COLLECTING SEMI-QUANTITATIVE SAMPLES OF BLACK FLY LARVAE (DIPTERA: SIMULIIDAE) AND OTHER AQUATIC INSECTS FROM LARGE RIVERS WITH THE AID OF ARTIFICIAL SUBSTRATES[1]

F.J.H. FREDEEN
Research Station, Research Branch
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan, Canada
S7N 0X2

D.T. SPURR
Research Station, Research Branch
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan, Canada
S7N 0X2

Quaestiones Entomologicae
14: 411–431 1978

Quantitative samples of aquatic insect larvae were obtained efficiently (in terms of man hours) from various sites in the two branches of the Saskatchewan River with the aid of several kinds of artificial substrates. Previously only the margins of these large rivers had been sampled, mainly during periods of steady river volumes.

Densest populations of simuliids occurred on smooth-surfaced substrates. Following a three-week exposure, mean populations on polyethylene-covered plates anchored near the river bed included 426 simuliid larvae and pupae per 100 cm² but only 47 non-simuliids. Densest populations of non-simuliids occurred on complex, rough surfaces, particularly those covered with debris. Following a three-week exposure mean populations on 100 cm² aluminum-mesh plates included 45 simuliids, 606 chironomids, 147 stoneflies, 13 mayflies and 98 caddis larvae. Large numbers of these same insects also colonized similar substrates on the river surface. Baskets of gravel on the river bed provided samples yielding larger numbers of species and higher diversity indices than did mesh-covered floats on the river surface. Samples of sand collected directly from stable areas of the river bed yielded fewest species and lowest diversity indices. Substrates other than those in contact with the river bed were colonized entirely by species prone to drift. Dragonfly larvae, hemipterans, beetle larvae and burrowing species of all taxa, even though relatively abundant, seldom occurred on artificial substrates.

Artificial substrates are used regularly in the Saskatchewan River to measure populations of simuliid larvae to determine need for larviciding, to measure impact of larvicide treatments on various taxa colonizing exposed sites and to study growth and behaviour of larvae of simuliid species.

L'emploi de plusieurs sortes de substrates artificiels nous a permis de ramasser dans un façon efficiente un grand nombre d'échantillons de larves des insectes aquatiques. Ces échantillons ont été ramassés dans des endroits variés dans la rivière Saskatchewan. Auparavant on a étudié seulement les marges des ces grandes rivierès, et surtout pendant des périodes de volume normal.

La population la plus dense de simulies s'est trouvée sur le substrate ayant un surface lisse. Après de trois semaines la population moyenne sur des plaques couvert de polyethylene était de 426 larves et pupes de simulies par 100 cm², mais seulement de 47 non-simulies. Les populations de non-simulies les plus denses s'est trouvées sur les surfaces complexes, couvertes de débris. La population moyenne sur des plaques de maille en aluminium de 100 cm² etait 45 larves de simulies, 606 Chironomidae, 147 Plecoptera, 13 Ephemeroptera et 98 Trichoptera.

Des échantillons du sable ramassés directement des endroits de base sable ont donné les moindres sortes d'espèces et les plus basses indices de diversité. Les substrates autres que ceux en contact avec le lit de rivière étaient complétement colonisés

1. Contribution No. 687 of the Research Station.

par des espèces ayant l'habitude de flotter. Odonata, Hemiptera et Coleoptera même si dans abondance relativement grand s'est trouvées rarement sur les substrates artificiels.

Les substrates artificiels sont en emploi regulier dans la rivière Saskatchewan pour déterminer le besoin de traitement chimique de simulies, pour mesurer l'efficacité de ces traitements sur les taxa varies, et pour étudier le dévelopment et les habitudes de larves des simulies.

INTRODUCTION

Collecting quantitative samples of insect larvae from large rivers presents formidable problems. During tests with black fly and shadfly larvicides in the Saskatchewan and St. Lawrence Rivers, semiquantitative samples of larvae were obtained mainly by collecting rocks by hand while wading along transects staked out in shallow rapids (Arnason *et al.* 1949; Fredeen *et al.* 1953, and Fredeen 1972). A net sampler (Surber 1937) was used occasionally. These methods were adequate only when river levels were stationary or falling for sustained periods of time. Quantitative samples were not obtained from stony areas in deep water because dredges, corers and other mechanical devices were inadequate for this type of work. However, sand beds in any depth of water were sampled with a Petersen dredge with auxiliary weights.

The senior author began to use artificial substrates during black fly larvicide tests in 1968, and by 1969 had converted entirely to their use (Fredeen 1974, 1975). This allowed improved flexibility in choices of assessment sites and seasons, and greatly improved manpower economy and accuracy in estimating populations during larvicide tests. Three related lines of endeavor were followed: (a) development of equipment and methods for anchoring and retrieving substrates; (b) development and comparisons of various substrates; and (c) studies of site effects and duration of exposure on the colonization of these substrates.

LITERATURE REVIEW

Macan (1958) and Cummins (1962) reviewed methods to sample benthic invertebrates in shallow stream beds. Since then other methods have been developed for use in streams shallow enough for wading. However, most of the sampling devices and methods described during the time our tests were in progress (1969 to 1972 inclusive) were not directly applicable to large rivers.

Wene and Wickliff (1940) and Moon (1940) were probably the first to have used artificial substrates. Their wire mesh trays placed on or in stream beds and filled with rubble, sand, and aquatic plants became populated within about a month with the same kinds of organisms that could be obtained in conventional ways. Different versions of these rubble-filled trays or baskets are still popular with stream ecologists, whether placed on the stream bed (Dickson *et al.* 1971; Ulfstrand *et al.* 1974; Hughes 1975) or suspended (Mason *et al.* 1967; Mason *et al.* 1973), or filled with artificial substrates such as pieces of concrete or plastic webbing (Benfield *et al.* 1974).

Hester and Dendy (1962), Hilsenhoff (1969) and others experimented with sets of horizontal, parallel plates, either anchored to the stream bed or suspended beneath the water surface. Glime and Clemons (1972) and Macan and Kitching (1972) used simulated mosses and leaves of cotton string and plastic to obtain quantitative samples from stream beds.

Several materials, variously shaped, have proved useful as attachment sites for black fly larvae in streams: plastic, metal or paper-covered cones (Phillipson 1956; Wolfe and Peterson 1958; Johnson and Pengelly 1966), polyethylene strips (Williams and Obeng 1962), wooden boards (Carlsson 1962), painted hardboard (Curtis 1968), sheets of fabric (Tarshis 1968; Simmons and Winfield 1971), leaves and bamboo strips (Disney 1972), and glazed or unglazed tiles (Zahar 1951; Lewis and Bennett 1974).

The hyporheos (Williams and Hynes 1974) of stream beds also has been sampled using standpipes or buried containers of rubble (Coleman and Hynes 1970; Radford and Hartland-Rowe 1971; Williams and Hynes 1974, *etc.*).

Net sampling methods were developed by Surber (1937), Frost *et al.* (1971), Crossman and Cairns (1974) and others.

OUTLINE OF STUDIES

In developing artificial substrates and anchoring methods for use in a large river such as the Saskatchewan, the major constraints were:

1. Irregular, large fluctuations in river volumes.
2. Pressure and interference from rapidly-flowing water, floating debris, wind and wave action.
3. Substrates had to be easily anchored and collected. They had to remain visible and accessible regardless of changes in water depth, velocity or turbidity.
4. Substrates selective for *Simulium* or other aquatic larvae were required.

Most of the data were obtained in August and September, 1969 and 1970, from tests designed to compare substrates and to determine distribution of larvae on certain substrates and effects of varying duration of exposure. Some data were obtained during black fly larvicide tests in May and early June of 1971 and 1972 (data from pretreatment and untreated check sites alone).

All tests were performed in the north and south branches of the Saskatchewan River as well as below their confluence. These are large rivers with a total drainage area of some 300,000 km^2. Volume flow in each river during the ice-free season generally ranges between 50 and 5500 m^3/sec. Increases or decreases in flow by factors of two to five or more in a single day have been recorded.

Saskatchewan River water is generally turbid, containing up to 6 g/1 suspended solids during periods of high volume discharges. Thus visibility in the water is generally limited and the nature of the river bed can be determined only by sounding. The river bed consists of alternating sections of "quicksand" which drifts with the current and yields readily under pressure, alternating with smooth firmly-set cobblestones, and shoals of loose rocks and boulders.

MATERIALS AND METHODS

Anchoring Devices

1. In shallow parts of the river and during periods of relatively stable river levels, pairs of long iron rods were driven vertically into the river bed with their tips left exposed above the river surface. The two rods were generally spaced about 1.2 m apart so that attached substrates could be serviced from a freighter canoe anchored between them. No other method was discovered for anchoring artificial substrates (other than mesh containers of gravel) on or near the river bed. The substrates were readily set and collected with the aid of a hooked pole which could be slid down the anchor rod. The anchor rods were easily loosened and removed from the river bed by cranking and lifting them in a circular motion.

2. An anchor that was generally dependable in relatively deep water even when the river level was unstable consisted simply of two 10 kg or larger stones separated with a three to 10 m length of rope, or a single sealed five gal (23 l) can of gravel, dropped to the river bed (Figs. 1(a), 1(b)). A two m length of steel cable was attached to the anchor to resist abrasion on the river bed and a 10 to 30 m length of rope connected this cable to a pair of buoys (1-gal plastic jugs separated by about three m of rope) on the river surface. A tether rope seven to 10 m long was left trailing from the buoys and the substrates were attached to this. The rope from the anchors to the buoys had to make an angle of about 20° or less with the river bed to avoid lifting the anchors. Generally only floating substrates were tethered to the buoys. However mesh containers of gravel on the

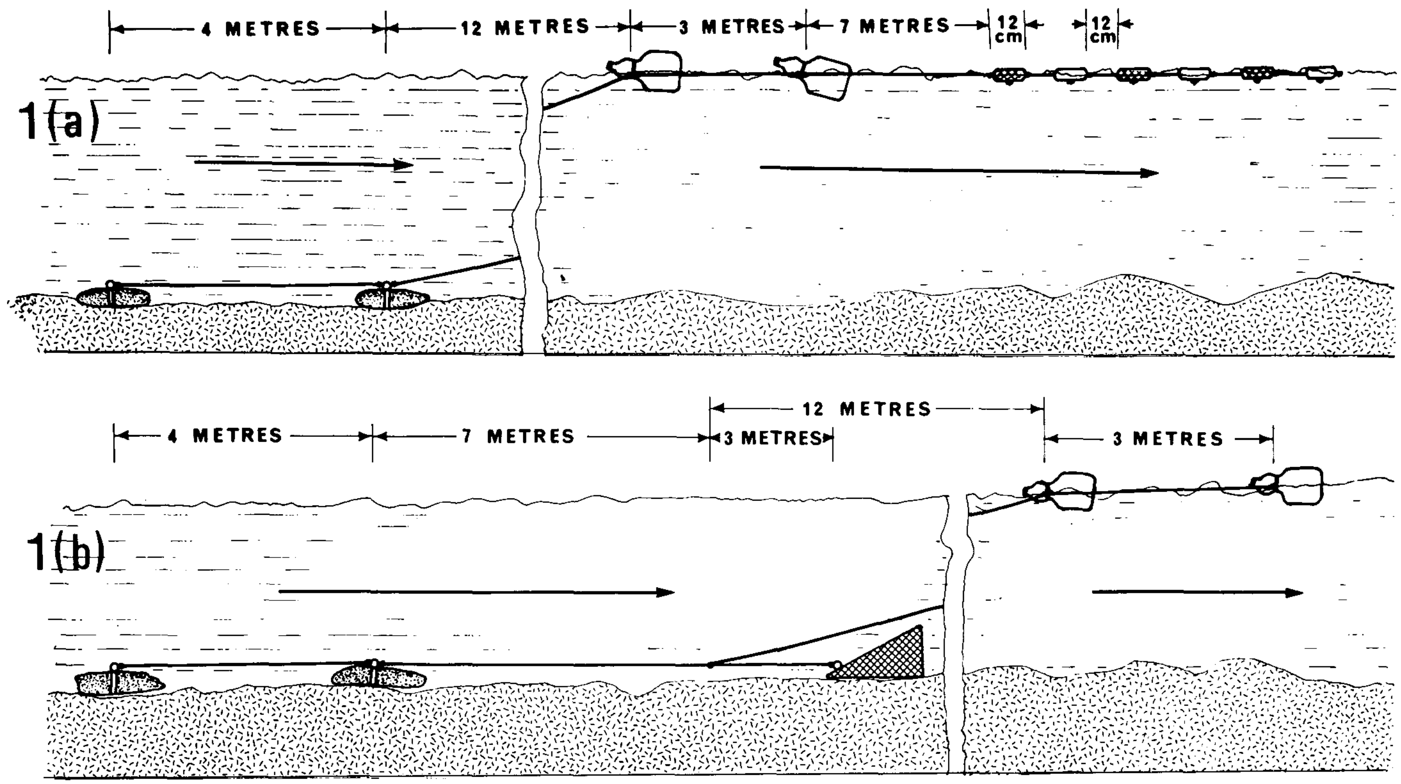

Fig. 1(a) and (b). Fig. 1(a). Anchors and buoys used to support artificial substrates on the surface of the Saskatchewan River. Arrow indicates direction of river flow. Fig. 1(b). Anchors and buoys used to support a wire-mesh basket of gravel on the river bed.

river bed were also successfully tethered and retrieved (Figs. 1(b), 2).

The senior author used such anchors continuously for six months or more in recent years with losses of about 10–20%. To minimize effects of losses, sets were at least duplicated. Some losses occurred when trees or branches became entangled in anchor ropes and the pressure either forced the buoys under or carried the anchors downriver. Masses of filamentous algae drifting down some rivers caused similar problems. Some submerged buoys were retrieved by dragging. Loss also occurred when the river level fell, allowing a portion of an anchor rope to lie on the river bed where it could be cut on sharp rocks.

3. The most reliable anchor of all was a 220 m fine steel cable or one cm diameter polypropylene rope stretched across the entire river, high enough above the water to allow canoeists to travel under it. This was strong enough to support 10 sets of substrates plus a pontoon craft for the entire summer. Tether ropes were clamped to this cable or rope at designated points and a gallon jug, about half filled with water and floating on the river surface was tied to each tether as a stabilizing buoy. (Without the water a buoy could be lifted by the wind.) Pairs of substrates were sampled from a canoe tied to a middle third tether.

In deploying the cable or rope, one end was clamped to a tree high above the water surface and the remainder was stretched upstream along the shore. Gallon jugs were used to float the cable; the rope floated by itself. The free end was attached to the rear end of a motorized canoe and towed across and downriver in an arc. Extra rope was allowed to compensate for the large belly that developed in the faster mid-section of the river. In passing the far shore it was hooked into an anchored rope piece. A chain hoist was required to elevate the cable or rope above the river surface.

Debris such as trees or masses of algae generally floated underneath the tethers and seldom became entangled. However, when considerable debris floated down the river, the quality of insect collections from the floating substrates may have been questionable. This was not investigated.

Artificial Substrates

Among the substrates anchored or pinned near the river bed the most practical included:

1. A wire mesh (openings 1 x 2 cm) closed basket, pyramid shaped and filled with two l of crushed gravel, one to two cm in diameter (Figs. 1(b), 2). This basket was retrieved from the river bed by lifting it with the buoy rope and was placed in a tub held at the water surface.

2. Pairs of rigid vertical plates, each 10 x 10 cm (Fig. 3). These plates were composed of expanded aluminum mesh (3 x 6 mm openings) or smooth acrylic plastic, plain or enclosed in an envelope of clear, smooth polyethylene film, 0.002 cm thick. They were clamped vertically in pairs onto an angle iron frame and faced the current at an angle of 45°. These vertical plates differed from the multiple horizontal plate sampler of Hester and Dendy (1962) mainly because the water struck the faces of these plates but the thin edges of theirs. Our plates offered maximal surface areas for the larvae of those species of *Simulium* that normally colonize the leading oblique surfaces of boulders.

The angle iron frame had rings welded onto it to allow it to be attached to a vertical post down which the frame could be slid to the river bed. The frame could be retrieved with a hooked rod, also slid down the anchor post and engaged into an eye on the end of the frame.

3. Rigid cones, with a 45° slope and a surface area of 200 cm^2 including both sides (Fig. 4). These cones were composed of expanded aluminum mesh and used plain or covered on the upstream side with a polyethylene film. The cones were attached to a frame with a twist of soft wire, and the frame pinned to the river bed as shown in Fig. 4.

Substrates which proved most practical on the river surface included:

1. A flexible vinyl plastic ribbon (red or white "seismic tape"), 0.001 cm x 2.56 cm x 19.5 cm

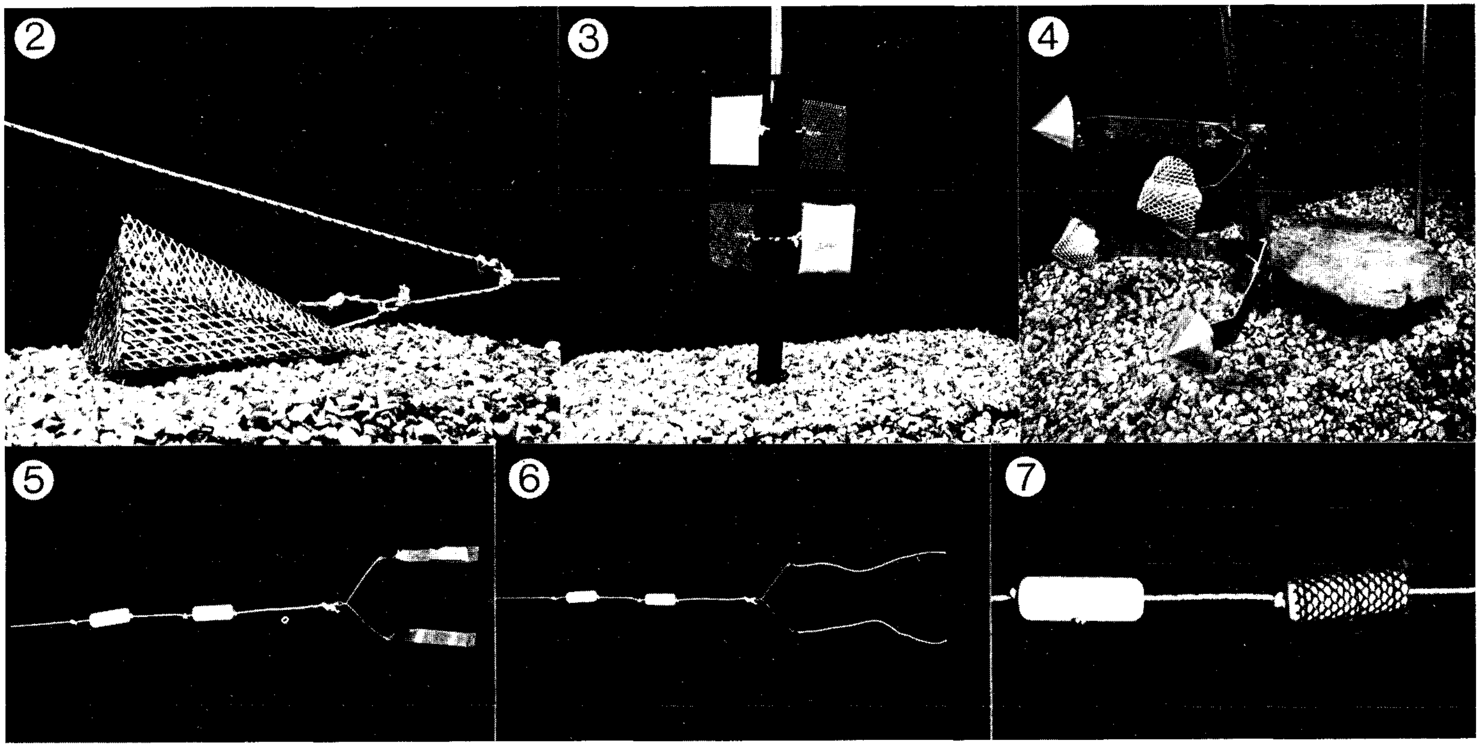

Fig. 2–7. Fig. 2, Wire-mesh basket of gravel on the river bed. Fig. 3. Pairs of expanded aluminum mesh and polyethylene-covered plates clamped in vertical positions to a frame supported on an iron post driven into the river bed. Fig. 4. Pairs of expanded aluminum mesh and polyethylene-covered cones attached to a frame supported by iron posts driven into the river bed. Fig. 5. Vinyl ribbons attached in pairs to a wire yoke and supported on the river surface by a pair of fish-net floats. Fig. 6. Pieces of polypropylene rope supported in pairs on the river surface. Fig. 7. Part of a long chain of plastic fish-net floats. Each float is weighted on one side with a metal screw and one of the floats is wrapped in a neoprene-impregnated cotton mesh material

(a surface area of 100 cm^2 including both sides). These were tied either singly or in pairs to a wire yoke supported by fish-net floats (Fig. 5).

2. A polypropylene rope, diameter 0.5 cm, with the ends heat-sealed to prevent unravelling The surface area of a 64 cm length of this rope was 100 cm^2. These were deployed either singly or in pairs attached to a wire yoke supported by fish-net floats (Fig. 6). When a long piece was used it was marked at 64 cm intervals with fluorescent paint to allow collecting of precisely measured pieces with shears.

3. Fish-net floats of rigid plastic, each 12 cm long and four cm in diameter (ca. 100 cm^2), weighted on one side with a metal screw to prevent rolling. These floats were threaded singly or in series onto a 0.5 cm polypropylene rope (Fig. 7). Knots in the tope kept the floats separated about 12 cm from one another.

4. Fish-net floats as above but wrapped in neoprene impregnated netting (openings about 6 x 10 mm) (Fig. 7). The submerged surface area of one of these floats, including the netting, was about 150 cm^2.

Collecting and Preserving

When a substrate (especially a float or a piece of rope) was collected, care was required to avoid moving or lifting adjacent substrates from the water. Substrates were collected into plastic bags, at the water surface if possible, and preserved in 95% alcohol.

TESTS

Test 1

Seven kinds of substrates were compared simultaneously at one site, not in connection with a larvicide test, in the South Saskatchewan River in 1969. They were anchored individually in shallow rapids in the margin of the river and were serviced by wading out from shore, during a period when the river volume was stationary. The tests included single vinyl ribbons, short ropes and plain weighted fish net floats on the river surface, and aluminum mesh and polyethylene covered vertical plates and cones, anchored near the river bed on rods. Complete sets were anchored on 8 August, 26 August and 11 September and were exposed for 18, 16, and 14 days, respectively. The water was clear with velocities of 84 to 108 cm/sec on the surface and 74 to 105 cm/sec near the river bed. The average depth was about 60 cm. Unlike later tests where *S. arcticum* was the predominant black fly species, in this test only 6% were *S. arcticum,* 92% were *S. vittatum* and 2% were other species. Larvae of stoneflies and mayflies were scarce and were not separated during sorting.

Results. – Black fly larvae showed a preference for colonizing rope pieces on the river surface and polyethylene-covered plates near the river bed (Table 1). Relatively dense populations also occurred on aluminum mesh plates near the river bed. All other taxa showed preferences firstly for mesh plates and secondly for mesh cones. Caddis larvae (mainly Hydropsychidae) also were relatively abundant on rope on the river surface. Coefficients of variation generally ranged in indirect proportions to the means. Thus polypropylene ropes provided the densest and most reliable counts of populations of black fly larvae, and mesh plates and mesh cones the densest and most reliable counts of populations of non-simuliid taxa.

A few eggs of *S. vittatum* were laid on some of the single floats but less than 5% of the larval populations on those floats could have originated from the eggs as estimated from egg shell counts.

Debris accumulated on the mesh plates and cones (but not on the smooth substrates) presumably enhancing their value as substrates, especially for non-simuliid larvae.

Vinyl ribbons and plain fish net floats provided the most efficient means for collecting

Table 1. Mean densities of aquatic insect larvae and pupae per collection from seven different artificial substrates, anchored in the South Saskatchewan River, August and September 1969.

Substrate*		Vinyl ribbon		Polypropylene rope		Plain weighted float		Aluminum mesh plate		Polyethylene-covered plate		Aluminum-mesh cone		Polyethylene-covered cone	
Location of substrate		RIVER SURFACE						RIVER BED							
Estimated cost per sample (man-hours)		0.3		0.4		0.3		0.7		0.5		0.7		0.5	
Number of samples**		12		12		8		18		16		12		12	
Statistics†		$\bar{x}$	C.V.	$\bar{x}$	C.V.	$\bar{x}$	C.V.	$\bar{x}$	C.V.	$\bar{x}$	C.V.	$\bar{x}$	C.V.	$\bar{x}$	C.V.
Simulium	pupae	15.4^{ab}	78	11.1^{abc}	81	2.8^{c}	131	2.4^{c}	138	22.1^{a}	43	4.8^{bc}	133	9.0^{abc}	69
"	larvae >1 mm	13.3^{cd}	33	56.0^{a}	16	7.6^{d}	47	30.1^{bc}	43	34.1^{ab}	16	6.4^{d}	53	19.0^{c}	38
"	larvae < 1 mm	1.0^{c}	126	9.0^{a}	37	6.4^{a}	83	6.1^{ab}	78	1.6^{bc}	71	0.8^{c}	166	0.9^{c}	142
Chironomidae	larvae >1 mm	4.0^{bcd}	94	4.5^{b}	31	0.9^{d}	192	62.7^{a}	25	4.2^{bc}	58	39.8^{a}	15	1.5^{d}	112
"	larvae < 1 mm	10.9^{bc}	103	9.7^{b}	43	0.8^{c}	208	74.8^{a}	58	4.6^{bc}	103	40.5^{a}	37	2.8^{bc}	87
PLECOPTERA‡	larvae >1 mm	0.8^{c}	166	1.8^{b}	66	0.1^{c}	283	15.6^{a}	58	0.6^{bc}	112	3.2^{b}	96	0.2^{c}	234
"	larvae < 1 mm	2.5^{bc}	184	1.3^{bc}	103	0.0^{c}	–	20.3^{a}	77	0.1^{c}	273	12.8^{b}	153	0.4^{c}	255
TRICHOPTERA	larvae >1 mm	4.3^{dc}	68	54.3^{a}	36	1.5^{d}	112	216.2^{a}	17	11.5^{b}	46	210.8^{a}	13	7.8^{bc}	43
"	larvae < 1 mm	3.8^{bc}	152	8.1^{b}	67	0.3^{c}	185	20.6^{a}	47	0.5^{c}	158	29.6^{a}	44	0.8^{c}	166

*Each ribbon, rope and float had a surface area of 100 cm^2; each plate and cone had a surface area of 200 cm^2 including both sides.

**Three complete sets of substrates were anchored in the river for each 18, 16, and 14 days respectively. Four floats and two polyethylene covered plates were lost.

†Coefficients of variation ($\frac{100\,\sigma}{\bar{x}}$) were calculated from log 10 (n + 1) values but the means were calculated arithmetically. Means with the same superscripts within each row are not significantly different (P > 0.05) using Duncan's New Multiple Range Test on the untransformed data.

‡ Including undetermined proportions of Ephemeroptera.

quantitative samples of larvae (about 0.3 man-hours per sample) and aluminum mesh plates and cones the least efficient (0.7) (Table 1). This efficiency was related in part to the ease with which the substrates could be anchored and collected and in part to the amount of debris that had to be removed from the samples before they could be analyzed.

Test 2

Three kinds of floating substrates were compared in seven sites in a 65-km section of the Saskatchewan River during two larvicide tests in May and early June of 1971. The river bed at these sites consisted mainly of compacted cobblestones and surface water velocities ranged from 85 to 170 (mean 120) cm/sec. Volume flow was about 300 m^3/sec and slowly declined.

At one site the substrates were anchored to an overhead cable but in all other sites they were attached with 10 m tethers to buoys anchored one third and two thirds of the way across the river. They were serviced from a motorized canoe.

A complete set of all three kinds of substrates (a plain fish net float, a mesh-covered float, and a piece of rope, connected in series) was attached to each tether for eight to 14 days. Data from 30 complete, untreated sets of each kind of substrate were used in this study.

Results. – Aquatic environments varied considerably between the seven sites. Thus the data were skewed and were converted to log 10 values before the means and coefficients of variation shown in Table 2 were calculated. Means given in the table have been converted back to arithmetic units.

Table 2. Mean densities of aquatic insect larvae and pupae per collection from three different artificial substrates anchored for 8 to 14 days in the North Saskatchewan River, May, 1971

Substrate*		Polypropylene rope		Plain, weighted fish-net float		Mesh-covered, weighted fish-net float	
Location of substrate		On the river surface					
Estimated cost per sample (man-hours)		0.4		0.3		0.6	
Statistics**		Mw	C.V.	Mw	C.V.	Mw	C.V.
Simulium	pupae	1	363	2	168	1	200
"	larvae >1 mm	64[a]	54	83[a]	39	45[a]	54
"	larvae <1 mm	16[a]	66	9[a]	65	10[a]	78
Chironomidae	larvae >1 mm	9[a]	62	1[b]	176	15[a]	35
"	larvae < 1mm	4[a]	70	1[b]	142	5[a]	59
PLECOPTERA	larvae >1 mm	1[a]	305	1[a]	206	3[b]	103
"	larvae< 1 mm	0	–	0	–	1	548
EPHEMEROPTERA	larvae >1 mm	3[a]	116	1[b]	199	8[c]	52
"	larvae < 1 mm	2[a]	140	1[b]	190	4[c]	84
TRICHOPTERA	larvae >1 mm	3[a]	130	1[b]	165	6[c]	77
"	larvae< 1 mm	1	206	1	381	1	233

*Each mesh-covered float had a submerged surface area of about 150 cm^2; each unit of the other two substrates had a surface area of 100 cm^2.

**Mw(Geometric mean) (Haddow 1960) and coefficients of variation ($\frac{100\,\sigma}{\bar{x}}$) were calculated from log 10 (n+1) values. Means with the same superscripts within each row are not significantly different ($P > 0.05$) using Duncan's New Multiple Range Test on the transformed data.

Mean populations of simuliid larvae (mainly *S. arcticum*) larger than one mm long and pupae were densest (differences not significant $P > 0.05$), and coefficients of variation smallest, for plain floats (Table 2). Populations of simuliids were least dense on the mesh-covered floats (differences not significant). These results differed from those in Test 1 possibly because of differences in river velocities, species, and the fact that these substrates were attached together in series, with the rope piece at the downstream end.

Mesh floats provided densest populations of non-simuliid taxa but densities of chironomid larvae were not significantly different from those on polypropylene rope. Polypropylene ropes provided samples of intermediate densities of both simuliid and non-simuliid taxa and provided relatively good manpower economy (about 0.4 man-hours per sample). During subsequent tests of larvicides for black flies, we were concerned about larvae of all insect orders with aquatic members and came to depend upon rope and mesh-covered floats as substrates to provide comparisons of populations before and after treatments.

Test 3(a)

In this test the distribution of larvae along chains of 10 plain, weighted floats and along ropes cut into 10 serial pieces was studied. The site and dates of sampling were identical to those in Test 1. There were six replicates of each kind of substrate.

Results. – Populations of simuliids (larvae plus pupae of *S. vittatum*) on chains of 10 floats were about six times denser than those on long ropes and were distributed less uniformly (Fig. 8). This happened because *S. vittatum* females had laid many masses of eggs on the floats but very few eggs on the ropes. Thus presumably the chains of floats were populated mainly by larvae that had hatched from these eggs whereas the ropes were populated mainly by larvae that had been drifting in the river. (Relatively few eggs were laid on single floats anchored in the same sites in Test 1.) Caddis larvae (mainly Hydropsychidae) were denser and more uniformly distributed along the ropes than along the chains of floats (Fig. 8).

Test 3(b)

The purpose of this test in September 1970 was to study distribution of black fly larvae, mainly of *S. arcticum*, along chains of three plain, weighted floats, and along short ropes, each cut into three serial pieces with surface areas of 100 cm^2 each. (During a larvicide test it was convenient to anchor substrate sets of three units each, of either floats or ropes about two weeks in advance of the treatment. The distal (furthest from anchor) piece of each set was collected immediately before chemical treatment, the middle piece immediately afterwards, and the proximal piece a week or more after treatment.)

This test was similiar to Test 3(a) in that a single site in shallow rapids was used. However, this site was located in the North Saskatchewan River where 99.97% of the black fly larvae were *S. arcticum*, the target species in larvicide tests. Ten replicates of each substrate were set and each was tied at the water surface to a single iron stake driven into the stony river bed and left in place for two weeks. Mean water velocity near the 10 ropes was 89 cm/sec (maximum = 107) and near the 10 chains of floats was 95 (maximum = 110) cm/sec.

Results. – These substrates were colonized entirely by larvae drifting in the water because *S. arcticum* females "bomb" their eggs singly into the river and do not attach them in masses to substrates as do females of *S. vittatum*. Distribution of larvae and pupae along chains of three floats was relatively uniform; larvae were distributed less uniformly along the short ropes (Fig. 8). Populations of larvae were densest towards the downstream ends of the ropes presumably because these short ropes did not lie straight in the water but were slightly curved laterally according to the way they had been wound on the spool of rope. Following completion of these tests, we have made it a practice to straighten the ropes by stretching, before anchoring them in the

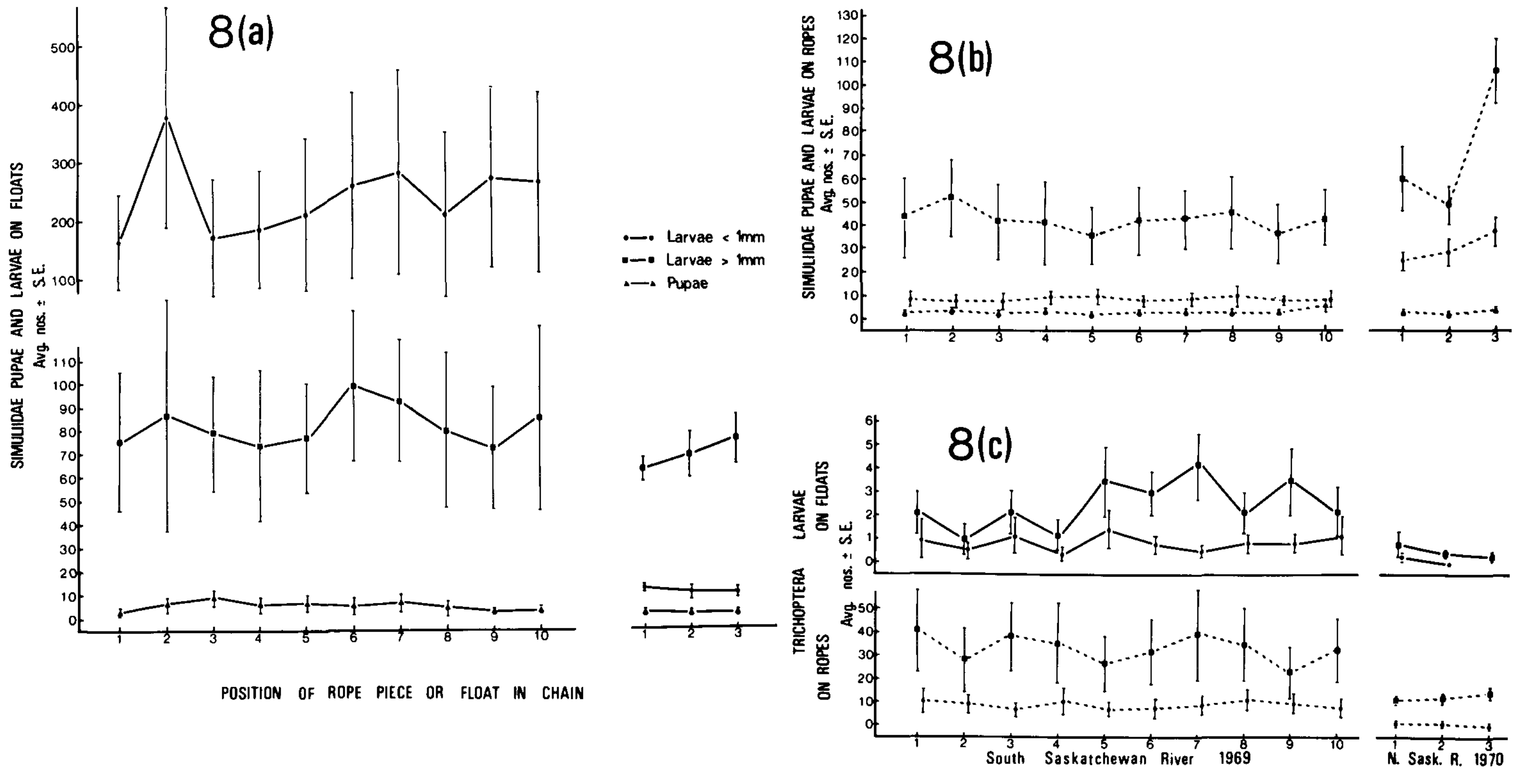

Fig. 8(a), (b), and (c). Fig. 8(a). Average number of simuliid larvae and pupae attached to long chains (10 floats) and short chains (3) of plain, weighted fish-net floats anchored in the Saskatchewan River in 1969 and 1970. Position 1 is the upstream end. Fig. 8(b), Average numbers of simuliid larvae and pupae attached to serial sections of long (640 cm) and short (192 cm) pieces of 0.5 cm diameter polypropylene rope anchored in the Saskatchewan River in 1969 and 1970. Position 1 is the upstream end. Fig. 8(c). Average numbers of Trichoptera larvae and pupae attached to long and short chains of floats, and ropes anchored in the Saskatchewan River in 1969 and 1970. Position 1 is the upstream end.

river.

Trichopterans also were densest on the ropes, but were distributed relatively uniformly along either the long or short ropes (Fig. 8(c)).

Populations of chironomid larvae (data not included in Fig. 8) were not distributed uniformly along either the long or short chains of floats. As with *S. vittatum* in Test 6, chironomid females laid masses of eggs on floats, particularly those at the upstream or anchored end, resulting in relatively dense populations of larvae there. Few eggs were laid on the ropes and there, larvae were distributed relatively uniformly. On the short ropes densest populations occurred at the downstream ends, presumably for reasons discussed above for the Simuliidae.

Densest populations of stonefly larvae occurred on the downstream ends of the short ropes, presumably for the same reason.

Mayfly larvae were distributed relatively uniformly along either the long chains of floats or the long ropes but populations were densest on the ropes. Populations were not uniformly distributed along the short ropes, presumably for the reasons discussed above.

Test 4

The purpose of this test (same site and dates as in Test 3(b)) was to determine if there were differences in densities of larvae attaching to vertical plates (Fig. 3) anchored at three different elevations above the river bed. (In some larvicide tests, plates were anchored in this way, with the top set being collected immediately before a test, the middle set immediately afterward and the bottom set one or more weeks later.) Thus in this test three pairs of plates (aluminum mesh and polyethylene covered in each pair) were attached to each of 10 stakes for two weeks. The bottom, middle and top pairs of plates were centered about 10, 23, and 36 cm, respectively, above the river bed where the mean water velocities were 69 (maximum 95), 77 (98) and 82 (106) cm/sec and the average depth of the water was about 70 cm.

Results. – Data from this test (Table 3) showed that the position of a plate substrate (whether centered 10, 23, or 36 cm above the river bed) had only a slight effect on the density of the population that colonized it. Populations on the top or middle polyethylene-covered plates were generally denser than populations on the lower plates (differences not significant), except for populations of black fly larvae which were relatively dense at all three depths. On the mesh plates populations of most taxa also were denser on the top or middle plates rather than on the lower plates. However, populations of caddis larvae were densest on the lower plates (differences not significant). Inverse relationships generally existed between the densities of populations of simuliids and mayflies, with those of the chironomids, stoneflies and caddis larvae.

As in previous tests, populations of black fly pupae, and of larvae larger than one mm long, were denser on the polyethylene-covered plates than on the mesh plates and populations of all other taxa were densest on the mesh plates.

Test 5

The pupose of this test, done in the same site as Tests 3(b) and 4, was to determine approximately how much time was required for populations of aquatic insect larvae to stabilize on four different substrates: aluminum mesh and polyethylene-covered plates anchored near the river bed, and short ropes and plain weighted fish net floats on the river surface. Twelve sets of each were collected after seven days of exposure, four sets after 14 days and four after 21 days.

Results. – Populations of black fly larvae on mesh plates had attained maximum densities by the end of the first week of exposure of these substrates (Table 4). Thereafter populations declined, presumably because of competition and predation by rapidly increasing numbers of non-black fly species. On ropes, maximum densities of black fly larvae were observed by the end of the second week. On floats and polyethylene-covered plates densities continued to increase right up to the end of the tests (three weeks).

Table 3. Mean densities of aquatic insect larvae per collection from polyethylene-covered plates and aluminum mesh plates anchored at three different depths in the North Saskatchewan River, September 1970.

Substrate*		Polyethylene-covered plates						Aluminum-mesh plates					
Estimated cost per sample (man-hours)		0.5						0.7					
Statistics**		$\bar{x}$			C.V.			$\bar{x}$			C.V.		
Position of plates re river bed†		T	M	B	T	M	B	T	M	B	T	M	B
Simulium	pupae	3.6	3.2	2.9	102	102	111	0.4	0.3	0.2	175	161	316
"	larvae >1mm	141.5	159.6	152.5	42	35	20	67.3	62.4	65.7	39	39	74
"	larvae <1 mm	35.8	36.6	33.6	59	36	35	56.3	52.3	56.4	37	40	49
Chironomidae	larvae >1 mm	7.8	3.1	2.3	162	115	80	178.3^{ab}	194.8^{a}	123.6^{b}	42	31	65
"	larvae <1 mm	1.8	0.7	1.1	159	179	198	27.4	28.2	24.3	70	61	134
PLECOPTERA	larvae >1 mm	2.2	1.3	1.0	90	141	105	65.9^{ab}	75.6^{a}	23.2^{b}	103	65	63
"	larvae <1 mm	0.0	0.0	0.0	–	–	–	5.6	7.0	2.8	101	103	157
EPHEMEROPTERA	larvae >1 mm	0.5	0.4	0.3	141	129	225	5.2	3.7	5.3	69	62	117
"	larvae <1 mm	0.0	0.1	0.0	–	316	–	0.7	0.4	0.6	69	129	116
TRICHOPTERA	larvae >1 mm	3.5	1.0	2.8	141	141	80	49.8	63.7	59.6	27	38	46
"	larvae <1 mm	0.1	0.2	0.1	316	211	316	3.4	4.0	3.8	80	91	65

*Each plate had a surface area of 200 cm^2 including both sides and was replicated 10 times at each depth.

**Arithmetic means: C.V. = $\frac{100\sigma}{\bar{x}}$ from untransformed data. Means with the same superscripts within each row (each substrate treated separately) are not significantly different ($P > 0.05$) using Duncan's New Multiple Range Test on the untransformed data.

†T = top plate, centered 36 cm above river bed; M = middle plate, centered 23 cm above river bed; B = bottom plate, centered 10 cm above river bed.

Populations of larvae of chironomids, stoneflies and mayflies continued to increase in density on all substrates right up to the end of the tests.

Populations of caddis larvae on substrates anchored near the river bed (polyethylene-covered and mesh plates) attained maximum densities by the end of the second week. Those on river surface substrates (ropes and floats) continued to increase in density to the end of the three-week test period.

As in previous tests, populations of simuliid larvae were significantly denser ($P > 0.05$) on polyethylene-covered plates and on polypropylene ropes than on floats or aluminum-mesh plates (Table 4). Populations of all other taxa were densest on the mesh plates.

At the end of the three-week exposure periods lowest coefficients of variation for population of black fly larvae and of chironomid larvae larger than one mm long occurred on polyethylene-covered plates. Lowest coefficients for all other taxa occurred on mesh plates. Of the two river surface substrates, polypropylene rope provided populations with the lowest coefficients for all taxa.

Test 6

Populations of larvae attached to two types of artificial substrates (a string of six mesh-covered floats on the river surface and a single two-l wire mesh container of gravel on the river bed) were compared with populations from two-l samples of sand collected from stable portions of shallow river margins during a larvicide test on the Saskatchewan River in May 1972. The substrates were anchored one third and two thirds of the way across the river in each of four sites in a 140-km section of the river. Most of the sets were exposed for 12–14 days, a few as long as 27 days in

Table 4. Mean densities of aquatic insect larvae and pupae per collection from four kinds of artificial substrates at the ends of 1, 2, and 3 weeks of exposure at one site in the North Saskatchewan River, September 1970.

Substrate*		Polypropylene rope					Plain-weighted fish-net float					Polyethylene-covered plate					Aluminum-mesh plate				
Location of substrate		RIVER SURFACE										RIVER BED									
Exposure period (days)		7	14	21	7–21	21	7	14	21	7–21	21	7	14	21	7–21	21	7	14	21	7–21	21
Number of replicates		12	4	4	20	4	12	4	4	20	4	12	4	4	20	4	12	4	4	20	4
Statistics**		Mw	Mw	Mw	Mw	C.V.	Mw	Mw	Mw	Mw	C.V.	Mw	Mw	Mw	Mw	C.V.	Mw	Mw	Mw	Mw	C.V.
Simulium	pupae	1	8	39	4^{ab}	19	1	2	6	2^{bc}	51	2	12	35	5^{a}	3	1	1	2	1^{c}	121
"	larvae >1 mm	85	185	177	114^{a}	13	28	54	87	40^{b}	20	82	293	373	143^{a}	5	35	27	24	31^{b}	12
"	larvae 1 mm	43	57	14	35^{a}	27	6	8	8	6^{b}	37	25	54	18	26^{a}	12	43	18	19	30^{a}	20
Chironomidae	larvae 1 mm	10	34	90	18^{b}	7	1	0	6	1^{d}	33	3	10	31	5^{c}	2	113	260	541	397^{a}	7
"	larvae <1 mm	3	7	11	4^{b}	32	0	0	1	1^{d}	200	1	3	4	1^{c}	36	15	21	65	20^{a}	8
PLECOPTERA	larvae 1 mm	2	2	11	2^{b}	14	1	0	3	1^{c}	35	1	3	7	1^{b}	26	20	82	127	37^{a}	5
"	larvae 1 mm	2	2	3	1^{b}	72	0	0	1	1^{c}	200	1	2	1	1^{c}	115	6	4	20	6^{a}	9
EPHEMEROPTERA	larvae 1 mm	1	1	2	1^{b}	72	0	0	1	1^{b}	200	0	0	2	1^{b}	73	4	11	12	5^{a}	13
"	larvae 1 mm	0	0	0	0^{b}	–	0	0	0	0^{b}	–	1	0	0	1^{b}	–	1	2	1	1^{a}	200
TRICHOPTERA	larvae >1 mm	3	15	18	5^{b}	16	0	0	2	1^{c}	73	1	2	2	1^{c}	116	18	103	93	34^{a}	3
"	larvae <1 mm	1	2	3	1^{b}	29	0	0	0	0^{c}	–	0	0	0	0^{c}	–	4	6	5	3^{a}	69

*Each float and rope had a submerged area of 100 cm^2; each plate had a submerged surface area of 200 cm^2 including both sides.

**(Geometric mean) (Haddow 1969) rounded to the nearest whole figure and C.V. $\left(= \frac{100\,s}{\bar{x}} \right)$ were calculated from log 10 (n + 1) values.

Means with the same superscripts within each row are not significantly different ($P > 0.05$) using Duncan's New Multiple Range Test on the transformed data.

untreated portions of the river. Each time substrates were collected, a two-l sample of sand (2,000 cm^2 x one cm thick) was collected with a shovel from about 60 cm of water near each river margin. Invertebrates were extracted from the sand with salt flotation and screens. The river volume flow was almost constant at about 250 m^3/sec and the suspended solids content of the water averaged about 50 mg/l.

Results.– Diversity indices of families of aquatic insects collected from 24 sets of floats, 27 baskets of gravel and 24 samples of sand were calculated using the formula of Shannon and Weaver (1963) as modified by Wilhm (1972): – $\bar{d} = -\Sigma\,[(ni/n)\log_2(ni/n)]$ where $\bar{d}$ = diversity within a set of samples, ni = number of specimens of the i^{th} family, n = total number of specimens of all families.

Wilhm showed that this formula was the most satisfactory of several that have been developed because (a) it most effectively expresses relationship between total numbers of families (or other taxonomic units) and of individuals and stresses the importance of each taxonomic unit collected, and (b) the index is relatively unaffected by sample size (total number of specimens).

Samples of larvae collected from baskets of gravel anchored on the river bed provided the largest diversity index (1.901) (Table 5). Samples collected from mesh-covered fish net floats anchored on the river surface also provided a relatively large index of 1.261. However, samples extracted from sand collected from stable portions of the river bed provided a very low index of only 0.074. (Samples from gravel or rock may have provided larger indices but none were collected.

Samples from the chains of floats yielded the largest mean populations of simuliids, those from sand samples the largest populations of chironomids, ephoronids and corixids and those from the baskets of gravel the largest populations of all other taxa. Actual densities cannot be compared because the surface areas of the sand, gravel and mesh-floats were not comparable.

Replicated samples were obtained relatively efficiently with the aid of the mesh floats. Collection and analysis of each sample from six mesh floats required only about 3.5 man-hours of work, whereas each sample from one basket of gravel or one sample of sand required about 10 man-hours.

This test demonstrates the importance (re accuracy and efficiency) of using artificial substrates for obtaining quantitative samples of aquatic insect larvae from a large river such as the Saskatchewan.

DISCUSSION

Introduction

A number of points require discussion: practical use of artificial substrates in a large river, comparisons of substrates in terms of manpower efficiency, comparisons of quality and size of collections in relation to substrate materials used, and effects of environmental variations such as duration of exposure and local site conditions on quality and size of collections. A discussion of the dynamics of drifting populations, as affecting colonization of artificial substrates also is included.

The Practical Use of Artificial Substrates to Obtain Quantitative Samples of Aquatic Insect Larvae from the Saskatchewan River.

The senior author has used artificial substrates for four main purposes:

(a) To compare populations of simuliid larvae in individual sites from year to year to determine whether or not larvicide treatments were required;

(b) To compare populations in series of sites before and after chemical larvicide treatments and to study rates of repopulation;

(c) To compare populations in non-larvicide pollution studies;

(d) To study growth and colonization rates of larvae of several species of *Simulium*.

The advantages of using artificial substrates to obtain quantitative samples included:

(a) The substrates could be anchored in almost any site thus allowing quantitative collections from sections of the river not amenable to dredging or coring.

(b) Artificial substrates allowed relatively efficient use of manpower since they were easily made, anchored and retrieved even from the deepest parts of the river. Also samples were readily packaged, and depending upon the kind of substrate used, samples could be obtained.

Table 5. Population densities per sample (mean values ± standard errors), and diversity indices, for populations of the aquatic larvae of 16 families of Diptera, Ephemeroptera, and Trichoptera, and of four other orders not sorted to families, on two kinds of artificial substrates exposed for 12–27 days, and in sand collected from the Saskatchewan River, May 1972.

	Chain of six mesh-covered floats	Basket of gravel	Sand from the river bed
Ceratopogonidae	0.0	1.3 ± 1.3	1.1 ± 0.6
Chironomidae	410.2 ± 102.1	703.9 ± 158.8	1058.6 ± 218.2
Simuliidae	2288.3 ± 943.1	41.0 ± 10.4	1.1 ± 0.5
Tipulidae	0.0	0.3 ± 0.2	0.0
TOTAL DIPTERA	2698.5	746.5	1060.8
Baetidae	0.6 ± 0.5	2.2 ± 1.1	0.0
Ephemerellidae	28.0 ± 8.1	38.7 ± 9.1	0.0
Ephemeridae	0.0	11.6 ± 10.9	0.0
Ephoronidae	0.3 ± 0.3	0.2 ± 0.2	2.0 ± 0.6
Heptageniidae	0.1 ± 0.1	9.3 ± 2.2	0.1 ± 0.1
Leptophlebidae	0.0	0.7 ± 0.3	0.0
Tricorythidae	0.1 ± 0.1	0.7 ± 0.2	0.6 ± 0.4
TOTAL EPHEMEROPTERA	29.1	63.4	2.7
Brachycentridae	1.0 ± 0.8	5.3 ± 2.8	0.4 ± 0.4
Hydropsychidae	335.0 ± 154.1	675.5 ± 166.7	0.8 ± 0.5
Hydroptilidae	0.1 ± 0.1	1.1 ± 0.7	0.0
Leptoceridae	0.0	0.1 ± 0.1	0.0
TOTAL TRICHOPTERA	336.1	682.0	1.2
TOTAL PLECOPTERA	77.1 ± 16.9	325.2 ± 82.2	0.1 ± 0.1
TOTAL COLEOPTERA	0.0	0.1 ± 0.1	0.0
TOTAL HEMIPTERA	0.0	0.1 ± 0.1	0.4 ± 0.4
TOTAL ODONATA	0.0	0.9 ± 0.7	0.4 ± 0.4
$\bar{d}$*	1.261	1.901	0.074

*Shannon's diversity index (Wilhm 1972): $\bar{d} = -\Sigma[(ni/n) \log 2 (ni/n)]$.

that were relatively clean and free from debris, thus simplifying sorting.

(c) The quality and quantity of samples of insect larvae could be controlled by varying the kind of substrate used and the kind of site it was anchored in. For example, polyethylene-covered plates were relatively attractive to black fly larvae and mesh plates to chironomids and caddisfly larvae.

(d) Substrate samples could be replicated more accurately than dredged samples.

The disadvantages of using artificial substrates included:

(a) The numbers of each taxon in a sample could not be presumed to be exactly proportional to the actual numbers inhabiting the river benthos because colonization of the substrates was dependent upon drifting populations. Drift rates are known to vary greatly between taxa, growth stages and a variety of environmental factors, none of which have been studied in this particular river. However, when a series of identical substrates was exposed throughout the same period of time the quality of individual samples was presumed to be approximately equally affected by many of these factors.

(b) Larvae of some taxa such as Odonata, Hemiptera and certain species of other orders rarely attached to artificial substrates.

(c) Duration of exposure required for maximum colonization by each taxon varied with the substrate used and with the site and season it was anchored in but otherwise was imperfectly known.

(d) Substrates were sometimes lost when anchors were disturbed. This problem generally could be circumvented by duplicating sets in each site.

Comparisons of Substrates in Terms of Manpower Efficiency

When large numbers of quantitative samples are required, manpower efficiency should be considered when selecting a substrate. Labour requirements were estimated for each type of substrate tested in terms of: – (a) fabrication of the substrates, anchors and buoys, (b) anchoring and retrieving individual substrates, exclusive of travel time between sets, and (c) concentrating and sorting the collections.

Smooth substrates anchored on the river surface such as vinyl ribbons and plain fish-net floats required an average of only about 0.3 man-hours per sample. They were readily fabricated, anchored and retrieved, and larvae were easily removed from them and were relatively free from debris which simplified sorting. Polypropylene rope also allowed good efficiency although larvae were less readily removed and the samples contained larger amounts of debris.

Polypropylene rope has been used in our larvicide tests more often than any other substrate. It has the additional advantages of being readily procurable and remaining submerged just under the water surface where it does not attract adult simuliids or chironomids searching for oviposition sites.

Mesh-covered fish-net floats required a longer time to make and the samples contained large amounts of debris and complex insect populations which required considerable time for sorting.

Substrates anchored near the river bed required relatively large amounts of time for fabrication, anchoring and retrieving. Such substrates generally collected more debris than those on the river surface but again this depended in part upon whether the substrate surface was smooth or complex.

Samples obtained from wire mesh baskets of gravel on the river bed were complex and heavily laden with debris and silt. Mainly for these reasons such samples required 15 to 35 times more time for sorting than did samples from other types of substrates.

Comparisons of Substrate Materials

These substrates were developed and tested in the north and south branches of the Saskatchewan River in sets of three or more during four different years. Ecological conditions varied between and within tests, precluding precise comparisons. General conclusions are possible however:

(a) The smooth surfaces of vinyl ribbons, plain fish-net floats, acrylic plates and polyethylene-covered plates were densely colonized by simuliid larvae but relatively sparsely by other taxa. Samples of larvae were readily removed from these smooth substrates and were relatively free from debris.

(b) Rough, complex surfaces such as mesh-covered fish-net floats and aluminum mesh plates were generally colonized by relatively few simuliid larvae but numerous larvae of non-simuliid taxa. Total populations of insect larvae were denser and more complex than those on smooth surfaces. However, larvae were difficult to remove from rough surfaces and the samples contained relatively large amounts of debris which made sorting difficult.

(c) Populations of all taxa on ropes were generally intermediate in density and complexity to those found on smooth or very rough substrates.

(d) Baskets of gravel anchored for 12–27 days on the river bed provided samples yielding larger numbers of species and higher diversity indices than mesh-covered floats on the river surface. Sand collected directly from stable portions of the river bed yielded samples with lower diversity indices.

(e) Debris and filamentous algae accumulated much more readily on rough surfaces than on smooth surfaces and this debris obviously improved the niches offered non-simuliid larvae. Amounts of debris varied with the season, thus introducing an additional bias.

Effects of Varying Duration of Exposure

During four years of tests with artificial substrates various exposures of three to 27 days were used and all provided measurable populations of larvae of four major orders – Diptera, Plecoptera, Ephemeroptera and Trichoptera. In one test, however, where substrates were collected at one, two or three-week intervals, populations of simuliid larvae attained maximum densitites on mesh plates by the end of the first week, on ropes by the end of the second week and on plain fish-net floats and polyethylene-covered plates by the end of the test (three weeks). Caddisfly larvae attained maximum densities on river bed substrates (mesh and polyethylene-covered plates) by the end of the second week, and on river-surface substrates by the end of the test regardless of substrate texture. All other taxa required at least three weeks to attain maximum densities on all substrates. Thus the rate at which each taxon accumulated on an artificial substrate depended in part upon the kind of substrate used and also the site in which it was anchored.

Stable population densities were not attained and this is not surprising in view of the numerous ecological factors involved such as seasonal fluctuations in physical, chemical, and biological conditions, differing life cycles of the various insect species involved, and interactions between species. Thus each new situation requires research to determine the approximate exposure period required for each taxon to attain maximum density. For purposes of studying downriver carry of a single injection of insecticide however, duration of exposure is not too important because percentage reductions in populations are calculated for each station individually.

Effects of Local Variations in Sites

Mean densities of populations of most taxa colonizing plate substrates anchored at three different elevations (10, 23, and 36 cm above the river bed) varied only slightly between elevations and generally in proportion to mean water velocities (69, 77, and 82 cm/sec respectively). Densities of populations of black fly and mayfly larvae generally varied inversely with those of chironomid, stonefly and caddis larvae suggesting in part prey-predator relationships.

On long ropes and chains of floats anchored on the river surface, larvae were distributed fairly uniformly from one end to the other. Major exceptions occurred when eggs of *S. vittatum* and of Chironomidae were laid on some of the floats (not on ropes) or when a rope did not lie straight in the water and thus different sections were in contact with varying quantities of flowing water at different points along its length according to whether portions of the rope lay parallel to or across the current. These results indicate the importance of straightening a rope before it is anchored in the river.

During some larvicide tests the senior author has depended upon series of plates anchored vertically above the river bed, or long ropes or chains of floats on the river surface, collecting serial pieces before and after treatment in check sites as well as in treated sites. Such samples of larvae are believed to have provided adequate comparisons of effects on larvae in exposed sites, when the above-noted problems with river-surface substrates were avoided.

General Comments Regarding Colonization of Artificial Substrates in a River

Artificial substrates anchored in a river are completely dependent upon drifting larvae for colonization unless those substrates are in direct contact with the river bed or are situated on the river surface where they may be populated by larvae hatching from eggs laid on them. Larvae of dragonflies, hemipterans and beetles, and burrowing species of all taxa, even though relatively abundant, seldom occurred on substrates anchored in the Saskatchewan River. Although factors affecting drift rates are imperfectly understood, the fact that drifting larvae will attach themselves to artificial substrates provides a means for certain qualitative and quantitative studies of those larval populations.

Three general kinds of drift have been recognized by Waters (1972). "Constant" drift occurs at a low level mainly as a result of accidental displacements. "Behavioural" drift is inherent, diurnally cyclical and believed to be largely density dependent. It accounts for major portions of drifting populations except in the event of "catastrophic" drift (Anderson and Lehmkuhl 1968) brought about by sustained deterioration of the habitat. Catastrophic drift was not a factor in our studies. Normally two major spates occur each year in the Saskatchewan River. The first of these, usually in April, is caused by snow melt on the plains combined with the damming effects of river ice during the break-up period. In midsummer a second series of spates occurs as a result of snow melt and precipitation in the mountains. None of our studies was perfomed during these periods.

Each species of larva and probably each instar as well may be affected differently by the various physiological and environmental conditions governing drift rates. Drift rates in relatively small, clear rivers, studied by various authors, were affected largely by competition for space, life stage, the diel environmental cycle (especially regarding light and temperature), water velocity and discharge rate changes. The extent to which such conditions governed drift rates in the large, silty Saskatchewan River were not determined. Even so, variations in densities of each species colonizing artificial substrates anchored in various sites in the Saskatchewan River at any given period of time were believed to be roughly proportional to variations in densities of the resident benthic populations that give rise to them. The kind of substrate used, duration of exposure and various local site conditions also affected densities of immigrant colonists but these were generally controllable variables.

CONCLUSIONS

These tests and data from nine years of additional use of artificial substrates in black fly larvicide tests (Fredeen 1974) and other studies commencing in 1969, indicate that artificial substrates can provide practical means of obtaining semiquantitative samples of black fly larvae and certain other aquatic insects from previously inaccessible portions of large rivers. Although one may have reservations about accuracy, at least samples may be efficiently replicated, with considerable control over quality depending upon the kinds of substrates used. Still required is a thorough understanding of the dynamics of the drifting and colonizing behaviour of populations of insect larvae before the full potentials of artificial substrates can be realized.

ACKNOWLEDGEMENTS

We are indebted to Gordon Glen for his assistance throughout this research, and to Drs. George E. Ball, J.F. Doane, L. Burgess and an unknown referee for reviewing the manuscript.

REFERENCES

Anderson, N.H., and D.M. Lehmkuhl. 1968. Catastrophic drift of insects in a woodland stream. Ecology 49: 198–206.

Arnason, A.P., A.W.A. Brown, F.J.H. Fredeen, W.W. Hopewell, and J.G. Rempel. 1949. Experiments in the control of *Simulium arcticum* Malloch by means of DDT in the Saskatchewan River. Scientific Agriculture 29: 527–537.

Benfield, E.F., A.C. Hendricks and J. Cairns, Jr. 1974. Proficiencies of two artificial substrates in collecting stream macroinvertebrates. Hydrobiologia 45: 431–440.

Carlsson, G. 1962. Studies on Scandinavian blackflies (Fam. Simuliidae Latr.). Opuscula Entomologica Supplementum 21: 1–279.

Coleman, M.J. and H.B.N. Hynes. 1970. The vertical distribution of the invertebrate fauna in the bed of a stream. Limnology and Oceanography 15: 31–40.

Crossman, J.S. and J. Cairns, Jr. 1974. A comparative study between two different artificial substrate samplers and regular sampling techniques. Hydrobiologia 44: 517–522.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67: 2. 477–504.

Curtis, L.C. 1968. A method for accurate counting of blackfly larvae (Diptera: Simuliidae). Mosquito News 28: 238–239.

Dickson, K. L., J. Cairns and J.C. Arnold. 1971. An evaluation of the use of a basket-type artificial substrate for sampling macroinvertebrate organisms. Transactions of the American Fisheries Society 100: 553–559.

Disney, R.H.L. 1972. Observations on sampling pre-imaginal populations of blackflies (Dipt. Simuliidae) in West Cameroon. Bulletin of Entomological Research 61: 485–503.

Fredeen, F.J.H., A.P. Arnason, B. Berck and J.G. Rempel. 1953. Further experiments with DDT in the control of *Simulium arcticum* Malloch in the North and South Saskatchewan Rivers. Canadian Journal of Agricultural Science 33: 379–393.

Fredeen, F.J.H. 1972. The temporary abatement of nuisance species of Trichoptera with DDD (TDE) larvicide. Canadian Entomologist 104: 145–163.

Fredeen, F.J.H. 1974. Tests with single injections of methoxychlor black fly (Diptera: Simuliidae) larvicides in large rivers. Canadian Entomologist 106: 285–305.

Fredeen, F.J.H. 1975. Effects of a single injection of methoxychlor black fly larvicide on insect larvae in a 161-km (100-mile) section of the North Saskatchewan River. Canadian Entomologist 107: 807–817.

Frost, S., A. Hunt and W.E. Kershaw. 1971. Evaluation of a kicking technique for sampling stream bottom fauna. Canadian Journal of Zoology 49: 167–173.

Glime, J.M. and R.M. Clemons. 1972. Species diversity of stream insects on *Fontinalis* spp. compared to diversity on artificial substrates. Ecology 53: 458–464.

Haddow, A.J. 1960. Studies on the biting habits and medical importance of East African mosquitoes of the genus *Aedes*. I. Subgenera *Aedimorphus, Banksinella* and *Dunnius*. Bulletin of Entomological Research 50: 759–779.

Hester, F.E. and J.S. Dendy. 1962. A multiple-plate sampler for aquatic macroinvertebrates. Transactions of the American Fisheries Society 91: 420–421.

Hilsenhoff, W.L. 1969. An artificial substrate device for sampling benthic stream invertebrates. Limnology and Oceanography 14: 465–471.

Hughes, B.D. 1975. A comparison of four samplers for benthic macro-invertebrates inhabiting coarse river deposits. Water Research 9: 61–69.

Johnson, A.F. and D.H. Pengelly. 1966. A cone trap for immature black flies (Diptera: Simuliidae). Proceedings of the Entomological Society of Ontario 96: 120.

Lewis, D.J. and G.F. Bennett. 1974. An artificial substrate for the quantitative comparison of the densities of larval simuliid (Diptera) populations. Canadian Journal of Zoology 52: 773–775.

Macan, T.T. 1958. Methods of sampling the bottom fauna in stony streams. Internationale Vereinigung für Theoretische und Angewandte Limnologie, Mitteilungen 8, 21 pages.

Macan, T.T. and A. Kitching. 1972. Some experiments with artificial substrata. Verhandlungen Internationale Vereinigung für Limnologie 18: 213–220.

Mason, W.T., J.B. Anderson and G.E. Morrison. 1967. A limestone-filled artificial substrate sampler-float unit for collecting macroinvertebrates in large streams. Progressive Fish-Culturalist 29: 74.

Mason, W.T., C.I. Weber, P.A. Lewis, and E.C. Julian. 1973. Factors affecting the performance of basket and multiplate macroinvertebrate samplers. Freshwater Biology 3: 409–436.

Moon, H.P. 1940. An investigation of the movements of freshwater invertebrate faunas. Journal of Animal Biology 9: 76–83.

Phillipson, J. 1956. A study of factors determining the distribution of the larvae of the blackfly *Simulium ornatum* Mg. Bulletin of Entomological Research 47: 227–238.

Radford, D.S. and R. Hartland-Rowe. 1971. Subsurface and surface sampling of benthic invertebrates in two streams. Limnology and Oceanography 16: 114–120.

Shannon, C.E. and W. Weaver. 1963. The mathematical theory of communication. University of Illinois Press.

Simmons, G.M. and A. Winfield. 1971. A feasibility study using conservation webbing as an artificial substrate in macrobenthic studies. Virginia Journal of Science 22: 52–59.

Surber, E.W. 1937. Rainbow trout and bottom fauna production in one mile of stream. Transactions of the American Fisheries Society 66: 193–202.

Tarshis, B.I. 1968. Use of fabrics in streams to collect black fly larvae. Annals of the Entomological Society of America 61: 960–961.

Ulfstrand, S., L.M. Nilsson and A. Stergar. 1974. Composition and diversity of benthic species collectives colonizing implanted substrates in a south Swedish stream. Entomologica Scandinavica 5: 115–122.

Waters, T.F. 1972. The drift of stream insects. Annual Review of Entomology 17: 253–272.

Wene, G. and E.L. Wickliff. 1940. Modification of a stream bottom and its effect on the insect fauna. Canadian Entomologist 72: 131–135.

Wilhm, J. 1972. Graphic and mathematical analyses of biotic communities in polluted streams. Annual Review of Entomology 17: 223–252.

Williams, D.D. and H.B.N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. Freshwater Biology 4: 233–256.

Williams, T.R.and L. Obeng. 1962. A comparison of two methods of estimating changes in *Simulium* larval populations, with a description of a new method. Annals of Tropical Medicine and Parasitology 56: 359–361.

Wolfe, L.S. and D.G. Peterson. 1958. A new method to estimate levels of infestations of black-fly larvae (Diptera: Simuliidae). Canadian Journal of Zoology 36: 863–867.

Zahar, A.R. 1951. The ecology and distribution of black-flies (Simuliidae) in south-east Scotland. Journal of Animal Ecology 20: 33–62.