Control of pest blackflies (Diptera: Simuliidae) along the Orange River, South Africa: 1990–1995

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ABSTRACT

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The efficacy of *Bacillus thuringiensis* var. *israelensis* (*B.t.i.*) and temephos in controlling the pest blackfly *Simulium chutteri* Lewis along the middle Orange River between 1990 and 1995, was assessed. Larvicides were applied by helicopter to rapids and riffles between Hopetown and Onseepkans, a river distance of 807 km. Larvicidal efficacy was based on the change in larval abundance at selected sites before and after each treatment. The success of the control programme was assessed independently by local farmers, who ranked adult blackfly annoyance on a 4-point scale.

Before treatment, blackfly annoyance showed consistent peaks in spring, and sometimes in autumn, and levels were unacceptably high for between 17 and 36 weeks of the year. After treatment started, blackfly annoyance levels were reduced significantly. The number of annual treatments necessary to reduce blackfly annoyance to acceptable levels was highly variable (3–13), and depended on river conditions, as well as the efficacy and timing of each treatment. During low-flow conditions (<50 m³/s), applications became increasingly difficult in braided sections of the river, and dosage calculations were inaccurate because of local abstraction and return flows. Both larvicides worked well in winter (water temperature 11–13 °C). Control of the spring outbreak can be planned well in advance, with the first treatment starting in mid July. A flexible protocol is required to control outbreaks at other times of the year. We recommended the use of *B.t.i.* for most applications, with increased dosages during algal blooms (>1 500 cells/mℓ). The use of temephos in the Orange River should be considered only during algal blooms or when flows exceed 300 m³/s. We conclude that helicopter application of larvicides is an effective method of controlling pest blackflies along the middle Orange River.

Keywords: *Bacillus thuringiensis* var. *israelensis,* blackflies, Orange River, Simuliidae,*Simulium chutteri*, South Africa, temephos

INTRODUCTION

Blackflies are a major pest of livestock along the middle and lower Orange River. The larvae and pupae are aquatic, and are restricted to flowing water (riffles, rapids and waterfalls). Adult males feed on nectar and remain in the vicinity of the river, whereas females feed on livestock, ostriches and, occasionally people, and are sometimes troublesome for up to 160 km from the river (H. Joubert, personal observation 1996). Blackfly bites are painful, and may cause severe local swelling in humans (De Villiers 1987) and even death of livestock (Rob Palmer, personal observation 1996).

Seven species of blackflies are known from the middle and lower Orange River (Palmer 1995). The main pest is *Simulium chutteri* Lewis, a large-river species,

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endemic to southern Africa. Although *S. chutteri* is not known to transmit disease, circumstantial evidence suggests that they do; they have been implicated in the spread of *Chlamydia* sp. (Howell, OVI, unpublished report 1978), and Rift Valley Fever (McIntosh, Jupp, Dos Santos & Barnard 1980). In 1996, the Northern Cape Agricultural Union estimated that *S. chutteri* accounted for up to R88 million per annum in lost animal production along 800 km of the Orange River, and a further R19 million in lost taxes.

The first attempts to control *S. chutteri* began in 1965, when DDT was applied to sections of the Vaal and Harts Rivers (Howell & Holmes 1969). These trials were not only successful, but also killed fish and non-target invertebrates, and resulted in excessive growth of benthic algae (Howell & Holmes 1969). The use of DDT to control blackflies in southern Africa was discontinued in 1967, and was replaced with flow-regulation, which was considered practical, safe and cheap (Howell 1980; Howell, Begemann, Muir & Louw 1981; Car 1983). The method involved stopping the flow for periods long enough for the water level to drop, thus disturbing larvae and exposing pupae to desiccation (Howell *et al.* 1981; De Moor 1994). The method was used successfully in the Soviet Union to control blackflies in canals (Kotel'nikov & Kivako 1985), and was tested against *S. chutteri* in the Vaal River in 1977, and in the Orange River in 1978. A 60 h closure of the Vaalharts Diversion Weir reduced blackfly abundance for 30 km downstream. In the Orange River, a 66-h closure at Van der Kloof and Buchuberg Dams reduced blackfly abundance for 370 and 242 km, respectively (Howell *et al.* 1981).

Despite the initial success of flow-regulation in controlling *S. chutteri* in the Orange River, rainfall in 1987 and 1988 was higher than in previous years, and the flow could not be regulated. This resulted in a major population outbreak of blackflies. Furthermore, flow-regulation was not a practical control option for most of the Orange River because of the dependence of riparian agriculture on a steady water supply, the long distances downstream of impoundments (over 1 200 km downstream of Van der Kloof Dam), and the time required for desiccating rapids. Also, a drop in water level, incorrectly timed, could be detrimental to recruitment of certain fish species by exposing fish larvae or eggs (Cambray 1984).

Because of the problems associated with flow-regulation in the Orange River, the Onderstepoort Veterinary Institute (OVI) and the Directorate of Natural Agricultural Resource Conservation, Department of Agriculture, started treating the middle Orange River with the soil bacterium *Bacillus thuringiensis* var. *israelensis* (alias *B.t.i.*) in 1991. This bacterium was the most promising larvicide for blackfly control out of numerous larvicides tested worldwide (De Joux & Guillet 1980; Guillet, Escaffre & Prud'hom 1982; Kurtak, Jamnback, Meyer, Ocran & Renaud 1987). The

bacteria were first isolated from dead mosquitoes found in a desert pool in Israel in 1977 (Goldberg & Margalit 1977). The following year *B.t.i.* was reported to kill blackfly larvae (Undeen & Nagel 1978), and is now used worldwide to control blackflies and mosquitoes. The toxic component is a protein crystal found in the parasporal inclusions produced during sporulation (Lacey & Undeen 1986). The crystals become active in the presence of proteases and the alkaline pH of the blackfly and mosquito midgut (Lacey & Undeen 1986). The toxins interfere with osmotic balance by binding to midgut epithelial cells, and kill larvae within minutes after the former have been ingested (Lacey & Undeen 1986). The active ingredient in a typical *B.t.i.* formulation constitutes less than 1 % of the volume. The remaining volume includes ingredients used to grow the bacteria, such as fish-meal, flour, soyabeans, casein, yeast, starch, molasses and dextrose (Dulmage 1989). In addition, acid is used to kill bacteria, and various other chemicals, such as benzene, toluene and xylene may be used to improve shelf-life, efficacy, dispersion and carry (Fortin, Lapointe & Charpentier 1986).

The main advantages of *B.t.i.* over conventional chemical larvicides and flow manipulation are its specificity against target insects, its harmlessness to vertebrates (including humans), its biodegradability, its efficacy in both cold and warm water, and the fact that, thus far, the development of resistance of blackfly larvae to *B.t.i.* is unknown (Heimpel 1967; Guillet, Dempah & Coz 1980; Lacey 1985; Morin, Back, Boisvert & Peters 1989). Tests in the Vaal (Car & De Moor 1984) and Orange Rivers (De Moor & Car 1986) showed that *B.t.i.* was effective against *S. chutteri* larvae, although its efficacy was reduced in polluted water (Car 1984).

Studies elsewhere have shown that the potency of *B.t.i.* varies greatly depending on the concentration of suspended solids (Morin *et al.* 1989), and it has a short (less than 24 h) residual effect in the field (Ohana, Margalit & Barak 1987). More importantly, current formulations of *B.t.i.* are relatively bulky, requiring roughly 2,4 times the volume of organophosphate insecticides. This means that application of *B.t.i.* to large rivers (> 300 m^3/s), is logistically difficult (Lacey & Heitzman 1985). Furthermore, *B.t.i.* does not carry as far as conventional larvicides, and therefore requires more application points (Walsh 1985; Palmer, Edwardes & Nevill 1996a). For these reasons, the organophosphate temephos "Abate® 200EC" (SA Cyanamid) was considered for blackfly control in the Orange River.

Temephos is used worldwide to control mosquitoes, blackflies, biting midges and sandflies. It was first used for blackfly control by the World Health Organisation's Onchocerciasis Control Programme (OCP) in West Africa in 1974, and was the only larvicide used by the OCP between 1974 and 1979 (Walsh

1985; Lèvêque, Fairhurst, Abban, Paugy, Curtis & Traore 1988). Temephos was chosen by the OCP because of its effectiveness against blackflies, low mammalian toxicity and safety for most "non-target" organisms, including fish (Mohsen & Mulla 1981; 1982; Walsh 1985). Although temephos is one of the safest organophosphates available for blackfly control (Gaines, Kimbrough & Laws 1967), overdosing does affect non-target fauna, including blackfly predators (Palmer 1993; Palmer & Palmer 1995).

A further drawback with temephos is poor efficacy at low temperatures (Back, Lanouette & Aubin 1979; Rodrigues & Kaushik 1984). Furthermore, larval resistance to temephos is a major problem in West Africa (Guillet, Escaffre, Ouedraogo & Quillévéré 1980b; Kurtak 1986; Adiamah, Raybould, Kurtak, Israel, Maegga & Opoku 1986).

The present paper forms part of the overall Blackfly Control Programme in the Orange River, and reports the results of 28 helicopter treatments of *B.t.i.* and temephos on larval and adult blackfly populations along the middle reaches of the Orange River between 1991 and 1995.

STUDY AREA

The blackfly problem along the Orange River stretches between Gariep Dam and Sendelings Drift (90 km upstream of the mouth), a distance of 1 470 km (Fig. 1). The area between the Gariep Dam and Hopetown was excluded from consideration because of fluctuating water levels caused by twice-daily generation of hydro-electricity, making dosage calculations inaccurate. The river downstream of Augrabies Falls was initially excluded because of inaccessibility and a sparse human population. Therefore, the stretch originally considered for blackfly control lay between Hopetown and Augrabies Falls, a distance of 663 km.

In 1991 the river between Buchuberg Dam and Augrabies Falls (a distance of 277 km), was treated with *B.t.i.*, leaving 375 km of river upstream untreated as a control area. The results of this treatment were encouraging, and in the following two years the river between Hopetown and Augrabies (a distance of 680 km) was treated, leaving a small (20–50 km) stretch in the middle (upstream of Upington) untreated as a control area.

In September 1993 blackfly breeding sites in the lower section of the river were surveyed, following complaints from farmers downstream of Augrabies Falls. Agriculture in this area was developing rapidly, and the area was becoming increasingly accessible by road. Blackfly control in this area was therefore becoming an economically viable option. A total of 90 rapids was identified in the 650 km between Augrabies Falls and the Orange River mouth. Many of the "rapids" consisted of long stretches of highly braided, fast-flowing river, providing ideal habitat for *S. chutteri*. However, the area between Onseepkans and the mouth was considered neither practical nor economically viable for blackfly control because it remained highly inaccessible and sparsely populated. However, the river between Augrabies Falls and the Onseepkans gorge (a distance of 154 km), was included in subsequent treatments.
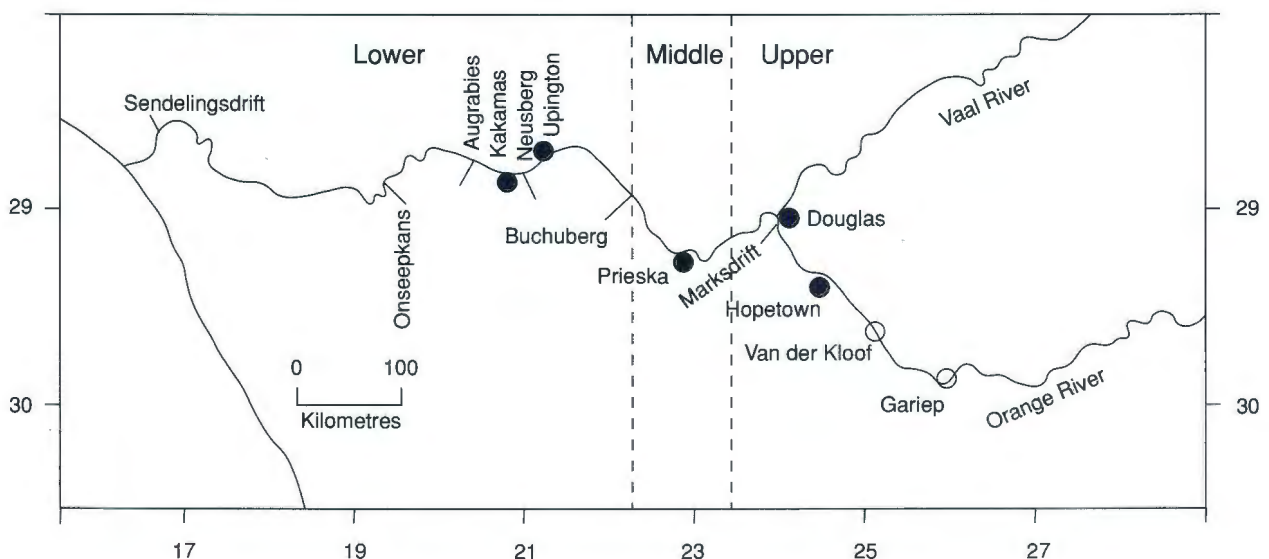

FIG. 1   Map of the middle and lower reaches of the Orange River showing major towns, impoundments, sites mentioned in the text, and the arbitrary delineation into three areas: Douglas (upper), Prieska (middle) and Upington (lower)

In July 1995 an aerial survey identified two large rapids some 30 km upstream of Hopetown. These two rapids were included in subsequent treatments. Therefore, the final study area stretched between the gorge upstream of Hopetown and the gorge downstream of Onseepkans, a total distance of 807 km (excluding the small control area in the vicinity of Upington). The total number of blackfly breeding sites in the study area was 148, an average of one every 5,7 km. Between rapids the river consisted mainly of shallow pools (1–2 m deep) with a sandy substrate, although there were places with pools as deep as 16 m. The river was mostly 100–300 m wide where it was a single channel, but in places the river was extensively braided, and up to 3,2 km wide. Average gradient over the final study area was 0,6 m/km, excluding a drop of 185 m over 20 km downstream of Augrabies Falls (Fig. 2).

METHODS

Larval abundance within the stones-in-current biotope in the vicinity of Upington was assessed weekly, starting in July 1991. Abundance was based on a 10-point, visual, semi-logarithmic ranked abundance scale developed for this purpose (Palmer 1994). Treatment was considered necessary if the median

larval abundance rank exceeded "7", equivalent to > 37 000 larvae per m². Larval abundance was also assessed at various sites before and after each treatment, and the change in the median abundance rank was used to estimate percentage mortality (Palmer 1994). Mortalities exceeding 80 % were considered satisfactory, providing that the median rank after control was less than rank "7". The number of sites at which larval mortality was satisfactory, expressed as a fraction of the number of sites monitored, provided an index of the overall success of each treatment, and were expressed as follows: Excellent (> 90 %); Good (80–90 %); Fair (70–80 %); Poor (50–70 %); Very Poor (< 50 %). With some exceptions, rapids in the vicinity of Upington were left untreated as control sites. These rapids were small, and did not contribute significantly to overall adult blackfly populations. However, the dramatic reduction of adult blackfly abundance along the river as a whole after the inception of the Control Programme, undoubtedly affected immature populations in the control section. For these reasons, the untreated rapids could not be construed as a control area in the strict sense. Nevertheless, they did provide some indication of trends in larval abundance in the absence of control.

When this project began, a Bell® Jet Ranger 3 helicopter with a Simplex® spray tank, with a capacity
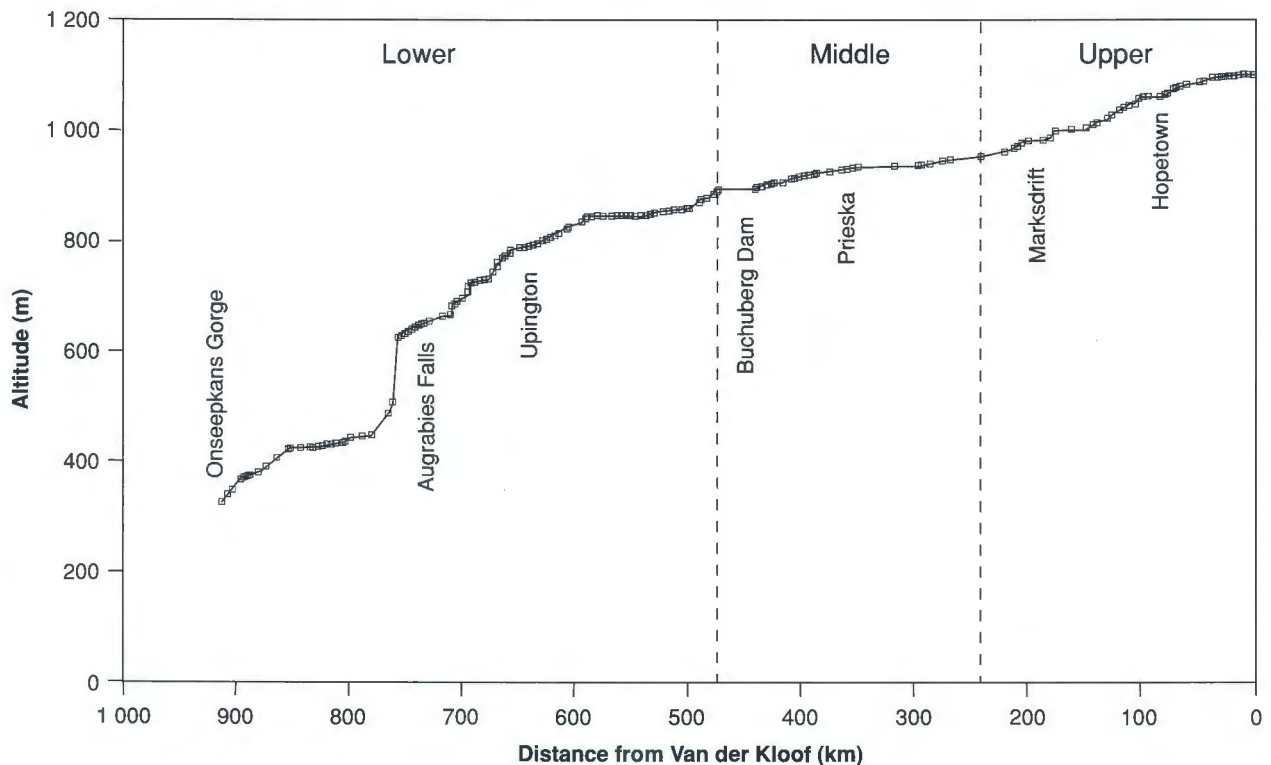

FIG. 2   Profile of the Orange River between Van der Kloof Dam and the Onseepkans gorge. Each point represents a blackfly breeding site (riffle, rapid or waterfall)

of 400 ℓ, was used for treatments. The tank was filled with 270-400 ℓ of larvicide (depending on air temperatures), allowing three to five applications per run. A short (1 m) boom with a single large nozzle (1 cm) was used, and applications at each site took roughly 20 s. On 22 September 1992, the Jet Ranger crashed between Prieska and Douglas, leaving the upper stretch of river untreated. Subsequent treatments, with a Squirrel® Helicopter, resumed on 26 July 1993. The new helicopter was fitted with two booms, a 600 ℓ Simplex® spray tank filled with 300–450 ℓ of larvicides, allowing five to eight applications per run.

The system was unsatisfactory, and was replaced with a single boom with eight nozzles (Fig. 3). Helicopter applications were supported by a ground crew of six people with three pick-up vehicles, each containing jet fuel and 600 ℓ larvicide tanks.

FIG. 3 Helicopter spray tank and boom

Bacterial larvicides [Teknar®HP-D (Sandoz Agro) and Vectobac® 12AS (Abbott Laboratories)] were applied at the recommended rate of 1,2 ppm over 10 min (0,72 ℓ per m^3/s). The organophosphate temephos (Abate®200EC) was applied at the rate of 0,1 ppm over 10 min (0,3 ℓ per m^3/s). During algal blooms, dosages with *B.t.i.* were increased by as much as 150 %. Timing of treatments was based on seasonal changes in the abundance of larvae, the rate of larval development and the survival of adults, detailed in Palmer, Edwardes & Nevill (1996b). Likewise, the distance between applications was based on the downstream carry of larvicides, detailed in Palmer *et al.* (1996a). Treatments always started downstream and worked upstream so as to prevent interference with water that had been treated.

The concentrations of Total Suspended Solids (TSS) and planktonic algae had important implications for the dosages applied, as well as the choice of larvicide. Temephos is suited to high TSS because efficacy is increased when it is adsorbed onto particles (Walsh 1985). *B.t.i.*, on the other hand, is suited to low TSS because it competes with TSS for ingestion by blackfly larvae (Guillet, Escaffre, Prud'hom & Bakayoko 1985). From work done in West Africa, it was found that *B.t.i.* no longer worked effectively when turbidity exceeded 150 JTU (roughly 150 mg/ℓ), or when the concentration of planktonic algae exceeded 1 500 cells per mℓ (Dan Kurtak, personal communication 1993).

The concentrations of TSS and planktonic algae were estimated weekly at rapids in the vicinity of Upington. Between 100 and 800 mℓ (depending on clogging) of river water was filtered through Whatman® GF/C (Whatman International) filters. Concentrations of TSS were determined gravimetrically. Filters were pre-mass-measured on a Masskof® microbalance accurate to 0,0001 g. After filtration, filters were dried for at least 24 h at 60 °C, and mass-measured again. Filters for phytoplankton determination were placed on glass slides containing a drop of Golden® (cane-sugar) syrup, and examined under a compound microscope at 400x magnification. All algal cells within each of ten randomly selected fields were counted, and numbers averaged. Filamentous algae were counted in units that were seven times the width of the filament, a method developed and used in West Africa (Dan Kurtak, personal communication 1993). The method was crude because different-sized cells scored the same, and there was great variance between counts. Nevertheless, the method provided a rapid and practical measure of phytoplankton abundance, suitable for the control programme.

In June 1993 we realized that Secchi depth values (a standard and rapid measure of suspended particles), would be more practical for the control programme than TSS measurements. Work conducted by Hart (1988) in Lake Van der Kloof and data collected in the present project, both showed a relationship between TSS and Secchi depth values (Palmer 1995). These data indicate that the threshold TSS value of 150 mg/ℓ approximates a Secchi depth of 12 cm (Palmer 1995).

At each site at which larval abundance was estimated, the 16-cm diameter Secchi depth and water temperature were measured. Daily-flow data for the Orange River were supplied by the Department of Water Affairs and Forestry. Reasonably accurate gauging weirs were situated at Van der Kloof Dam (D3R003-M01), Marksdrift (D3H008), Prieska Bridge (D7H002), Buchuberg (D7H008) and Neusberg (D7H014).

The success of the control programme was monitored daily by 40 farmers who assessed adult blackfly populations in the vicinity of livestock on a 4-point "annoyance" scale, a method initiated by Dr L. Jordaan (Jordaan & Van Ark 1990). Because of the long distances involved, the study area was delineated into three arbitrary zones, here referred to as the

Douglas (upper), Prieska (middle) and Upington (lower) areas (Fig. 1 and 2).

RESULTS

For most of the study period flow was low (<100 m³/s) (Fig. 4). The concentration of Total Suspended Solids (TSS) varied between 5 and 144 mg/ℓ (Fig. 5). Concentrations of planktonic algae varied between 100 and 48 000 cells/mℓ, and were consistently high in autumn, and sometimes in spring (Fig. 6). Larval abundance showed consistent seasonal trends, with highest values towards the end of winter (July to August) (Fig. 7).

A total of 76 392 ℓ of *B.t.i.*, and 6 746 ℓ of Abate®200EC, was applied to the Orange River from July 1991 to October 1995 (Table 1). At sites which were monitored, adequate larval control (>80% mortality) was
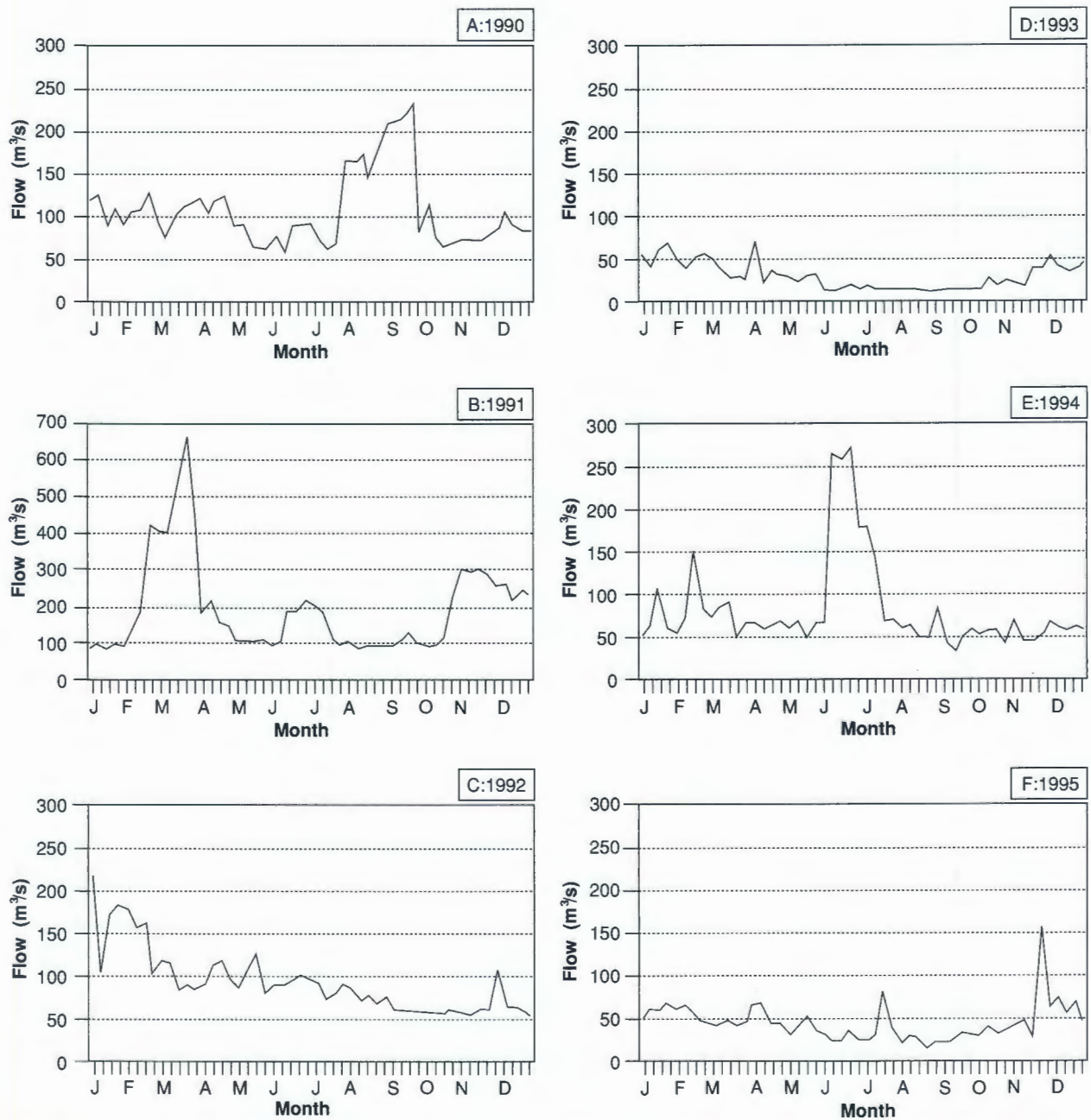

FIG. 4 Daily average flow in the Orange River, measured at Buchuberg Weir (D7H008), between 1990 and 1995. Data obtained from the Department of Water Affairs and Forestry, Upington
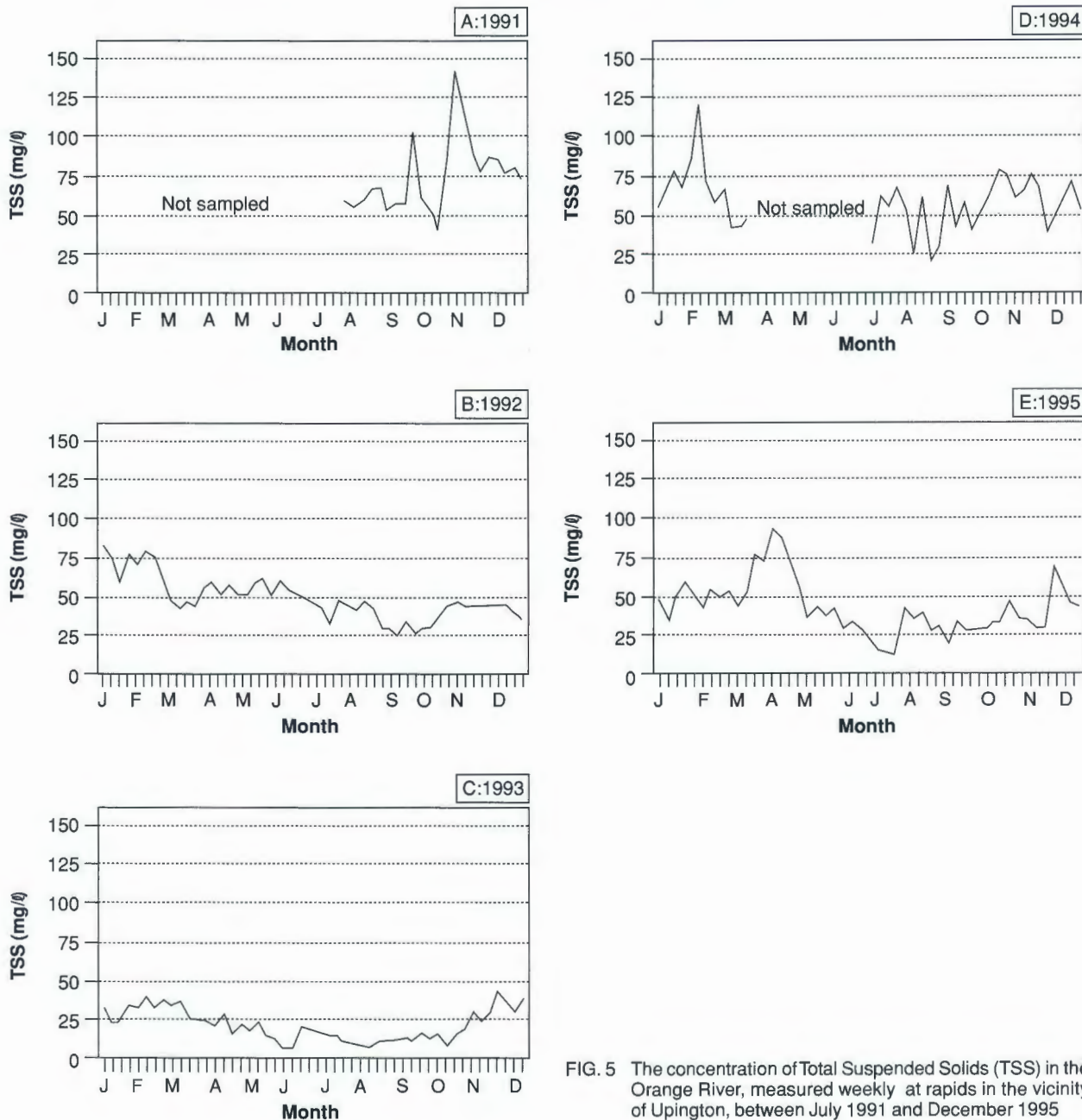
FIG. 5   The concentration of Total Suspended Solids (TSS) in the Orange River, measured weekly at rapids in the vicinity of Upington, between July 1991 and December 1995

obtained at 177/259 sites (68 %) treated with *B.t.i.*, and 37/43 sites (86 %) treated with Abate®200EC. After the beginning of treatment, average adult annoyance was generally kept below 1, regarded as the threshold value above which annoyance is unacceptably high (Fig. 8).

1990

In 1990, before control operations started, there were two major peaks in adult annoyance: autumn and spring (Fig. 8a). In the Douglas and Prieska areas,

annoyance was higher in summer than in winter, whereas in the Upington area, the opposite was true. The total number of weeks during which average adult annoyance exceeded 1, ranged between 28 in the Douglas area and 37 in the Prieska area (Table 2).

In the Douglas and Prieska areas, adult annoyance increased towards the end of February, remained high until May, and was very low in June and July. Annoyance began to increase in August, and reached a peak towards the end of September. By November, annoyance was very low, and remained low until the following February.
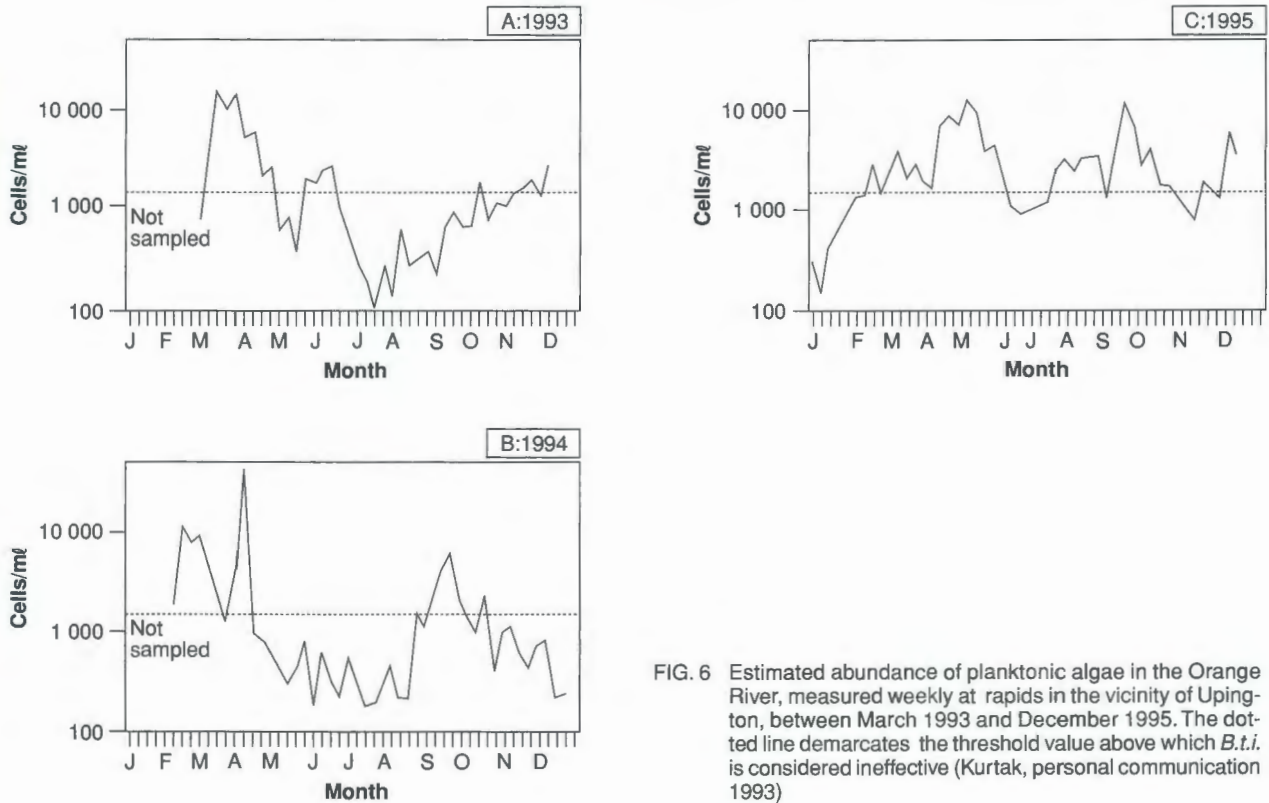
A:1993

B:1994

C:1995

FIG. 6 Estimated abundance of planktonic algae in the Orange River, measured weekly at rapids in the vicinity of Upington, between March 1993 and December 1995. The dotted line demarcates the threshold value above which *B.t.i.* is considered ineffective (Kurtak, personal communication 1993)

In the Upington area, on the other hand, adult annoyance started increasing in March, and reached a peak towards the end of April. Although annoyance dropped in June/July, average values remained above the threshold value of 1 throughout winter. Peak annoyance occurred in September, and dropped to below 1 towards the end of October.

1991

Annoyance levels in 1991 were lower than in 1990 (Fig. 8), despite higher flow in 1991 (Fig. 4). In the untreated Douglas and Prieska areas, the number of weeks in which average adult annoyance exceeded 1, was 17 and 28, respectively. In the lower reaches, treated twice, average adult annoyance exceeded 1 for 20 weeks (Table 2).

Although trends in adult annoyance were similar in 1990 and 1991, there were two exceptions. Firstly, there was no spring outbreak in the Douglas area in 1991, despite an increase in flow (> 300 m³/s), the reason for which is not known. Secondly, annoyance levels in the Upington area in 1991 were reduced to low levels in winter. Adult annoyance started to decline before larvicides were applied at the end of July. Water temperatures in 1990 were not recorded, but at the end of July 1991, spot water temperatures at Upington were 11 °C. It may have been that water

temperatures in the lower reaches in 1990 were warmer than in 1991.

The first aerial application of larvicide took place towards the end of July 1991 (Table 1). A total of 4 160 ℓ of Teknar®HP-D was applied to 52 rapids between Augrabies Falls and Buchuberg Dam, a distance of 277 km (Table 1). Larval populations were assessed on 30 rocks at each of five sites, the day before and one day after treatment. Excellent control (> 97 % mortality) was obtained at all five sites monitored (Table 1). A second treatment was planned for the end of September, but was aborted because of motor failure of the spray tank. Consequently, adult annoyance started increasing towards the end of September (Fig. 8b). At the same time, flow in the river increased from 100 to over 300 m³/s (Fig. 4b). The spray motor was repaired, and the second treatment took place on 26–28 November (Table 1). Three sites between Buchuberg Dam and Upington were treated with Abate®200EC. Flow at the time was high (290 m³/s). Excellent control was obtained at all three sites at which larval abundance was monitored (Table 1), and downstream carry was excellent (50–70 km). The first treatment effectively delayed the outbreak in the Upington area by some 30 d (Fig. 8b). However, despite the good larval mortality obtained with both treatments, the overall impact of these treatments in reducing annoyance levels for the year as a whole, was negligible (Fig. 8b).
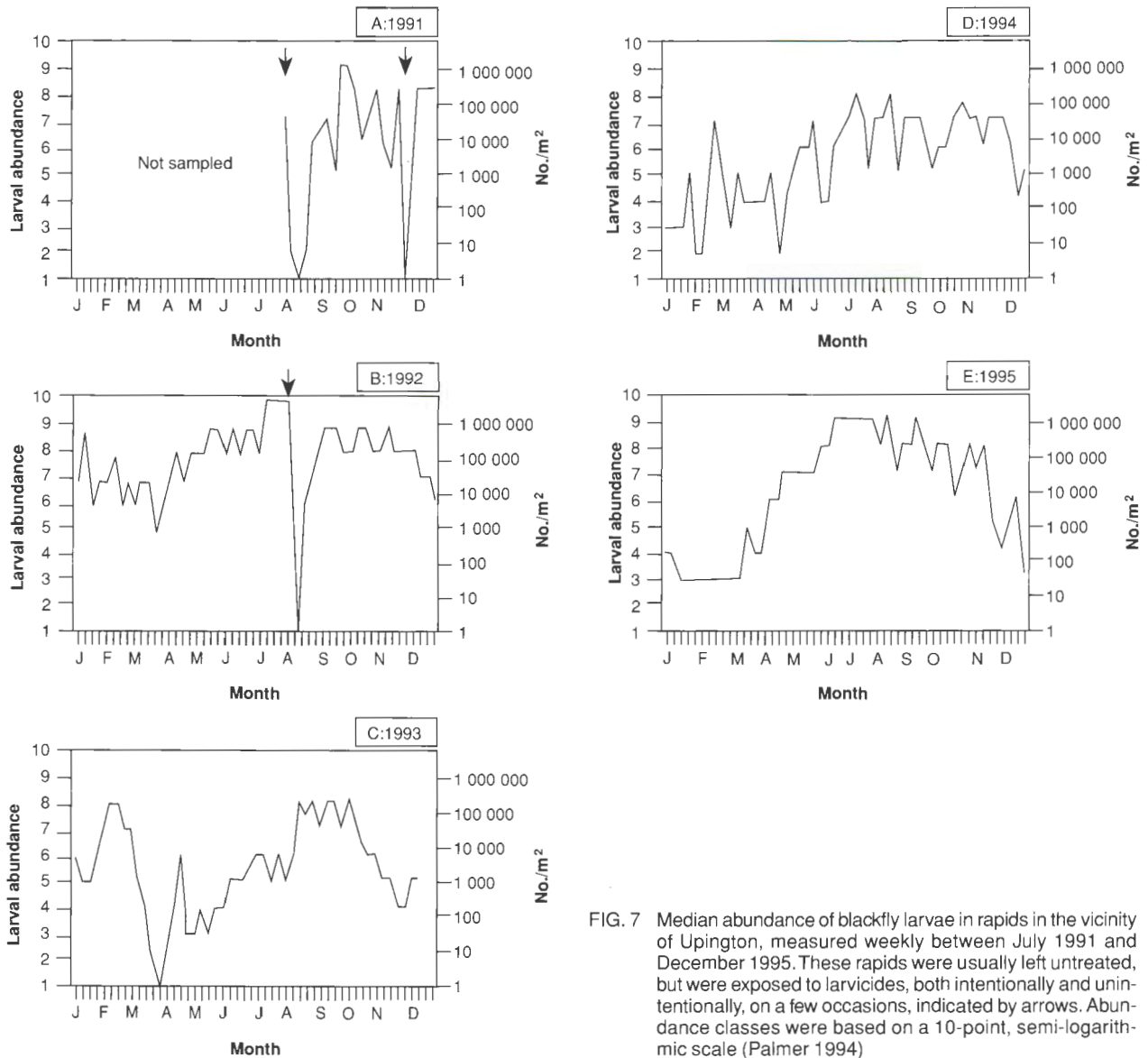
FIG. 7 Median abundance of blackfly larvae in rapids in the vicinity of Upington, measured weekly between July 1991 and December 1995. These rapids were usually left untreated, but were exposed to larvicides, both intentionally and unintentionally, on a few occasions, indicated by arrows. Abundance classes were based on a 10-point, semi-logarithmic scale (Palmer 1994)

1992

Larval abundance in autumn 1992 did not warrant treatment, and adult annoyance remained low (Fig. 8c). Later in the year, between 57 and 80 breeding sites between Hopetown and Augrabies Falls were treated three times (Table 1). The first treatment was about 2 weeks later than planned, partly because of a delay in the purchasing of larvicide, and partly because of warmer water temperatures, which speeded larval development. Consequently, a slight outbreak of adults occurred in all three areas in August (Fig. 8c). However, applications of Teknar®HP-D (between Hopetown and Marksdrift) and Abate®200EC (between Marksdrift and Augrabies) were successful, despite the cold water (11–13 °C) (Table 1), and the outbreak was short-lived (Fig. 8c).

The second treatment, with Teknar®HP-D, was similarly successful, with good (> 80 %) larval mortality at 3/3 of the sites monitored. Fixed helicopter bookings delayed the third treatment by 1 week, and pupae formed, resulting in a slight outbreak of adults in the Douglas and Prieska areas (Fig. 8c). The third treatment was cut short because the helicopter crashed opposite the farm "Paal se werf", about 20 km downstream of Douglas, leaving approximately 25 rapids and 150 km of river between Hopetown and "Paal se werf" untreated. Consequently, an outbreak of adults occurred in the upper reaches after the crash (Fig. 8c). However, good control was obtained at treated sites.

The number of weeks in which average adult annoyance exceeded 1, ranged from 0 (in the Upington

TABLE 1 Details of blackfly larvicides applied to the Orange River between 1991 and 1995 for purposes of blackfly control. Each bar in the "distance treated" represents 50 km of river, starting at Van der Kloof Dam. The river was divided into three zones: upper (Douglas area), middle (Prieska area) and lower (Upington area). Larvicides used are shown as follows: V = Vectobac®12AS, T = Teknar®HP-D, A = Abate®200EC. "Success rate" refers to the number of sites at which larval mortality exceeded 80 % as a fraction of the number of sites monitored

Treat-ment	Date	Flow (m³/s)	Temp (°C)	Secchi (cm)	No. rapids treated	Volume applied (ℓ) Per rapids	Total	Distance treated Upper	Middle	Lower	(km)	Success rate*	
1991													
Spring													
1	30/7–2/8	113	11–12	≈25	52	80	4160	– – – – –	– – – –	T T T T T T T T – –	277	5/5	E
2	26–28/11	290	22	≈20	3	87	261	– – – – –	– – – –	A A A – – – – – – –	163	3/3	E
1992													
Spring													
1	3–5/8	100	11–12	≈35	10	80	800	– – T T –	– – – –	– – – – – – – – – –	76	2/2	E
		92	11–13	≈35	70	28	1960	– – – – A	A A A A	A A A A A A A A – –	577	3/3	E
2	24–25/8	85	11–14	≈42	80	62	4960	– – T T T	T T T T	T T T – T T T T – –	632	3/3	E
3	21–22/9	82	13–21	≈46	57	49–60	3447	– – – – –	T T T T	T T T – T T T T – –	491	2/3	F
1993													
Spring													
1	26–27/7	15–30	11–14	≈50–60	132	11–22	2060	– – T T T	T T T T	T T T – T T T T – –	693	1/8	VP
2	10–11/8	16	9–14	≈48–60	132	20	3140	– – T T T	T T T T	T T T – T T T T – –	693	11/11	E
3	25–26/8	14–32	12–17	≈55	132	20–23	3300	– – T T T	T T T T	T T T – T T T T – –	693	12/13	E
4	8–9/9	15–32	16–20	50	132	11–24	2760	– – V V V	V V V V	V V V – V V V V – –	693	14/15	E
5	25–26/9	10–32	17–21	51	132	8–25	2340	– – T T T	T T T T	T T T – T T – T – –	693	12/13	E
1994													
Autumn													
1	3–4/3	67	22–28	7–26	68	11–21	1375	– – A A A	A A A A	A A A – A A A A – –	693	8/10	G
2	14–15/3	130	23–26	9–32	68	20	1825	– – A A A	A A A A	A A A – A A A A – –	693	7/9	F
Spring													
1	19–21/7	58–120	8–12	13–19	74	42–87	4300	– – V V V	V V V V	V V V – V V V V – –	693	9/15	P
2	16–18/8	33–77	10–13	12–19	94	24–56	3750	– – V V V	V V V V	V V V – V V V V – –	693	7/13	P
3	1–3/9	59–66	13–17	15–20	10	43	430	– – – – –	– – – –	– – V V – – – – – –	80	–	NS
					78	43–48	3620	– – T T T	T T T T	T T – – T T T T – –	613	3/7	VP
4	12–14/9	44	15–18	14–22	40	36	1430	– – – – –	– – – –	– – V – V V V V – –	164	6/7	G
		48–80			55	36–58	2480	– – T T T	T T T T	T T – – – – – – – –	478	6/7	G
5	21–23/9	60–63	17–19	19–28	56	44–46	2480	– – – – –	– – – –	– – – – V V V V V V	278	5/6	G
6	8–9/11	67	23–26	16–24	71	48	3215	– – – – –	– – – –	V V V – V V V V V V	472	4/10	VP
1995													
Autumn													
1	14–15/2	48–90	25–27	16–26	61	40–65	3213	– – V V V	V V V V	V V V – – – – – – –	479	7/8	G
2	23–24/3	47–83	21–24	11–21	45	34–60	2404	– – V V V	V V V V	V V V – – – – – – –	402	6/6	E
					12	25	300	– – A A –	– – – –	– – – – – – – – – –	76	2/2	E
3	11–12/4	58–85	18–25	15–23	54	42–62	2330	– – V V V	V V V V	V V V – – – – – – –	479	3/8	VP
					6	25	150	– – – – –	– – – –	– – – – A A A A – –	125	3/3	E
4	25–26/4	41–60	14–18	24–32	54	14–18	875	– – A A A	A A A A	A A A – A A A A – –	693	11/13	G
Spring													
1	19–21/7	37–123	7–11	2–115	88	27–62	3610	– – V V V	V V V V	– – V – V V V V V V	688	5/16	VP
2	15–18/8	25–40	13–19	21–90	123	18–58	2330	– V V V V	V V V V	V V V – V V V V V V	807	10/18	P
3	5–7/9	14–46	14–17	30–74	88	22–74	2970	– V V V V	V V V V	V V V – V V V V V V	807	8/17	VP
4	27–29/9	23–65	18–21	27–60	127	15–72	4795	– V V V V	V V V V	V V V – V V V V V V	807	11/16	P
5	10–12/10	23–70	16–20	26–42	124	12–63	3910	– V V V V	V V V V	V V V – V V V V V V	807	13/16	G
6	24–26/10	21–46	17–21	20–43	88	15–60	2160	– V V V V	V V V V	V V V – V V V V V V	807	12/16	F

NB: In 1991, 1992 and the part of 1993, Secchi depth was not measured directly. An approximate value was obtained from the concentration of total suspended solids (Palmer 1994)

* Keys: E = Excellent   P = Poor
F = Fair   VP = Very poor
G = Good
NS = Not sampled

area, treated three times) to 16 (in the Douglas area, treated twice) (Table 2).

TABLE 2   The number of times the Douglas (upper), Prieska (middle) and Upington (lower) sections of the Orange River were treated annually for blackfly control, and (in brackets), the number of weeks in which adult blackfly annoyance exceeded a threshold value of 1

Year	Douglas (Upper)	Prieska (Middle)	Upington (Lower)
1990	0 (28)	0 (36)	0 (31)
1991	0 (17)	0 (28)	2 (20)
1992	2 (16)	3 (7)	3 (0)
1993	5 (4)	5 (10)	5 (1)
1994	6 (8)	6 (26)	8 (8)
1995	10 (11)	10 (20)	8 (0)

1993

Flow in 1993 was very low (13–50 m³/s; Fig. 4d). Larval abundance in autumn did not warrant treatment (Fig. 7c), and adult annoyance remained low (Fig. 8d). Later in the year the river between Hopetown and Augrabies was treated five times with *B.t.i.* (Table 1). The Squirrel Helicopter was used here for the first time. In the first treatment, leakage from spray nozzles resulted in a suspected under-dosing at all sites. Loss of larvicide due to leakage was estimated at 4–5 ℓ per site.

Consequently, each day two sites were not treated, owing to a shortage of larvicide. Larval mortality was poor, and effective control was recorded at only one of the eight sites monitored (Table 1). Consequently, adult annoyance increased in August, although the outbreak was contained by treatment (Fig. 8d). In subsequent treatments, the leakage problem was partially remedied by the use of a single boom only, and by compensating for the leakage. Although good control was obtained in all subsequent treatments (Table 1), an estimated 300–500 ℓ of larvicide were required to compensate for leakage during each treatment. The leakage problem was finally solved by the fitting of nozzles equipped with shut-off valves, although these arrived in time only for the 1994 treatments.

With the drop in flow, the water became increasingly clear, and a *Microcystis* sp. and *Anabeana* sp. bloom was evident in March 1993 (Fig. 6a). On several occasions, larval mortality was 100 % on one side of the river, and 0 % on the other. This reflects the difficulty of applying small volumes of larvicides (sometimes as little as 8 ℓ per site) evenly. It also highlights the importance of keeping records of exactly where larvicides were applied, and exactly where larval populations were monitored. Furthermore, flow determinations became increasingly difficult at low flow (< 50 m³/s) because of spatial changes caused by

evaporation, abstraction and return flows. Daily average releases from Van der Kloof Dam in September 1993, ranged between 40 and 55 m³/s, of which roughly 15 m³/s (or 33 %) reached Buchuberg, and roughly 3 m³/s (or 6 %) reached Vioolsdrift. At Neusberg Weir, 98 % of the river's flow was diverted into the Kakamas canal system, leaving 0,2 m³/s in the river as compensation. Water from the Kakamas canals was returned to the river downstream of Kakamas, and flow at Augrabies Fall was estimated at 5–7 m³/s. The stretch of river between Neusberg and Kakamas was therefore not treated for blackflies on 26 September 1993.

The number of weeks in which average adult annoyance exceeded 1, ranged between one (in the Upington area, treated five times), and ten (in the Prieska area, treated five times) (Table 2).

1994

An outbreak of blackflies was anticipated in autumn 1994, after flow increases in January and February (Fig. 4e). Five treatments with temephos were planned for March, but only two were considered necessary because of low larval abundance (Fig. 7d). Good control was obtained after both treatments (Table 1).

In June and July 1994, releases from Van der Kloof Dam were considerable (Fig. 4e), creating ideal conditions for an outbreak. Five treatments with *B.t.i.* were planned for spring 1994. However, the results of these treatments were poor, and a sixth treatment was carried out in the lower reaches (Buchuberg to Onseepkans). The poor results were attributed to several factors. Firstly, faulty water-level information resulted in large sections of river being under-dosed. In the upper reaches of the river, hydroelectric releases resulted in large fluctuations in flow. For example, typical flows at Marksdrift varied between 70 and 120 m³/s within 12 h, making dosage calculations in the upper reaches nearly impossible. Secondly, problems were encountered in applying the larvicide. The problems were partly caused by cavitation resulting from corrosion on the motor impeller, and partly by a recirculation tube within the spray tank, which had twisted and was directing air into the sump. Furthermore, larvicide stocks stored in the Upington area started to agglomerate, and were clogging the 30-mesh in-line filter. Lastly, water temperatures during the 1994 spring treatments were colder than during previous years. Consequently, the fourth and fifth treatments were too close together for optimal control, and an outbreak of adult blackflies began 1 month after the fifth treatment (Fig. 8e). For these reasons, control in 1994 was not very successful. The number of weeks in which average adult annoyance exceeded 1, ranged between 8 (in the Douglas area, treated six times, and in the Upington area, treated eight times) and 26 (in the Prieska area, treated six times) (Table 2).
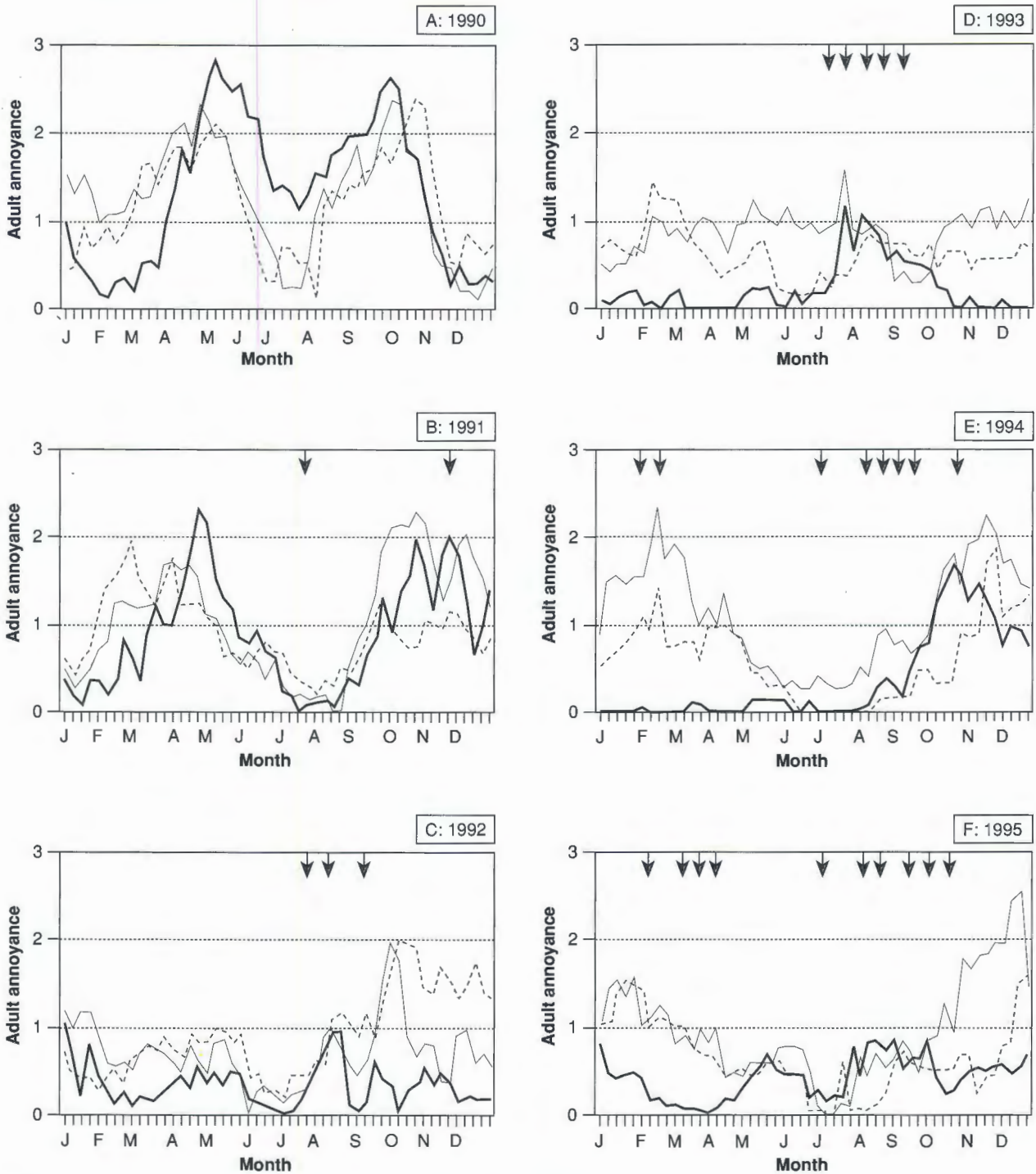
FIG. 8 Average annoyance of adult female blackflies in the vicinity of livestock in the Douglas (- - - - - -), Prieska (———) and Upington (———) areas between 1990 and 1995. Annoyance was based on daily reports submitted by stock-farmers in the affected areas, ranked as 0 = no blackflies; 1 = present but not a nuisance; 2 = common and troublesome; 3 = abundant and causing severe nuisance (for details, see Table 1)

1995

In January 1995, larval abundance in the Douglas and Prieska reaches was exceptionally high (unpub-

lished data 1995). Consequently, the river between Hopetown and Upington was treated four times, starting 14 February (Table 1). Larval abundance in the Upington area started increasing in April (Fig. 7e),

and this section of the river was treated twice only. Treatments were generally successful, and the outbreak was brought under control (Fig. 8f).

The first "spring" treatment of 1995 took place during 19–21 July (Table 1). This was bad timing, because the blackfly-control operators were unaware of the fact that Buchuberg Dam had been drained the previous week. A pulse of muddy water (Secchi depth 2–8 cm) resulted in fish and blackfly mortality directly downstream of the dam. Consequently, the river between the dam and Groblershoop Bridge (a distance of 42 km) was not treated. In contrast, the water at Augrabies Falls, before treatment, was unusually clear (Secchi depth 115 cm), and blackfly larvae were abundant. The clear water was attributed to agricultural seepage, which constituted a large portion of the water downstream of the Neusberg Diversion Weir. Dosage calculations at the time of treatment in the lower section (downstream of Neusberg), were inaccurate because of the draining of Buchuberg. Flow data became available after treatment, and showed that the lower section of the river (between Neusberg and Onseepkans) was under-dosed. Likewise, dosage calculations in the upper reaches were inaccurate because the automatic data loggers at Marksdrift and Prieska were not working. Poor control in the upper reaches suggested under-dosing due to hydro-electric releases.

In the second spring treatment of 1995, poor larval mortality was attributed to a high concentration of planktonic algae (2 300–3 300 cells/mℓ; Fig. 6c), and to low-flow conditions (25–40 m^3/s), making applications to braided sections of the river difficult. Furthermore, when *B.t.i.* was being used, the spray tank was found to be under-dosing by 10%. This was because the tank was originally calibrated with water, which is less viscous than *B.t.i.* In subsequent treatments with *B.t.i.*, dosages were increased to compensate for under-dosing, and results were good (Table 1). Despite the problems encountered, adult abundance remained within acceptable levels. However, after the treatments had ended in October, an outbreak occurred in the Prieska area towards the end of the year (Fig. 8f). The number of weeks during which average adult annoyance exceeded 1, ranged from 0 (in the Upington area, treated 8 times), to 20 (in the Prieska area, treated ten times) (Table 2).

DISCUSSION

The estimated number of annual generations of *S. chutteri* in the middle Orange River ranges from 11–13 (Palmer *et al.* 1996b). Therefore, 11–13 annual treatments, on the assumption that they are all successful, would guarantee control. However, good control may be achieved with fewer treatments. In this study, the number of annual treatments necessary to curb blackfly population outbreaks was highly vari-

able. In 1992, three treatments in the Upington area were sufficient to reduce the population to within acceptable limits, whereas in 1995, in the Prieska area ten treatments were unable to curb an outbreak (Table 2). There are many reasons for this variation.

Firstly, treatments were not equally successful, as highlighted during the spring applications of 1994 (Table 1). Conditions in the river, the products and formulations applied, their age and storage conditions, and the people applying them were never the same from one treatment to the next, this providing infinite permutations for potential failure. Furthermore, accurate dosage calculation, particularly in braided sections, was difficult, resulting in some over-dosing and some under-dosing.

Secondly, the timing of treatments is critical for successful control. Timing depends on predicting, well in advance, when an outbreak is likely. The spring outbreak was triggered by increases in water temperature, and was consistent from year to year. It is therefore recommend that the first application for the spring season should take place in mid July. The timing of successive treatments is detailed in Palmer *et al.* (1996b). However, the main factor affecting blackfly outbreaks along the Orange River, was river flow, which varied considerably from year to year. In 1994, large quantities of water (> 250 m^3/s) were released from Lake Van der Kloof in mid-winter, a condition which would probably have led to a major outbreak of blackflies, had the river not been treated with larvicides.

Part of the difficulty of predicting an outbreak, is that river conditions change downstream. Winter water temperatures in the Douglas and Prieska areas were colder than further downstream, and adult annoyance in winter was minimal. By contrast, adult blackflies were present throughout winter in the Upington area. Furthermore, different sections of the river experienced different flow regimes, particularly during low flow (< 50 m^3/s). Consequently, larval abundance was spatially variable, thus complicating the decision of whether or not to apply larvicides. For example, the outbreak of blackflies in the Prieska area towards the end of 1995 may be attributed partly to higher flows than further downstream.

Predicting an outbreak is also difficult because high larval populations do not always lead to high adult populations. This is because adult blackflies do not survive hot and dry conditions (Rob Palmer, personal observation 1992). For this reason, adult annoyance in the Upington area in summer was usually low.

A previous study of blackflies along the Orange River showed that adult annoyance levels increased with increases in flow (Jordaan & Van Ark 1990). However, the present study has shown that unacceptably high levels of adult blackflies were present even when flows were as low as 50 m^3/s. The present study has

also shown that winter treatments of both temephos and *B.t.i.* were effective at recommended dosages, at water temperatures between 11 and 13 °C (Table 1). Therefore, increased dosages because of cold water do not appear necessary. Furthermore, this study has shown that, for most of the time, concentrations of TSS in the Orange River were well within the limits for optimal efficacy of *B.t.i.* Therefore, it is unlikely that TSS constitutes a limiting factor for the use of *B.t.i.* in the Orange River. On the other hand, concentrations of planktonic algae often exceeded the limits for optimal efficacy of *B.t.i.* Therefore increased dosages of *B.t.i.* are recommended under these conditions. The use of temephos should be restricted to high-flow conditions because of the difficulties of accurate dosage determination at low flow, the detrimental impacts on non-target fauna at high dosages (Palmer 1993; Palmer & Palmer 1995) and potential problems with resistance (Guillet *et al.* 1980; Kurtak 1986; Adiamah *et al.* 1986).

Although numerous problems in the control of blackflies along the Orange River were encountered, annoyance levels of adult blackflies were significantly lower than in previous years. The programme may therefore be considered a success. Furthermore, many of the logistical teething problems of treating a river the size of the Orange have been overcome. With improvements in larvicide formulations, future control should be more effective.

In conclusion, the following recommendations are made:

• Control of the spring outbreak should be planned well in advance, with the first treatment starting in mid July. A flexible protocol is required to control outbreaks at other times of the year.

• *B.t.i.* should be applied in most cases, although increased dosages are recommended when the number of algal cells exceeds 1 500/mℓ.

• The use of temephos in the Orange River should be considered only during algal blooms when flows exceed 300 m³/s.

• The Department of Water Affairs and Forestry should try to ensure that the river does not remain high for periods exceeding 4 weeks in winter, 3 weeks in spring and autumn, and 2 weeks in summer.

We conclude that helicopter application of larvicides is an effective method of controlling pest blackflies along the middle Orange River.

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