TRENDS IN NUMBERS OF AQUATIC INVERTEBRATES IN A LARGE CANADIAN RIVER[1] DURING FOUR YEARS OF BLACK FLY LARVICIDING WITH METHOXYCHLOR (DIPTERA: SIMULIIDAE)

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ABSTRACT

Methoxychlor was injected at about 0.3 parts a.i per million parts of water, maintained for 15 minutes, into the Saskatchewan River System in Saskatchewan once in 1976, six times in 1977, seven in 1978, 19 in 1979, and five times in 1980. Severe outbreaks of Simulium luggeri *originated from various portions of the river up to 200 km long during the first three years, but not in 1979 or 1980.*

With suprageneric taxa serving as units, trends in numbers of non-simuliids were measured 1977 through 1980. Average densities of combined non-simuliid invertebrate populations attaching weekly to artificial substrates in mid-river sites in all three branches of the Saskatchewan River peaked in 1979 ($P<0.01$) the year of maximum larvicide use, but in 1980 returned to just above the 1977 level. Average numbers of invertebrates in benthic samples from river margins also generally peaked in 1979 or 1980 in all three river branches. In one or more of the six locations sampled, however, numbers of certain families of Ephemeroptera (baetids, heptageniids, caenids, leptophlebiids, and polymitarcyids), of Trichoptera (hydroptilids, leptocerids, and brachycentrids), and of Diptera (simuliids, tanypodines, orthocladiines, tanytarsines, and empids) declined after 1977 or 1978; in other locations many of these taxa peaked in 1979 or 1980.

Some larvae dislodged by methoxychlor treatments apparently reattached in downstream sites. In 25 to 73 percent of 23 tests there were increases rather than decreases in numbers of various non-simuliid and simuliid taxa attaching to rope-piece substrates, 25 to 92 km downstream during the week following an injection.

In summary, significant upward trends in average annual densities of suprageneric taxa indicated that effects of methoxychlor treatments essentially were neutral when compared with effects of unidentified extrinsic ecological processes. Furthermore, check lists of benthic species collected from all three rivers at the conclusion of tests in 1980 proved the survival of a varied fauna representing apparently complete ranges in feeding habits, activity patterns and life cycles. Thus, the relatively intensive series of methoxychlor larvicide treatments required to prevent damaging outbreaks of S. luggeri *from the Saskatchewan River was not permanently harmful to non-simuliid taxa in the river, at least at the suprageneric level.*

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[1]The Saskatchewan River in Saskatchewan.

RÉSUMÉ

Une solution de méthoxychlor (0.3 ppm d'ingrédients actifs) fut versée pendant 15 minutes dans le réseau de la rivière Saskatchewan à savoir: en 1976 (une fois), 1977 (six fois), 1978 (sept fois), 1979 (19 fois) et 1980 (cinq fois). Au cours des trois premières années, les populations de Simulium luggeri *ont explosé à divers endroits de la rivière, atteignant une étendue de 200 km près.*

En adoptant le niveau supragénérique comme critère de classification, l'auteur a dénombré les populations d'invertébrés non-simuliides de 1977 à 1980. La densité hebdomadaire moyenne de l'ensemble des populations s'attachant aux substrats artificiels placés au milieu du cours d'eau, dans la rivière Saskatchewan et ses deux tributaires, a culminé en 1979 (P<0.01), l'année d'utilisation maximale du larvicide. En 1980, cependant, la densité populations a diminué presqu'au niveau enregistré en 1977. Egalement, l'amplitude des moyennes d'invertébrés dans les échantillons prélevés du fond le long des rives a généralement culminé en 1979 ou en 1980 dans la rivière et ses deux tributaires. Toutefois, à l'un ou plusieurs des six sites échantillonnés, les populations de certaines familles d'Ephéméroptères, de Trichoptères et de Diptères ont diminué après 1977 ou 1978; aux autres sites, plusieurs de ces taxons ont culminé en 1979 ou 1980.

Des larves délogées par les traitements au méthoxychlor ont paru se réattacher plus bas dans la rivière. Dans 25 à 73% des 23 tests effectués, on a remarqué un accroissement inattendu du nombre des taxons simuliides et non-simuliides s'attachant à des substrats faits de corde, situés de 25 à 92 km en aval durant la semaine suivant l'application du larvicide.

En résumé, un accroissement annuel significatif de la densité moyenne des populations étudiees a indiqué un effet neutre des traitements. Les listes des espèces recouvrées de la rivière Saskatchewan et de ses deux tributaires en 1980 ont démontré la survie de toute une gamme d'organismes. L'auteur conclut que les traitements relativement intensifs nécessaires pour contrôler S. luggeri *dans la rivière Saskatchewan n'ont pas affecté les taxons non-simuliides de façon permanente.*

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INTRODUCTION

Single 7.5– to 15–minute injections of methoxychlor [2,2–bis(p–methoxyphenyl)–1,1,1–trichloroethane] have been used to reduce populations of black fly larvae in selected sections of the Saskatchewan River in Saskatchewan almost every year, 1968 to the present time. Reports about efficacy and environmental impact of 12 injections during the first six years of these tests have been published (Fredeen,1974, 1975).

In the final and most comprehensive test in that series, populations of aquatic insect larvae were measured weekly in one untreated site and in four treated sites spaced at 40 km intervals in the North Saskatchewan River, throughout 11 consecutive weeks commencing one week before a single 7.5 minute injection of 0.6 parts of methoxychlor per million parts of water (p.p.m.). Downstream 161 km from the injection point, 66 percent of larval instars three to six of *Simulium arcticum* Malloch and 96 percent of instars one and two disappeared within the first week. Larger percentages were removed from nearer sites. Larvae of plecopterans were similarly affected but ephemeropterans, trichopterans, and chironomids were less affected. All four treated sites were rapidly repopulated. Populations of chironomid larvae larger than one mm long equalled or exceeded pre-treatment densities within one to three weeks, ephemeropterans within one to four weeks, trichopterans in one to seven weeks, plecopterans in four to five weeks, and simuliids within two to ten weeks. Populations of larvae smaller than one mm long were generally restored more rapidly. Fish were not visibly affected (Fredeen, 1975).

In 1979 this "single-injection" pattern for methoxychlor was registered in Canada for control of larvae of *S. arcticum* in large rivers. Before that, methoxychlor was registered for use in Canada as a black fly larvicide only if applied by air across networks of shallow streams in 200 m wide swaths centered 400 m apart. Dosages of about 25 to 85 g of active ingredient (a.i.) per swath - ha would have been achieved with this method, equivalent to less than 0.01 p.p.m., a.i. sustained for about 0.5 minutes in a deep river such as the Saskatchewan River. Such a dosage would not have been effective against black fly larvae in this river because tests showed that exposures to about 0.2 p.p.m., maintained for 15 minutes were only partly effective (Fredeen 1974). Futhermore, logistics and cost of applying aerial swaths at 400 m intervals throughout the entire infested portion of the Saskatchewan River (150 to 200 km) would have been impractical.

It is not surprising that certain large rivers are sources of troublesome, chronic outbreaks of insects. Nor is it surprising in view of wide differences in habitats between rivers, that varieties of troublesome species vary widely between rivers. Munroe (1951) and Peterson (1952) listed 34 species of Trichoptera, mainly hydropsychids, emerging in nuisance numbers from the Niagara River. Corbet *et al.* (1966) reported that eight species of Trichoptera, again mainly hydropsychids, dominated nuisance swarms of insects emerging from the St. Lawrence River at Montreal. These insects created allergic reactions among residents, and navigational problems for ships in the St. Lawrence Ship Channel and vehicles on nearby highways. Fremling(1960(a), (b)) reported that massive flights of two species of mayflies (*Hexagenia bilineata* (Say) and *H. limbata* (Serville)) and one species of caddisfly (*Cheumatopsyche campyla* Ross) caused major nuisance and health problems in cities along the upper Mississippi River. Fredeen (1969) reported that larvae of the black fly *S. arcticum* Malloch were widespread in rivers and streams draining the eastern slopes of the Rocky Mountains, and that massive outbreaks, resulting in livestock losses, originated from certain portions of the Saskatchewan and Athabasca Rivers. Thus of the five large Nearctic rivers reported to have produced troublesome numbers of aquatic insects, economically important outbreaks of black flies have originated only from the Saskatchewan and Athabasca Rivers.

In the early 1970's, *S. luggeri* Nicholson and Mickel replaced *S. arcticum* as the dominant black fly species breeding in the Saskatchewan River in Saskatchewan, and within a few years it became a major pest of man and non-hominid animals (Fredeen, 1977). These changes in black fly populations coincided with major changes in their larval environments in the Saskatchewan River system in the 1970's. Summertime monthly water-flow volumes declined in the South Saskatchewan River to as low as 7.5 percent of the long term monthly averages (June, 1977) and in the North Saskatchewan River to as low as 34 percent (August, 1975) (Environment Canada 1977, 1978, 1979, 1980, 1981). This occurred in part because of completion of three hydroelectric dams in the river system and in part because of widespread drought in the mid 1970's. Previously these rivers had been deep, swift and turbid during summer months. Now they are relatively shallow, slow-flowing and clear, allowing dense growths of several species of water weeds for the first time. These plants are favored attachment sites for larvae of *S. luggeri* and several other black fly species previously found only in smaller rivers. An increase in tolerance to methoxychlor is not considered to have been responsible for these changes of black fly species because populations of larvae in treated sections are continually replenished by downstream drift from extensive untreated sections of the rivers. However, L.D. 50's for larvae of these species of black flies have not been determined.

These changes in black fly communities and river conditions forced changes in abatement strategies. Whereas *S. arcticum* required control only in May, *S. luggeri* cycles continuously throughout May to September. Thus, in some recent years, larvicide has been injected at two- to four-week intervals to prevent damaging outbreaks.

Furthermore, it became necessary to space larvicide injection sites closer together geographically. Vast beds of water weeds developed upon previously barren sand bars when the river became relatively shallow and clear due to the combined effects of drought and summertime impoundment of water behind newly-built hydroelectric dams (Fredeen, 1977). These weed beds not only provided large extensions of larval attachment sites but unfortunately also rendered larvicide treatments less effective, presumably because of filtering effects. Thus it is now sometimes necessary to space larvicide injection sites only 20 to 50 km apart to achieve adequate control.

A four-year environmental impact study reported herein was initiated in 1977 to investigate long-term effects of this recently intensified larviciding program. An earlier study (Fredeen 1975) had indicated that when a 161 km section of the North Saskatchewan River was treated with methoxychlor, populations of invertebrates were restored to pre-treatment densities within a few weeks.

EXPERIMENTAL

Larvicide

The larvicide used throughout was a commercial emulsifiable concentrate containing 0.24 kg methoxychlor per litre. Treatments were performed under federal and provincial permits, renewed annually.

Injection sites

Locations of sites of larvicide injections are shown in Figure 1 and Table 1. All sites were located in central Saskatchewan within less than 130 km from the confluence of the north and south branches of the Saskatchewan River. Specific locations within each site that were used for injections and/or assessments are described in greater detail in the following pages.

Most injections were made from motorized ferries which allowed four continuous swaths across the entire river during each 15–minute injection. Only three injections were from fixed points instead of swaths across the river, all from a traffic bridge (Site 2, Fig. 1) spanning the North Saskatchewan River at Prince Albert in 1978. The main Saskatchewan River just downstream from the confluence of the north and south branches (Site 4) was injected from a Sikorsky helicopter with a long tube discharging just beneath the water surface. The helicopter crossed the river four times during each 15–minute injection.

Tests in 1977 and 1978 showed that injections from a single location (either Fenton Ferry Site 6 or Birch Hills Site 7) on the South Saskatchewan River were inadequate. Much of that river remained infested despite treatments, presumably because dense weed beds reduced effectiveness of the larvicide. Thus, in 1979 treatments sometimes were spaced 20 to 50 km apart and treatments also were initiated at the confluence (Site 4) when it became evident that treatments had not travelled effectively beyond that point.

TABLE 1. LIST OF SITES WHERE METHOXYCHLOR BLACK FLY LARVICIDE WAS INJECTED, AND/OR IMPACT STUDIES CONDUCTED, SASKATCHEWAN RIVER SYSTEM IN SASKATCHEWAN.

	Site[1]	Distance to Confluence (km)	(miles)
	North Saskatchewan River		
1.	Wingard Ferry	128	80
2.	Prince Albert traffic bridge	61	38
3.	Cecil Ferry	36	22
4.	The Confluence, N. and S. Saskatchewan Rivers	0	0
	South Satchatchewan River		
5.	St. Laurent-Grandin Ferry	125	78
6.	Fenton Ferry	73	45
7.	Birch Hills Ferry	41	26
8.	Weldon Ferry	20	12
4.	The Confluence	0	0
	Main Saskatchewan River Below Confluence		
4.	The Confluence	0	0
9.	Gronlid Ferry	71	44

[1]See Fig. 1 to locate these sites on map.

Sampling sites for invertebrate populations

Sampling sites were fixed throughout the four-year study period. Permanently untreated check sites were not selected at the outset because it was not possible to predict where larvicide would be injected in each of the four years and also because our research team was not large enough to cope with additional sites.

Sampling methods

Two methods were used consistently throughout the four summers to measure invertebrate populations: (a) artificial substrates (rope pieces) anchored in three mid-river locations to measure weekly increments of drifting populations; and (b) Surber-type net sampling in six locations along river margins to collect samples of benthic populations.

Artificial substrates.— One-m lengths of 0.5 cm diameter polypropylene rope (Fredeen and Spurr, 1978) served as artificial substrates. Each rope piece was anchored so that it floated just under the water surface. Polypropylene has the correct specific gravity for this purpose. Two anchors, each with one attached rope piece, were placed about mid-channel, about one km upriver from each of the three selected sites about one week after ice break-up each spring in water flowing at about 0.5 to 1.0 m/sec depending upon river volume. The rope pieces were collected and replaced with new rope pieces weekly throughout each summer. One pair of

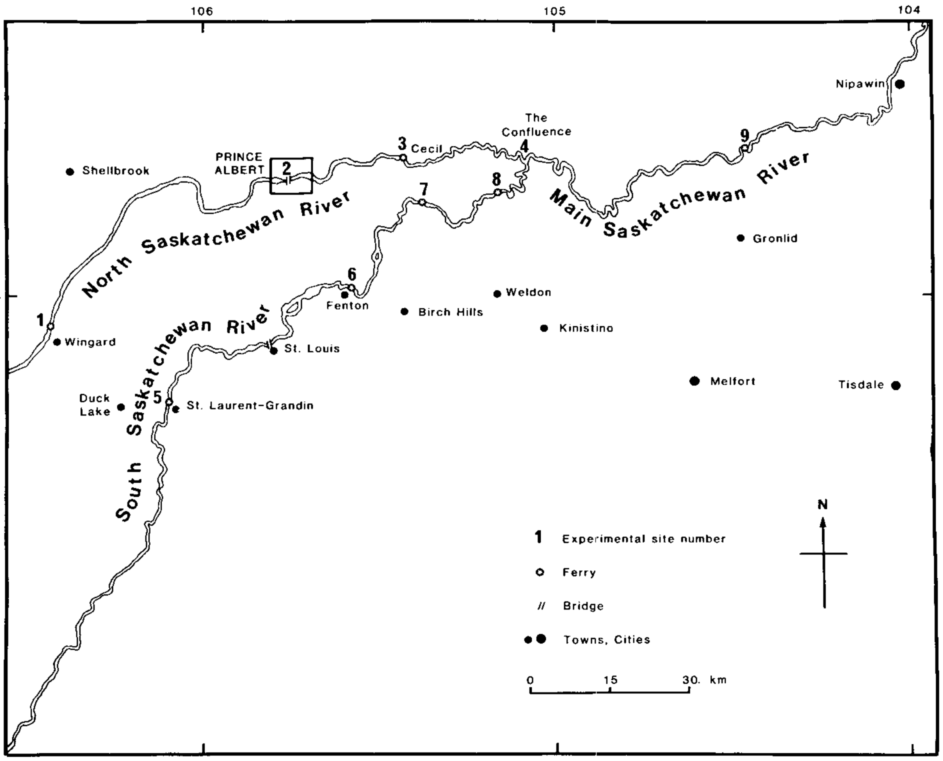

Fig. 1. Map showing experimental sites on the North, South, and Main Saskatchewan Rivers in Saskatchewan.

anchors was located about one km upstream from Cecil Ferry in the North Saskatchewan River (Site 3, Fig. 1), another pair was located about one km upstream from Birch Hills Ferry in the South Saskatchewan (Site 7), and the third pair was located about one km upstream from Gronlid Ferry in the main Saskatchewan River (Site 9). All three sites were served by "all weather" roads to ferries which ensured uninterrupted weekly access throughout all four summers. More than 60 percent of all larvicide injections occurred above these sites and 40 percent downstream (Tables 2, 3, and 4). Rope pieces were exchanged weekly for 17 consecutive weeks in Sites 3 and 7, and for 15 consecutive weeks in Site 9. The samples were individually preserved in 95 percent ethanol until analysis of attached invertebrates. Generally only one sample from each pair was analyzed.

These samples from artificial substrates were used for two purposes: (1) To provide weekly counts of immigrant populations of black fly larvae to estimate need for larvicide treatments. (A weekly accumulation of 1000 or more black fly larvae per 100 cm of rope indicated that larvae were arriving in numbers sufficient to cause damaging outbreaks unless controlled.); (2) To measure long-term trends in numbers of drifting invertebrates in mid-river locations. It was assumed that populations seen in these samples were related numerically to river bed populations from whence the drifting invertebrates had originated even though exact sources were not known (Fredeen and Spurr, 1978).

Benthic samples.— Samples of benthic invertebrates were collected from river margins under 50 to 60 cm of water with a 645 cm^2 Surber-type net with 0.2 mm mesh openings at weekly intervals for three consecutive weeks each August. Rocky beds precluded sampling with an automatic dredge. The month of August was selected because larvicide treatments were completed by that time each year, and because river levels were generally stable or slowly declining, allowing weekly collections without interruptions, from permanently inhabited portions of the river bed accessible on foot. In 1979, a one-week interruption (August 21) of the weekly regime occurred due to a brief rise in the level of the South Saskatchewan River. In 1979, there were no collections from the main Saskatchewan River (Site 9) because of insufficient staff.

In each of the three selected weeks each year, five 645 cm^2 samples (from a total of approximately 3225 cm^2) of river bed material to a depth of more than five cm were collected from each of six locations: each side of the North Saskatchewan River about one km above Cecil Ferry (Site 3), the north side of the North Saskatchewan about one km above the confluence (Site 4), the south side of the South Saskatchewan about two km above the confluence (Site 4), and each side of the main Saskatchewan River about one km above Gronlid Ferry (Site 9). Most sites were subjected to one or more larvicide treatments each year, the notable exception being the two Site 3 locations which were not treated in 1980. Collections from the North Saskatchewan River, Site 3 north side, were from the effluent path of a pulp mill, nine km upstream.

Each batch of five samples was combined into a single sample and preserved in 95 percent ethanol. Specimens were analyzed to families or sub-families. In 1980, keys became available for identification of species of Ephemeroptera, Plecoptera, Trichoptera, and Diptera inhabiting the Saskatchewan River in Saskatchewan, allowing preparation of a check list of species found in benthic samples during that year.

Data analysis.— Extreme variabilities characterized substrate and benthic populations (x_i) and for analysis, logarithmic transformations of the form log (x_i + 1) were applied. Transformed data were analyzed by the least squares method using the formula: $y_{ij} = \mu + t_i + w_j + e_{ij}$ where y_{ij} was the transformed observation in the j^{th} week (w) of the i^{th} year (t). Anti-log conversions of least squares means obtained in analyses provided the average values shown in tables and text. All tests of significance were based upon transformed data.

RESULTS AND DISCUSSION

Physical and chemical condition of the rivers, 1977-1980

Ice-free conditions on the Saskatchewan Rivers commenced each year during the third week of April except in 1979 when it commenced May 3 for the north branch and May 12 for the south. Both rivers refroze during the second or third week of November each year.

Mean monthly water discharge rates for the North Saskatchewan River, 1977, 1978, 1979, and 1980 for the months of May, June, July, and August were about 365, 490, 410, and 260 m^3/sec respectively, and for the south branch about 85, 165, 115, and 85 m^3/sec for the same months (Environment Canada, 1978, 1979, 1980 and 1981; Fisheries and Environment Canada 1977).

Turbidity varied approximately with the discharge rates and ranged from about 10 to 1000 gm/m^3 of water in the north branch and from about 10 to 100 gm/m^3 in the south branch.

Mean daily water temperatures increased from about 1° to 22°C in May and ranged from 16° to 24°C in June, 17° to 27°C in July, and 14° to 23°C in August.

The pH ranged from about 7.9 to 9.0 in May to about 8.0 to 9.1 in August in both rivers.

Phenolphthalein alkalinity ranged from 0 to about 20 (as p.p.m. $CaCO_3$) and total alkalinity ranged from about 100 to 200 (as p.p.m. $CaCO_3$). Hardness ranged from about 130 to 200 p.p.m. (as $CaCO_3$) in both rivers.

Larvicide treatments

Complete lists of injections of methoxychlor into the north, south, and main branches of the Saskatchewan River, 1974 to 1980 inclusive, are shown in Tables 2, 3, and 4. All previous treatments were reported by Fredeen (1974, 1975).

The larviciding campaign on the Saskatchewan River System was expanded from one treatment in 1976 to six in 1977, seven in 1978, and 19 in 1979, in attempts to reduce intensity and duration of outbreaks of *S. luggeri* that frequently extended 100 to 150 km or even further from the river in 1976, 1977, and 1978. Initially, the campaign was based upon one developed for control of *S. arcticum*, where one or two larvicide injections per year were generally sufficient to prevent a major outbreak. However, *S. luggeri*, which became the dominant species in 1976, cycled continuously all summer, and larvae attached in large numbers in aquatic weed beds newly developed in shallow sections of the rivers. Injections spaced about four weeks apart in 1977 and 1978 successfully removed many larvae but the relatively long intervals between treatments allowed many other larvae to complete growth and produce abundant females which returned to re-populate the rivers with eggs. Also, injections from a single location in the South Saskatchewan River in 1977 and 1978 were inadequate. Much of that river sometimes remained infested, presumably because dense weed beds reduced effectiveness of the methoxychlor, perhaps by adsorbing it from the water. Furthermore, treatments did not seem to extend effectively beyond the confluence of the North and South Saskatchewan Rivers. Increasingly massive outbreaks originated from the main Saskatchewan River some 70 km or further downstream from the confluence in 1977 and 1978.

Requirement for increased numbers of methoxychlor treatments was believed not due to development of increased tolerance. Weekly samples collected from artificial substrates above Site 3 in 1980 and Site 7 in 1977, years in which these sites were not treated, showed that downriver drift of black fly larvae from untreated sections occurred continuously throughout each summer.

Thus in 1979, the program was expanded to allow as required (a) injections to be spaced closer together in time, (b) multiple simultaneous injections at several sites in the weedy South Saskatchewan River, and (c) injections for the first time into the main Saskatchewan River below the confluence. Infestations of larvae were treated with methoxychlor larvicide injected at eight locations that year, three of which were injected only once during the summer, two, twice, and the others, three to five times. Relatively few larvae were allowed to mature and produce adults. For the first time in four years, livestock and people along the entire river experienced major relief from black flies.

In 1980 only one injection was required on the North Saskatchewan River, two at two sites each on the south branch, and none on the main branch.

TABLE 2. COMPLETE LIST OF METHOXYCHLOR BLACK FLY LARVICIDE[1] TREATMENTS, NORTH SASKATCHEWAN RIVER, 1974 TO 1980, INCLUSIVE.

Year	Site[2]	Date	Volume discharge of river (M^3/sec)	Amount of methoxychlor injected (kg. A.I.)	Av. conc. A.I. during 15-min injection (p.p.m.)
1974	No treatments	–	–	–	–
1975	3	May 27	286	80.4	0.312
1976	3	July 7	253	98.5	0.433
1977	3	May 19	337	85.8	0.283
1977	2	July 4	314	84.3	0.299
1977	3	August 2	248	62.5	0.280
1978	2	May 26	228	53.8	0.253
1978	2	June 20	583	135.0	0.257
1978	2	August 8	280	80.5	0.319
1979	1	June 5	360	102.0	0.315
1979	1	June 21	235	58.6	0.278
1979	1	July 17	242	53.9	0.248
1979	1	July 31	273	59.4	0.242
1979	1	August 16	214	53.9	0.280
1979	3	August 1	239	64.8	0.302
1980	3	May 16	198	70.0	0.391

[1] Emulsifiable concentrate containing 0.24 kg active ingredient per litre.

[2] See Fig. 1 to locate sites on map, and Table 1 for distances.;

TABLE 3. COMPLETE LIST OF METHOXYCHLOR BLACK FLY LARVICIDE(1) TREATMENTS, SOUTH SASKATCHEWAN RIVER, 1974 TO 1980, INCLUSIVE.

Year	Site(2)	Date	Volume discharge of river (M^3/sec)	Amount of methoxychlor injected (kg. A.I.)	Av. conc. A.I. during 15-min injection (p.p.m.)
1974	No treatments	–	–	–	–
1975	No treatments	–	–	–	–
1976	No treatments	–	–	–	–
1977	7	May 19	66	10.6	0.177
1977	7	July 4	53	13.2	0.277
1977	7	August 2	55	12.6	0.253
1978	6	May 26	56	10.9	0.211
1978	6	June 20	430	107.7	0.278
1978	6	July 21	217	59.3	0.304
1978	6	August 8	175	80.5	0.510
1979	5	June 5	274	80.5	0.327
1979	5	June 21	130	43.0	0.368
1979	5	July 12	72	16.3	0.251
1979	6	June 28	81	27.2	0.373
1979	6	July 12	72	16.3	0.251
1979	7	June 28	81	27.2	0.373
1979	7	July 12	72	16.3	0.251
1979	8	July 12	72	16.3	0.251
1980	6	May 16	86	27.0	0.349
1980	6	June 11	56	10.9	0.216
1980	7	May 16	86	27.0	0.349
1980	7	June 11	56	10.9	0.216

(1)Emulsifiable concentrate containing 0.24 kg active ingredient per litre.
(2)See Fig. 1 to locate sites on map, and Table 1 for distances.

TABLE 4. COMPLETE LIST OF METHOXYCHLOR BLACK FLY LARVICIDE[1] TREATMENTS, MAIN SASKATCHEWAN RIVER, 1974 TO 1980, INCLUSIVE.

Year	Site[2]	Date	Volume discharge of river (M^3/sec)	Amount of methoxychlor injected (kg. A.I.)	Av. conc. A.I. during 15-min injection (p.p.m.)
1974	No treatments	–	–	–	–
1975	No treatments	–	–	–	–
1976	No treatments	–	–	–	–
1977	No treatments	–	–	–	–
1978	No treatments	–	–	–	–
1979	4	June 6	625	177.0	0.318
1979	4	June 22	370	113.0	0.295
1979	4	July 13	340	86.0	0.281
1979	4	August 16	280	70.2	0.279
1979	9	August 1	332	81.2	0.273
1980	No treatments	–	–	–	–

[1]Emulsifiable concentrate containing 0.24 kg active ingredient per litre.

[2]See Fig. 1 to locate sites on map, and Table 1 for distances.

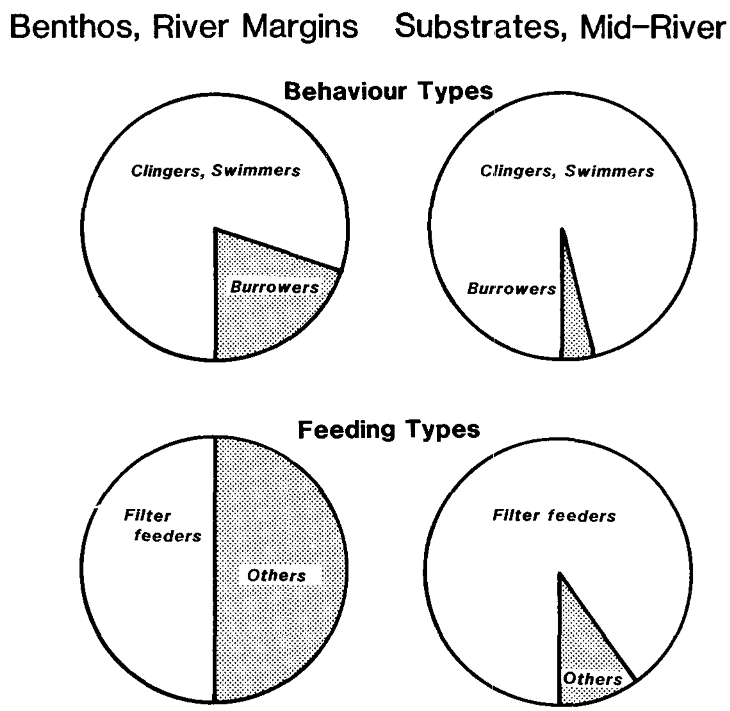

Fig. 2. Diagrammatic representations of approximate proportions of invertebrates representing major behaviour and feeding types in marginal benthos and in mid-river substrate samples collected from the Saskatchewan River, 1977 through 1980.

Habits and trophic relationships of invertebrates collected

Insect larvae.— The varied habits and trophic relationships of larvae of aquatic insects inhabiting the Saskatchewan River (Table 5, Fig. 2) are important when considering potential impact of larvicide treatments. In benthos samples from the margins of the Saskatchewan River most taxa (representing about 80 percent of the total insects collected) were considered to be clingers or climbers (Merritt and Cummins, 1978). The remainder, mainly *Chironomus* spp. and tanytarsines, as well as the rarer polymitarcyids and anisopterans were presumed to be burrowers or tube builders. The relatively abundant hydropsychids inhabited fixed retreats. About one percent of the total population were case-building trichopterans.

In samples from artificial substrates from mid-river sites more than 95 percent of the total insects collected were clingers or climbers.

Regarding feeding habits, according to Cummins (1973), Merritt and Cummins (1978), and Wiggins (1977), most or all of our ephemeropterans, trichopterans, and dipterans were considered to be collectors of periphyton, debris, and plankton. Many of these, including simuliids, hydropsychids, and many species of Ephemeroptera, Chironomini, and Tanytarsini, were filter feeders. In benthos samples about 50 percent of the larvae were considered to be filter feeders (Fig. 2) and in samples from mid-river artificial substrates about 90 percent (mainly simuliids) were filter feeders. About two-thirds of the remainders were assumed to

TABLE 5. HABITS AND TROPHIC RELATIONSHIPS[1] OF AQUATIC INSECTS INHABITING THE SASKATCHEWAN RIVER IN SASKATCHEWAN.

Taxa	Habits	Trophic Relationships
EPHEMEROPTERA		
Siphlonuridae: *Isonychia*	Swimmers, clingers	Collectors (filterers); engulfers (predators)
Baetidae: *Baetis*	Swimmers, climbers, clingers	Collectors (gatherers) (detritus, diatoms); scrapers
Pseudocloeon	Swimmers, clingers	Scrapers; collectors (gatherers)
Heptageniidae: *Heptagenia*	Clingers, swimmers	Scrapers; collectors (gatherers) (engulfers)
Stenonema	Clingers	Collectors (gatherers); scrapers
Ephemerellidae: *Ephemerella*	Clingers, swimmers	Collectors (gatherers) (detritus, algae)
Tricorythidae: *Tricorythodes*	Sprawlers, clingers	Collectors (gatherers)
Caenidae: *Caenis*	Sprawlers	Collectors (gatherers); scrapers
Leptophlebiidae: *Traverella*	Clingers	Collectors (filterers)
Polymitarcyidae: *Ephoron*	Burrowers	Collectors (gatherers)
ODONATA		
Anisoptera: *Ophiogomphus*	Burrowers	Engulfers (predators)
Zygoptera: *Ischnura*	Climbers	Engulfers (predators)
PLECOPTERA		
Pteronarcidae: *Pteronarcys*	Clingers, sprawlers	Shredders (detritovores) engulfers (predators)
Perlidae: *Acroneuria*	Clingers	Engulfers (predators)
HEMIPTERA: *Sigara*	Swimmers, climbers	Piercers (herbivores); collectors (gatherers)
COLEOPTERA:		
Dytiscidae: *Deronectes*	Swimmers, climbers	Piercers (carnivores)
Helodidae	Climbers	Scrapers; collectors; shredders; piercers (herbivores)
TRICHOPTERA		
Psychomyiidae: *Psychomyia*	Clingers (tube retreats)	Collectors (gatherers)
Polycentropodidae: *Neureclipsis*	Clingers (net builders)	Collectors (filterers) (herbivores, predators)

(continued on next page)

Table 5 (continued)

Taxa	Habits	Trophic Relationships
Hydropsychidae:		
Cheumatopsyche	Clingers (net builders)	Collectors (filterers) (herbivores, predators)
Hydropsyche	Clingers (net builders)	Collectors (filterers) (herbivores, predators)
Hydroptilidae: *Hydroptila*	Clingers (case builders)	Piercers; scrapers (herbivores)
Maytrichia	Clingers (case builders)	Piercers; scrapers (herbivores)
Brachycentridae:		
Brachycentrus	Clingers (case builders)	Collectors; filterers; scrapers (herbivores, predators)
Leptoceridae: *Ceraclea*	Sprawlers, climbers (case builders)	Collectors; shredders (herbivores, predators)
Nectopsyche	Climbers (case builders)	Shredders; collectors (herbivores, predators)
Oecetis	Clingers, climbers (case builders)	Engulfers, shredders (predators, herbivores)

collect food by 'gathering' rather than by 'filtering' and about one third were assumed to be either herbivores (piercers or shredders) or carnivores (Table 5).

In general, the invertebrate fauna of the Saskatchewan River was dominated by filter-feeding black fly larvae (tables 6, 7, 8, 9).

Crustaceans.— Five major taxa of crustaceans were collected. All could be considered free-swimming although in these rivers they would have lived near or on the substratum (Ward and Whipple 1959). Ostracods comprised about 80 percent of the total crustacean population and occurred regularly in all six sites sampled with the Surber-type net. Copepods and cladocerans were found in the North and South Saskatchewan Rivers but not in the main river below the confluence. Conchostracans and malacostracans were seldom collected.

Ostracods and copepods are shredders and feed on decaying plant and animal materials. Cladocerans are filterers (plankton) and malacostracans (*Hyalella* spp.) are shredders and filterers.

Acari.— Larvae of Parasitengona, found in all sites, are parasitic on aquatic insects and the adults are predaceous.

Mollusca.— Pelecypods (Sphaeridae) were relatively abundant and widely distributed in the Saskatchewan River. They are filterers, subsisting on detritus and plankton. Gastropods (mainly Ancylidae) were scarcer and less widely distributed. They are browsers, feeding on algae and detritus.

Identification of Invertebrates

It was within our expertise to identify Simuliidae to species from the outset. However, keys to identify many species in other major taxa were not available until after we had completed analyzing substrate and benthic samples in 1980. All samples have been retained at our Research Station in the event that identification of additional taxa to species levels would eventually prove productive.

Trends in numbers of invertebrates attached to artificial substrates

Population trends for taxa sampled with artificial substrates weekly during the summers of 1977 to 1980, inclusive, are given for the North Saskatchewan River (Site 3) in Table 6, for the South Saskatchewan River (Site 7) in Table 7, and for the main Saskatchewan River about 70 km downriver from the confluence of the two branches (Site 9) in Table 8.

Note that Site 3 received only one treatment in 1977, three in 1978, five in 1979 and none in 1980. Site 7 received no treatments in 1977, four in 1978, five in 1979 and two in 1980. The main Saskatchewan River below the confluence was not treated in 1977, 1978 or 1980 so that Site 9 received four treatments in 1979 but none in the other three years unless one assumes that effects from some or all of the six, seven, 14, and five injections into the two branches above the confluence may have affected populations at Site 9. Permanently untreated check sites were not available for reasons stated earlier in this paper.

Mites peaked in 1979 at Sites 3 and 7 ($P<0.01$ at Site 7) and in 1980 at Site 9 ($P<0.01$). This suggests that there were parallel increases in numbers of certain invertebrate taxa upon which these animals preyed. Alternatively, as discussed in a following section, displaced larvae may have reattached further downriver.

Mean annual numbers of plecopterans attaching weekly to artificial substrates declined after 1978 at Site 3 ($P<0.01$) but remained relatively unchanged at Sites 7 and 9. Larvae of ephemeropterans remained relatively abundant and unchanged in numbers at Sites 3 and 7 but peaked in 1980 at Site 9 ($P<0.01$). Larvae of trichopterans remained relatively abundant but unchanged in numbers at all three sites. Larvae of chironomids, the most abundant of all non-simuliid taxa, peaked in 1979 in all three sites with highly significant differences between years in Sites 7 and 9 ($P<0.01$).

Numbers of larvae of *S. luggeri* declined annually after 1977 in Site 3 (n.s.) and after 1978 in Sites 7 and 9 ($P<0.01$ at both sites) to four-year lows in all three sites. Numbers of *S. arcticum* and *S. meridionale* Riley were relatively small compared to numbers of *S. luggeri* and remained unchanged in Sites 3 and 9, but declined after 1977 in Site 7 ($P<0.05$). Numbers of *S. vittatum* Zetterstedt peaked in 1977 in Site 7 ($P<0.01$) and in 1979 in Site 9 ($P<0.01$).

Larvae of these four species of *Simulium* were considered to be relatively susceptible to methoxychlor, not only because they inhabited sites that would have ensured direct contact with the larvicide but also because they were filter feeders and thus would have ingested suspended particles containing adsorbed methoxychlor (Fredeen *et al.*, 1975). Despite this, no single species of Simulium was eliminated during the four years of treatment. In fact, *S. vittatum* (not a pest species) actually attained maximum abundance at two sites in 1979, the year of maximum use of methoxychlor.

These data help to explain why prominent non-simuliid taxa remained abundant, and of greater importance, suggest that trends in numbers of each non-simuliid order or family as shown in Tables 6, 7, 8 and 9 are actually representative of parallel trends in numbers of most or all of the species comprising those suprageneric taxa.

Densities of populations of invertebrates on rope-piece substrates were believed related to densities of the benthic populations from whence the drifting populations had originated. Substrates offered convenient means of obtaining uninterrupted series of weekly samples from otherwise inaccessible mid-river sites throughout the four-year study. However, it was not possible to determine how far larvae had drifted in the rivers before attaching to the substrates. Presumably many (most?) larvae originated from treated sections of the rivers because

TABLE 6. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES ATTACHED TO ROPE PIECES[2] ANCHORED FOR ONE-WEEK PERIODS THROUGHOUT 17 WEEKS EACH YEAR, MAY TO SEPTEMBER, ONE KM UPRIVER FROM SITE 3[3] (CECIL FERRY), NORTH SASKATCHEWAN RIVER, SASKATCHEWAN, 1977 TO 1980 INCLUSIVE.

Year Number of larvicide injections above this site	1977 1	1978 3	1979 5	1980 0	All years combined	Significance of differences between years[4]
ACARI	0.14a	0.18a	1.11b	0.34ab	0.40	n.s.
PLECOPTERA	0.68ab	3.75c	1.56bc	0.21a	1.21	P<0.01
EPHEMEROPTERA	27.15a	20.13a	45.59a	54.04a	34.14	n.s.
TRICHOPTERA	28.41a	25.63a	25.41a	31.19a	27.56	n.s
Chironomidae	192.64a	170.40a	622.73b	135.46a	229.67	n.s.
S. luggeri	3236.43b	2439.05b	1855.26ab	921.36a	1916.79	n.s.
S. arcticum	18.58a	17.75a	21.73a	21.90a	19.91	n.s.
S. meridionale	28.60a	41.48a	31.29a	61.88a	38.98	n.s.
S. venustum etc.	0.00a	0.23ab	1.03b	0.00a	0.26	P<0.05
S. vittatum	215.52ab	95.72a	1175.25b	65.42a	200.09	n.s

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.

(2)Polypropylene rope: length = 100 cm; diam. = 0.5 cm.

(3)See Fig. 1 to locate sites on map, and Table 1 for distances.

(4)These statistics were calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly (P<0.05) as indicated by Duncan's New Multiple Range tests.

TABLE 7. MEAN NUMBERS(1) OF AQUATIC INVERTEBRATES ATTACHED TO ROPE PIECES(2) ANCHORED FOR ONE-WEEK PERIODS THROUGHOUT 17 WEEKS EACH YEAR, MAY TO SEPTEMBER, ONE KM UPRIVER FROM SITE 7(3) (BIRCH HILLS FERRY), SOUTH SASKATCHEWAN RIVER, SASKATCHEWAN, 1977 TO 1980 INCLUSIVE

Year Number of larvicide injections above this site	1977 0	1978 4	1979 5	1980 2	All years combined	Significance of difference between years(4)
ACARI	0.10a	1.18a	17.69c	5.50b	3.13	P<0.01
PLECOPTERA	1.16b	0.58ab	0.87a	0.10a	0.63	n.s.
EPHEMEROPTERA	29.23a	15.33a	23.65a	23.55a	22.38	n.s.
TRICHOPTERA	41.42a	33.90a	42.90a	28.11a	36.09	n.s.
Chironomidae	72.86ab	104.08b	143.05b	41.84a	82.18	P<0.01
S. luggeri	1045.41b	1550.67b	270.83a	229.45a	563.68	P<0.01
S. arcticum	7.10b	6.02b	2.14ab	1.12a	3.41	P<0.05
S. meridionale	0.72b	0.00a	0.22ab	0.17a	0.25	P<0.05
S. venustum etc.	0.04a	0.22a	3.76b	0.14a	0.62	P<0.01
S. vittatum	246.46c	82.43b	21.52a	33.21ab	62.15	P<0.01

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.

(2)Polypropylene rope: length = 100 cm; diam. = 0.5 cm.

(3)See Fig. 1 to locate sites on map, and Table 1 for distances.

(4)These statistics were calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly (P<0.05) as indicated by Duncan's New Multiple Range tests.

TABLE 8. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES ATTACHED TO ROPE PIECES[2] ANCHORED FOR ONE-WEEK PERIODS THROUGHOUT 15 WEEKS EACH YEAR, MAY TO SEPTEMBER, ONE KM UPRIVER FROM SITE 9[3] (GRONLID FERRY), MAIN SASKATCHEWAN RIVER, SASKATCHEWAN, 1977 TO 1980 INCLUSIVE

Year Number of larvicide injections above this site[4]	1977 0 (6)	1978 0 (7)	1979 4 (18)	1980 0 (5)	All years combined	Significance of difference between years[5]
ACARI	0.05a	0.54ab	1.30bc	3.04c	0.97	P<0.01
PLECOPTERA	0.16a	0.11a	0.23a	0.28a	0.19	n.s.
EPHEMEROPTERA	10.48a	5.51a	9.15a	39.23b	12.22	P<0.01
TRICHOPTERA	11.53a	30.46a	16.16a	23.22a	19.12	n.s.
Chironomidae	38.44a	54.72ab	115.04b	24.95a	49.72	P<0.01
S. luggeri	158.11ab	603.51c	315.23bc	61.55a	207.83	P<0.01
S. arcticum	3.23a	6.30a	6.99a	4.50a	5.07	n.s.
S. meridionale	0.72a	0.20a	0.67a	0.13a	0.40	n.s.
S. venustum etc.	0.00a	0.00a	2.16b	0.00a	0.33	P<0.01
S. vittatum	52.83b	2.71a	191.35b	4.10a	20.04	P<0.01

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.

(2)Polypropylene rope: length = 100 cm; diam. = 0.5 cm.

(3)See Fig. 1 to locate sites on map, and Table 1 for distances.

(4)Numbers in brackets indicate numbers of treatments in the entire Saskatchewan River system above the sampling site. Unbracketed numbers indicate numbers of treatments in the Main Saskatchewan River alone.

(5)These statistics were calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 9. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES ATTACHED TO ROPE PIECES[2] ANCHORED FOR ONE-WEEK PERIODS THROUGHOUT 15 WEEKS EACH YEAR, MAY TO SEPTEMBER, 1977 TO 1980 INCLUSIVE. COMBINED DATA FROM THREE SITES[3], SASKATCHEWAN RIVER, SASKATCHEWAN.

	1977	1978	1979	1980	All years combined	Signifiance of difference between years[4]
Total non-simuliids	162.68a	201.30a	423.62b	167.27a	219.29	P<0.01
Total Simuliidae except *S. vittatum*	982.78b	1540.35b	627.35ab	321.40a	743.39	P<0.01
Total Simuliidae including *S. vittatum*	1488.36b	1765.04b	1882.65b	408.26a	1015.25	P<0.01

[1]Geometric means calculated from $\log_{10}(x + 1)$ values.

[2]Polypropylene rope: length = 100 cm; diam. = 0.5 cm.

[3]One km upriver from each of sites 3, 7, and 9 (Fig. 1), in the North, South, and Main Saskatchewan Rivers respectively.

[4]These statistics were calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 10. PERCENTAGES OF METHOXYCHLOR LARVICIDE TESTS IN WHICH SAMPLES OF AQUATIC INVERTEBRATES FROM ROPE-PIECE SUBSTRATES[1] WERE LARGER THAN THOSE OF THE PREVIOUS WEEK, SASKATCHEWAN RIVER SYSTEM, 1977 TO 1980, INCLUSIVE.

Larvicide injection 7 to 14 days earlier	Yes	Yes	No
Distance upstream from substrates (km)	71-92	25-32	
Number of tests[2]	11	12	36
Percentages of tests showing increased densities (%)			
ACARI	64	38	25
PLECOPTERA	37	25	28
EPHEMEROPTERA	64	33	61
TRICHOPTERA	64	58	61
Chironomidae	73	50	56
Simuliidae	64	33	36

(1)One-metre lengths of 0.5 cm diameter polypropylene rope anchored for one week at sites 3, 7, and 9 (Fig. 1).

(2)Data from many weeks during the four summers could not be included because:

a.) the river was reinjected within less than two weeks before post-treatment samples could be collected,

b.) injections were repeated on one date in more than one site in a single river,

c.) samples from site 9 in the Main Saskatchewan River were not included in this summation if either of the two branches above the confluence had been injected within the two previous weeks.

sampling sites were located many km downriver from many or all larvicide injection sites. The most distant injection sites upstream from the three sampling sites were 92 km for Site 3, 84 km for Site 7 and 198 km for Site 9.

In summary, combined data from numbers of invertebrates attaching weekly to artificial substrates anchored mid-river in three sites (Table 9) show that mean densities of non-simuliid taxa in treated sections of these rivers peaked in 1979, but in 1980 returned to about 1977 densities. Differences between years were highly significant ($P<0.01$). Mean annual densities of simuliids (excluding *S. vittatum*) peaked in 1978 and then declined rapidly during the final two years of the program to a four-year low in 1980 (about one-fifth the density of 1978) and differences between years were highly significant. When numbers of *S. vittatum* larvae are included in these means, total populations peaked in 1979 and then also declined in 1980 to about one-fifth of the peak value. *S. vittatum* larvae were totalled seperately because some females of this species laid eggs on floats supporting rope-piece substrates and some larvae found attached to the rope pieces may have hatched from those eggs rather than arriving as drifting larvae.

Increases in numbers of invertebrates following larvicide injections

Many collections of invertebrates from mid-river rope-piece substrates were larger immediately after larvicide injections than before (Table 10). This was particularly true for rope pieces anchored at relatively great distances downstream from injection sites. Thus collections from rope pieces anchored for one week 71 to 92 km downstream from an injection site contained larger numbers of mites, ephemeropterans, trichopterans, chironomids, and simuliids in 64 to 73 percent of the samples collected immediately after an injection than before. In 37 percent of those same post-treatment collections, numbers of plecopterans were larger than in pre-treatment collections.

From substrates anchored nearer the injection sites (i.e. 25 to 32 km downstream) numbers of these same taxa in post-treatment samples exceeded those in pre-treatment collections in only 25 to 58 percent of the collections.

In comparison, in the absence of larvicide treatments, consecutive weekly pairs of collections showed increases in the second week in 36 to 61 percent of the samples (Table 10).

These data provided new evidence that certain detached larvae survived and successfully reattached in sites further downriver as reported earlier by Fredeen (1974, 1975). The relatively substantial recolonization following methoxychlor treatments would also have been aided by regular drift of larvae newly hatched from eggs unaffected by methoxychlor, and larvae from untreated upstream sections and from protected niches in treated sections. Fredeen (1975) showed that larvae in sand beds in the Saskatchewan River were entirely unaffected by passage of methoxychlor-treated water. Pupae in general appeared to be resistant to methoxychlor and as well, pupae of certain chironomids and hydroptilids drifted into treated sections, attached to fragments of water weeds.

A prerequisite to successful reattachment by larvae would have been the reduction of methoxychlor concentrations to tolerable levels. The main Saskatchewan River downstream from the confluence would generally have received diluted larvicide from the branches. Although both branches above the confluence often were injected with methoxychlor on the same day (Tables 2 and 3) it was very unlikely that treated masses of water arrived at the same time at the confluence.

Also Fredeen *et al.* (1975) showed that as an injected mass of water travelled downstream it became progressively attenuated due to friction with the river bed. Furthermore adsorption to river bed sand was demonstrated. Alternatively, adsorption of methoxychlor to particles suspended in the water, especially in the relatively turbid North Saskatchewan River, would have aided long distance transport of methoxychlor.

Adsorption to water weeds, and filamentous algae, especially in extensive beds of several species in the South Saskatchewan River, was not proved but may be assumed. Edwards and Glass (1971), Butler *et al.* (1975), Paris and Lewis (1976) and others demonstrated that methoxychlor was rapidly adsorbed to grass, many species of algae, fungi and bacteria.

Data from limited laboratory tests indicate that larvae of certain aquatic invertebrates are less susceptible to methoxychlor than are black fly larvae. Sebastien and Lockhart (1981) showed that 100 percent of stonefly nymphs (*Pteronarcys dorsata* Say) were moribund after 24 hours of exposure to 0.3 mg/l of methoxychlor formulated as an emulsifiable concentrate, in recirculated, dechlorinated water at 17°C. Forty-eight hours of exposure of chironomid larvae (*Chironomus tentans* Fabricius) to 0.3 mg/l at 20°C followed by 48 hours in fresh water produced 99 percent mortality. In comparison, fifth and sixth instar black fly larvae (*S. decorum* Walker) suffered 100 percent detachment during 16-minute exposure to 0.3 mg/l of methoxychlor at 19°C, and 100 percent mortality when returned to fresh water for about 20 hours. Fredeen (1972) reported that the L.C. 50 for relatively full-grown larvae of *Hydropsyche morosa* Hagen following a six-hour exposure at 10°C to methoxychlor and 18 hours in fresh water was 0.04 mg/l of methoxychlor. Anderson and DeFoe (1980) reported that following continuous exposure to methoxychlor in flowing water throughout 28 days the L.C. 50 for the isopod *Asellus communis* Say was 0.42 mμg/l, and for *Hydropsyche* sp. larvae was 1.3 mμg/l. Stonefly larvae *P. dorsata* Say and a snail *Physa integra* did not die at the highest concentration tested, 4.2 mμg/l.

Muirhead-Thomson (1973) suggests several reasons why one cannot use data from laboratory bioassays of toxicants to accurately predict events in field tests. Furthermore, the above bioassays were based upon relatively long exposures (6 hours to 28 days) whereas in our field tests with methoxychlor a treated pulse of water lasted only 15 minutes at the point of origin. Nevertheless, data quoted above from these few bioassays, and especially those from Sebastien and Lockhart (1981) suggest that certain non-simuliid species are less sensitive than simuliid larvae to small concentrations of methoxychlor.

Long-term effects of downstream displacements of larvae

As to long-term effects of downstream displacements of larvae due to larvicide injections and other causes, comparisons of data presented in Tables 6, 7, and 8 show that numbers of mites, plecopterans and ephemeropterans attaching weekly to artificial substrates anchored in Site 9 (about 70 km below the confluence) peaked in 1980, one to three years after peaks were observed in the tributaries (Sites 3 and 7). Numbers of trichopterans did not trend significantly at any of the three sites but remained relatively abundant throughout the four years. Larvae of chironomids also remained abundant throughout but peaked in all three sites in the same year (1979) and differences between years were highly significant. Identification to the species level may have revealed differences in responses between species in each of these major taxa but this was not investigated. For reasons previously explained, changes in species complexes are believed not to have occurred.

Downstream displacements of black fly larvae presumably were responsible for increasingly dense accumulations of larvae of *S. luggeri* in the main Saskatchewan River and in the downstream end of the South Saskatchewan which resulted in major outbreaks from those regions in 1977 and 1978. Average weekly numbers of larvae of *S. luggeri* near Site 7, South Saskatchewan River (Table 7) increased from 1045 in 1977 (the year that that river was injected below the collecting site) to 1551 in 1978 when the river was injected some 32 km upstream (Tables 1 and 3). But when this weedy river was injected at four sites in 1979, average number of larvae was reduced to 271 per week and there were no destructive outbreaks that year from the South Saskatchewan River.

In the North Saskatchewan River treatments carried longer distances, presumably because that river was deeper, more turbid, and contained sparser weed beds. Injections at single sites (Table 2) were sufficient to steadily reduce populations of black fly larvae from a weekly mean of 3236 larvae in 1977 to 921 in 1980 (Table 6).

In the main Saskatchewan River at Site 9, mean weekly populations of black fly larvae attaching to artificial substrates increased from 158 in 1977 to 604 in 1978 (Table 8) apparently due to downstream drift of larvae from the North and South Saskatchewan Rivers. There were numerous severe outbreaks along the entire main Saskatchewan River in 1978. Some outbreaks inflicted losses 100 or more km from the river. Outbreaks were reduced to tolerable levels in 1979 following initiation of methoxychlor treatments that year at the confluence (Table 4).

Trends in numbers of invertebrates in benthic samples

Quantitative samples of benthic organisms collected with Surber-type nets each August provided additional substantial evidence of increases in populations of many taxa and of non-significant trends in others between 1977 and 1979 or 1977 and 1980 (Tables 11 to 17). Details of living habits and trophic relationships are shown in Table 5.

Populations of crustaceans in four of the six locations (all three rivers) attained peak abundance in either 1979 or 1980 ($P<0.01$ in three sites). In only one location (Site 3, north side, in the effluent path of a pulp mill located nine km upstream from the sampling site) did crustaceans decline in abundance after 1977 ($P<0.05$). Ostracods comprised about 80 percent of the total populations; copepods and cladocerans about 20 percent. Conchostracans and malacostracans (*Hyalella* sp.) were rare throughout. All could be considered free-swimming although in lotic waters they would have lived on or in the substratum which may have offered them some protection from passage of the treated masses of water.

Mean August numbers of larvae of all taxa of Ephemeroptera combined, peaked in all six locations in 1980. Differences between years were significant in all three locations in the North Saskatchewan River, highly significant in the South Saskatchewan, but not significant in the main Saskatchewan River.

Examining data for various families of Ephemeroptera individually, baetids (about 98 percent *Baetis* nr. *pluto*) were relatively abundant and peaked in 1980 in at least one location in each of the three river branches. Differences in means between years were significant only in the South Saskatchewan River. Heptageniids (about 80 percent *Heptagenia* spp.), also relatively abundant in most locations, peaked in 1979 in the North Saskatchewan River (Site 3, south side) with significant differences between years in Site 3, north side in 1980 and the North Saskatchewan near the confluence in 1978. In the South Saskatchewan near the confluence they peaked in 1979, and in the main Saskatchewan River (Site 9) in 1977 (no

TABLE 11. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES[2] COLLECTED ABOUT ONE KM UPRIVER FROM SITE 3 (CECIL FERRY), NORTH SASKATCHEWAN RIVER, SOUTH SIDE.

Year Number of larvicide injections above this site	1977 1	1978 3	1979 5	1980 0	All years combined	Significance of difference between years[3]
Crustaceans	83.22b	0.44a	460.00c	102.87a	48.11	P<0.01
Siphlonuridae	0.00a	0.00a	0.45a	0.82a	0.58	n.s.
Baetidae	637.26b	52.95a	268.77ab	463.52b	255.45	n.s.
Heptageniidae	400.79a	175.60a	994.41b	476.53b	427.55	P<0.05
Tricorythidae	57.08a	10.64a	45.77a	177.65b	47.75	n.s.
Caenidae	3.38a	0.26a	7.75a	16.31b	4.38	n.s.
Leptophlebiidae	1.22a	0.71a	0.00a	25.22a	2.16	P<0.05
Polymitarcyidae	11.76a	7.85a	2.48a	140.71a	14.36	p<0.01
EPHEMEROPTERA combined	1136.63b	270.02a	1357.31b	1369.88b	869.96	P<0.05
ODONATA	0.26a	0.00a	7.25b	2.30ab	1.42	n.s.
PLECOPTERA	19.38bc	5.14b	0.00a	74.68c	8.86	P<0.01
HEMIPTERA	0.00a	0.26a	24.88b	4.83ab	2.71	P<0.05
COLEOPTERA	1.22a	2.21a	2.96a	1.52a	1.90	n.s.
Hydropsychidae	442.61a	1418.06a	1478.11a	2093.11a	1179.32	n.s.
Hydroptilidae	0.00a	1.22a	1.76a	1.80a	1.04	n.s.
Leptoceridae	7.67a	9.83a	5.69a	10.08a	8.13	n.s.
Brachycentridae	0.91a	18.28b	0.00a	0.26a	1.61	P<0.01
TRICHOPTERA combined	449.82a	1461.18a	1509.08a	2112.49a	1204.04	n.s.
Simuliidae	57.82a	43.45a	41.43a	8.89a	31.37	n.s.
Tanypodinae	159.69ab	91.26a	284.76b	234.50ab	176.84	n.s.
Orthocladiinae	128.72a	37.73a	51.12a	31.89a	53.20	n.s.
Chironomini	869.96bc	161.93a	1240.65c	231.81ab	448.78	P<0.05
Tanytarsini	228.61a	14.49a	29.97a	48.09a	47.19	n.s.
Empididae	5.14a	5.14a	37.84a	3.95a	8.22	n.s.
DIPTERA combined	1495.24b	522.60a	1848.27b	575.77a	956.19	P<0.01
ACARI	12.11a	76.20ab	178.31b	18.68a	42.48	P<0.05
Gastropoda	18.90a	19.64a	22.11a	16.37a	19.15	n.s.
Pelecypoda	119.01a	127.23ab	615.03b	38.37a	138.00	n.s.
MOLLUSCA combined	150.36ab	162.31ab	689.24b	56.81a	176.42	n.s.

[1]Geometric means calculated from $\log_{10}(x + 1)$ values.
[2]In each year a set of five, 645 cm^2 samples were collected each week for three consecutive weeks.
[3]Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 12. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES[2] COLLECTED ABOUT ONE KM UPRIVER FROM SITE 3 (CECIL FERRY), NORTH SASKATCHEWAN RIVER, NORTH SIDE.

Year Number of larvicide injections above this site	1977 1	1978 3	1979 5	1980 0	All years combined	Significance of difference between years[3]
Crustaceans	196.70b	9.84a	166.11b	136.40b	82.75	P<0.05
Siphlonuridae	0.00	0.00	0.00	0.00	0.00	
Baetidae	301.27a	67.12a	60.90a	221.33a	128.75	n.s.
Heptageniidae	193.54a	89.78a	163.82a	287.40a	169.22	n.s.
Tricorythidae	15.94a	35.22ab	36.84ab	136.09b	41.27	n.s.
Caenidae	20.16a	12.00a	3.95a	2.45a	7.28	n.s.
Leptophlebiidae	0.00a	0.26a	2.45ab	31.17b	2.44	P<0.05
Polymitarcyidae	2.48a	9.23a	7.25a	33.12a	9.00	n.s.
EPHEMEROPTERA combined	553.63ab	285.42a	345.74a	834.60b	462.45	P<0.05
ODONATA	2.17ab	0.59a	0.59a	4.09b	1.53	n.s.
PLECOPTERA	5.14b	0.26a	0.00a	123.54c	4.57	P<0.01
HEMIPTERA	0.00a	0.26a	2.96a	5.14a	1.35	n.s.
COLEOPTERA	0.26a	0.26a	0.26a	0.59a	0.33	n.s.
Hydropsychidae	347.34a	1293.20b	4334.11c	2127.14bc	1427.89	P<0.01
Hydroptilidae	0.00a	2.14a	0.00a	2.53a	0.82	n.s.
Leptoceridae	0.26a	3.63a	1.22a	1.22a	1.32	n.s.
Brachycentridae	10.74a	3.67a	1.22a	0.82a	2.86	n.s.
TRICHOPTERA combined	366.28a	1323.34b	4344.10c	2141.89bc	1457.81	P<0.01
Simuliidae	8.91a	49.12a	21.76a	16.70a	20.14	n.s.
Tanypodinae	243.91a	23.77a	283.45a	139.93a	124.03	n.s.
Orthocladiinae	144.55a	31.66a	108.40a	83.33a	80.47	n.s.
Chironomini	314.50ab	189.99ab	578.43b	79.72a	229.14	n.s.
Tanytarsini	114.61a	119.23a	59.53a	72.79a	87.72	n.s.
Empididae	1.22a	15.93a	7.67a	5.14a	5.69	n.s.
DIPTERA combined	876.00a	513.04a	1128.80a	433.51a	686.07	n.s.
ACARI	12.65a	19.46a	479.84b	56.81a	51.84	n.s.
Gastropoda	63.94b	4.09a	5.14a	12.65ab	11.90	n.s.
Pelecypoda	34.48a	13.60a	16.06a	24.67a	20.82	n.s.
MOLLUSCA combined	101.57a	15.83a	28.85a	46.97a	38.63	n.s.

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.
(2)In each year a set of five, 645 cm^2 samples were collected each week for three consecutive weeks.
(3)Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 13. MEAN NUMBERS(1) OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES(2) COLLECTED FROM THE NORTH SASKATCHEWAN RIVER NORTH SIDE, ABOUT ONE KM UPRIVER FROM SITE 4 (THE CONFLUENCE)

Year Number of larvicide injections above this site	1977 3	1978 3	1979 6	1980 1	All years combined	Significance of difference between years(3)
Crustaceans	0.00a	2.94a	204.73b	40.73b	12.56	P<0.01
Siphlonuridae	0.00	0.00	0.00	0.00	0.00	
Baetidae	3.66a	9.69ab	10.42ab	342.72b	20.03	n.s.
Heptageniidae	5.99a	20.95a	6.61a	12.65a	10.23	n.s.
Tricorythidae	78.43ab	56.81ab	41.76a	145.22b	72.11	n.s.
Caenidae	0.00a	0.00a	1.76a	0.00a	0.29	n.s.
Leptophlebiidae	0.00a	22.04b	0.00a	4.52b	2.36	P<0.01
Polymitarcyidae	9.83a	3.95a	0.00a	6.13a	3.42	n.s.
EPHEMEROPTERA combined	149.66a	176.42a	83.33a	520.19b	148.35	P<0.05
ODONATA	0.00	0.00	0.00	0.00	0.00	
PLECOPTERA	1.22a	0.00a	0.00a	44.95b	2.18	P<0.01
HEMIPTERA	12.65b	0.00a	6.61b	0.00a	2.19	P<0.05
COLEOPTERA	0.00	0.00	0.00	0.00	0.00	
Hydropsychidae	529.88a	989.83b	1201.26b	1281.33b	947.42	P<0.05
Hydroptilidae	1.22a	33.03b	324.84c	0.00a	11.53	P<0.01
Leptoceridae	0.00a	0.00a	0.00a	1.22a	0.22	n.s.
Brachycentridae	0.00a	12.65b	25.44b	0.26a	3.62	P<0.01
TRICHOPTERA combined	533.56a	1036.53b	1583.89b	1284.29b	1029.39	P<0.01
Simuliidae	19.51a	9.99a	9.99a	45.88a	17.45	n.s.
Tanypodinae	208.41bc	39.83ab	250.77c	28.85a	88.54	P<0.05
Orthocladiinae	476.53b	58.02a	886.16b	234.50ab	276.33	P<0.05
Chironomini	653.64a	315.96a	2778.71b	532.33a	743.73	P<0.01
Tanytarsini	366.28a	149.66a	1917.67b	125.18a	339.41	P<0.01
Empididae	3.33a	15.93ab	258.72b	3.95a	16.51	P<0.05
DIPTERA combined	1818.70b	637.26a	6250.73c	1022.29ab	1650.95	P<0.01
ACARI	27.58a	135.77a	873.98b	85.10a	129.92	P<0.01
Gastropoda	0.00a	6.61ab	1.22ab	19.30b	3.31	n.s.
Pelecypoda	16.06b	0.00a	2.48ab	14.62b	4.52	P<0.05
MOLLUSCA combined	16.06ab	6.61ab	2.96a	32.85b	10.48	n.s.

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.
(2)In each year a set of five, 645 cm^2 samples were collected each week for three consecutive weeks.
(3)Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 14. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES[2] COLLECTED FROM THE SOUTH SASKATCHEWAN RIVER, SOUTH SIDE, ABOUT TWO KM UPRIVER FROM SITE 4 (THE CONFLUENCE).

Year Number of larvicide injections this site	1977 3	1978 4	1979 8	1980 4	All years combined	Significance of difference between years[3]
Crustaceans	0.00a	10.61b	451.90c	180.13c	30.26	P<0.01
Siphlonuridae	0.00	0.00	0.00	0.00	0.00	
Baetidae	68.02a	126.64ab	458.20b	611.35b	222.36	P<0.05
Heptageniidae	16.82a	20.13a	402.65b	62.10ab	54.72	n.s.
Tricorythidae	223.39a	178.06ab	439.55bc	943.06c	358.75	P<0.01
Caenidae	0.00a	1.76a	50.44b	0.00a	2.45	P<0.01
Leptophlebiidae	1.22a	22.91a	5.05a	0.00a	3.23	n.s.
Polymitarcyidae	0.00a	0.00a	13.92b	1.22ab	1.40	n.s.
EPHEMEROPTERA combined	332.43a	418.76a	1526.57b	1654.77b	769.90	P<0.01
ODONATA	0.00a	1.22a	2.45a	3.04a	1.36	n.s.
PLECOPTERA	0.00a	1.76a	11.08a	2.98a	2.39	n.s.
HEMIPTERA	0.00a	0.00a	0.00a	1.22a	0.22	n.s.
COLEOPTERA	0.00	0.00	0.00	0.00	0.00	
Hydropsychidae	237.78a	477.63ab	940.89ab	1065.60b	581.10	n.s.
Hydroptilidae	39.27a	10.89a	110.69ab	207.93b	56.81	n.s.
Leptoceridae	0.00a	0.00a	2.94a	1.76a	0.82	n.s.
Brachycentridae	1.22a	1.76a	0.00a	0.00a	0.57	n.s.
TRICHOPTERA combined	337.84a	526.23ab	1095.48ab	1317.26b	711.85	n.s.
Simuliidae	3.95a	111.49b	204.97b	163.55b	64.90	n.s.
Tanypodinae	167.27a	36.41a	27.97a	35.22a	49.70	n.s.
Orthocladiinae	104.93ab	83.92a	499.03bc	698.84c	236.14	P<0.05
Chironomini	565.24b	169.22a	366.28b	634.33b	386.26	P<0.01
Tanytarsini	447.75a	373.97a	549.81a	726.78a	508.33	n.s.
Empididae	0.00a	1.22ab	19.49b	26.50b	4.95	n.s.
DIPTERA combined	1335.60a	904.73a	1944.36a	2370.37a	1537.15	n.s.
ACARI	1149.80ab	1060.70a	2186.76bc	3242.40c	1716.19	P<0.05
Gastropoda	0.00a	0.00a	0.00a	1.22a	0.22	n.s.
Pelecypoda	5.14b	0.00a	0.59ab	0.00a	0.77	n.s.
MOLLUSCA combined	5.14a	0.00a	0.59a	1.22a	1.16	n.s.

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.
(2)In each year a set of five, 645 cm^2 samples were collected each week for three consecutive weeks.
(3)Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 15. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES[2] COLLECTED ABOUT ONE KM UPRIVER FROM SITE 9 (GRONLID FERRY), MAIN SASKATCHEWAN RIVER, SOUTH SIDE.

Year Number of larvicide injections above this site[3]	1977 0 (6)	1978 0 (7)	1979 4 (18)	1980 0 (5)	All years combined	Significance of difference between years[4]
Crustaceans	168.43a	347.34a	-	231.81a	238.33	n.s.
Siphlonuridae	0.00	0.00	-	0.00	0.00	
Baetidae	190.87a	49.35a	-	40.40a	72.62	n.s.
Heptageniidae	375.70a	150.71a	-	211.81a	181.81	n.s.
Tricorythidae	33.12ab	21.23a	-	209.38b	53.20	n.s.
Caenidae	1.22a	0.00a	-	0.00a	0.31	n.s.
Leptophlebiidae	1.62a	0.00a	-	1.80a	0.94	n.s.
Polymitarcyidae	2.83a	2.96a	-	29.58a	6.74	n.s.
EPHEMEROPTERA combined	446.71ab	237.23a	-	694.02b	418.76	n.s.
ODONATA	0.00a	0.44a	-	0.00a	0.13	n.s.
PLECOPTERA	0.00a	0.00a	-	43.65b	2.55	P<0.01
HEMIPTERA	7.17a	0.00a	-	0.00a	1.01	n.s.
COLEOPTERA	3.95b	0.00a	-	0.00a	0.70	n.s.
Hydropsychidae	1620.81ab	1243.51a	-	2493.59b	1712.96	n.s.
Hydroptilidae	11.96b	0.00a	-	3.95ab	3.00	n.s.
Leptoceridae	1.76a	29.19b	-	0.00a	3.37	P<0.05
Brachycentridae	6.71ab	34.88b	-	0.59a	6.60	P<0.05
TRICHOPTERA combined	1670.09ab	1320.30a	-	2505.11b	1769.11	n.s.
Simuliidae	74.86a	49.93a	-	26.23a	46.21	n.s.
Tanypodinae	177.65a	75.21a	-	71.28a	98.54	n.s.
Orthocladiinae	169.73b	28.48b	-	1.22a	21.37	n.s.
Chironomini	400.79b	146.91ab	-	31.43a	123.45	P<0.05
Tanytarsini	81.70b	61.24b	-	3.95a	28.42	P<0.05
Empididae	8.46b	0.00a	-	0.00a	1.11	P<0.01
DIPTERA combined	938.72b	445.68b	-	154.60a	401.72	P<0.05
ACARI	106.65a	51.12a	-	313.77a	119.78	n.s.
Gastropoda	58.53a	25.56a	-	5.27a	20.48	n.s.
Pelecypoda	29.48a	60.38a	-	90.41a	54.46	n.s.
MOLLUSCA combined	90.62a	95.38a	-	123.45a	102.28	n.s.

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.
(2)In each year a set of five, 645 cm^2 samples were collected each week for 3 consecutive weeks.
(3)Numbers in brackets indicate numbers of treatments in entire Saskatchewan River System above sampling site. Unbracketed numbers indicate numbers of treatments in Main Saskatchewan River alone.
(4)Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 16. MEAN NUMBERS[1] OF AQUATIC INVERTEBRATES IN SURBER-NET SAMPLES[2] COLLECTED ABOUT ONE KM UPRIVER FROM SITE 9 (GRONLID FERRY), MAIN SASKATCHEWAN RIVER, NORTH SIDE.

Year Number of larvicide injections above this site[3]	1977 0 (6)	1978 0 (7)	1979 4 (18)	1980 0 (5)	All years combined	Significance of difference between years[4]
Crustaceans	216.77a	320.37a	-	678.20a	361.24	n.s.
Siphlonuridae	0.00	0.00	-	0.00	0.00	
Baetidae	59.55a	6.97a	-	61.78a	30.17	n.s.
Heptageniidae	41.70a	8.66a	-	16.06a	18.16	n.s.
Tricorythidae	84.51ab	20.12a	-	224.42b	73.13	P<0.05
Caenidae	0.00	0.00	-	0.00	0.00	
Leptophlebiidae	0.26a	0.26a	-	0.26a	0.26	n.s.
Polymitarcyidae	6.27b	0.59a	-	0.26a	1.44	P<0.05
EPHEMEROPTERA combined	204.12ab	39.18a	-	338.63b	139.93	n.s.
ODONATA	0.00	0.00	-	0.00	0.00	
PLECOPTERA	0.26a	0.82a	-	6.61a	1.59	n.s.
HEMIPTERA	1.22a	0.00a	-	1.22a	0.70	n.s.
COLEOPTERA	0.26a	0.00a	-	0.00a	0.08	n.s.
Hydropsychidae	938.72b	90.20a	-	352.18ab	310.89	n.s.
Hydroptilidae	0.00a	2.14a	-	0.26a	0.58	n.s.
Leptoceridae	23.09b	1.80a	-	0.00a	3.07	P<0.01
Brachycentridae	13.77b	1.62a	-	0.82a	3.11	P<0.05
TRICHOPTERA combined	985.28b	99.93a	-	353.81ab	327.10	n.s.
Simuliidae	23.67a	96.36a	-	2.71a	19.73	n.s.
Tanypodinae	133.52a	13.92a	-	13.13a	29.49	n.s.
Orthocladiinae	119.86a	7.69a	-	5.99a	18.43	n.s.
Chironomini	646.14b	42.45a	-	49.35a	111.20	P<0.01
Tanytarsini	344.14a	18.19a	-	43.46a	65.53	n.s.
Empididae	3.95a	1.22a	-	0.00a	1.22	n.s.
DIPTERA combined	1347.96b	227.56ab	-	146.23a	355.45	n.s.
ACARI	108.90ab	85.90a	-	362.92b	150.71	n.s.
Gastropoda	84.33b	5.95a	-	0.00a	7.40	P<0.01
Pelecypoda	7.08a	16.60a	-	10.39a	10.74	n.s.
MOLLUSCA combined	92.30b	30.00ab	-	10.39a	31.06	n.s.

(1)Geometric means calculated from $\log_{10}(x + 1)$ values.
(2)In each week a set of five, 645 cm^2 samples were collected each week for 3 consecutive weeks.
(3)Numbers in brackets indicate numbers of treatments in entire Saskatchewan River System above sampling site. Unbracketed numbers indicate numbers of treatments in Main Saskatchewan River alone.
(4)Calculated from $\log_{10}(x + 1)$ values. Means followed by different letters, differ significantly ($P<0.05$) as indicated by Duncan's New Multiple Range tests.

TABLE 17. SUMMARY OF TABLES 11 TO 16, INCLUSIVE, IDENTIFYING THOSE YEARS WHICH PROVIDED MAXIMUM DENSITIES OF BENTHIC INVERTEBRATES IN EACH OF THE SIX LOCATIONS IN THE NORTH, SOUTH, AND MAIN BRANCHES OF THE SASKATCHEWAN RIVER[1]

Site Number	3	3	4	4	9	9
River Branch	North	North	North	South	Main	Main
River Side	South	North	North	South	South	North
Notes		EFFLUENT[2]				
					1979 DATA MISSING[3]	
CRUSTACEANS	1979	1977	1979	1979	1978	1980
	(143) (HS)	(61) (S)	(64) (HS)	(140) (HS)	(108)	(211)
Siphlonuridae	1980	–	–	–	–	–
	(0.25)	–	–	–	–	–
Baetidae	1977	1977	1980	1980	1977	1980
	(198)	(93)	(106)	(189) (S)	(59)	(19)
Heptageniidae	1979	1980	1978	1979	1977	1977
	(309) (S)	(89)	(6.5)	(125)	(117)	(13)
Tricorythidae	1980	1980	1980	1980	1980	1980
	(55)	(42)	(45)	(293) (HS)	(65)	(70) (S)
Caenidae	1980	1977	1979	1979	1977	
	(5.1)	(6.2)	(0.55)	(16) (HS)	(0.38)	
Leptophlebiidae	1980	1980	1978	1978	1980	means alike
	(7.8) (S)	(9.7) (S)	(6.8) (HS)	(7.1)	(0.56)	(0.08)
Polymitarcyidae	1980	1980	1977	1979	1980	1977
	(44) (HS)	(10)	(3.1)	(4.3)	(9.2)	(1.9) (S)
EPHEMEROPTERA	1980	1980	1980	1980	1980	1980
(combined)	(425) (S)	(259) (S)	(162) (S)	(514) (HS)	(215)	(105)
ODONATA	1979	1980	-	1980	1978	
	(2.2)	(1.3)	-	(0.94)	(0.14)	
PLECOPTERA	1980	1980	1980	1979	1980	1980
	(23) (HS)	(38) (HS)	(14) (HS)	(3.4)	(14) (HS)	(2.1)
HEMIPTERA	1979	1980	1977	1980	1977	1977
	(8) (S)	(1.6)	(3.9) (S)	(0.38)	(2.2)	(0.38)
COLEOPTERA	1979	1980	-	-	1977	1977
	(0.92)	(0.18)	-	-	(1.2)	(0.08)
Hydropsychidae	1980	1979	1980	1980	1980	1977
	(648)	(1346) (HS)	(388) (S)	(331)	(773)	(291)
Hydroptilidae	1980	1980	1979	1980	1977	1978
	(0.56)	(0.78)	(101) (HS)	(64)	(3.7)	(0.66)
Leptoceridae	1980	1978	1980	1979	1978	1977
	(3.1)	(1.1)	(0.38)	(0.91)	(9.0) (S)	(7.2) (HS)

(continued on next page)

Table 17 (continued)

Site Number	3	3	4	4	9	9
River Branch	North	North	North	South	Main	Main
River Side	South	North	North	South	South	North
Notes	EFFLUENT(2)				1979 DATA MISSING(3)	
Brachycentridae	1978 (5.7) (HS)	1977 (3.3)	1979 (7.9) (HS)	1978 (0.55)	1978 (11) (S)S	1977 (4.3) (S)
TRICHOPTERA (combined)	1980 (656)	1979 (1349) (HS)	1979 (491) (HS)	1980 (408)	1980 (777)	1977 (306)
Simuliidae	1977 (18)	1978 (15)	1980 (14)	1979 (64)	1977 (23)	1978 (30)
Tanypodinae	1979 (88)	1979 (88)	1979 (78) (S)	1977 (52)	1977 (55)	1977 (41)
Orthocladiinae	1977 (40)	1977 (45)	1979 (275) (S)	1980 (217) (S)	1977 (53)	1977 (37)
Chironomini	1979 (385) (S)	1979 (180)	1979 (862) (HS)	1980 (197) (HS)	1977 (124) (S)	1977 (201) (HS)
Tanytarsini	1977 (71)	1978 (36)	1979 (594) (HS)	1980 (226)	1977 (25) (S)	1977 (107)
Empididae	1979 (12)	1978 (4.9)	1979 (80) (S)	1980 (8.2)	1977 (2.6) (HS)	1977 (1.2)
DIPTERA (combined)	1979 (573) (HS)	1979 (350)	1979 (1940) (HS)	1980 (736)	1977 (291) (S)	1977 (418)
ACARI	1979 (55) (S)	1979 (149)	1979 (271) (HS)	1980 (1015) (S)	1980 (97)	1980 (112)
Gastropoda	1979 (6.9)	1977 (20)	1980 (6.0)	1980 (0.38)	1977 (18)	1977 (26) (HS)
Pelecypoda	1979 (191)	1977 (11)	1980 4.5(S)	1977 (1.6)	1980 (28)	1978 (5.1)
MOLLUSCA (combined)	1979 (214)	1977 (32)	1980 (10)	1977 (1.6)	1980 (38)	1977 (29)

(1)Notations in parentheses indicate annual mean (number/m^2) (geometric, calculated from $\log^{10}(n+1)$ transformations), and also indicate whether differences between the four years were significant (S) or highly significant (HS).

(2)Samples from this location were collected nine km downstream from a pulp mill (newsprint), directly in the effluent path.

(3)No samples were collected from Site Nine in 1979.

samples collected there in 1979). Differences between years were not significant in either site.

Tricorythids (almost 100 percent *Tricorythodes minutus* Traver), the third of three ephemeropteran families most abundantly represented, peaked in 1980 in all six locations. Differences between years were highly significant in the South Saskatchewan River and significant in one location in the main Saskatchewan River.

Larvae of all three of these families are considered to be swimmers, climbers, and clingers, and feed by collecting and scraping detritus, diatoms, etc. from substrates (Table 5). Fredeen *et al.* (1975) showed that methoxychlor was rapidly adsorbed to solids in river water. Thus these larvae could have been exposed to methoxychlor either or both as a contact or stomach poison. Despite this they appeared to resist harmful effects.

The less abundant caenids (about 98 percent *Caenis tardata* McDunnough) and leptophlebiids (about 100 percent *Traverella albertana* (McDunnough)) which possessed similar living and feeding habits, and filter-feeding siphlonurids (about 100 percent *Isonychia sicca*) also peaked in the North Saskatchewan River in one or more locations in 1980, in the South Saskatchewan in 1978 (leptophlebiids) and 1979 (caenids) with highly significant differences between years, and in the main Saskatchewan River in 1977 (caenids) and 1980 (leptophlebiids), with differences between years not significant.

Burrowing polymitarcyids (100 percent *Ephoron album* (Say)) peaked in the North Saskatchewan River in two locations in 1980, with highly significant differences between years in one location. They also peaked in the South Saskatchewan River in 1979 and in the main Saskatchewan River (south side) in 1980.

Mean August populations of Plecoptera, all taxa combined, peaked in five of the six locations in 1980 ($P<0.01$ in four locations), and peaked in the sixth location (the South Saskatchewan River), in 1979. Larvae were scarce however, peaking at 38 or fewer larvae per m^2 of river bed (Table 17). Larvae of *Isoperla* would not have hatched until after the August collection dates each year.

Larvae of Odonata and Coleoptera were generally present although rare (absent from some sites) and significant trends in numbers were not evident.

Immature hemipterans (corixids) also were relatively scarce in most sites but numbers peaked in two rivers in 1980 and in the main Saskatchewan River in 1977. Samples were not collected there in 1979. Corixids migrate from surrounding regions to overwinter in the rivers.

Mean numbers of trichopteran larvae, all taxa combined, peaked in one or more locations in all three rivers in 1980. In two of the three locations in the North Saskatchewan River, however, peaks occurred in 1979 with differences between years highly significant. Ninety-eight percent of the trichopterans were hydropsychids which, because of their size and number, easily comprised the most important portion of the total invertebrate biomass of the river. Sixty to 90 percent of the hydropsychids were *Cheumatopsyche* spp. and the the remainder were mainly *Hydropsyche alternans* (Walker) and *H. confusa*. It had been thought that filter-feeding hydropsychid larvae (Table 5) might have been relatively sensitive to methoxychlor which is known to readily adsorb to particles suspended in the water (Fredeen *et al.*, 1975). However, population numbers showed no indication of this.

Larvae of three other families of Trichoptera, the Hydroptilidae (*Mayatrichia ayama* Mosely), Leptoceridae (*Nectopsyche diarina* (Ross)), and Brachycentridae (*Brachycentrus ocidentalis* Banks), all considered to be herbivores (Table 5), were relatively scarce. In the North and South Saskatchewan Rivers their populations peaked in either 1979 or 1980. The one exception was Brachycentridae in the South Saskatchewan, peaking in 1978. In the main

Saskatchewan River they peaked in 1977 or 1978. However, no samples were collected there in 1979, which could have been their peak year as in the other rivers.

Larvae of Diptera, of which about 98 percent were chironomids, peaked in all three benthic sampling locations in the North Saskatchewan River in 1979, with differences between years highly significant in two locations. Numbers peaked in the South Saskatchewan in 1980 and in the main Saskatchewan in 1977 (samples were not collected in 1979) and differences between years were significant in one North Saskatchewan location.

Of the Chironomidae about 50 to 75 percent of the specimens were species of Chironomini, a subfamily with many filter-feeders, but otherwise with very diverse living and feeding habits (Table 5). In the North Saskatchewan River numbers of Chironomini peaked in 1979, and in the South Saskatchewan in 1980 with significant or highly significant differences between years in three of the four sampling locations.

Larvae of the less abundant predaceous Tanypodini peaked in the three North Saskatchewan River locations in 1979, with differences between years significant in one location, and peaked in the South and main Saskatchewan Rivers in 1977 with non-significant differences between years.

Larvae of the herbivorous Orthocladiinae peaked in 1979 and 1980 in the North and South Saskatchewan Rivers at Site 4 with significant differences between years but elsewhere showed non-significant trends. Larvae of Tanytarsini peaked in 1979 in the North Saskatchewan River (Site 4) with highly significant differences between years and in the South Saskatchewan (Site 4) in 1980. Elsewhere populations did not trend significantly.

Trends in the relatively small populations of Empididae and Simuliidae were generally inconclusive but peaked in the North Saskatchewan River in 1977 or 1980, in the South Saskatchewan River in 1979 or 1980 and in the main Saskatchewan River in 1977 or 1978 (where no benthic samples were collected in 1979).

Mites, whose larvae are parasitic, and adults are predators of various aquatic invertebrates, peaked in all three locations in the North Saskatchewan River in 1979 (with significant or highly significant differences between years in two locations). They peaked in the South Saskatchewan River in 1980 (with significant differences between years), and in the main Saskatchewan River in 1980 (with non-significant differences between years). These trends provide indirect evidence that numbers of their prey species also may have increased in abundance during these four years.

Molluscs were scarce in most locations and trends in numbers were not significant.

Thus in general, data from benthic samples collected each August from all three branches of the Saskatchewan River System indicated that with few exceptions populations of non-simuliid taxa increased rather than decreased throughout three years of increasingly intensive use of methoxychlor black fly larvicide followed by a fourth year of less intensive use.

Check-list of taxa in benthic samples

A detailed list of taxa (Table 18) was prepared from benthic samples collected in 1980. (Samples collected in earlier years were not analyzed in such detail because of inadequate systematic keys. However, samples from previous years are being retained in the event that re-examinations in greater detail are required.)

These benthic samples would not have contained species which would have been in the egg stage in August, particularly some heptageniid mayflies and some plecopterans. But data in Table 18 show that sufficient other taxa were present in some or all locations sampled to

TABLE 18. LIST OF INVERTEBRATE TAXA COLLECTED IN SURBER-TYPE NETS FROM SIX SITES IN THE NORTH, SOUTH, AND MAIN BRANCHES OF THE SASKATCHEWAN RIVER IN SASKATCHEWAN, AUGUST 5, 12, AND 19, 1980[1] [2].

Saskatchewan River Branch	North	North	North	South	Main	Main
Site[3]	Above Site #3		Above Site #4		Above Site #9	
River Margin	North	South	North	South	North	South
CONCHOSTRACA	0	0	X	0	0	0
CLADOCERA	X	X	0	X	0	0
OSTRACODA	X	X	X	X	X	X
COPEPODA	X	X	X	X	0	0
MALACOSTRACA						
AMPHIPODA: *Hyalella azteca*	0	0	0	X	0	0
INSECTA						
EPHEMEROPTERA						
Siphlonuridae:						
Isonychia sicca	X	X	0	0	0	0
Baetidae: *Baetis insignificans*	0	X	X	X	X	X
B. tricaudatus	0	X	X	X	X	X
Baetis nr. *pluto*	X	X	X	X	X	X
Baetis sp.	X	X	X	X	X	0
Centroptilum bifurcatum	0	0	0	0	X	0
Pseudocloeon sp.	X	X	0	X	X	0
Heptageniidae:						
Heptagenia adequata	0	0	0	0	0	X
H. elegantula	0	X	0	0	0	X
H. pulla	0	X	0	X	0	X
Heptagenia sp.	X	X	0	X	X	X
Stenonema terminatum	X	X	X	X	X	X
Tricorythidae:						
Tricorythodes corpulentus	0	0	0	0	0	X
T. minutus	0	X	0	X	0	X
Tricorythodes sp.	X	X	X	X	X	X
Caenidae: *Caenis tardata*	X	X	0	0	0	0
Leptophlebiidae:						
Traverella albertana	X	X	X	0	X	X
Polymitarcyidae:						
Ephoron album	X	X	X	0	X	X

(continued on next page)

Table 18 (continued)

Saskatchewan River Branch	North	North	North	South	Main	Main
Site(3)	Above Site #3		Above Site #4		Above Site #9	
River Margin	North	South	North	South	North	South
ODONATA						
Anisoptera:						
Ophiogomphus severus	X	X	0	X	0	0
Zygoptera: *Ischnura* sp.	0	0	0	X	0	0
PLECOPTERA (Immatures)	X	X	X	X	X	X
Pteronarcyidae:						
Pteronarcys dorsata	0	0	0	X	0	0
Perlidae:						
Acroneuria abnormis	X	0	0	0	0	0
HEMIPTERA						
Corixidae (Immatures)	X	X	0	X	X	0
COLEOPTERA						
Dytiscidae: *Deronectes* sp.	X	X	0	0	0	0
Helodidae (Immatures)	0	X	0	0	0	0
TRICHOPTERA						
Psychomyiidae:						
Psychomyia flavida	0	X	0	0	0	0
Polycentropodidae:						
Neureclipsis bimaculata	0	0	0	0	0	X
Hydropsychidae:						
Hydropsyche alternans	X	X	X	X	X	X
H. placoda	X	X	X	X	X	X
H. occidentalis	0	0	0	X	0	0
H. confusa	X	X	X	0	X	X
Cheumatopsyche sp.	X	X	X	X	X	X
Hydroptilidae:						
Hydroptila ajax	X	0	0	X	0	0
Mayatrichia ayama	X	X	0	X	X	X
Brachycentridae:						
Brachycentrus occidentalis	X	X	X	0	X	X
Leptoceridae:						
Ceraclea tarsipunctata	0	X	0	X	0	X
Nectopsyche diarina	0	X	X	0	0	X
Oecetis avara	0	X	0	0	0	0
Unidentified sp.	X	X	0	0	0	

(continued on next page)

Table 18 (continued)

Saskatchewan River Branch	North	North	North	South	Main	Main
Site(3)	Above Site #3		Above Site #4		Above Site #9	
River Margin	North	South	North	South	North	South
DIPTERA:						
Simuliidae:						
Simulium luggeri	X	X	X	X	X	X
S. meridionale	X	X	X	0	X	0
S. vittatum	X	X	X	X	0	X
Chironomidae:						
Chironominae						
Chironomini:						
(unidentified)	X	X	X	X	X	X
Chironomus (s.s.) sp.	X	X	X	0	0	0
Cryptochironomus sp.	0	X	X	0	0	X
Microtendipes sp.	X	X	X	X	X	X
Paracladopelma sp.	0	X	0	0	0	0
Polypedilum sp.	X	X	X	X	X	X
Robachia sp.	0	X	0	0	0	0
Tanytarsini (unidentified)	X	X	X	X	X	X
Rheotanytarsus sp.	X	X	0	0	X	0
Orthocladiinae (unidentified)	X	X	X	X	X	X
Cricotopus (s.s.) sp.	0	0	0	X	0	X
Tvetenia sp.	0	0	0	X	0	X
Tanypodinae (unidentified)	X	X	X	X	X	X
Thienemannimyia sp.	X	X	X	X	X	X
ACARI						
Parasitengona	X	X	X	X	X	X
MOLLUSCA						
GASTROPODA (unidentified)	0	0	0	0	0	X
Ancylidae	X	X	X	0	0	0
Limnaeidae	0	X	0	0	0	0
Physidae	0	0	0	X	0	0
Planorbidae	X	X	X	0	0	0
PELECYPODA						
Sphaeridae	X	X	X	0	X	X

(1)On each of the three dates, five 645 cm^2 river bed samples were collected from each of the six sites. The diameter of the mesh openings in the net was 0.2 mm.
(2)"0" = absent in samples; "X" = present
(3)See Fig. 1 to locate sites on map, and Table 1 for distances.

indicate that a complex invertebrate fauna still existed following four years of relatively intensive use of methoxychlor black fly larvicide. Included were representatives of widely varied life cycles, larval activity patterns, and feeding habits (Table 5). Particularly abundant and/or widespread in 1980 were mayfly larvae (especially the clinging, herbivorous heptageniids, tricorythids, and leptophlebiids); swimming herbivores (baetids); carnivorous odonatids; herbivorous stoneflies; filter-feeding, herbivorous or detrivorous hydropsychids; herbivorous hydroptilids, brachycentrids, and leptocerids; filter-feeding simuliids and chironomids (many taxa); herbivorous and predatory chironomids (tanypodines and orthocladiines); parasitic mites and various molluscs.

Included also were species with life cycles as short as four to five weeks (especially *S. luggeri* or others with larvae continuously abundant throughout the summer (heptageniids and other mayfly taxa, hydropsychids and many chironomids)), and species with life cycles lasting one or more years (pteronarcid and perlid stoneflies). With repeated insecticide treatments throughout four consecutive summers one might have expected that species with relatively short life cycles such as simuliids would have become relatively more abundant in comparison with species which spent longer periods as larvae. However, there was no evidence of this occurring and in fact simuliid larvae, excluding *S. vittatum*, became less abundant in successive years and differences between years were highly significant, at least in mid-river sites (Table 9), whereas species which spent much of each summer as larvae, such as many ephemeropterans, trichopterans, and chironomids, either peaked in the third or fourth years of the tests or trended insignificantly between years (Tables 6, 7, and 8).

Need for Control of Black Flies at Sites of Breeding

Throughout four consecutive years of tests with methoxychlor as a black fly larvicide in the Saskatchewan River system in Saskatchewan, populations of larvae of the problem species of black fly, *S. luggeri* declined progressively to their lowest levels ($P<0.01$) in the final year (Table 9). Residents in east-central Saskatchewan experienced major outbreaks in 1976, 1977 and 1978 but almost complete relief from black fly outbreaks during 1979 and 1980. Maximum use of larvicide occurred in 1979, both as regards numbers of sites and numbers of injections. Also, in 1979, the main Saskatchewan River below the confluence of the two branches was injected for the first time. Greatly reduced populations of *S. luggeri* larvae throughout 1980 allowed reductions in numbers of treatments that year (Tables 2, 3, 4).

Provincial and Federal Departments of the Environment are rightfully concerned about the invertebrate fauna of the Saskatchewan River when renewals of permits for larviciding are requested each year. Data presented in this paper should help to rationalize those concerns. At the same time there has to be concern for human environments in some one to three million ha of land sometimes blanketed by widespread, prolonged outbreaks of *S. luggeri*. Not only were people unable to work out-of-doors during outbreaks in 1976 through 1978 unless well protected, but also livestock owners incurred considerable financial losses (Fredeen, 1981).

Despite many years of research towards protecting livestock individually from black fly attacks, both in this country and elsewhere, there still are no practical or economical means of protection available, especially for animals in large pastures. Within the region affected by outbreaks of *S. luggeri* in east-central Saskatchewan (up to three million ha in 1978) there are estimated to be more than 250,000 beef and dairy cattle in community and private pastures each summer. Most of these animals could not be regularly rounded up for insecticide treatments, even if durable, registered insecticides were available, because management and chemical costs would be prohibitive. Labour and chemical costs are more efficiently used if infestations of black fly larvae are reduced when in their relatively limited river environments, rather than by attempting to reduce numbers of adults that have dispersed widely into the countryside. Furthermore, dispersals of adult black flies are affected by varying weather conditions which frequently catch livestock producers unprepared.

Thus at this time, black fly larviciding with methoxychlor remains the most practical method for minimizing damage from widespread outbreaks of *S. luggeri* from the Saskatchewan River, and this study shows that larviciding throughout a four-year period was relatively harmless to the natural environment of that river in the long term.

Alternatively one might consider reducing numbers of larvae of *S. luggeri* by reversing whatever ecological trends in the river system may have encouraged invasion by populations of this species in the early 1970's, and proliferation within a few years to the extent that widespread outbreaks of economic proportions were possible. Other haematophilic species of black flies such as *S. meridionale*, *S. venustum*, and *S. tuberosum* recently have become established in this river and may also require control in future years (Fredeen, 1981). Thus one might consider attempting to reverse recent ecological trends but such a "biological control" method would also affect the present day environments of non-simuliid taxa.

CONCLUSIONS

Trends in numbers of non-simuliid invertebrates throughout 1977 to 1980 in the North, South, and main branches of the Saskatchewan River in Saskatchewan were generally directly related to the numbers of methoxychlor larvicide injections each year. Thus when total numbers of larvicide injections were increased from one in 1976, to six in 1977, seven in 1978, 19 in 1979, and five in 1980, densities of most non-simuliid taxa in benthic samples also peaked either in 1979 or 1980, many significantly so (Table 17). Mean numbers of total non-simuliids in all mid-river sites combined, also peaked in 1979 ($P<0.01$) (Table 9). Thus numbers of non-simuliid aquatic invertebrates showed similar upward trends during these years whether collected with artificial substrates from mid-river, or with Surber-type nets from benthic sites along the river margins.

Repopulation of treated sections was assured by drift of invertebrates downstream from extensive untreated sections, as well as by hatching of eggs and by movement of larvae from protected niches within each treated section. The abundant and complex benthic fauna surviving along the river margins presumably served as a rich source of emigrants for depopulated areas.

Some observed increases appear also to have been due to downstream displacements of larvae which had been stimulated to release during larvicide treatments.

Qualitatively also, the non-simuliid fauna appeared healthy at the conclusion of tests in 1980 (Table 18). Benthic samples collected from all three river branches throughout August that year contained a variety of species representing normal ranges of activity patterns, feeding habits, and life cycles. Although data in Tables 6 through 17 relate mainly to suprageneric taxa, qualitative analyses showed each of these taxa to be represented by relatively few dominant species throughout the four years of tests. Thus upward trends in numbers throughout two or more of the four years of treatments were caused mainly by increases in the numbers of relatively few species.

The fact that significant upward trends in numbers of most suprageneric taxa occurred during three years of increasingly intensive use of methoxychlor and a fourth year of less intensive use suggests that long-term effects of this larvicide on numbers of most non-simuliids were essentially neutral when compared with effects of natural ecological processes.

In general, this study of trends in quantities and qualities of invertebrate taxa inhabiting the three branches of the Saskatchewan River throughout four years of injections of methoxychlor larvicide indicates that *S. luggeri* may be successfully controlled in a limited portion of the Saskatchewan River without permanently harming major non-simuliid taxa. The results support data from an earlier study (Fredeen, 1975) which showed relatively rapid repopulation of a 160-km section of the Saskatchewan River following a single injection of methoxychlor.

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