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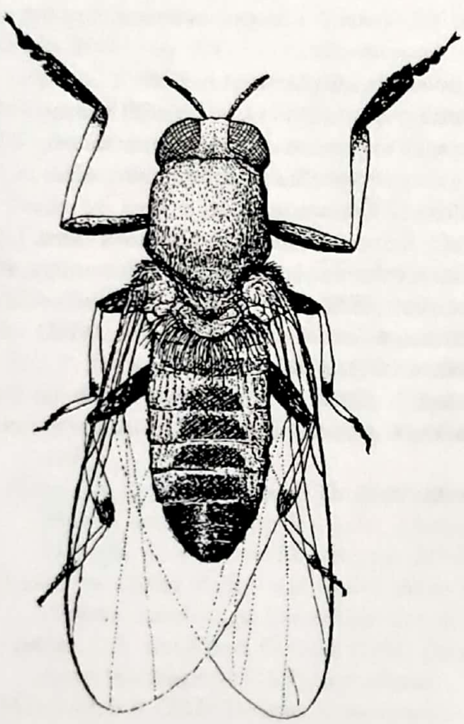
Black flies (Simuliidae)



Black flies belong to the family Simuliidae and have a worldwide distribution. There are more than 2000 species in 25 genera. However, only three genera, *Simulium*, *Prosimulium* and *Austrosimulium*, contain species that commonly bite people.

Medically, *Simulium* is by far the most important genus as it contains many vectors. In Africa, species in the *S. damnosum* complex and the *S. neavei* group, and in Central and South America, species in the *S. ochraceum*, *S. metallicum* and *S. exiguum* complexes, transmit the parasitic nematode *Onchocerca volvulus*, which causes human onchocerciasis (river blindness). In Brazil, *S. amazonicum* transmits *Mansonella ozzardi*, a filarial parasite that is usually regarded as non-pathogenic.

The Simuliidae are commonly known as black flies, but in some areas, especially Australia, they may be called sand flies. As explained in Chapter 5, this latter terminology is confusing and best avoided because biting flies in the family Ceratopogonidae are sometimes also called sand flies, while flies in the subfamily Phlebotominae are regarded as the true sand flies.

4.1 External morphology

Adult black flies are quite small, about 1.5–4 mm long, relatively stout-bodied and, when viewed from the side, have a rather ***humped*** thorax. As their vernacular name indicates they are usually ***black*** in colour (Plate 5), but some species have contrasting patterns of white, silvery or yellowish hairs on their bodies and legs, while others may be predominantly orange or bright yellow.

Black flies have a pair of large compound eyes, which in females are separated on the top of the head (a condition known as *dichoptic*) whereas in males the two eyes touch each other and occupy most of the head (a condition known as ***holoptic***). In males, but not females, the lenses of the eyes are larger on the upper half than on the lower half (Fig. 4.1b). The antennae are short, stout, cylindrical and distinctly segmented (usually 11

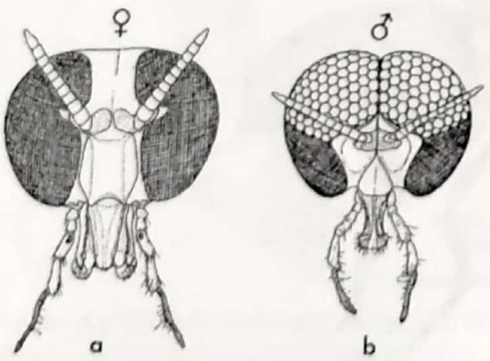


Figure 4.1 Front view of adult *Simulium* heads: (a) female with dichoptic eyes; (b) male with holoptic eyes.

segments) and lack long hairs. The mouthparts are short and relatively inconspicuous, but the five-segmented maxillary palps hang downwards and are easily seen. ***Only females*** bite. The mouthparts, being short and broad, do not penetrate deeply into the host's tissues. Teeth on the labrum stretch the skin, while the rasp-like action of the maxillae and mandibles cuts through the skin and ruptures its fine blood capillaries. The small pool of blood produced is then sucked up by the fly. This method of feeding is ideally suited for picking up the microfilariae of *Onchocerciasis volvulus*, which occur in human skin, not blood. Morphologically the mouthparts are similar to those of the biting midges (Ceratopogonidae, Chapter 6).

The thorax is covered dorsally with very fine and appressed hairs, which can be black, white, silvery, yellow or orange and may be arranged in various patterns. The relatively short legs are also covered with very fine and closely appressed hairs and may be unicolourous or have contrasting pale and dark bands. Each tarsus has a pair of claws, which are untoothed (i.e. simple) in mammal-feeders.

Wings are characteristically short and broad and ***lack*** both scales and prominent hairs. Only the veins near the anterior margin are well developed; the rest of the wing is membranous and has indistinct venation (Fig. 4.2, Plate 5). The wings are colourless or almost so, and when at rest are closed over the body like the blades of a closed pair of scissors.

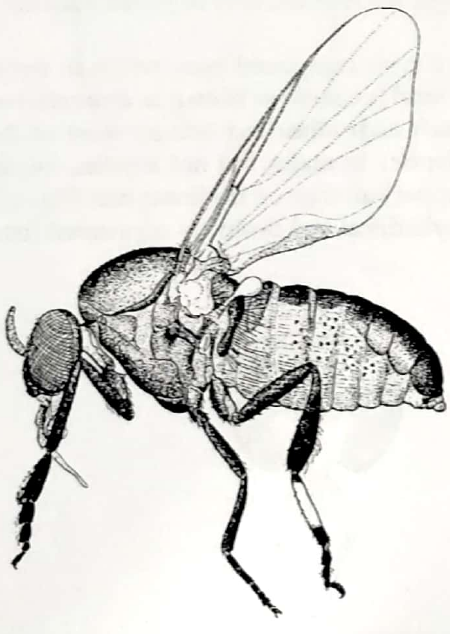


Figure 4.2 Adult simuliid black fly (*Simulium damnosum*) in lateral view. (Courtesy of R. W. Crosskey and the Natural History Museum, London.)

The abdomen is short and squat, and covered with inconspicuous closely appressed fine hairs. In neither sex are the genitalia very conspicuous. Black flies are easily *sexed* by looking to see whether their eyes are dichoptic (females) or holoptic (males).

4.2 Life cycle

Eggs are about 0.1–0.4 mm long, brown or black, and are more or less triangular in shape but have rounded corners and smooth unsculptured shells (Fig. 4.3a) and are covered with a sticky substance. Eggs are always laid in *flowing water*, but the type of larval habitat differs greatly according to species. Habitats can vary from small trickles of water, slow-flowing streams, lake outlets and water flowing from dams to fast-flowing rivers and rapids. Some species prefer lowland streams and rivers whereas others are found in mountain rivers. In species such as *S. ochraceum*, a Central American vector of onchocerciasis, eggs are scattered over the surface of flowing water while females are in flight. In most species, however, ovipositing females alight on partially immersed objects such as rocks, stones and vegetation to lay some 150–800 eggs in sticky masses or strings. Females

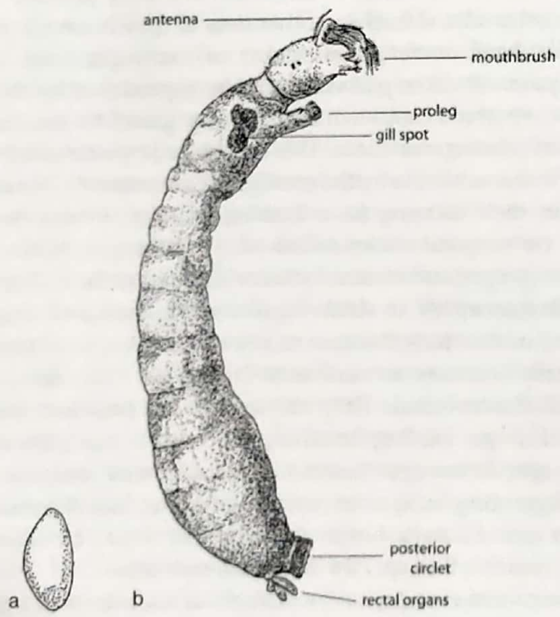


Figure 4.3 (a) *Simulium* egg; (b) lateral view of the last larval instar, showing principal diagnostic simuliid characters. The species figured is *Simulium damnosum*, a species which has the body covered with minute dark setae and has small dorsal tubercles, i.e. small humps.

may crawl underneath the water and become completely submerged during oviposition. There are sometimes a few favoured oviposition sites in a stream or river, resulting in thousands of eggs from many females being found together. *Simulium damnosum*, for example, frequently has such communal oviposition sites. Eggs are unable to survive desiccation.

Eggs of *S. damnosum* hatch within about 1–2 days, but in many other tropical species the egg stage lasts 2–4 days. Eggs of species inhabiting temperate or cold northern areas may not hatch for many weeks, and some species pass the winter as diapausing eggs.

There are six to eleven (usually seven) larval instars and a mature larva, depending on the species, is about 4–12 mm long. It is easily distinguished from all other aquatic larvae (Fig. 4.3b). The head is black, or almost so, and has a prominent pair of ***feeding brushes*** (cephalic fans), while the weakly segmented cylindrical body is usually greyish, but may be darker or sometimes even greenish. The body is slightly swollen beyond the head and in most, but not all, species distinctly swollen towards its end. Ventrally, just below the head, is a small thoracic ***proleg*** which is armed with a small circlet of hooklets. The rectum has a finger-like rectal organ which on larval preservation may be extruded and visible as a dorsal protuberance towards the end of the abdomen.

Larvae do not swim but remain sedentary for long periods on submerged vegetation, rocks, stones and other debris. Attachment is achieved by the ***posterior hook-circlet*** (anal sucker of many previous authors) tightly gripping a small silken pad which has been produced by the larva's very large salivary glands and which is firmly glued to the substrate. Larvae can nevertheless move about. This is achieved by alternately attaching themselves to the substrate by the proleg and the posterior hook-circlet, which results in their moving in a looping manner. When larvae are disturbed they can deposit sticky saliva on a submerged object, release their hold and be swept downstream for some distance at the end of a silken thread. They can then either swallow the thread of saliva and regain their original position, or re-attach themselves at a site further downstream.

Larvae normally orientate themselves to lie ***parallel*** to the flow of water with their heads downstream. They are mainly filter-feeders, ingesting, with the aid of large feeding brushes, suspended particles of food. However, a few species have predaceous larvae and others are occasionally cannibalistic. Depending on species and temperature, larval development may be as short as 6–12 days, but in some species it may be extended to several months, and in other species larvae overwinter.

Mature larvae can be recognized by a blackish mark termed a ***gill spot*** (respiratory organ of the future pupa) on each side of the thorax (Fig. 4.3b). These larvae spin, with the silk produced by their salivary glands, a protective slipper-shaped brownish ***cocoon***. This is firmly attached to submerged vegetation, rocks or other objects, and its shape and structure

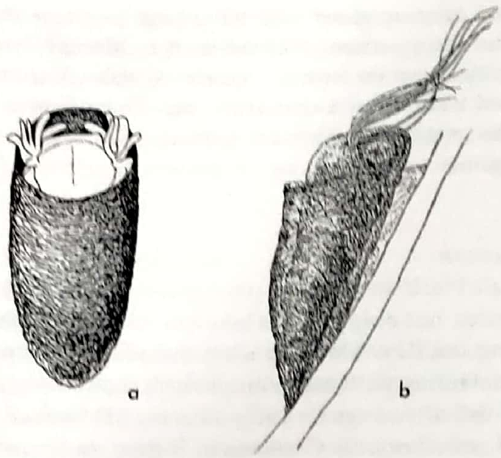


Figure 4.4 *Simulium* pupae in their cocoons: (a) dorsal view of a species (*S. damnosum*) with broad and short respiratory filaments (courtesy of R. W. Crosskey and the Natural History Museum, London); (b) lateral view of a species (*S. striatum*) with long and thin respiratory filaments.

vary greatly according to species (Fig. 4.4). After weaving the cocoon the enclosed larva pupates. The pupa has a pair of thin-walled ***respiratory gills***, which are usually prominent and may be filamentous or broad. Their length, shape and number of filaments or branches provide useful taxonomic characters for species identification. These gills, and the anterior part of the pupa, often project from the entrance of the cocoon (Fig. 4.4). In both tropical and non-tropical countries the pupal period lasts only 2–6 days and is unusual in not appearing to be dependent on temperature. On emergence adults either rise rapidly to the water surface in a protective bubble of gas, which prevents them from being wetted, or they escape by crawling up partially submerged objects such as vegetation or rocks. A characteristic of many species is the almost simultaneous mass emergence of thousands of adults. On reaching the water surface the adults immediately take flight.

The empty pupal cases, with gill filaments still attached, remain enclosed in their cocoons after the adults have emerged and provide a means of identifying simuliid species that have successfully emerged.

A few African and Asian black fly species have a very unusual aquatic association. For example, in East Africa larvae and pupae of *S. neavei* do not occur on submerged rocks or vegetation but on other aquatic arthropods, such as the immature stages (nymphs) of mayflies (Ephemeroptera), and various crustaceans including freshwater crabs. Such an association is termed a ***phoretic*** relationship. As eggs are not found on these animals they are probably laid on submerged stones or vegetation.

Nuclei of the larval salivary gland cells have large *polytene chromosomes* which have banding patterns that are used to identify otherwise morphologically identical species within a species complex. For example, chromosomal studies have shown that there are 57 cytoforms in the *S. damnosum* complex, many of which are known to be distinct species and have scientific names.

4.2.1 Adult behaviour

Both male and female black flies feed on plant juices and naturally occurring sugary substances, but ***only females*** take blood-meals. Biting occurs out of doors during the day. Many species, including *S. damnosum* in Africa, have bimodal biting patterns, with peak biting in the early morning and again in the afternoon or early evening. However, in some species, such as *S. ochraceum* in Guatemala, biting continues more or less throughout the day. Many species seem particularly active on cloudy, overcast days and in thundery weather. Black flies may exhibit marked preferences for feeding on different parts of the body; for example, *S. damnosum* feeds mainly on the legs whereas *S. ochraceum* prefers to bite the head and torso. When feeding on animals, adults crawl down the fur of mammals, or feathers of birds, to bite the host's exposed skin; they may also enter the ears to feed.

Many species of black fly feed almost exclusively on birds (*ornithophagic*), others on non-human mammalian hosts (*zoophagic*), while several species also bite people (*anthropophagic*). Some of these, however, prefer various large animals such as donkeys or cattle and bite humans only as a second choice, whereas other species find humans almost equally attractive hosts; no species feeds exclusively on people. After feeding, blood-engorged females shelter in vegetation, on trees and in other natural outdoor resting places until the blood-meal is completely digested. In the tropics this takes 2–3 days, while in non-tropical areas it may take 3–8 days or longer, the speed of digestion depending mainly on temperature. A few species can lay eggs without a blood-meal (i.e. they are *autogenous*). Relatively little is known about black fly longevity, but it seems that adults of most species live for 3–4 weeks.

Females of some species may fly considerable ***distances*** (15–30 km) from their emergence sites to obtain blood-meals. They may also be dispersed long distances by winds. For example, it is not exceptional for adults of *S. damnosum* to be found biting 60–100 km from their larval habitats, and in West Africa there is evidence that prevailing winds can carry adults up to 400–600 km. These long distances can hinder control programmes, because areas freed from black flies can be reinvaded from distant larval habitats. In Central and South America black flies generally disperse only about 2–15 km.

In Europe and temperate and northern areas of America and Asia (i.e. the Palaearctic region) the biting nuisance from simuliids is seasonal. This is because adults die in the autumn and new generations do not appear until the following spring or early summer. In many tropical areas there is continuous breeding throughout the year, but there may nevertheless be dramatic increases in population size during the rainy season.

4.3 Medical importance

4.3.1 Annoyance

In both tropical and non-tropical regions black flies can cause very serious biting problems. Although the severity of the reaction to bites differs in different individuals, localized swelling and inflammation frequently occurs, often accompanied by intense irritation lasting for several days, or even weeks. Repeated biting by black flies such as *S. erythrocephalum* in central Europe, *S. posticatum* in England, *S. venustum* and *S. vittatum* in North America can cause headaches, fevers, swollen lymph glands and aching joints. In some areas of North America outdoor activities are almost impossible at certain times of the year due to the intolerable numbers of biting simuliids. The classical example of the nuisance caused by black flies was the seasonal exodus during the eighteenth century of people from the Danube valley area in central Europe, largely to save their livestock from attack by enormous numbers of *S. colombaschense*. However, it is as disease vectors that black flies are most important medically.

4.3.2 Onchocerciasis

Onchocerciasis is a non-fatal disease, often called river blindness, that is caused by the filarial parasite *Onchocerca volvulus*. There are no animal reservoir hosts, so the disease is not a zoonosis. Worldwide an estimated 37 million people are infected, of whom about 300 000 are blind or partially blind in 37 countries where the disease is endemic. About 99% of all cases occur in 30 countries in West Africa, Central Africa and much of East Africa. Yemen also has a few cases of onchocerciasis. In the Americas 500 000 people are at risk of getting onchocerciasis, and 180 000 are infected in localized areas of Brazil, Colombia, Ecuador, Guatemala, Mexico and Venezuela.

Black flies are the only vectors of human onchocerciasis. Their habit during feeding of tearing and rasping the skin to rupture blood capillaries makes them particularly suited to the ingestion of the ***skin-borne microfilariae*** of *O. volvulus*. Most microfilariae ingested during feeding are destroyed or excreted, but some penetrate the stomach wall and migrate to the thoracic muscles. Here they develop into sausage-shaped stages (called L_1 larvae), then moult to L_2 stage larvae, a few of which moult again to become elongate and thinner L_3 worms which pass through the head and down the proboscis. These ***infective third-stage*** worms (about 660 μm in length) leave the proboscis and penetrate the host's skin when black flies feed. The interval between the ingestion of microfilariae and the time when infective larvae (L_3) are in the proboscis is about 6–12 days, depending on temperature.

African vectors of onchocerciasis

Chromosomal studies show that the *S. damnosum* complex is composed of about 57 cytoforms, many of which merit species status. The *S. damnosum* species complex is widespread in tropical Africa, and some of the species are the most important vectors of onchocerciasis.

Adults of the *S. damnosum* species complex are mainly black. They can be recognized by their broad and flattened front tarsi having a conspicuous dorsal crest of fine hairs, and by a very broad white area on the first segment of the hind tarsus (basitarsus) (Fig. 4.2). Larvae are more or less covered with fine setae, and there are usually prominent dorsal abdominal tubercles (Fig. 4.3b). Branches of the pupal respiratory gills are thick and finger-like and are located within the neck of the cocoon (Fig. 4.4a). The immature stages are found in the rapids of small or very large rivers in both savanna and forested areas of Africa. Adults frequently disperse hundreds of kilometres from their larval habitats. The vectorial status of species within the *S. damnosum* complex varies, the most important vectors of onchocerciasis being *S. damnosum* s. str., *S. sirbanum*, *S. sanctipauli* and *S. leonense*.

Other, but much less important, vectors include *S. neavei*, which is responsible for transmission in the Democratic Republic of the Congo and Uganda. *Simulium neavei* is a ***phoretic*** species. That is, the larvae and pupae are attached to other freshwater fauna, mainly crabs of the genus *Potamonautes* and mayfly (Ephemeroptera) nymphs, both of which occur in small, rocky, rather turbid streams and rivers. *Simulium neavei* was eradicated from Kenya in the 1950s by bush clearing and insecticidal dosing of streams.

American vectors of onchocerciasis

Only eight species are involved in transmission in the Americas, and only the more important ones are mentioned here. *Simulium ochraceum* is widely distributed in Central America and northern parts of South America and is the principal onchocerciasis vector in southern Mexico and Guatemala. Adults are very small and are easily recognized by their dark brown legs, bright orange scutum (dorsal surface of the thorax) and yellow basal part of the abdomen, which contrasts with the black apical part. Females oviposit while in flight, dropping their eggs onto floating vegetation. Larval habitats consist of trickles of flowing water and very small streams, often concealed by bushes, vegetation and fallen leaves. Adults do not appear to disperse far. The main biting season is unusual in being in the drier months of the year.

Simulium metallicum occurs in Mexico and through Central America to northern areas of South America. In northern Venezuela it appears to be the most important vector, whereas in other areas such as in Mexico and Guatemala it is considered a minor vector. It is a black species and has a broad white area on the first segment of the hind tarsus. Larvae occur in small or large streams and rivers. Adults fly further from their larval habitats than do those of *S. ochraceum*.

Simulium exiguum is the only known vector in Colombia, and a primary vector in Ecuador. Above 150 m in the Brazilian Amazonas the main vector is *S. guianense*; below this height the vector is *S. oyapockense*.

4.3.3 *Mansonella ozzardi*

Mansonella ozzardi is a filarial parasite of humans that is usually regarded as non-pathogenic, although it has been reported as causing morbidity in Colombia and Brazil. It is transmitted in the Caribbean islands, Trinidad, Surinam and also Argentina by *Culicoides* species, mainly *C. furens* and *C. phlebotomus* (Chapter 6), but in northwestern Argentina, Brazil, Colombia, Guyana, Venezuela and southern Panama *S. amazonicum* is the main vector.

4.4 Control

Some protection can be gained by using repellents such as DEET, or by wearing pyrethroid-impregnated or sprayed clothing.

However, the only practical control method is to apply insecticides to larval habitats. These need be applied to only a few selected sites on watercourses for some 15–30 minutes, because as the insecticide is carried downstream it kills simuliid larvae over long stretches of water. Flow rates of the water and its depth are used to calculate the quantity of insecticide to be released. In the past dosing rivers with DDT has given good control of *S. damnosum* in Africa, but because of its accumulation in food chains DDT is no longer used. Nowadays insecticides such as temephos or *Bacillus thuringiensis* var. *israelensis* (*Bti*) are often used. Treatment has to be regularly repeated, sometimes at intervals of 1–2 weeks, throughout the year to prevent recolonization. In Guatemala insecticide-treated briquettes have been used to control *S. ochraceum*, which breeds in small rivers.

In many areas ground application of larvicides is difficult, either because of the enormous size of the rivers requiring treatment or because breeding occurs in a large network of inaccessible small streams and watercourses. Under these conditions aerial applications from small aircraft or helicopters may be appropriate.

4.4.1 Onchocerciasis control programmes

Because of the severity of river blindness in the Volta River Basin area of West Africa and its devastating effect on rural life, the world's most ambitious and largest vector control programme, the Onchocerciasis Control Programme (OCP), was initiated in 1974 by the World Health Organization (WHO). The programme was operational between 1974 and 2002. By 1986 there were 11 participating countries, namely Benin, Burkina Faso, Ivory Coast, Ghana, Mali, Niger and Togo all receiving vector control, and Bissau, Guinea Bissau, Senegal and Sierra Leone without vector control but receiving community treatment with ivermectin. In countries having vector control, rivers over an area of 1.3 million km^2 that were breeding the *S. damnosum* species complex were dosed weekly with aerial applications of temephos. Because of the appearance of temephos resistance in 1980 in some populations and species of the *S. damnosum* species complex, some rivers were treated with other insecticides or with *Bacillus thuringiensis* var. *israelensis* (*Bti*). In 1982, to hinder the spread of further resistance, different insecticides such as the organophosphates phoxin, pyraclofos and temephos and the pyrethroids permethrin and etofenprox were used in rotation.

In 1988 the OCP started large-scale distribution of the microfilaricidal drug ***ivermectin*** (Mectizan), which was given orally to people once or twice a year. In many areas vector control was included in this strategy. The programme was very successful, and by 2008 onchocerciasis was no longer a public health problem, except in Sierra Leone and some areas of Benin, Guinea and Togo.

In 1995 the African Programme for Onchocerciasis Control (APOC) was created to cover populations at risk in 19 countries outside the OCP. The objective was to establish, within 12 years, a sustainable community-based ivermectin treatment regimen, backed up with focal larviciding in some areas. Because ivermectin does not kill adult worms, control needs to continue for about 20–25 years to allow time for the reservoir of infection (adult onchocercal worms) in the human population to die out. Since APOC was launched 40 million people have been treated annually with ivermectin. The long-term objective is to eliminate blindness caused by onchocerciasis by 2020.

An estimated 95% of the population in Central and South America at risk of onchocerciasis live in Mexico, Guatemala and Venezuela. There are 13 main endemic areas in the Americas. In 1993 the Onchocerciasis Elimination Programme for the Americas (OEPA) was launched, which was based mainly on the distribution of ivermectin every six months. It was estimated that if 85% or more of the infected people were treated the disease could be eradicated. In 2007 Colombia became the first country in the world to have halted transmission of river blindness, and a further six of the endemic foci, and one subfocus of transmission, have probably also interrupted transmission. The hope was to stop transmission by 2007, but this was later changed to stopping transmissiom by 2012.

In 2007 resistance to ivermectin in *O. volvulus* was reported from Ghana. This has stimulated greater efforts to find new drugs, one of which is Moxidectin, which appears will be more effective than ivermectin.