENTIAL ROLE OF FISHERY MANAGEMENT IN THE REDUCTION OF CHAOBORID MIDGE POPULATIONS AND WATER QUALITY ENHANCEMENT

S. F. Cook, Jr.

ABSTRACT: Information has been acquired indicating that at least partial biological control of chaoborid midges and planktonic algae may be possible with the use of fish. Two basic concepts pertaining to this relationship have been explored: control through the direct influence of predation and control through competition for nutrient energy. The emphasis is placed on the latter concept, and means for its implementation are discussed. The work has centered primarily upon the trophic relationships between the midges and plankton and two species of atherinid silversides and the threadfin shad.

As the water resources of California continue to be developed and the numbers of low-and mid-elevation storage reservoirs increase, concern is growing over various problems that are frequently associated with such artificial environments. The fisherman wants good fishing; the recreationist wants nuisance abatement; we all want clean water. These are three biological problems that are intimately related within the confinement of a lacustrine (lake) environment. They can and should be regarded within the same ecological framework, rather than as individual components of a forest of special interests.

For 7 years the Lake County Mosquito Abatement District carried a program directed toward the biological control of the Clear Lake "gnat," *Chaoborus astictopus* Dyar and Shannon (Diptera: Chaoboridae). Although the program was brought to an abrupt halt by the County in January 1968, enough background information has been gathered to indicate that at least partial biological control of chaoborid midges and planktonic algae may be possible through food-web adjustments and alterations.

Control of *Chaoborus astictopus* has been achieved at Clear Lake with the use of chemical toxicants (Lindquist, et al., 1951; Hazeltine 1963). Although the methyl parathion presently being employed for this purpose has appeared effective and safe to date, past experience has demonstrated the possible risks and limitations involved in a prolonged program such as this. If and when the Clear Lake gnat develops resistance to this material, or adverse side effects appear, the time may come when biological control may become the only recourse available.

Planktonic algae present problems in lakes and water impoundments that have defied solution except on a limited scale, and it is doubtful whether a complete solution is forthcoming in the near future in environments of the character and size of Clear Lake. Nevertheless, when placed in perspective with other ecological and limnological parameters, it appears possible that reduction in planktonic algae could also be achieved by biological manipulation.

Early in these studies it became apparent that the need for control of the Clear Lake gnat and possibly algae reduction might best be served with a manipulation of the fishery. Were this need clearly defined in relation to other considerations, such as the sport fishery interests, it might be possible to achieve the desired end in a manner that could also serve these interests. It is toward these goals that this program has been directed.

Biological foundation and background

There are two major parameters to the midge/fish relationship that bear directly on the prospects of the biological control of *Chaoborus astictopus:* (1) midge reduction through the direct influence of predation and (2) population suppression through the subtle and complex manifestations of competition for nutrient energy. Although *C. astictopus* should be vulnerable to regulation through a combination of these population regulatory parameters, the emphasis has been placed on the latter concept.

There are about 20 species of fishes inhabiting Clear Lake at this time (Cook, et al., 1964, 1966). From the myriads of summer-emerging midges, it was obvious that these fishes were exerting little influence upon the midge population from an economic standpoint. The first thing to be determined, then, before any thought could be given to the introduction of alien species, was why the existing fishes were not doing a better job of midge control. With this information superimposed upon what is known of the biology of *Chaoborus astictopus,* it might then be possible to predict those characteristics that would be most desirable in a fish species, or assemblage of species, to reduce the population levels of the Clear Lake gnat.

In order to shed some light on this problem, several important aspects of the problem needed clarification. First, it was necessary to determine insofar as possible the trophic relationships between the midges and the fishes of the lake. Second, information was needed pertaining to the causative agents influencing these relationships, such as water temperatures, turbidity, dissolved oxygen, plankton levels, etc. Also to be considered were the relative densities of each fish species in the lake and their limnetic distributions throughout the year (Cook, et al., 1964).

It would be presumptuous to infer that all this information was acquired. Nevertheless, enough has been gathered to justify conclusions as to why the fish species inhabiting Clear Lake are unable to cope with the great midge population. (1) No species of fish in Clear Lake (with the possible exception of the Sacramento perch) utilizes the midge larvae as its primary food; at least no species appears dependent upon them. (2) Most of the fish species, particularly those that will eat midge larvae, confine themselves to a large extent to the littoral or adlittoral areas of the lake, whereas the midge larvae develop throughout the entire body of the lake. (3) The abundance, or density, of those species that incorporate midge larvae into their diet is insufficient to cope with the great midge numbers occurring in this body of water. (4) Although several fish species consume the zooplanktonic food of the midge larvae, their numbers are also insufficient to limit the supply at the expense of the midge population -- i.e., interspecific "competition for food" cannot be regarded as a limiting factor for the midge larvae in this environment.

Concurrent with the studies that provided the above conclusions, information was also being acquired relative to the midge/fish relationships in other bodies of water. Closely related chaoborids inhabit the profundal zones of virtually every freshwater lake and reservoir in the more temperate regions of North America. It is significant, however, that very few of these waters outside California produce sufficient numbers of these midges to cause serious "nuisance problems" (Cook, 1967). Although there are likely many interrelated factors that govern these densities in different bodies of water, the most conspicuous difference between the lakes and reservoirs in California and comparable environments in other parts of the country lies in the structure of the fishery.

A casual perusal of the literature is sufficient to reveal the great diversity of fish species native to this country east of the Rocky Mountains; for example, 71 species inhabit Lake Texoma, Oklahoma/Texas, and its immediate watershed (Riggs and Bonn, 1959). Although not all of these are native to this drainage, most are native to the general area. There are perhaps a dozen native species extant in the Clear Lake area. In contrast to most California lakes and reservoirs, the numerically predominant fish species in most mid-western water impoundments are those that occur throughout the open water (limnetic or pelagic) zones. Although larvae of the midge *Chaoborus punctipennis* (Say) are perhaps the predominant benthic macro-organisms in Lake Texoma, they are only about 5% as abundant as *Chaoborus* *astictopus* larvae in Clear Lake (Sublette, 1957; S. F. Cook, Jr., unpub. data).

On the basis of this information, it became apparent that fish species considered for midge reduction in California lakes and reservoirs must fill the open water "niche" now occupied to a large extent by a few species of benthic and planktonic invertebrates. First and foremost, then, appeared the need for a good pelagic, or open water fishery.

In addition to the necessary pelagic character of those fishes selected for incorporation into California waters, they should also possess the following characteristics: (1) As a group, they should form a natural trophic unit, self-sustaining and reasonably independent of the influence of fishes already present in California waters. (2) Reciprocally, they must be compatible with existing sport fishing and ichthyological interests. (3) They must be adapted to the conditions to which they would be subjected in California waters. (4) They should be highly prolific with a rapid rate of development and be capable of attaining densities commensurate with the available food resources. (5) They should form a natural extension to the profundal-limnetic food web now dominated by the more basic components of the food chain, i.e., the plankton and midges.

It appears conceivable that midge populations in Clear Lake and perhaps other waters in the state could be reduced by incorporating into California waters a carefully selected assemblage of open water species of fishes. If the selection were based upon sport fishery enhancement and water quality considerations as well as midge reduction, it is possible that all interests could be served simultaneously.

The concept of competition for nutrient energy

Within a lacustrine environment there is an impoundment of nutrient energy as there is an impoundment of water. Although there is usually an inflow and outflow through the system, the major energy output, at least in Clear Lake during much of the year, is provided through a re-cycling of a constant nutrient supply. During the re-cycling process this energy is tied up in varying degrees within the different components of the food web. The degree to which this energy supply can be utilized by any trophic entity is governed by a complex of environmental conditions and interrelationships between other trophic groups and determines the standing crop levels of any particular organism at any particular time. In the case of Clear Lake this degree of utilization of the energy supply is manifest in the production of great quantities of planktonic algae and *Chaoborus astictopus*. The major objective was an attempt to reduce the standing crop of these lower trophic levels by concentrating greater amounts of nutrient energy in a more desirable and perhaps harvestable form -- in this case, fish protein.

Figure 1 represents in schematic form the major energy reservoirs and pathways through the food web as they exist in Clear Lake at this time. Although detailed measurements pertaining to these relationships are unavailable, the schematic does approximate present conditions in a general way. Figure 2 represents the hypothetical goal of this program with the incorporation into the system of fishes specifically adapted for the purpose of utilizing energy. It should be noted that the *rate* at which the basic nutrients are incorporated into the system remains about the same; the difference lies in where the available energy is stored.

Although the role of predation should not be ignored, it should be incorporated into the flow diagram only in view of these other considerations. Certain behavioral characteristics inherent in the biology of *Chaoborus astictopus* larvae reduce their vulnerability to the direct influence of predation by fish (Cook, et al., 1964).

Fish selection and introduction

With the need generally defined, the next step involved locating fish species with those characteristics necessary to fulfill this need.

For economic and other reasons, only fishes indigenous to the United States were considered as potential candidates. The literature was meticulously surveyed, inquiries were directed to many of the country's foremost fishery biologists and ichthyologists and two trips were made to the midwest for the purposes of consultation and first-hand observation.

Of the many species considered, five were eventually selected for detailed study: the Mississippi and brook silversides, *Menidia audens* Hay and *Labidesthes sicculus* (Cope) (Atherinidae); the emerald shiner, *Notropis atherinoides* Rafinesque (Cyprinidae); the white bass, *Roccus chrysops* (Rafinesque) (Serranidae); and the threadfin shad, *Dorosoma petenense* (Günther) (Clupeidae). The

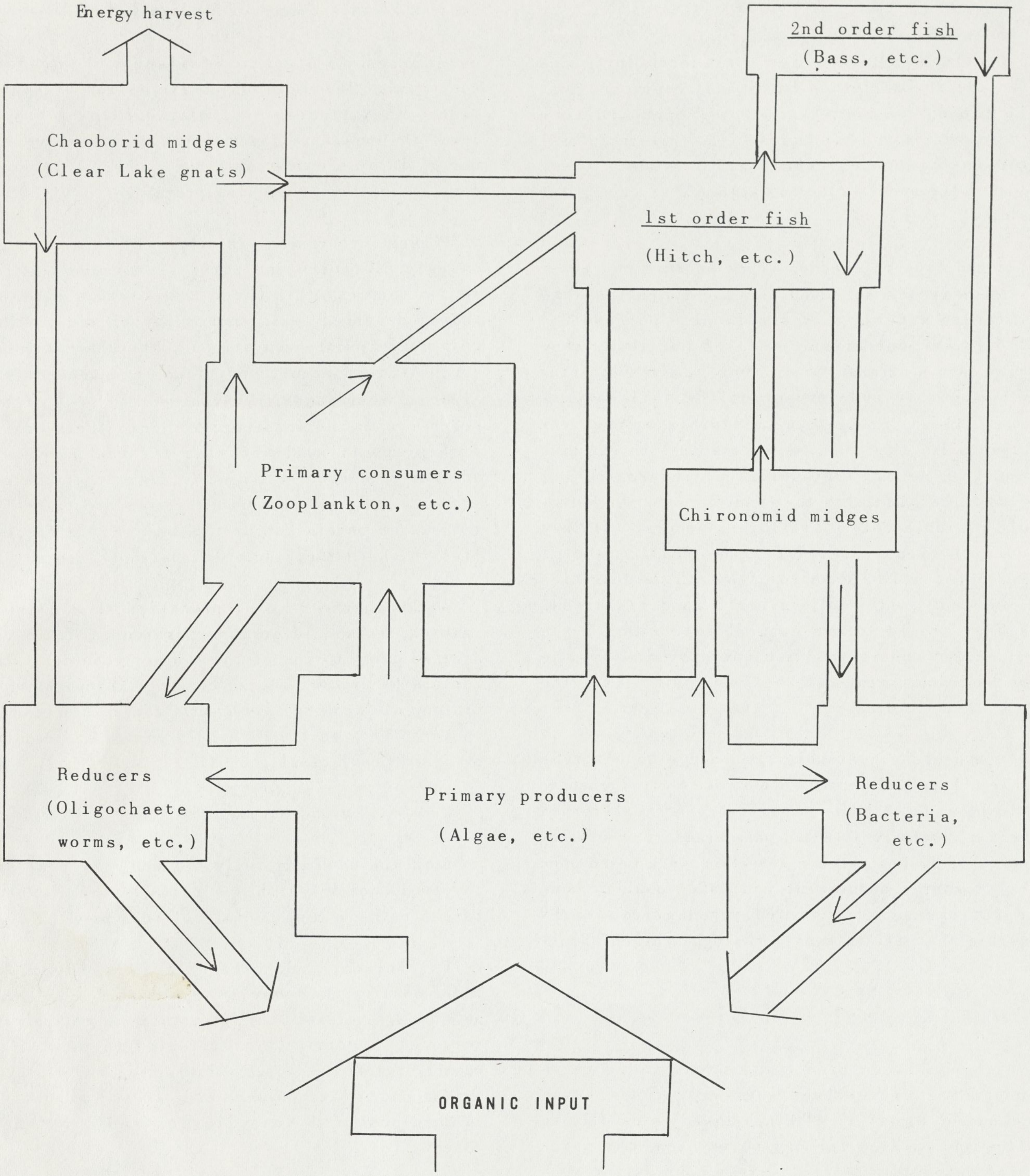


Figure 1. Major nutrient energy pathways and reservoirs as they generally exist in Clear Lake today. Note the amounts of energy tied up in the plankton and gnats as compared to the fish.

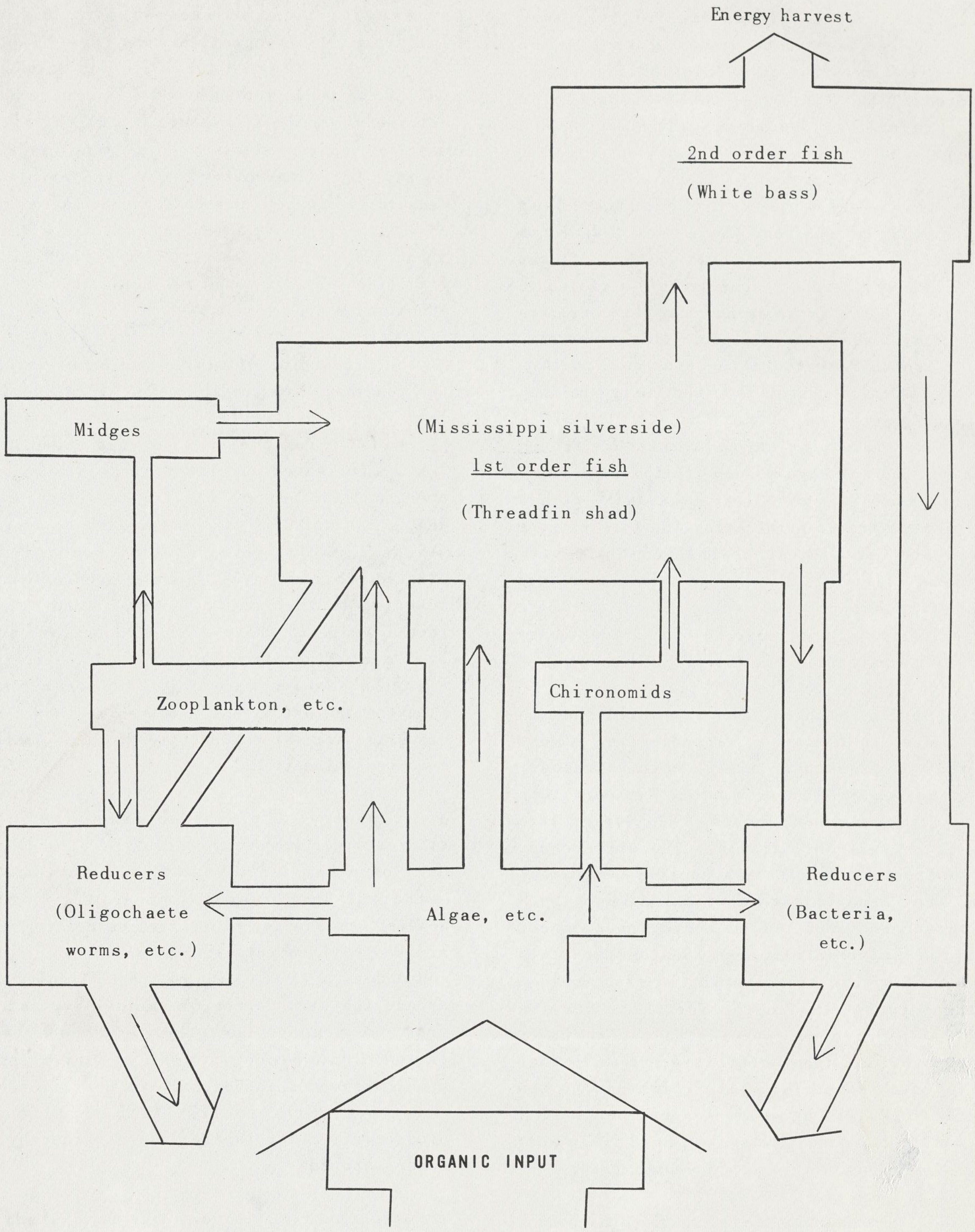


Figure 2. Major nutrient energy pathways and reservoirs considered desirable for [illegible]rposes of reduction in standing crop levels of midges and planktonic algae in Cle[illegible] Note that the major reservoirs of energy are tied up in fish flesh. Ene[illegible] could be removed from the system with the harvest of fish.

threadfin shad was already under observation as it had been widely introduced into California. Authorization for the introduction of the other species into experimental ponds was granted by the Fish and Game Commission in 1963-64. Difficulties encountered in locating a suitable stock of the emerald shiner precluded their introduction and subsequent study.

It is the combination of threadfin shad, Mississippi silversides, and white bass that forms the backbone of the off-shore boat fishery of Lake Texoma (Al Houser, personal communication). Although the gizzard shad, *Dorosoma cepedianum* (LeSueur), is perhaps the most abundant species in that reservoir, its rapid growth rate and large size permit this species to gradually escape from the energy pathway of the food chain which culminates with the white bass and other more piscivorous species. Although the gizzard shad may have good potential as a population suppressant of the Clear Lake gnat, it has been eliminated from consideration for this purpose in this state because of possible conflict with sport fishing interests. Furthermore, in the absence of this species, population levels of the more desirable species may increase beyond that attainable when in competition with the gizzard shad.

Of the species studied, the threadfin shad is perhaps lowest in the food chain, feeding almost exclusively on planktonic algae, entomostracans, and other suspended organic matter. Although this species seldom exceeds 8 inches, the average size is usually considerably smaller. The silversides differ subtly in their feeding habits. Generally, however, they feed to a greater extent upon both insect larvae and adults from the water surface, although they also incorporate zooplankters into their diet. They are elongate little fish, seldom exceeding 5 inches in length. The white bass is generally a piscivorous species, although it is also known to feed upon entomostracans and other higher invertebrates. This little brother to the striped bass usually grows no larger than 2 to 3 pounds. All four are highly prolific, open water species, with a very rapid growth rate.

Upon their introduction into experimental ponds, all did well with the exception of the bass, which apparently failed to reproduce. Of the silversides, the *Menidia* appeared most adaptable to the pond conditions, although the *Labidesthes* did well in one pond for 3 years.

Experimental pond studies

A series of 10 ponds (30' x 40' x 7') plus a deep well was constructed in 1963 by the Lake County Mosquito Abatement District for the express purpose of evaluating experimental fishes and their influence on biological productivity. *Labidesthes* and *Menidia*, obtained from Ohio and Oklahoma, were put in two ponds for each. Seven juvenile white bass obtained from the California Department of Fish and Game were put in another pond along with *Gambusia affinis* Baird and Girard. The general plan was to measure the insect emergence and plankton production of all the ponds in a similar manner and compare the productivity in those ponds with fish and without fish. The threadfin shad was being studied elsewhere (Cook and Moore, 1966).

The production of midges and other insects from the ponds was measured by means of emergence traps. These were constructed as 2-foot square screened pyramids. From the apex was suspended a 15 inch 2 x 2 inch stick covered with "stickum." Insects emerging from beneath the trap would become permanently entangled in this material upon contact. The sticks were collected weekly, wrapped in clear plastic ("Saran Wrap"), and replaced. The organisms adhering to the "sticky boards" were counted and identified with the aid of a binocular microscope by direct examination through the plastic covering. Plankton samples were collected with a standard plankton tow net with 125 meshes to the inch. These organisms were also identified to a major group and measured volumetrically.

In general the data obtained from the pond studies are somewhat inconclusive although a great deal of otherwise valuable information has been gathered. This was not completely unexpected, however, in view of other studies dealing with such limited environments (Huffaker, et al., 1963; Bay and Anderson, 1966). The major difficulty centered around the high degree of variability encountered from one pond to the other irrespective of the presence or absence of fish. In many respects the ponds assumed the successional character of newly constructed reservoirs, with an initial high productivity that tapered off considerably as the ponds matured.

Although results from the pond studies were somewhat inconclusive, they did, nevertheless, indicate certain trends in midge emergence and plankton production in the presence and absence of the experimental fishes. Midge production (including chironomid midges) in those ponds WITH fish stabilized to a far greater degree than in those ponds WITHOUT fish. Although the mean production in the ponds WITH fish was not considerably lower than in those ponds WITHOUT fish, the magnitude in fluctuation in numbers was considerably less. Mayfly (ephemerid) production in those ponds WITHOUT fish was consistently and significantly higher than in those ponds WITH fish.

Perhaps the most conspicuous difference in the two sets of ponds was in the plankton production and biological turbidity. There was generally less fluctuation at a lower standing crop average in those ponds WITH fish over those WITHOUT fish. This was frequently reflected in the water of the fish ponds being quite clear over extended periods while the control ponds would vary to a greater degree in their turbidity.

Besides the above, there were a few points that were clarified with little doubt. First of all, all fish species studied appeared well adapted to the conditions to which they were subjected; temperatures typically varied throughout the year from 40 to 80°F. Both species of silversides successfully reproduced in the limited confines of the small artificial ponds. Stomach analyses were consistent with results obtained elsewhere (Saunders, 1959) and no evidence of cannibalism of eggs or fry was noted.

In addition to the experimental pond studies, the threadfin shad has been studied for the past 6 years in a half-acre farm pond near Lakeport as well as in larger environments such as East Park and Stoney Gorge reservoirs northeast of Clear Lake. Results from the farm pond study clearly indicate a suppressing effect of threadfin shad on midge and plankton populations (Cook and Moore, 1966). Also, there appears to be a correlation between the average densities of chaoborid midges and the presence or absence of threadfin shad in many northern California reservoirs; the reservoirs examined without shad had consistently higher midge populations than those with shad (Cook, 1967).

From the pond studies it is obvious that in order to adequately evaluate the potential of fish on the biological productivity of lakes and reservoirs, a larger environment must be utilized. It is also essential that this environment be one that can provide a maximum amount of pertinent information with a minimum of risk to existing sport fishing interests.

Present program outlook

On the basis of the information acquired relative to these studies, authorization was granted by the California Fish and Game Commission in August 1967 for the introduction of the silversides into Blue Lakes northwest of Clear Lake. During the fall of 1967 several thousand Mississippi silversides were released into these small (50 and 100 acres) natural lakes that had been under intensive study for several years. The original plan called for an introduction of both silversides into Upper Blue Lake, and these plus the threadfin shad and white bass into Lower Blue Lake. A small dam precludes migration from the lower to the upper lake; however, both are in the Clear Lake watershed. Although the Mississippi silversides were thriving in District ponds at the time of the introduction, the brook silversides could not be introduced because they had died out from unknown causes. Plans to introduce the threadfin shad and white bass into Lower Blue Lake have not yet been approved by the California Department of Fish and Game because of possible adverse effects of the white bass on the Central Valley and Delta anadromous fishery if they eventually got downstream through Clear Lake. It is hoped that eventually this introduction will be permitted.

The introduction of Mississippi silversides into Blue Lakes marks the initial introduction of this species into California waters. It is unlikely, however, that this species by itself will be able to cope with the midge problems in these lakes. They should, however, provide excellent and needed forage for the game fish and hopefully will enhance the sport fishery to a significant degree if they successfully establish themselves.

Unfortunately, there are no immediate plans to carry this program beyond the present stage. As a result, any field evaluation or demonstration upon which conclusions may be reached must await a resumption of the study, if such is forthcoming.

ACKNOWLEDGMENTS

I would like to express my deep appreciation to the California Department of Fish and Game for their constant help and cooperation throughout the course of this study. I would also like to acknowledge the assistance provided by R. L. Moore who gathered much of the data upon which this report is based.

LITERATURE CITED

Bay, E. C., and L. D. Anderson. 1966. Studies with the mosquitofish, *Gambusia affinis*, as a chironomid control. Ann. Entomol. Soc. Amer. 59:150-153.

Cook, S. F., Jr. 1967. The increasing chaoborid midge problem in California. Calif. Vector Views 14:39-44.

Cook, S. F., Jr., J. D. Conners, and R. L. Moore. 1964. The impact of the fishery on the midge populations of Clear Lake, Lake County, California. Ann. Entomol. Soc. Amer. 57:701-707.

Cook, S. F., Jr., and R. L. Moore. 1966. Population fluctuations of threadfin shad, Clear Lake gnat larvae, and plankton in a Lake County farm pond 1961-1965. Proc. and Papers Calif. Mosquito Control Assoc. 34:60-61.

Cook, S. F., Jr., R. L. Moore, and J. D. Conners. 1966. The status of the native fishes of Clear Lake, Lake County, California. Wasmann J. Biol. 24:141-160.

Hazeltine, W. E. 1963. The development of a new concept for control of the Clear Lake gnat. J. Econ. Entomol. 56:621-626.

Huffaker, C. B., K. P. Shea, and S. G. Herman. 1963. Experimental studies on predation. Complex dispersal and levels of food in an acarine-prey interaction. Hilgardia 34:305-330.

Lindquist, A. W., A. R. Roth, and J. R. Walker. 1951. Control of the Clear Lake gnat in California. J. Econ. Entomol. 44:572-577.

Riggs, C. D., and E. W. Bonn. 1959. An annotated list of the fishes of Lake Texoma, Oklahoma and Texas. Southwest Naturalist 4:157-168.

Saunders, R. P. 1959. A study of the food of the Mississippi silverside, *Menidia audens* Hay, in Lake Texoma. MS Thesis, Univ. Oklahoma, Norman. 42 p.

Sublette, J. E. 1957. The ecology of the macroscopic bottom fauna in Lake Texoma, Oklahoma and Texas. Amer. Midland Naturalist 57:371-402.

Vol. 15 No. 7 **CALIFORNIA VECTOR VIEWS** July 1968

Published Monthly by the CALIFORNIA STATE DEPARTMENT OF PUBLIC HEALTH, Bureau of Vector Control

2151 Berkeley Way, Berkeley, California 94704

Donald D. Linsdale, Editor — Thomas D. Peck, Managing Editor

Thomas D. Mulhern, Associate Editor — Gretchen A. Neilson, Production Assistant

SECOND-CLASS POSTAGE PAID at Berkeley, California

UNIVERSITY OF CALIFORNIA, DAVIS

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

DEPARTMENT OF ZOOLOGY

STORER HALL
DAVIS, CALIFORNIA 95616

P.O. Box 1211
Lakeport, CA 95453

February 26, 1970

Dr. Robert Behnke
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

Dear Bob:

It was good hearing from you. I learn through the grapevine that you are doing well back there. You must have introduced the natives to your fine home brew.

I am still floundering around trying to find work, preferably something that will permit me to continue with the program I started at Clear Lake. So far, no luck. The F&WS contract that I have been working on for the last year gave out as of the first of the year. The Zoology Department has permitted me to retain my position with no pay! We do have some irons in the fire, however.

The Menidia erupted in Clear Lake last summer to an extent that you would have to see to believe. Millions, billions, everywhere! You can feel them bouncing off your hand if you stick your hand in the water from a moving boat. I suspect they are here to stay. All indications to date indicate a great improvement in the sport fishing. Unfortunately CFG has taken a very "saur grapes" attitude toward the introduction and is doing little by way of evaluating its effect on the sport fishery. First they accused me of making an "illegal" introduction (which is only technically true by the letter of the law), then they rejected my recent Trans. A.F.S. paper, which was originally submitted to them.

There is little doubt but that the silversides were responsible, at least in part, for the dramatic reduction in the algae of Clear Lake last summer. Just how they achieved this is still speculative. Until a better explanation comes along, I will stick with my original thoughts expressed in the enclosed Calif. Vector Views article (1968). After all, the course of ecological events are following a course predicted and prescribed in this paper.

Labidesthes sicculus do not seem to be as adaptable as Menidia audens. In our pond studies they did not survive, although they did well for a couple of years. Also, as was reported by Riggs and Bonn (1959), they can not compete with Menidia under conditions of Lake Texoma or Lake County experimental ponds. An accidental introduction of a few Menidia into a Labidesthes pond resulted in a complete replacement of the latter species by the former in less than one year. On the basis of what I know, I believe Menidia would best serve your purposes. I would, however, carefully evaluate the conditions in relation to the geographical and ecological distribution of both species.

One lovely feature of the atherinids as a forage species over the threadfin shad, for example, is that they spawn continually during the spawning season for most game species. This provides readily available forage for all age classes at all times.

I will try to keep in contact with you and let you know how things progress. I am looking forward with great anticipation to the spring fishing season. Please let me know if I can be of further assistance to you.

Very best regards,

Jerry

Sherburne F. Cook, Jr.
Associate Specialist

Enclosures