

S
61
.R47
No.483
1960



Biology and Possible Control Of Nuisance Caddisflies Of the Upper Mississippi River

by Calvin R. Fremling

Department of Zoology and Entomology

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology

RESEARCH BULLETIN 483

SEPTEMBER 1960

AMES, IOWA

IOWA STATE TRAVELING LIBRARY
DES MOINES, IOWA

CONTENTS

Summary	856
Introduction	857
Caddisfly abundance in Keokuk	858
Description of the adults	859
Behavior of the adults	860
Oviposition	861
Larvae	864
Hatching and early distribution	864
Case and net construction	865
Ecological distribution of larvae	867
Larval feeding behavior and growth	870
Pupae	870
Generations per year	871
Caddisfly control	873
Adulticides	873
Light traps	874
Changes in street and store lighting	876
Larvicides	876
Literature cited	878

SUMMARY

The principal nuisance species of caddisflies at Keokuk, Iowa, are *Hydropsyche orris* Ross, *Cheumatopsyche campyla* Ross and *Potamyia flava* (Hagen), all members of the family Hydropsychidae (Order Trichoptera). The larvae of these species require considerable water current so that food may be carried into the nets which they construct upon submerged rocks and other silt-free structures. Keokuk lies along the tailwaters of the largest dam on the Upper Mississippi River, and the current and subsequent lack of silting create a large area which is favorable for hydropsychid larval habitation. Consequently, Keokuk is host to more caddisflies than the other river cities.

H. orris larvae build rigid catching nets and are most abundant in the fastest currents. *C. campyla* larvae construct loose, voluminous nets and are most abundant in the tailwaters and other areas where the current is moderated. *P. flava* larvae also build loose nets, but they are found most frequently in the rock and sand areas of the main channel of the river. Hydropsychid larvae are capable of populating areas by drifting with water currents.

Ovipositing females of the three species were collected beneath the surface of the water with an underwater light trap. *P. flava* females were collected as deep as 20 feet and *H. orris* and *C. campyla* as deep as 12 feet. Females may re-enter the water several times, and emergence traps captured many more fe-

males than males. Experiments with a vertically floating pole indicated that oviposition was most concentrated at a depth of 3 to 4 feet. *C. campyla* and *P. flava* oviposition was observed in the laboratory, where adult females were seen to remain submerged for several hours.

An analysis of the numbers of caddisflies which were captured nightly at a downtown cafe window indicated that *H. orris*, *C. campyla* and *P. flava* are bivoltine species, reaching peaks of abundance in early and late summer. Size-frequency distributions of *H. orris* larvae collected from navigation buoys also indicated that *H. orris* completes two generations per year. *C. campyla* adults were reared from eggs in 51 days in the laboratory.

A blacklight trap was developed and may serve as a caddisfly abatement device at Keokuk. Insecticide space sprays applied to *H. orris* swarming areas hold promise, as do residual sprays applied to riverside foliage where the caddisflies rest during the day. *H. orris* caddisflies were shown to be vulnerable to four organic phosphorus insecticides. Of these, malathion is the most lethal. Granular larvicides applied to the tailwaters may control local larval populations temporarily. Low solubility of the granular formulation may prevent injury to fish. A loss of caddisfly larvae in the tailwaters should affect the fish very little since fish scarcely utilize the hydropsychid caddisfly larvae in this area.

Biology and Possible Control of Nuisance Caddisflies of the Upper Mississippi River¹

BY CALVIN R. FREMLING²

Caddisflies are present in all cities which lie along the Mississippi River. They are extremely abundant

¹Project 1373, Iowa Agricultural and Home Economics Experiment Station. Iowa Cooperative Fisheries Research Unit, sponsored by the Iowa State Conservation Commission and Iowa State University of Science and Technology, with the cooperation of the U. S. Fish and Wildlife Service. This project was also supported by the National Science Foundation grant G-3831. This paper reports a portion of the author's Ph.D. thesis, "Biology and possible control of economically important Trichoptera and Ephemeroptera of the Upper Mississippi River."

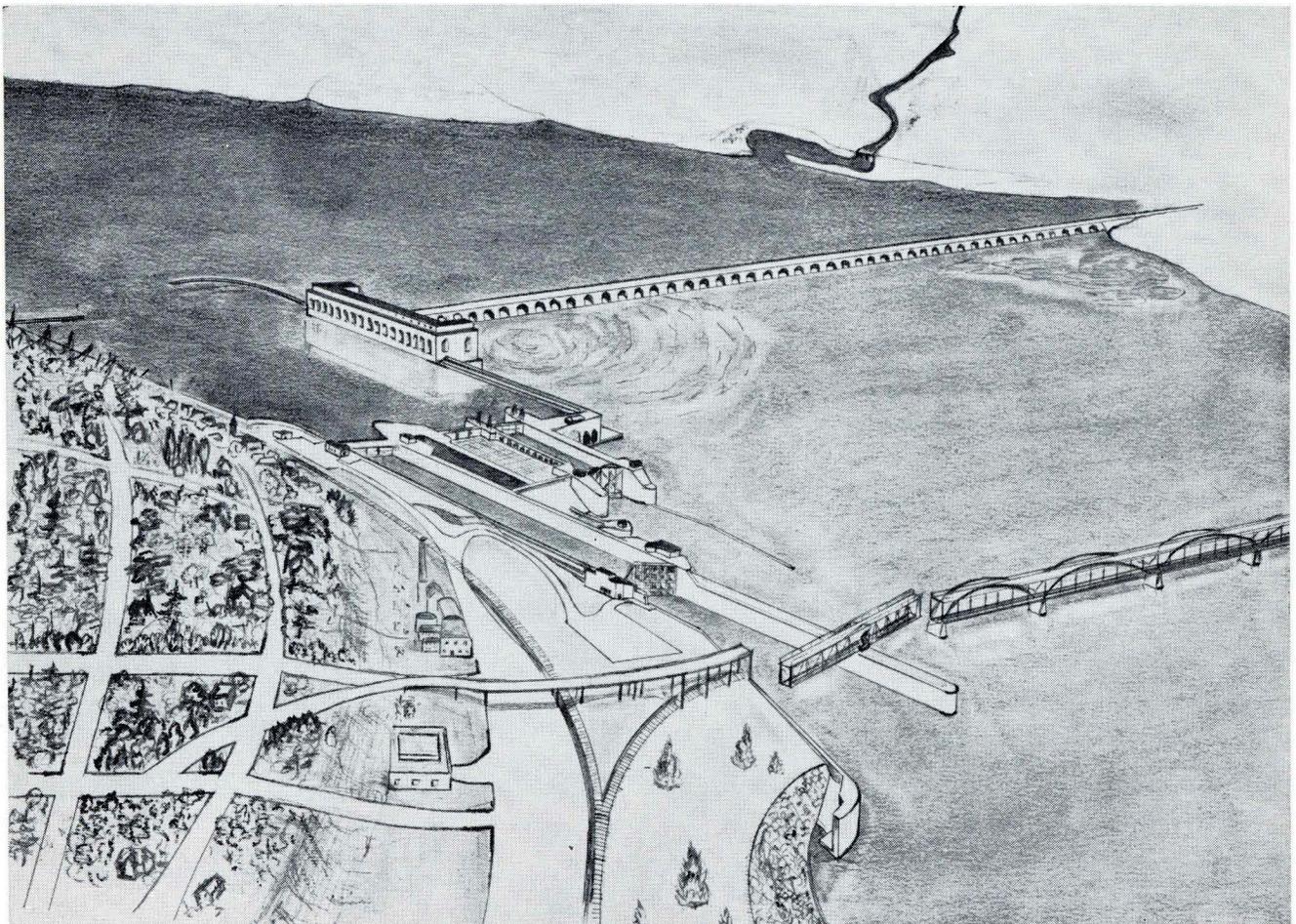
²Formerly graduate assistant, Department of Zoology and Entomology, Iowa State University of Science and Technology. Now assistant professor of biology, Winona State College, Winona, Minnesota. One of the most interesting and gratifying aspects of this study has been the unanimous cooperation and the sincere interest expressed by many people from many diversified walks of life. My major professor, Dr. Kenneth D. Carlander, initiated this investigation and provided guidance throughout the study and the preparation of this paper. David T. Hoopes assisted during two summers of field work. Mayor James O'Brien encouraged the research program at Keokuk and arranged for lodging, a boat and a motor which were provided by the City of Keokuk. The Jones Construction Company provided laboratory space for one summer. Lockmaster Donald Pullen and the personnel of Lock 18 provided laboratory space, allowed the use of their facilities and made daily observations of insect activities. Captain Donald Meyers and the crew of the U.S. C. G. Lantana assisted in sampling and provided lodging and transportation during sev-

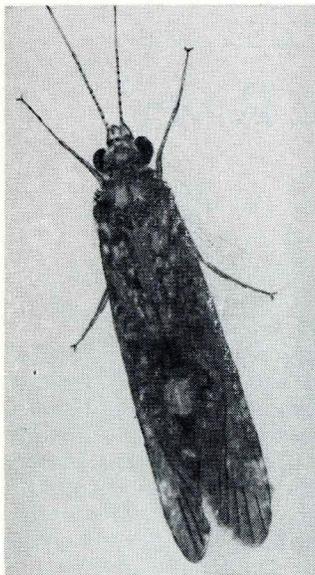
eral collecting trips on the Mississippi River. Ray Buchan, power plant superintendent, allowed the use of the facilities and data of the Union Electric Company at Keokuk. My wife, Arlayne, served as laboratory assistant and typed the first drafts of this manuscript. Dr. Herbert H. Ross of the Illinois Natural History Survey identified caddisflies and offered many valuable research suggestions. Technical advice was received at Iowa State University from Drs. Jean Laffoon, Martin Ulmer, Edwin Hibbs and John Lilly. Mr. H. E. Thompson, past president of the Fort Erie, Ontario, Lions Club, offered information concerning the caddisfly control program at Fort Erie. My fellow graduate students James Schmulbach, Fred Meyer, Robert Johnson and Clarence Carlson assisted at various times in the field.

(footnote 2 continued)

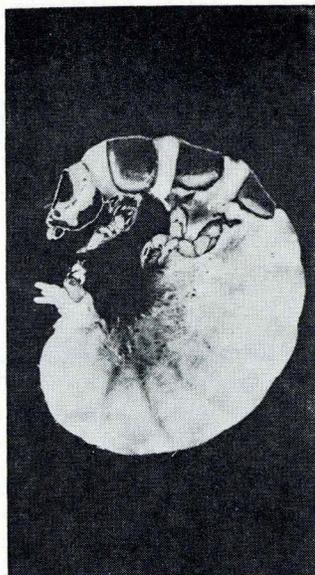
eral collecting trips on the Mississippi River. Ray Buchan, power plant superintendent, allowed the use of the facilities and data of the Union Electric Company at Keokuk. My wife, Arlayne, served as laboratory assistant and typed the first drafts of this manuscript. Dr. Herbert H. Ross of the Illinois Natural History Survey identified caddisflies and offered many valuable research suggestions. Technical advice was received at Iowa State University from Drs. Jean Laffoon, Martin Ulmer, Edwin Hibbs and John Lilly. Mr. H. E. Thompson, past president of the Fort Erie, Ontario, Lions Club, offered information concerning the caddisfly control program at Fort Erie. My fellow graduate students James Schmulbach, Fred Meyer, Robert Johnson and Clarence Carlson assisted at various times in the field.

Fig. 1. View of locks, power house and dam at Keokuk, Iowa, 1958. The river bluff is shown at left. Main Street meets the river at the bottom of the picture. (Photo by Louis Facto, drawing by Merle Banks.)

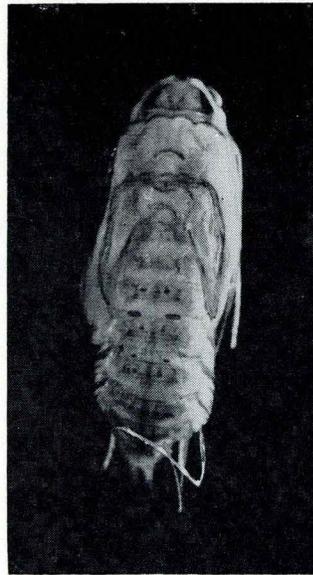




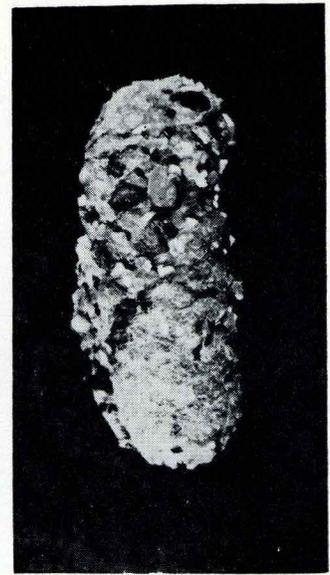
a. Adult female



b. Larva



c. Pupa



d. Cocoon

Fig. 2. Life history stages of the caddisfly, *Hydropsyche orris* Ross.

wings and bodies of the caddisflies cause swelling and soreness in the the eyes of hypersensitive individuals. Many Keokuk residents have become hypersensitive to caddisfly emanations and have developed typical hay fever symptoms.

It is inadvisable to paint houses along the river bluff (fig. 1) during the caddisfly season, and outdoor lighting is impractical. Spider webs become pendulous with captured caddisflies, making the riverside homes unsightly.

Similar nuisance problems have been reported from New Zealand (Tillyard, 1926), Africa (Corbet and Tjonneland, 1955) and along the Niagara River, particularly at Fort Erie, Ontario (Betten 1934, Munroe 1951, Peterson 1952). Allergic reactions to caddisflies in the Fort Erie area have been reported by Parlato (1929, 1930, 1932, 1934), Parlato *et al.* (1934) and by Osgood (1934, 1957a, 1957b).

Caddisflies (Order Trichoptera) are inconspicuously colored insects which superficially resemble small moths. The species which are most abundant at Keokuk are about $\frac{3}{8}$ inch long. Although several species have been collected in the Keokuk area, only three of them are abundant enough to contribute significantly to the nuisance problem. They are *Hydropsyche orris* Ross, *Cheumatopsyche campyla* Ross and *Potamyia flava* (Hagen), all members of the family Hydropsychidae. The three hydropsychids are much alike in general appearance and life cycle (fig. 2). Members of two other families taken in the Keokuk area, psychomyiidae and Leptoceridae, are mentioned later, but they were never taken in numbers sufficient to create a nuisance problem.

Caddisflies spend most of their lives under water as wormlike larvae. These larvae build cases of many types in which they live. Some cases are portable and resemble snail shells, sticks or miniature log cabins. The three hydropsychid species at Keokuk do not build portable cases but instead construct silken tubes and catching nets which they fasten to solid structures in swift currents. The constructions of *H. orris* larvae

are rigid, and at the Union Electric hydroelectric plant they form dense mats on cooling-siphon gratings, thus impeding the flow of water to the generators. Previous cases of water obstruction by hydropsychid larvae have been reported from California (Simmons *et al.*, 1942) and Japan (Uéno, 1952).

CADDISFLY ABUNDANCE IN KEOKUK

Relative abundance of the nuisance caddisflies in downtown Keokuk was estimated by collecting them

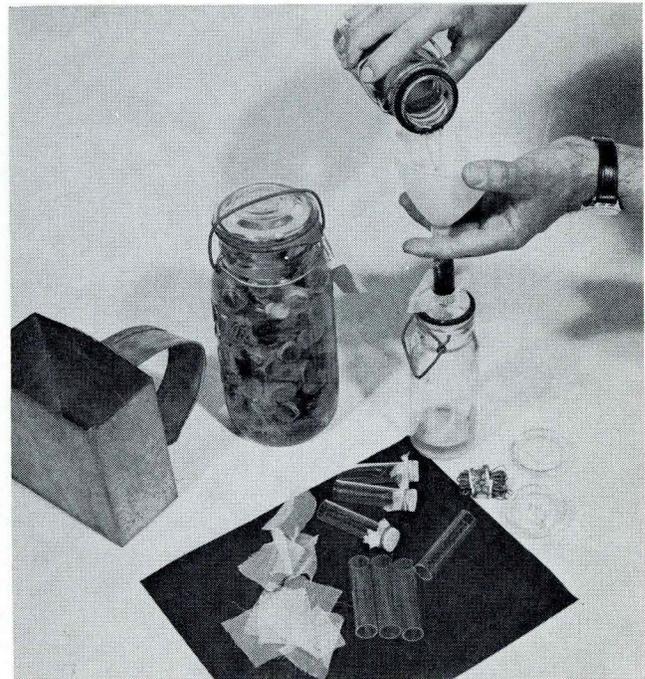


Fig. 3. Collecting pan, funnel, sections of glass tubing and certain materials used to collect, concentrate and store large numbers of small insects.

DESCRIPTION OF THE ADULTS

from the lighted window of a restaurant 2 blocks from the Mississippi River. The window was lighted with blue argon-mercury vapor lights which were very attractive to the insects. At 10 p.m. each night, a collecting pan half full of 75-percent alcohol was pushed up the window from the bottom to a height of about 8 feet. Two sweeps with the pan were made each night—one on the left and one on the right side of the window. The insects, alcohol and an identifying label were transferred from the pan to a pint bottle for temporary storage. The whole procedure took less than 2 minutes. Later the insects were transferred to gauze-capped sections of glass tubing for storage (fig. 3).

Window samples were taken from June 25 until Sept. 10 in 1957, and collections were made as early as May 6 and as late as Oct. 6 during the 1958 season. The maximum number of caddisflies collected at the window in 1957 was 1,963 on July 21 (fig. 4), and in 1958 the largest collection was 316 on June 4 (fig. 5).

C. campyla was the most abundant caddisfly in downtown Keokuk, and *P. flava* and *H. orris* were second and third in abundance in that area (figs. 4 and 5). *H. orris*, however, swarms along the river bluff and is the most troublesome species in the residential district.

For identification of the adult caddisflies, the reader is referred to Ross (1944). Field identification of the three species is extremely difficult. The following suggestions will help where several specimens are available for comparison.

The newly emerged *H. orris* and *C. campyla* adults are distinctly marked with gray and white (fig. 2), but as they become older their markings usually wear off, and the caddisflies become a uniform slate-gray color. After 2 days in captivity, the distinctive markings are almost always rubbed off—even when the adults are kept in a large cage. Both *H. orris* and *C. campyla* bear a diagonal black streak on each antennal segment, and this characteristic quickly separates them from the other common species in the Keokuk area. They may be rather readily separated by size, as *C. campyla* adults are 8-8.5 mm. long (from head to tip of folded wings), while *H. orris* adults measure 9.5-10 mm. *P. flava* adults are uniformly straw-colored, and their eyes appear to be unusually black and beady. The antennal segments do not bear any diagonal black streaks, and the antennae resemble thin canes of bamboo.

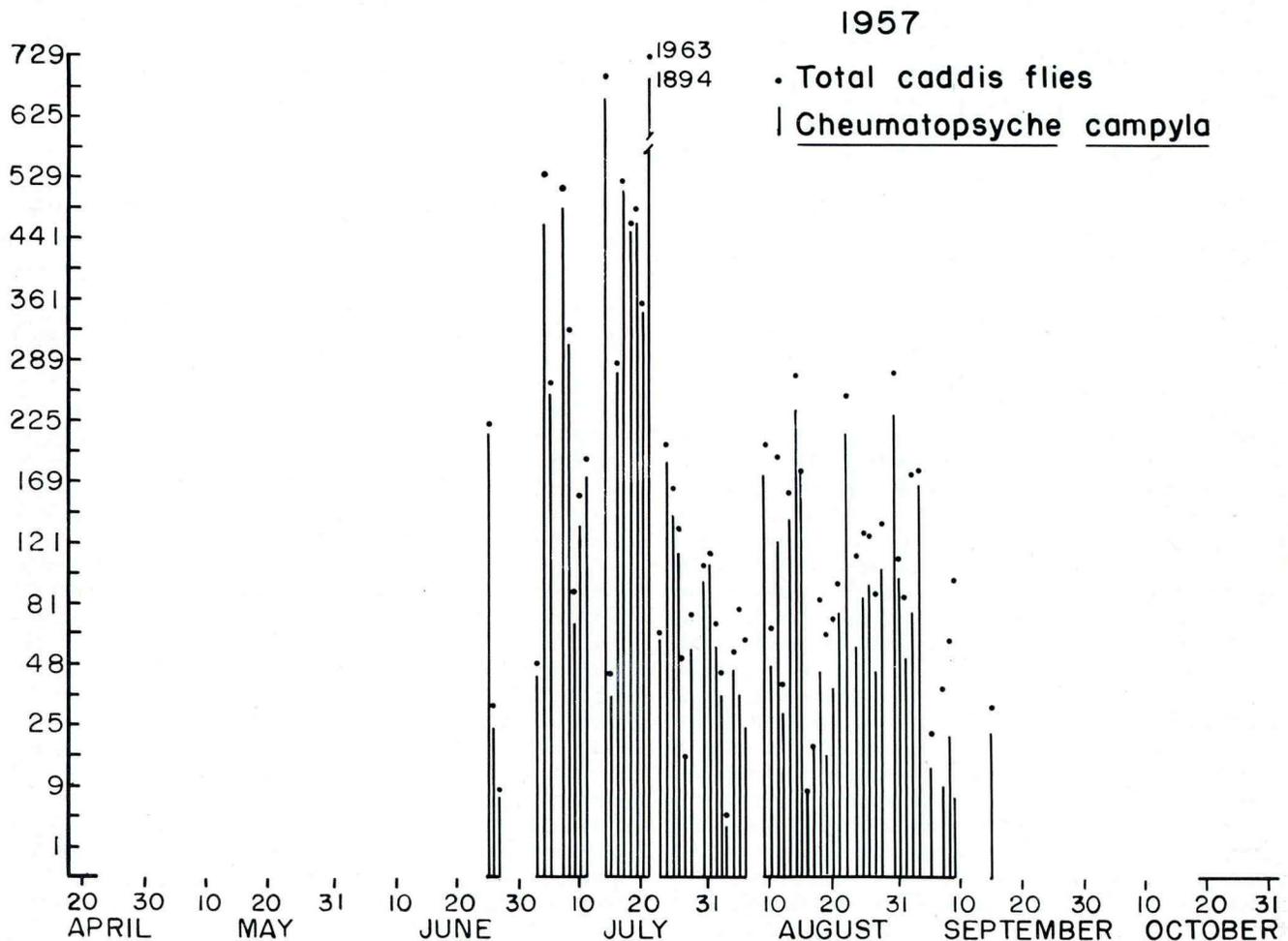


Fig. 4. Number of *Cheumatopsyche campyla* and the total number of caddisflies collected nightly at a lighted cafe window in Keokuk, Iowa, during 1957. A broken baseline indicates nights when collections were not made.

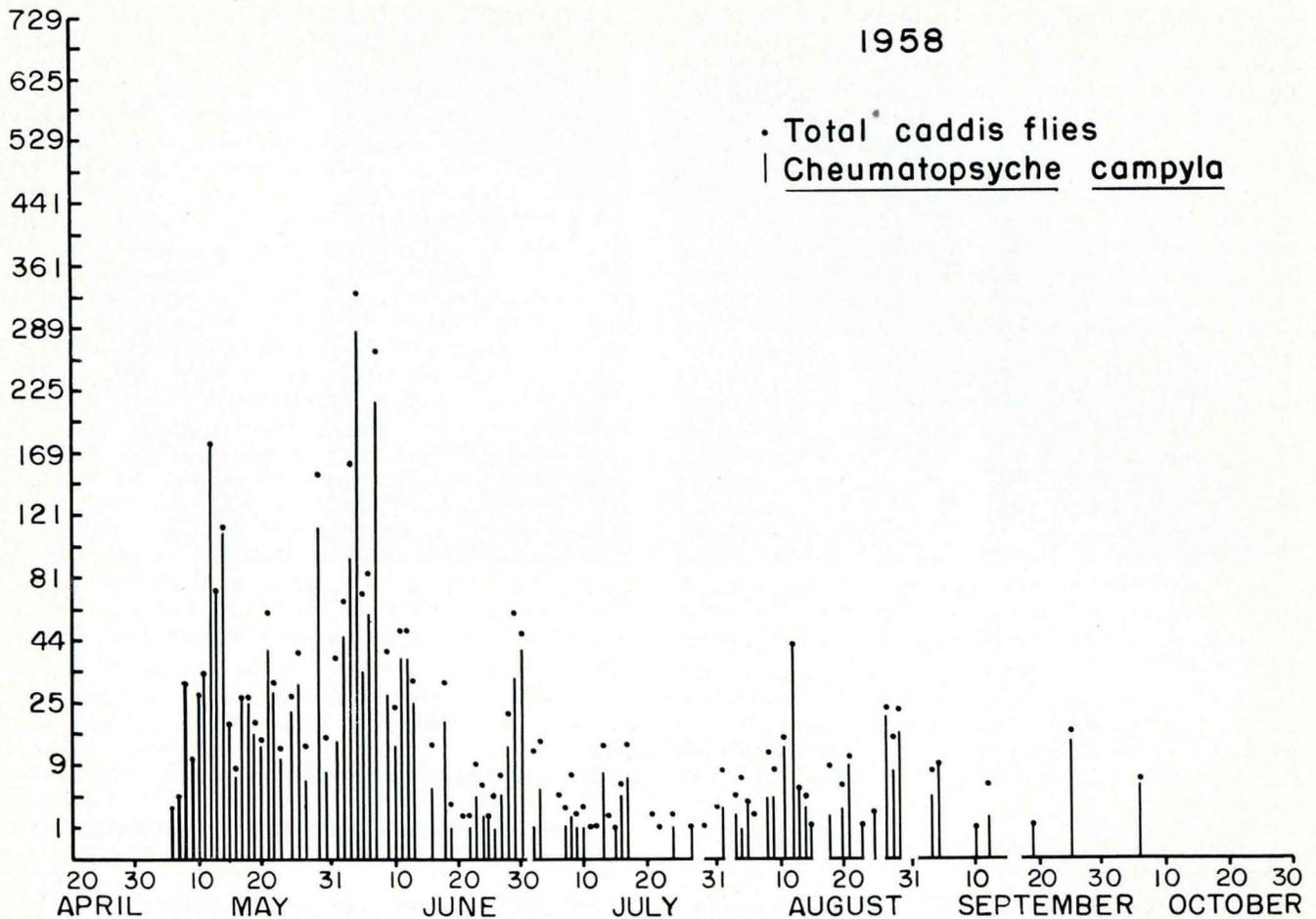


Fig. 5. Number of *Cheumatopsyche campyla* and the total number of caddisflies collected nightly at a lighted cafe window in Keokuk, Iowa, during 1958. A broken baseline indicates nights when collections were not made.

BEHAVIOR OF THE ADULTS

During the day, the adults of all three species remain in shady, sheltered locations. Shrubbery, the undersides of bridges and the leeward walls of buildings are favored resting places. If they become exposed to the sun or if they are disturbed, the insects fly rapidly and erratically to another nearby location. The insects are quite docile, however, and may be easily caught by hand when they are at rest.

H. orris mating activity reaches its maximum intensity at dusk, and a minor peak of activity occurs during the pre-dawn hours. At dusk, the *H. orris* caddisflies swarm above and in the lee of the trees along the Mississippi River bluff at Keokuk, Iowa (fig. 1). From the river, the swarms appear as dense plumes of black smoke which undulate slowly in the breeze. This species also swarms on the lee side of objects such as buildings, towers, dragline booms and light poles which are near the river. The swarms occur in the same locations nightly and persist until after darkness has fallen. While the swarms are familiar phenomena at Keokuk, many river residents 2 miles from the Keokuk dam have never observed them. Swarms were never personally observed more than a mile up or downstream from the dam. The swarms are composed almost entirely of males, and

net captures from the swarms yield only an occasional female (e.g., 179 males and 1 female, 55 males and 0 females, 120 males and 1 female).

The males within the swarms maintain a rapid up and down, ziz-zag flight pattern. The mass behaves as a unit and responds quickly to gusts of wind. A strong gust of wind may blow the tail of the swarm out and away from the head of the swarm, but the dispersed individuals recover quickly, and the swarm contracts to become a dense mass again.

The female *H. orris* caddisflies exhibit a deliberate, straight-line flight pattern, and those females which fly through a swarm or very near to one are attacked by the males. The male seizes the abdomen of the female with his legs and clings to her. He ceases to fly, and his dead weight causes the female fly to flutter slowly to the ground or to the object around which the swarm occurs. The male appears to be partially in copula with the female during her descent from the swarm, and when they land, the wings of the female rest upon those of the male. The male turns around after landing and assumes the characteristic caddisfly mating position with the male and female facing in opposite directions. The male then spreads his wings and lays them over those of the female. If the caddisflies are disturbed, or if they land on the water, the female drags the male behind her as she

runs on the ground or skims along the surface of the water. On clear days, the mating swarms occur only during the very early and very late daylight hours, but on dark overcast days, meager mating swarms were observed during most of the daylight hours. An extreme example of daytime swarming was observed on the afternoon of June 22, 1958, when it was very dark and cool in advance of a heavy rain. At 4:30 p.m. C.S.T. dense swarms formed at many places on Lock and Dam 19, and the caddisflies became so numerous that most of the tourists left. No swarms of caddisflies were observed above the bluff at this time, however. On a clear day, at this time of year, swarming would not usually occur until about 7:30 p.m.

Adult *H. orris* which were retained in a large glass container in the laboratory exhibited a marked light intensity preference. During the day, the caddisflies moved little in their container and remained dispersed randomly about its surface. At dusk, or when the sky became extremely overcast, the caddisflies milled around excitedly but were always most concentrated on the side of the cage toward the windows. When the cage was turned 180 degrees, they quickly shifted their positions and once again congregated on the window side. When a 100-watt incandescent lamp was held 5 feet away from the cage, on the side opposite the window, the caddisflies immediately left the window side and dispersed, but did not become attracted to the incandescent lamp. When the lamp was turned off, they once again returned to the window side of the cage.

On the evening of May 31, 1958, large swarms were seen over the trees along the river bluff in spite of a strong, gusty wind and a driving rain. The swarms were repeatedly forced down to the level of the street by the wind and rain, but they rose again, between gusts, to the level of the tree tops. Mating pairs fluttered down continually during the storm, and when darkness fell the swarming was still in progress, even though the rain and wind were severe.

Mating swarms of *C. campyla* and *P. flava* were not observed. All three species were observed to mate on lighted windows, however, and *H. orris* and *C. campyla* were often observed to mate during the daytime without swarming.

The female caddisfly seems to have scent-attractant glands along the sides of her abdomen. When a female is approached by males, while they are on a surface such as a window or in a laboratory container, the males run excitedly around the female and nuzzle her along the sides of her abdomen before mating. Scent glands exist as eversible structures arising from behind the head in the genus *Hydroptila* (Mosely, 1919, 1924; Eltringham, 1919).

Most female *H. orris* mated more than once under laboratory conditions, and mating pairs which were collected as they descended from a swarm often remained in continuous copulation for 12 hours or more. If the pairs were separated, mating usually took place again, often several times. Two reports indicate that female caddisflies are inseminated very shortly after they emerge from the water (Tillyard, 1926; Denning, 1937).

Adult caddisflies probably eat no solid food after emerging from the water. They drink water, however, and the adult life span may be increased by providing them with sugar solution in addition to water.

Corbet and Tjønnehand (1955) considered it likely that the adult Trichoptera which they studied at Lake Victoria lived only about 2 days. Glasgow (1936) found that none of the female *Hydropsyche colonica* which he collected were void of eggs and suggested, therefore, that the females die soon after they have laid their eggs. Badcock (1953) observed a female *Hydropsyche angustipennis* which lived for a day and a half following oviposition.

Unfortunately, adult *H. orris* known to have been newly emerged were never available for longevity experiments. It was assumed, however, that the copulating males and females which descended from mating swarms were quite recently emerged because their color patterns were still distinct. The copulating pairs were utilized in longevity experiments.

When they were provided with water and sugar solution, female *H. orris* lived as long as 10 days and males as long as 13 days in large containers. Males and females usually began dying on the second day of the experiment, and the death rate continued quite uniformly for both sexes throughout a 10-day period. Caddisflies which received no water generally died within 3 days. Those which were provided with sugar solution in addition to water lived an average of about 2 days longer than those which received water only. It seems probable that the life span of *H. orris* adults is at most 15 days and, most likely, it is considerably less than this in nature.

OVIPOSITION

Although several attempts were made to determine the length of time between mating and oviposition for *H. orris*, the time was not fixed with certainty. Many mating pairs were placed in large containers and provided with cotton swabs saturated with water and with sugar water. Pans of water were placed in the cages in the hope that the caddisflies would lay eggs in them. No eggs were laid by *H. orris* females in these experiments, even though the females copulated repeatedly as late as the fifth day and remained alive for as long as 10 days. Silfvenius (1906), however, found that *H. angustipennis* oviposited during the night following insemination. One female *H. colonica*, which was kept alive by Glasgow (1936) for 6 days, died without laying her eggs. Glasgow suggested that female *H. colonica* live for some time prior to oviposition, as the ovaries are much smaller in a newly emerged specimen than they are later.

H. orris females were found to have small egg products in the proximal ends of their vitellaria at all times. When female *H. orris*, which were found dying in longevity experiments, were dissected, their eggs tumbled loosely from the ovarioles. Ovipositing females which were collected in an underwater light trap also contained loosely held eggs. Females which were collected as they descended from mating swarms, on the other hand, contained eggs which were difficult to remove from the ovaries, even though the eggs

were fully as large as those of the females in the preceding two instances. Apparently a short time, probably a day or two, elapses between mating and oviposition in nature, and during this time the eggs complete their development. Four female *H. orris*, which died in captivity after they had mated, contained 465, 371, 331 and 423 mature eggs, respectively.

Several species of Trichoptera are known to oviposit under water, and Denning (1937) and Badcock (1953) have reported female caddisflies to remain submerged for prolonged periods of time.

Observations were made of oviposition of *C. campyla* females in the laboratory. About 100 *C. campyla* adults collected from around an incandescent light on the night of Aug. 16, 1958, were placed in an aquarium. A continuous current was maintained in the aquarium by means of a propeller driven by a ¼-horsepower electric motor. A vertical concrete slab extended down the center of the aquarium (fig. 6). Two minutes after the caddisflies had been placed in the aquarium, one female walked down the side of the glass, laid one large and one small mass of eggs on the glass and then floated to the surface. The total time from entering the water to leaving it was 1 minute and 45 seconds. The individual was lost among the others in the aquarium, and it could not be ascertained how much longer it lived. On the following morning, however, all of the specimens, both males and females, were dead, and egg masses were found on all surfaces of a floating, waterlogged board. In four oviposition experiments which involved several hundred female *C. campyla*, none lived longer than 24 hours after they had laid their eggs.

C. campyla females often remained submerged for prolonged periods. In one instance, a group of females was placed in the lotic aquarium late in the evening, and on the following morning at 8:30, one female was seen resting on the concrete partition just under the surface of the water. Its position and movements were marked with wax pencil on the glass. Except for its silvery appearance, the insect appeared as if it were at rest on a terrestrial cement wall, and its antennae moved gently with the current much as they would move in the wind. By 9:45 a.m., the caddisfly had moved 5 inches lower and was still facing downward. It angled 3 inches upward, faced the surface and was motionless at 11:20 a.m. When the caddisfly was to be checked again at 11:30 a.m. it was gone and could not be found because it had mingled with others on the surface of the water. The female laid no eggs, even though it had remained submerged for about 3 hours.

About 100 *P. flava* females were collected from around a light, anesthetized, isolated from the other captured insects and then placed in a covered aquarium which was half full of aerated, but not circulating, water. By 10 a.m. the following morning some of the insects had laid egg masses on a floating, waterlogged board. About half the flies were dead and had sunk to the bottom of the aquarium. The remainder of the caddisflies floated motionless on the surface. When the floating board was jarred, however, two of the floating caddisflies grasped the board, walked to its lower surface and remained there for about an hour without

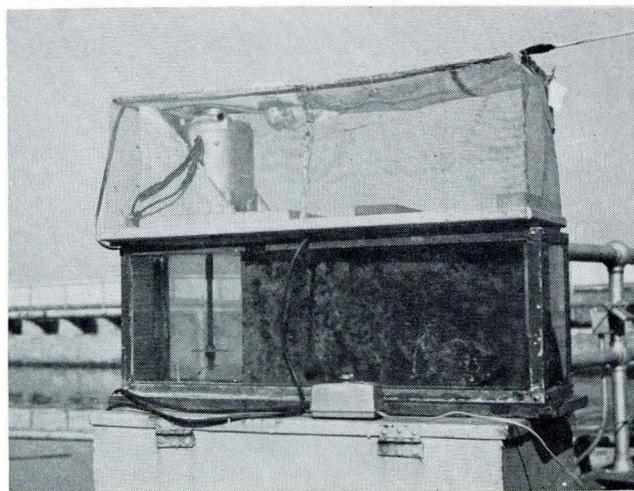


Fig. 6. Lotic aquarium used to rear and observe hydropsychid larvae.

laying eggs. All of the insects were dead by evening, many of them having laid eggs on the board. In several instances, female *P. flava* have been seen to walk beneath the surface of the water and to rest motionless on some submerged object, only to be found dead an hour later. Upon examination they were found to be full of mature-size eggs.

An underwater light trap was developed to collect ovipositing female caddisflies from the river. This trap (fig. 7) consisted of a 6-volt sealed-beam headlight fastened to an inverted gallon glass jar so that



Fig. 7. Light trap used to capture caddisflies which oviposit underwater.

TABLE 1. CATCHES MADE OF FEMALE CADDISFLIES IN AN UNDERWATER LIGHT TRAP AT KEOKUK, IOWA

Date	Time	Operation time in minutes	Depth ft.	<i>H. orris</i>	<i>C. campyla</i>	<i>P. flava</i>	Unidentified
Aug. 18, 1957	7:35 p.m.	10	3	3	41	28	5
Aug. 19, 1957	7:40 p.m.	5	3	9	2	5	1
June 27, 1958	8:00 p.m.	30	2	5	32	0	2
Aug. 4, 1958	7:35 p.m.	10	6	1	1	1	0
Aug. 16, 1958	7:35 p.m.	7	3	0	220	1	0
Aug. 16, 1958	7:45 p.m.	7	12	1	8	10	0
Aug. 16, 1958	7:55 p.m.	7	20	0	0	2	0
Aug. 18, 1958	7:35 p.m.	7	3	0	29	0	3
Aug. 18, 1958	7:45 p.m.	7	12	1	3	4	4
Aug. 18, 1958	7:55 p.m.	7	20	0	0	1	0

the light shone through the bottom of the jar and out its mouth. The trap, which was weighted with a sash weight, was lowered into the water by its electric cord. Caddisflies which were attracted to the light source entered the jar, came to rest in the trapped air space and were raised to the surface. The light was not turned on until it had attained the depth at which sampling was desired.

Before the apparatus was taken from the water, an insect net was pulled snugly across the opening of the jar to determine whether any of the captured flies had emerged from pupae while in the trap. If they had done so, their floating pupal skins would have been caught by the net. No flies were found to have emerged from pupae in the trap, and no males of any species were collected. The captured females either contained eggs which were full size and loose in the ovarioles or they were void of macroscopic primordia. Caddisflies were collected as deep as 20 feet, where they were presumed to be laying eggs. *C. campyla* females were consistently taken in greater numbers than either *P. flava* or *H. orris* when the submerged light trap was used at moderate depths (table 1).

Twelve *H. orris* females which were collected by means of the underwater light trap were introduced into the screen cage of the lotic aquarium. One-half hour later, two of the females were found dying on the water surface. When dissected, they were found to be void of macroscopic eggs. The other females could not be found on the following morning and were presumed to have died and been destroyed by the propeller. It seems probable that *H. orris* females, like *C. campyla* females, die soon after they have laid their eggs.

On July 30 an experiment was initiated in an effort to determine (1) whether the caddisflies must walk down some partly exposed object into the water or whether they are capable of finding small, completely submerged objects upon which to lay their eggs and (2) the depths at which the caddisflies lay their eggs. A tandem float arrangement was set out in 24 feet of still water, 100 feet upstream from the dry dock, at the Keokuk dam. One float remained at the surface and was anchored to the river bottom. Another float was similarly anchored but was adjusted so that it floated 4 feet beneath the surface of the water. The two anchors were connected to each other by a 15-foot nylon line. Both floats were made of 12-inch pieces of 6-inch x 6-inch wooden plank, and the apparatus was set in such a manner that the two anchors and their buoys were 15 feet apart. The anchors and their interconnecting cord sank a short distance into the silt of the river bottom, and it was assumed that female caddisflies, therefore, could not walk from the

visible float to the submerged float via the interconnecting line. If caddisflies were to oviposit on the submerged float, they would be forced to find it while swimming underwater or by walking on the bottom of the river and ascending the anchor cord.

When the floats were examined 6 days later, more caddisfly egg masses were found per area on the submerged float than on the surface float. The experiment was repeated four more times, with the lower float being as deep as 24 feet beneath the surface. In all instances numerous egg masses were found on the lower float. No attempt was made to determine to which species the egg masses belonged.

On Aug. 23, 1958, a simple experiment was initiated to determine at which depth caddisfly eggs were most often laid. A wooden dowel, 2 inches in diameter and 12 feet long, was weighted to float vertically with about 1 foot protruding out of the water. The dowel was removed from the water after 6 days, and the number of egg masses was tallied for each succeeding foot of depth. Oviposition was most concentrated at a depth of about 3 to 5 feet (table 2).

During the twilight hours, when the caddisflies were swarming, the surface of the water above the dam was a mass of ripples, giving the appearance of a light rain. On occasion, some of the marks were made by rising methane gas bubbles, but close inspection revealed that most of the tiny swirls on the surface were caused by caddisflies emerging from beneath the surface of the water. In addition to the small single swirls which were caused by caddisflies entering or leaving the water, there were swirls caused by caddisflies which repeatedly skipped over the water. These skipping caddisflies were observed to touch the surface as many as 37 times in succession. After the last skip, the caddisflies often were observed to climb straight upward and slightly toward the Keokuk shore until they were lost from view.

In an effort to determine the significance of the skipping, an insect net was used to catch only the caddisflies which had been observed to skip repeatedly. The captured caddisflies, on the evening of June 27, 1958, included six females of *H. orris*, one male of *H. orris* and one female of *C. campyla*. Five of the *H. orris* females contained well-developed eggs. The remaining female *H. orris* was void of eggs, except for a small number of minute ones. The female *C. campyla* contained well-developed eggs only. Although it is probably associated with oviposition, the

TABLE 2. RELATIONSHIP BETWEEN WATER DEPTH AND CADDISFLY OVIPOSITION ON A 12-FOOT, WEIGHTED, WOODEN DOWEL, AUG. 23-29, 1958.

Depth interval (feet)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11
Egg masses	0	18	33	68	56	30	28	21	18	14	24

TABLE 3. WEEKLY TOTAL OF CADDISFLIES CAPTURED IN EMERGENCE TRAPS ABOVE THE KEOKUK DAM, AUG. 12, 1957, TO SEPT. 9, 1957.

First day of week	<i>H. orris</i>		<i>P. flava</i>		<i>C. campyla</i>		Unidentified caddisflies	Total trap nights
	Male	Female	Male	Female	Male	Female		
Aug. 12.....	1	32	1	55	2	25	70	42
Aug. 19.....	2	34	0	76	6	37	177	37
Aug. 26.....	1	28	0	39	1	36	66	24
Sept. 2.....	0	36	0	39	0	41	14	33
Totals.....	4	130	1	209	9	139	327	136

significance of the skipping activity remains obscure, since these species are known to oviposit under water.

On July 11, 1957, two tent-type emergence traps were set out at each of three stations above the dam at Keokuk. These traps were operated on most nights until Sept. 4, 1957. The results of this experiment show that the preponderance of the caddisflies which leave the water are females (table 3). Most of the females which were captured had obviously not emerged from pupae in the traps. If they had done so, the sex ratio would be closer to one. The captured females contained mature eggs or were void of eggs, and they were assumed to be returning to the surface after they had descended into the water to lay their eggs. Great care must be taken, consequently, in using emergence trap catches as a measure of caddisfly populations. A count of males alone would probably give a truer account than a tally of both males and females. No evidence was found to indicate that the male caddisfly enters the water again after its initial emergence.

Consistently more male *C. campyla* than females have been collected at the lighted store windows in downtown Keokuk. Light traps which were operated on the Keokuk dam, however, collected 15,690 female and only 48 male *C. campyla* from July 21 to Aug. 8, 1958. The preponderance of females at the dam probably is due to two factors: (1) Since the females must return to the river to lay their eggs, they may be expected to be more abundant there than the males which remain ashore. (2) Gravid females probably fly upstream to lay their eggs just above the tailwaters and thus congregate around the dam.

Upstream flights of gravid female caddisflies have been reported previously. Harris (1952) cited female *Hydropsyche* as flying upstream to fast water to lay their eggs. The problem caddisflies at Fort Erie, Ontario, swarm above the trees in the evening and later move upstream en masse toward the outlet of Lake Erie (Peterson, 1952). Roos (1957), in his experiments on the River Ammeran in Sweden, found that females of *Cheumatopsyche lepida* were collected in greater numbers flying upstream than down. Roos stated further that there was a marked decrease in the number of up-stream-flying females as soon as the uppermost rapid of a river section was passed and unruffled water was reached.

LARVAE

HATCHING AND EARLY DISTRIBUTION

On the night of Aug. 8, 1958, 20 female *P. flava* were collected at a light, anesthetized, sorted and placed in a polyethylene bag which had a wet paper

towel secured in its neck. Six egg masses were found on the polyethylene bag the following morning. The egg masses, on polyethylene patches which were cut from the bag, were floated eggside down in a Petri dish of water. The eggs exhibited pronounced eye spots on Aug. 17, and larvae were visible in the eggs on Aug. 19. The larvae in the eggs were very active on Aug. 22 and began hatching on Aug. 24. Hatching continued until Aug. 30. Eggs which were laid loosely on the periphery of the egg mass hatched first; those in the center of the mass hatched last or died. In the warm water of the Petri dish, the difference in hatching time may have been due to a smaller amount of oxygen being available to the eggs which were most crowded.

A female *H. orris* which had mated on June 22, 1958, was seen to be dying on June 26, and her eggs were dissected into a Petri dish of river water. Eye spots were evident in the eggs after the fifth day. Larvae began to hatch in 8 days and continued to do so until the eleventh day. It is unlikely that the eggs were fertilized intraovarially since in most insects the sperm is stored in the spermatheca until just prior to oviposition. Probably the eggs developed parthenogenetically, though it is possible that they were accidentally fertilized during dissection. This was the only batch of *H. orris* eggs to be hatched successfully, although several other attempts were made. Glasgow (1936) reported that the eggs of *H. colonica* take at least 16 days to hatch.

The newly hatched *H. orris* larvae were virtually colorless but were easily recognizable as caddisfly larvae. In addition to crawling over the substrate, the first instar larvae wriggled much like mosquito larvae. Such capable swimmers obviously could be carried some distance by water currents during their first stadium.

Most first instar Trichoptera larvae are capable of swimming, and first instar hydropsychid larvae have been observed to do so in a laboratory aquarium (Siltala, 1907; Glasgow, 1936). Weerekoon (1956) has reported that the first instar larvae of *Phryganea* sp. are planktonic and that larval Trichoptera probably repopulate McDougall Bank in Loch Lomond as plankters.

The tandem float apparatus which was used in oviposition experiments also yielded information concerning the wanderings of caddisfly larvae. The float apparatus was set out and recovered four times, and hydropsychid or psychomyiid larvae were found on the submerged float each time. The larvae included 2 large *H. orris* larvae (10 mm. long), 14 Psychomyiidae sp. larvae (7-10 mm. long) and 1 *P. flava* larva (8 mm. long). A single first or second instar larva was collected from the buoys, but it could not be identified except as a member of the family Hydro-

psychidae. It is probable that more larvae of this size existed on the buoys but were not found because of their extremely small size. Numerous Cladocera, Hydra, chironomid larvae and Amphipoda also were found on the buoys.

The large hydropsychid and psychomyiid larvae could have reached the floats (1) by actively swimming, (2) by crawling over the bottom and up the anchor lines or (3) by drifting with the current, either alone or as riders on water-carried debris. The larvae, except for the first instar, were not seen to swim in the laboratory, and it seems unlikely that they would be able to do so in the river. The floats were anchored in a fine silt bottom, and it is improbable that the larvae crawled over the bottom to the anchor lines. It seems very possible that current-carried trash could have transported the larvae to the floats. At no time, however, was debris found lodged on the floats or the float lines. Glasgow (1936) found that if the larva of *H. colonica* is dislodged from its shelter it attaches its silk thread to some object as it is swept past. In this way the larva anchors itself until it has regained a foothold. *H. orris* and *P. flava* larvae, when placed in the lotic aquarium, have been observed to spin threads and to use them as anchor lines. The threads were spun, however, after the larva had become attached to an object, and larvae were not seen to spin a thread while they were being swept along by the current. The larvae were quick to grasp an object with their legs as they were swept past, and they clung tenaciously with the claws on their anal prolegs. If a larva spins a strand of silk and then is dislodged by the current, it seems to have considerable difficulty in returning to its foothold unless it is swept back by the current. Dying larvae often have been observed to swing in the current on the end of their silken line until they died and decomposed.

It is possible that caddisfly larvae drift downstream using silken threads to catch the water currents such as small spiders "balloon" for long distances via air currents. No evidence of this was observed in the laboratory.

CASE AND NET CONSTRUCTION

Descriptions of *Hydropsyche* cases and nets have been prepared by Clarke (1884), Fielde (1887), Wesenberg-Lund (1911 and 1913), Noyes (1914), Alm (1925), Krawany (1930), Philipson (1953a) and Sattler (1955 and 1958). Wesenberg-Lund (1911) compiled all the records of larval net construction and, in addition, presented complete descriptions of the nets of *H. pellucida* and *H. angustipennis*. Additional descriptions and drawings of the houses and nets of *Hydropsyche* sp. were provided by Wesenberg-Lund in 1913. In 1925 Alm described the larval tube-house and catching net of *H. angustipennis* in detail. His descriptions suit the larval tube and net of *H. orris* remarkably well, and his discussion of net construction is detailed. The following excerpts are from some of the most pertinent portions of his paper:

"The actual catch net is very sturdy, spun from thick threads

which cross one another regularly in quadrangular fashion. These threads, which are about 0.016 mm. in diameter, are, as Lucas and Wesenberg-Lund have already proved, double threads. . . .

"When the thread is fastened to the substrate or other threads, it seems to be flattened, often, in finer threads, completely dissolved. Almost always the double thread is dissolved in both its branches, and furthermore, it seems to flow out in a sticky secretion. I emphasized this especially, for no special secretion is apparently discharged, but one gathers the impression that the thread immediately upon discharge is sticky, still flexible and pliable and that afterwards, when it is drawn out, it stiffens in the water.

"The larva, when spinning, seems first to press the labium against the substrate. When it then turns back, the fastened thread runs out of the labium. It is then fastened to a new point, by strongly pressing the labium. It is therefore, very clear that the thread, flexible and sticky at the discharge, is simply glued to the substrate. The thread is also very elastic, which one may easily observe when the larva is pulling it along.

"The same applies also for the threads in the net areas. These are also apparently simply glued to one another. I can, therefore, not agree with Wesenberg-Lund when he says that wherever threads cross each other, the corners are strengthened by a special secretion. . . . In all *Hydropsyche* larvae examined by me the spinning glands on both sides of their whole length were always filled which justifies the assumption that they have no rest period, but are in constant secretion."

More recently, Sattler (1958) has presented a detailed discussion of the structure of the hydropsychid spinning organs and the double thread which they produce. His observations of the mechanics of *Hydropsyche* net construction (1955 and 1958) are especially comprehensive. Details of *H. orris* net construction are illustrated in fig. 8.

Larval *H. orris* occur in greatest abundance in areas of the river where the current is fast and where there are solid, silt-free objects upon which they can build their cases and nets. *H. orris* larvae never were observed to inhabit wooden structures as *C. campyla* and *P. flava* often do.

A larval *H. orris* builds a silken case which it attaches to a firm, rough surface such as rock, cement or rusted iron (fig. 8). The larval case is usually a semi-tube which rests upon, and is firmly attached to, a substrate by the silken strands which make up the case. If small sand particles, shell fragments or other materials are available, they are incorporated as a reinforcing veneer on the case. Even bryozoan statoblasts often have been observed to be used as a building material. In the laboratory, larvae constructed perfect cases and nets with no sand at all. In this situation the larvae chose crevices and concavities in which to build their abodes. They circumvented the need for riprap reinforcement by extending a series of silken reinforcing strands to the edges of the concavity in which they lived.

In the Mississippi River, which carries a large volume of soil particles, the larval cases of *H. orris* are always sand- or silt-encrusted. Thus reinforced, the cases may even be constructed on convex surfaces.

The screenlike net of *H. orris* (fig. 8) is a modified portion of the wall of the larval dwelling. In small tubes, the net is usually windowlike and extends from the mouth of the tube backward for about one-third of the tube length. In larger tubes, however, the net window seems to have increased at a disproportionately rapid rate, becoming so exaggerated in size that

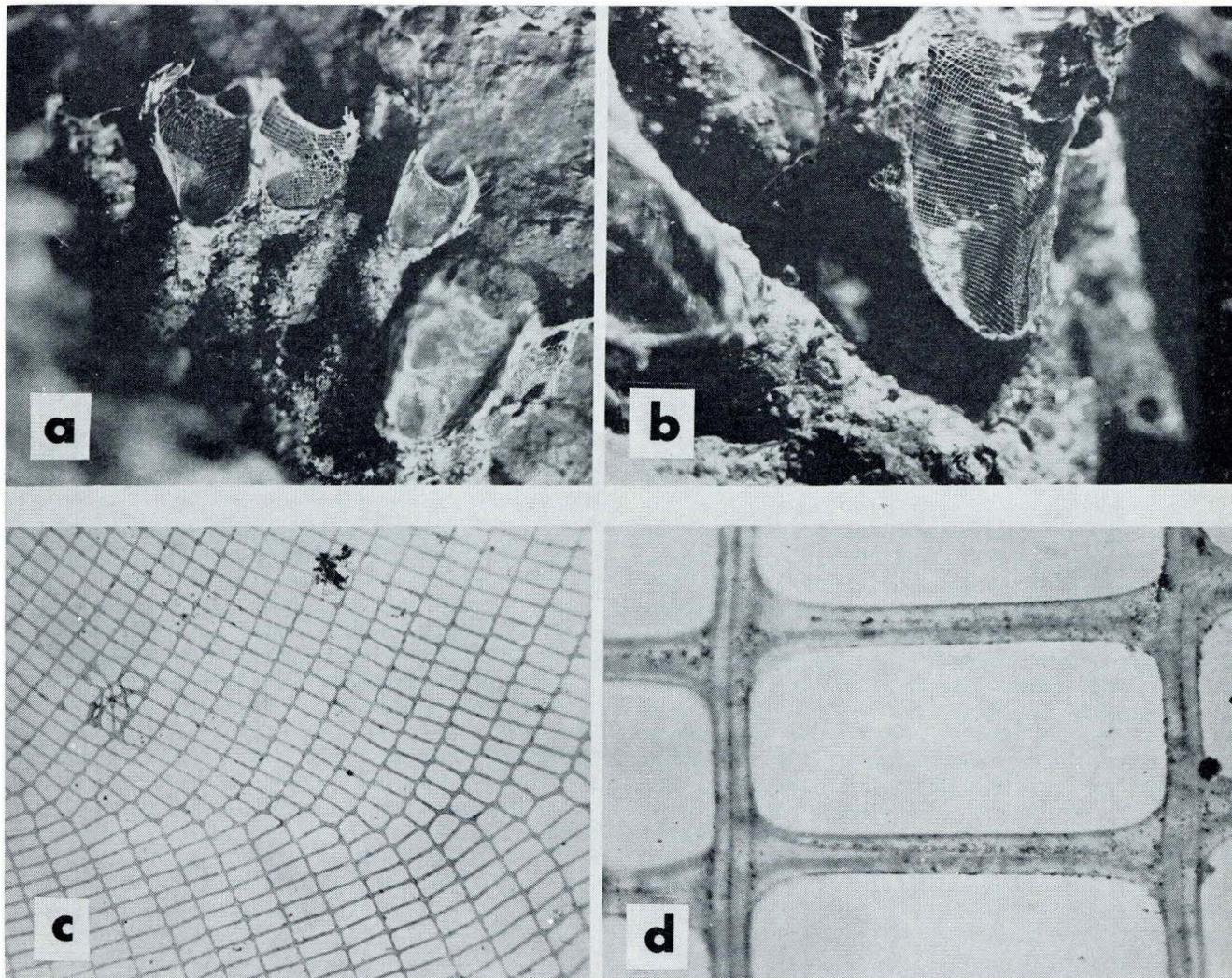


Fig. 8. *Hydropsyche orris* larval constructions. (a) Larval tube and catching net. (b) Catching net. (c) Close-up of catching net. Note where it has been patched. (d) Microphotograph of catching net. Note double nature of the strands and the flattening of the strands at their points of intersection.

it no longer resembles a window. Instead, it extends forward and upward and appears to be stretched between two armlike supports. The supports are, in reality, modified segments of the rim of the tube mouth and are usually constructed of vegetable matter. Water enters the mouth of the larval tube, which may be extremely large, and passes out through the huge screen window. The larva clings to the roof of its case (usually, then, with its back to the substrate) and gleans food from the screen as it is filtered from the water.

In the lotic aquarium, the larvae had no vegetable matter with which to construct the supporting framework of their nets. They adjusted to the situation by constructing their nets between the sides of the crevices in which they resided. From the foregoing discussion it is obvious that the larvae are very versatile and that no single description can fit all of the *H. orris* cases and nets.

C. campyla larvae construct loose, funnel-shaped nets with no rigid supports as part of the net. Consequently, a larva often constructs its net in a concavity

in which the net can be supported. When one rock lies loosely atop another, the space between them usually is utilized as a net-building site. In the lotic aquarium, the larvae usually selected the angles along the floor of the aquarium, but they also constructed nets between the concrete slab and the glass where the two were about $\frac{3}{4}$ inch apart. The net is comparatively flimsy and is adapted to slower water velocities. It becomes green as algae accumulate in its meshes, and the larva resides in a crescent-shaped, tubular extension of the silken funnel trap. The tube, in all observed instances, was actually only half a tube, since the substrate formed the tube floor. Although pulverized fingernail clam shells and other small objects are sometimes incorporated into the larval tube, the net and tube are supported principally by the current, and they fall into a shapeless, slippery, green mass when the current stops or when they are lifted from the water. *C. campyla* nets are very efficient filters, and when the water in the lotic aquarium was made extremely turbid, it was filtered clear in about 2 hours.

Larvae of *P. flava* often construct loose, flowing nets similar to those of *C. campyla*, and the two species may be found together on rocks. The greatest concentrations of *P. flava* larvae, however, are found in sandy, silt-free areas of the river where the current is strong. The larvae apparently prefer to construct their nets and dwellings on a firm, rough object—such as a stone which lies partially buried in a sand bottom. *P. flava* larvae often are abundant on the large, concrete blocks which serve as anchors for navigation buoys. They are most abundant along the line where the surface of the block intersects a sand bottom. They incorporate a large amount of fine sand into their constructions, and although the tubes, nets and cocoons are sand-encrusted, the structures remain pliable and will partially collapse when their substrate is lifted from the water.

The *P. flava* larval habitat has not been sampled well, since the water was usually too deep and fast and the bottom too rocky for swimming or dredging. The larval habitat has been indirectly sampled by Hoopes (1959), however. In examining the stomach contents of the shovelnose sturgeon, *Scaphirhynchus platyrhynchus*, he found that *P. flava* larvae form 68 percent of the volume of the food of this sturgeon and that their stomachs, when filled with *P. flava* larvae, always contained a considerable amount of sand, but no silt. These observations substantiate the supposition that *P. flava* larvae occur most frequently in sandy areas.

Wesenberg-Lund (1911), Ussing (1909), Noyes (1914) and Alm (1925) reported that *Hydropsyche* larvae constructed no catching nets during periods when the water temperature was near freezing. Wesenberg-Lund, Ussing and Alm believed that the larvae were virtually dormant during the coldest winter months. Noyes, on the other hand, believed them to be quite active and found an abundance of food material in their digestive tracts in February.

When commercial fishermen in Pool 19 set their nets during late spring, summer or early fall, the nets become covered with hydropsychid larvae in about a week. If the fishermen's nets are set in early fall and not lifted until winter, the nets are still covered with caddisfly larvae. If nets are set during the winter, however, they remain free of larvae and larval constructions all winter long. The activity of hydropsychid larvae must, therefore, be lessened considerably during the winter, and their ability to populate newly submerged objects during the winter is very obviously curtailed.

H. orris larvae were collected from a navigation buoy on March 5, 1959, when the river still contained ice floes. Some of the *H. orris* larval nets were erect

and intact, but others apparently had been torn away and not reconstructed. All the nets were covered with fine, flocculant organic matter. During the summer months, however, the nets are kept clean of residue at all times. Nets which were undamaged and clean, and which were obviously being used, were observed on April 12, 1959. The nets were smaller than those of midsummer, even though they were constructed by last instar larvae.

ECOLOGICAL DISTRIBUTION OF LARVAE

The hydropsychid and psychomyiid larvae in the Keokuk area are, for the most part, sedentary animals, depending upon water currents to bring their food to them. Of prime importance to these larvae are (1) a silt-free solid substrate upon which to construct their catching nets and dwellings and (2) a constant current of water which will carry food into their catching nets.

The underwater structures of Lock and Dam 19 at Keokuk and the submerged rubble area below the dam provide a very large area which is suitable for habitation by the larvae (fig. 1). Water velocity limits the distribution of the various species, and to understand more completely the relationship between water velocity and species composition, a series of larval collections was made in the tailwaters of the Keokuk dam.

On Aug. 7, 1958, collections were made from rocks at eight stations, and the water velocity was measured at each location with a Gurley current meter. Although the sampling units were not identical, they provided an approximation of the relative numbers of each species in fast and slow water.

It is evident from table 4 that *H. orris* is less abundant in the areas of slower water velocity. The slower current areas (which constitute most of the tailwaters) are inhabited predominantly by *C. campyla* and in some areas by *P. flava* and species of Psychomyiidae.

The deep tailrace below the hydroelectric plant, where the bulk of the water from the turbines is conducted, was not sampled. The depth and velocity of the water in the tailrace prohibited dredging or diving for samples. It seems logical to assume, however, that a very high *H. orris* population exists in the tailrace area.

The flat limestone slabs which compose most of the rubble in the tailwaters are piled loosely, and their total surface area is much greater than that of the river bottom. If water is able to circulate beneath a rock, larvae are usually found on the underside of the rock as well as on its upper surface. A single rock

TABLE 4. COMPOSITION OF THE LARVAL CADDISFLY POPULATION AT VARIOUS WATER VELOCITIES AND DEPTHS ON AUG. 7, 1958. THE NUMBER OF EACH SPECIES IS EXPRESSED AS A PERCENTAGE OF THE TOTAL SPECIMENS IN THE SAMPLE.

Water velocity, ft./sec	Station	Water depth, ft.	<i>H. orris</i>	<i>C. campyla</i>	<i>P. flava</i>	Psychomyiidae	Total larvae
0.4.....	1	1	3	90	0	7	31
0.8.....	4	5	3	60	30	7	98
1.1.....	7	3	0	93	4	3	28
1.2.....	5	5	29	70	1	0	91
1.3.....	3	2	6	86	2	6	94
1.9.....	8	7	74	19	7	0	94
2.6.....	6	4	31	67	1	1	114
3.0.....	2	3	97	2	1	0	95

in fast water often supports a line of *H. orris* nets on its leading edge and scattered *H. orris* nets atop prominences and in niches which are exposed to the force of the current. Larvae of *C. campyla*, *P. flava* and Psychomyiidae were found in the interspaces between the *H. orris* nets and on the surfaces where the current was lessened. *P. flava* larvae preferred the line at which rocks met a sandy bottom. Psychomyiid larvae which were collected in the tailwaters were represented principally by *Cyrnellus marginalis* (Banks), and, when examined grossly, their nets were virtually indistinguishable from those of *C. campyla*. The cocoons of the psychomyiid larvae are not as rigid as those of *C. campyla*, however, and while *C. campyla* utilized a considerable amount of sand in its cocoon, the psychomyiid larvae incorporated vegetable matter and large pieces of fingernail clam shells.

An inverse relationship exists between the catching-net size and the water velocity in which the larva lives. If it is assumed that the larvae consume approximately the same volume of similar food, the larvae must filter somewhat equal volumes of water. The larvae of *H. orris* inhabit faster water than the other species and consequently require less net area to filter the same amount of water. The loose, voluminous nets of *P. flava*, *C. campyla* and the psychomyiid species are adapted for slower water, and the area of their nets must be greater since the water moves through the nets at a slower rate. Also, the force exerted by the faster currents effectively curtails the construction of voluminous nets, thus the net of *H. orris* is of necessity a compact, rigid structure.

Indeed, *H. orris* never constructed a catching net in the laboratory unless the water in the aquarium was rapidly circulated. Philipson (1954) found that *Hydropsyche instabilis* would spin only a crude shelter in still water but made shelters and nets readily when the water in the aquarium was stirred to 30 cm. per sec.

Large concentrations of *H. orris* larvae were found on buoys which mark the navigable channel of the Mississippi River (figs. 9 and 10). The buoys and their anchor chains are made of iron which is usually pitted and rusty and provides excellent sites for attachment by the larvae. The buoys rise and fall with fluctuations in water level, and they always receive a rapid flow of water because they lie in the main channel of the river. A relatively stable environment is thus afforded the larvae which attach themselves to the buoys during the summer months. Those larvae which overwinter on the buoys often are scoured off by floating ice during the spring breakup, however.

During the summers of 1957 and 1958, over 100 navigation buoys and their anchor chains were examined in the area from Louisiana, Mo., to Burlington, Iowa. *H. orris* was found to be the principal trichopteran larva on both buoys and chains throughout the entire river segment. Furthermore, an analysis of the larval populations on the anchor chains indicated that, on any given date, all the chains were about equally populated with *H. orris* larvae. It would follow then that this entire main channel segment of the Mississippi River is potentially good *H. orris* habitat and that the principal limiting factor for large populations is a lack of silt-free objects for them to attach upon.

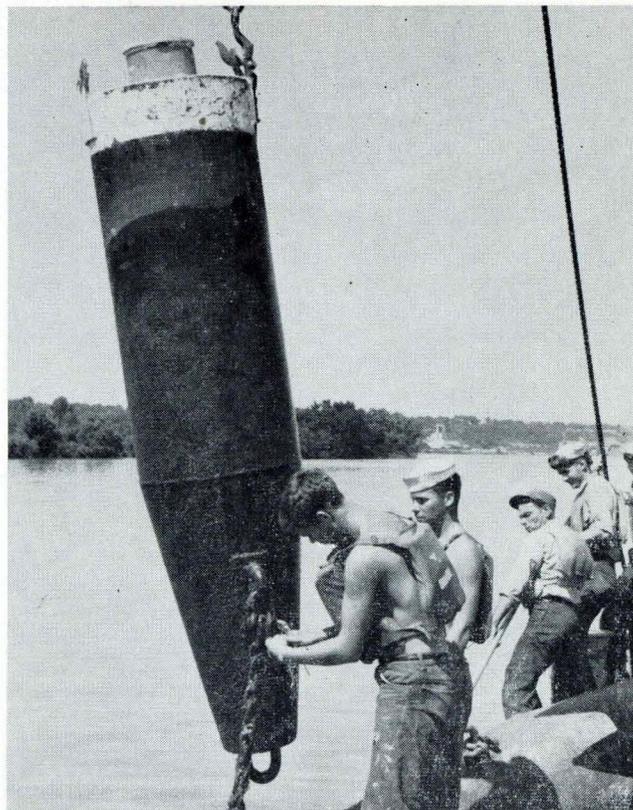


Fig. 9. Navigation buoy and its anchor chain being raised from the river.



Fig. 10. Larval *Hydropsyche orris* mat on a navigation buoy.

The larvae extended down the buoy chains to the mudline (about 20 to 25 feet in most instances). The larval cases and the pupal cocoons at the bottom of the chains usually were composed of larger sand grains than those at the tops of the chains, probably because larger, heavier sand grains remain near the

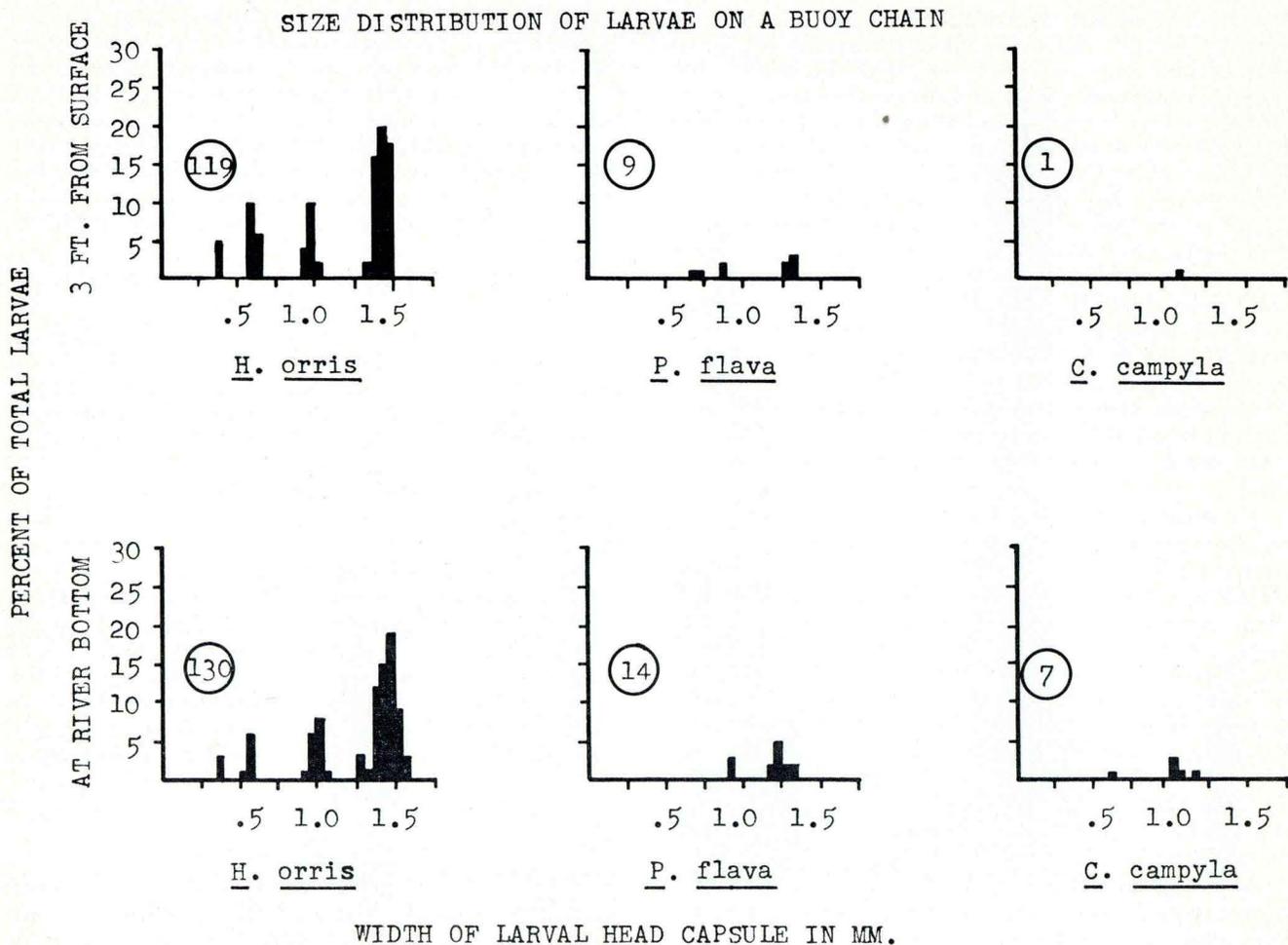


Fig. 11. Size distributions of three species of hydropsychid caddisfly larvae near the top and bottom of a 24-foot buoy chain, New Boston, Ill., Oct. 30, 1958.

bottom of the river. Pupae, in their cocoons, were found at all depths, and the heaviest concentrations of larvae were always found on the upstream sides of the buoys.

Two samples were taken from a buoy chain on Oct. 30, 1958, to determine whether the size distribution and species composition of larvae were the same at the bottom (24 feet) as at the top of the chain. It is evident from these data (fig. 11) that the size distribution of the *H. orris* larvae on the chain was very similar at top and bottom. Proportionately more *P. flava* and *C. campyla* larvae were found at 24 feet than near the surface, but too few of either species were collected to allow any generalizations to be made. It seems plausible, however, that *P. flava* and *C. campyla* could be most abundant near the bottom since the current is probably moderated there.

Several excellent opportunities were afforded to observe larval populations intact on submerged structures at Lock and Dam 19. These instances will be reported in detail because they clearly illustrate the effect of water velocity upon larval distribution.

On Aug. 11, 1957, the Union Electric Power Company shut down one of its turbines at the Keokuk hydroelectric plant for repair. A scroll chamber

which normally conducts water to a turbine was dammed off and partially drained. The humidity was so high in the chamber that the larvae remained in their shelters on the exposed walls instead of descending to the water on individual silken threads as they usually do. About 100 *H. orris* larvae were found on each square foot of the walls and roof of the chamber. Additional larvae were found on every structure in the tunnel except for the polished steel blades of the turbine. No other species of larvae was found. Each scroll chamber remains virtually in total darkness at all times when its turbine is functioning, and the velocity of the water along the midline of the chamber is 5 feet per second.

Large iron grills guard the entrances to the scroll chambers, and when they were raised for repair it was found that they accommodated very large *H. orris* larval populations. The larval cases and nets virtually blanketed the grills at times, and the larvae extended downward in undiminished numbers to the bottom of the water inlet, which is 40 feet below the surface of the river. *C. campyla* also were found on the grill but only in a ratio of three *C. campyla* to 100 *H. orris*.

The water which is impounded directly behind the

Illinois half of the dam at Keokuk has virtually no current because the main channel courses the Iowa side of the river, where it is directed through the power installation. A steel gate on the dam was examined when it was raised from the water on June 24, 1958. Sponges covered much of the face of the gate, and a few lentic caddisfly larvae (Leptoceridae) were found. No net-spinning caddisfly larvae were found on the face of the gate where water movement was negligible. Along the edges of the gate, on the other hand, water leaks had developed, and they were well defined by the presence of many net-spinning caddisfly larvae. The ratio of *C. campyla* to *H. orris* was 58 to 2 in the leakage areas, and psychomyiid larvae were represented by four *Cyrnellus marginalis*. This species composition indicated that the leaks had created small niches in which the current was sufficient for *C. campyla* but less than optimum for *H. orris*.

An excellent opportunity to observe the effect of water velocity upon caddisfly larval distribution presented itself on Aug. 27, 1958. A vertical concrete pit which is about 6 feet wide, 12 feet long and 20 feet deep extends downward from the surface level of Lock 19 into the main water-conducting tunnels. Large metal trap doors normally seal off the bottom of the chamber and keep the chamber full of stagnant water. If the trap doors do not close completely, however, an 8-inch pipe automatically conducts water into the chamber and keeps it full at all times. Such was the case during the summer of 1958. To repair the steel floor plates, the pit was completely drained by shutting off the 8-inch pipe.

When the exposed walls of the pit were examined, it was immediately evident that the faulty floor plates had allowed considerable water circulation to take place. The walls of the chamber bore a large population of the net-spinning psychomyiid, *Cyrinellus marginalis*. Pupae of this species were particularly abundant, and a cumulative count of both larvae and pupae was made. The concentration of both was estimated to be about 100 per square foot of surface.

The 8-inch pipe, which functions when floor plates are ajar, jets a current of water across the water-filled chamber about 3 feet from the floor. On the wall opposite the pipe outlet, a well-defined circular area was seen, which, in contrast to the rest of the chamber, was bare of sponges and bryozoans. Further examination revealed that *C. marginalis* larvae were replaced by *H. orris* larvae in the circular, fast-water area. As a practical consideration it seems that leaks could be detected and water velocity patterns could be plotted accurately and inexpensively in many situations similar to this one by an examination of the larval caddisfly populations.

The aforementioned pit is covered at all times and is virtually inaccessible to ovipositing female caddisflies from the outside. Adults which were reared in the chamber could live and mate in the air space at the top, however, and then further populate the chamber by laying eggs in it. Thus the species which initially populated the pit by means of current-carried larvae could quickly become the dominant species. In the Keokuk area, *C. campyla* and the psychomyiid

caddisflies seem to prefer the same habitat, and yet *C. campyla* is dominant in almost every instance. In the chamber, however, no *C. campyla* were found. *C. marginalis* probably was the pioneer species in the chamber when new Lock 19 was made operational for the first time in 1956. This hypothesis seems plausible because *C. marginalis* is almost always the first larva to appear on newly immersed objects such as emergence traps, trotline buoys and underwater floats.

LARVAL FEEDING BEHAVIOR AND GROWTH

In the aquarium, *C. campyla* larvae were observed to rest ventral side down as well as ventral side up, and the larval tube often was constructed vertically. The larvae were continually active and seemed constantly to be gleaning food from their nets. They frequently turned temporarily end for end in their tubes and occasionally crawled onto the outside of their abodes, but no matter how far they stretched, the larvae always kept their anal claws hooked into some part of their larval constructions.

C. campyla larvae were observed to have either brown or green abdomens. In fact, the larval population upon a single rock often was composed of both brown and green individuals. The significance of this is not understood, but it is plausible that the green individuals were larvae which were feeding actively. The brown individuals may have stopped feeding as they prepared to molt. Aquatic isopods (*Asellus* sp.) were always found in association with *C. campyla* larvae.

Nine quantitative samples of *H. orris* larvae were collected from navigation buoys during the interval from June, 1957, to March, 1959. A subsample was taken from each collection, and all of the larvae in the subsample were measured. A frequency distribution of their measurements is presented in fig. 12. It is evident from these data that *H. orris* has a minimum of five instars during its larval life. One or two other instars must exist between the egg and the smallest larvae shown in the figure.

PUPAE

Haller (1948) and Sattler (1958) have presented extensive works concerning the morphology and biology of *Hydropsyche* pupae.

In the present study, no evidence was found to indicate that *H. orris* leaves its larval tube to pupate, as has been reported for other species of *Hydropsyche* (Wesenberg-Lund, 1943; Uéno, 1952; Philipson, 1953a; Sattler, 1958). Two *H. orris* larvae constructed their tubes and nets just 4 inches from the propeller in the lotic aquarium, and daily observations were made of their activities. Instead of leaving its tube to pupate, each larva extended its tube into the vestibule behind its catching net. When the anterior end of one pupal case was almost closed, the larval net was still intact. A day later, only shreds of the net remained, and the pupal case was complete. The second larval net was gone by the time the larva had begun to seal itself in its cocoon. Evidently, the larva cuts the net loose during construction of the cocoon

SIZE DISTRIBUTION OF HYDROPSYCHE ORRIS LARVAE COLLECTED FROM
23 JULY 1957 TO 5 MARCH 1959

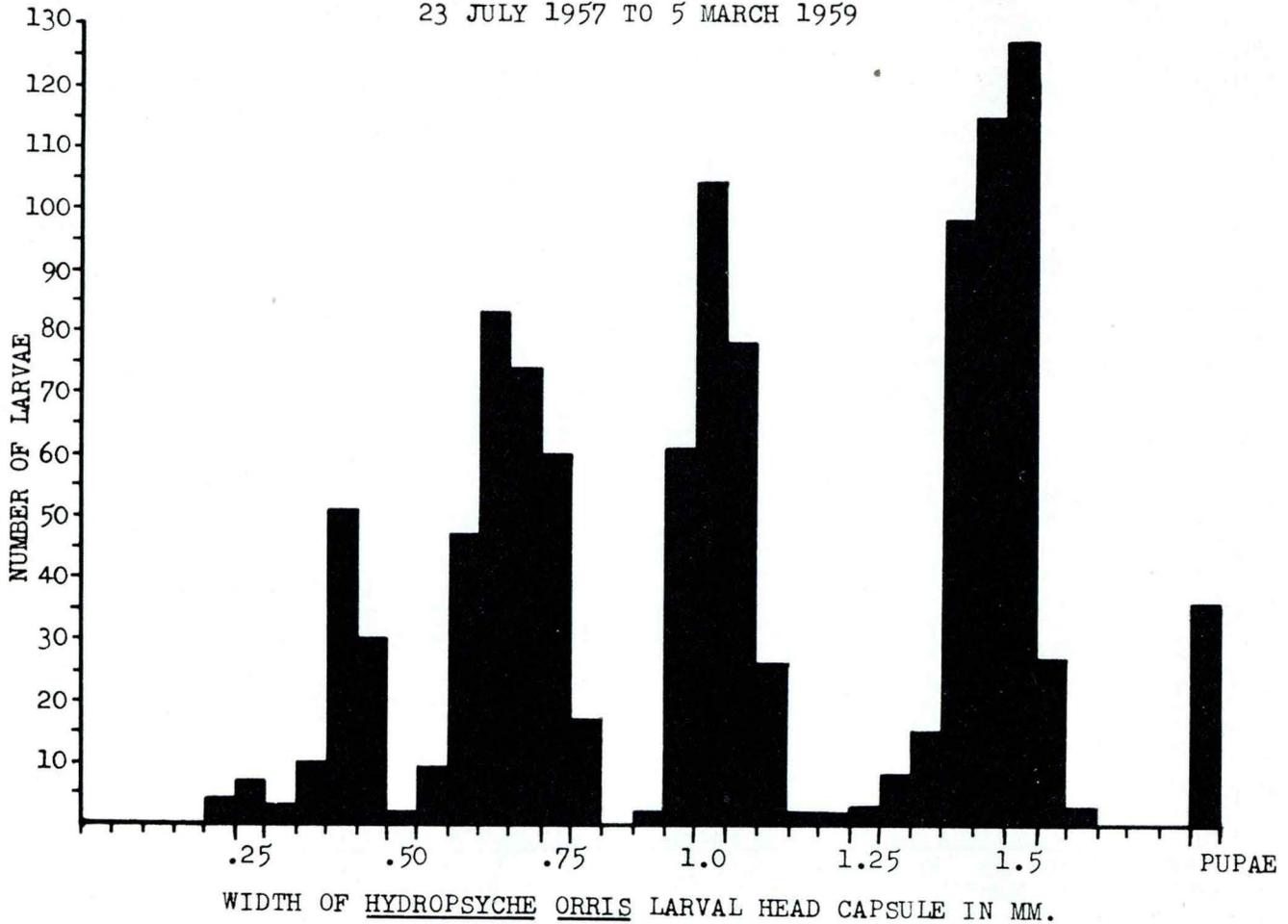


Fig. 12. Size distribution of *Hydropsyche orris* larvae collected from navigation buoys between Hannibal, Mo., and New Boston, Ill., July 23, 1957, to March 5, 1958.

or weakens it sufficiently so that the current can carry it away.

H. orris cocoons are rigid, sand-encrusted structures which often incorporate the substrate as one wall. The cocoons of *C. campyla* at Keokuk are pliable and usually incorporate fragments of fingernail clam shells and toilet tissue in addition to sand.

The pupae of *C. campyla* often have red compound eyes when dissected alive from their cocoons. The color fades rapidly, however, and was not observed in preserved specimens. The black eye spots (lateral ocelli) of *C. campyla* prepupae were often absent from the white patches in which they are centered in the larvae. Close observation revealed, however, that the eyespots were faintly visible through the prepupal integument slightly posterior to the white eye patches. Dissection showed that each eyespot now was located on the posterior edge of one of the compound eyes of the pupa which was forming inside the prepupal integument. In more mature pupae, the black eyespots were no longer visible because they seemingly had atrophied or had been grown over by the enlarging compound eyes. The significance of this phenomenon was not investigated, but the apparent disappearance

of the eyespots was found to be a good criterion by which to identify *C. campyla* larvae which were ready to pupate. Also, the disappearance of the pigment spot behind the compound eye of the pupa indicates when the pupa is mature and is ready to emerge from its cocoon.

No observations were made of the emergence of hydropsychid adults from their pupal exuviae. It is known, however, that they complete this molt on the water's surface and that the emergence takes place mostly at dusk. Cast pupal skins of all three species often appeared in large numbers on the surface of the water at dusk.

GENERATIONS PER YEAR

Nightly catches of *H. orris* in downtown Keokuk are plotted in fig. 13. Window sampling was not begun until the latter part of June in 1957, but residents along the river bluffs reported that *H. orris* swarms were very bad during the latter part of May and during the first half of June. The residents added that caddisfly swarms are always largest and most bothersome over the bluff during late spring and early fall.

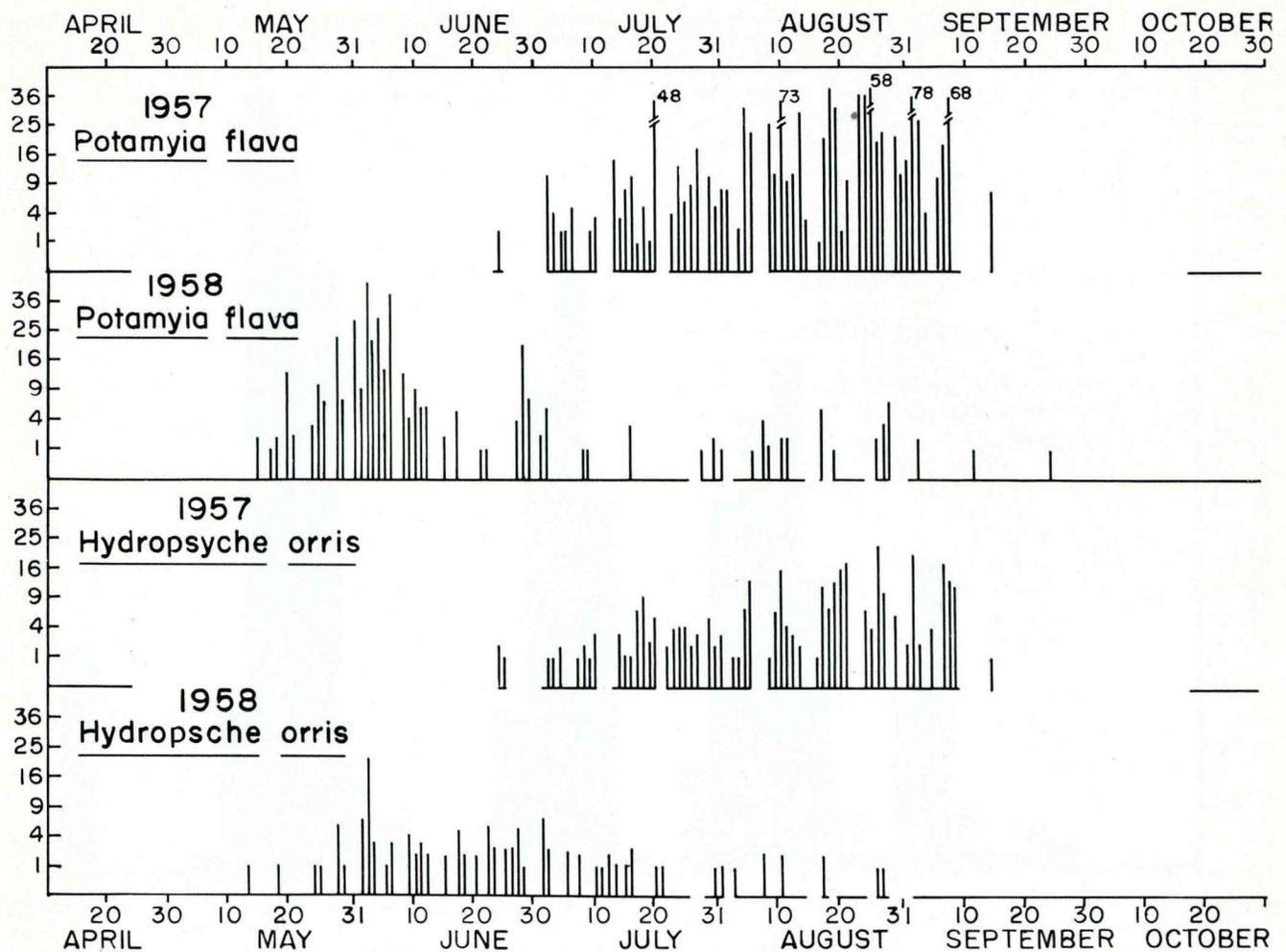


Fig. 13. Nightly catches of *H. orris* and *P. flava* from a lighted cafe window in downtown Keokuk during the summers of 1957 and 1958. A broken baseline indicates nights when collections were not made.

There is evidence in the 1957 window samples of increased emergence in late August and early September. In 1958 only an early summer peak is evident from the window sampling, but field observations definitely indicated a second peak of emergence.

Samples of *H. orris* larvae were collected at intervals from navigation buoys. The larval size distributions (fig. 14) tend to substantiate the supposition that there are two principal emergences of *H. orris* per year. In bivoltine species such as *H. orris*, eggs which are laid in early summer hatch and become adults during the same summer. Larvae which hatch from eggs laid in late summer will, on the other hand, take at least 8 months to become adults, since they do not emerge until the following spring.

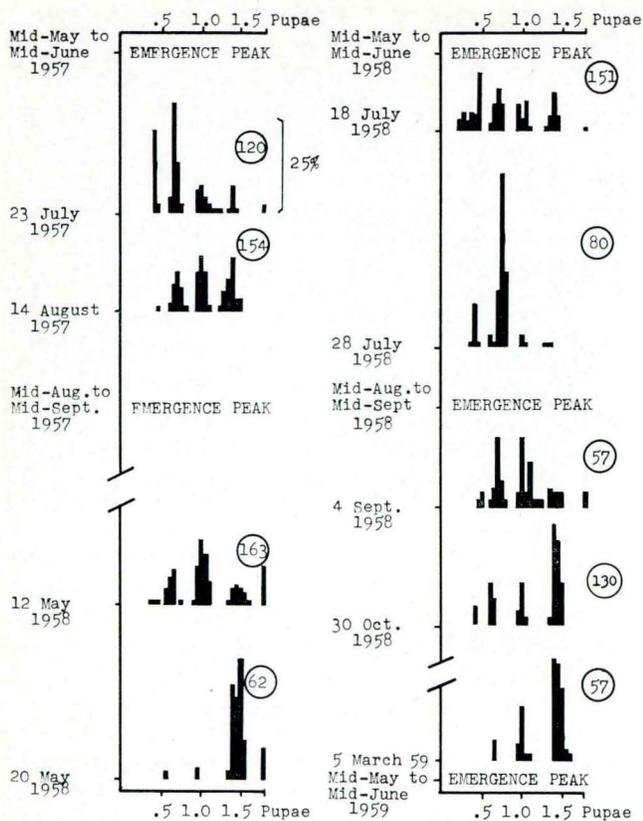
The size-frequency distributions also indicate that mature *H. orris* larvae tend to pass the winter as last instar larvae or prepupae instead of pupae. Indeed, it seems that the less mature larvae continue to grow in late fall and early spring and "catch up" to the quiescent last instar larvae. Larvae of varying ages thus would be able to pupate as a group in May and to emerge en masse in late spring.

Marshall (1939) in her work at Put-in-Bay, Ohio, reported the *C. campyla* seasonal frequency of abun-

dance to be definitely bimodal with peaks in early June and the latter part of August. She thought that there were probably two generations per year.

Figures 4 and 5 (shown earlier) present a summary of the numbers of *C. campyla* which were collected in the window samples at Keokuk. It is unfortunate that sampling was not begun earlier in 1957 because it is difficult to surmise whether there were one or two emergence peaks during that summer. Furthermore, the apparent high in 1957 occurred during midsummer, but in 1958 the low occurred at this time. The 1958 data, however, indicate that a peak of emergence occurred during the early summer and that another occurred during the latter part of the summer.

The lotic aquarium yielded confirmatory information concerning the length of time necessary for *C. campyla* to complete one generation. Adult *C. campyla* first were placed in the aquarium to lay their eggs on July 7, 1958. When the aquarium was drained and inspected on Aug. 27 it contained 63 mature *C. campyla* larvae, 3 mature *C. campyla* pupae and 2 large psychomyiid larvae. The pupae appeared to be completely developed, and thus the aquatic life of *C. campyla*, from egg to adult, was estimated to be about 51 days under laboratory conditions.



WIDTH OF *Hydropsyche orris* LARVAL HEAD CAPSULE IN MM.

Fig. 14. Length-frequency distribution of *H. orris* larvae collected from navigation buoys at various times during 1957 and 1958, between Hannibal, Mo., and New Boston, Ill. The number of individuals in each sample is circled.

The cleaned aquarium was restocked on Aug. 27 with a large number of *H. orris*, *P. flava* and *C. campyla* larvae which had been collected from the rubble below the Keokuk dam. The aquarium was drained again on Sept. 2, and while it was being drained a *C. campyla* pupa emerged from its cocoon. The entire pupal instar had thus been completed in 6 days, under laboratory conditions, at temperatures ranging between 75° and 85° F. Four more mature pupae were found still in their cocoons. Rearing experiments and adult frequency distributions indicate that *C. campyla* is a bivoltine species at Keokuk.

Window samples (fig. 13) indicated that *P. flava*, like *H. orris* and *C. campyla*, is a bivoltine species. *P. flava* were collected at Keokuk as early as May 16 and as late as Sept. 25.

CADDISFLY CONTROL

ADULTICIDES

Only one caddisfly control program has been reported in the literature. It is being carried on at the present time in the city of Fort Erie, Ontario, where a program was initiated in 1949 to study the biology of the pest species of caddisflies and ultimately to find methods for controlling them. Progress reports concerning the caddisfly program at Fort Erie have

been made by the Fort Erie Times-Review (June 28, 1951, and June 10, 1954) and by the Buffalo (New York) Courier-Express (Aug. 13, 1950). These newspaper accounts, and personal communications with Mr. H. E. Thompson of the Fort Erie Lions Club and Dr. D. G. Peterson, Canadian Department of Agriculture, form the basis for the following account.

The caddisfly study and the subsequent control measures at Fort Erie were undertaken as a long-term service project by the Fort Erie Lions Club. The biological investigations of 1949, 1950 and 1951 were done principally by volunteer workers who cooperated with the University of Toronto.

The adult hydropsychid caddisflies, after emergence, congregate for a day or two in trees and shrubbery along the river bank before swarming up the river to lay their eggs at the outlet of Lake Erie.

In 1954, the Fort Erie Lions Club purchased a model 100 John Bean Rotomist sprayer to spray the river front every 2 weeks. Wettable DDT (50 percent) was used at first, but because of excessive nozzle wear a change was made to 25-percent DDT in an oil base. No complaints concerning oil damage to shade trees have been received during the spraying program. Spraying is begun on the first of June and is continued until the middle of September. In 1957 the results were not as good as had been expected, and it was thought that the concentration of the 2 percent DDT oil-water emulsion spray should be doubled.

The basic problems at Keokuk are similar to those at Fort Erie. The *H. orris* and *C. campyla* adults, which emerge below the Keokuk dam, rest in the shrubbery along the shore during the day and would be vulnerable to contact poisons. Those *C. campyla* and *P. flava* which emerge and rest downstream from Keokuk and then migrate up the river to oviposit would be more difficult to control by a spraying program, since the areas where they rest are rather inaccessible.

H. orris adult males are vulnerable when they are swarming over the trees along the river bluff at Keokuk. The swarms of males are very obvious at dusk, and meteorological conditions at that time usually are favorable for the use of space sprays. Since the swarms occur in the same locations, night after night, a spraying schedule could be easily planned. A mist blower could apply the insecticide at the height desired. Drift from a space spray directed at the swarms of males would undoubtedly kill many females which approach the swarms from the trees and from the river. It is doubtful whether a fog generator would have sufficient range to reach the swarms.

The early summer peak of *H. orris* emergence coincides with the songbird nesting season, and DDT application at that time might not be desirable. Lethane and/or pyrethrins might kill the caddisflies without damage to the bird populations. The late summer peak occurs at a time when songbirds are less vulnerable to insecticides.

A large apiary is situated directly across the river from Keokuk, and the apiary officials became concerned when airplane spraying of insecticides was suggested by some Keokuk residents. The apiarists felt that an insecticide drift from such a large-scale

operation would be carried into their bee yards by the prevailing winds. Officials at the Dadant Apiary had no objection to sprays which were applied from the ground instead of from the air, however. Spraying in the evening against swarming caddisflies should present little danger to bees.

Space sprays also may prove of value in lessening the caddisfly infestation in the downtown area. Each street lamp serves as a light attractant, as does each lighted store window, and an insecticidal fog perhaps would be effective if applied about 1 hour after the street lights are turned on in the evening.

On Aug. 6, 1959, screening tests were run to determine the susceptibility of adult caddisflies to the emulsifiable concentrates of several insecticides. Since no attempt was made to standardize the concentrations of the insecticides, the results of this report should be accepted with reservation. The procedure was as follows: Four pieces of window screen, cut to fit in the top of pint ice cream cartons, were dipped in the emulsifiable concentrate of each of nine insecticides. (See table 5 for names and concentrations of these insecticides.) The screens were dried for 10 hours.

Male *H. orris* caddisflies, which were collected at dusk from a mating swarm, were anesthetized. Four caddisflies were placed in each ice cream carton, and the treated screen cover was placed over the carton. Four cartons of caddisflies were treated with each insecticide, and four untreated cartons of caddisflies served as controls.

During the period of recovery from the anesthetic, a bright light inhibited movement of the insects. When recovery was complete, a dim light was used to stimulate movement of the caddisflies in the screened cartons. The caddisflies milled around sporadically, walking across the screens.

They were examined at 10-minute intervals for 2 hours, and the time required for each insecticide to kill 50 percent of each group of 16 insects was recorded in table 5.

The experiment was repeated on Aug. 7, 1959, 34 hours after the screens had been treated (table 5).

It appears that malathion, parathion, Dibrom 8 and Diazinon concentrates killed caddisflies most rapidly under these conditions. Since speed of knock-down is important, additional tests were run with these four organic phosphorus insecticides.

About 100 male *H. orris* were anesthetized and placed in each of five clean cartons fitted with new, untreated screens. When the caddisflies had fully

TABLE 5. TIME (IN MINUTES) REQUIRED FOR VARIOUS INSECTICIDES TO KILL 50 PERCENT OF MALE *HYDROPSYCHE ORRIS* CADDISFLIES.

Emulsifiable concentrate	Percent active ingredients	Screens treated prior to exposure:	
		10 hours	34 hours
Malathion	57	20	30
Parathion	25	30	50
Dibrom 8	64.5	20	60
Diazinon	25	40	50
Chlordane	75	50	80
Guthion	17.3	50	—
DDT	25	50	110
Endrin	19.5	70	120
Sevin	12	80	110
Control	0	—	—

TABLE 6. RELATIVE EFFECTIVENESS OF FOUR INSECTICIDES AGAINST MALE *HYDROPSYCHE ORRIS* CADDISFLIES.

	Malathion	Parathion	Diazinon	Dibrom	Control
L/T/50	5 min.	18 min.	81 min.	3 hr.	14 hr.
Complete kill	15 min.	41 min.	2 hr.	14 hr.	30 hr.

recovered from the anesthetic, four of the clean screens were replaced for 5 minutes with screens that had been treated 34 hours earlier. Because of crowding, the caddisflies milled about rapidly in the cartons. After 5 minutes, the treated screens were replaced by clean screens and the insects observed for mortality. Malathion was the fastest acting of the four insecticides (table 6).

Malathion was further tested by exposing about 100 caddisflies to a treated screen for 1 minute. Half the insects were dead after 4 minutes, and all were dead in 14 minutes.

Further investigations with malathion are warranted. It is possible that this insecticide could be used as a space spray along the river front with a high degree of safety to fish, birds and humans. Effective dosages and formulations must still be determined, however.

LIGHT TRAPS

The most abundant caddisflies in the shopping district of Keokuk are the males of *C. campyla*. They do not restrict themselves to the river, as do the ovipositing females. The main street of Keokuk, which is well lighted, runs directly to the river and provides an avenue for a constant influx of males from the river to the shopping district. Since the caddisflies are initially attracted by light, it seemed logical to consider light as an aid in control measures.

Trichoptera are especially attracted to lights with wave lengths of 3,200 to 3,800 Angstroms (Frost, 1953, 1954, 1955; Pfrimmer, 1955).

An experimental light trap (figs. 15 and 16) was devised to test the relative attractiveness of three types of lights. They were a cool-white fluorescent lamp (F4T5/CW), a blacklight fluorescent lamp (F4T4/BL) and a germicidal lamp (G4T4/1). The lamps, each of which was rated at 4 watts, peaked at 5,650 Angstroms, 3,500 Angstroms and 2,537 Angstroms, respectively. They were supplied through the courtesy of Sylvania Electric Products, Inc.

To eliminate the effect of light position upon the catches, the three lights were arranged in all possible permutations (6), and each permutation was randomly scheduled for a different night. The complete experiment was run twice for a total of 12 trap nights. The experimental trap was operated on the dam.

The exterior of the trap was painted yellow and the inside of each of the three lighted compartments was coated with aluminum paint. Each light was suspended horizontally over a pan of water with sufficient detergent to wet the insects as they fell to the water. The bare bulbs were placed low inside the compartments and were not readily visible to the attracted insects. The lights were fitted with long electric cords so that they could be interchanged easily from chamber to chamber. The ballasts and start-

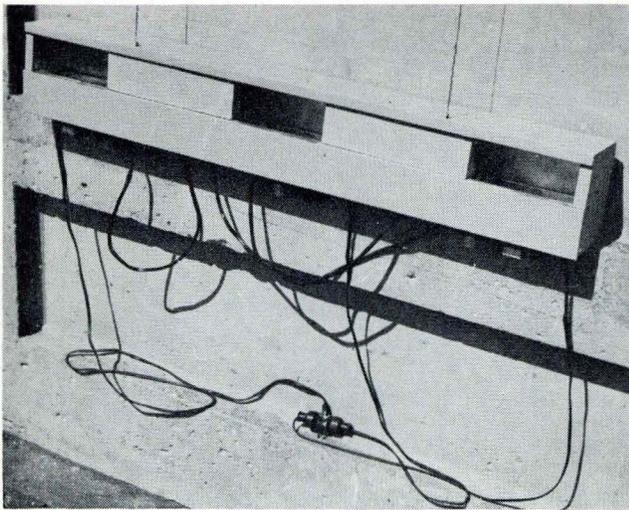


Fig. 15. Experimental light trap which tested three types of lights as caddisfly attractants.

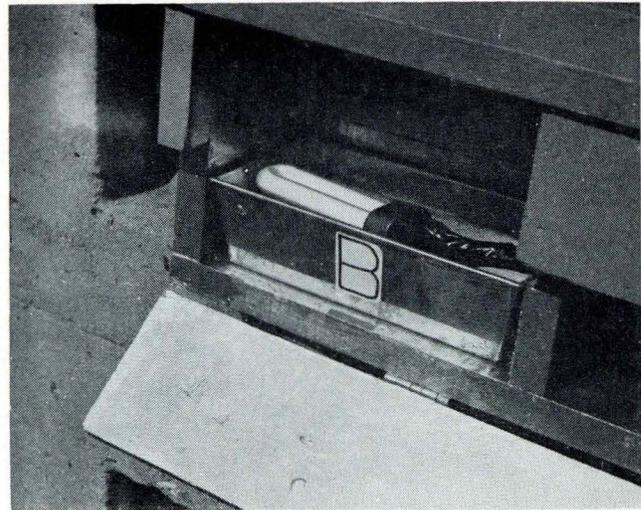


Fig. 16. A compartment of the experimental light trap. A blacklight lamp is suspended over a pan of detergent water. Note that the front of the trap is hinged.

ers for the lamps were secured permanently to the bottom of the trap. The lights were turned on simultaneously and were left on for exactly 5 minutes each evening. The experiment was initiated on July 21, 1958, and the lights were arbitrarily turned on at 8 p.m. on the first evening. Each evening thereafter, the starting time was 2 minutes earlier than that of the preceding evening to make the interval from sunset to starting time fairly constant.

The *H. orris*, *C. campyla* and *P. flava* were separated from the other trapped species and were sexed and counted. The black light (3,500 Angstrom) was by far the best attractant for caddisflies, collecting in all instances more individuals than the germicidal and cool-white lights combined (table 7).

Females of all three species were collected in much larger numbers than males at all three lights. It is doubtful that females are attracted more to light than males, however, since in the downtown area the ratios of males to females over two seasons for *H. orris*, *C. campyla* and *P. flava* were 1.4, 2.6 and 0.59, respectively.

The preponderance of females at the dam is probably due to two factors: (1) Females return to the river to lay their eggs and thus spend more time in that area than do the males, which seem to desert the river for the shore immediately after emergence. (2) Females probably migrate upstream to lay their eggs and thus congregate at the dam. This seems to be especially true of *P. flava* females.

P. flava females were consistently more abundant than males both at the dam and in the downtown area. The relative scarcity of males may indicate that the *P. flava* females have migrated upstream a consid-

erable distance from their place of emergence, leaving most of the males behind.

C. campyla larvae are known to be abundant in the tailwaters of the Keokuk dam, and since the males are believed to migrate but little, the large number of males which were taken in the downtown window samples indicates that the greatest part of the pest population of *C. campyla* originates just below the dam.

The sex ratio of *H. orris* is closer to 1 than is the sex ratio of either *C. campyla* or *P. flava*. This is true both at the dam and in downtown Keokuk. *H. orris* females probably migrate little, and most of the males and females at Keokuk have probably emerged from the tailwaters. Furthermore, male *H. orris* often swarm at the dam and probably increase the ratio of males at the oviposition site of the species.

It seems likely that if an extensive series of blacklight insect traps were placed along the water front and at the foot of main street they would intercept many of the resident caddisflies and upstream migrant species which are attracted to the downtown lights. Such light traps should (1) require little care, (2) withstand heavy rain and wind and (3) be efficient and inexpensive. Several such traps were designed for use at Keokuk. The most effective traps utilized blacklights as attractants, and one such trap is illustrated in fig. 17.

A 20-watt blacklight was mounted opposite a quarter section of a 50-gallon drum which was bolted to the rim of an intact 50-gallon drum. A standard fixture for the fluorescent lamp was sealed against the weather with rubber tape. The drum was filled two-thirds full of water, and 5 gallons of fuel oil were

TABLE 7. CADDISFLIES CAPTURED AT THE KEOKUK DAM IN 12 NIGHTLY PERIODS WITH THREE TYPES OF LIGHT, 1958.

Light	Wave length peak in Angstroms	<i>C. campyla</i>		<i>H. orris</i>		<i>P. flava</i>		Unidentified species	Total
		Male	Female	Male	Female	Male	Female		
Black	3,500	40	11,818	103	512	67	925	530	13,995
Germicidal	2,537	4	2,453	30	89	16	180	340	3,112
Cool white	5,650	4	1,419	16	30	7	80	145	1,701
Total		48	15,690	149	631	90	1,185	1,015	18,808

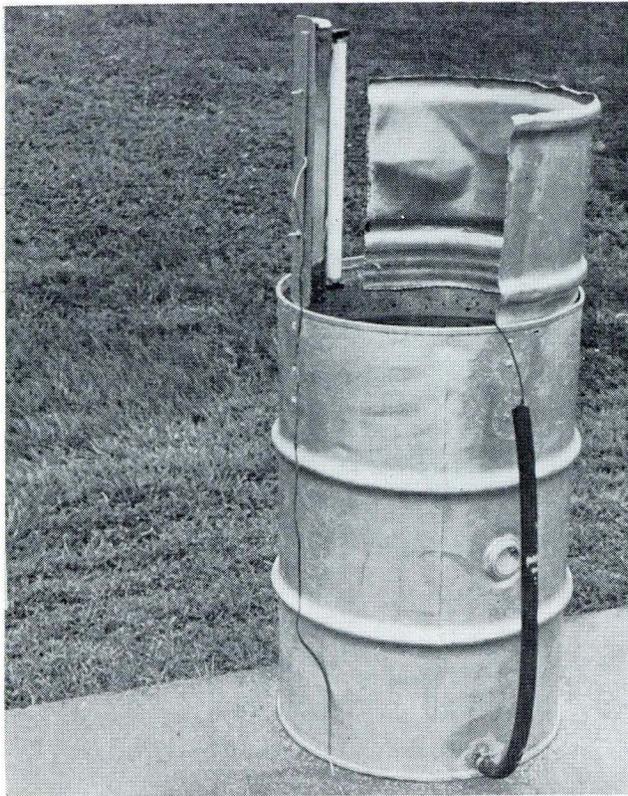


Fig. 17. Blacklight caddisfly trap used at Keokuk. Recommended for use in possible control measures.

floated upon the water. A section of rubber garden hose, which extended upward from the bottom of the drum, acted as a standpipe and maintained a constant liquid level in the barrel. Insects which were attracted to the light fell into the oil and sank to the water level since their specific gravity was greater than that of the oil. The insects decomposed in the water at the bottom of the barrel. The oil layer prevented water evaporation, and each time it rained a portion of the water in the barrel was forced out the standpipe. The trap was flushed automatically by rain in this manner. If the trap were to be emptied, the standpipe had only to be lowered. By enclosing the light units in polyethylene bags, the complete traps may be stored outside to save space during the winter months. The materials necessary for construction of such a trap cost less than \$10.

Counts were made of the insects which were killed by this type of trap on three occasions, and the nightly kill was estimated volumetrically to vary from 625,000 to 800,000 caddisflies per trap.

The blacklight was a poor attractant for mayflies. This is an advantage in a caddisfly trap, since a heavy emergence of *Hexagenia* mayflies would quickly fill any trap which was attractive to them. The traps are not unsightly, as they are painted with aluminum paint and their action is impressive to the public. This psychological advantage should not be overlooked because the public can immediately see that something is being done. Light traps are harmless to people, domestic animals and wildlife.

Two disadvantages exist for the suggested light

traps. The water in the bottom of the barrels becomes foul-smelling because of the decomposing insects. This is noticed only when the traps are emptied, however, because the floating oil layer prevents the odor from escaping while the traps are in use. The traps should be placed at a sewer inlet or in a position so that the effluent can run directly into the river. The traps undoubtedly will be subject to vandalism; consequently they should be operated in areas where they can be supervised.

The fast knock-down exhibited by malathion also suggests its use in conjunction with light traps. Such traps could employ blacklights shielded by window screens which could be painted with a concentrated malathion solution twice each week. As was shown previously, 1-minute exposure to such a screen is sufficient to kill *H. orris* caddisflies.

CHANGES IN STREET AND STORE LIGHTING

Many shopkeepers and restaurant owners could reduce their caddisfly problems by altering their outside lighting. Blue and green "neon" tubes are very good caddisfly attractants and should be replaced by red or yellow tubes which are much less attractive to these insects.

LARVICIDES

Larval caddisflies do not inhabit navigation buoys which have been painted with plastic-base, antifouling paint. Submerged structures which become clogged with caddisfly larval constructions could be effectively treated with this paint.

Killing the larvae in the tailwaters with an insecticide before they mature and emerge would be another possible method of control. Such a plan immediately calls to mind the following problems: (1) the insecticide must kill caddisfly larvae but not fish, (2) elimination of the larvae might deprive fish of their food supply, (3) the "biological balance" may be upset, and (4) application of the insecticide must be economical and safe to man and other water users.

It should be stressed that only localized control of the caddisflies is considered in this discussion. Elimination of caddisflies over broad areas of the Mississippi River would present many more complicated problems. The control should be experimental, and carefully studied on a small scale, before any attempt is made to eliminate the caddisflies from an area such as the entire tailwaters of the Keokuk dam.

Susceptibility of hydropsychid larvae and fish to DDT. Several studies have indicated that caddisfly larvae are extremely susceptible to DDT and that they may be killed without decimating cyprinid, centrarchid and ictalurid fish populations (Hoffmann and Merkel, 1948; Adams *et al.*, 1949; Gjullin *et al.*, 1949; Hoffmann and Surber, 1948 and 1949). As has been suggested by Hoffmann and Surber (1948), the nets of the hydropsychid caddisfly larvae probably concentrate wettable powders by their filtering action. It seems very possible that this filtering action can be used to advantage in eradicating the larvae without injuring fish.

Hydropsyche orris larvae which were reared in a lotic aquarium in the laboratory constructed normal catching nets, and when bits of foreign material (e.g., crumbs of dry dog food) were swept into the larval net by the current they became lodged inside the antechambers of the larval tubes. The larvae usually were able to wrestle the particles out of their tubes, over their nets and into the current to be swept away. While struggling with the larger pieces, the larvae were intimately in contact with them for prolonged periods (often several minutes). Hydropsychid larvae are constantly engaged in cleaning their nets. The significance of this activity becomes apparent when the larvae die, for their nets very soon become heavily laden with algae, dirt and debris. DDT impregnated granules might be very effective in controlling the larvae, if the granules are caught by the nets and thus come in contact with the larvae.

Depletion of fish food. Hoopes (1959) has shown that the larvae of *C. campyla* and *H. orris*, which are the most abundant larvae in the tailwaters, are utilized little by fish. Only one species of fish, the shovelnose sturgeon (*Scaphirhynchus platorhynchus*) ate caddisfly larvae extensively, and these larvae were *P. flava*, which are most common in areas other than the tailwaters. It is doubtful, therefore, whether a dearth of caddisfly larvae in the tailwaters would seriously affect the fish below the dam.

Change in species dominance. When an animal population is eradicated, the void is sometimes filled by species which are less desirable than those which were exterminated. Caddisfly larvae were replaced by prodigious numbers of chironomid larvae in the Miramichi River tributaries after DDT spraying. The alteration of the proportional representation of the two groups was thought to result from the shorter life cycles among the Chironomidae and the lack of predators and competitors (Ide, 1957).

It seems doubtful that such a population change would occur below the dam at Keokuk following local decimation of the larval caddisfly population. Repopulation by caddisfly larvae probably would be rapid because of the upstream migration of ovipositing females and the downstream drifting of larvae. If areas were repopulated by drifting larvae, it is probable that *Cyrinellus marginalis* would replace *Cheumatopsyche campyla* for a time in the slower water areas. *Cyrinellus marginalis* has been shown previously to be a pioneer species.

Application. Because the volume of flow of the

Mississippi River is great, dilution would be a problem if liquid insecticides such as oil solutions or emulsions were used. DDT-impregnated granules which would catch in the caddisfly larval nets might prove to be a feasible method of control. A mixture of assorted-size granules may be best—the heavier granules settling in the fast current and the fine granules being carried farther with the current. A hand-operated alfalfa seeder probably would be adequate for spreading the insecticide in the tailwaters. Before any insecticide is applied for control purposes, however, laboratory and field experiments should be conducted to determine the practicability of the operation. Such experiments most certainly should include aquarium experiments to determine the relative toxicity limits of hydropsychid caddisfly larvae and various species of river fish.

If DDT-impregnated granules are used, they should be applied in two major areas: (1) at the water entrance to the power house and (2) in the tailwaters of the dam. The insecticide pellets, when applied along the immediate upstream edge of the power house, would continue with the current through the water-conducting tubes of the power plant into the turbines, contacting larvae on the trash racks and in the water-conducting tunnels as they went. Continuing downstream, the DDT granules, thoroughly mixed in the water by this time, probably would deal effectively with the *H. orris* larvae in the tailrace below the power house.

The broad tailwaters, which are below the dam (fig. 1), constitute an area of slower, shallower water. During periods of low water (usually midsummer, fall and winter) the average depth of the water in this area is about 4 feet, and in most areas the current is less than 1 mile per hour. Channels of faster water course through the tailwater area, however, and the water in these channels attains a velocity of about 1.5 to 2 miles per hour.

Insecticides could be applied most effectively to the tailwaters during July, when the water is low. The larvicide probably would curtail the generations of *H. orris*, *C. campyla* and *P. flava* which would emerge from the tailwaters in late summer. If the granules are retained in caddisfly nets, it is conceivable that they may remain as a residual poison in the net remnants and make the area relatively uninhabitable to the larvae for several weeks.

It should be recognized that one insecticide application in the tailwaters of the dam will not permanently reduce the resident larval population. At least one insecticide treatment per year probably will be required to give continued relief.

LITERATURE CITED

- Adams, L., Nanavan, M. B., Hosley, N. W., and Johnston, D. W.
 1949. The effects on fish, birds and mammals of DDT used in the control of forest insects in Idaho and Wyoming. *Jour. Wildlife Mgt.* 13(2):245-254.
- Alm, Gunnar.
 1925. Beitrage zur Kenntnis der netzspinnenden Trichopteren-Larven in Schweden. *Int. Rev. Hydrobiol.* 14:233-275.
- Anonymous.
 1956. Clinical memoranda on economic poisons. Publ. U.S. Public Health Serv. 476.
- Badcock, Ruth M.
 1953. Observation of oviposition under water of the aerial insect *Hydropsyche angustipennis* (Curtis) (Trichoptera). *Hydrobiol.* 5(102):222-225.
- Betten, Cornelius.
 1934. The caddis flies or Trichoptera of New York State. *Bul. N. Y. State Mus.* 292.
- Clarke, Cora H.
 1884. Description of two interesting houses made by native caddisfly larvae. *Proc. Boston Soc. Nat. Hist.* 22:67-71.
- Corbet, Philip S. and Tjonneland, Audfinn.
 1955. The flight activity of twelve species of East African Trichoptera. *Univ. Bergen, Årbok Naturv. rekke* 9:1-49.
- Denning, Donald G.
 1937. The biology of some Minnesota Trichoptera. *Trans. Amer. Ent. Soc.* 63:17-43.
 1943. The Hydropsychidae of Minnesota (Trichoptera). *Ent. Amer.* 23:101-171.
- Eltringham, H.
 1919. On the histology of the scent-organs in the genus *Hydroptila*. *Trans. Ent. Soc. London.* pp. 420-430.
- Fielde, A. M.
 1887. On an aquatic larva and its case. *Proc. Acad. Nat. Sci. Phil.* 39:293-294.
- Fremling, Calvin R.
 1959. Biology and possible control of economically important Trichoptera and Ephemeroptera of the Upper Mississippi River. Unpublished Ph.D. thesis. Iowa State Univ. Library, Ames, Iowa.
- Frost, S. W.
 1953. Response of insects to black and white light. *Jour. Econ. Ent.* 46(2):376-377.
1954. Response of insects to black and white light. *Jour. Econ. Ent.* 47(2):275-278.
 1955. Response of insects to ultra-violet lights. *Jour. Econ. Ent.* 48(2):155-156.
- Gjullin, C. M., Cope, O. B., Quisenberry, B. F. and DuChanois, F. R.
 1949. The effect of some insecticides on black fly larvae in Alaskan streams. *Jour. Econ. Ent.* 42(1):100-105.
- Glasgow, J. P.
 1936. The bionomics of *Hydropsyche colonica* McL., and *H. philpotti* Till. (Trichoptera). *Proc. Royal Ent. Soc. London (A)* 11:122-128.
- Haller, P. J.
 1948. Morphologische, biologische, und histologische Beiträge zur Kenntnis der Metamorphose der Trichopteren (*Hydropsyche*). *Mitt. Schweiz. Ent. Ges.* 21 (3):301-360.
- Harris, J. R.
 1952. *An angler's entomology.* Collins, London.
- Hoffman, C. H. and Drooz, A. T.
 1953. Effects of a C-47 airplane application of DDT on fish-food organisms in two Pennsylvania watersheds. *Am. Midl. Nat.* 50(1):172-188.
- and Merkel, E. P.
 1948. Fluctuations in insect populations associated with aerial applications of DDT to forests. *Jour. Econ. Ent.* 41 (3): 467-472.
- and Surber, E. W.
 1948. Effects of an aerial application of wettable DDT on fish and fish-food organisms in Back Creek, West Virginia. *Trans. Amer. Fish. Soc.* 75:48-58.
1949. Effects of an aerial application of DDT on fish and fish-food organisms in two Pennsylvania watersheds. *Prog. Fish Cult.* 11(4):203-211.
- Hoopes, David T.
 1959. Utilization of mayflies and caddisflies by some Mississippi River fishes. Unpublished M.S. thesis. Iowa State Univ. Library, Ames, Iowa.
- Ide, F. P.
 1957. Effect of forest spraying with DDT on aquatic insects of salmon streams. *Trans. Amer. Fish. Soc.* 86:208-219.
- Krawany, Hans.
 1930. Trichopterenstudien im Gebiete der Lunzer Seen. *Int. Rev. Hydrobiol.* 23:417-427.

- Marshall, Anne C.
1939. A qualitative and quantitative study of the Trichoptera of western Lake Erie (as indicated by light trap material). *Ann. Ent. Soc. Amer.* 32:665-688.
- Mosley, Martin E.
1919. Scent organs in the genus *Hydroptila* (Trichoptera). *Trans. Ent. Soc. London.* 1918:393-397.
1924. Scent organs in the genus *Hydroptila*. *Trans. Ent. Soc. London.* 1923:291-294.
- Munroe, E. G.
1951. Pest Trichoptera at Fort Erie, Ontario. *Canad. Ent.* 83(3):69-72.
- Noyes, Alice Ayr.
1914. The biology of the net-spinning Trichoptera of Cascadilla Creek. *Ann. Ent. Soc. Amer.* 7(4):251-271.
- Osgood, Howard.
1934. Comparison of reagins to separate species of caddis fly. *Jour. Allergy* 5(4):367-372.
1957a. Allergy to caddis fly (Trichoptera). I. The insect. *Jour. Allergy* 28(2):113-123.
1957b. Allergy to caddis fly (Trichoptera). II. Clinical aspects. *Jour. Allergy* 28(4):292-300.
- Parlato, Salvatore J.
1929. A case of coryza and asthma due to sand flies (caddis flies). *Jour. Allergy* 1(1):35-42.
1930. The sand fly (caddis fly) as an exciting cause of allergic coryza and asthma. *Jour. Allergy* 1(4):307-312.
1932. Emanations of flies as an exciting cause of allergic coryza and asthma. *Jour. Allergy* 3(1):459-468.
1934. Studies of hypersensitiveness to the emanations of caddis flies (Trichoptera). *Jour. Amer. Med. Assoc.* 102(1):910-913.
- , LaDuca, P. J. and Durham, O. C.
1934. Studies of hypersensitivity to emanations of caddis fly (Trichoptera). *Ann. Int. Med.* 7(11):1420-1430.
- Peterson, D. G.
1952. Observations on the biology and control of pest Trichoptera at Fort Erie, Ontario. *Canad. Ent.* 84(4):103-107.
- Pfrimmer, Theodore R.
1955. Response of insects to three sources of black light. *Jour. Econ. Ent.* 48(5):619-620.
- Philipson, G. N.
1953a. The larva and pupa of *Hydropsyche instabilis* Curtis (Trichoptera, Hydropsychidae). *Proc. Royal Ent. Soc. London (A)* 28:17-23.
1953b. A method of rearing trichopteran larvae collected from swift flowing waters. *Proc. Royal Ent. Soc. London (A)* 28:15-16.
1954. The effect of water flow and oxygen concentration on six species of caddis fly (Trichoptera) larvae. *Proc. Zool. Soc. London* 124:547-564.
- Roos, Tage.
1957. Studies on upstream migration in adult stream-dwelling insects. *Rept. Inst. Freshwater Res., Drottningholm* 38:167-193.
- Ross, Herbert H.
1944. The caddis flies, or Trichoptera, of Illinois. *Bul. Ill. Nat Hist. Surv.* 23(1).
- Sattler, Werner.
1955. Über den Netzbau der Larve von *Hydropsyche angustipennis* Curt. *Naturwissenschaften* 42:186-187.
1958. Beiträge zur Kenntnis von Lebensweise und Körperbau der Larve und Puppe von *Hydropsyche* Pict. (Trichoptera) mit besonderer Berücksichtigung des Netzbaues. *Z. Morph. u. Ökol. Tiere* 47(2):115-192.
- Silfvenius, A. J.
1906. Trichopterologische Untersuchungen I. Ueber den Laich der Trichopteren. *Acta Soc. Fauna et Flora Fenn.* 28(4).
- Siltala, A. J.
1907. Über die Nahrung der Trichopteren. *Acta Soc. Fauna et Flora Fenn.* 29(5).
- Simmons, Perez, Barnes, Dwight F., Fisher, Charles K. and Kaloostian, George H.
1942. Caddisfly larvae fouling a water tunnel. *Jour. Econ. Ent.* 35(1):77-79.
- Tillyard, R. J.
1926. The insects of Australia and New Zealand. Angus and Robertson, Ltd., Sydney, N.S.W., Australia.
- Uéno, Masuzo.
1952. Caddis fly larvae interfering with the flow in the water way tunnels of a hydraulic power plant. *Kontyû* 19(3):73-80.
- Ussing, H.
1909. Om Hydropsyche-Larvens Fangnet. *Flora og Fauna, Silkeborg.* 1909:71-72.
- Weerekoon, A. C. J.
1956. Studies on the biology of Loch Lomond. 2. The repopulation of McDougall Bank. *Ceylon Jour. Sci. (C)* 7(2):95-133.
- Wesenberg-Lund, Carl Jorgen.
1911. Biologische Studien über netzspinnende Trichopteren Larven. *Int. Rev. Hydrob. Hydrog. (Biol. Suppl. 3)* 4:1-64.
1913. Wohnungen und Gehäusebau der Süßwasserinsekten. *Fortschr. Naturw. Forschung* 9:55-132.
1943. Biologie der Süßwasserinsekten. V. J. Springer, Berlin u. Wien.

STATE LIBRARY OF IOWA



3 1723 02103 9722