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Drastic reduction of populations of *Simulium sirbanum* (Diptera: Simuliidae) in central Sierra Leone after 5 years of larviciding operations by the Onchocerciasis Control Programme

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The major vectors of the blinding form of human onchocerciasis in West Africa are two blackfly species, *Simulium sirbanum* and *Simulium damnosum* s.s. (Diptera: Simuliidae), identified at the adult stage as the 'savanna group' of the *Simulium damnosum* complex. In 1988, in the central part of Sierra Leone, the average daily biting rate (females/man/day) by savanna blackflies (mostly *S. sirbanum*) during the peak of the dry season (April–May) was 59·9, making up 69·1% of total captures on average. There was evidence of a strong long-range immigration of adult females of *S. sirbanum* through eastern Guinea in the dry season, with a reverse movement towards Guinea in the rainy season. Therefore, in 1989, the World Health Organization's Onchocerciasis Control Programme (OCP) extended its vector control operations from central West Africa to rivers of central and northern Sierra Leone, and to rivers of eastern Guinea. Four years of efficient larviciding drastically reduced adult populations of *S. sirbanum* in Sierra Leone. In the peak of the dry seasons of 1993 and 1994, the average biting rate by savanna blackflies in central Sierra Leone had dropped to 1·0, making up only 4·3% of total captures on average. Yearly biting rates by *S. sirbanum* in central Sierra Leone were therefore reduced to 2% of their pre-intervention levels. Based on larval samples, the *S. sirbanum* has been replaced by two forest species, *S. leonense* in the south and *S. squamosum* in the north.

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Since 1992, it has been possible to calculate accurate transmission rates for blinding onchocerciasis, based on DNA-probe identifications. From 1993, the risk of transmission has not only been reduced by vector control but also by mass distribution of ivermectin to rural communities. In terms of control strategy, the authors conclude that larviciding operations could be alleviated in central Sierra Leone without increasing the risk of blinding onchocerciasis transmission, as long as the migration of *S. sirbanum* through eastern Guinea and northern Sierra Leone is prevented.

Onchocerciasis (river blindness) is one of the major endemic diseases of Africa. In West Africa, larvae of the parasite (*Onchocerca volvulus*) are transmitted from man to man by adult female blackflies belonging to the *Simulium damnosum* complex (Diptera: Simuliidae). The Onchocerciasis Control Programme in West Africa (OCP), launched in 1975, initially covered a highly endemic area of West Africa, centred on southern Burkina Faso and including south-eastern Mali and northern areas of Côte d'Ivoire, Ghana, Togo and Benin. The strategy of the OCP was to interrupt the transmission of blinding human onchocerciasis by controlling larval populations of the vectors in their river breeding sites. The objective was to suppress transmission of parasites to humans for a period longer than the life-span of the adult worm, thereby depleting the human reservoir of the disease.

OCP operations were initially successful, but hampered along the borders of the control area by infected flies invading from neighbouring areas where blinding onchocerciasis also prevailed (Garms *et al.*, 1979; Cheke and Garms, 1983). To try and prevent such invasion and effectively cover all areas of blinding onchocerciasis, the OCP area was extended, first in 1978, to southern Côte d'Ivoire (Walsh *et al.*, 1981), and again in 1988, to southern areas of Ghana, Togo and Benin.

Re-invasion still occurred in the west, and detailed studies (Baldry *et al.*, 1985; Baker *et al.*, 1987) showed intensive blackfly movements between the western fringe of the OCP area (northwestern Côte d'Ivoire, southern Mali) and the northern part of Sierra Leone, through the eastern part of Guinea. *Simulium sirbanum*, a member of the 'savanna' group of the *S. damnosum* complex and an important vector of blinding onchocerciasis in West Africa, was the main species involved in these re-invasions. At the onset of the rainy season (June), there was a southwest–northeast migration of *S. sirbanum* females, synchronized with similar movement of the Inter-Tropical Convergence Zone. There was also a reverse movement of *S. sirbanum* females (northeast–southwest) at the onset of the dry season (December–February), favoured by strong Harmattan winds from the Sahel region. The OCP vector-control area was therefore further extended in 1989 to include the river basins of eastern Guinea and of north and central Sierra Leone, in order to block these seasonal blackfly movements. This extension of treated areas had an immediate effect, lowering biting rates by 70% in the re-invaded areas, and by 90% in the newly treated areas (Baker *et al.*, 1990).

Larvicide treatments have been maintained in eastern Guinea and Sierra Leone since 1989, and transmission of *Onchocerca volvulus* has been kept to extremely low levels. Another consequence of these treatments has been a change in the species composition of the remaining blackfly populations. The present study is of this change as observed in central Sierra Leone, where a drastic reduction in the populations of the savanna vectors has recently been observed.

MATERIALS AND METHODS

Study Area

Six blackfly capture points were selected in the major river basins of central Sierra Leone: Yirafilaia, Arfanya, Makpankaw and Katik on the Rokel River, and Sankalaia and Yifin on the Sewa River (Fig. 1). All six are located well within the bounds of the OCP treatment area. The general landscape is one of degraded forest, with a mosaic of wooded and cleared areas (Gwynne-Jones *et al.*, 1978) and very

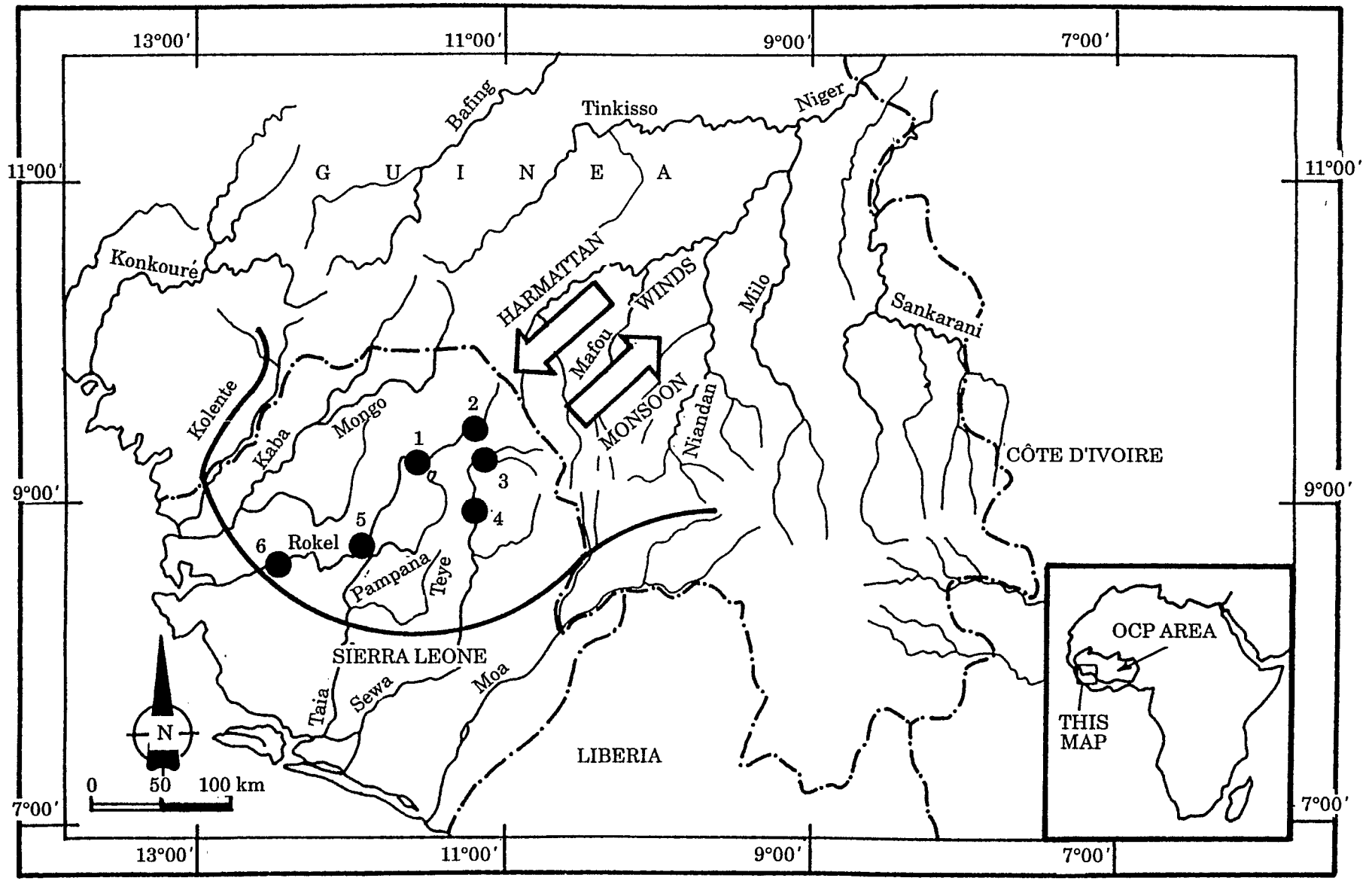

Fig. 1. Map of Sierra Leone and surrounding countries, showing the location of the six capture points (●) surveyed during the study, the southern limit of the area treated by the OCP (~) and the international borders (– · –). Arrows indicate the general direction of winds for the dry season (Harmattan) and for the rainy season (monsoon). 1, Arfanya; 2, Yirafilaia; 3, Sankalaia; 4, Yifin; 5, Makpankaw; 6, Katik.

high rainfall (2000–2500 mm/year). Most of the rain falls between June and January.

Capture, Identification and Dissection of Adult Female Blackflies

Daily biting rates (females/man/day) were estimated using the OCP standard protocol (Walsh *et al.*, 1979). At each capture point, flies were captured for 11 h/day. Flies landing on the legs of an observer were captured in a tube and kept alive for counting, identification and dissection. 'Savanna' flies (*S. sirbanum* and *S. damnosum* s.s.) were separated from 'forest' flies (the rest of the *S. damnosum* complex) as described by Wilson *et al.* (1993). Separation of parous and nulliparous females was achieved by dissection and examination of the ovarioles and Malpighian tubules. The numbers of days of capture were particularly high in 1988, when intensive capture efforts were performed in the context of re-invasion and pre-treatment studies (Table 1). In 1993 and 1994, capture points were visited on a weekly or bi-weekly schedule, as part of the established routine for the entomological evaluation network of OCP in river basins submitted to weekly larviciding operations. The methods used for vector control operations and entomological assessment have already been described (Agoua *et al.*, 1991; Hougard *et al.*, 1993).

Sampling and Identification of Blackfly Larvae

Larval samples for cytotaxonomy were collected in the rivers, close to capture points. Larvae were preserved in Carnoy's fixative and identified following the criteria described by Boakye (1993). The nomenclature used in this paper follows that of Boakye *et al.* (1993).

Study Period

The dry season is rather short in Sierra Leone, usually lasting from February to May. The period of April–May was selected for the comparison of data before treatment (1988) with those recorded after 4 and 5 years of vector control (1993–1994), since it is then that populations of the 'savanna' blackflies of the *S. damnosum* s.l. complex peak (Fig. 2). For comparison purposes, the results of 1993 and 1994 were pooled.

RESULTS

Previous to Vector Control (1988)

Overall, the mean daily biting rate (females/man/day) in 1988 was 66·3, the mean values ranging from 20·4 at Yirafilaia to 150·6 at Arfanya. 'Savanna' blackflies comprised 69·1% of all captures (Table 1), with a range from 42·0% in Katik to 98·8% in Arfanya. The average daily biting rate by 'savanna' females was therefore estimated to be 49·9. Parous rates were similar at all six capture points (51·6%–75·6%), with an overall mean of 66·3%.

According to cytotaxonomic identifications of the larval samples collected in the main rivers close to capture points (Table 2), *S. sirbanum* was the main 'savanna' blackfly involved in man-biting, as *S. damnosum* s.s. was only found in one site (2% of samples in Yifin). In the north (Yirafilaia), *S. sirbanum* made up to 100% of larval samples, whereas towards the south 'forest' blackflies predominated. The main species encountered that belonged to the 'forest' group of blackflies were *S. squamosum*, *S. yahense*, *S. leonense* and *S. konkourense* Menankaya form. *Simulium leonense* was the dominant species in the south (65% and 53% of larvae in Katik and Makpankaw, respectively). *Simulium squamosum* larvae were found in small numbers in Arfanya, Sankalaia and Yifin; *S. konkourense* Menankaya form was present in small numbers everywhere except in Yirafilaia but only a few *S. yahense* larvae were found (in Yifin).

Results After 4–5 Years of Vector Control (1993–1994)

In 1993–1994, the average daily biting rate (Table 1) had dropped to 21·0, with a range of 3·1 (in Yifin) to 80·1 (in Sankalaia). This represented a 3·2-fold reduction from pre-treatment levels. However, the most significant change was the drastic reduction in the proportion of 'savanna' blackflies, which only made up 4·3% of the captures. No 'savanna'

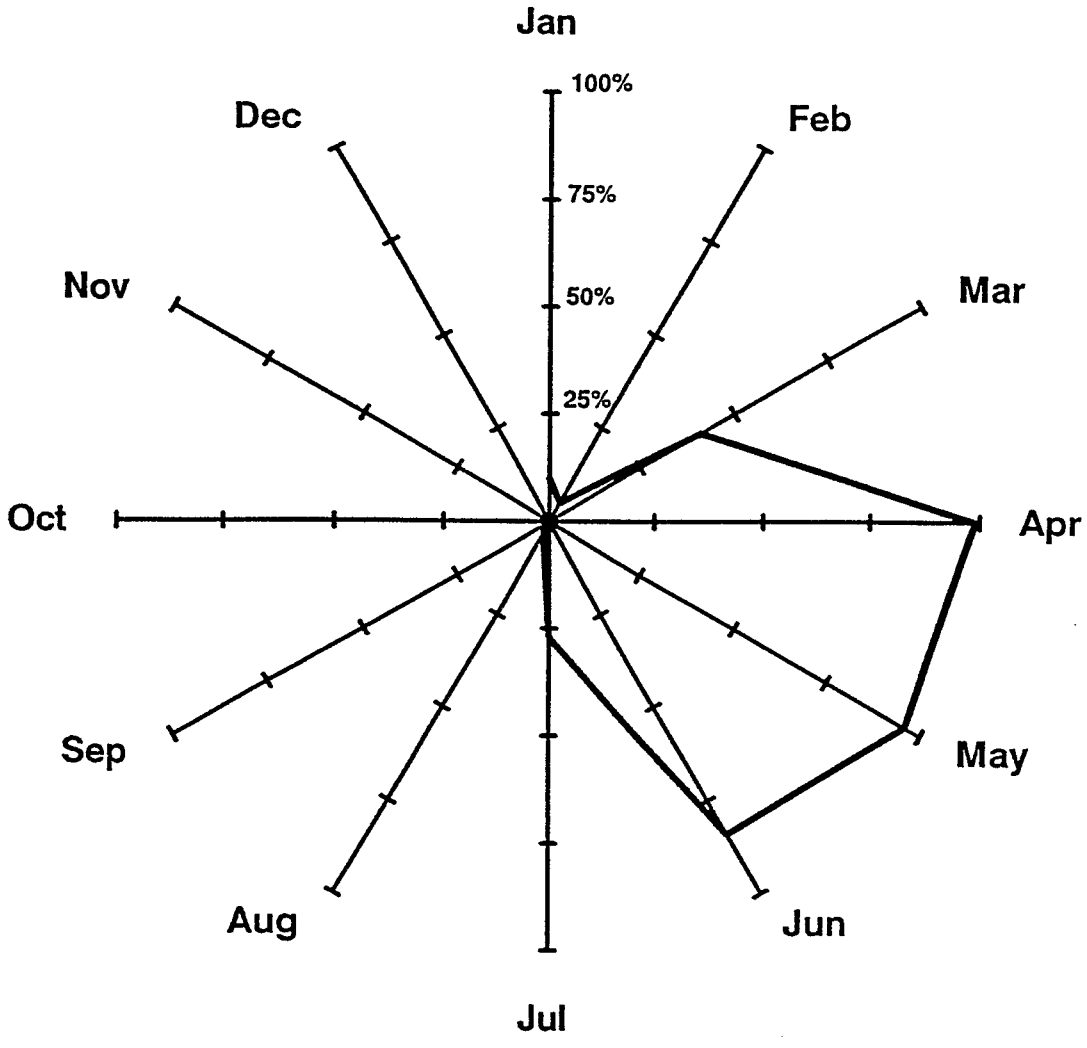

Fig. 2. Relative abundance of 'savanna' blackfly females of the *Simulium damnosum* complex at the six capture points of central Sierra Leone surveyed in 1988.

blackflies were caught at two capture points (Yifin and Makpankaw) during the dry seasons of 1993 and 1994, whereas they made up 73·4% and 54·7% of captures in 1988, respectively. At the peak of the dry season, the average daily biting rate by 'savanna' blackflies was down to 1·0, compared with 49·9 in 1988. Therefore it is estimated that 4–5 years of vector control in Sierra Leone reduced the yearly biting rates by 'savanna' blackflies to just 2% of the pre-treatment value, since, in general, adult 'savanna' blackflies are only present during the dry season.

The parous rates were lower and more variable in 1993–1994 than in 1988, with a range of 36·4% to 77·8% (mean=51·3%). The higher variability of parous rates, common in areas under vector control by OCP, is explained by the smaller sample sizes and by the alternance of full control periods, when parous rates climb up, and of periods when some local breeding provokes bursts of nulliparous flies, bringing the parous rates down.

In 1993–1994, fewer larval samples were available for cytotaxonomic identification (Table 2), due to the high efficacy of larviciding operations. However, obvious changes occurred in the proportion of species among samples. *Simulium sirbanum* was only found in two localities, Yirafilaia and Katik, where it made up only 21% and 18% of samples, respectively. *Simulium damnosum* s.s. was only found in one locality (Sankalaia), where it made up 19% of samples, and no *S.*

TABLE 1
Female blackflies caught at six locations in central Sierra Leone

Locality	*All species*				*'Savanna' species*	
	No. caught	*No. of collection days*	*Daily biting rate (females/man/day)*	*Parity (% parous)*	*Frequency (% of catch)*	*Daily biting rate (females/man/day)*
APRIL–MAY 1988						
Yirafilaia	879	43	20·4	63·3	98·4	20·1
Arfanya	6778	45	150·6	69·7	98·8	148·8
Sankalaia	82	2	41·0	75·6	47·6	19·5
Yifin	3346	37	90·4	68·9	73·4	66·4
Katik	977	17	57·5	51·6	42·0	24·1
Makpankaw	940	25	37·6	69·7	54·7	20·6
All six locations			66·3	66·3	69·1	49·9
APRIL–MAY IN BOTH 1993 AND 1994						
Yirafilaia	268	15	17·9	77·8	3·0	0·5
Arfanya	92	15	6·1	57·1	13·1	0·8
Sankalaia	1202	15	80·1	44·1	4·8	3·8
Yifin	25	8	3·1	36·4	0·0	0·0
Katik	232	16	14·5	43·4	5·1	0·7
Makpankaw	25	6	4·2	50·0	0·0	0·0
All six locations			21·0	51·3	4·3	1·0

TABLE 2

Species composition of samples of the larval Simulium *populations collected near the six adult collection sites, as determined by cytotaxonomy*

Location	*Frequency (% of collection)*						
	S. sirbanum	S. damnosum *s.s.*	S. squamosum	S. yahense	S. leonense	S. konkourense *Menankaya form*	N
APRIL–MAY 1988							
Yirafilaia	100	0	0	0	0	0	66
Arfanya	98	0	1	0	0	1	161
Sankalaia	83	0	13	0	1	3	78
Yifin	72	2	7	2	0	16	136
Katik	31	0	0	0	65	4	134
Makpankaw	46	0	0	0	53	1	151
APRIL–MAY IN BOTH 1993 AND 1994							
Yirafilaia	21	0	79	0	0	0	71
Arfanya	0	0	91	9	0	0	44
Sankalaia	0	19	66	16	0	0	32
Yifin	0	0	97	3	0	0	29
Katik	18	0	5	0	76	0	38
Makpankaw	0	0	0	0	100	0	26

konkourense Menankaya form were recorded. Correspondingly, there was an increase in the proportions of three species of the 'forest' group of blackflies: *S. squamosum* was present in five of the six localities and had become the dominant species in the four northernmost (66%–97% of samples); *S. leonense* was still the dominant species in Katik and Makpankaw (76% and 100%, respectively) and *S. yahense* was present in low numbers (3%–16%) in three localities (Arfanya, Sankalaia and Yifin).

DISCUSSION

Post and Crosskey (1985) found that 'savanna' blackflies were abundant only in the extreme north of Sierra Leone and rare elsewhere. This was confirmed in 1988 during the present study, if the whole year is considered. However, these vectors made up the majority of the man-biting blackfly fauna in central Sierra Leone during the peak of the short dry season. The main result of vector control by the OCP has been a drastic reduction in this peak of abundance, and the replacement of *S. sirbanum* by 'forest' blackflies throughout the year. The replacement of *S. sirbanum* in the southern part of the study area by *S. leonense* has occurred because *S. leonense* still breeds in large rivers south and east of the vector control area. In the northern part of the study area, *S. sirbanum* has been replaced by *S. squamosum* and to a lesser extent by *S. yahense*, two species that readily breed in small forest and mountain streams, common larval habitats in central Sierra Leone. OCP larviciding operations are targeted at breeding sites of *S. sirbanum* and *S. damnosum* s.s. in main rivers, and many hillside streams which are inaccessible for aerial operations must be left untreated. Therefore, residual populations of *S. squamosum* and *S. yahense* from these streams may recolonize main rivers at any time.

In spite of the residual biting rates due to 'forest' blackflies in central Sierra Leone, the risk of transmission of blinding onchocerciasis is now considered negligible (Bissan *et al.*, 1994); both *S. squamosum* and *S. yahense* have poor vectorial competence (Quillévéré, 1979). Additional confidence in the evaluation of transmission potentials has been provided recently by the implementation of DNA-probe techniques. Since 1992, a central OCP laboratory located in Bouaké (Côte d'Ivoire) has identified all parasites found in dissected flies, using the specific DNA probes described by Zimmerman *et al.* (1992). According to these identifications, most residual transmission in Sierra Leone consists of parasites other than the blinding form of *O. volvulus* (Toé *et al.*, 1994). Apart from vector control operations, mass distributions of ivermectin were initiated in Sierra Leone in 1990, which further reduced transmission potentials throughout the study area.

In conclusion, vector-control operations in central Sierra Leone from 1989 to 1994 clearly had a strong impact on the population dynamics of the major vector species of blinding onchocerciasis, *S. sirbanum* and *S. damnosum* s.s. The drastic reduction in the abundance of *S. sirbanum* was undoubtedly due to sustained vector control operations, since this mobile species was still present in the study area, and in the adjacent areas of northern Sierra Leone and Guinea. In view of the above results, and with the added safety of accurate parasite identifications and ivermectin distribution, it is now possible to envisage a partial reduction of vector-control operations in central Sierra Leone.

The hypothesis that there are massive, yearly *S. sirbanum* invasions of central Sierra Leone from Guinea has been confirmed. Therefore, the maintenance of effective vector control in northern Sierra Leone and Guinea, especially at the onset of the dry season, should prevent the buildup of *S. sirbanum* populations, and decrease the need for intensive, year-round treatments in central Sierra Leone.

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