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QUANTITATIVE DETERMINATION OF THE INSECT FAUNA OF RAPID WATER

By
F. P. IDE
(From the Department of Biology
University of Toronto)

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No. 1. Report on the 1936 Lake Trout Investigation, Lake Opeongo, Ontario, by F. E. J. Fry and W. A. Kennedy. University of Toronto Studies, Biol. 42. Pub. Ont. Fish. Res. Lab., 54, 1937.

No. 2. Birds of Algonquin Provincial Park, Ontario, by D. A. MacLulich. Contributions of the Royal Ontario Museum of Zoology, no. 13, 1938.

No. 3. A Comparative Study of Lake Trout Fisheries in Algonquin Park, Ontario, by F. E. J. Fry. University of Toronto Studies, Biol. 46. Pub. Ont. Fish. Res. Lab., 58, 1939.

No. 4. Quantitative Determination of the Insect Fauna of Rapid Water, by F. P. Ide. University of Toronto Studies, Biol. 47. Pub. Ont. Fish. Res. Lab., 59, 1940.

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QUANTITATIVE DETERMINATION OF THE INSECT FAUNA OF RAPID WATER

Abstract

A method is described of trapping and counting the insects which emerge from one square yard of stream surface involving the use of a cage-trap device. Some preliminary results obtained by its use are given showing the total emergence of different groups of insects throughout the season. An account of the emergence of four species of the genus *Leptophlebia* is included and an estimate made of the total egg production and survival in these species.

Introduction

The bottom fauna of the rapid stretches of streams consists largely of the immature stages of aquatic insects. Methods have been devised of estimating the quantity of this fauna which give a good measure of the standing bottom crop. Application of these methods to the problem of stream productivity has been made by a number of workers including Needham (1934), Moore *et al.* (1934), Viosca (1935), Moffett (1936), and Tarzwell (1937).

Owing to the coarse and irregular nature of the substratum in rapids, however, the taking of a complete sample which would include the small immature stages of all the insects is next to impossible by any method of sampling now in vogue. Nevertheless if the procedure in sampling is standardized and the samples are taken in a consistent manner the figure obtained for bottom fauna will be valid as a basis for comparison of the quantity of this fauna in different localities and at different times.

The capture of insects emerging from a given area of water will give a measure of the population which will be valid for comparison and has definite advantages in estimating the insect population of streams. It gives a more accurate determination of the numbers, particularly of the smaller insects, it gives a measure of the turnover and the adults are more readily identified than are the nymphal or larval stages.

Method

During the last three years various methods for capturing emerging aquatic insects have been employed. The most successful apparatus used in this connection was essentially a modification of the tent-trap described by Needham (1908). The trap (figure 5), measured a yard in all dimensions and was constructed of 15 mesh to the inch copper screen on a wooden framework. Covering a square yard of bottom the sides reached to the bottom of the stream but did not fit closely to it so that the nymphs were not confined to but were free to move in and out of the area. The collection was made by entering a door in the side of the cage, closing the door, and collecting the insects at leisure using forceps for the larger individuals and a cotton swab dipped in alcohol for the smaller. The collections were made at approximately the same hour of the day and all the insects were removed from the trap daily so that each collection represented the emergence over a twenty-four hour period. All insects were preserved in alcohol and final results will be published at a later date.

A Negretti and Zambra distance recording thermometer gave a continuous record of temperature of the water from May 25 to September 18, 1937, and from May 5 to September 18, 1938, and from the recording thermometer charts the daily mean temperatures were read and plotted in figure 1. During the summer of 1938 the oxygen varied from 4.2 to 7.0 c.c. per litre, the pH from 6.2 to 6.8 with chlorphenol red, the CO_2 from 3.8 to 5.8 ppm., and the level of the water, measured on a stake in quiet water near the cage, dropped a total of six inches from May to August.

This method of obtaining quantitative data on insects emerging from the surface of streams has been in use during the summers of 1937-8 and 1939 at the Ontario Fisheries Research Laboratory in the rapids of Costello creek, Algonquin Park, Ontario. Junior members of the laboratory staff have assisted in this field, Mr. J. B. Buchanan in 1937 and Mr. W. M. Sprules in 1938 and 1939. During the last two years Mr. Sprules has expanded the application of the method to the problem of comparing the productivity of various habitats in the stream.

In 1938 and 1939 this work was aided by a grant from the National Committee on Fish Culture made through the agency of the National Research Council of Canada.

Neither this method of determining the numbers of adults nor methods of determining the standing bottom fauna will, however

accurately employed, give a measure of productivity from the standpoint of availability of insects as fish food. Insects of rapids dwell, for the most part, under stones where they are well protected from predation by fish. They are vulnerable to attack at certain times only, as for instance when they are on their way to the surface to emerge or when the adults are ovipositing or again during times of heavy flooding when aquatic stages may become dislodged and swept downstream. Needham (1938), White (1924), and others have found that the speckled trout feeds mainly on the insects which are swept out of the rapids into pools in which the fish lie in wait. In all probability there is, nevertheless, a close correlation between the number of insects present on the bottom and the number which are available to fish and hence between the number of insects and the number of fish which a stream will support. It seems probable also that there would be a close correlation between the number of adult insects emerging as well as between the quantity of immature stages on the bottom and the number available for food.

Preliminary Results

The cages or traps were placed in a series along Costello creek which has its source in a small lake, Costello lake, and empties into large lake Opeongo. The creek, which is about four miles in length, has alternate rapid and quiet reaches and is typical of the many streams connecting lakes in Algonquin Park.

Cage number 1 was placed near the centre of a rapids (figure 5), two hundred feet long, and was in operation from May 25 to September 20 in 1937 and from May 4 to September 18 in 1938, that is, from a time soon after the ice went out of the lake above until late September when the number of insects emerging was small. The emergence of insects in this cage is given in table 1 as an example of the total catch recorded in one season.

Of the total 15,077 which emerged in this cage during this interval 77 per cent emerged before the middle of July, the remaining 23 per cent appearing in the latter half of the summer.

A similar cage, number 4, placed at the head of the same rapids collected over the same period in 1938 a total of 33,818 insects of which 19,738 were Simuliidae.

TABLE 1.—The numbers of insects emerging in cage number 1 from May 4 to September 18, 1938.

Simuliidae	4,257
Ephemeroptera	4,564
Chironomidae	4,653
Plecoptera	263
Trichoptera	1,001
Neuroptera (Spongilla flies)	6
Miscellaneous (mainly Empidae & Tipulidae)	333
Total	15,077

In 1937 a third cage, number 2, was in operation below these same rapids in the more gently flowing stream with silted bottom and emergent aquatic plants.

In table 2 a comparison is made of the emergence of insects in cage 1 in 1937 and 1938, of cage 4 in 1938 and cage 2 in 1937. In this table the material collected in all cages between May 25 and September 18 is considered, since in 1937 the cages were in place between these dates only.

TABLE 2.—The emergence of insects in cage 1 (1937 and 1938), cage 2 (1937), and cage 4 (1938) from May 25 to September 18.

	Cage 4	Cage 1		Cage 2
	1938	1937	1938	1937
Simuliidae	13,508	889	3,380	205
Ephemeroptera	6,527	4,411	4,542	399
Chironomidae	4,249	5,634	4,068	8,188
Plecoptera	738	784	249	3
Trichoptera	1,504	1,525	981	157
Neuroptera (Spongilla flies)	99	1	6	.....
Odonata	.....	.....	.....	5
Miscellaneous (mainly Empidae and Tipulidae)	178	571	322	108
Totals	26,803	13,815	13,548	9,065

Professor Needham's tent-trap covered an area six feet square and in a month during which it was in operation (July 16 to August 15, 1905) a total of 3,844 insects emerged corresponding to an emergence of 960 from a square yard. Between the same dates the emergence in cage 1 of the above series was 2,288 in 1937. This discrepancy is probably indicative of a richer fauna in the Costello creek rapids than that sampled by Needham in Beaver Meadow brook, N.Y. state.

Sources of Error

Some obvious sources of error are present in the foregoing method. A few noxious insects such as blackflies, mosquitos, and sandflies enter the cage with the collector. Accordingly mosquitos, with the exception of some *Anopheles* emerging in cage 2, were omitted from the counts since no larvae of other genera were found in the water. The number of blackflies which entered any one cage with the collector was probably less than 200 for the season. In cage 2 situated about two hundred feet from cage 1 approximately two hundred blackflies were captured. Most of this number represents individuals which followed the collector into the cage but a few of them actually emerged from the water within the cage. Evidence for this was furnished by the finding of a few larvae on vegetation in the cage and the presence of some male individuals in the collections.

Some terrestrial insects such as aphids and plant bugs were found in the cages and these were omitted from the totals. Of these some may have floated downstream and found their way into the cage and others may have passed through the mesh of the screening. Small insects of some groups pass out of the trap through the meshes of the screening. *Simulium* were observed to do this. Some of the small chironomids escaped in this way but in general these insects and those of other orders remained resting on the wire or woodwork of the cage.

Spiders were found frequently and these reduced the numbers of insects to some extent. Empidae, which emerged in the cage, preyed on some of the smaller insects.

An occasional insect escaped through the door when the collector was entering and some individuals fell into the water and were not counted. These insects which fell into the water usually collected on the downstream side of the cage and an examination of the debris adhering to the wire revealed a small number of such casualties.

A cage such as this cannot be placed in the water without altering some of the environmental conditions. The current in the upper layers of the water within the cage is retarded and the light is reduced in intensity by the wire mesh. Most of the insects, however, are under stones so that this change in light intensity is not as serious a complication as it might at first appear.

Stepping on the stones within the cage inevitably causes a mortality in the insect population but if the stones are fairly large and relatively immovable, as they were in cages 1 and 4, loss from this cause will be small.

Utility of the Method

The ease of collecting and the greater accuracy made possible by this method of sampling the insect fauna and the fact that the turnover of bottom fauna is determined rather than merely the standing population seems to give promise of making it a more useful one than others at present in vogue. The exacting nature of this method in which daily samples are taken make it, however, impracticable for extended surveys. Some modification would be necessary in which the cages would be employed at intervals for short periods of time. In order to make the sampling statistically significant a number of cages would be necessary also to compensate for irregular distribution of organisms on the bottom and their migration inshore or up- and downstream.

By a slightly modified floating tent-trap the bottom fauna of lakes may also be sampled. Adamstone and Harkness (1923) by this means secured figures for the emergence of Chironomids from the surface of lake Nipigon. Miller, during 1937 and 1938, made more extensive samplings of the bottom fauna of Costello lake, Algonquin Park, Ontario, by the same method (unpublished thesis, University of Toronto).

POPULATION STUDIES

The method outlined above lends itself to studies of the populations of individual species of aquatic insects. As an example of some of the data which may be obtained on this subject the results pertaining to one genus of mayflies emerging in cage 1 in Costello creek are given.

The emergence of subimago males and females of *Leptophlebia adoptiva* McD., *Leptophlebia mollis* Walk., and *Leptophlebia volitans* McD. for 1937 and 1938 is recorded in Plate I, figure 2. The numbers have been plotted on semi-logarithmic paper in order to depress the peaks and thus restrict them to a reasonable height. In table 3, below, the total numbers of each species are listed as well as their sex ratios.

TABLE 3.—Numbers of *Leptophlebia* emerging from one square yard of stream bottom.

		Males	Females	Ratio Males/Females	Total
L. adoptiva	1937	Males emerged before collecting began	5	....	5
	1938	6	5	1.20	11
L. mollis	1937	641	815	0.78	1,456
	1938	898	907	0.99	1,805
L. volitans	1937	96	212	0.45	308
	1938	50	86	0.58	136

All three species have one generation a year, *L. adoptiva* emerging in May, *L. mollis* in June and early July, and *L. volitans* in the latter half of July and in August. A general agreement is apparent between the minor peaks of emergence and the fluctuation in the temperature of the water. The bimodal form of the histogram for *L. mollis* would seem however, to be more than the result of temperature fluctuation alone. This species would appear to have two races or to be actually two species in this stream and these are accordingly referred to as *L. mollis A.* corresponding to the early and *L. mollis B.* corresponding to the later group. It may be that *L. mollis B.* is in reality *L. swannanoa* Travers, a species recognized further south where it follows *L. mollis* in the season.

The emergence of *L. adoptiva* occurred about five days earlier in 1938 than in 1937 and that of *L. mollis* began three to four days earlier in 1938 than in 1937. *L. volitans* began to emerge and the emergence was over about two weeks earlier in 1938 than in 1937. The earlier emergence of these species in 1938 may be a result of generally warmer temperatures in the fall of 1937 and spring of 1938. Noticeable also is a great reduction in the number of individuals of *L. volitans* in 1938 as compared with 1937 and particularly significant in this connection is the elimination in 1938 of a large population which appeared in August of 1937. Conversely the number of individuals of *L. mollis A.* and *B.* was greater in 1938 than in 1937 and correlated with these facts is the higher temperature of the water during late July and August in 1938.

Comparison of the Numbers of Nymphs with the Numbers of Subimagos Emerging

Collecting was not confined entirely to the subimago but nymphal stages were also taken. For this purpose a square yard of bottom adjacent to the cage was marked off and all the stones in the area lifted out individually and the nymphs of all sizes removed. This was done on June 1, June 22, July 25, August 23, and September 16 in 1937. In tables 4 and 5 below the results of these collections are given, the letters A, B, C, etc., denoting nymphal groups; A being the last instar, B the next to the last, and so on.

TABLE 4.—Numbers of nymphs of *L. mollis* recovered from one square yard of bottom in 1937.

	June 1	June 22	July 25	August 23	September 16
L. mollis—A........	270	178	0	0	0
B........	95	17	0	0	0
C........	52	2	0	0	0
D........	19	2	0	0	0
E........	3	..	..	..	..
F........	..	..	..	..	..
G........	..	..	..	2	..
Total..........	439	199	0	2	0

TABLE 5.—Numbers of nymphs of *L. volitans* recovered from one square yard of bottom in 1937.

	June 1	June 22	July 25	August 23	September 16
L. volitans—A......	..	..	15	10	..
B......	..	2	16	4	..
C......	2	7	6	10	..
D......	1	9	4	11	..
E......	..	12	6	16	..
F......	..	15	15	20	..
G......	..	..	16	11	..
Total..........	3	45	78	82	0

That these collections give a low figure is demonstrated by a comparison of the total number of nymphs of *L. mollis* collected from one square yard on June 22, with the number of subimagos which emerged from an adjacent square yard covered by the cage in the period following June 22. On June 22, 199 nymphs, all fairly well grown and therefore fairly readily collected, were taken from one square yard adjacent to the cage. From June 23 to July 14, 620 *L. mollis* individuals emerged in the cage indicating that only about one-third of the nymphs present in the square yard were recovered by careful collecting, assuming that the number of subimagos emerging represents the total number present. In this connection there is a possibility that the square yard from which nymphs were collected and the square yard covered by the cage were not comparable owing to differences in bottom conformation and to migrations of nymphs prior to emergence, although the areas were similar as far as could be determined by casual observation. In collections of nymphs made at times when the smaller stages are present in the water the estimating of their numbers would be practically impossible owing to their small size. In general it would seem that an estimation of abundance based on subimagos emerging is more easily made than one based on nymphal collections.

Change in the Size of Individuals and Change in the Number of Eggs in the Females

The series of subimagos taken by cage-trap is valuable also in that it is taken daily and thus shows change in size, colour, and other characteristics of the individuals during the summer.

In a study of the subimagos of *L. mollis* represented in this material a very perceptible decrease in size, as indicated by dry weight, was noted, the largest individuals emerging earliest and the smallest latest in the season. Lots of thirty subimago individuals were evaporated to dryness allowing a period of twenty-four hours in an electric oven kept at 50° C. and weighed on a chemical balance to give values with an error of less than 1 per cent. In Plate II, figure 3, the weight of these individuals in lots of 10 was plotted against the time in lines A (females) and B (males) for 1937. The marked decrease in weight of both sexes is evident and this decrease is regular except for a rise in the curve about June 22 coinciding with the first appearance of *L. mollis B.*

It will be noted that the discrepancy between the weights of males and females is not uniform but greatest at the beginning and least at the end of the emergence period. The explanation of this discrepancy is found in the number of eggs formed in the female and the progressive decrease in this number. In the female subimagos the eggs are already fully formed and may be readily dissected out. This was done and the eggs of 50 individuals in all, of this species were counted. Line D records the number of eggs per female in *L. mollis A.* and *L. mollis B.* for 1937. Each point on the curve is the average of a count of the eggs in six individuals except for those taken on June 8, 14, 19, 23 and July 14 when the eggs of 2, 3, 7, 5, and 2 individuals respectively were counted. The females emerging earliest had an average of over 900 eggs, those emerging last an average of less than 300 eggs. A small increase in the number of eggs per female is evident about June 26 coinciding with the appearance of the early females of *Leptophlebia mollis B.*

In figure 3, line C, the number of eggs per female of *L. adoptiva* is indicated. The numbers of eggs in three individuals were 1,157, 1,181, and 1,125 all of which are greater than the number in any of the fifty individuals of *L. mollis* whose eggs were counted. From the above it is evident that in *L. mollis* the larger individuals have more eggs per individual than do the smaller and that *L. adoptiva*, a larger species than *L. mollis*, has a larger number of eggs.

Line E, figure 3, shows the change in the number of eggs per individual in *L. volitans* from about 430 at the beginning to about 350 at the end of the emergence period. These points are not as reliable as those for the other species since the points represent in each case the average of the number of eggs in three individuals only but the same decrease in numbers of eggs is indicated by the counts made.

Such reduction in the numbers of eggs has been shown experimentally to be correlated in part at least with development under temperatures higher than optimal and complete sterilization of the female is possible by this means (Atwood, unpublished data on *E. Kuehniella*, 1937; Norris, 1933; Uvarov, 1931; Schultze, 1926; and Enderlein, 1902).

In Plate III, figure 4, the dotted line shows the total number of eggs produced in the females of *L. adoptiva*, *L. mollis A.* and *L. mollis B.* and *L. volitans* in 1937. The number of eggs per female were read from curves C, D, and E of figure 3 and the totals calculated by multiplying these figures by the number of females emerging on corresponding days. This curve obviously does not represent the number of eggs which hatch in the water or even the number of eggs laid. These will be reduced by mortality in the females, by predation on subimago and imago stages, and by failure to reach the imago condition successfully. There is probably a failure to mate on the part of many of the females and unfavourable climatic conditions will take a further toll of adults. In those eggs which are laid there will be a high mortality and in nymphs which hatch a further high mortality. The total mortality from all causes will be the difference between the number of eggs formed by the females in 1937 and the numbers of adults, males and females, which emerge in 1938. The number of eggs formed in the ovaries thus represents a potential reproductive capacity only, setting an upper limit to the number of individuals possible in the next generation. Table 6 below compares the potential of reproduction with the actual survival.

TABLE 6.—Reproductive potential and survival in *Leptophlebia* from one square yard.

	No. of females 1937	No. of eggs 1937	No. of males and females 1938	per cent survival
L. adoptiva	5	5,800	11	0.19
L. mollis	815	411,000	1,805	0.44
L. volitans	212	56,000	136	0.24

Leptophlebia mollis survives in greatest and *L. adoptiva* in smallest numbers for the eggs produced. This suggested what might be termed a curve of efficiency with respect to reproduction as indicated by the solid line in figure 4. This line is the result of plotting the ratio of the number of individuals (♀s) emerging daily in 1937 to the number of eggs per female. The number of individuals was given by the histogram in figure 2 smoothed so as to eliminate the minor peaks. From this curve it would appear that *L. mollis B.* is the most efficient in this regard producing as large a number of adults as does *L. mollis A.* with a mean egg production in the former of about one-half that of the latter. *L. adoptiva* is the least efficient of the group producing a small number of adults in spite of a higher number of eggs per female than any of the other species.

Significance of the Number of Eggs

It would seem logical to conclude that high fecundity has a role in compensating for high mortality rate. *L. adoptiva* at cage 1 is near the lower limit of its distribution in the stream and has a short period of emergence so that the chances of its being eliminated from the stream at this point, when environmental conditions in any season are adverse, are great. Its large size and large number of eggs will tend to lessen this possibility. For these groups *L. adoptiva*, *L. mollis A.*, and *L. mollis B.* at cage 1, the length of the emergence period has been found to be inversely proportional to the mean number of eggs per female. The length of the emergence period is important in the survival of an insect, the longer this

period the less the possibility of all individuals of a species being eliminated by adverse conditions. The length of this emergence varies in different places in a stream (Ide, 1935) and will increase nearer the source in the case of *L. adoptiva* thus ensuring the continuance of this species in the stream.

Correlation between Size, Number of Eggs, and Pigmentation

Spieth (1938) has drawn attention to the dark colouration of early emerging species as compared with the paler colouration characteristic of species of the same group which emerge later in the season. The early emerging are larger than the later emerging species and correlated with the size difference is a difference in the number of eggs. The above observations suggest that a correlation exists between size, number of eggs, and the quantitative deposition of pigments, all being expressions of altered physiological processes.

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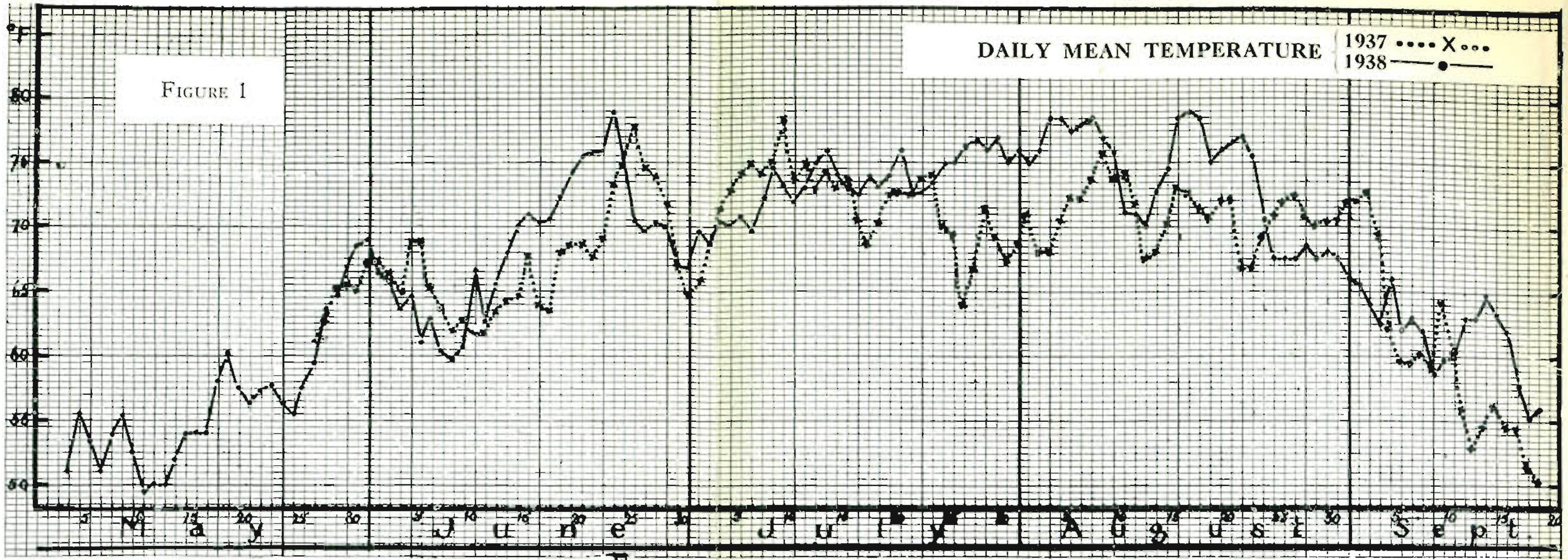

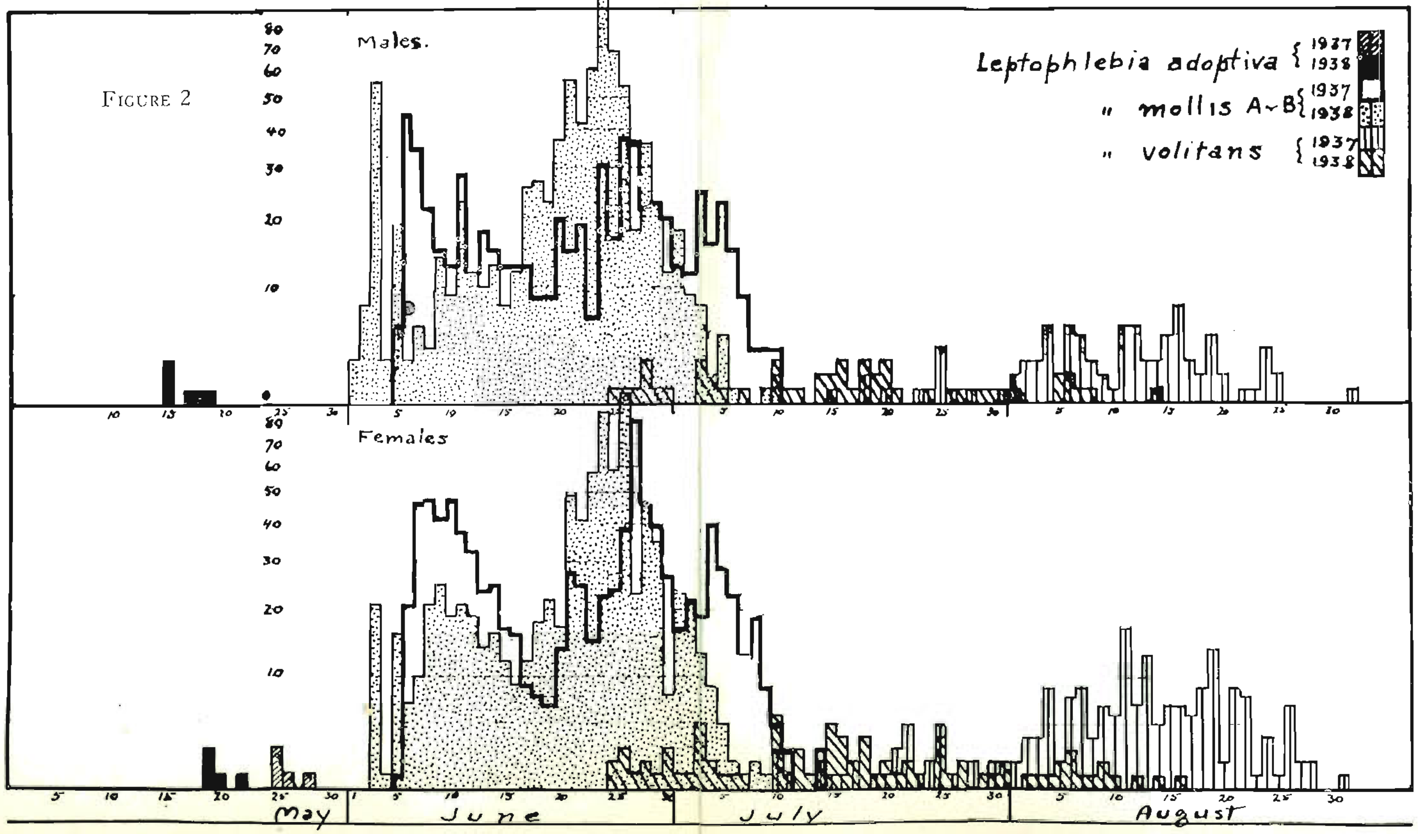

FIGURE 1.—Daily mean temperature of water in 1937-8.
FIGURE 2.—Frequency histogram showing daily emergence of *L. adoptiva*, *L. mollis A.*, *L. mollis B.*, and *L. volitans* in 1937-8.

PLATE II

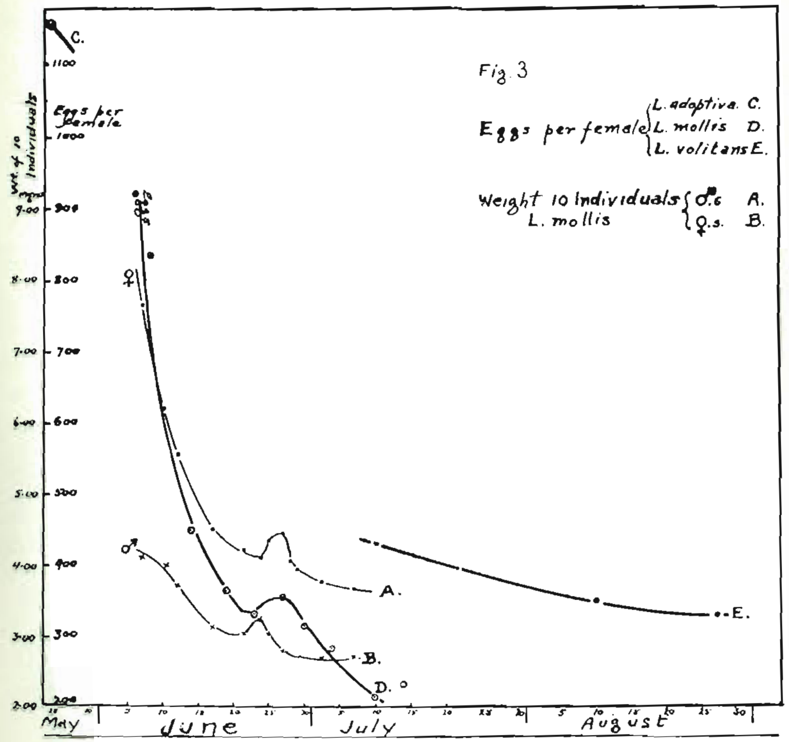

FIGURE 3.—Lines A and B, weights of females and males of *L. mollis A.* and *B.* Lines C, D, and E, numbers of eggs per female in *L. adoptiva*, *L. mollis A.* and *B.*, and *L. volitans* in 1937.

PLATE III

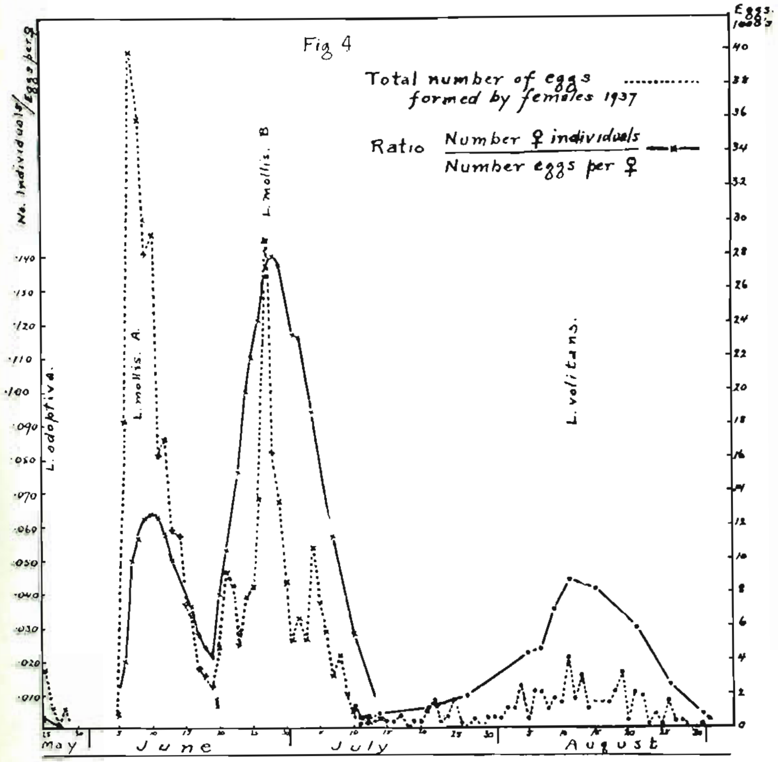

FIGURE 4.—The dotted line indicates total number of eggs developed by females in 1937 and the solid line the ratio of the number of female individuals emerging at any time to the number of eggs per female at the same time.

PLATE IV

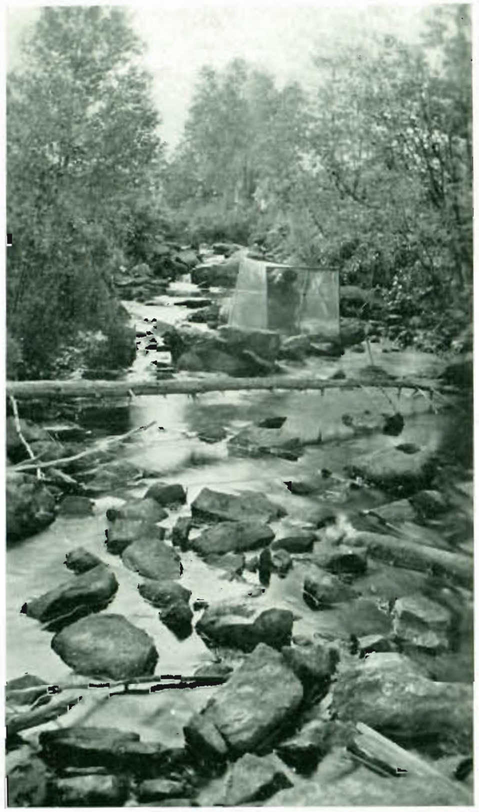

FIGURE 5.—The cage-trap in position at station I, Costello creek, Algonquin Park, Ontario.