Eliminating Onchocerciasis after 14 Years of Vector Control: A Proved Strategy

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From 1976 through 1989, weekly aerial spraying operations against blackflies were carried out along the rivers of a wide savanna area of West Africa (~700,000 km²) where onchocerciasis was hyperendemic. The level of endemicity began to decrease significantly after 4 years of vector control and became very low in 1989. This situation has been maintained without any vector control activity or chemotherapy, and no incidence of any new cases has been detected. An ophthalmological study carried out in 2000 has confirmed these good results, showing only cicatricial ocular lesions in the examined population. These results led to the conclusion that 14 years of vector control may achieve long-term elimination of onchocerciasis, even in the absence of chemotherapy, provided that the treated areas are not subjected to any contamination by exogenous parasites carried in infected humans or flies.

Despite advances in therapy and vaccine research, the control of vectorborne diseases is still dependent, to a large extent, on vector control. This strategy helps to slow down or stop transmission and to reduce or eliminate the clinical manifestations of the disease. It is sometimes difficult to apply because of the complexity of some parasitic cycles or immune mechanisms. The control of human onchocerciasis, the most serious manifestations of which are blindness and incapacitating skin lesions [1], lends itself more to a vector-control strategy. Indeed, the frequency and severity of the symptoms are correlated closely with the number of microfilariae of *Onchocerca volvulus,* which depend on the number of adult filariae. This, in turn, is governed by the number of infective larvae received by the subject and therefore by the number of bites received from infected blackflies in relation to the length of time spent in an endemic area. Since onchocerciasis is an accumulative disease, clinical onchocerciasis manifests itself only after an accumulation of infections over several years (the development of *O. volvulus* in the vector blackfly results in a reduction of parasite quantity), and, with regard to eye lesions, blindness generally does not appear before age 30 years, although it may occur at an earlier age in inhabitants of certain hyperendemic areas.

By reducing the blackfly population at its larval stage through aerial application of selective insecticides on infested rivers [2], the transmission of infecting *O. volvulus* larvae and the appearance of microfilariae and macrofilariae are reduced greatly. The full interruption of transmission during a period exceeding the reproductive life span of the adult worm, which is ~12–14 years [3], leads to the gradual extinction of the parasite in man and therefore to the elimination of onchocerciasis in the area of vector control. The Onchocerciasis Control Programme (OCP) in West Africa [4], which was launched in 1974, helped to validate this assumption. The first aerial treatments began in February 1975 and by the end of 1977 were extended gradually to cover a "core" area of ~700,000 km² spread over 7 countries, where the incidence of blindness was highest (Burkina Faso, southeastern Mali, southwestern Niger, the northern parts of Côte d'Ivoire, Benin, Ghana, and Togo). In some villages, the prevalence of infected individuals sometimes exceeded 80%, and the rates of onchocercal blindness could reach 9%. Moreover, the frequency and level of evolution of ocular lesions and of onchocercal blindness were among the highest in the world.

Since evidence supported that the borders of this area were affected by infective blackflies originating from beyond these borders, the hyperendemic regions suspected to be sources of invasion were put progressively under aerial treatment, to control onchocerciasis and thus to protect the border of the core area from any exogenous parasitic contamination. However, the size of the core area was such that the regions located at its center were protected continuously since the inception of the OCP. This is why, a quarter century after the vector control operations began and 10 years after their cessation, the parasitic "insularity" of these landlocked regions has facilitated the elimi-

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nation of onchocerciasis. Although the vector returned to pre-control densities, several hyperendemic areas of several thousand square kilometers thus were "freed" without further intervention, particularly through the use of drugs, usually ivermectin, which is a microfilaricide now used widely for onchocerciasis control [5].

Although onchocerciasis unquestionably is no longer a public health problem (the clinical manifestations of onchocerciasis, which were still noted even during the first years of vector control, are no longer reported by health centers), the complete absence of the parasite is yet to be confirmed. Indeed, it would appear that, in the particular case of these areas, there has been no more transmission of the parasite over the past 10 years and that onchocerciasis has been completely and permanently eliminated. The entomological and parasitological data collected since 1975 have been used for a dynamic and detailed review of the situation, 10 years after the end of insecticide treatments, to analyze the validity of the vector-control strategy.

Methods

Study area. The study area (figure 1) is located in the middle of the core area that was treated starting in 1976. Its size is equivalent to that of Switzerland (~40,000 km^2). A major part of the study area is located in Burkina Faso, southeast of Ouagadougou, in the upstream basins of Sissili, Nazinon, Nakambé, and Koulpéolgo. It is a Sudan savanna region, which is relatively homogeneous with respect both to blackfly species (*Simulium sirbanum* exclusively) [6] and to parasite strains ("savanna" strain of *Onchocerca volvulus*) [7] .

Vector-control operations. Insecticide treatments were conducted exclusively in the study area with temephos, a cheap and efficient organophosphorous insecticide, with insignificant impact on nontarget aquatic invertebrates and vertebrates. The spraying, which was carried out essentially by aircraft, began in 1976 and was completed in late 1989 (i.e., 14 years after the beginning of control operations). All the rivers and tributaries of the study area that hosted larval stages of *S. sirbanum* were treated on a weekly basis each time the hydrological conditions were favorable for the development of blackfly larvae.

Entomological evaluation. An entomological evaluation network was established shortly before the beginning of control operations, to ensure a permanent follow-up of the efficiency of insecticide spraying. The catching points were selected from accessible sites where transmission would be noticeable and, if possible, near villages earmarked for epidemiological evaluation. About 30 catching points thus had been gradually put in place in the study area. For the purpose of longitudinal monitoring, we selected 4 of these catching points, where pretreatment data collection was the most complete: Kampalaga and Ziou Zabré on the Nazinon, Loaba on the Nakambé, and Bitou on the Nouhao, which is a tributary of the Nakambé (figure 1). Among the entomological indices monitored over these years, we essentially retained the annual biting rates (ABRs), the annual transmission potential (ATP), and the infectivity rate. ABR is the annual number of bites that a man located at an area heavily exposed to blackfly bites, 12 h a day and 12 months a year, theoretically would receive. ATP is the index used most frequently to quantify transmission. It is defined as the theoretical number of infective *O. volvulus* larvae that would

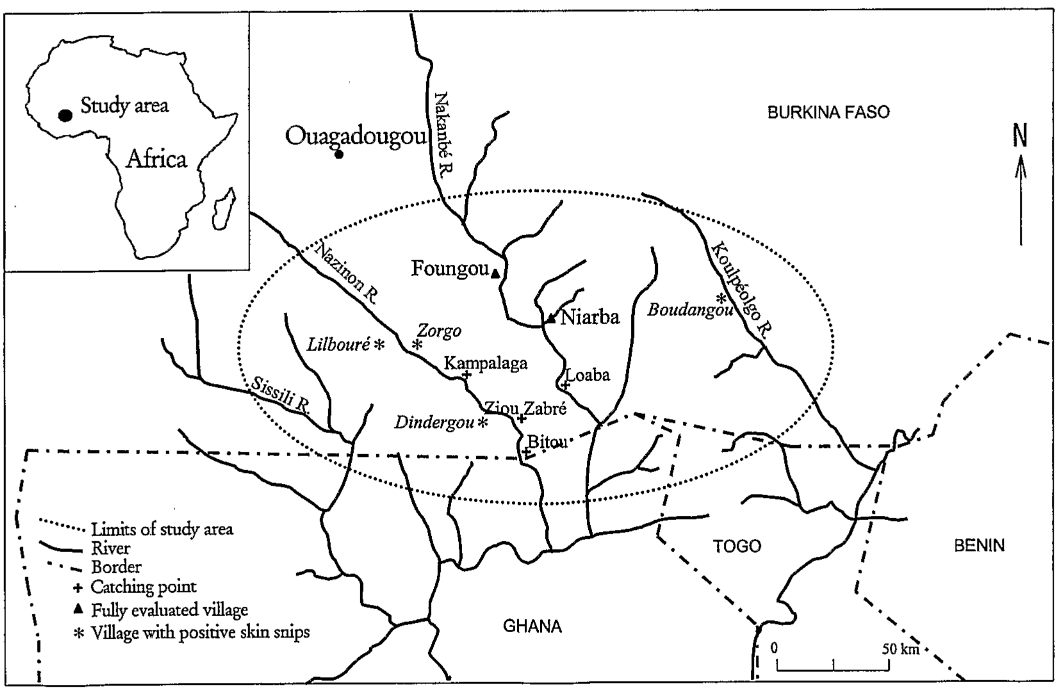

Figure 1. Map of the area showing the location of the catching points and evaluated villages

be received by an individual placed at a catching point during the same period of time. An ATP >800 infective larvae per person per year is associated with clinical signs of hyperendemicity [8]. An ATP <100 infective larvae per person and per year indicates that onchocerciasis transmission has been interrupted and that the disease is no longer a major public health problem. The infectivity rate is a way of expressing the intensity of transmission and is independent of blackfly density and corresponds to the number of infectious female blackflies (carrying infective larvae in the head) per 1000 female blackflies caught. This index was used mostly to evaluate the residual transmission after the complete cessation of insecticide spraying, because the collection of field data entailed less operational constraints, compared with those for the calculation of ATP. The infectivity rates were recorded before treatment, then twice a year, and 10 years after discontinuing insecticide spraying at 2 catching points, Ziou Zabré and Loaba.

Parasitological evaluation. The parasitological evaluation is based on the count of the microfilariae contained in 2 skin-snip samples taken from the iliac crests. The parasitological indices considered were the prevalence [9] of subjects carrying microfilariae and the community microfilarial load (CMFL) [10]. Prevalence is a composite indicator that depends on incidence, population movements, and deaths and births. It indicates, at a given time, the magnitude of parasite infestation among the population. CMFL is clearly more sensitive than prevalence and is considered to be the best indicator of onchocercal endemicity. It corresponds to the geometric mean of the number of microfilariae per skin snip in subjects ⩾20 years old, including those who are not or are no longer infected with microfilariae. Incidence is the number of new cases recorded every year in a selected population. A new case is an individual with microfilariae whose skin-snip samples were negative during the preceding 2 examinations or an individual born after control started who was found to have microfilariae. Incidence is theoretically nil in the absence of transmission. The data available to us were obtained from a cohort of individuals whose skin-snip samples were found to be negative shortly after the end of vector control operations (1990) and who then had been monitored 4 other times (1995, 1996, 1998, and 2000).

Opthalmological evaluation. The opthalmological evaluation helped to determine the consequences of the infection as ocular manifestations of the disease. Seventeen villages, preferably located near the entomological catching points, were selected in the study area before the beginning of vector control. Two of these 17 villages, Niarba and Foungou, which are located along the Nakambé river and have the highest blindness rates, were selected for this evaluation (figure 1). The examination was limited to individuals ⩾5 years old and consisted of measuring visual acuity, looking for and counting microfilariae in the cornea and in the anterior chamber of the eye, detecting early lesions (punctate keratitis), recording the lesions of the anterior and posterior segments of the eye (sclerosing keratitis, iridocylitis, optic atrophies, and choroido-retinitis), and determining the nature of blindness of onchocercal origin. For the study area, we collected detailed data for the village of Foungou, which was monitored 5 times, before the beginning of treatments and after 5, 7, and 10 years of vector control. This village also underwent the latest opthalmological survey in March 2000 (i.e., 11 years after treatment was discontinued).

Demographic surveys. During the periodic epidemiological surveys, the individuals found infected in the freed areas were subjected to perfunctory migration questionnaires. The individuals interviewed were asked specifically to give their profession, place of birth, and movements over the past 15 years, as well as a number of questions related to onchocerciasis. The questionnaires of 10 individuals who were distributed among the 17 villages of the study area were analyzed. They had been found to have positive skin-snip samples during the most recent parasitological surveys (from 1996 to 2000).

Results

Entomological evaluation. ABR and ATP values recorded at Ziou Zabré, Kampalaga, Bitou, and Loaba before the beginning of operations varied from 5865 to 11,879 bites and from 309 to 880 infective larvae per person per year (table 1 and figure 2). Figure 2 also shows, for the same catching points, ATP evolution from 1975 through 1991; ATP values remained <100 infecting larvae per person per year, at least during the last 8 years of vector control. These figures were correlated with the ABR values (table 1), which were very low compared with those recorded in the untreated periods (1975 and 1991). The infectivity rates recorded at Ziou Zabré and Loaba varied from 33.05 and 37.48 per 1000 infectious female blackflies caught before vector control to 0.25 and 0.17, respectively, in 1991. Ten years after the complete cessation of vector control, the infectivity rates remain nearly nil, with only 1 infectious female blackfly of 18,600 blackflies caught at Ziou Zabré and no infectious female blackflies of 8500 blackflies caught at Loaba.

Epidemiological evaluation. Table 2 shows the very high level of onchocercal endemicity in the 17 villages surveyed in the study area before the beginning of operations. An average of 7 of 10 individuals was infected with microfilariae in the study area in 1976 (2622 individuals of 3830 examined tested positive for microfilariae). Figures 3 and 4 show the epidemiological trends (prevalence, CMFL, and blindness rates) in the populations of Foungou and Niarba from 1975 and 1976 through 2000. At Niarba, 162 individuals, on average, were examined at each passage (of 226 listed; i.e., 72% participation) versus 262 at Foungou (of 350 listed; i.e., 75% participation). In the 2 villages, prevalence and CMFL started to decrease significantly after the fourth year. At Foungou, the prevalence of infection in the population examined the year when treatments were stopped was only 7.7%, and CMFL was 0.16. At Niarba, the values were close to 0 (0.6% prevalence and 0.1 for

Table 1. Values of annual biting rate before, during (average of 14 years), and after vector control.

Catching point	Precontrol period, 1975	Control period, 1976–1989	Postcontrol period, 1991
Ziou Zabré	11,879	1465	30,739
Kampalaga	7821	351[a]	—
Bitou	5865	233[a]	—
Loaba	6090	238	8617

[a] Average on 8 years only (data after 1983 not available).

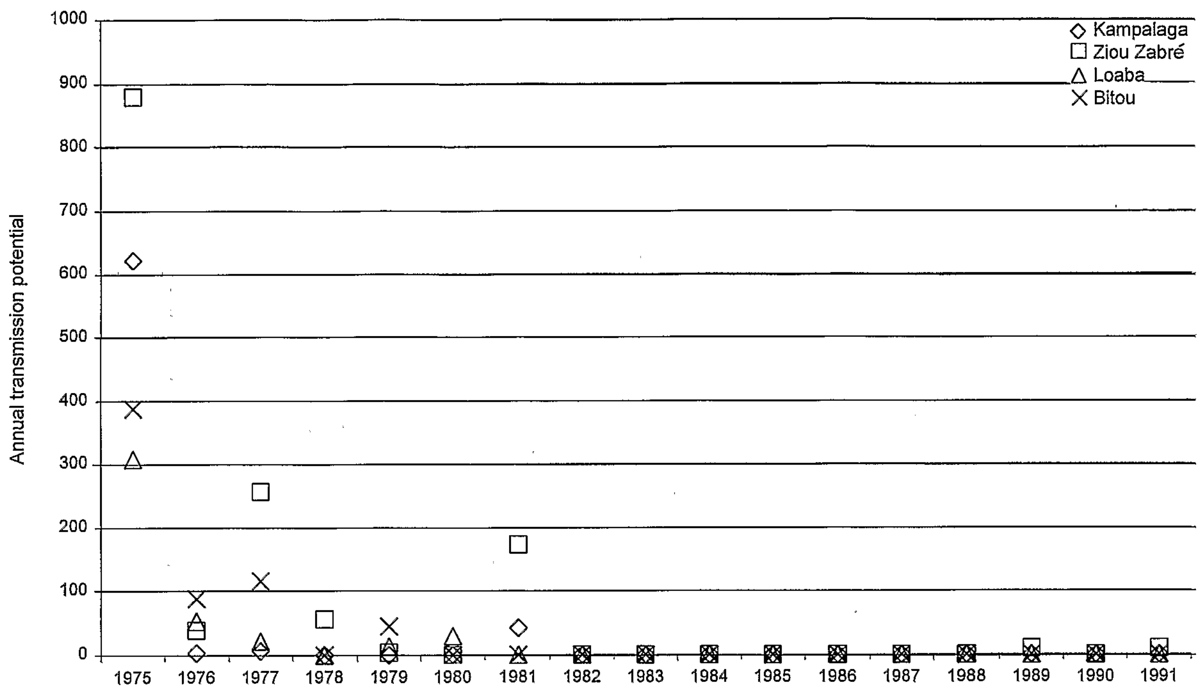

Figure 2. Trend in annual transmission potential of infective *Onchocerca volvulus* larvae in 4 catching points of the study area (Kampalaga, Ziou Zabré, Loaba, and Bitou), 1975–1991.

CMFL). The downward trend was confirmed the years after, with values negligible to nil through 2000.

With regard to the incidence of infection, the cohort selected in November 1990 at Foungou included 257 individuals: 129 female blackflies and 128 male blackflies. At Niarba, it included 117 individuals: 70 female blackflies and 47 male blackflies. No new infection was detected during the later surveys conducted in these 2 cohorts (374 individuals in total) from November 1995 through March 2000; therefore, the incidence of infection during the 10 years after the complete cessation of insecticide treatments therefore was nil at Foungou and Niarba. In April 2000, an opthalmological survey in these 2 villages gave the opportunity to practice skin snipping, as well as patch tests using diethylcarbamazine (DEC) [11]. None of the 168 individuals examined at Niarba and none of the 335 individuals at Bétaré were found to be positive via either skin snip or DEC patch tests.

Opthalmological examinations. Before the beginning of vector-control operations, 66.9% of the individuals examined at Foungou had ocular problems, including 3.4% with punctate keratitis, 38.1% with microfilariae in the cornea and/or the anterior chamber of the eye, and 25.4% with severe and irreversible onchocercal ocular lesions [12]. In March 2000 (i.e., 11 years after the definitive cessation of insecticide spraying), we observed neither punctate keratitis nor microfilariae in the cornea and/or the anterior chamber, which had virtually disappeared after 10 years of vector control [13]. Among the 7.19% of severe ocular lesions, we only observed cicatricial ocular lesions but no inflammatory or progressive lesions. Opthalmological examination also was conducted in March 2000 in 2 other villages of the study area, Niarba and Bétaré. The results are identical to those from Foungou.

Migration surveys. Of the 10 individuals with positive skin-snip samples, 3 were found to have positive samples in 1996

Table 2. Prevalence, community microfilarial load (CMFL), and onchocercal blindness rates in the study area before the beginning of vector-control operations.

Village	Basin	No. examined[a]	Prevalence, %	CMFL	Blindness rate, %
Niarba	Nakanbé	122	71.9	21.76	9.03
Foungou	Nakanbé	253	76.6	40.57	8.85
Wayen	Nakanbé	275	52.7	12.79	6.66
Bangasse	Koulpéolgo	108	71.1	89.05	6.36
Loaba	Nakanbé	222	77.0	53.83	6.28
Yakala	Nakanbé	177	67.5	16.89	6.28
Boudangou	Koulpéolgo	311	76.4	47.00	6.01
Kounou	Sissili	78	75.1	17.81	5.74
Zorgo	Nazinon	193	73.0	31.85	4.42
Lamiougou	Koulpéolgo	500	68.1	21.41	3.51
Dindergou	Nazinon	115	79.2	74.88	3.34
Tili	Nazinon	285	91.8	24.45	3.09
Nianlé	Nakanbé	375	65.8	27.25	2.42
Natiédougou	Sissili	149	83.6	45.48	2.27
Koumbili	Sissili	144	71.1	47.20	1.86
Betaré	Nazinon	294	63.2	28.12	1.41
Lilbouré	Nazinon	229	58.1	15.57	0.00

[a] Subjects ⩾20 years old.

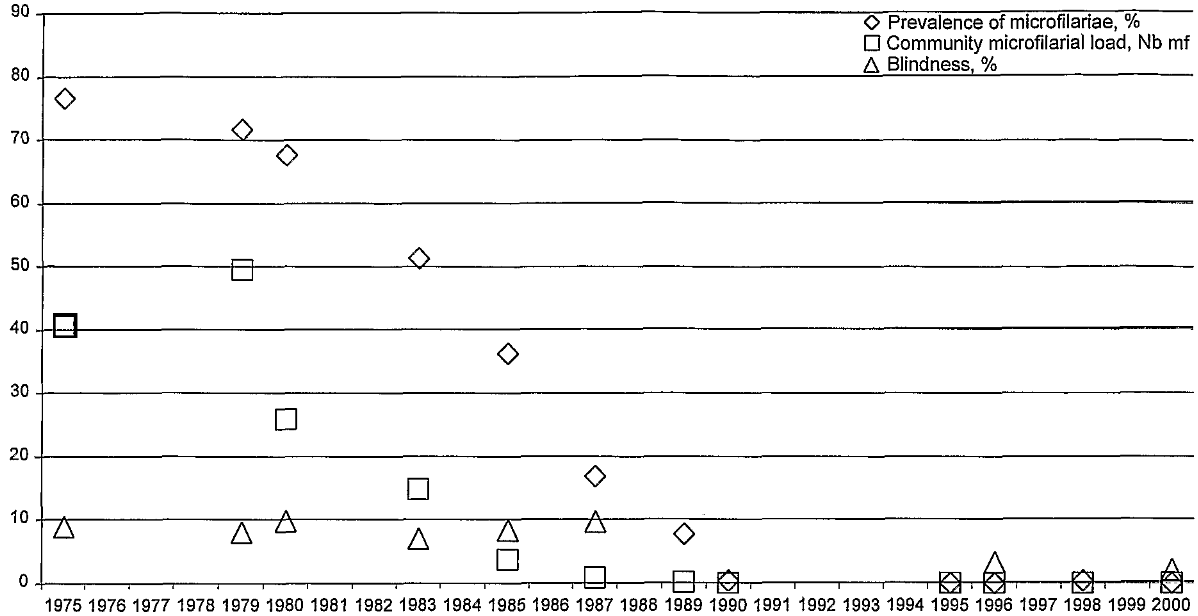

Figure 3. Epidemiological trend or prevalence of microfilariae, community microfilarial load, and blindness at Foungou village, 1975–2000. Nb mf, no. of microfilariae.

at Zorgo on the Nazinon, whereas the others were found to have positive samples in 1998 (4 individuals at Dindergou near the Nazinon, 2 at Lilbouré near the Nazinon, and 1 at Boudangou near the Koulpéolgo). At Zorgo, a 34-year-old man, a native from the village, lived 10 years in the humid forest zone of Côte d'Ivoire. A 27-year-old woman spent 10 years in the forest zone of Côte d'Ivoire, whereas her daughter spent the first 5 years of her life there. At Dindergou, a 40-year-old man and a 35-year-old woman, who were village natives, had recently lived for ~10 years in the humid forest zone of Ghana and Côte d'Ivoire. The other 2 individuals, a 36-year-old man and a 31-year-old woman, said that they had never left their village of origin. At Lilbouré, the 38-year-old man was a native from the village, whereas his 10-year-old daughter was born in Côte d'Ivoire in a forest zone where both of them had spent 5 years. A 34-year-old man from Boudangou, a native from that village, claimed that he had not left the village over the past 15 years. The results of the parasitological examination of the 3 individuals who seem to have not left the village or, at least, the study area are shown in table 3.

Discussion

As shown in figure 2, a drastic and sustainable reduction of transmission has been achieved throughout the duration of vector control and after, since ATP values remained unchanged despite the return of blackfly densities to pretreatment levels (table 1). The measurement of infectivity rates after discontinuing vector control confirms these good results: with infectivity rates <0.5 infectious female blackflies per 1000 female blackflies caught, transmission is considered to be virtually interrupted, and no control measure is required [14].

The results of table 2 show that the area under study is located, according to the parasitological criteria defined by Prost and Prod'hon [9], in an area of onchocercal hyperendemicity, thus confirming the high ABR and ATP values recorded during the precontrol period. The very low transmission after vector-control operations is confirmed by the parasitological level in the 2 villages longitudinally monitored (figures 3 and 4), with clearly declining trends in terms of prevalence of microfilariae and of CMFL (prevalence and CMFL were close to 0 in 1990 before becoming nil during the following years). These results also are confirmed by the incidence surveys conducted in those 2 villages, as well as by the opthalmological survey conducted independently in 3 villages of the area in April 2000 (old lesion that did not redevelop since vector control was discontinued).

Answers to questionnaires given to the 10 individuals more recently found to be carrying microfilariae indicate that 7 of these 10 individuals probably were infected during stays outside the study area, specifically in neighboring countries—Ghana and Côte d'Ivoire—in humid forest zones, where onchocerciasis with less incidence of blindness prevails [15]. For the 3 individuals who claim that they did not leave the study area (table 3), a first interpretation could be that this infection was due to an artifact of skin snip reading, particularly for the 2 patients of Dindergou who had very low parasite loads and who were found to test positive for the first time in 1998. A second in-

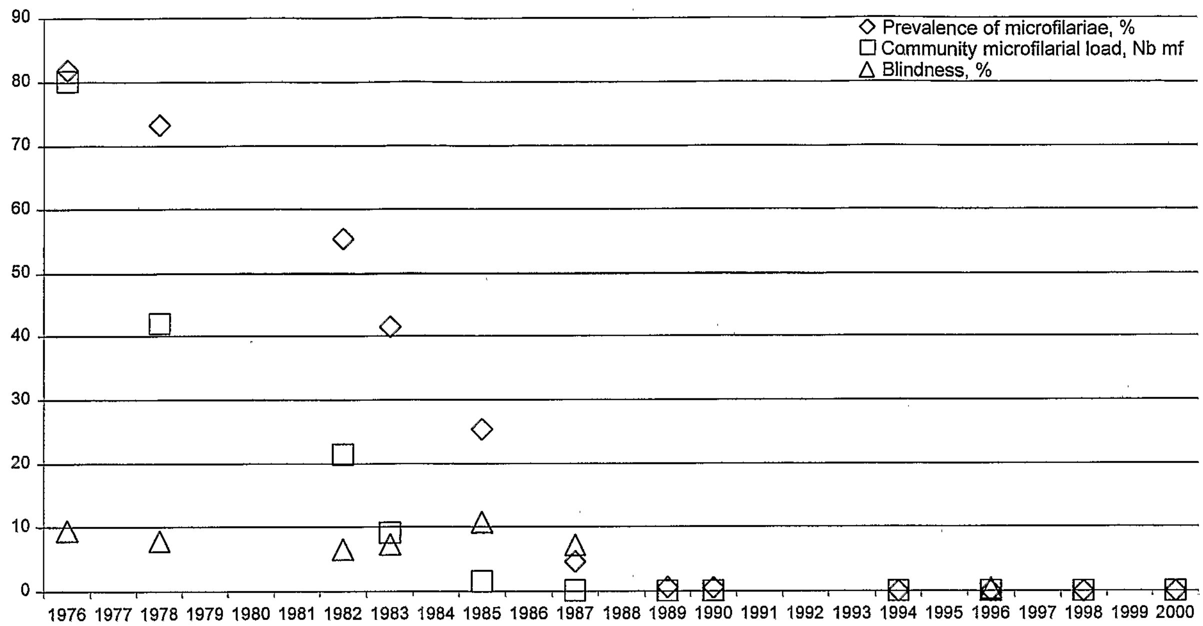

Figure 4. Epidemiological trend of prevalence of microfilariae, community microfilarial load, and blindness at Niarba village, 1974–2000. Nb mf, no. of microfilariae.

terpretation would be the unreliability of the account given by the individuals interviewed (omission of information or bad understanding of the message delivered). The last assumption could be the maintenance of a residual transmission, which sometimes is not insignificant; for example, at Boudangou, the individual positive for *O. volvulus* carried out 13 microfilariae per skin-snip sample.

In conclusion, the review of entomological and parasitological results for the whole study area confirms the strong and sustainable reduction of the transmission of *O. volvulus* after the complete cessation of vector control in the absence of ivermectin distribution. The absence or, at least, the very low level of transmission of *O. volvulus* by *S. sirbanum* in so wide an onchocercal area that used to be hyperendemic is quite spectacular, given that OCP was used as a control rather than as an eradication program. The results suggest that the initial vector-control strategy, which was developed in the early 1970s on the basis of a few pilot studies [16], was a realistic option, since the treated areas had been protected permanently from parasite reinfestation of human populations or infected blackflies. Unfortunately, this opportunity was not offered everywhere, as witnessed by some residual foci reported within the core area. Therefore, particular attention was paid to these foci, which led to the identification of the factors of failure as climatic (e.g., migration of flies), logistic (e.g., inappropriate location of catching points), or demographic (e.g., migrants in search of new farmlands) [17]. The creation of the Bagré dam in 1992 on the Nakambé, upstream of the Loaba catching point, is a good example of such foci to be carefully surveyed. This important water dam, essentially meant for fishing and agriculture, causes new migratory flows in the subregion that are potential sources of parasite reintroduction. Therefore, monitoring of the evolution of transmission is advised in this onchocerciasis-freed zone, especially since this region has developed considerably over the past few years. Residual activities of surveillance and control are now in the hands of the participating countries, since OCP ends in December 2002, after a 5-year process of phasing out.

Table 3. Average load of *Onchocerca volvulus* microfilariae (mf), by analysis of skin-snip samples from 3 subjects who did not leave the study area.

	Average parasite load, mf		
	Dindergou		Boudangou
Year of survey	Subject 1 (male; 1963)	Subject 2 (female; 1965)	Subject 3 (male; 1964)
1978	—	—	45.0
1982	—	—	43.0
1985	—	—	12.5
1992	0.0	0.0	—
1994	0.0	0.0	0.0[a]
1998	1.0	0.5	13.0

[a] Subject 3 probably was treated with ivermectin.

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