11. THE VECTORS

Blackflies (Diptera: Simuliidae) are the only known vectors of *Onchocerca volvulus*. In Africa and in southern Arabia onchocerciasis is transmitted mainly by members of the *Simulium damnosum* complex, but in East and Central Africa species of the *Simulium neavei* group also transmit the disease. In the western hemisphere the situation is complicated by the presence of a large number of man-biting species.

11.1 Africa and South Arabia

11.1.1 *Simulium damnosum* complex

(a) Taxonomy and distribution. *Simulium damnosum* was formerly regarded as a fairly uniform species, but it is now known to be a complex of numerous sibling species. These species are very similar morphologically but can be distinguished by the banding patterns of their larval chromosomes. The taxa included in this complex are summarized in Table 5. From the practical viewpoint they form three categories, according to their diagnostic criteria and nomenclature: (1) formally Latin-named taxa (sibling species or “cytospecies”) based on chromosomal characters, but to some extent either morphologically or enzymatically identifiable; (2) formally Latin-named taxa based on morphological characters as yet unsupported by chromosomal or enzymatic characters; (3) vernacularly named taxa based on chromosomal characters, poorly or not studied morphologically, and unknown enzymatically.

Category (1) includes the geographically widespread sibling species that have been well investigated in West Africa notably *S. sirbanum*, *S. damnosum* s.s., *S. sanctipauli*, *S. soubrense*, *S. yahense*, and *S. squamosum*. The first two of these six species are termed “savanna” species, and the other four “forest” species. *S. sirbanum* is the dominant, if not the only species in the northern most areas of the Sudan savanna. *S. damnosum* s.s., although essentially a savanna-dwelling species, adapts itself to more wooded biotopes and may form small permanent populations even in dense forest. The *S. sanctipauli* subcomplex, including *S. sanctipauli*, *S. soubrense*, *S. soubrense* “B”, and the “Beffa” and “Konkoure” forms, is under revision; criteria and status need to be reassessed. The species of this subcomplex vary morphologically, and in their adaptation to the
<table>
<thead>
<tr>
<th>Taxon</th>
<th>Category</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. buisseti</em></td>
<td>2</td>
<td>W. Zaire (prob. non-vector)</td>
</tr>
<tr>
<td><em>S. damnosum s.s.</em></td>
<td>1</td>
<td>Senegal to Central African Republic (mainly savanna), Uganda and Sudan (Nile basin) (vector)</td>
</tr>
<tr>
<td><em>S. cinquitatum</em> syn. <em>S. cinquitatum</em> syn. <em>Nil</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. dieguerense</em> syn. <em>Dieguera</em></td>
<td>1</td>
<td>Mali (savanna) (? vector)</td>
</tr>
<tr>
<td><em>S. kilibanum</em> syn. <em>Nyamagasani</em> syn. <em>Kiliba</em></td>
<td>1</td>
<td>Burundi, Malawi, United Republic of Tanzania, Uganda, E. Zaire (vector some areas)</td>
</tr>
<tr>
<td><em>S. latipollex</em></td>
<td>2</td>
<td>South Africa (non-vector)</td>
</tr>
<tr>
<td><em>S. luadiense</em></td>
<td>2</td>
<td>S.W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. maertensi</em></td>
<td>2</td>
<td>W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. mengense</em></td>
<td>1</td>
<td>N. and S. Cameroon, N.W. Central African Republic, United Republic of Tanzania (?) (vector)</td>
</tr>
<tr>
<td><em>S. microlepdom</em></td>
<td>2</td>
<td>W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. nganganum</em></td>
<td>2</td>
<td>S.W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. repentum</em></td>
<td>2</td>
<td>W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. sanctipaulii</em> syn. <em>Bandama</em></td>
<td>1</td>
<td>Sierra Leone/Guinea to S.W. Nigeria (forest) (vector)</td>
</tr>
<tr>
<td><em>S. sirbanum</em> syn. <em>S. sudanense</em> syn. <em>Sirba</em></td>
<td>1</td>
<td>Senegambia to N.W. Central African Republic (savanna), Sudan (vector)</td>
</tr>
<tr>
<td><em>S. soubrense</em> syn. <em>Soubre</em></td>
<td>1</td>
<td>Sierra Leone/Guinea to Nigeria (forest) (forest-savanna mosaic) (vector)</td>
</tr>
<tr>
<td><em>S. squamosum</em> syn. <em>Bille</em></td>
<td>1</td>
<td>Sierra Leone to Central African Republic/W. Zaire (forest-savanna mosaic) (vector)</td>
</tr>
<tr>
<td><em>S. wambahum</em></td>
<td>2</td>
<td>S.W. Zaire (? vector)</td>
</tr>
<tr>
<td><em>S. yahense</em> syn. <em>Yah</em></td>
<td>1</td>
<td>Sierra Leone/Guinea to Togo (forest) (vector)</td>
</tr>
<tr>
<td><em>Beffa</em></td>
<td>–</td>
<td>Benin, Liberia, Nigeria, Togo (vector)</td>
</tr>
<tr>
<td><em>Bole</em> (unpublished)</td>
<td>3</td>
<td>N.W. Central African Republic (? vector)</td>
</tr>
<tr>
<td><em>Hammerkopf</em></td>
<td>3</td>
<td>United Republic of Tanzania (Ruaha) (prob. non-vector)</td>
</tr>
<tr>
<td><em>Jimma</em></td>
<td>3</td>
<td>S.W. Ethiopia (prob. vector)</td>
</tr>
<tr>
<td><em>Jovi</em></td>
<td>3</td>
<td>United Republic of Tanzania (prob. non-vector)</td>
</tr>
<tr>
<td><em>Kagera</em></td>
<td>3</td>
<td>United Republic of Tanzania/Uganda (prob. non-vector)</td>
</tr>
<tr>
<td><em>Kaku</em></td>
<td>3</td>
<td>Uganda (Kigezi) (prob. non-vector)</td>
</tr>
<tr>
<td><em>Kapere</em></td>
<td>–</td>
<td>E. Zaire (forest) (? vector)</td>
</tr>
<tr>
<td><em>Ketaketa</em></td>
<td>3</td>
<td>United Republic of Tanzania (Ruaha) (prob. non-vector)</td>
</tr>
<tr>
<td>Taxon</td>
<td>Category</td>
<td>Distribution</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>&quot;Kibwezi&quot;</td>
<td>3</td>
<td>Kenya, United Republic of Tanzania (E. Usumbara) (prob. non-vector)</td>
</tr>
<tr>
<td>&quot;Kipengere&quot;</td>
<td>3</td>
<td>United Republic of Tanzania (Ruaha) (prob. non-vector)</td>
</tr>
<tr>
<td>&quot;Kisiwani&quot;</td>
<td>3</td>
<td>Ethiopia, Kenya, United Republic of Tanzania (non-vector)</td>
</tr>
<tr>
<td>&quot;Konkoure&quot;</td>
<td>3</td>
<td>Guinea (? vector)</td>
</tr>
<tr>
<td>&quot;Kulfo&quot;</td>
<td>3</td>
<td>Ethiopia (non-vector)</td>
</tr>
<tr>
<td>&quot;Mutonga&quot;</td>
<td>3</td>
<td>Kenya (Mt Kenya area) (non-vector)</td>
</tr>
<tr>
<td>&quot;Ngaraba&quot; (unpublished)</td>
<td>3</td>
<td>S. Central African Republic (? vector)</td>
</tr>
<tr>
<td>&quot;Nkusi&quot;</td>
<td>3</td>
<td>W. Kenya, United Republic of Tanzania, Uganda (? vector in United Republic of Tanzania, non-vector Kenya)</td>
</tr>
<tr>
<td>&quot;Sanje&quot;</td>
<td>3</td>
<td>Malawi, United Republic of Tanzania (incl. E. Usumbara) (vector)</td>
</tr>
<tr>
<td>&quot;Sebwe&quot;</td>
<td>3</td>
<td>United Republic of Tanzania, Uganda (prob. non-vector)</td>
</tr>
<tr>
<td>&quot;soubrense B&quot;</td>
<td>3</td>
<td>Sierra Leone (? vector)</td>
</tr>
<tr>
<td>&quot;Turiani&quot;</td>
<td>3</td>
<td>United Republic of Tanzania (prob. non-vector)</td>
</tr>
<tr>
<td>Undescribed new cytospecies</td>
<td>3</td>
<td>Yemen (vector)</td>
</tr>
<tr>
<td>Undescribed new cytospecies (three different)</td>
<td>3</td>
<td>South Africa (non-vector)</td>
</tr>
<tr>
<td>Undescribed new cytospecies</td>
<td>3</td>
<td>Swaziland (non-vector)</td>
</tr>
</tbody>
</table>

*Formally Latin-named and vernacularly named taxa are distinguished, and names are alphabetical in each set. Category classification indicates the nature of the taxonomic criteria and nomenclature (see text). The entry (?? vector) indicates absence of data or extent of anthropophily but some involvement in transmission appears possible; (non-vector) indicates occurrence in onchocerciasis-free areas; (prob. non-vector) indicates that the taxon is zoophilic or virtually so.

*The taxonomy of *S. sanctipauli* subcomplex is under revision.

*Member of *S. sanctipauli* subcomplex.

different bioclimatic zones, host preferences, and vectorial roles. They are mainly forest species inhabiting large rivers, but in the rainy season some of them may extend their areas of distribution into the Guinea savanna (10–11° N). *S. yahense* is associated with the rain-forest and generally breeds in small watercourses. *S. squamosum*, which is probably also a subcomplex, has a focal distribution, with a preference for small or medium-sized rivers in hilly and mountainous areas in West Africa. However, east of Nigeria it occurs in different biotopes, including large rivers.

Category (2) includes cautiously described morphospecies of uncertain validity from the Zaire basin.

Category (3) includes taxa from eastern Africa with restricted distributions (most of them are probably valid sibling species). A few taxa fall outside these main categories, e.g., the West African
“Beffa” form, which has been chromosomally and morphologically characterized but remains unnamed because its taxonomic status is uncertain. Many problems of status and interrelationship of taxa within the complex have still to be resolved, and an in-depth cytotaxonomic review of the complex remains very necessary, even for West Africa. The vernacularly named East African cytotaxa remain inadequately described. Incomplete knowledge of basic taxonomy continues to be a constraint on understanding the epidemiological significance of distributional and bionomic data.

The total known morphospecies range for S. damnosum s.l. is shown in Fig. 3, with an indication of anthropophilic range. Fig. 4–6 show the pre-control ranges of the common West African cytospecies and the extent of savanna and forest and forest/savanna mosaic. Ranges of the characteristically savanna cytospecies, S. damnosum s.s. and S. sirbanum, extend east to the Nile system (Uganda–Sudan); and that of S. squamosum at least into the Zaire basin.

There are apparently no new data for S. damnosum s.l. from Angola, Chad, Equatorial Guinea, Mozambique, Rwanda, Somalia, Uganda, Zambia or Zimbabwe; the complex is found in all of these countries. New data from the other countries are listed below.

Burundi. S. kilibanum is present in rivers south of Bujumbura.

Cameroon. The complex is widespread both in the northern (savanna) and southern (forested) areas; the mid-west and far north have not been fully investigated. The existence of S. damnosum s.s., S. sirbanum, S. mengense, and S. squamosum, has been confirmed. There are unexpectedly wide north-south distributions of some taxa: S. damnosum s.s. extends to the forested south (Kumba), and S. squamosum and S. mengense far into savanna north (8° 38' N).

Central African Republic. The complex is widespread in the north-flowing Chari system headwater rivers of the west and north and across the south from Bangui to Bangassou in rivers flowing south to the Zaire (Congo) river. The existence of S. damnosum s.s., S. sirbanum, S. mengense, S. squamosum, and “Bole” has been confirmed; the S. squamosum subcomplex occurs in the Zaire basin rivers and upper Oubam river, the others are all confirmed in the north-west. The situation in the east and north-east is unknown.

Congo. S. squamosum is found in the Congo and Djoué rivers.

Ethiopia. The complex has a widespread but patchy distribution over much of the country (at least to 13° N and 40° E), not confined to the onchocerciasis endemic area of the south-west (many
Fig. 3. Approximate known distribution of *Simulium damnosum* s.l. (shaded areas)*

*Solid line indicates the areas in which members of the complex are anthropophilic and can be expected to act as onchocerciasis vectors; broken lines indicate additional range over which the complex is zoophilic.*
Fig. 4. Pre-control ranges of *Simulium damnosum* s.s. and *S. sirbanum* in West Africa.

*Broken lines indicate limit of forest plus forest/savanna mosaic.*
populations are assumed to be zoophilic). Three chromosomal taxa are recorded, “Jimma” (presumed vector) in the south-west, “Kulfo” and “Kisiwani” elsewhere.

_Gabon._ S. damnosum s.l. has been found in the Ogooué river system.

_Kenya._ No onchocerciasis; many populations of the complex are zoophilic. Four chromosomal taxa have been confirmed, and new isoenzyme studies show diagnostic differences between Western/Nyanza and Mt Kenya populations, that probably correlate with cytotype identity (“Nkusi” in western Kenya, “Mutonga” or “Kisiwani” around Mt Kenya).

_Liberia._ The complex is widespread throughout the country. The distributions are characteristic of West African forest; the _S. sanctipauli_ subcomplex and _S. yahense_ are widespread; and there are intrusions of savanna _S. damnosum_ s.s. into northern areas.

_Malawi._ The complex is widespread, but its complete distribution has not yet been studied and mapped. A current project focuses on the Thyolo Highlands endemic area, where breeding distribution has
Fig. 6. Pre-control ranges of *Simulium yahense* and *S. squamosum* in West Africa*

"?" = identification whether *yahense* or *squamosum* not certain

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*Broken lines indicate the limit of the forest plus forest/savanna mosaic.*
been mapped. The existence of three cytospecies in the Thyolo area has been confirmed—a “Ketaketa” group sibling from the Lintchip river, and “Nyamagasani” (= *S. kilibanum*) and “Sanje” siblings from the Nkudzi river.

**Nigeria.** The complex is widespread over the greater part of the country. The existence of several cytospecies is confirmed: *S. sirbanum*, *S. damnosum* s.s., *S. squamosum*, and the *S. sanctipauli* subcomplex. Distributions are essentially analogous to those of the same cytospecies in the area covered by the Onchocerciasis Control Programme. *S. sirbanum* and *S. damnosum* s.s. occur in the northern savanna; *S. squamosum* is widespread in the forest-savanna mosaic/forest area, especially south and west of the Niger river on the Jos Plateau fringes, and also east of the lower Niger; the *S. sanctipauli* subcomplex occurs mainly south and east of the Niger river (with isolated reports from the north).

**Sierra Leone.** The existence of *S. sirbanum*, *S. damnosum* s.s., *S. squamosum*, *S. yahense*, and the *S. sanctipauli* subcomplex, including a new sibling species designated *S. soubrense* “B” has been recently confirmed. *S. sirbanum* and *S. damnosum* s.s. are found in the extreme northern savanna area; most other cytospecies are widespread in the essentially forested remainder of the country; *S. soubrense* “B” is found in the forested south and west.

**South Africa.** There is no onchocerciasis, and the *S. damnosum* complex populations are zoophilic. Unpublished work indicates the existence of at least 3 sibling species differing in chromosomal inversions from any of those previously known.

**Sudan.** In the Abu Hamed and the south-western foci, *S. damnosum* s.s. and *S. sirbanum* have been recorded. The cytospecies of the eastern foci have not been determined.

**Swaziland.** Recently, the *S. damnosum* complex has been found in this country. Larvae from the Usutu river have different chromosomal banding patterns from South African siblings.

**United Republic of Tanzania.** The complex has a restricted focal distribution in an arc-like chain of upland areas from the eastern Usumbura Mountains (Amani area) near the Kenya border in the north-east to Tukuyu near the Malawi and Mozambique borders in the extreme south. Two named species, *S. kilibanum* and *S. mengense*, and 11 unnamed siblings or cytotypes have been recorded with varied distributions. Recent work has been confined to the Tukuyu focus. The cytospecies situation remains unclear, although the “Sanje” sibling has been identified there.
North Yemen. The complex has a scattered distribution in perennial west-flowing wadis from at least 15° 11′ N (Wadi Surdud) in the north to 13° 16′ N (Wadi Barakani) in the south. Only one cytotype has been recognized, and this does not conform to any African mainland taxon. There is as yet no evidence that the vector occurs in Saudi Arabia and Southern Yemen, although suitable ecological conditions may exist.

Zaire. The complex is widespread in all areas of the country. The S. squamosum subcomplex has been confirmed both near and 200 km to the north-east of Kinshasa. Nine putatively new species based solely on morphology have been described. These are S. microlepidum, S. maertensi, S. repertum, S. wambanum, S. luadiense, S. nganganum, S. buisseti, S. juxtapamosum, and S. kilibanum. Such premature formal descriptions, that do not include cytotaxonomic evidence, elucidate nothing and create confusion.

(b) Bionomics. Most recent work outside the countries covered by the Onchocerciasis Control Programme (Burundi, Cameroon, Central African Republic, Congo, Liberia, Malawi, Sierra Leone, Sudan, Tanzania, Yemen, Zaire) focuses on transmission, vector identification, and control feasibility surveys. There has been little investigation of "bionomics" per se, and knowledge of S. damnosum s.l. biology outside the Control Programme countries and the Sudan has therefore not altered much since the last Expert Committee report (18).

The most relevant point, therefore, is the significance for other areas of the findings from the countries covered by the Control Programme.

(i) Aquatic stages. Little that is significant to control has been published recently on the bionomics of the aquatic stages of the S. damnosum complex. The food of blackfly larvae, the fine structure of the mouthparts, and the biophysics of filter-feeding have been studied in detail. Although these studies have been done mainly on North American species, they have implications for the control of vectors. Studies of the speed of development of aquatic stages have supported earlier findings. However, in Mali, S. sirbanum may pass only 5 or 6 days in the larval stage, and this could make a weekly dosing periodicity inadequate.

Larvae that are suitable for cytotaxonomic identification and adults that can be reared from captured, blood-engorged females using a simple and effective technique developed by the Onchocerciasis Control Programme.
This technique has been valuable in studies on migratory behaviour and in helping to refine methods of identifying females of different cytospecies. Some success has also been achieved in colonizing the “Beffa” form through as many as five generations.

(ii) Adults. The main advance made in vector biology during the past ten years has been in the field of migratory behaviour (see section 15).

Host location and selection by *S. damnosum* s.l. is still not well understood, although studies in Cameroon and Côte d’Ivoire have shown that flies in forested areas are attracted to man primarily by scent and exhaled breath, whereas those in savanna areas probably rely more on visual clues. Different members of the *S. damnosum* complex in West Africa may exhibit considerable degrees of zoophily and this can have an important influence on vector efficiency. Even within a cytospecies, the degree of zoophily is probably highly labile; for example, both *S. sirbanum* and the *S. sanctipauli* complex become more zoophilic at the northern limit of their ranges.

*Simulium damnosum* s.l. from the Control Programme area exhibits complete gonotrophic concordance, and recent findings suggest that the gonotrophic cycles take 3–6 days, with the first cycle being slightly longer, since there is a time-lag between emergence and the first bloodmeal. Thus, under normal circumstances, the cycle is always shorter than the developmental period of *O. volvulus* in the fly. Earlier studies suggesting differences in the behaviour of nulliparous and parous flies have been confirmed by findings made by the Control Programme. In particular, it is clear that nulliparous flies take bloodmeals much further away from rivers than do parous flies, especially those old parous flies that have apparently migrated long distances.

Female *S. damnosum* s.l. are known to rest briefly in riverine vegetation just prior to oviposition, and flies of both sexes can be found low down in the riverine vegetation during periods of eclosion. Presumably long-distance migrants rest very close to the breeding site between oviposition and the next bloodmeal. From studies using non-attractant sticky traps it has been established that both sexes, and most physiological stages, may be found at all heights in the riverine vegetation close to breeding sites. Confirmation of the location of resting sites has come from spraying riverine vegetation with insecticides for the control of tsetse flies, and from experimental adulticiding targeted against *S. damnosum* s.l.
Gravid flies exhibit strong positive phototaxy and have been caught in large numbers in light traps. The effectiveness of aluminium plate traps is presumably because the gravid flies are sensitive to the glint of “white water” when they are seeking areas for oviposition (see also section 12.5.5).

Fly fecundity is related to size, age, and possibly the level of parasitism. During the first gonotrophic cycle from 500 to 900 eggs may be laid. The number of eggs produced in subsequent cycles drops substantially, but attempts to use this as a way of determining the age of fly populations in Côte d’Ivoire could not be reproduced. There is some evidence to suggest that infection with *Onchocerca* spp. reduces vector fecundity. Observations on the decline of biting populations of flies following the introduction of larviciding support earlier estimates that the longevity of *S. damnosum* s.l. females is usually not more than 4 weeks in the wild. However, studies of the movement of waves of migrating flies suggest that maximum longevity may be around 6–7 weeks.

(c) Vector–parasite relationships and transmission. All known West African species of the *S. damnosum* complex are able to transmit *O. volvulus* (however, *S. dieguerense* has not been studied).

Under experimental conditions, the most efficient vectors, both in terms of the proportion of flies that become infective and the parasite load that develops in them, are, in order of importance, the *S. sanctipauli* subcomplex, *S. yahense*, *S. squamosum*, *S. damnosum* s.s., and *S. sirbanum*. However, under natural conditions there are great variations within and between species. These differences are determined by numerous factors, in particular longevity, host preferences, and relative abundance of hosts. Nevertheless all these species are capable of maintaining annual transmission potentials that are regarded as unacceptable at least in terms of savanna onchocerciasis. In ideal conditions, the highest loads of infective larvae for a given number of biting flies occur in forest populations of *S. yahense*, followed by members of the *S. sanctipauli* complex at low latitudes, and to a far lesser extent by *S. squamosum*. *S. damnosum* s.s. and *S. sirbanum* have the lowest loads.

Although knowledge of the comparative vector potentials of the different members of the *S. sanctipauli* subcomplex is incomplete, and requires further study, it is clear that at the northern limits of their range in Burkina Faso, Côte d’Ivoire, Ghana, and Mali the ability of members of this subcomplex to act as vectors declines markedly.
The migratory populations of *S. damnosum* s.s. and *S. sirbanum* that seasonally invade the controlled savanna areas of the Onchocerciasis Control Programme are perfectly capable both of establishing themselves there and of transmitting the local parasite. However, there is evidence that some migrating populations are non-anthropophilic.

(d) **Vectors and epidemiological characteristics.** In West Africa it is customary to make an implicit association between the clinical and parasitological patterns of onchocerciasis and bioclimatic zones by referring to savanna onchocerciasis and forest onchocerciasis. Foci of “savanna type” (with heavy microfilarial loads and associated high rates of serious ocular lesions and blindness due to onchocerciasis, and with lack of settlement in the main valleys) are only very exceptionally found south of latitude 7–8° N. The savanna area north of 8° N is the domain of *S. sirbanum* and *S. damnosum* s.s. and locally of small foci of *S. squamosum*; and, with the exception of a few unusual concentrations, especially in the rainy season, the *S. sanctipauli* subcomplex does not appear to play a significant role as a vector. South of 7° N the *S. sanctipauli* subcomplex, and *S. yahense* predominate as vectors.

In West Africa and across to the Sudan, no foci of “savanna type” onchocerciasis are known that are not associated with the presence of *S. sirbanum* and *S. damnosum* s.s. On the other hand, foci of “forest type” onchocerciasis are always associated with transmission by the *S. sanctipauli* subcomplex and/or *S. yahense* in West Africa, or with *S. squamosum* and *S. mengense* in Cameroon.

Nevertheless, where the forest merges gradually into the savanna (6–8° N) there is a wide zone in which foci of blinding hyperendemic onchocerciasis do occur, although the blindness rates are not usually as high as in the true savanna and the relationship between microfilarial loads and the frequency of serious ocular lesions is less clear. The “savanna-dwelling” and “forest-dwelling” vector species populations that coexist in this intermediate zone are each separately capable by virtue of the annual transmission potential that they maintain, of accounting for the observed level of disease severity. Unfortunately there is, at present, no way of telling which of the putative forms or strains of *O. volvulus* the different vector species are transmitting in the wild in this zone.

In Togo, this intermediate zone extends to the southern limit of the distribution of the *S. damnosum* complex, and it reaches to the north of the eighth parallel of latitude on the Black Volta, in Côte
d'Ivoire and Ghana and along the tributaries of the Upper Niger in Guinea. In these places, the *S. sanctipauli* subcomplex per se maintains levels of transmission that must be regarded as unacceptable in terms of savanna onchocerciasis, irrespective of the annual transmission potentials of the "savanna-dwelling" species (*S. damnosum* s.s. and *S. sirbanum*) associated with it in the same areas.

(e) *Onchocerca volvulus*–*Simulium* complexes. There is much evidence concerning the heterogeneity of *O. volvulus* as a species.

The existence of very high annual transmission potentials (sometimes 6–30 times greater than those in the worst savanna foci) associated with typically forest forms of onchocerciasis is well known. It shows that the severity of the disease in relation to the eyes is not due to a greater intensity of transmission in savanna than in the forest. This lack of relationship between the annual transmission potential and the seriousness of the disease in forest and savanna, that was discovered originally in Cameroon has now been confirmed throughout West Africa.

Poor experimental parasite yields have been found in some species of the *S. damnosum* complex, after ingesting microfilariae of *O. volvulus* strains whose geographical origin differs from that of the vector, and this suggests that local parasite strains adapt genetically to the autochthonous vector species. Incompatibilities that were observed in Cameroon between vector–parasite pairs of the savanna and the forest have been confirmed in West Africa. Experimentally, the savanna-dwelling vector species effect very poor transmission of forest strains of *O. volvulus*, while *S. yahense* is a poor transmitter of savanna-dwelling strains of parasites. On the other hand, West African savanna *O. volvulus* seems to develop in species of the *S. sanctipauli* subcomplex as easily as the autochthonous forest strains.

All the facts—preferential transmission by certain vectors, differential experimental pathogenicity, different enzymatic and immunological reactions—provide evidence in support of the plurality of the parasite. Although it appears premature to think in terms of an *O. volvulus* "complex", it is certain that different vector–parasite complexes do exist.

The only way to resolve this confusion is by the reliable identification of vector–parasite pairs. There have been great advances in vector identification during the last few years, even if there are still some gaps in knowledge concerning the identification
of individual biting insects. However, once the female vectors have been identified, the more crucial problem remains the identification of the parasite strain(s) and forms; in this area there has been little progress. The question of "which vector transmits which parasite" is more topical than ever as part of the Onchocerciasis Control Programme and the capability to identify the strain or form of each *O. volvulus* parasite is urgently needed. Such identifications are needed for the microfilariae and adult worms in man and, above all, for the infective larvae in the vectors.

11.1.2 *Simulium neavei* group

(a) Taxonomy and distribution. The *S. neavei* group includes all simulids in which the larvae and pupae live in a phoretic association on river crabs. The group contains nine described species and some forms of uncertain taxonomic status.

The structural uniformity of members of the *S. neavei* group and the lack of any cytological or enzymatic studies, makes the identification of potential vector species especially difficult. The larval cuticular microsculpture can be used to differentiate taxonomically most members of the group. Since cytotaxonomy has increased our understanding of the *S. damnosum* complex, special efforts should be made to correlate the present taxonomy of the *S. neavei* group with cytotaxonomic investigations.

The *S. neavei* group occurs widely but sporadically in Africa from Ethiopia southwards to Malawi and westwards through the Zaire river basin to Cameroon and Liberia (Fig. 7). No vector species extends into West Africa. In many foci *S. neavei* s.l. and *S. damnosum* s.l. occur together and act in conjunction as vectors. This happens in the foci of eastern Zaire, the central highlands of Tanzania, southwestern Ethiopia, and two or three areas in Uganda. In such foci the *S. neavei* group species tend to be of greater relative importance at the higher altitudes within the transmission area.

A few foci are maintained entirely by *S. neavei* group vectors, notably the Mount Elgon and Bugoma foci of Uganda, where *S. neavei* s.s. is the only vector, and the Usambara (Amani) focus in Tanzania, where *S. woodi* is responsible for transmission.

(b) The situation in individual countries.

*Ethiopia*. Although exact data are lacking, *S. ethiopiense* probably maintains a moderate level of continuous transmission in the high-
Fig. 7. Geographical distribution of the *Simulium neavei* group.

*Solid lines enclose the known localities with vector species. Open circles outside these lines indicate localities with non-vector species (unpublished map produced and made available by Dr R.W. Crosskey).*
lands of south-western Ethiopia, overlapping with *S. damnosum* s.l. at intermediate altitudes.

**Kenya.** Kenya is unique in having eradicated the vector of onchocerciasis. *S. neavei* s.s. is believed to have been the sole vector of the disease in Kenya and its eradication from 40000 km$^2$ in western Kenya by DDT larviciding was virtually complete by 1956. The subsequent disappearance of onchocerciasis is well documented. Some restricted breeding of *S. neavei* s.s. continues on the Kenya flank of Mount Elgon but no cases of onchocerciasis have been reported there recently.

**Malawi.** The *S. neavei* group species *S. nyasalandicum* and *S. woodi* were originally discovered in Malawi. They were little studied until 1960, by which time *S. woodi* (a vector in the United Republic of Tanzania) had become uncommon in the locality, probably as a result of deforestation.

**United Republic of Tanzania.** *S. damnosum* s.l. is the main vector of onchocerciasis in Tanzania except in the Usambara and Nguru Mountains where the *S. neavei* group alone is responsible for transmission. Within most transmission areas in the southern highlands, where *S. damnosum* s.l. predominates, there are localities where anthropophilic *S. neavei* group species probably contribute to transmission. *S. woodi* is the vector in the Usambara Mountains. Elsewhere in the country man-biting members of the *S. neavei* group may be a form of *S. nyasalandicum* or an undescribed species. *S. neavei* s.s. has not been reported in Tanzania.

**Uganda.** *S. neavei* s.s. has been identified in 7 onchocerciasis foci situated within the periphery of Uganda. In all 7 areas, except possibly Ruwenzori, it has been found to contribute to transmission. In the Budongo Forest focus near Masindi, *S. neavei* s.s. was apparently eradicated by 1962 by a process of attrition. In the Mount Elgon, Bugoma Forest, Imatong Mountains, and possibly West Nile foci, *S. neavei* s.s. is the only known vector. The forest above Bufumbo on Mount Elgon is the most intense *S. neavei* s.s. biting area in Uganda.

**Zaire.** In eastern Zaire, man-biting populations of *S. damnosum* s.l. and *S. neavei* s.l. are of widespread importance and both groups of vector appear to contribute to transmission in most areas. The *S. neavei* group vector has in most cases been identified as *S. neavei* s.s. although in some areas its identity has not been ascertained. Large tracts of land remain to be surveyed in detail and other vectors in the group may yet be found.
Zambia. Man-biting *S. neavei* s.l. have been collected in Zambia where the presence of endemic onchocerciasis is suspected but as yet unproven.

(e) Bionomics. The three main vector species *S. neavei* s.s., *S. ethiopiense*, and *S. woodi* breed in heavily shaded, small to medium-sized permanent streams passing through forest or woodland. The species depend heavily on the dense vegetational cover over the streams. Deforestation leads to the disappearance of these vectors or to a decrease in population density. The number of man-biting *S. woodi* in the Usambara Mountains in the United Republic of Tanzania has been falling for many years, probably because deforestation has exposed forest streams thus making them less suitable as breeding sites.

The oviposition sites of the *S. neavei* group are unknown and need to be located. The eggs are not laid directly onto crabs, nor have first instar larvae been found on crabs. The larvae are mostly small or medium-sized when they reach the crab. The most frequent larval attachment sites are the sides of the crab, the limb bases, and the eyesockets. Several species of crab of the genus *Potamonauta* are involved, but the relation is not host-specific, nor is the localization of the *S. neavei* group restricted by the lack of crab partners since the crabs are widely distributed. Larval development is slow, and small newly-attached larvae of *S. woodi* require 26–72 days to reach the pupal stage.

Although little is known about the dispersal of *S. neavei* group females, the flight range is known to be much more limited than that of *S. damnosum* s.l. *S. neavei* s.s. bites mostly in forest areas, while *S. woodi* prefers forest clearings. Little is known about the degree of zoophily of the *S. neavei* group of vector species. Man is the only known host of *S. woodi*, but infective filarial larvae other than *O. volvulus* have been found in *S. neavei* s.s. biting man in Uganda, suggesting that there are alternative animal hosts.

11.1.3 Other vectors in Africa

The long-suspected vectorial role of *S. albivirgulatum* has recently been confirmed for the “Cuvette centrale” focus in Zaire. This species also occurs in Zambia.
11.2 Guatemala and Mexico

11.2.1 Blackfly species and onchocerciasis

Knowledge of the distribution and role of the vectors of the disease in Guatemala has increased, while there is little new information on the transmission of onchocerciasis in Mexico (see Table 6).

<table>
<thead>
<tr>
<th>Focus</th>
<th>Simulium species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guatemala, Mexico</td>
<td>1. <em>S. ochraceum</em></td>
</tr>
<tr>
<td></td>
<td>2. <em>S. metallicum</em> s.l.</td>
</tr>
<tr>
<td></td>
<td>2. <em>S. callidum</em></td>
</tr>
<tr>
<td>Colombia</td>
<td>1. <em>S. exiguum</em> s.l.</td>
</tr>
<tr>
<td>Ecuador</td>
<td>1. <em>S. exiguum</em> s.l.</td>
</tr>
<tr>
<td>Venezuela</td>
<td></td>
</tr>
<tr>
<td>Carpe &amp; Altamira</td>
<td>1. <em>S. metallicum</em> s.l.</td>
</tr>
<tr>
<td></td>
<td>? <em>S. exiguum</em> s.l.</td>
</tr>
<tr>
<td>Brazil/Venezuela</td>
<td></td>
</tr>
<tr>
<td>highland areas</td>
<td>1. <em>S. guianense</em> (pinto) p</td>
</tr>
<tr>
<td></td>
<td>? <em>S. limbatum</em> (incrustatum, yarzabali)</td>
</tr>
<tr>
<td>lowland areas</td>
<td>1. <em>S. oysapockense</em> s.l. (amazonicum,</td>
</tr>
<tr>
<td></td>
<td>cuastasanguineum,</td>
</tr>
<tr>
<td></td>
<td>minusculum,</td>
</tr>
<tr>
<td></td>
<td>sanguineum)</td>
</tr>
</tbody>
</table>

*1 = primary vector; 2 = secondary vector; ? = suspected vector.
*Includes other names given to the species in the literature.

Of the 45 blackfly species known to occur in Guatemala, 8 were found to be anthropophilic in the endemic areas (*S. ochraceum, S. colvini, S. horacoi, S. callidum, S. haematopotum, S. metallicum, S. gonzalezii*, and *S. veracruzanum*). *S. ochraceum* is considered to be the principal vector of *O. volvulus* in Guatemala and Mexico, because it is highly anthropophilic, reaches highest biting densities in the endemic areas, bites the upper parts of the body where microfilariae are most numerous, and shows the best survival rate after infection with *O. volvulus*. Natural infections assumed to be due to *O. volvulus* were found in *S. ochraceum*, while infective larvae probably of animal origin were only present in *S. metallicum* and *S. callidum*. Infection rates of *S. ochraceum* were highest in the dry season, when transmission is most intensive. *S. ochraceum* is also abundant in some areas where onchocerciasis does not occur; whether this can be explained by the existence of non-vector siblings of *S. ochraceum*, is being investigated. *S. ochraceum* was the only
target of the pilot control scheme performed from 1979 to 1984, but the possible role of the other anthropophilic species as secondary vectors, should not be ruled out completely.

11.2.2 **Bionomics and distribution of S. ochraceum in relation to control**

Breeding sites of *S. ochraceum* are distributed in mountainous terrain at altitudes of 500–1500 m. Immature stages are found in streams with a water discharge of less than 50 l/s, but mainly in smaller streams with less than 10 l/s. Larvae are sometimes even found in minute streams with a discharge of 0.1 l/s. Maximum densities of *S. ochraceum* are recorded at water velocities of 50–60 cm/s and a depth of less than 1 cm. The fine distribution of *S. ochraceum* breeding has been studied in relation to geological features.

Biting of *S. ochraceum* occurs throughout the day with two peaks, the higher of the two in the morning and the lower in the afternoon. The gonotrophic cycle was found to be 3–4 days at an altitude of 650 m, while *O. volvulus* completed its development to the infective stage within 8–9 days. At an elevation of 1480 m, and by means of mark-release recapture experiments carried out in the rainy season, the gonotrophic cycle of *S. ochraceum*, including the host-seeking and oviposition phases, was also 3–4 days. However, the development of *O. volvulus* was estimated to require about 11 days under these conditions. Thus *S. ochraceum* would normally have completed 3 gonotrophic cycles before reaching the epidemiologically dangerous age and, at the earliest, would transmit the infection only when coming for its fourth bloodmeal.

11.3 **South America**

Little is known about the bionomics of vectors of onchocerciasis in South America. The reasons for this are the low public health importance of the disease and the inaccessibility and recent discovery of some of the foci.

11.3.1 **Proven vectors**

The following species are proven vectors of onchocerciasis in South America (see Table 6).
(a) *S. exiguum* s.l. is widespread in South America, from Colombia and Venezuela in the north to Argentina and Bolivia in the south (Fig. 8), and it occurs in all the foci of onchocerciasis. It is a species complex in Ecuador consisting of at least three cytotypes. It is the primary vector of onchocerciasis in the Santiago focus in Ecuador, the only vector in Colombia, and a presumed sporadic vector in the northern Venezuelan focus. In Ecuador, the high transmission potential is reflected in high natural infection rates and the rapid appearance of parasite transmission in new onchocerciasis foci resulting from the migration of infected Amerindians from the main focus of infection. *S. exiguum* s.l., like other Latin American vector species, ingests large numbers of microfilariae when feeding. This can cause the death of the fly, particularly in species that lack a cibarial armature (*exiguum* s.l., *guianense*, *metallicum* s.l.). *S. exiguum* s.l. bites man, but may also bite large domestic animals, and in some localities total zoophily occurs. Larvae and pupae of *S. exiguum* s.l. are typically found in the middle reaches of large rivers and their tributaries (wider than 5 m), attached to submerged vegetation in deeper parts of the rivers and in shallow water running over shingle beds. *S. guianense* (close to or synonymous with *S. pintoi*) has a wide distribution from southern Venezuela to southern Brazil and also occurs in the Guyanas (Fig. 9). It is a natural vector of *O. volvulus* in the Brazil/Venezuela onchocerciasis focus. Its predominance (with *S. limbatum*) in the mountainous (mainly hyperendemic) localities of the focus suggest that it is the primary vector of onchocerciasis in this region. It is only a sporadic vector in the lowland localities because of its low anthropophily. Immature stages are typically found on emergent vegetation in large fast-flowing rivers, but in the Brazil/Venezuela onchocerciasis focus the breeding grounds of the anthropophilic form have not been found.

(b) *S. metallicum* s.l. is common in Latin America, some Caribbean Islands, the Andes as far south as Ecuador, and in the northern coastal belt of Venezuela (Fig. 9). In Latin America *S. metallicum* is known to be a complex of at least 3 sibling species. *S. metallicum* s.l. is the only proved vector of onchocerciasis in the northern Venezuelan foci of Altamira and Caripe. At low microfilarial intakes it is an efficient vector of *O. volvulus*, but its efficiency decreases when higher microfilarial intakes increase fly mortality. Larvae are found on submerged vegetation in small streams.
Fig. 8. Known distribution of *Simulium ochraceum* and *S. exiguum* in Latin America and the Caribbean Islands.

**Key:**
- S. ochraceum
- S. exiguum
- Primary vector
- Secondary or suspected vector

Areas of proved or suspected transmission are shaded darker. Key to the onchocerciasis foci of Latin America: Mexico: Oaxaca (1); North Chiapas (2); Guatemala: South Chiapas (3); Huehuetenango (4); Yepocapa (5); Venezuela: Altamira (6); Caripito (7); Amazonia (8); Brazil: Amazonia (8); Colombia: San Antonio (9); Ecuador: Esmeraldas (10); North Chiapas and San Antonio are no longer active foci (see section 2).
Fig. 9. Known foci of *Simulium metallicum* and *S. guianense* in Latin America.

Key:

- S. metallicum
- S. guianense
- Primary vector
- Secondary or suspected vector

*Areas of proved or suspected transmission are shaded darker. For key of onchocerciasis foci see Fig. 8.
Fig. 10. Known foci of *Simulium quadrivittatum* and *S. oyapockense* in Latin America and the Caribbean islands.

Key:
- S. quadrivittatum
- S. oyapockense
- Primary vector
- Secondary or suspected vector

*Areas of proved or suspected transmission are shaded darker. For key of onchocerciasis foci see Fig. 8.*
(c) *S. oyapockense* s.l. is one of the commonest anthropophilic species of the lowland forests and savannas of the Amazon and Orinoco basins of Colombia, Brazil, and Venezuela and is also present in the Guyanas (Fig. 10). Female *S. roraimense* are indistinguishable from female *S. oyapockense* s.l. and, because of their sympatry in the Brazil/Venezuela onchocerciasis focus, references to *S. oyapockense* s.l. include *S. roraimense* as well. *S. oyapockense* s.l. is the only significant vector of onchocerciasis in the lowland forested areas of the Brazil/Venezuela focus. Biting occurs on all exposed parts of the body with a slight preference for areas above the waist.

(d) *S. quadrivittatum* is a Latin American species, and has only been recorded in South America from the coastal lowlands of Ecuador, west of the Andes (Fig. 10). It is a natural vector of *O. volvulus* in Ecuador where, because of its low biting rate, it plays a secondary role to *S. exiguum* s.l. at the end of the wet season. This species breeds in small shaded forest streams on submerged plants and debris.

11.3.2 Suspected vectors

*S. exiguum* s.l. may act as a sporadic vector in lowland areas of the Brazil/Venezuela onchocerciasis focus. In the highland areas of the same focus the only species that is suspected of significantly contributing to transmission is *S. limbatum*. This species is commonly found throughout Venezuela, the Guyanas, and northern Brazil (Fig. 11). It is a suspected vector because of its high anthropophily in the focus.

11.4 Suggestions for further study

(a) Study further the taxonomic status and biology of Latin American vectors.

(b) Study the cytology of the *S. neavei* group.

(c) Investigate all aspects of the behaviour of fly populations caught on adhesive plate traps, well inside controlled areas (in the absence of man-biting).

(d) Study further the integration of human ecology with the assessment of epidemiological dynamics.

(e) Study the clines of host-feeding preference in vector species in relation to their distribution.
Fig. 11. Known foci of *Simulium callidum* and *S. limbatum* in Latin America

Key:
-  S. callidum
-  S. limbatum
-  Secondary or suspected vector

*Areas of proved or suspected transmission are shaded darker. For key of onchocerciasis foci see Fig. 8.*

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(f) Investigate the effectiveness of the biconical tsetse trap for the capture of *S. damnosum* s.l.

(g) Develop traps for anthropophilic female *Simulium* that are searching for bloodmeals.

12. VECTOR CONTROL

12.1 Methods of control

12.1.1 Larviciding

Control methods against onchocerciasis vectors have been directed almost entirely against *Simulium* larvae by treating their breeding sites with insecticides. Adult populations are difficult to control because of their broad dispersal and the wide variety of their resting sites, about which little is known.

The formulations of the insecticides that are used for large-scale campaigns have to satisfy a wide range of requirements. They must be highly effective against the vectors, but must be safe for the rest of the environment. Each formulation must be specially devised for blackfly control, the supply of the insecticide must be guaranteed over a long period of time, and the cost kept as low as possible. Biodegradable constituents are required but there must also be maximum carry downstream from the point of application. In addition, since the vectors are under constant insecticide pressure in very extended control zones, alternative larvicides must be available, preferably belonging to different chemical classes, so that any resistance to one or more compounds can be dealt with promptly.

1. Temephos. After the first control campaigns that used organochlorines, in particular DDT, the organophosphorus compound temephos has become the preferred larvicide. A 20% emulsifiable concentrate of temephos has been specially developed for *Simulium* control and has been widely used in Africa, especially in the Control Programme area. Experience has shown that formulation plays an important role in the efficiency and selectivity of the active ingredient. Each formulation has to be carefully adapted to suit different ecological conditions. In West Africa, temephos is applied at a dosage of 0.05 mg/l for 10 min in the wet season and at 0.1 mg/l in the dry season. During the wet season the carry of the formulation is 20–40 km downstream from the
application point. When the water-levels are low, the carry is reduced, and the vector breeding sites have to be treated individually.

In Guatemala, slow-release, solid formulations and water dispersible powders have been used against *S. ochraceum*.

2. *Chlorphoxim*. Following the local development of resistance to temephos by some members of the *S. damnosum* complex in West Africa and Cameroon, a 20% emulsifiable concentrate of the organophosphorus compound chlorphoxim was chosen as an alternative. Although this formulation is less selective than temephos, it has proved to be operationally acceptable.

3. *Bacillus thuringiensis serotype H-14*. This control agent, which is specific for Diptera, has very little impact on the non-target fauna. It is in operational use by the Onchocerciasis Control Programme although formulations are not yet ideal because of the high dosages required. Nevertheless substantial improvements in formulation have already been achieved and more are in prospect.

4. *Permethrin and carbosulfan*. Permethrin (pyrethroid) and carbosulfan (carbamate) are both in operational use by the Control Programme, although they are less selective as regards the non-target invertebrate fauna than the organophosphates discussed above.

5. *Insect growth regulators*. Another group of compounds that seem to be promising for the control of onchocerciasis vectors is insect growth regulators, that inhibit the production of chitin. Small-scale field trials have already been carried out with such agents and some of them have been found to be effective against blackfly larvae.

12.1.2 *Adulticiding*

Helicopter spraying of gallery forests with deltamethrin to control tsetse flies also reduced the blackfly population. Because of this success, the use of adulticide treatment has been considered as a means of destroying reinvading blackflies (see section 15.1.1). Experimental applications of permethrin by helicopter have been carried out in the Mô basin in Togo, but the results were inconclusive.
12.1.3 Biological control

1. *Bacillus thuringiensis* serotype H-14. This is a spore-forming bacterium that produces a crystal of toxic protein that is a stomach poison for blackfly larvae. It is already in operational use by the Control Programme (see section 12.1.1 paragraph 3).

2. **Insect pathogens.** Microsporidia, entomophagous fungi, and mermithids have all been found in blackflies, including some vector species. These pathogens certainly act as natural agents to control the blackfly density. They have been studied as potential control agents, but no convincing results have been obtained.

12.1.4 Environmental management

Dams constructed for power-generation or large-scale irrigation schemes can reduce the current speed of water for long distances and this can eliminate *S. damnosum* s.l. breeding. However, the cost of and justification for such constructions go far beyond the problem of onchocerciasis, the control of which is no more than a positive spin-off from such development programmes.

The construction of small hillside dams, causeways, irrigation channels, etc., that bring breeding places of vectors close to human populations, constitutes a real threat and contributes to the spread of onchocerciasis. Such artificial breeding sites, should be removed when they are no longer needed or are broken.

For the *S. neavei* group, well-developed gallery forests are necessary. This characteristic can be used to plan the control strategy, as was clearly demonstrated when *S. neavei* was eliminated by selective bush clearance in the onchocerciasis focus at Riana, Kenya. Therefore, properly planned resource management and land utilization may offer one way of controlling members of the *S. neavei* group. Such methods need to be used with caution to avoid exacerbating the disastrous soil erosion that is already taking place in many areas.

12.1.5 Integrated control

"Integrated vector control can be considered as the utilization of all appropriate technological and management techniques to bring about an effective degree of vector suppression in a cost-effective manner" (15).

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For onchocerciasis this concept assumes a wider significance and requires the availability of several control methods, e.g., medical approaches, such as chemotherapy and noduletomy, combined with techniques aimed at the vector. At present, vector control is entirely based on the use of chemical or biological larvicides. Until now the integrated control of the vectors has been a matter of necessity when insecticide resistance has developed and biological agents have been used seasonally; or it has come about fortuitously, when large dams built for power-generation have eliminated blackfly breeding sites over long distances.

The development of effective drugs suitable for the large-scale treatment of onchocerciasis, and better formulations of chemical and biological larvicides for *Simulium* would allow the integration of techniques and resources and the use of chemotherapy in association with vector control.

### 12.2 Control programmes

#### 12.2.1 Review of control programmes

About 50 onchocerciasis vector control schemes have been carried out. With a few exceptions they were not successful, because the areas under control were too small or the projects were not sustained for long enough to have much impact on the disease. However, a few projects have been extremely successful and, in some cases, have even led to the eradication of the vector.

Eradication of *S. neavei* s.s. has been achieved in five schemes, four in Kenya and one in Uganda. Success was probably due to the very specialized larval habitat of this species and the relatively small and isolated nature of the foci.

On the Victoria Nile at Jinja, Uganda and on the Congo river at Kinshasa (then Leopoldville) and Inga, Zaire, control campaigns using DDT were strikingly successful. The precise reasons for these lasting successes remain unclear.

In West and Central Africa several control projects were carried out from 1955 in Burkina Faso, Chad, Côte d'Ivoire, Ghana, Mali, Nigeria, and Sierra Leone. The tactics and strategy developed from some of these projects permitted the successful launching of the Onchocerciasis Control Programme, which is described in section 15 of this report.
12.2.2 Control of *S. ochraceum* in Guatemala

A vector control project was started in 1979 in the small focus of San Vicente Pacaya, Guatemala. Initially, temephos in a solid, slow-release formulation was applied every 2 weeks. From 1982 this procedure was changed to fixed dosing with 24 g of 5% water-dispersible powder in every 50–100 m stretch of breeding stream, irrespective of water discharge. The area under control was gradually increased, eventually covering about 90 km². Thanks to very careful planning and dedicated field-work this control strategy resulted in epidemiologically significant reductions in biting rates.

12.3 Suggestions for further study

(a) Develop insecticide formulations that suit the larval habitats of different vector species.

13. METHODS FOR THE ASSESSMENT OF ONCHOCERCIASIS, ITS TRANSMISSION, AND ITS CONTROL

13.1 Medical assessment

13.1.1 Parasitological methods

Parasitological methods are still the most frequently used techniques to assess the prevalence and severity of onchocerciasis. Based on the 10-year experience provided by the epidemiological surveys carried out by the Control Programme and various chemotherapeutic trials, some improvements have been made in these techniques. It must be remembered that parasitological methods may fail to detect prepatent and some early or light infections. They are, therefore, of limited use in assessing the onset of transmission or the early recrudescence of infection.

(a) Adult worms. The detection of nodules is of limited use for establishing the diagnosis of onchocerciasis since some people, especially those who are lightly infected, do not have detectable nodules. This method may therefore have a low sensitivity but, because of its specificity and ease of application, may be of great use for the rapid preliminary assessment of infection at a community level. The presence of nodules in patients living in areas where
transmission has been interrupted for several years is less conclusive since these nodules may contain only dead worms.

(b) Microfilariae. Evidence of the presence of *O. volvulus* microfilariae in the skin is the method most frequently used to determine prevalence and intensity of infection. Corneoscleral punches are most commonly used to take bloodless skin snips in epidemiological, research, and chemotherapeutic studies. Of the various punches available, the 2-mm Holth punch is still the preferred model for large-scale use in the field because it is cheaper than other models and robust; the Walser punch has advantages for research studies. There are disadvantages in the use of all punches when compared with the use of a needle and razor blade to obtain skin snips. These include their cost and the need for both sterilization and resharpening. However, the use of punches may be less painful and threatening to the patient than a razor blade and, in practised hands, may give more uniform biopsies. For the precision required in epidemiological or chemotherapeutic research studies, all biopsies should be weighed.

Any instrument that is reused to collect skin snips must be adequately sterilized after each patient. Instruments should be soaked in 2% glutaraldehyde for 10 minutes and then rinsed twice in clean water and dried before use.

It is important that the microfilariae recovered are distinguished from those of *Mansonella streptocerca* in areas where the distribution of this parasite overlaps with that of *O. volvulus*.

The preferred site for obtaining skin snips is the pelvic girdle, usually below the iliac crest from which at least one snip should be taken on each side. This is true not only for Africa but also for America. Sensitivity is improved by taking additional snips. In Africa, South America, and Yemen, these should be taken from the calf. In Guatemala and Mexico, additional snips should be taken from the shoulder region—usually over the scapula. Further improvement in sensitivity can be obtained by taking 6 snips (from the shoulders, iliac crests, and calves of each side of the body). Snips may be taken near the outer canthus of the eye since these may provide an indication of ocular involvement, but this site is not recommended for general use.

For routine epidemiological assessment, skin snips should be incubated for 24 hours in isotonic saline before being transferred to glass slides for microscopic examination to detect and count the microfilariae present.
The following method is given as an example of a repeatable and quantifiable method of assessing microfilarial density in the skin during the course of chemotherapeutic trials. Six skin snips are taken from each patient at each examination, one each from the scapula, iliac crest, and calf on each side of the body using a Holth punch. First, the skin is prepared with an alcohol swab and allowed to dry completely. The punch is sterilized with 2% glutaraldehyde after each patient and is well rinsed and dried before use. The snips are kept in a moist chamber until all 6 snips from a patient have been collected and then each of them is weighed. Snips weighing less than 1 mg are discarded and an additional snip is taken. Each snip is then immersed in about 0.1 ml of isotonic saline solution (or in tissue culture medium) in a separate well of a microtitration plate. The plate is covered and stored at ambient temperature in a high humidity atmosphere. Microfilariae are counted 24 hours later using a microscope. Results from each snip are expressed as the number of microfilariae per mg of skin, and the geometric mean of the figures for the 6 snips is then calculated and used as the measure of intensity of microfilarial infection.

The use of collagenase to digest the skin snip makes it possible to count the total number of microfilariae contained in that snip. The time required for complete digestion of the tissue is at least 48 hours. When compared to incubation in saline for 24 hours, the use of collagenase increases the sensitivity of this test significantly only in patients with very low parasite loads. However, the collagenase technique can be useful for the examination of a limited number of snips such as when monitoring drug efficacy or for other research purposes. Collagenase digestion can be performed on ethanol-fixed material stored at ambient temperature (17).

The presence of microfilariae in the urine is easy to detect technically in the field by filtration through a membrane or by simple sedimentation and centrifugation. However, this technique cannot be considered to have any diagnostic value since microfilariae are almost exclusively found in the urine of heavily infected persons and infrequently in light to moderate infections. The presence of *O. volvulus* microfilariae can occasionally be demonstrated in the peripheral blood. In such cases a differential diagnosis has to be made to distinguish the infection from other filarial infections.

(c) **Collagenase digestion of excised nodules.** The technique of collagenase digestion was developed recently, and has been used routinely by the Onchocerciasis Control Programme to study the
dynamics of the declining adult worm population in areas under vector control. This method has also been used extensively in chemotherapeutic studies to assess the effects of drugs on adult worms and embryogenesis.

13.1.2 Diagnosis and assessment of ocular onchocerciasis

The following steps should be followed during the detailed assessment of ocular involvement.

(a) Visual acuity. Visual acuity at distance should be tested using an illiterate E or Landolt ring. Each eye should be tested independently using distance spectacle correction if normally worn. Pinhole correction should be used in those with reduced acuity. Visual acuity should be recorded according to the accepted levels of impairment (ICD–9).

(b) Visual fields. Visual fields have been less frequently tested routinely in field studies, but should at least be assessed in individuals who exhibit other signs of ocular involvement.

Peripheral visual fields may be readily assessed by confrontation testing. The examiner should sit facing the patient approximately 50 cm away, and each eye is then tested independently comparing the field of the patient to the field of the examiner. A red target (approximately 8 mm in diameter) on the end of a wand is brought from outside the visual fields towards fixation and the patient is instructed to report as soon as the colour red is seen. The visual field should be assessed in the vertical, horizontal, and oblique (45° and 135°) meridians.

If more sophisticated visual field-testing equipment and an experienced tester are available, they may be used to advantage provided that patient cooperation can be ensured.

(c) Detection of intraocular microfilariae

(i) Anterior chamber. First the patient must sit with his head down for at least 2 minutes and is then examined using a slit-lamp. The procedure of ocular massage cannot be standardized and therefore is not recommended. The anterior chamber is carefully scanned with an intense oblique beam and the total number of microfilariae seen is counted.

(ii) Cornea. Next the cornea is carefully examined for intracorneal microfilariae using high magnification (×25). Live microfilariae have a transparent hyaline appearance and are usually coiled. They are best seen by retroillumination produced by an oblique beam of
light, using either the red reflex through the dilated pupil or the light reflected from the iris. Dead microfilariae are more opaque and lie straightened out. They are therefore easier to see by direct illumination. The total number of live and dead microfilariae in the cornea should be recorded and their location charted.

(d) Punctate keratitis. Onchocercal punctate keratitis appears as small, “fluffy” corneal opacities approximately 0.5 mm in diameter that must be differentiated from other corneal opacities such as those caused by viral infections or corneal foreign bodies. The number of punctate opacities should be recorded.

(e) Sclerosing keratitis. The earliest change observed in sclerosing keratitis is increased haze of the peripheral cornea without frank opacification. This is frequently associated with pigment migration onto the cornea which, however, is a nonspecific sign and may result from many other conditions. Sclerosing keratitis can be usefully graded according to the extent and degree of stromal opacification from early peripheral opacification up to the final involvement of the central optical zone.

(f) Limbitis. Limbitis is most often seen after microfilaricidal drug treatment. It is assessed by slit-lamp examination and is observed as dilation of the limbal vessels, limbal oedema, and the formation of small, white globular opacities at the limbus. Episcleritis may also occur after drug treatment.

(g) Anterior uveitis. Inflammation in the anterior chamber should be assessed by slit-lamp examination and the intensity of “flare” and cells should be recorded.

(h) Intraocular pressure. Intraocular pressure should be measured routinely in patients over 30 years of age. A Goldman applanation tonometer is the preferred instrument for this, although other instruments may be used.

(i) Dilated fundus examination. The pupils of both eyes should be dilated (1% tropicamide and 5% phenylephrine are the preferred drugs for this). When the pupil is fully dilated, direct and indirect ophthalmoscopy should be performed. Particular attention should be paid to the optic disc for any signs of optic neuritis or optic atrophy. The macular areas and the peripheral retina should be examined in detail for intraretinal deposits, retinal pigment epithelial changes, areas of chorioretinitis, and other chorioretinal changes. Any fundus abnormalities should be documented on a diagram of the retina. For more detailed examination of the retina, a contact lens examination can be performed on the slit-lamp. Careful colour
photography of the fundus may be essential to provide an objective record of the changes seen. Fluorescein angiography may be necessary to reveal the extent and severity of certain early lesions.

13.1.3 Immunological methods

Immunological diagnostic methods are still at the laboratory stage of development and can not yet be used for the field assessment of infection or for control.

The highest priority has been given to the development of assays that allow the detection of early infection (preferably in the prepatent period), since it is particularly important to have a test available that will reveal new infections in an area under vector control. Other important, but less critical uses of immunodiagnostic techniques might be to: (a) detect recent exposure to infective larvae (i.e., estimate the intensity of transmission or the effectiveness of vector control programmes); (b) monitor the success of chemotherapy (i.e., assess activity against adult worms or developing larvae); and (c) estimate the intensity of infection in individual patients.

Unfortunately, no effective immunodiagnostic test is available for any of these purposes.

13.1.4 Summary of medical diagnostic methods

The advantages and disadvantages of the various actual and potential diagnostic methods available for assessing the medical aspects of onchocerciasis control programmes are summarized in Table 7.

13.1.5 Endemicity levels in onchocerciasis

The level of endemicity of onchocerciasis has already been mentioned several times in this Report. Previous definitions of endemicity levels have been given in the Second Report of the WHO Expert Committee on Onchocerciasis (9) and in the Report of a WHO Expert Committee on the Epidemiology of Onchocerciasis (18). However, the present Report has used the following set of definitions that apply specifically to the West African savanna zone and cannot be used universally. These definitions are useful in that
Table 7. Diagnosis of onchocerciasis: advantages and disadvantages

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parasitology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection of microfilariae</td>
<td>Simple, fast, quantitative</td>
<td>Useless in prepatent infections</td>
</tr>
<tr>
<td>in the skin</td>
<td></td>
<td>Low sensitivity in early or mild infections and variability in counts</td>
</tr>
<tr>
<td>Presence of nodules</td>
<td>Head nodules are a risk factor for ocular onchocerciasis</td>
<td>Low sensitivity</td>
</tr>
<tr>
<td><strong>Ophthalmology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection of microfilariae</td>
<td>Estimates the risk factors for ocular pathology</td>
<td>Complicated method</td>
</tr>
<tr>
<td>in the eye</td>
<td>Indicates the intensity of infection</td>
<td>Special equipment needed</td>
</tr>
<tr>
<td>Diagnosis of eye lesions</td>
<td>Assesses the severity of the disease</td>
<td>Specialized training required</td>
</tr>
<tr>
<td><strong>Immunology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antigen or antibody assay</td>
<td>Detection of infection is simple and sensitive</td>
<td>Appropriate reagents not yet available</td>
</tr>
<tr>
<td></td>
<td>Detects exposed individuals with prepatent infections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assesses infection intensity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Detects transmission</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Facilitates accurate monitoring of chemotherapy by assessing fate of adult</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or developing worms</td>
<td></td>
</tr>
</tbody>
</table>

they relate the degree of endemicity to clinical and socioeconomic manifestations, rather than to prevalence of microfilarial infection.\(^1\)

(a) **Hyperendemicity** is characterized by the presence of more than 60% *Onchocerca volvulus* microfilaria carriers in the population and an average of more than 10–15 microfilariae per skin snip. In savanna areas, such a percentage of carriers is generally accompanied by demonstrable ocular microfilariae in 20% of patients, and with irreversible eye lesions in more than 10%. Blindness rates under these circumstances can exceed 10% representing a 50% blindness rate in males over 40 years of age. In this situation the very survival of rural communities is at risk, valleys are often unoccupied, and the disease is socially intolerable.

(b) **Hypoendemicity** is when the prevalence rate is below 40% and the disease has no social effects. Under these circumstances, fewer


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than 10% of the population show ocular microfilariae and fewer than 2.5% have irreversible eye lesions. The blindness rate due to onchocerciasis is generally below 1%.

(c) Mesoendemicity is between these two limits, where the prevalence rate is over 40% but less than 60%. Many different epidemiological and human ecological factors may substantially modify the impact of onchocerciasis. The definition of mesoendemicity is mainly negative: it is a situation where the disease is socially recognizable, but has not yet reached a level that is intolerable to the community.

13.2 Entomological assessment

13.2.1 Objectives

Entomological assessment methods are required to carry out research and surveys in all onchocerciasis areas and they are vital for the smooth operation of control programmes. In control programmes this type of assessment has four objectives:

(a) To provide pre-control data or determine: (i) the identity, distribution, and abundance of vectors; (ii) their susceptibility to operational larvicides; (iii) the intensity of transmission (annual transmission potential).

(b) To evaluate the immediate effects of the insecticide treatment (or other approach) on the aquatic and adult stages of the vector(s).

(c) To provide up-to-date information on the physical state of the rivers so that insecticide application techniques and dosages may be adapted accordingly.

(d) To measure the effect of control methods on annual biting rates (ABR) and annual transmission potentials (ATP).

13.2.2 Information required

The information obtained should show the seasonal distribution, plotted on maps, of the breeding sites of all vectors. Adult fly data should provide biting and parous rates and transmission indices for all vector species for each month; these data should be collected at a sufficient number of sites, to represent effectively the region covered by the scheme and the surrounding area. If possible, separate data should be obtained for each species involved. Samples of larvae, pupae, and adult flies should be preserved to provide a
reference collection. If a laricide is to be used, then hydrological data will be required to provide the seasonal and total annual discharge for each river. Regular checks must be made on insecticide susceptibility levels.

13.2.3 Techniques employed

(a) Searches for aquatic stages. Pupae and larvae can be collected from submerged vegetation, sticks, dead leaves, and rocks in fast-flowing rivers or from artificial substrates. Special crab traps are needed to monitor the *S. neavei* group. Collection sites should be varied from time to time to give the greatest possible fluvial coverage. Representative samples of larvae should be preserved in Carnoy’s fixative for cytotaxonomic determination. Adults may be reared from pupae for morphological and biochemical studies.

(b) Vector collections. This technique, which allows the calculation of annual transmission potentials, is the most important means of determining the success of a vector control operation during the first 5 or 6 years, before human parasitological parameters have changed significantly.

Catching points should be chosen in collaboration with the epidemiological assessment unit. These points are normally sited at the river bank or at another place where biting flies are known to accumulate. *S. damnosum* s.l. catches are usually made from 07 h 00 to 18 h 00 regularly throughout the year to avoid bias caused by seasonal changes in daily activity for both nulliparous and parous flies. Normally two vector collectors catch for alternate hours. In Guatemala, for *S. ochraceum*, catches have been made from 09 h 00 to 12 h 00 and fly rounds have been used to assess control. All catches are usually segregated and recorded by hour, together with a note on rainfall and cloud cover; and the flies are kept cool until they can be identified and dissected. In the Onchocerciasis Control Programme this method has proved both reliable and extremely sensitive for the assessment of vector population fluctuations.

(c) Identification and dissection for parity and parasites. Samples from each hour are identified and dissected to determine the parous rate; for this the indicators used are the state of the ovaries, Malpighian tubules, and fat body. (The presence of nulliparous *S. damnosum* s.l. usually indicates the presence of breeding within 20 km of the point of capture. The presence of meromithid worms usually indicates nulliparity and local origin.) Parous flies are then
examined further to detect possible infection with *O. volvulus*. The stage and number of the parasites and their location in the body of the fly are recorded. An atlas of all third-stage filarial larvae that have been found in blood-sucking arthropods, and which belong to the family Onchocercidae, is in preparation.

A careful examination has to be made to distinguish infections due to other filariae that are morphologically different from *O. volvulus*, since this will indicate the zoophilic behaviour of the flies. Records should be kept of all other parasites found in the flies, e.g., mermithids, other nematodes, and fungal infections of the ovaries.

13.2.4 Transmission indices

The basic index for expressing adult *Simulium* biting densities is the monthly biting rate (MBR).

\[ MBR = \frac{\text{No. of flies caught} \times \text{No. of days in the month}}{\text{No. of catching days}} \]

The basic index for expressing the level of transmission of *O. volvulus* infective larvae (L₃) is the monthly transmission potential (MTP) calculated from larvae found during dissection.

\[ MTP = \frac{\text{MBR} \times \text{No. of } O. \text{ volvulus } L₃ \text{ larvae in the head}}{\text{No. of flies dissected}} \]

The annual biting rate (ABR) is the sum of the 12 monthly biting rates for the year and the annual transmission potential (ATP) is the sum of the 12 monthly transmission potentials.

When calculating annual transmission potentials some workers have counted all ineffective-stage larvae (L₃) wherever they are found in the fly; therefore, it is best to differentiate between the ATP value when only head larvae have been counted (ATP(H)) and the ATP when all larvae have been counted (ATP(A)).

The periodicity of catches has to be determined with regard to the length of the life cycle of the vector, season, reinvasion, etc.

13.2.5 Use of traps

As mentioned earlier, capture by vector collectors permits the collection of anthropophilic females in search of a host and is at present irreplaceable for evaluating the intensity of transmission.
However, it is not adequate for ecological research and necessitates a large staff. Considerable research has been carried out on trapping, with the aim of reducing the number of vector collectors and exploring the bionomics of adult blackflies.

Adhesive-covered aluminium plates positioned near the sites of oviposition are particularly efficient in catching gravid flies. In the dry season in West Africa, such plates have often yielded more flies than are caught by vector collectors, and sometimes they detect the presence of flies when catches on man are negative, possibly because non-anthropophilic females are involved. In northern Nigeria and Mali, vehicle-mounted net traps have been found to catch large numbers of S. damnosum s.l. including many engorged flies. Identification of the bloodmeals has permitted conclusions to be drawn regarding the host preferences of the flies. Modified tsetse-traps have been used successfully to catch large numbers of the S. sanctipauli subcomplex and S. yahense in forest areas. Many other types of trap have been tested, and some have proved useful for different purposes.

13.2.6 Methods of detecting insecticide resistance

(a) Aquatic stages. A test for resistance of larvae of the S. damnosum complex has been developed, that can be performed in the field. The larvae are placed in contact with the insecticide for 3 hours in preoxygenated stagnant water. The mortality reading is made directly on completion of the exposure time. Discriminative dosages can be determined for the rapid detection of specimens suspected of being resistant.

(b) Adult flies. Methods under study show that a close correlation exists between adult resistance and that of the larvae. These methods are based either on the topical application of microdrops or on placing the flies in contact with surfaces coated with insecticides. Resistance can be detected in adults at times of the year when collection of larvae is difficult. It should also be possible to test susceptibility to certain adulticides, such as the pyrethroids.

13.2.7 Precise identification methods

Most research on taxonomy and methods of identification of vectors has been concentrated on the S. damnosum complex, especially in West Africa. The taxonomy of New World vectors is
still at an early stage, as is that of the *S. neavei* complex in East and Central Africa.

(a) Chromosomes. The larvae of the members of the *S. damnosum* complex can be distinguished by the cytological identification of polytene chromosomes, although in Central and East Africa the taxonomic status of members of the complex needs to be clarified. Identification of banding patterns on the polytene chromosomes uses simple techniques, but requires skill and is time consuming. Only the larval stages can be used for routine identification. Although recent advances in the preparation of adult polytene chromosomes have been made, the technique requires that the flies used are at a precise physiological stage and thus it is unlikely to become a routine method of identification.

(b) Morphology. Identifications based on morphological features are the most practical for use in the field. However, since many of the sibling species are virtually isomorphic, the conventional morphological criteria are of limited value. Certain characters have proved to be useful in the field, but may not be consistent throughout the range of the species and consequently need to be used with caution.

(c) Biochemistry. The biochemical techniques that have been used for the identification of *Simulium* species are enzyme electrophoresis, gas liquid chromatography of cuticular hydrocarbons, and DNA-DNA hybridization techniques.

(i) Enzyme electrophoresis. Enzyme electrophoresis was the first biochemical technique to be applied. However, speciation in the *S. damnosum* complex does not appear to have been accompanied by a wide divergence of enzyme variants, and investigation of 44 enzyme systems has revealed only 2 that are of diagnostic value. *S. yahense* can be distinguished from the other West African *S. damnosum* s.l. by a unique phosphoglucomutase variant; and *S. squamosum* and *S. yahense* can be separated from other members of the complex on the basis of their trehalase enzyme variants. To date little work has been done on East African blackflies. A preliminary investigation indicated that the enzymes phosphoglucomutase and xanthine dehydrogenase may be useful in distinguishing members of the *S. damnosum* complex from Tanzania, and there is a recent report of allozyme differences in populations of the *S. damnosum* complex from Kenya. Enzyme electrophoresis is a relatively simple technique that does not require much in the way of sophisticated equipment and it can be carried out on larvae, pupae
or adults. Its major limitation is that most enzymes are very unstable and the samples must be preserved alive in liquid nitrogen.

(ii) Gas–liquid chromatography analysis. The first application of gas–liquid chromatography to the analysis of cuticular hydrocarbons made it possible to separate individual females of *S. squamosum* and *S. sirbanum*. Recent work with this technique and mass spectrometry has succeeded in separating individual adults of four species of the *S. damnosum* complex, i.e., *S. damnosum* s.s., *S. sirbanum*, *S. sanctipauli* subcomplex, and *S. yahense*. Although the equipment required is expensive and highly sophisticated, the collection and preparation of samples is very simple. Dead, dried specimens in glass tubes, or even pinned flies, can be stored for years without loss of activity. The technique still needs to be evaluated on allopatric populations, but already it shows potential for the *S. damnosum* complex and could be important in studies on New World vector complexes.

(iii) DNA hybridization. The analysis of DNA represents the most direct way of determining genetic variation that is possible and it is thus very attractive as a tool for specific identification. Recent work has resulted in the isolation of 3 cloned DNA sequences (pSO3, pSO11, pSO1) that can be used, in combination, to separate individual adult flies into one of three groups: *S. squamosum*, *S. yahense*, *S. sanctipauli* subcomplex, and *S. sirbanum*. Other species have yet to be examined and the probes evaluated on geographically separate populations.

The collection of material for DNA analysis is simple, the flies being preserved in propanol at ambient temperature. Larvae, pupae, and adults can be identified and more than 100 flies a day can be analysed. The limitation to the application of DNA probes in the field is in the handling of radioactive reagents and the short life (3 weeks) of *32*P-labelled DNA probes. However, with the present enormous activity in DNA research it is probable that during the next 2 years non-radioactive methods of labelling DNA will be developed.

13.3 Socioeconomic assessment

In onchocerciasis control schemes, socioeconomic monitoring has four objectives:

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(a) to provide reliable pre-control data on occupancy of land, demographic situation, human ecology, and economic and cultural specificities;

(b) to evaluate the intervening changes in location and size of existing villages, in density and pattern of land occupancy, in professional activities, and in forms and modes of production;

(c) to evaluate demographic dynamics, emergence of new settlements, and bringing land into cultivation;

(d) to provide up-to-date information on sociocultural trends that are related to onchocerciasis control.

Data under item (a) are relevant for the initial planning of the scheme. Items (b) and (c) will allow the effect of the control to be assessed in terms of public health welfare, especially after several years of control. Item (d) will serve to answer questions asked by epidemiologists about the ongoing control of disease, as well as the concerns of planners dealing with problems of resettlement and patterns of land use.

13.3.1 Information required

Precontrol information should show the spatial characteristics of human ecology plotted on maps. This may require the use of teledetection and/or documentation by aerial photographs of the following:

—location, size, and housing density of settlements;
—utilized and non-utilized land;
—concentration or dispersion of cultivated lands;
—cropping patterns.

In the early stages of a control scheme, small-scale investigations are important for validating the above data and preparing an appropriate epidemiological survey.

Postcontrol information requires:

—evaluation of the changes in the above characteristics (using the same methodology);
—more detailed monitoring at the community level through a sample of localities chosen in agreement with entomologists and epidemiologists.
The purpose of these two approaches is to permit a progressive analysis to be made of the overall impact of control, as well as its effects on specific problems, such as blindness.

As a rule, the results of vector control rapidly become apparent; the epidemiological consequences take longer to become detectable, and the socioeconomic impacts will manifest themselves much later.

13.3.2 Methods and techniques employed

In matters of social (or economic) change, both quantitative and qualitative methods have to be used. A quantitative analysis is necessary, to provide indices or rates of change in land occupancy, and to assess their evolution every 5 years. However, for the assessment of changes in the economy, macroanalyses may lead to simplistic conclusions and are not satisfactory when the elements to be aggregated show marked heterogeneity. The same is true of sociological inquiries. In both instances, quantitative global analyses have to be complemented by more detailed qualitative micro-economic and microsociological (anthropological) case studies.

Means of data collection include large surveys using questionnaires, individual contacts through group discussions, and single or repeated interviews. Means of data interpretation range over a wide spectrum:

— at the macrolevel, the exploitation of maps, indices, and rates requires the application of geographical, economic, demographical, and statistical tools (with computing support);
— at the microlevel, the techniques of participant observation and intensive interviews, often using audiovisual aids, contribute significantly to the process of assessment and evaluation of onchocerciasis control programmes.

Whether applied at the macro- or micro-level, the above quantitative and qualitative methods and techniques have to be implemented by trained scientists who must cooperate closely with entomologists and epidemiologists.

13.4 Suggestions for further study

(a) Determine at what stage of infection a person is first capable of acting as a transmission source and whether this occurs before microfilariae can be detected in skin snips obtained in a routine way.
(b) Develop preservation techniques for flies that would permit age-grading and examination of parasites.

c) Develop novel vector age-grading techniques, appropriate to the field situation that would facilitate the entomological evaluation of control programmes.

d) Develop traps for anthropophilic female flies that are searching for bloodmeals in order to reduce the number of vector collectors and hence costs.

e) Improve methods for distinguishing different members of *Simulium* species complexes, particularly at the adult stage.

(f) Perform qualitative enquiries that complement quantitative socioeconomic assessments.

14. SOCIAL AND ECONOMIC ASPECTS OF ONCHOCERCIASIS

Epidemiological studies on onchoceriasis have shown that individuals and communities living under apparently similar conditions of transmission exhibit different clinical manifestations that may in part be related to the pattern of human settlements, agricultural practices, and occupational activities.

This means that it is of primary importance to take account of social, behavioural, and economic factors when evaluating the effects of the disease and measures for its control. The following are some of these factors and they are all interrelated: human ecology, systems of land use, environmental modifications, economic organization of the area, sociocultural patterns, and demographic dynamics (including migration).

Hence, in addition to more usual entomological and epidemiological studies, an analysis of this complex of behavioural and socioeconomic factors must also be carried out before, during, and after any onchoceriasis control operation.

14.1 Human behaviour and transmission

While rates of transmission can be used to estimate the maximum risk incurred by the human population in areas of endemic onchoceriasis, additional information is needed to characterize man–vector contacts (i.e., frequency and duration of exposure to *Simulium*). For the epidemiological evaluation of an onchoceriasis
focus it is necessary to know the distribution and mobility of human populations, which means establishing movements and changes in density according to season and functional space, as well as taking sex and age group into account. This kind of population dynamics is linked to the system of land use, including the type of economic production, the type of dwelling, and the social division of labour.

Factors that limit man–vector contact within an area at risk include:

— greater distance from the breeding sites;
— a large human population relative to the maximum production of vector *Simulium* from the local breeding sites;
— a human population living in compounds alongside their livestock, which may attract *Simulium* to feed on animals, thereby limiting their contacts with man;
— specific occupations; e.g., the disease may be less severe among women and children if their daily activities are traditionally confined to the immediate neighbourhood of the houses and do not extend to sites of high transmission;
— the use of protective clothing.

The combination of the opposites of these factors will inevitably result in higher transmission, e.g., small villages located beside watercourses and close to breeding sites; desertion of the fields close to the village and cultivating farms near breeding sites; other occupations carried out near breeding sites; small settlements with scattered dwellings.

As a general rule, the more extensive the area of land cultivated by a community (giving a very low man to land ratio), the more intense will be the transmission; but in such situations, the location of the cultivated land in relation to breeding sites has to be taken into account. If there is no other land left for cultivation, the population may have to cultivate hitherto neglected land near the river; or economic incentives may compel them to grow certain crops close to the watercourse, e.g., rice, maize, tubers. In addition, a more intense transmission of onchocerciasis may be associated with a low density of workers, small production units, widely scattered plots, the cultivation of crops such as sorghum, and long periods of exposure to a vector that normally bites at the same time of day and during the same seasons that farmers are working.
14.2 Demographic correlates of onchocerciasis

14.2.1 Population density and community survival

In communities in the West African savanna, the percentage of persons blind from onchocerciasis is related to the number of inhabitants per km$^2$ of land used by the community. Starting from the assumption that the higher the human population density, the more transmission is diluted by “bite-sharing”, there are interesting correlations in the Red and White Volta basins. If population density exceeds 50 inhabitants per km$^2$ of used land, there are very few villages where more than 5% of the people are blind, whereas villages with densities below 35 inhabitants per km$^2$ of utilized land frequently exhibit blindness rates that are higher than 5%. However, these correlations cannot be extrapolated to all areas since there are many combinations of human and vector populations in terms of size, dispersion, distribution, mobility, and duration of exposure. In the Bourgouriba valley, for example, or elsewhere with very high outputs of flies from local breeding sites, villages with 100 inhabitants per km$^2$ of used land may exhibit blindness rates of 5% or more. Nevertheless, it would appear that relatively densely populated communities are better able to support life in highly endemic onchocerciasis zones. Thus, if there is a threat of resurgence of *O. volvulus* transmission following the cessation or breakdown of a vector control scheme (such as the Onchocerciasis Control Programme), it might be reasonable to suggest that any resettlement (spontaneous or planned) in controlled areas should aim at giving a population density, in terms of land used, that will be greater than 50 persons per km$^2$, so as to reduce individual risk of severe infection.

14.2.2 Blindness and its social consequences

Blindness is the major complication of onchocerciasis that makes the disease a public health problem. Blindness may affect a great many persons in communities where onchocerciasis occurs, and produces permanent and irreversible disability, particularly in West African savanna areas. Blindness strikes mainly at economically-active adults in the prime of life; it is the direct cause of substantial excess mortality and the indirect cause of a stagnation or decline in the population of communities. Eventually it may even result in villages and lands being abandoned.
Recently, a great deal of information about the epidemiology of blindness due to onchocerciasis has become available as a result of a series of studies in the area covered by the Onchocerciasis Control Programme on determinants, incidence, cohort-effects, longevity and mortality, and demographic and economic consequences.

(a) Incidence rate of blindness, age at onset, and age at death. From official census figures, the blindness incidence rate has been calculated for a population of 50000 people living in the Bougouriba focus of Burkina Faso. The annual blindness incidence rate ranges from 4 to 7 cases per 1000 persons in areas where onchocerciasis is hyperendemic, from 1 to 2 cases per 1000 persons in mesoendemic areas, and from 0.4 to 0.6 cases per 1000 persons in hypoendemic areas. In the hypoendemic areas the incidence of blindness could be attributed almost entirely to causes other than onchocerciasis and was compatible with the blindness prevalence rate observed in Burkina Faso outside the onchocerciasis foci, i.e., 0.3–0.5% of the resident population. The incidence of blindness is also compatible with the finding by the Control Programme ophthalmology team that 80% of blind persons observed in 1975 from a sample of 759 people in a hyperendemic area were blind because of onchocerciasis, i.e., a prevalence rate of 0.8–1.4 per 1000 attributable to causes other than onchocerciasis.

From the same study it was possible to calculate the average age at the onset of blindness, the age of death, and the average life expectancy after becoming blind. Blindness occurs 5–10 years earlier in zones where onchocerciasis is hyperendemic and the differences between men and women become blurred as endemicity levels decrease. The life expectancy of the blind is always less than 10 years, regardless of their age at the onset of blindness.

If these results are accepted—a mean annual incidence rate of 4–7 per 1000, a mean age at onset of blindness of 39 years, and a remaining lifespan of 9–10 years—the prevalence rate observed in the affected communities should lie between 4% and 6%. This rate is not exceptional; in the surveillance sample composed by WHO for the evaluation of the Onchocerciasis Control Programme, one-quarter of the villages in Burkina Faso and one-third of the villages in eastern Mali had an age-adjusted blindness prevalence rate above 5%, with extreme values as high as 13%.

(b) Excess mortality in blind persons.

(i) Epidemiological consequences. Analysis of the very precise longitudinal surveillance data for the Control Programme sample
showed that mortality among blind persons over 30 years of age was 3-4 times higher than for non-blind persons in the same age group. In adults, blindness reduces life expectancy by at least 13 years, the excess mortality being associated with blindness and not with onchocerciasis itself. In subjects with no eye lesions, significant excess mortality has been demonstrated only in males with more than 100 microfilariae per skin snip (reading in distilled water after 30 minutes), but the rate is still 1.5 times lower than the excess mortality demonstrated in blind persons. On the other hand, blindness is a determinant of excess mortality in all populations, even those free from onchocerciasis. The explanation for this lies in the status of the blind person, in his economic and nutritional dependence, and because people find it difficult, or are reluctant, to give him effective assistance.

Excess mortality and high blindness incidence rates are evidence of the rapid renewal of the blind population. Most prevalence surveys reveal the stability of blindness rates over time, but for individuals it is different. For example, during a 9-year study in a village in the Bougouriba focus, the overall blindness rate remained unchanged, but 12 of the 16 blind persons identified during the first examination died during the study period.

This speed of renewal means that prevalence surveys do not fully reveal the devastating impact of blindness on a generation. If 5% of the population are blind at the time of a survey, many more of that population will become blind before they die. The probability that 15-year-olds will become blind before their death has been calculated in two different endemic situations. Where onchocerciasis is hyperendemic, with an annual incidence of blindness of 5.76 per 1000 as in the Bougouriba focus, an astounding 46% of males and 35% of females in this cohort will become blind before they die. In a mesoendemic situation, with a mean annual blindness incidence of 1.25 per 1000, the probability is reduced to 13% for males and 9% for females.

These observations mean that the extent and impact of blindness are always underestimated. The “snapshot” picture of reality given by epidemiological surveys is far removed from the much more severe situation revealed when blindness is placed in its true time perspective. It is bad enough when 5% of people in a village are blind but, to appreciate how desperate is the plight of such communities, it must be realized that this figure reflects a situation in which almost half the adult males and one-third of the females are doomed to go
blind. The figures are of course still higher in the villages where the blindness prevalence rate is 10–13%, as it was in some villages of the Volta basin prior to the start of the Onchocerciasis Control Programme.

(ii) Demographic consequences. A mean reduction in life expectancy of 13 years for 30–40% of the adult population is a major direct demographic consequence of the blindness caused by onchocerciasis. Nevertheless, studies of human geography carried out in the Volta basin have revealed additional indirect consequences.

A study of 77 villages in the Tumu district of Ghana showed that all those where the blindness rate exceeded 5% of the resident population had fewer than 200 inhabitants, and that the population of these villages had declined between 1921 and 1948. A recent review of the situation in the basin of the White and Red Volta south of Ouagadougou also produced similar results. In severely affected villages (blindness rates of 5% or more and fewer than 200 inhabitants), population growth was less than 1.8% per annum compared with the national average of 2.7%. Furthermore, those villages with the highest proportion of blind people exhibited an absolute population decline. This negative population growth results from the people's perception of an intolerable situation, with blindness and the risk of becoming blind threatening the survival of the community. A blindness prevalence rate of 4–5% seems to be the threshold beyond which the same demographic consequences are always seen, i.e., emigration by young people, low marriage rate and endogamy, falling birth rate, aging of the population, drop in production, economic stagnation, and inexorable social disintegration. The interaction of these factors in turn increases the proportion of blind among those few people remaining in the village and concentrates transmission of the disease among a smaller number of individuals, in whom the relative risk increases. The final stage is the abandonment of the village or the death of its last inhabitants, almost all of them blind.

14.3 Economic consequences of onchocerciasis

The economic consequences of onchocerciasis are most marked in heavily-infected communities living in the belt that extends across Africa below the Sahara in the sub-sahelian savanna. Here blindness rates due to ocular onchocerciasis may rise to 15% in some
communities and reach 40% of the adult male workforce. In these hyperendemic areas the life expectancy of the blind is reduced and a large number of other persons, although not yet blind, will suffer from severe visual loss due to onchocerciasis. Under such a degree of pressure from onchocerciasis, communities soon become unstable and the villages are abandoned.

One study (19) in such hyperendemic communities in the Hawal Valley in northern Nigeria, has shown how blindness and reduced vision, particularly among the adult male working population, are enough to interfere with farming activities. Although blind persons may not be idle and may be occupied in basket making, rope making, drawing water from wells, or even weeding farms by sense of touch, they are a handicap to themselves. Although their life expectancy is shortened because of their blindness, they survive long enough to become a burden to the community of sighted persons, who are obliged to concentrate their farming activities on the production of food crops at the expense of cash crops. The lack of cash crops leads to poverty, onchocerciasis-infected villages being generally poorer than those unaffected, and it is noticeable that individual family compounds tend to be poorer the earlier the compound head has become blind. These factors lead, in turn, to an emigration of young people from the village, away from poverty and the threat of blindness and they also discourage immigration; thus, an imbalance in the population results, with a disproportionate number of the old and the blind remaining. Depopulation of the community follows and the rate of this process is in direct proportion to the prevalence and severity of ocular onchocerciasis; the community becomes increasingly isolated and remote; the birth rate falls; the food-producing farms cannot be satisfactorily protected from the ravages of baboons, monkeys, and other wild animals; and this process of attrition leads eventually to desertion, an event that may be finally precipitated by some additional chance disaster, such as an epidemic of cerebrospinal fever or sleeping sickness.

In other parts of the world, where onchocerciasis is endemic but where the blindness rates are less alarming, the economic consequences of onchocerciasis are less striking and have not been so well recorded. In several countries, the debilitating effects of dermal and ocular onchocerciasis lead to considerable loss of working time by attendance at hospitals and clinics for treatment. Thus, working efficiency is reduced both directly and indirectly. These factors, and the fear of blindness, add to difficulties in
recruiting labour for various agricultural and other enterprises, especially those sited near rivers or in other places where infected *Simulium* vector biting densities are high. This applies to coffee and cardamom plantations in Guatemala and Mexico; cotton and oil-seed farming and coffee and timber production in Ethiopia; tea planting in Malawi; teak plantations and timber production in Sudan; and cocoa, coffee, and banana plantations, and aluminium production in Cameroon. In Nigeria, the threat of onchocerciasis in areas where large hydroelectric dams are to be built has meant that local *Simulium* control has been necessary to protect the construction work force. Finally, the occupations of river fishing, working river ferries, and digging sand from river beds for building purposes may all result in dangerously high levels of exposure to *Simulium*.

14.4 Economic benefits of onchocerciasis control

Desertion of villages and fertile land in the West African savanna zone (see section 14.2) was common in the area of the Onchocerciasis Control Programme before control started. Beneficial changes are now seen in the control area that result from 8–10 years of *Simulium* control, thus interrupting the transmission of *O. volvulus*, together with the ensuing planned or spontaneous resettlement and agricultural development. However, in the western extension area of the Control Programme, where control is due to start in 1986/1987, the effects of blindness, visual incapacity, general physical disability, and the “nuisance effect” of blackfly bites are still apparent. It has been estimated that in 1980 the population living in the onchocerciasis-endemic areas of Guinea Bissau, Guinea, western Mali, and Senegal was 5.39 million of whom 914,000 were infected with *O. volvulus* and 33,700 were blind.\(^1\) The annual loss of manpower due to onchocerciasis was estimated at 11 million working days or about US$ 9 million of potential production per year. The benefits to be expected from control are similar to those seen already in the original Onchocerciasis Control Programme area and will result primarily from:

(a) increasing the available manpower and raising its productivity, particularly in the primary sector (agriculture);  

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(b) exploiting the "new lands" freed from endemic onchocerciasis, for food and cash crops;

(c) improving the productivity of old lands that had previously been overexploited, leading to deterioration of the soil;

(d) improving the overall productivity of the population in the secondary and tertiary sectors (housing, handicrafts, dam construction, public works).

The cost-effectiveness of the Control Programme in Burkina Faso has been assessed and compared with that of measles immunization. This is a new approach and it assesses the number of healthy years added by preventing the permanent disability and premature death attributable to onchocerciasis. It also emphasizes the economic importance of health gains among productive individuals, discounting the costs and effectiveness over the 20-year life of the project. The cost of the Onchocerciasis Control Programme in Burkina Faso, in terms of blindness prevention alone, is US$ 20 per year of healthy life added; US$ 20 per productive year of healthy life added; US$ 150 per discounted year of healthy life added; and US$ 150 per discounted productive year of healthy life added. The corresponding figures for measles immunization in Côte d'Ivoire were US$ 10, US$ 20, US$ 49, and US$ 190. In terms of discounted productive years of healthy life added, onchocerciasis control is more cost-effective than measles immunization because blindness prevention results in an immediate gain of productive years, whereas the gain in productive years generated by measles immunization is deferred for 14 years (20). It should be noted that this analysis of the benefits of onchocerciasis control focuses on blindness only and excludes the additional health and economic benefits of preventing the much more common problems of partial visual impairment and other debilitating manifestations of onchocerciasis. If these could be included the cost-effectiveness of control would be even more marked.

14.5 Suggestions for further study

(a) Carry out socioeconomic studies, in onchocerciasis areas with and without control, on dynamics of settlement, situation of cultivated lands, and patterns of human behaviour in relation to epidemiological/entomological assessments.

(b) Research the social and economic implications of blindness.
15. THE ONCHOCERCIASIS CONTROL PROGRAMME

The Onchocerciasis Control Programme in West Africa (OCP) is presently (1986) operating in Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Guinea Bissau, Mali, Niger, Senegal, Sierra Leone, and Togo, all countries that had extensive areas of hyperendemic savanna onchocerciasis when field activities began in 1974. The Programme is a corporate undertaking of the 11 participating countries in West Africa and the Control Programme donor community (countries, foundations, and development banks) and four United Nations agencies (UNDP, FAO, the World Bank, and WHO) which together make up its governing body, the Joint Programme Committee (JPC). WHO is the executing agency with the World Bank as the financial trustee; scientific and technical advice is provided by an independent Expert Advisory Committee (EAC), and a Committee of the Sponsoring Agencies (CSA) provides managerial support.

The objective of the Programme is to eliminate onchocerciasis as a disease of public health and socioeconomic importance throughout the area covered by the Programme and to ensure that there is no recrudescence of the disease in the future, thus allowing the repopulation and development of those valleys previously almost deserted because of onchocerciasis.

Since large-scale chemotherapy is currently not feasible, because no effective and convenient drug without serious side-effects exists, the control strategy of the Programme is to interrupt the transmission of *O. volvulus* by the weekly application of rapidly biodegradable larvicides delivered by aircraft to all breeding sites of the savanna species of the *S. damnosum* complex; to carry this out over a sufficiently large area so as to counteract reinvasion by flies from outside; and to continue until such time as the human reservoir of microfilariae is eliminated, i.e., perhaps 15 years. The results of vector control are monitored by measuring the annual biting rates (ABR) and annual transmission potentials (ATP) and in terms of changes in the intensity, prevalence, and morbidity of onchocerciasis as assessed by epidemiological evaluation of sample populations.

The rationale behind the control strategy of the Programme is the belief that there are different forms of the parasite *O. volvulus* transmitted by different members of the *S. damnosum* vector complex, with only the savanna form being of real importance in blinding onchocerciasis. On this basis control is targeted against *S.*
*Simulium* s.s., *S. sirbanum*, and *S. squamosum*, as well as against *S. sanctipauli* subcomplex in areas where it is associated with the savanna species.

Since the last WHO Expert Committee Report on the Epidemiology of Onchocerciasis (J8), the operations of the Onchocerciasis Control Programme have been phased in to cover the originally planned area. Subsequently, the limits of the Programme have been redefined to include the whole belt of severe blinding onchocerciasis in the savanna west of Nigeria (Fig. 12).

Control activities have continued without interruption in the area covered by the Onchocerciasis Control Programme since February 1975 and they now cover an area of more than 750,000 km². Almost all the larvicide has been applied to breeding sites from helicopters and fixed-winged aircraft. During the wet season a fleet of 8 helicopters and one fixed-wing aircraft operate over 23,000 km of rivers. Temephos is at present the most cost-effective and the least environmentally damaging larvicide. It is still being used in more than 50% of the present Control Programme area. Following the development of resistance to this insecticide in some parts of the Programme area, first chlorphoxim and then *Bacillus thuringiensis* H-14 were introduced at certain seasons on some rivers.

To evaluate the efficiency of the control measures, a network of fly catching points is visited at weekly or fortnightly intervals by teams of two vector collectors, who work alternate hours from 07 h 00 to 18 h 00. Most of the catch is dissected and the effectiveness of control is judged by comparing daily, monthly, and annual biting rates and transmission potentials.

The Programme is also active in the field of socioeconomic evaluation in onchocerciasis controlled zones, in manpower training, and in a wide range of fundamental and applied research aimed at solving operational problems.

### 15.1 Problems encountered by the Programme

#### 15.1.1 *The Simulium damnosum s.l. reinvasion phenomenon*

It has long been known that *S. damnosum* s.l. is capable of travelling over great distances. With this in mind, the boundaries of the original Programme were set so that a large central area would be protected. When, in 1975, the Phase I area of the Onchocerciasis Control Programme (Fig. 12) was brought under control, the full...
Fig. 12: The Onchocerciasis Control Programme area
extent of the migratory abilities of *S. damnosum* s.l. became apparent. Initially, throughout the whole area in which breeding sites were treated there was a spectacular reduction in the number of biting flies. However, this success was short-lived. At the end of the dry season (March, April) of that year biting rates again rose considerably in large parts of the area, particularly in those river valleys located in the southwestern sector, and they stayed high until the end of the rainy season. It soon became evident that the flies were immigrants originating from breeding places outside the treated zone. The same phenomenon recurred every year and is referred to as “reinvasion”. To overcome the threat posed by reinvasion, the Control Programme made an exhaustive study of the phenomenon.

The vast majority of invading flies belonged to the 2 cytospecies *S. damnosum* s.s. and *S. sirbanum*; and practically all of them caught deep inside the area were parous. Furthermore, there was evidence that the proportion of old parous flies in the biting population rose with increasing distance from the boundary of the control area. Many of the invading flies carried infective larvae indistinguishable from *O. volvulus*.

From the beginning it was thought that reinvasion, with the concentration of fly populations in certain areas, was wind-supported and governed by the movements of the Inter-Tropical Convergence Zone (ITCZ), as had been described for other insect species. The main direction of movement of the migrating flies was from the south-west, the same direction as the prevailing monsoon winds.

The origins of the flies invading the western parts of the Control Programme area therefore had to be in regions to the south and west of the Programme area where *S. damnosum* s.s. and *S. sirbanum* were breeding profusely at the end of the dry season and during the wet season. In 1979, when the Control Programme was extended into southern Côte d’Ivoire (Phase IV, Fig. 12) to include all areas where savanna cytospecies were known to breed, the reinvasion was reduced to a very low level in most of those areas that had been invaded originally. However, an influx of flies was still observed along the Léraba river in Burkina Faso, a site that was then about 400 km from the nearest known, uncontrolled breeding site of savanna cytospecies; and large numbers of flies continued to invade areas in western Côte d’Ivoire and further north in Mali. The sources of these flies were thought to be in the river systems to the west of the Programme area, particularly in the Republic of Guinea. It was
not until 1985, when it became possible to treat the head-waters of the Sassandra river in southeastern Guinea, that a more than 90% reduction in biting and transmission rates was achieved in the reinvasion zones of northern Côte d'Ivoire and southwestern Burkina Faso. It was thus clearly demonstrated that by extending the Programme area and treating the appropriate breeding sources, the problem of reinvasion could be solved, even though the distances covered by the invading flies were enormous, certainly more than 400 km from their presumed points of departure.

The areas that are still (1985) reinvaded annually are located in the western part of the Mali section and in the northern parts of Togo and Benin. For the reinvasion in the west, the sources of migration are suspected to be in Guinea. In the east, the sources are thought to be in the southern extension area and possibly also in Nigeria. In Togo the migrating flies include *S. squamosum*, a species that breeds profusely in the mountainous country along the Togo–Ghana boundary.

In the original Onchocerciasis Control Programme area of 654 000 km², about 247 000 km² located in the north and north-east are completely without flowing water for at least 4 months a year, but the long-range migratory behaviour of the savanna cytospecies, *S. damnosum* s.s. and *S. sirbanum*, enables them to populate temporary habitats. Each year they can thus recolonize large areas that are without permanent breeding sites.

There is good evidence that at least one member of the *S. sanctipauli* subcomplex has a tendency to extend its range northwards in the rainy season, but it does not make long-range movements. *S. yahense* is the species that has the least tendency to migrate, and it is rarely found more than a few kilometres from its breeding sites.

15.1.2 *Insecticide resistance*

From the beginning of larviciding early in 1975 and, until 1980, temephos was the only insecticide used in the Programme area. In 1978/1979, larvicide treatments were extended to the south, and included breeding sites of the *S. sanctipauli* subcomplex.

In 1980, a series of treatment failures on the lower Bandama river in Côte d'Ivoire was shown to be due to resistance to temephos; this resistance was found to be limited to the *S. sanctipauli* subcomplex. The resistance spread rapidly to include all the previously known distribution of the subcomplex in the treated parts of Côte d'Ivoire,
southern Burkina Faso (mid 1981), and subsequently into western Ghana (early 1982), eastern Mali, and eastern Guinea (early 1986).

The first response to this resistance was the use of another organophosphate, chlorphoxim, which was, at that time, the only operationally tested alternative. In less than one year, the same vector population developed full resistance to this compound as well. Chlorphoxim was then replaced by *B. thuringiensis* H–14. In 1982, it was found that the chlorphoxim-resistant population had reverted to normal susceptibility some months after the withdrawal of the insecticide. This allowed year round control of the *S. sanctipauli* subcomplex by alternating the use of *B. thuringiensis* H–14 with chlorphoxim.

During the dry season 1982/83 an isolated population of *S. damnosum* s.s. on the lower Bandama river in southern Côte d'Ivoire, became resistant to temephos. In order to eliminate this resistant population, blanket *B. thuringiensis* H–14 treatments were carried out in this zone and continued until the end of 1984. The treatments were effective. When, after 4 months suspension of larviciding, savanna species reappeared in April 1985, they were found to have a normal level of susceptibility to temephos. Subsequently, temephos resistance in savanna flies has been detected in a few other foci and has been successfully dealt with in a similar manner.

Development of resistance in savanna species is a serious threat to the Onchocerciasis Control Programme. Even though replacement compounds are available, they are more difficult and more expensive to use than temephos. This threat will increase as the extension areas, that until now have provided reservoirs of susceptible flies, come under treatment. A strong network of resistance monitoring, conducted by specialized mobile teams, has been established and must remain part of the Control Programme activities until vector control ceases.

15.1.3 *Environmental impact of larvicidal control*

The continued use of larvicides over a large area for 20 years may have serious ecological implications. Therefore a monitoring protocol was developed to evaluate the impact of the larviciding campaign on the aquatic fauna. An environmental monitoring network has been established in several countries. In addition, ecological studies are undertaken on all new larvicides. An
independent advisory body, the Ecological Group, assesses the data obtained and conveys its conclusions to the Joint Programme Committee, through the Expert Advisory Committee.

After an initial application of temephos there is a very marked fall in the density of aquatic invertebrates. This modification of the fauna lasts for about a year. It is followed by repopulation from untreated rivers, that make up more than 35% of the total flowing waters within the Programme area, so that a new balance is established. The various taxa are not affected in the same way. However, most of those species present before the start of operations are still to be found after treatment, though a few have disappeared from large areas. In general, the impact of temephos after 8 years of weekly applications, has been a 30% reduction in the invertebrate biomass. Nevertheless, a wide variety of organisms persists in all treated river basins.

The dynamics of fish populations do not operate on the same time-scale as invertebrates and must be studied for many years before meaningful results can be obtained, but at least in the medium term, temephos seems to have no detrimental effects on fish.

All larvicides used operationally have been carefully screened by hydrobiologists for their effects on non-target organisms and have been approved by the Ecological Group who have placed certain restrictions on the use of some of them (e.g., permethrin).

15.2 Results of 11 years of *Simulium* control

15.2.1 Entomological evaluation

A WHO working group in 1977\(^1\) concluded that an area under vector control in the West African savanna could be considered safe for resettlement if the annual biting rates were less than 1000 and the annual transmission potentials less than 100 for 2 consecutive years. However, the present strategy of the Control Programme is to reduce transmission to insignificant levels by means of vector control and to maintain this control for a sufficiently long period to allow the initial reservoir of infection to fall so low that vector control can be safely interrupted.

For most catching points in the Control Programme area, the entomological evaluation started only shortly before the start of control operations, and the lack of sufficient pre-control data complicates the general assessment of the changes in the entomological pattern that have been brought about by vector control. However, data collected before the Programme started by the Organisation de Coordination et de Coopération pour la lutte contre les Grandes Endémies (OCCGE) and the Institut français de Recherche scientifique pour le Développement en Coopération (ORSTOM) provide important clues about the impact of the large-scale control implemented by the Onchocerciasis Control Programme. Annual biting rates in the White Volta basin, along the Bougouriba, the upper Comoe, the Léraba, and the upper Bandama rivers reached levels of 50 000–250 000 in the 1960s and early 1970s. Local vector control along the latter three rivers from 1967 to 1975 reduced these figures to about 25 000 bites per man per year. More limited results available on transmission suggest that the annual transmission potentials were usually more than 2500 and could reach levels as high as 10 000 along the White Volta and 18 000 along the Léraba. Most of the data from the 1960s were collected in years when the rains were heavier than they have been since the Programme started; but the information that is available for the early 1970s does not suggest that the intensity of transmission was much lower along these rivers during the droughts in those years. Against the background of these figures the achievements of the Control Programme are impressive.

(a) Central well-controlled area. In this area, covering about 85% of the original Control Programme area, and where the vectors are almost exclusively *S. damnosum* s.s. and *S. sirbanum*, control has been very effective. However, taking account of the entomological results over the last 6 years of vector control (1980–85) a somewhat different entomological pattern can be distinguished.

In 50% of the central area, *S. damnosum* s.l. has been virtually eliminated. Annual biting rates are usually zero and rarely exceed 100, while annual transmission potentials are zero throughout the area. This zone includes the dry, northern sectors of the Programme area where most rivers flow only for a few months during the rainy season. It includes former notorious onchocerciasis areas, such as the middle parts of the White and the Red Volta river basins and the lower Koulepolgo basin in Burkina Faso, all of which had extremely high intensities of infection and high blindness rates before control began.
Further south, *S. damnosum* s.l. has not been eliminated, but is usually only present at low densities with annual biting rates normally below 500 and rarely exceeding 1000. At most of the catching points, infective flies are detected only on very rare occasions. Such points are classified as having annual transmission potentials that are below the measurable threshold using the present sampling methods and are probably close to zero.

The results for the White Volta basin in Ghana, including the Red Volta, Sissili, and Kulpawn rivers were less satisfactory because of localized treatment failures in 1981 and 1985.

(b) Reinvaded areas. As already outlined in section 11.1.1, immigrant flies usually bite close to their oviposition sites. As a consequence, in reinvaded zones where there is satisfactory control of local breeding, transmission is virtually confined to the vicinity of breeding rivers, where transmission potentials may remain unacceptably high. For example, reinvasion is especially heavy along the Baoulé and Bagóé rivers in Mali, along the Mô, Kara, and Keran rivers in Togo, and the Alibori and Sota systems in Benin. In all these areas there are places where annual transmission potentials of up to 1000 have been registered in some years.

It has been clearly shown that extension of control to source areas can prevent reinvasion. This has been demonstrated for the Bandama, Bougouriba, Léraba, and Sassandra river systems.

(c) Southern Côte d'Ivoire. Results in this area are complicated by the development of resistance in the *S. sanctipauli* subcomplex that occurred within one year of the start of the control operation. In some years, annual biting rates and annual transmission potentials due to this subcomplex have been high, although the savanna species have usually been effectively controlled. The epidemiological significance of this remains uncertain.

15.2.2 Epidemiological evaluation

The final assessment of the success of vector control must be to measure its impact on the incidence of *O. volvulus* infection. Information on the incidence of infection comes from epidemiological evaluation, the objectives of which are to study the regression of the reservoir of infection in man and to assess the decrease in the incidence of severe ocular pathology. For this evaluation the populations of about 150 indicator villages representing all the major river basins, are examined at intervals of
3–4 years. Skin snip examinations and visual acuity tests are carried out in all surveys and these are supplemented by a detailed ophthalmological examination in a sample group of about 30 villages.

The three indices of epidemiological evaluation that are determined as a result of these surveys are as follows.

(i) The infection rate in children born after the start of control. The observed number of infected children is compared with the expected number if there had been no vector control. The expected number is calculated using the pre-control age-specific prevalences for each village.

(ii) The trend in the community microfilarial load (CMFL). The geometric mean microfilarial load per skin snip for a cohort of adults is calculated before control and at intervals after control has started, and the decline in this parameter is recorded.

(iii) The trend in the community microfilarial load in the anterior chamber of the eye (CMFL.AC). This is also calculated as a geometric mean for a cohort of adults and its decline is followed in a similar way.

(a) Incidence and regression of infection.

(i) Central well-controlled area (not subject to reinvasion). The epidemiological results available to date confirm that transmission of O. volvulus has been virtually interrupted in the central area. Out of a total of 6700 children examined, all of whom were born after the start of control, only one was found to be infected. This compares with an expected number of infected children in excess of 400 if there had been no control.

For most of the central area there is now a nearly linear decrease in the community microfilarial load and, following 8 years of control, it has fallen by more than 70%. For those villages that have been examined after 10 years of control, the linear decrease has continued, reducing this parameter by more than 90%. In these villages, the microfilarial loads are now so low that the prevalence in adults has also started to fall abruptly. The prevalence and the microfilarial loads in children born during the 10 years previous to the start of control are now decreasing significantly after having remained stationary, as expected, during the first 5–8 years of control.

(ii) Reinvaded areas. The results of the epidemiological evaluation show clearly that reinvasion is directly responsible for the continuing transmission of O. volvulus. From the reinvasion zones, 1612
children born after control started have been examined, 37 were infected, 26 of whom were from the southeastern area and 11 from the western area. However, this number is still considerably lower than the expected number of 225 and shows that vector control, by eliminating local breeding, has significantly reduced the level of transmission in these areas. Confirmatory evidence for this reduction in transmission comes from the observed decrease in community microfilarial loads in all villages examined in the western reinvaded area, although these decreases are variable and are always far less than those observed in the central area. However, in several villages the community microfilarial loads are tending to stabilize, suggesting that a new equilibrium, at a lower transmission level, has been reached. Results from villages in the southeastern reinvaded area, especially in the Mô, upper Kara, and upper Keran basins have been much less satisfactory and only a few villages show a significant reduction in the community microfilarial load.

(b) Evolution of ocular onchocerciasis.

(i) Central well-controlled area. The community microfilarial load in the anterior chamber of the eye (CMFL/AC), known to be an important risk factor for the development of ocular lesions, has decreased dramatically during the first 7–8 years of control, as have the microfilarial loads in the cornea and the number of cases of onchocercal punctate keratitis.

The rapid reduction in ocular microfilarial loads is the reason why the incidence of new serious lesions of ocular onchocerciasis (sclerosing keratitis, iridocyclitis, chorioretinitis, optic nerve lesions) has been so low since the onset of vector control, and why the progression of some severe lesions at early stages has been dramatically slower than was observed previously in uncontrolled areas. This has been clearly demonstrated by the results of the ophthalmological examination of a cohort population from 12 villages, which was followed-up over a period of 7–8 years of control. The incidence of blindness due to onchocerciasis was only 1.5% during the 7–8-year period, and exclusively involved people who already had, at the start of control, both serious lesions of ocular onchocerciasis and heavy ocular microfilarial loads.

(ii) Reininvaded areas. The evolution of ocular onchocerciasis in a cohort population from 5 villages in the reinvasion areas, after 7–8 years of local vector control, has been intermediate between the evolution in uncontrolled areas and that seen in the central area. Ocular microfilarial loads have generally decreased, but much less so
than in the central area. Consequently, the incidence and progression of all types of serious ocular lesion have been lower than would be expected without vector control, but are significantly higher than in the central area.

15.2.3 Socioeconomic evaluation

Compared with the entomological and epidemiological consequences of onchocerciasis control, the socioeconomic effects have been relatively slow to emerge, and meaningful analyses are confined to regions where there has been control for a long time. The following paragraphs give an indication of what is known about some settlements and resettlements, as well as about bringing land under cultivation, following onchocerciasis control.

(a) Farako basin, Mali. Between 1962 and 1975 the cultivated areas in the flood plain increased by 625% and the region is now fully settled. A tea plantation supplies one-sixth of Mali's needs. The amount of "dry" crops produced continues to increase at the rate of 4% per year. The village communities, whose very existence was in jeopardy before the blackfly control campaigns began, are now expanding.

(b) White Volta and Red Volta basins, Burkina Faso. In both basins, development areas planned by the Autorité pour l'Aménagement des Vallées des Volta (AVV) exist alongside spontaneous undertakings. During the 20 years preceding the Control Programme, the growth in area of land utilized was 0.2-0.3% per year, i.e., far less than the population growth of Burkina Faso (1.2-2% per annum). Since the start of the Programme, the annual increase in utilized areas has averaged 11%, more than doubling within 10 years.

(c) Bougouriba and Black Volta basins, Burkina Faso. In the Dagara and the Birifor areas north and south of the junction of the 2 rivers, the annual growth of utilized land has been 2.4-7.8%.

(d) Samandeni Region, Burkina Faso. In the 1960s, cultivated areas represented less than 5% of the total land available. Since then the area under cultivation have increased by 300% and, after 1981, the upper valley of the Black Volta, which used to be deserted, has been brought under cultivation. This region has experienced substantial immigration by the Mossi tribe, with the total population growing by 229% between 1977 and 1982.
(e) Saint-Pierre Region, Burkina Faso. In the district as a whole, the cultivated area has increased by 600% and now represents 24.7% of the available land. In several valleys, notably that of Kéralié, almost the entire cultivable land surface is now occupied.

Other less well-documented examples of settlement and expansion exist in the controlled valleys in northern Côte d'Ivoire, eastern Mali, and northern Togo.

In conclusion, it appears that the higher the population density and resultant overcrowding were between the rivers before control, the more intensive has been the process of land occupation in the valleys following control. Land has, in general, been brought under cultivation faster than villages have been established. The general process of valley occupation has been gathering pace during the past 5 years.

15.2.4 Conclusions after 11 years of control

Both the entomological and epidemiological evaluations have confirmed that larvicidal vector control has effectively interrupted transmission of *O. volvulus* in the central area. To achieve the objective of the Programme this control will have to be maintained until the residual microfilariae have died out in the human population. The most recent estimate for the average lifespan of the adult female worm is 12 years, to which must be added a further 3 years for the life expectancy of the last microfilariae produced, thus making a total of 15 years. However, some of the adult worms will live longer than 12 years. The significance of these long-lived worms has to be taken into account when planning the future of the Programme.

In the reinvaded areas, transmission has definitely not been interrupted, but the elimination of local breeding has reduced the level of transmission below that existing before control began. However, the remaining level of transmission in many places is still too high and is associated with high intensities of infection and a significant incidence of serious ocular lesions. Therefore, it cannot be claimed that adequate control of the disease has been achieved in those areas; this will have to await the western and southern extensions of vector control in 1987.
15.3 Planned developments

In spite of the striking progress made during the first few years of larviciding control over the entire original Control Programme area, and the continuing elimination of vector breeding within that area, the Programme had, by 1983, reached stalemate. No further progress could be made without resolving the problem of vector reinvasion. For this reason, in order to achieve the Programme's objectives and bring operations to a successful conclusion within the foreseeable future, a long-term strategy was adopted that is to be implemented during the period 1986–97.

The Onchocerciasis Control Programme will extend its larvicidal operations to the west (in Guinea, Guinea Bissau, western Mali, Senegal, and Sierra Leone), and to the south (in Benin, Ghana, and Togo) as far as the limits of the habitats of the savanna species of the *S. damnosum* complex. The total area under control will expand to 1,300,000 km², the length of rivers under control will extend to 46,000 km, and the population protected will increase by 8 million to a total of 25 million.

Larviciding will remain the principal means of control throughout the Programme area. Nevertheless should any new drug become available that is suitable for large-scale use against *O. volvulus*, it will have operational repercussions both on the Control Programme and on the participating countries. It may then be possible to provide preventive treatment for those heavily infected persons who are still at high risk of blindness even though they are living in controlled areas; such a drug could supplement larvicidal control by reducing the microfilarial reservoir in those few problem areas where local larviciding is not totally effective at present.

According to the long-term strategy forecast, the Onchocerciasis Control Programme will cease operations at the end of its fourth financial phase (1992–97), when all operational zones in the extension areas will have been under control for at least 10–12 years and those in the original Programme area for considerably longer. It is anticipated that the participating countries will progressively assume responsibility for the continuing surveillance activities that will be needed. It is expected that onchocerciasis epidemiological surveillance operations will be conducted within the framework of the countries' primary health care systems, with the Control Programme (or after 1997 possibly WHO) providing overall collation and evaluation of results.
However, it should be noted that in 1997 there will be large areas that have been under vector control for only 9–11 years. Should vector control continue as the sole means of attack, there will still be human populations with high prevalence rates. Therefore, control will have to be continued for several more years if a disastrous recrudescence of the disease is to be avoided.

15.4 Suggestions for further study

(a) Study the behaviour and fate of larvicides in breeding rivers in the Programme area.
(b) Develop biochemical methods for the detection of insecticide-resistant flies.
(c) Evaluate further the socioeconomic effects of onchocerciasis and its control in the original Control Programme area and in the extension zones.

16. PRIMARY HEALTH CARE AND ONCHOCERCIASIS

The strategy of the World Health Organization, having as its goal “Health for All by the Year 2000” emphasizes the importance of applying modern science and technology through primary health care and community involvement in order to treat, control, and prevent disease.

The control of onchocerciasis still depends mainly on large-scale vertical programmes using larvicides against the vector *Simulium*, and because of this, the involvement of the primary health care worker in its control is particularly difficult to define. The present report endeavours to remedy this deficiency, especially in the greater part of the global endemic area where there are at present no prospects of widespread vector control being undertaken.

16.1 General considerations on the role of the primary health care worker

16.1.1 Primary health care workers and priorities

At present, and probably far into the future, primary health care workers in developing tropical countries are likely to be overburdened, performing a multitude of health tasks and serving a
large number of people. Against this background it is obvious that only in those communities where onchocerciasis is high on the list of public health problems, especially because of the blindness it causes, would it be justified for the primary health care worker's training, time, effort, and resources to be devoted to its treatment and control. In areas of low endemicity, where onchocerciasis is of little public health importance, the primary health care workers will be well advised to concentrate their efforts on other more pressing health problems.

16.1.2 The dual role of the primary health care worker in onchocerciasis

In those communities where onchocerciasis does merit serious attention, the primary health care worker should concentrate on two aspects. The first is the clinical diagnosis of the disease at the acute stage, when the patient is seeking, and ready to accept, treatment, and when treatment at a referral centre may succeed in relieving the acute manifestations of infection and preventing the development of advanced, chronic and disabling disease, particularly blindness. The second is the education of the population about the cause of the disease, how it is spread, local or personal measures that can help prevent infection, and the stage at which treatment is effective.

16.1.3 Recognition of the disease at the community level

In communities where onchocerciasis is highly endemic, some of its main signs and symptoms are often well recognized by the inhabitants as specific "diseases." Frequently, the people have names for these conditions in their local language but, without the benefits of health education, they may not know what causes them or the treatment for them. The following are manifestations or conditions associated with onchocerciasis infection that are often known to villagers and should be recognized by the primary health care worker:

— the presence of a nodule;
— the itching, papular hyperpigmented skin in acute or chronic infections;
— leopard skin;
— the brownish cornea (due to sclerosing keratitis) associated with painful eyes and loss of vision;
the night blindness that is associated with the involvement of
the posterior segment of the eye.

16.1.4 The primary health care worker as a link between the
community and the health services (including control
programmes)

Despite the communities' ability to recognize these clinical
conditions, there is unlikely to be a general awareness of the
association between the acute manifestations of the disease and the
subsequent development of chronic blinding lesions, or between the
disease and the vectors that spread it. In this context, primary health
care workers can be particularly valuable since they can explain the
risk of presently available filaricidal treatment; why treatment may
be ineffective in the late stages of the disease (e.g., blindness, gross
atrophic skin lesions) when specialized tissues have been irreparably
damaged; or, in the future when safer drugs become available, why
otherwise healthy carriers of microfilariae may need to be treated in
order to reduce transmission for the good of the community.

The primary health care worker should not only act as a sanitary
educator, but should also stimulate the active involvement of the
community in health matters, as well as act as a link between village
communities and the next level of the health service. Because the
complex biology of *O. volvulus* and its *Simulium* vectors makes
control difficult, the primary health care worker cannot hope to
eliminate from the community all infection or disease caused by this
filarial parasite. This task of elimination must be left to those
responsible for the treatment or control of onchocerciasis in the area,
whether this is based on vector control, nodulectomy, chemotherapy,
or a combination of all three. However, it is essential
that the primary health care workers should be aware of, and should
be involved in, any treatment or control activities that affect their
community.

16.1.5 Limitations for intervention by the primary health care
worker

Although, in endemic areas, a high proportion of the population
may become infected with *O. volvulus*, many of them will tolerate the
parasites and will show little or no clinical evidence of disease. Such
persons are usually ignorant of the fact that they harbour the
parasite; being almost symptom-free they do not seek treatment voluntarily, and there is no grave risk that they will develop clinical disease in the future. For these people, treatment will not produce any immediate clinical benefit and it may indeed harm them by provoking an allergic reaction to the parasites. The only reason for treating healthy carriers of filarial parasites would be as part of a large-scale chemotherapeutic campaign to interrupt transmission of the parasite by eliminating the reservoir of microfilariae from the entire infected human population. However, such campaigns are not possible until new effective drugs of low toxicity become available. Until this happens, the primary health care worker should not treat those cases that have no, or only minor, symptoms; they should be provided with reassurance or left in blissful ignorance of their parasitosis.

16.2 Specific primary health care activities in onchocerciasis

16.2.1 Individual treatment

(a) The hazards of treatment. There is at present (1986) no chemotherapeutic or other treatment regimen available that can be used safely and effectively against onchocerciasis at the primary health care level. As a result, assessing the need for treatment in onchocerciasis patients who present to, or are found by, the primary health care worker, and subsequently arranging for their care, are most difficult problems.

It is now recognized that treatment with the standard drugs, diethylcarbamazine, and probably also suramin, for all that they may benefit anterior segment eye lesions, can worsen or provoke lesions in the posterior segment of the eye (chorioretinitis, optic neuritis, and atrophy), particularly in patients with intraocular microfilariae. Both drugs can also cause severe Mazzotti reactions and systemic disturbance in those who have microfilariae in their skin. Definitive treatment, with suramin and diethylcarbamazine, is often unpleasant for the patient and carries with it an element of danger (see section 8.4.2). It needs facilities for quantitative examination of skin microfilariae, eye examination for microfilariae and ocular lesions, urine examination, intravenous injections, and access to corticosteroids for treatment of severe reactions, and it takes 2–3 months to complete. The high degree of care and supervision needed requires referral to a hospital or treatment centre.
where medical supervision is available. The primary health care worker cannot be expected to have the necessary skills and should not undertake treatment with these drugs.

The dangers, particularly to the eye, of haphazard, unsupervised dosage with diethylcarbamazine in onchocerciasis must be recognized as being far greater than previously thought. Therefore the custom, formerly common and still practised in many dispensaries, clinics, and hospitals, of handing out diethylcarbamazine tablets to onchocerciasis patients for subsequent self-treatment, can no longer be justified, unless it is accompanied by a careful assessment of the probable risks to the individual patient.

(b) Referral of patients by the primary health care worker. Another difficulty for the primary health care worker is to decide which patients should be referred for treatment. If the health and social systems are not to become overloaded, referral for treatment should be confined to those cases that are suffering from symptomatic infections or who are at a high risk of blindness. Moreover, it should not be forgotten that, even after successful treatment, if these patients return to live in the same environment and no Simulium control is carried out, they will almost certainly be reinfected.

The primary health care workers in an onchocerciasis area should, therefore, be trained to recognize the clinical manifestations of onchocerciasis that merit, and will benefit from, chemotherapy treatment or nodulectomy, and they should concentrate on detecting and referring such cases to a higher level of the health care system for quantitative diagnosis and treatment. These manifestations are:

— presence of a nodule on the head;
— pruritic, dermal onchocerciasis, especially in the early stages;
— progressive ocular onchocerciasis of the anterior segment, i.e., early sclerosing keratitis, or iridocyclitis leading to a red, often painful eye, photophobia, and watering;
— the symptoms and signs of early posterior segment disease, i.e., night blindness and reduced visual field.

Such cases should be referred to a higher level of health care that is capable of confirming the diagnosis and providing full chemotherapy treatment and/or nodulectomy with suitable medical supervision so as to avoid or deal with any possible complications. Of those patients meriting treatment some, especially those with severely itching skins or with painful eye lesions, may be
expected to present themselves to the primary health care worker. Others, even those with relatively severe visual loss, will not present themselves voluntarily, but have to be recognized by the primary health care workers in the community for which they are responsible. If patients are reluctant to take treatment when this is considered necessary, they may be convinced by showing them microfilariae from their skin snip wriggling under the microscope.

(c) The primary health care worker and nodulectomy. In areas where nodulectomy campaigns are being carried out for onchocerciasis control, e.g., Guatemala and Mexico, the primary health care worker's function should be to alert these teams to those persons in the community with nodules and to assist in the after-care of those treated.

(d) Conclusion. In summary, therefore, it is recommended that the functions of the primary health care worker in the management of cases of onchocerciasis should be:

(i) to make a presumptive diagnosis of onchocerciasis based on the clinical picture, and refer to a higher level those who fall into the categories requiring treatment;
(ii) to avoid treating cases of onchocerciasis with diethylcarbamazine or suramin because of the risks of producing lesions in the posterior segment of the eye;
(iii) in areas where nodulectomy teams operate, to direct patients with nodules (particularly those on the head) to the team for removal, and to assist with their after-care.

16.2.2 Primary health care and possible future suppressive chemotherapy

It is hoped that the present unsatisfactory treatment of onchocerciasis will be improved by the availability of ivermectin. If ivermectin lives up to the promise of early clinical trials and does indeed prove, after more prolonged testing, to be a non-toxic, single-dose, relatively long-acting microfilaricide and microfilarial suppressant, then a form of individual or even large-scale suppressive chemotherapy, that could be applied via the primary health care system, may become available (see section 8.5.6).
16.3 Primary health care and health education

One of the important roles of health education must be to encourage community involvement and support. If health education is to succeed, it must involve field workers at all levels. In addition, full use must be made of non-health communication channels as well as those traditionally employed by the health care system.

The primary health care workers should act within their own village as a health educator on onchocerciasis. They can explain the association between the disease and Simulium bites and hence with the rivers in which these flies breed. As far as such measures are practicable in the community, they can advise on personal and community methods that can protect against Simulium bites. These include: wearing long trousers, shoes, and socks in S. damnosum s.l. areas in Africa; wearing a shirt and head veil during periods of heavy exposure to S. ochraceum in Guatemala and Mexico (e.g., when working in coffee plantations); avoiding, where possible, occupations that greatly increase exposure to Simulium infective biting, such as fishing, working a river ferry, or digging sand from the river bed.

Likewise, as far as is practicable, the primary health care worker can advise the community on how to modify its way of life so as to reduce the risks of heavy transmission of onchocerciasis. In some African savanna areas the biting density of infective S. damnosum s.l. is many times higher near the river bank than it is further away. Community exposure may thus be reduced by siting settlements several kilometres away from the banks of breeding rivers and by installing deep wells inside the village. These measures help to avoid the necessity for many people to go down to the river bank daily to draw water for washing, bathing, cooking, laundering, etc. However, without careful consideration in each individual case, these measures may not be enough to prevent the development of severe blinding onchocerciasis.

16.4 Health education in the Onchocerciasis Control Programme

Health education as part of the Onchocerciasis Control Programme has four main purposes:

— to make the populations concerned aware of the cause and transmission cycle of the disease;
— to prepare them for the planned control measures and secure their collaboration;
— to explain the purpose and mechanics of epidemiological evaluation and invite their full cooperation in this activity;
— to promote active community involvement.

Health education has been, since the inception of the Control Programme, an integral part of the field activities carried out by the sector/subsector staff and by the epidemiological evaluation teams. The people living in the Control Programme area have been well informed about the reason for the operations of the Programme, and the results expected from its various activities. Such preparations have greatly contributed to the smooth running of the Programme and have resulted in excellent cooperation with the village people for more than 10 years. The Programme also benefits from a considerable amount of goodwill because of the almost immediate, tangible results of larviciding.

Programme success can, however, have untoward effects. The mere fact that transmission has been interrupted in three-quarters of the original Programme area, so that no new cases are seen and old infections are dying out, tends to make villagers forget how serious a health and socioeconomic problem onchocerciasis can be. People will therefore become increasingly wary of requests for active participation in maintenance/surveillance operations, a trend that can only be reversed by conducting regular health education and information programmes. A special effort will be required to prepare the populations concerned for the eventual return of blackflies into the Control Programme area, once the human reservoir of parasites has been eliminated and the risk of reappearance of infective flies is therefore abolished.

16.5 Community involvement in onchocerciasis control

The primary health care workers can help promote community involvement when it is needed, in any Simulium control programme undertaken by the health authorities in their area. Examples of such involvement would be the clearing and treating of artificial breeding sites of S. damnosum s.l. on disused causeways (Sudan) or on the spillways of small dams. In Guatemala, the owners of coffee plantations cooperate by providing labour for ground treatment with larvicides in the many small breeding sites of S. ochraceum, and
for assessment of the effects on the vector population. Both activities are supervised by technical staff. An example of successful village involvement in vector control is on the Bandiagara Plateau in Mali within the Control Programme area. Aerial control of the vectors of onchocerciasis in this area has been successfully replaced by control on the ground, using techniques that can be mastered by rural communities. It seems likely that in this area the communities will take almost complete responsibility in the fairly near future for entomological evaluation operations and blackfly control. Although this example is exceptional, because of the combination of many favourable factors, it shows that, provided certain conditions are satisfied, blackfly control activities can be entrusted to communities to a large extent. It also suggests that these activities could be integrated into national multipurpose control programmes dealing with other diseases whose vectors or intermediate hosts are associated with water.

17. TRAINING AND MANPOWER DEVELOPMENT

Onchocerciasis research and control is an especially demanding, long-drawn out, and taxing task, because of the currently available resources. It would be impossible if there was not a serious and sustained training effort for large numbers of staff at all levels. Onchocerciasis has, for many years, been the subject of considerable attention; this attention predated the launching of the Onchocerciasis Control Programme, which could never have been implemented if there had not been enough well-trained specialists available.

17.1 The disciplines

Because of the multidisciplinary nature of onchocerciasis research and control, staff training has, in effect, been carried out in all the areas involved — namely, epidemiology, public health, parasitology, ophthalmology, immunology, entomology, hydrology, hydrobiology, sociology and anthropology, and economics.

17.2 The levels

Training plans make provision for the following:
(a) Candidates for higher posts in research and control, in all disciplines; these candidates may pursue long courses of university education so that they can specialize in one of the disciplines listed in section 17.1. When qualified as specialists, they may pursue shorter, "tailor-made" courses to learn a specific method or technique.

(b) Candidates for intermediate-level posts (technicians, assistants) are also trained for each discipline. The training courses are shorter.

17.3 The training centres

There are many such centres located in different places, depending on the discipline and the level.

17.3.1 University level

(a) At the outset, the long-term training of specialists was carried out exclusively in Europe and North America. Now, thanks to the programme of assistance by WHO, it is possible to acquire training in certain special subjects, such as entomology and ophthalmology, at several African universities in countries where the disease is endemic.

(b) Short courses in specific subjects may be given in all research centres working on onchocerciasis in the developed countries (especially courses on laboratory techniques) or in the endemic zones (generally field work).

17.3.2 Technician training

Training for technicians is carried out in the endemic zones.

17.4 Conclusions

It should be strongly emphasized that the subject of onchocerciasis and its control must be included in the curricula of medical schools and paramedical teaching institutions; this, of course, applies particularly to areas of the world endemic for onchocerciasis.

The role of the primary health care worker in onchocerciasis has already been discussed (see section 16). Training methods
appropriate for primary health care work must be developed, and at the present time should concentrate on the most important diagnostic tasks and problems that the primary health care worker may be expected to face.

A considerable number of specialists from all the disciplines connected with onchocerciasis have been trained during the last decade; clearly, this training has been related to the needs of the Onchocerciasis Control Programme and to the increasing importance being attached to onchocerciasis in research programmes, at least in Africa. Nevertheless, it should be mentioned that the problem has altered in recent years. Whereas there was primarily a lack of well-trained national or regional specialists, it is now the lack of posts within ministries, national research and control establishments, and universities that is the obstacle to the assumption of responsibility for all activities by the countries in which onchocerciasis is endemic.

The ambitious training programme set out above will be of little benefit without the creation of a career framework for the young nationals involved in the Control Programme and from other countries who have been trained, and without the allocation of the resources to enable them to work.

18. CONCLUSIONS

(1) Onchocerciasis, in the sub-sahelian area of Africa and in Zaire, is of outstanding medical and socioeconomic importance. In countries such as Cameroon, Central African Republic, Chad, Nigeria, Sudan, and Zaire, large numbers of people are severely afflicted by river blindness but, as yet, little progress has been made in the control of the disease.

(2) The incidence of blindness due to onchocerciasis is now known to be much higher than was previously thought. Recent research has shown a reduced life expectancy among blind people in West Africa and a lesser, but not insignificant, reduction in life expectancy among severely parasitized, but non-blind sufferers from the disease.

(3) In the last decade, tremendous advances have been made through the activities of the Onchocerciasis Control Programme in seven West African countries. Over a large area transmission has been interrupted by vector control measures. Infection intensities and rates have declined considerably, no new severe disease has
developed, and children born since the onset of control live free from the risk of infection.

(4) Although chemotherapy with presently available drugs is unsatisfactory, certainly for large-scale use, ivermectin shows great promise as a well-tolerated, single-dose oral drug, that has good microfilaricidal activity for the treatment of onchocerciasis. It is anticipated that it will be available for clinical use by late 1987.

(5) In recent years, research on onchocerciasis has been stimulated by the filariasis component of the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases and by the Onchocerciasis Control Programme. As clearly demonstrated in this report, this Programme has produced important results that provide a better understanding of the disease and improved means for its control.

19. RECOMMENDATIONS

(1) Further studies are urgently needed on the identification and classification of the putative forms of *O. volvulus* to improve our understanding of the epidemiology of onchocerciasis and for efficient control measures. Suitable identification techniques should be developed for all stages of the parasite.

(2) Studies are needed on the pathogenicity of the putative forms of *O. volvulus* and on the roles of the parasite, host, and vector in the expression of geographically distinct clinical patterns of onchocerciasis.

(3) The pathogenesis and natural history of eye lesions in onchocerciasis should be elucidated, especially those involving the posterior segment of the eye.

(4) Immunodiagnostic tests should be developed that are capable of detecting early (especially prepatent) infections.

(5) Research to discover a safe macrofilaricidal drug effective against *O. volvulus* must continue to be given high priority.

(6) Optimally cost-effective distribution methods need to be determined for new micro- and macrofilaricidal compounds suitable for large-scale use. The effects of such drugs on the evolution of ocular and dermal lesions and on the transmission of *O. volvulus*

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1 The sequence of recommendations is not intended to reflect the priorities of the Committee, but follows the order of the sections of the report.
need to be investigated. In the immediate future this recommendation is likely to apply particularly to ivermectin.

(7) Further cytotoxic studies of the S. damnosum complex with regard to onchocerciasis are required, especially in Central and East Africa.

(8) Determination of the epidemiological significance of different levels of transmission (as defined by the annual transmission potential) is required, including a consideration of human behaviour.

(9) Methods should be improved for the identification of the species of anthropophilic females of the various vector Simulium complexes.

(10) Further research is required on chemical insecticides and their formulation for the successful completion of the Onchocerciasis Control Programme in West Africa.

(11) Because a number of behavioural and socioeconomic factors influence the degree of man–vector contact, sociological variables should be taken into account by epidemiologists and by those responsible for resettlement.

(12) Since there are no safe drugs available in 1986, treatment of onchocerciasis patients by primary health care workers cannot be recommended. Reassessment of this recommendation will be needed if ivermectin becomes available.

(13) Regarding the many unsolved problems in relation to onchocerciasis and its control, it is essential that WHO and other agencies should continue to sponsor research and training in this field.

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