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A Community of simulium species in the Vaal River near Warrenton

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PLATE 5: Polythene artificial-substrate colonized by clumps of simuliid larvae, and pupae.



PLATE 6: Metal rod with attached artificial substrates. The central substrate had been dislodged.

The volume of separated animal groups collected from stone samples was estimated at monthly intervals. As volume is not as frequently used as biomass (Hynes, 1972) equations to convert volume (easily measured in the laboratory) to the more involved and complex biomass determinations were derived from a selected data base (Appendix 2.5).

The amount of food present in the river was considered as a possible factor that might influence the population size of Simuliidae. For an estimation of the amount of food available the total organic carbon (TOC) from filtered and unfiltered samples of river water was compared at weekly intervals. It was postulated that the difference in TOC between these two samples would give an indication of the amount of particulate organic carbon present. However highly variable results showed that this method was unsuitable and a method using Ultra Violet light absorbance was used to determine the amount of particulate organic material present. A description and discussion of this technique is given in Appendix 2.6.

At monthly intervals from June 1979 to July 1980 a one litre sample of water was collected from running water in the study rapid and preserved with formalin. Diatoms (Bacillariophyta) were identified and the dominance of various species was determined by Dr R E M Archibald of the NIWR. In addition the diatoms in 120 microscope fields at a magnification of 1 250 times were counted from each sample of water which had been concentrated down to 5 or 10 mℓ and a 0,1 mℓ sub-sample of this was then prepared on a microscope slide. This allowed a monthly estimation of the density of drifting diatoms. From the determined surface area of each 0,1 mℓ drop of water (planimetry) an extrapolation of diatom counts expressed as numbers per litre of water was obtained. As diatoms are recognized as a good food source for Simuliidae (Ch. 7.3.7) simultaneous fluctuations in population densities of drifting diatoms and Simuliidae would indicate that diatom density was a factor influencing simuliid abundance.

The recording of air and water temperatures, pH, rainfall, water level of the river at a selected site, water velocities and volumes of water released are described in Appendix 2.7. Results are presented in Appendix 2.7, Table 2.24. Population estimates of fauna from artificial

substrates and stones from the current are expressed as Sichel mean values (Appendix 2.8, Table 2.25; Appendix 5, Tables 5.1 to 5.3). Faunal counts from the drift are expressed as numbers per 1 000 litres of water (Appendix 2.7, Table 2.27).

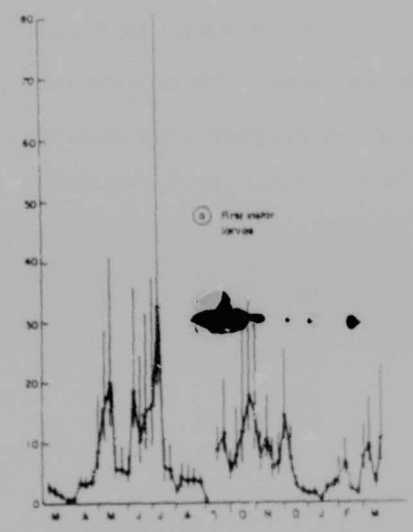
4.3 RESULTS AND DISCUSSION

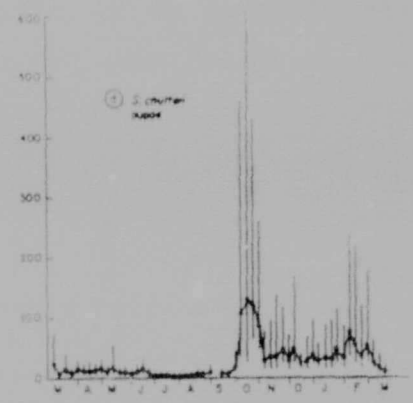
4.3.1 Fluctuations in simuliid abundance in the study rapid

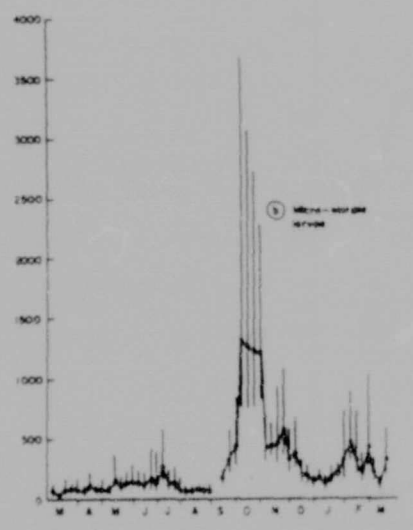
During a year when no management of water flow was carried out, simuliid population levels on artificial substrates were studied in detail. Figure 3 shows that *S. chutteri* and *S. adersi* were always present. Recruitment of first instar and micro-sample larvae also occurred throughout that year (Fig. 3a and b), and the presence of simuliid eggs in the drift (Fig. 4a) at all times indicated that breeding occurred throughout the annual cycle.

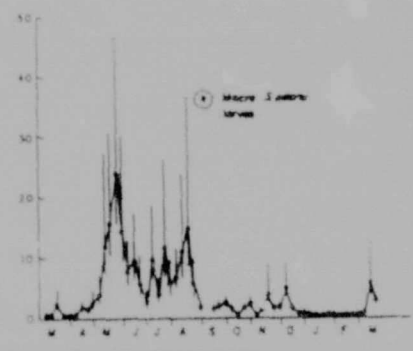
The simuliid population on artificial substrates in the study rapid as borne out by micro-sample larvae (Fig. 3b) was greatest in October 1979. The species mainly responsible for this increase was *S. chutteri* (Fig. 3c and d). A correspondingly high number of first instar simuliid larvae on artificial substrates also occurred at that time of the year (Fig. 3a). An earlier distinct increase of first instar larvae from May to July 1979 could however not be associated with a corresponding increase in *S. chutteri* larvae and pupae. Figure 3e shows that there was an increase in the population of *S. adersi* at that time. It thus appeared that first instar larvae, not yet identifiable to species level, could belong to *S. adersi* from May to July.

Comparing the actual numbers of first instar larvae to the numbers of micro-sample and *S. chutteri* larvae (Fig. 3a, b and c) it does not seem possible that such low numbers of first instars could account for the increased population levels of *S. chutteri* in October. It could be that first instar *S. chutteri* larvae occurred at other sites and not only within the rapid where the population levels were monitored on artificial substrates. Population levels of *S. adersi* were lower than *S. chutteri* and from May to July it seemed feasible that the first









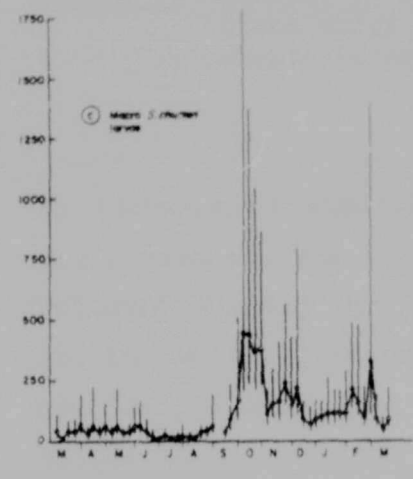


FIGURE 3: Numbers of simuliid larvae on artificial substrates at weekly intervals from 4 March 1979 to 20 March 1980, counts expressed as Sichel mean numbers per substrate with 90 per cent confidence limits

instar population of Simuliidae on artificial substrates could account for the numbers of *S. adersi* encountered then (Fig. 3a and e). These observations indicate that *S. chutteri* and *S. adersi* are temporally and spatially separated and this aspect is taken up in greater detail in Chapter 7.

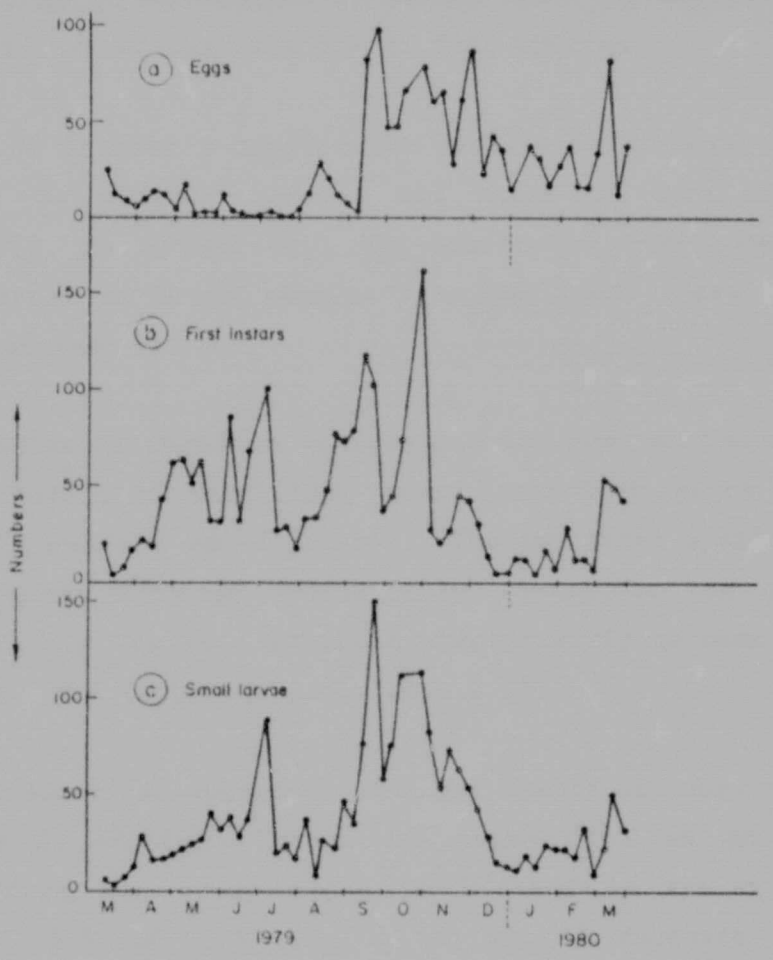


FIGURE 4: Numbers of Simuliidae encountered in 1 000 litres of drifting river water, samples collected upstream of the study rapid at weekly intervals from 4 March 1979 to 20 March 1980

An increase of simuliid eggs, first instar and other small larvae in drift samples from September to November 1979 (Fig. 4a, b and c) was followed closely by an increase in the numbers of *S. chutteri* on artificial substrates. Eggs in drift thus appear to belong to *S. chutteri*, a conclusion which is supported by studies reported in Chapter 6.3.4a.

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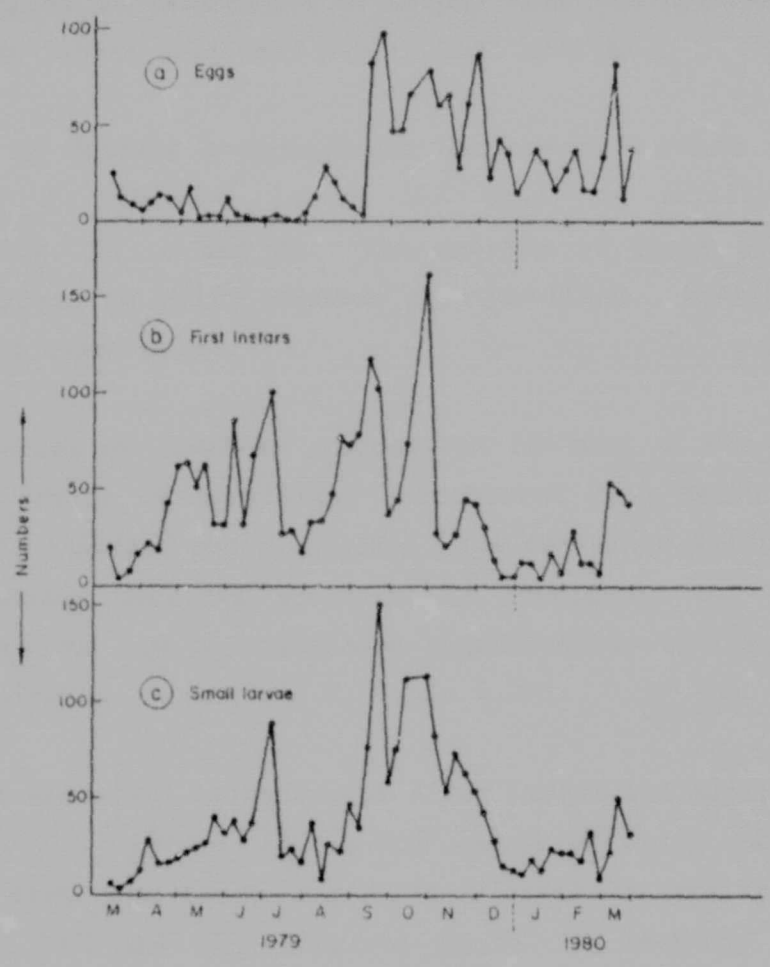


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There were also large numbers of first instar simuliid larvae present in drift samples collected from May to July, but then there were no correspondingly large increases in the numbers of eggs (Fig. 4a and b). This again indicated that another species of *Simulium* was responsible for the abundance of first instar larvae found in drift samples at that time of the year. As *S. adersi* was the only other abundant species at that time of the year, it is reasonable to assume that the observed increases in first instar larvae then were due to that species.

At the end of October a significant decline in numbers of micro-sample larvae and *S. chutteri* larvae and pupae on artificial substrates occurred (Fig. 3b, c and d). The density of first instar and small simuliid larvae in drift samples also declined. Possible reasons for this are discussed below.

The two species of *Simulium* responsible for most of the fluctuations in population levels of Simuliidae encountered from March 1979 to March 1980 were *S. chutteri* and *S. adersi*. The two other species, *S. mamahoni* and *S. damnosum* occurred sporadically throughout the year but their numbers were too low to contribute significantly to simuliid population changes monitored (Appendix 2.8, Table 2.25).

Significant numerical increases of first instar and micro-sample larvae, as well as *S. chutteri* larvae and pupae occurred on stone samples collected from the study rapid at Witrand in spring (September to October) of 1978 and 1979 (Fig. 5a to d). A decrease in *S. chutteri* larvae and pupae from September to October 1980 was due to a water flow manipulation programme and for that reason the highest population densities of these stages were attained in July and August that year.

The greatest increase in numbers of both *S. adersi* larvae and pupae on stone samples from the study rapid occurred from June to August for all three years (Fig. 5e). *Simulium mamahoni* had a similar increase in population size during the winters of these years but in this species, population numbers remained high until September (Fig. 5f). A peak in the number of *S. damnosum* s.l. larvae and pupae occurred in September 1979 with a dramatic decline in numbers following in October and November (Fig. 5g). In 1980 *S. damnosum* increased numerically from March

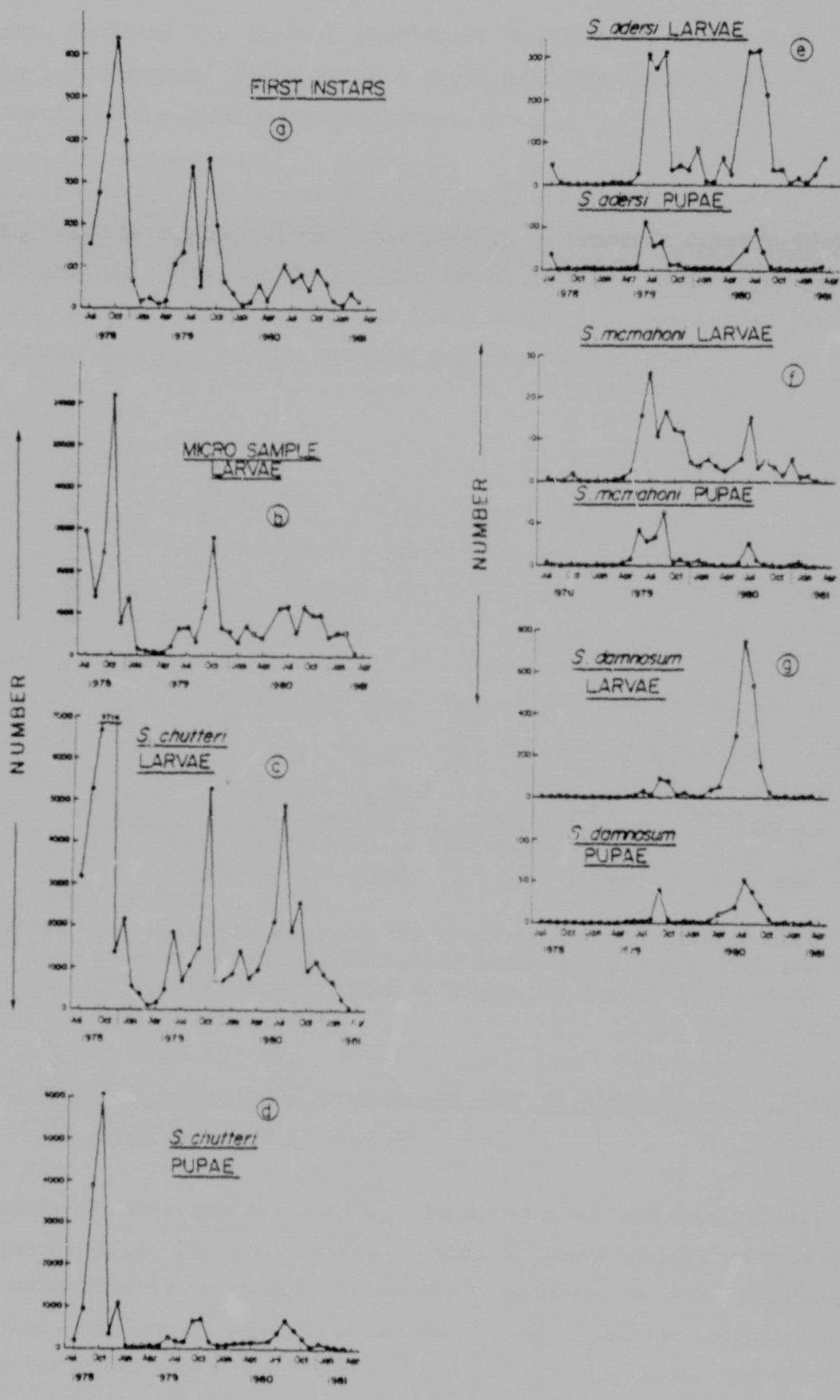


FIGURE 5: Numbers of Simuliidae on stone samples from the study rapid collected at monthly intervals from July 1978 to April 1981, counts expressed as Sichel mean numbers per 1 000 cm^2 of stone surface area

onwards reaching its highest population density in July. From August there was a gradual decrease in numbers probably strongly influenced by the water flow manipulation programme.

A steady increase in the total simuliid biomass occurred every year in spring and the highest biomass was usually recorded in October (Fig. 6). The unexpected decrease in biomass which occurred after July 1980 was due to the successful application of a water flow management programme to control the size of the simuliid population that year.

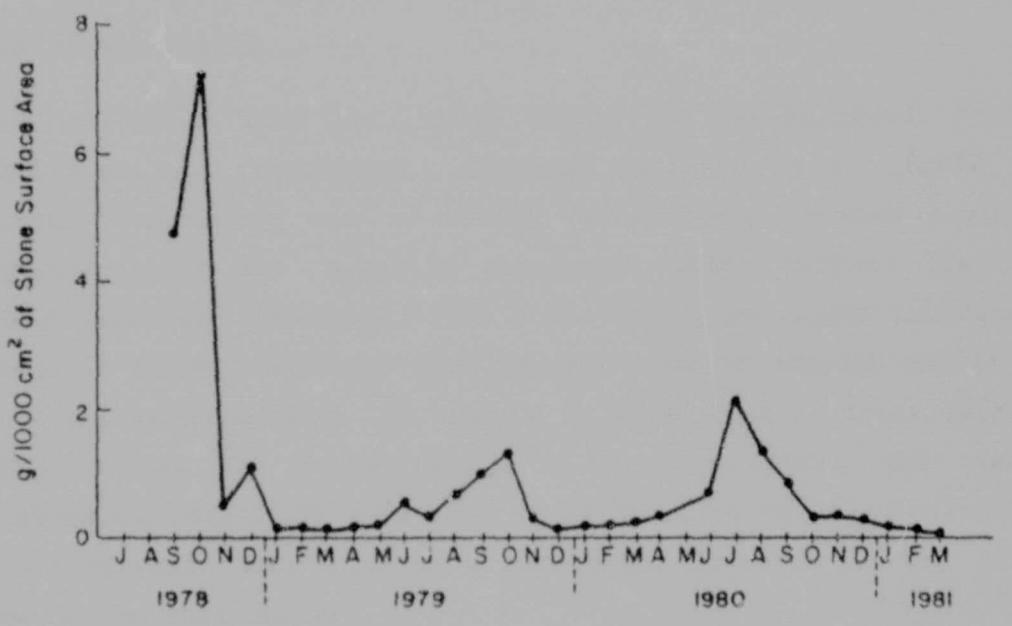


FIGURE 6: Dry weight biomass of the total number of Simuliidae on stone samples at monthly intervals between September 1978 and March 1981, biomass expressed in grams per 1 000 cm^2 of stone surface area

4.3.2 Possible factors influencing the size of simuliid populations in the selected rapid at Witrand

A number of environmental factors, both physical and biological, were monitored during the study period. Some of these factors were selected and independently examined as to their effects on the pre-imaginal simuliid population size fluctuations. Only general trends in the variables which might control the abundance of Simuliidae are discussed below. Correlations between the various factors and simuliid populations were not determined because both simuliid population estimates and the physical and biological parameters measured were not under control and

were subject to natural variability (Laws and Archie, 1981). Attempts to correlate any particular variable with simuliid numbers, without taking into account all the other variables which would have an effect on each other and a combined effect on the population size of Simuliidae would probably give rise to spurious correlations (Simpson *et al.*, 1963). A multiple regression analysis using the combined physical and biological variables to determine how much a selected combination of variables influenced population fluctuations in Simuliidae is carried out in Chapter 8.

a) Food availability

Only potential food for larval Simuliidae was examined, food for adults was not considered. Although Carlsson *et al.* (1977) concluded that there was no direct relationship between planktonic concentrations and simuliid abundance, other workers (Harrison, 1960; Erman and Chouteau, 1979) found that significant increases in simuliid numbers occurred when nanoplankton or organic matter concentrations were high. It should be noted that a direct relationship between the concentration of organic matter and simuliid numbers is not to be expected, as an increase in organic matter or plankton would only lead to a subsequent increase in the animals feeding on this matter.

The estimated particulate organic carbon (Fig. 7) (see Appendix 2.6 for details) was above 1 mg per litre from September 1979 to February 1980 and this was also the period when significant increases in Simuliidae occurred (Figs 3, 4 and 5). Maciolek (1966) concluded that the total population of filter feeding consumers in Convict Creek California was probably only limited by minimum seasonal concentrations of microseston (defined as organic detritus, diatoms and miscellaneous organisms smaller than 400 µm) below 0,5 mg per litre. He also speculated that levels of microseston higher than 1 mg per litre, would probably not be fully exploited.

Taking into account only the particulate organic carbon concentrations from UV estimates (Fig. 7), low levels in June and July 1979 might be considered as a factor restricting simuliid population size. Considering however that the concentration of dissolved

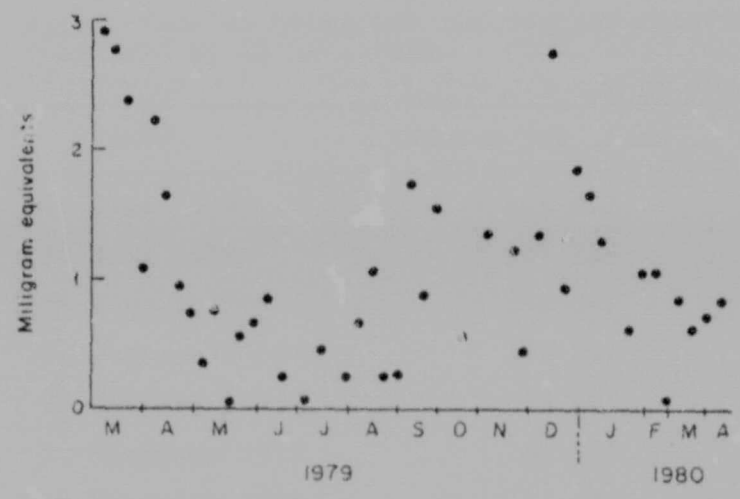


FIGURE 7: Estimated amount of particulate organic carbon in river water samples collected at weekly intervals from 10 March 1979 to 18 April 1980. Particulate organic carbon expressed as milligram equivalents of humic acid per litre of water

organic matter in locic waters is generally higher than particulate organic matter (Weber and Moore, 1967) it can be understood that total organic carbon measures (Appendix 2.6, Fig. 2.9) were considerably higher than the estimated particulate organic carbon (Fig. 7). As dissolved organic matter may also be utilized by micro-organisms, and is known to flocculate out in alkaline waters (Lush and Hynes, 1973, 1978), this section of organic matter may in time also become available as fine particulate matter to the *Simulium* spp. larvae. It would thus seem that particulate organic food matter was always present in sufficiently high concentrations to be ignored as a factor limiting simuliid population size. The nutritive value of organic matter may however vary considerably (Carlsson *et al.*, 1977) and this would then influence simuliid population levels in a way apparently unrelated to organic matter concentrations. The role of low standing crop, rapid turnover periphyton must also be considered and this could contribute considerably to the available food supply for filter feeders (Wallace and Merritt, 1980).

Table 2 shows the estimated numbers of diatoms from drifting river water at monthly intervals. As water samples were not collected over an extended period of time, density estimates of diatoms are suspect and should be viewed with caution. A seasonal trend,

TABLE 2: The estimated total number of diatoms in one litre of water. Samples collected (at monthly intervals) from 21 June 1979 to 30 July 1980

Date	Number per litre
21 June 1979	7 629 032
26 July 1979	5 907 258
23 August 1979	2 262 097
20 September 1979	572 581
25 October 1979	2 033 485
22 November 1979	60 071
19 December 1979	37 671
17 January 1980	93 750
21 February 1980	159 091
20 March 1980	229 630
18 April 1980	9 479
26 May 1980	5 618
25 June 1980	(?) 0
30 July 1980	328 947

showing higher numbers of diatoms in winter and spring than in summer, is however apparent. This would then indicate a more abundant food supply of diatoms for simuliid larvae during the period when their population growth was most pronounced (Figs 5 and 6).

b) Temperature

Temperature as a factor influencing the aquatic simuliid population size has two components. Water temperature which has a direct effect on the aquatic stages and air temperature which directly influences water temperature but furthermore could affect adult flight activity and hence egg laying and recruitment rates of the aquatic stages.

Although simuliid eggs were found in drift samples throughout the year (Fig. 4a) an increase in their numbers from August onwards

coincided with an increase in water temperatures taken in the late afternoon (Appendix 2.7, Table 2.24). It appeared that when water temperatures reached 15 °C or higher, an increase in egg laying activity could be expected (Fig. 8).

An annual decline in the number of eggs in the drift usually occurred in November and December (Fig. 8) when mean maximum weekly air temperatures reached 30 °C or higher (Appendix 2.7, Table 2.24). An exception was seen when a single sample collected on 5 December 1980 contained a very high number of eggs, first instar and other small larvae. This increased recruitment did however not lead to large increases in simuliid population densities on stones in the study rapid in subsequent months (Fig. 5) and remains an unresolved anomaly in this study.

An increase of eggs in drift samples was discernible towards the end of February and early March 1980 (Fig. 8) when mean maximum weekly air temperatures had dropped below 30 °C once more (Appendix 2.7, Table 2.24). It was thus apparent that air temperatures over 30 °C in some way might have inhibited egg laying activity in *S. chutteri*.

The low annual rainfall for the Warrenton area (Ch. 2) should also be considered and during dry hot months low relative humidities may have played a bigger role in restricting adult activity than maximum air temperatures.

The effects of temperature on the developmental rates of Simuliidae are discussed in Chapter 6, and temperature is also considered as a contributing factor to simuliid population fluctuations in Chapter 8.

c) Wind

The influence of wind on simuliid egg, larval and pupal densities is limited to the effect it would have on adult flight and ovipositing activity. Steenkamp (1972) found that at wind velocities exceeding 5 m/s no adult Simuliidae were observed. During windy days a decrease in host seeking activity of female *S. damnosum* s.l.

was also reported by Magor and Rosenberg (1980). In the present study it was often observed that flight activity of adult male *S. chutteri* mating swarms (Downes, 1969) was reduced or even absent in strong winds.

Wind velocity varies considerably within any one day and as it was not possible to monitor wind activity continuously, one can only speculate on the influence that wind would have on adult ovipositing activity and hence population levels of Simuliidae.

d) Rainfall

An increase in rainfall would cause a decrease in air temperature and an increase in relative humidity. It is thus not surprising that a rainfall of 78,6 mm towards the end of February 1980 coincided with a drop in air temperature and a corresponding increase in the number of eggs encountered in the drift (Figs 4a and 8, and Appendix 2.7, Table 2.24).

Heavy falls of rain would appear to be a stimulus to ovipositing activity in *S. chutteri*. The occurrence of most of the precipitation between September and April (Appendix 2.7, Table 2.24) should however not be overlooked, and it may be that a combination of seasonal factors influenced population increases of Simuliidae.

The direct effects of rainfall are difficult to assess. Rainfall undoubtedly influences the run off of allochthonous organic (food) matter into the river and the pH of the river water. Hynes (1972) mentioned that seasonal rainfall in the tropics played an important role in reducing population densities of invertebrates in rivers. In a study discussed by Hynes (van Someren, 1952) the effects of temperature changes and seasonal breeding were minimal, and therefore reductions in invertebrates could be more directly equated with increased rainfall which led to spates and fluctuating discharges of water down steep valleys. Chutter (1963) found that floods reduced filamentous algal growths and the fauna associated with them in rivers. Hynes (1972) concluded that the two most important factors leading to reduced faunal numbers during spates were abrasion and flow fluctuation.

In the present study the effects of summertime floods on reducing invertebrate number were considerably reduced by the presence of a number of impoundments on the Vaal River upstream of the sampling stations. Rainfall is further considered as a contributory factor to simuliid population fluctuations in Chapter 8.

e) Flow rates and manipulated water level fluctuations

Falling water levels and uneven flows of water are unsuitable for blackfly larvae and cause drastic decreases in numbers when larvae enter the drift to find more suitable habitats further downstream (Carlsson, 1967; Minshall and Winger, 1968; Hall and Edwards, 1978). A decreased flow of water over a prolonged period was noted by Marr (1962) to cause an increase in algal growth which hampered colonization of substrates by Simuliidae. Simuliid larvae were able to withstand a sudden rise in water level if there was not a simultaneous increase in the current speed, and the major factor which contributed to larvae migrating appeared to be current velocity, becoming either too slow or too fast (Crisp, 1956; Carlsson, 1967).

Gore (1978) found that discharge rates in the Tongue River, Montana in the United States would have to be kept at 3,68 m^3/s to keep the faunal composition of the river as it was prior to the introduction of a reservoir. At a flow rate of 3,4 m^3/s changes were already noted and at 3,1 m^3/s massive drift of the fauna was observed, which would lead to drastic changes in the faunal population structure.

Chutter (1972b) noted that a sudden flood caused a reduction in the population of *S. nigritarse* Coquillett. In another study a prolonged duration of high water levels however increased the area available for simuliid larval colonization and subsequent population levels of *S. chutteri* were noted to increase (Chutter, 1968).

Variation in discharge rates in the Vaal River below the Vaalhartz Weir created different conditions of flow and current speed in the rapids at Witrand (Appendix 2.1, Fig. 2.1a to d). If the assumption

is made that at a water velocity of 56 cm/s substrata throughout the rapid would be colonized by Simuliidae at a density equal to that attained on stones collected at monthly intervals, and if the further assumption, that the river bed consisted of uniform spherical stones of surface area 624 cm^2 (mean value calculated from 156 stones collected from the study rapid), is made, then it would take 50,3 stones to cover 1 m^2 of river bed. As 50,3 stones represent 31 387 cm^2 of stone surface area monthly estimates of population densities (Appendix 5, Table 5.1) can then be extrapolated to present the total number of Simuliidae in the study rapid at different flow regimes (Table 3).

TABLE 3: Estimated surface area of river bed exposed to water at velocity $\geq$ 56 cm/s at various water flow rates, and extrapolated total number of Simuliidae from population estimates obtained from stones-in-current samples for the months indicated

Date rapid marked off	Flow rate of water released from weir m^3/s	Surface area of river bed m^2 with flow rate $\geq$ 56 cm/s	Density of *S. chutteri* on stones nos/1000 cm^2	Extrapolated total population in rapid
18 Mar 1979	12,8	120,51	399	6 317 546
3 May 1979	3,03	48,55	1 598	10 193 385
18 Feb 1980	15,0	146,03	4 359	83 633 708
24 Jul 1980	6,0	125,69	11 294	186 509 478

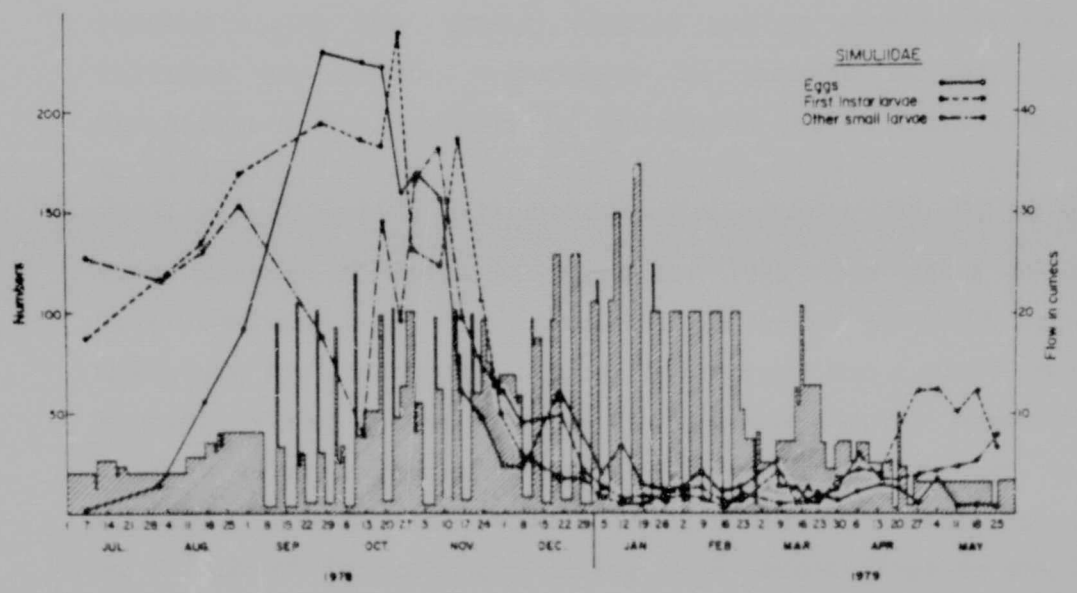
Water flow rates are thus important in controlling the size of the habitat suitable for simuliid colonization, and hence strongly influence the potential population size of Simuliidae in the river. A number of other factors such as the duration of the life cycle at different times of the year, the rate of ovipositing activity of female flies, the abundance of predators in the rapid, the duration of a particular flow regime (lasting long enough to enable colonization and development of Simuliidae to be completed) are all major additional contributors to the realized population size of Simuliidae in the rapid. The extrapolated figures (Table 3) should thus be viewed with considerable reserve. The point that emerged was however that flow rates were important factors in determining

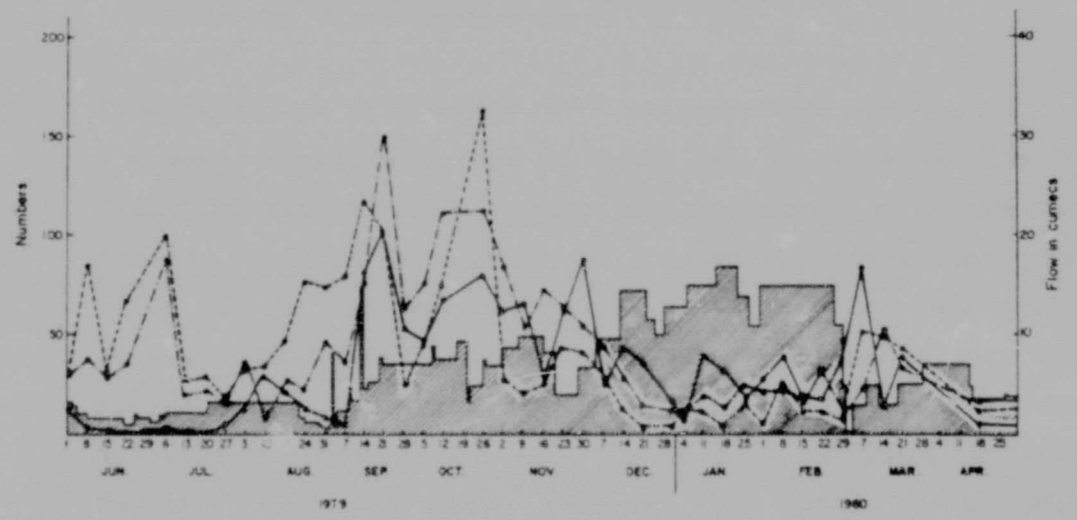
simuliid population size, and that prolonged higher discharges of water (e.g. from 3,03 to 15 m^3/s would increase the potential area of colonizable substrata by a factor of three.

It was noted that the area where velocities were $\geq$ 56 cm/s was larger at flow rates of 6 m^3/s than at 12,8 m^3/s . As only a limited number of current speed measurements were made in the rapids on each occasion and flow rates after being plotted on graph paper were drawn up into regions of similar flow, a considerable margin of error could be expected and no absolute values should be attached to the calculated surface area values.

During this study simuliid population levels were monitored when water flow management programmes, to reduce blackfly numbers, were carried out. A water management programme consisted of a number of river 'shut downs' carried out at weekly intervals. Each 'shut down' consisted of halting the flow of the Vaal River below the Vaalhartz Diversion Weir for a period of 60 or 72 h and 'shut downs' were usually commenced on Fridays at 08h00, lasting until 20h00 on the following Sunday or 08h00 on the following Monday.

The first series of shut down programmes started in September 1978 and lasted until February 1979 (Fig. 8). During the first five 'shut downs', commenced on the 7th September and carried on at weekly intervals until the 8th October, the number of simuliid eggs and first instar larvae in drift samples actually increased which indicated that recruitment of Simuliidae remained high throughout that period. Four more intermittent irregular 'shut downs' were carried out between October and November and there was then a marked decrease in egg, first instar and other simuliid larvae in the drift. From 13 November to 7 December no further river flow cessation occurred. The number of *S. chutteri* pupae on stones, which had declined dramatically between October and November, showed a significant increase again on the 7th December (Fig. 5d). A subsequent increase in the number of eggs in drift samples followed two weeks later. It would thus seem that unless a series of 'shut downs' is carried on for a sufficiently long period, recruitment levels of Simuliidae may pick up rapidly.





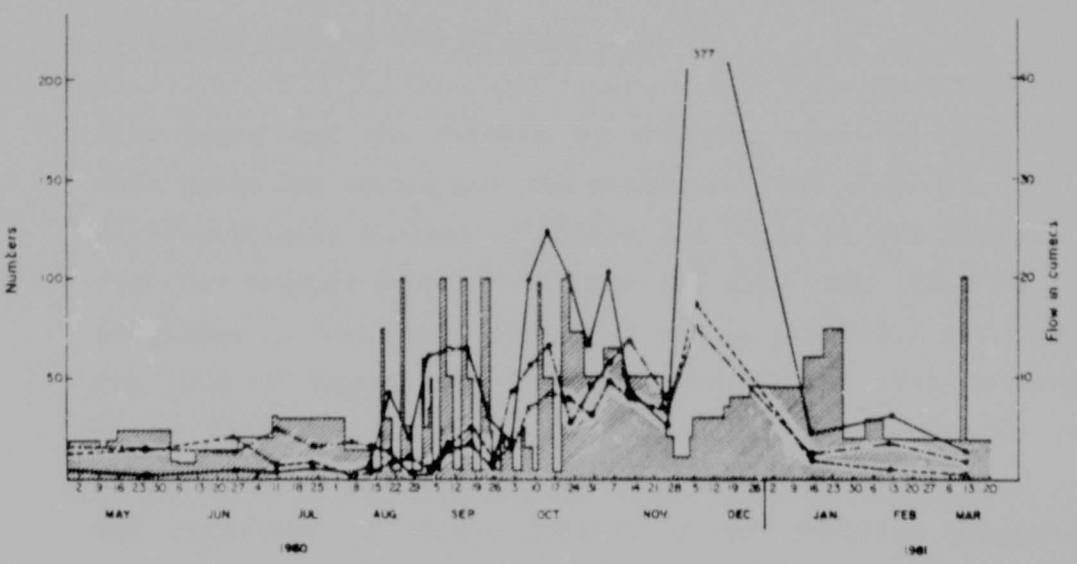
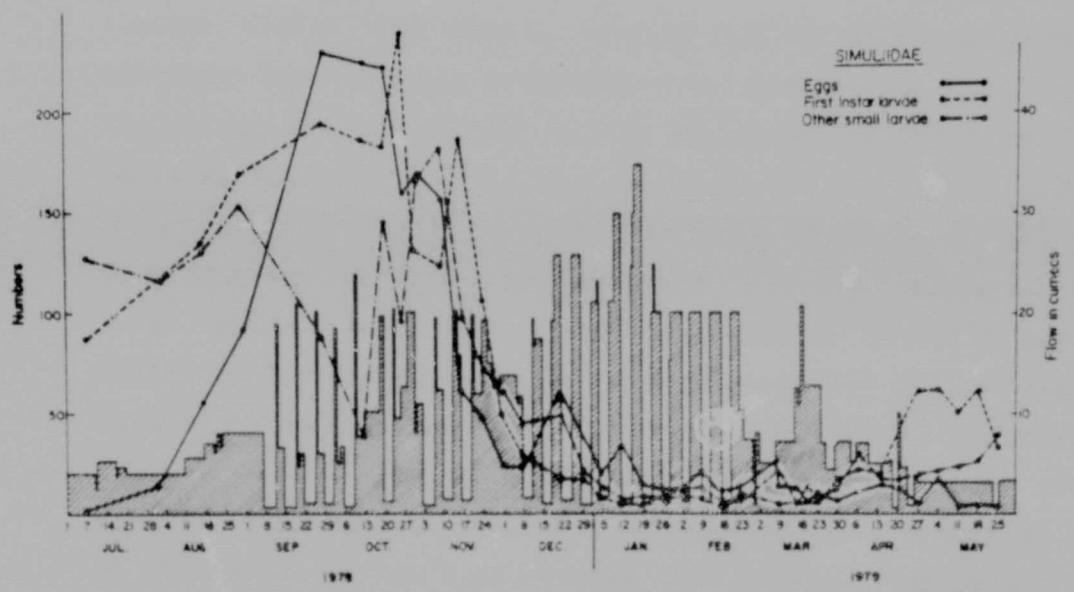
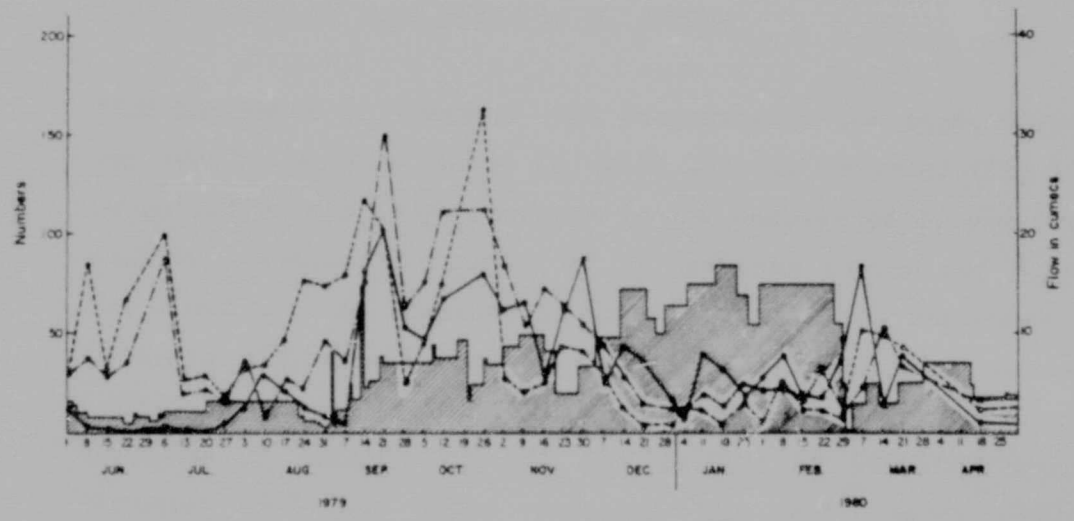


FIGURE 8: Numbers of drifting organisms per 1 000 litres of water and the flow of the Vaal River below the Vaalhartz Weir in cubic metres per second (shaded area) from July 1978 to March 1981





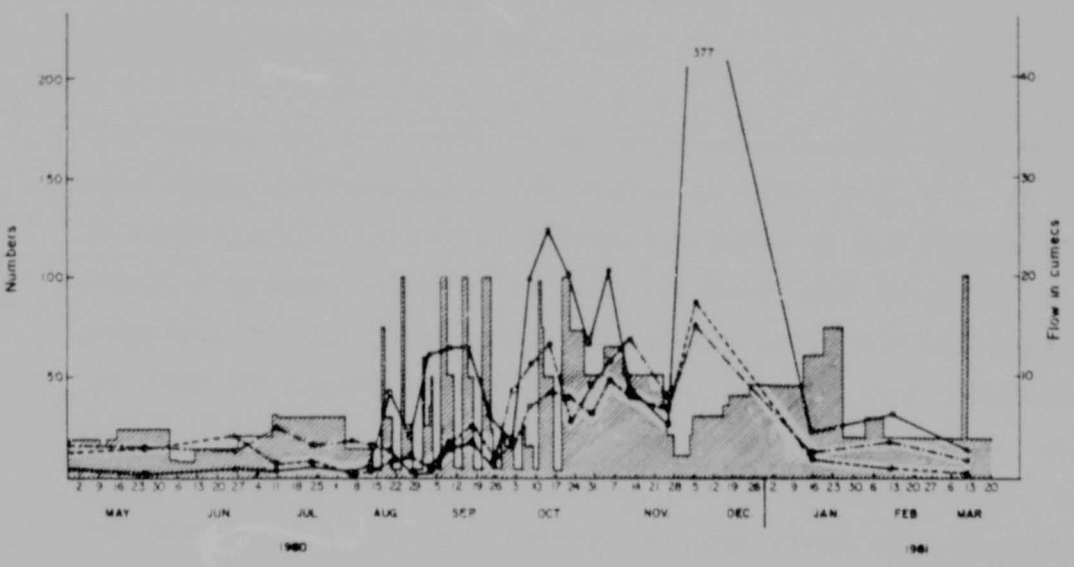


FIGURE 8: Numbers of drifting organisms per 1 000 litres of water and the flow of the Vaal River below the Vaalhartz Weir in cubic metres per second (shaded area) from July 1978 to March 1981

From the 8th of December 1978 until the 18th February 1979 a further eleven shut downs, carried out at weekly intervals, were followed by drastic reductions in numbers of all stages of Simuliidae both on stones in the rapids and in drift samples (Fig. 5a to d, Fig. 8).

From the end of April to September 1979 flow rates of the Vaal River remained below 5 m^3/s and the number of simuliid eggs in the drift was low throughout this period except for a minor increase in August. First instar and small simuliid larval numbers in the drift however increased after April and remained high throughout winter. This increase could be attributed to a numerical increase of *S. adersi* in the rapid during this period (Figs 3e and 5e). It was thus apparent that lower flow rates were more suitable for colonization of substrates by *S. adersi*.

From September to November 1979 increases in the eggs, first instar and small simuliid larvae in drift samples occurred (Fig 4). This coincided with a large increase in the numbers of *S. chutteri* and a smaller increase in numbers of *S. damnosum* larvae and pupae (Fig. 5c, d and g). An increase in the flow rate from September 1979 to February 1980 could however not be associated with corresponding increases in population levels of Simuliidae. On the contrary, a decrease in numbers of all the species of *Simulium* occurred in November 1979 and these remained low until March 1980. This decrease occurred even though there was no water management programme carried out at this time.

Flow rates and the numbers of drifting simuliid eggs and larvae were again low throughout the winter of 1980 (Fig. 8). An increase in identifiable numbers of larvae and pupae of all four most common *Simulium* species occurred in June and July 1980 (Fig. 5c to g). A programme of ten 'shut downs' at weekly intervals was commenced on the 14th of August 1980 and completed on the 19th October. This river flow manipulation was planned as an integrated programme using combined water manipulation, the life cycle of *S. chutteri* and predators to affect control of the *Simulium* population size (see Chs 6, 7 and 8).

Although simuliid eggs showed an increase in numbers between September and October 1980 (Fig. 8), the larvae and pupae of *S. chutteri* and *S. damnosum*, which were the two most abundant species in July, showed a significant drop in numbers from September onwards. Taking into account only the possible effect of water flow manipulation on simuliid population levels it can be concluded that water 'shut downs' effectively bring down population levels of large larvae and pupae and cause a subsequent reduction in recruitment rates. Thus sudden fluctuations in flow rates obviously have a considerable impact on the mortality of Simuliidae and in particular *S. chutteri* in the Warrenton district.

To determine the time when water flow programmes are to be carried out is important and several factors can considerably increase the impact of a water management programme (Ch. 8).

f) Predation

A number of confirmed and potential predators of Simuliidae are noted (Ch. 7), but only some of these could be quantitatively associated with reductions in simuliid populations.

A review of Trichoptera as predators on Simuliidae was done by Burton and McRae (1972). More recently serological techniques have been used to identify predators of *S. damnosum* s.l. in the Ivory Coast (Service and Elouard, 1980). The exclusion of predators of Simuliidae were also noted by Hynes (1960) to cause a rapid population increase of Simuliidae. Chutter (1968) concluded that all hydropsychid Trichoptera were probably predators of Simuliidae. *Cheumatopsyche thomasseti* and *Amphipsyche scottae* were identified in this study as predators of Simuliidae (Ch. 7) and an *Orthotrichia* sp. was recognized as a predator on simuliid eggs and pupae by Disney (1972b).

An increase in the number of *C. thomasseti* larvae on stones-in-the-current in November 1978 and 1979 and October 1980 could be associated with a simultaneous decrease in Simuliidae (Fig. 9).

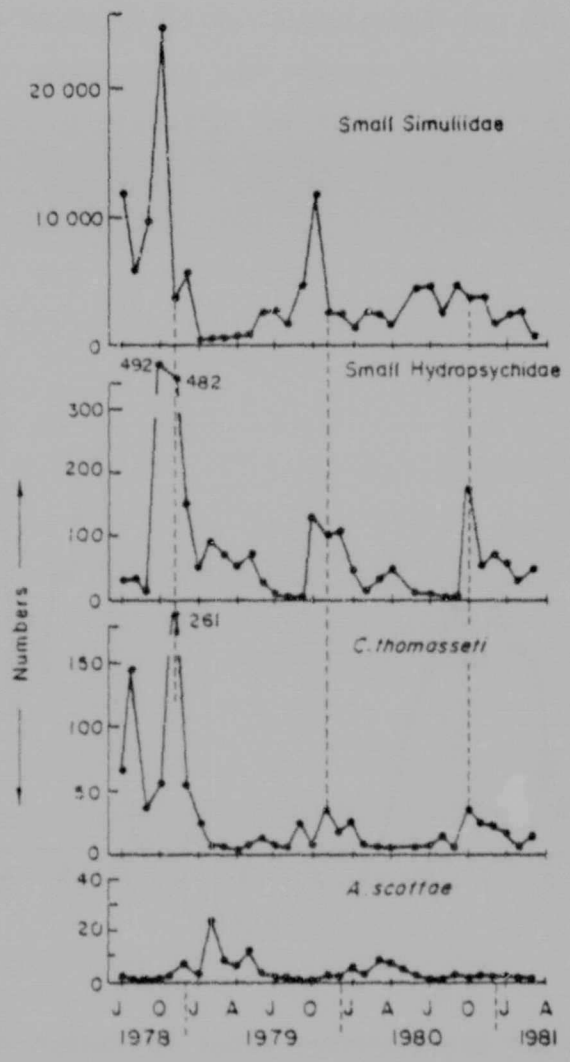


FIGURE 9: Numbers of Simuliidae and Hydropsychidae on stone samples collected at monthly intervals from July 1978 to March 1981. Counts are expressed as Sichel mean numbers per 1 000 cm^2 of stone surface area

The sudden increase of small juvenile hydropsychid larvae in October of each of the three years of this study, preceded an increase of *C. thomasseti* larvae. An increase in the numbers of both small Hydropsychidae and *C. thomasseti* in October 1980 cannot be explained. It can however be assumed that the juvenile Hydropsychidae on stones-in-the-current in October each year (Fig. 9) and also those encountered in drift samples from September onwards (Fig. 10) belonged to *C. thomasseti*.

From December 1978 to May 1979 and from January to May 1980 there

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