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Phlebotomid Sandflies

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The article presents a synthesis of present knowledge concerning sandflies of the family Phlebotomidae in relation to leishmaniasis. Over 500 species of Phlebotominae are known, most of which belong to the genera Phlebotomus *and* Sergentomyia *in the Old World and* Lutzomyia *in the New World.* Phlebotomus *is the dominant genus in the palaearctic region, extending also into the other regions of the Old World where* Sergentomyia *is the principal genus. Sandflies are of little importance in temperate North America but in tropical America* Lutzomyia *is the main genus and is found over large areas. The distribution of sandflies largely determines the occurrence of leishmaniasis. Certain species of* Phlebotomus *and* Lutzomyia *transmit dermal leishmaniasis in large areas of the palaearctic and neotropical regions. Visceral leishmaniasis is transmitted by some species of* Phlebotomus *in much of the palaearctic region, except desert areas of North Africa, and in limited areas of Africa and India, and by a species of* Lutzomyia *in north-eastern Brazil. Sandflies are quite likely to bite man in the open country of much of the Old World; they tend however to be localized in distribution on account of their need for a suitable microhabitat (e.g., the burrow of the Central Asian large gerbil, which has been extensively studied in relation to dermal leishmaniasis). It is noted that the distribution of sandflies and leishmaniasis appears to be changing.*

A few species of sandfly are regarded as proved vectors of human leishmaniasis according to five criteria; other species which are the only man-biting sandflies in the area are probably vectors. Although it is not possible to make a clear-cut list of vectors, a table of some proved and suspected vectors is included.

Many aspects of the structure and biology of sandflies have a bearing on the epidemiology of leishmaniasis; some of these aspects are discussed below. Although most sandflies are much alike in general appearance, there are great biological differences, which result in different epidemiological situations in the Old and New Worlds and in the northern and southern hemispheres. These epidemiological differences are largely due to the predominance of one or other of the three main genera. The recognition of species as vectors is discussed in the final section of this article; the names of vectors and some suspected vectors are listed in the accompanying table.

Methods of study are described in numerous publications, including the forthcoming fourth edition of Smart (1956). References to accounts of the external and internal anatomy of sandflies may be found in works on taxonomy.

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TAXONOMY

Over 500 species of Phlebotomidae are known from various parts of the world and there is an extensive literature on their classification. Some general works are those of Abonnenc & Minter (1965), Fairchild (1955), Forattini (1970), Lewis (1967), Perfil'ev (1966), Quate (1962, 1965), and Theodor (1970).

The sandflies were regarded as a family, the Phlebotomidae, by Perfil'ev (1966). Theodor's system of classification, in which most species are assigned to three genera—*Phlebotomus* and *Sergentomyia* in the Old World and *Lutzomyia* in the New—is used here. The two latter genera are large. *Lutzomyia* is difficult to divide into subgeneric groups but this is not due to uniformity; in fact, there is great diversity in this genus.

The status of four sandflies

Phlebotomus andrejevi is closely related to *Phlebotomus caucasicus*, and V'jukov has reported finding some intermediate specimens in the USSR, suggesting that the former may be a synonym of the latter.

The status of *Sergentomyia dentata*, which has been studied by Perfil'ev and Theodor, has been the subject of recent discussion. *Sergentomyia dentata arpaklensis*, referred to by Theodor & Mesghali (1964), is evidently a synonym for *Sergentomyia dentata*. The two forms differ chiefly in the size and number of the large lateral cibarial hind teeth of the female, which lie on each side of the central small teeth. In *Sergentomyia dentata* there are about 4 large teeth on each side, and in *Sergentomyia arpaklensis* about 6 or 7. Saf'janova, however, reported finding a female with fewer teeth among a number of typical *Sergentomyia arpaklensis* from Turkmenia, and this specimen proved to be very similar to the holotype of *Sergentomyia dentata* from Quetta in West Pakistan. It now seems that *Sergentomyia dentata* should be regarded as one species with no subspecies, *bruchoni* having already become a synonym (Theodor, 1958).

The sandfly generally known as *Sergentomyia arpaklensis* in the USSR proved to be two species, *S. dentata* and *S. sintoni* Pringle, 1952. The latter has 12–14 cibarial hind teeth of uniform size, and was referred to as *Sergentomyia arpaklensis* by Perfil'ev (1939). Examination of a number of specimens indicated that *Sergentomyia sintoni* is the dominant species of the *Sergentomyia dentata* complex in Turkmenia, Uzbekistan, and northern Iran, whereas *Sergentomyia dentata* is sporadically distributed from Greece to Central Asia and in the Azerbaidzhan SSR.

Phlebotomus langeroni orientalis is treated as a subspecies by some authors and as a species by others. Here, it is treated as a subspecies in accordance with the facts set out by Quate (1964).

DISTRIBUTION

Sandflies occur in the tropics and other warm areas but, according to Dolmatova, they exist as far north as 48°N in Khazakhstan and Kirgizia in the USSR; they are also reported from the Beauvais area north of Paris, the Isle of Jersey, and Kamloops in Canada. They are widespread north of the Tropic of Cancer and, like *Leishmania tropica*, are tropical in the sense of inhabiting warm countries, though most species of the important genus *Phlebotomus* occur outside the tropics.

Since sandflies breed in soil or litter, they are largely independent of surface water, while their small size enables them to use many microhabitats. For these reasons, they are present in vast regions of the world but are much more limited by cold than are the medically important groups of insects with aquatic larvae.

The Old World

Phlebotomus is the dominant genus in the palaearctic region, and it extends into the other three zoogeographical regions of the Old World, in which *Sergentomyia* is the principal genus. There are several species of *Phlebotomus* in the north and east of the Ethiopian region but remarkably few in the west. In the Old World, many species live in rather dry, open country.

In the USSR, sandflies occur in the Mediterranean (Caucasus and Crimea) and Central Asian (Central Asian republics, including Khirgizia and Kazakhstan) subzones of the palaearctic region, each subzone having its particular fauna. Lysenko has reported that the northern limit of urban dermal leishmaniasis occurs at latitude 44° 45′ N, to the south of the northern limit of sandflies. At this latitude the temperature allows at least one passage of the parasite through the vectors, *Phlebotomus papatasi* and *Phlebotomus sergenti*, during one season of transmission.

The New World

In the nearctic region there is no genus comparable to *Phlebotomus* and there are few species of sandfly, and none of medical importance. In the neotropical region, many sandflies live in the extensive forests, the main genus being *Lutzomyia*.

The forest environment

In the Old World forests there are few important man-biting sandflies; in many forests of the New World, however, there are vast numbers of potential man-biters. These flies normally have no contact with man, but in some areas various factors bring man into contact with potential vectors of leishmaniasis. In Belize, mahogany workers enter the forests regularly and *chicleros* do so during the rains, at which time sandflies abound. Road building in Panama has brought many people into contact with sandflies, while in Costa Rica agricultural development has had the same effect. Heyneman has described many other examples. Forest sandflies are not uniformly distributed, but little is known of limiting factors. Some Venezuelan species occupy microhabitats but these may not afford significant microclimates (Scorza & Ortiz, 1960).

The open environment

In many areas of savanna, steppe, and desert, particularly in the Old World, man-biting sandflies are common, and travel, now so much more frequent, brings man into contact with them. The distribution of vectors largely determines whether leishmaniasis in any area is strictly a disease of animals, a sporadic zoonosis, a permanent zoonosis, or a rural or urban disease that has lost its animal reservoir. Examples of a sporadic zoonosis and of a permanent zoonosis are seen in Iran. In the region around Isfahan nomads occasionally become infected with *Leishmania donovani*, which is probably transmitted among wild Canidae by *Phlebotomus major*. People living in villages near Isfahan, on the other hand, become infected with *Leishmania tropica* from rodent colonies.

Garnham reported that one leishmaniasis that has lost its original animal reservoir is caused by anthroponotic *Leishmania tropica* and is urban and more widespread than the zoonotic form. According to Lysenko, this leishmaniasis tends not to affect small groups of houses, apparently for immunological reasons.

Much open country in areas of endemic leishmaniasis is hot and wind-swept by day and sandflies are obliged to shelter in microhabitats. Thus in some areas, sandflies, and therefore leishmaniasis, are localized. In Central Asia, important sandfly microhabitats are the extensive burrows of the large gerbil, *Rhombomys opimus*, and other rodents, which, because of the climatic conditions, need to burrow much more than do their forest counterparts. These resting and breeding sites are so significant in some areas of steppe that the local sandflies are termed either " burrow sandflies " or " settlement sandflies ".

Nevertheless, localization is not universal in open country; in the Sudan savanna, soil fissures provide an extensive and continuous system of shelter.

Distribution of vectors

Of the species shown in the accompanying table, most of the *Phlebotomus* occur north of 10° N in the Old World and most of the *Lutzomyia* are found in tropical America. Detailed information about some species can be found by reference to articles on taxonomy.

The distribution of dermal and visceral leishmaniasis is largely determined by the presence of certain sandflies. The general distribution of dermal leishmaniasis corresponds roughly to the main area of *Phlebotomus* (the south of the palaearctic region) and to much of the *Lutzomyia* area of tropical America. There is an outlying area in Africa where diffuse dermal leishmaniasis occurs.

Visceral leishmaniasis exists in many parts of the *Phlebotomus* area of the palaearctic region except the driest part of northern Africa where the subgenus *Larroussius* does not flourish. Elsewhere in the Old World the disease is distinctly localized. Lysenko reported that in tropical Africa visceral leishmaniasis occurs south of the dermal leishmaniasis zone in parts of the areas occupied by *Phlebotomus langeroni orientalis* and *Phlebotomus martini*. The main area in the orient, India, is partly within the range of *Phlebotomus argentipes*. In tropical America visceral leishmaniasis is present in a dry eastern area of the *Lutzomyia longipalpis* range and also in some other areas where the limiting factors are not yet understood.

Some factors influencing distribution

Sandflies, being insects of warm climates, are not usually found at great altitudes. The upper limit of sandflies in Central Asia is higher in the southern latitudes according to Maruašvili. Nadžafov reported that in Azerbaidzhan sandflies are found up to heights of 1000 m and species of *Larroussius* tend to occur in the hills. In South America, sandflies, living largely in caves, transmit *uta*, a form of dermal leishmaniasis, at altitudes as high as 2 800 m.

The type of soil in a particular area affects sandflies in many ways. For instance, in the USSR, the distribution of gerbil burrows is to some extent determined by the nature of the soil while the physicochemical composition of the soil and the height of the water table have an important influence on the distribution of various species of sandfly (Saf'janova & V'jukov, 1967). In parts of Central Asia, new irrigation canals have raised the water table for distances of several kilometres on each side of the canals. The changed conditions may favour the breeding of gerbils and therefore of sandflies. Under such conditions it is possible to predict the occurrence of *Leishmania tropica*, and sometimes of *Leishmania donovani*. There is an important difference between riverain areas and dry intervening stretches; *Phlebotomus papatasi* and *Sergentomyia sintoni* tend to flourish near rivers, while *Phlebotomus caucasicus*, which is not very anthropophilic, tends to predominate in relatively dry sandy areas. In India, the type of forest soil determines the main area of *Phlebotomus argentipes*.

Some vectors and suspected vectors of human leishmaniasis

Genus and subgenus or group	Species or subspecies	Type of leishmaniasis with which sandfly is, or may be, associated		General distribution of sandfly
		Dermal	Visceral	
Phlebotomus				
(*Phlebotomus*)	*duboscqi*	+		North Africa, Arabia
	papatasi	+	(+) [a]	Mediterranean, western Asia, northern Africa, India
(*Paraphlebotomus*)	*caucasicus*	+ [b]		Caucasus, western Asia
	sergenti	+		Mediterranean, western Asia, northern Africa, Arabia
(*Synphlebotomus*)	*celiae*		+ [c]	Kenya
	martini		+	Kenya, Ethiopia, Sudan
	vansomerenae		+ [c]	Kenya
(*Larroussius*)	*ariasi*		+	France, Spain, Portugal, Morocco, northern Algeria
	kandelakii		+	West Asia, Caucasus
	langeroni orientalis		+	Sudan, Ethiopia, Kenya, Chad, Niger, southern Arabia
	longicuspis		+	Northern Africa
	longipes	+		Ethiopia, Sudan
	major syriacus		+	Mediterranean, Crimea, Caucasus
	perfiliewi	+		Mediterranean, Crimea
	perniciosus tobbi		+	Eastern Mediterranean, Caucasus, Iran
(*Adlerius*)	*chinensis chinensis*		+	Mainland China
	c. halepensis		+	Caucasus, Iran, Syria
	c. longiductus		+	Uzbekistan, West Pakistan, northern India
	simici		+	South-eastern Europe, western Asia
(*Euphlebotomus*)	*argentipes*		+	Burma, Ceylon, India, Malaya, West Pakistan, Sabah, Thailand, Viet-Nam
Lutzomyia (*Lutzomyia*)	*renei*	+		Brazil (Bahia and Minas Gerais)
	longipalpis	+	+	Mexico to Brazil
(*cruciata* group)	*cruciata*	+		Central America, USA (Florida)
	gomezi	+		Central America, Venezuela, French Guiana, Ecuador, Brazil
(*migonei* group)	*migonei*	+		Venezuela, Brazil, Paraguay, Argentina
(*vexator* group)	*sanguinaria*	+		Costa Rica, Honduras, Panama
(*Nyssomyia*)	*anduzei*	+		Central America, Venezuela, French Guiana, Brazil
	flaviscutellata [d]	+		Brazil, French Guiana, Ecuador
	intermedia	+		Brazil, Paraguay, Argentina
	olmeca	+		Mexico, Guatemala, Belize
	trapidoi	+		Honduras, Costa Rica, Panama, Ecuador
	whitmani	+		French Guiana, Brazil, Paraguay
	ydephiletor	+		Central America, Mexico
(*Psychodopygus*)	*panamensis*	+		Mexico, Central America, Venezuela, Colombia, Brazil, Peru
(*Pintomyia*)	*fischeri*	+		Brazil, Paraguay
	pessoai	+		Brazil, Paraguay

[a] In part of Iraq.
[b] Mainly animal infections.
[c] Secondary vectors.
[d] Animal infections.

Leishmaniasis areas in relation to species of sandfly

According to Heyneman, the specificity of *Leishmania* infection is usually more restricted in the invertebrate host than the vertebrate host; the ecological requirements of certain sandflies therefore tend to delimit the leishmaniases they transmit. Often, however, the vector species is more widespread than the disease.

In the southern USSR, dermal leishmaniasis extends nearly to the northern limit of *Phlebotomus papatasi*, and the rural form is prevalent, or serious, where the large gerbil has 2 generations a year. *Phlebotomus argentipes* in West Pakistan is too scarce to be significant, and in Malaya it seldom bites man. The south-east coast of India, with lateritic soil and little woodland, has some *Phlebotomus argentipes* but very little kala azar. Oriental kala azar occurs mainly in a riverain area of eastern India, 200–300 m above sea level; the land is wet and well-wooded, and is also favourable to hookworm transmission.

Maps of leishmaniasis distribution show a number of sporadic records in areas where few or no man-biting sandflies are known. Since some such records may be due to imported cases, studies on the distribution of vectors should be based on proved foci.

Notes on some palaearctic vectors

The sandflies of Uzbekistan have been studied by Dergačeva and others who reported finding 11 species in large-gerbil burrows and in human settlements. *Phlebotomus caucasicus* and *Phlebotomus andrejevi* predominate in the large-gerbil colonies outside oases. *Phlebotomus caucasicus* is never abundant in villages and bites man much less often than does *Phlebotomus papatasi*. *Phlebotomus caucasicus* probably transmits the zoonotic *Leishmania tropica* among gerbils and may occasionally transmit it to man. *Phlebotomus sergenti* could more readily be infected with the anthroponotic form of *Leishmania tropica* than could *Phlebotomus papatasi*, and was therefore regarded as the vector. Around Kirovabad in Azerbaidzhan, *Phlebotomus sergenti* is somewhat exophagous, often biting out of doors; therefore, microfoci of *Leishmania tropica* include open spaces in the town.

Dolmatova has reported that *Phlebotomus kandelakii* is probably the vector of kala azar in Georgia and the Azerbaidzhan SSR, and Nadžafov reported that *Phlebotomus chinensis* in parts of Azerbaidzhan flourishes in more humid environments than do some species of *Larroussius*. *Phlebotomus chinensis* probably transmits *Leishmania donovani* in Georgia, the Azerbaidzhan SSR, south-western Kirghiz SSR, and the Turmenian SSR (Petriščeva et al., 1966). According to Dolmatova this species is markedly anthropophilic in Tadjikistan and endophilic farther east, where it may exist as a different subspecies.

Sergentomyia sintoni in the USSR feeds mainly on reptiles and sometimes on gerbils; if it is abundant, it may on rare occasions attack man. This effect of population density is a feature of some other sandflies and certain other biting flies. The host preference of this sandfly, alone, suggests that it is unimportant as a vector. However, during the study of its role as a vector, some confusion was caused by the finding that *Leishmania tropica* in *Sergentomyia sintoni* developed in the anterior station (Saf'janova & Alekseev, 1967b), but Dergačeva reported that, for various reasons, this sandfly is now considered to be negligible as a vector of human leishmaniasis and of no practical significance. Its exact role, however, can be defined only with reference to certain foci and it may play some part in maintaining infection. Despite its practical insignificance, this sandfly deserves special attention because it exhibits problems of taxonomy, biology, and relationships with *Leishmania*.

Sergentomyia grekovi in the USSR was excluded as a vector of *Leishmania tropica* because it was not abundant in the epidemic season (July–August), most flies were nulliparous when the population was largest (September), and most of the parasites found were *Crithidia*.

Phlebotomus papatasi and *Phlebotomus mongolensis* are associated with colonies of *Rhombomys opimus* in Iran (Mesghali et al., 1967; Nadim et al., 1968a, 1968b), and *Sergentomyia sintoni* seems to play no part in the transmission of mammalian leishmaniasis in north-eastern Iran (Nadim et al., 1968c). Theodor reported in 1967 that *Phlebotomus major* is the vector of kala azar in Israel and that the related *Phlebotomus p. tobbi* and *Phlebotomus simici* may be involved in transmission.

Phlebotomus ariasi, the habitual vector of kala azar in southern France (Rioux & Golvan, 1969), is one of the three main anthropophilic sandflies there, and is much commoner than *Phlebotomus perniciosus*, according to Rioux et al. (1968). These authors found it both indoors and outdoors, and assessed its numbers per square metre of sticky trap. Difficulty in finding infected females was not considered significant in view of low infection rates in other parts of the world.

Five species of *Phlebotomus* and one of *Sergentomyia* have been reported from Tunisia (Dancesco et al., 1968), in contrast to the fauna of the Ethiopian region, where *Sergentomyia* is dominant.

Notes on some tropical sandflies in relation to Leishmania

Southgate & Minter have reported that *Sergentomyia clydei*, which is widespread in Africa, India, and some neighbouring areas, is the vector of the lizard parasite *Leishmania adleri* in Kenya. This may cause transient infections in man and thus affect the result of immunity surveys.

Lutzomyia longipalpis is the vector of *Leishmania donovani* in the relatively dry area of Ceará in northeastern Brazil. This association provides an interesting parallel to the occurrence of kala azar in various dry areas of the Old World. Dávalos reported that kala azar exists in a markedly dry area of Mexico.

Changing conditions

The distribution of sandflies and leishmaniasis is not static. In some areas, sandflies have been destroyed by human activities, sometimes inadvertently. Deforestation affects some species, and cultivation has made sandflies difficult to find in parts of Azerbaidzhan, according to Nadžafov et al., and around Lahore in West Pakistan (Lewis, 1967a). Urbanization has reduced sandfly numbers in Teheran and, according to Theodor, in Israel also.

On the other hand, certain sandflies in areas at one time free of leishmaniases can become vectors. Infected persons or animals may spread leishmaniasis (Guilhon, 1965; Minter, 1964), and Heyneman reported that anthropozoonotic leishmaniasis has been known to advance into new areas. Garnham has suggested that American kala azar might become an important disease and suggested that a close watch should be kept on its incidence and distribution. According to Heyneman, populations will continue to advance into zoonotic areas, and it is even possible that new leishmanial diseases are in the course of development. Vector sandflies may spread, and it is difficult to foresee the limit of westward extension of *Phlebotomus l. orientalis* in Africa (Lewis & Hitchcock, 1968).

Further knowledge required

The possible spread of leishmaniasis points to the need for more information about sandfly distribution in uninfected areas. Research is concentrated mainly on the limited areas of human leishmaniasis, and general biological expeditions elsewhere yield little information about sandflies because methods of collecting, though simple, are specialized. Lysenko has said that widespread surveys are needed to help in predicting epidemiology and in constructing prognostic maps of leishmaniasis.

Among the species needing further attention is *Phlebotomus papatasi*, which is known to occur in the palaearctic region as far east as Central Asia but which has not been recorded from the coast of mainland China. Nothing is known about its occurrence in much of Asia. More information is required about the African species *P. martini* and *P. l. orientalis*, both of which may escape attention unless they are captured on human or animal baits.

Among the many survey methods, the use of light traps may be mentioned here. They are little used in Africa because they usually catch non-anthropophilic *Sergentomyia*, but experience in the USSR and southern Europe (Rioux & Golvan, 1969) has shown how useful such traps can be. Petriščeva has reported that oiled-paper traps, used in the USSR in 1930, have been useful in many dry countries.

In recent decades, sandfly taxonomists have concentrated largely on the basic work of describing species and classifying them. Distribution maps have been produced for a few countries, and this work should now be extended. Much could be achieved if leishmaniasis workers would send sandflies from little-studied areas to experienced sandfly taxonomists with access to good reference collections so that new maps could be prepared.

BIOLOGY

Larvae

The minute size of the early stages, and the subterranean habit of many species, make sandfly larvae difficult to find. Thus, little is known about them in most areas. Indirect methods of observation, such as the use of emergence traps, which can be left for a month over a suspected breeding site, can be useful.

Larvae of *Phlebotomus sergenti* in Iraq are evidently favoured by a high water table (Pringle, 1952), which often is due to irrigation canals or to urban drainage water. Such developments can thus affect the incidence of dermal leishmaniasis.

In the dry Golodnaja Steppe of Uzbekistan, the equable microclimate of large-gerbil burrows affords good breeding sites for sandflies. In one instance, a chamber 120 cm below the surface of the ground was found to contain some 500 larvae and pupae, nourished by rodent faeces. In another example, larvae were present in a nesting chamber 3 m below the surface. Larvae of *Phlebotomus papatasi* were found at a higher level than those of *Sergentomyia sintoni*.

Sandfly larvae develop very slowly, and those of some northern species pass the winter in diapause of the fourth stage. For this reason, adults can appear early in summer, and leishmaniasis can exist in places with a cold winter.

Adult habitats

Forests. Vertical stratification of forest species, familiar in certain mosquitos and tabanids, has been observed in America, and may determine the vertebrate food of some sandflies. In Panama, for instance, where the animal reservoir may be arboreal, *Lutzomyia trapidoi* is abundant in the canopy layer (Johnson et al., 1963). Williams (1970) showed that in Belize most species of sandfly were active too high among the foliage of trees to be likely vectors of *Leishmania mexicana* among rodents near the ground.

Open country. A few types of resting place used by sandflies are as follows. The temperature in some is different from that of the environment and this factor must have an important effect on the life cycle of *Leishmania* (Garnham, 1964). In the Gezira area of the Sudan the temperature of the soil surface often exceeds 80°C, but vast numbers of delicate sandflies live by day in the extensive labyrinth of soil cracks.

Phlebotomus kandelakii, one of the " wild " sandflies of Central Asia, often rests in hollow trees, and *Phlebotomus major syriacus* and *Phlebotomus perniciosus* tend to occur in gardens in Crete (Theodor, 1965). *Phlebotomus l. orientalis* in the Sudan occurs among patches of acacia (Hoogstraal & Dietlein, 1963) and sometimes rests in certain evergreen trees; it might, therefore, be possible to combat the fly by the use of residual sprays (Quate, 1964).

Dubrovskij has described the remarkable Central Asian biotope formed by the burrow of *Rhombomys opimus*, which may be a complex colony with 1000 m of tunnels and hundreds of openings. These colonies are situated in sloping soil, which is usually loose and sandy; inside, there is a moderate temperature and high humidity. The equable microclimate, with a temperature range of only 1 or 2 degC and a relative humidity fluctuation of only 10%, contrasts with the extreme climate of the Golodnaja Steppe, for instance, where the temperature of the soil surface may reach 80°C. The distribution of the sandflies has an important effect on leishmaniasis, and the study of the relationship is an example of landscape ecology. Other rodents provide shelters for sandflies but are of minor epidemiological importance. The humidity of some resting sites can increase with a rise in the water table, and Saf'janova (1964) reported a local increase in numbers of *Phlebotomus papatasi* for this reason.

In the tropics, many species of sandfly rest in the air shafts of termite hills, and *Phlebotomus martini*, which occupies old shaded termitaria, is the vector of " termite hill kala azar " in Kenya (Minter, 1963). Such microhabitats can lead to much localization of sandflies and consequently to microfoci of leishmaniasis.

Caves. Many sandflies occur in certain types of cave, and some belong to man-biting species. It is possible that the cave-dwelling habit was a step in the development of anthropophily. Sandflies can live throughout the year in some Central Asian caves, where they are part of a biocoenosis that includes the porcupine, a host of *Leishmania donovani*.

When sandflies have been cleared from villages by insecticides, cave sandflies may enable the species to recolonize the villages.

The size of spiracles

The anterior thoracic spiracles of certain palaearctic sandflies in relatively humid environments are known to be slightly larger (measured in relation to the length of the thorax) than those of some sandflies in dry conditions. This difference sometimes applies to flies of one species in different biotopes (Dergačeva, 1967b). Scorza et al. (1963) observed seasonal variation in the spiracles in two Venezuelan species.

Physiological age of sandflies

Detinova and others have studied this important subject in relation to the transmission of disease by biting flies. Recognition of parous sandflies is important because flies must survive at least one oviposition to be potentially infective, but this aspect of the study of sandflies is limited by the small size of the ovaries and the difficulty of tracing evidence of more than one oviposition. In Central America, nearly all parous females can be recognized by the state of the ovarioles, but dissection and inspection take some time and it is practicable to examine only small samples of a population (Lewis, 1965). In the Old World, parous females can often be recognized by the appearance of the accessory glands, but in some American species the glands are unsuitable for this purpose. Age grading of sandflies, and its uses, have been discussed by Lewis et al. (1970).

Nulliparous individuals of some species have a well-developed fat-body, and this is one of the physiological differences between parous and nulliparous flies. The process of blood digestion and egg maturation, during which females tend to be less active than young nulliparous flies, can be divided into several stages. During the intermediate stages, females of *Phlebotomus caucasicus* are only slightly susceptible to infection with *Leishmania infantum.*

There is some indication that parous *Lutzomyia cruciata* have a special biting cycle and, if this is substantiated, it could aid the difficult search for naturally infected flies (Williams, 1966b). Nulliparous flies can usually be disregarded during this search but Williams (*op. cit.*) has shown that one may occasionally become infected with *Leishmania* without having sucked blood.

Length of life

Little is known about the natural duration of life of sandflies but some idea may be gained from infected flies. To transmit kala azar, sandflies must bite twice, and, in the Mediterranean area, each gonotrophic cycle lasts about a week. A normal life may be assumed to be approximately a week, although some flies live a month in captivity. There is no indication that life is shortened by leishmanial infection. Dolmatova reported that a summary of records shows that, in certain areas, sandflies in nature can live 2–3 weeks, and that some individuals have survived for 2 months. During *Leishmania* infectivity experiments, Alekseev found that ingestion of a large volume of liquid with many parasites increased the flies' length of life and confirmed that the presence of flagellates appeared not to affect the flies adversely but to benefit them in some way.

In Kenya weather can have an indirect effect on species of *Synphlebotomus*. Minter (1964) showed that low rainfall favoured them by reducing competition by *Sergentomyia garnhami*. Transmission of *Leishmania donovani* to man is therefore particularly intense after the rains.

Movement

Time of activity. Sandflies are crepuscular–nocturnal insects but some may bite by day. Dergačeva has pointed out that daytime biting occurs in dark buildings in Asia as well as in parts of Central American forests (Williams, 1966a), where *Leishmania* can be transmitted at this time. In some areas, different species are active at different times. For instance, some species of *Larroussius* enter houses later in the day than do *Phlebotomus papatasi*; Dolmatova has suggested this is possible because they require a higher humidity.

Flight range. Sandflies often move in short hops. Dergačeva has reported that in Uzbekistan most flies were found to travel only a few metres, but a few have been known to travel 1.5–2 km. The vast majority of sandflies remain within 20–30 cm of the soil surface. Sorties from rodent burrows are proportional to the density of the sandfly population.

Sandflies are occasionally seen on trains and river steamers, but there is no evidence of any species being transported except, perhaps, the occurrence in Mauritius of the Indian species *Sergentomyia babu.*

Effect of wind. Wind greatly limits sandfly activity and is an important feature of savanna country as opposed to forest. It doubtless limits transmission in many places. In Uzbekistan the wind always blows by day and night, and sandflies are therefore more active in human settlements than near rodent burrows. Near rodent burrows, most sandflies bite in sheltered spots. Hoogstraal et al. (1962) reported that in the Sudan even a light wind could prevent sandflies from biting.

Effect of temperature. In Uzbekistan sandflies do not bite at temperatures below 20°C, and most biting occurs between temperatures of 25°C and 28°C.

Attraction to light. Phlebotomus perfiliewi and *Phlebotomus perniciosus*, but not *Phlebotomus papatasi*, are attracted by artificial light, and according to Dergačeva *Phlebotomus perfiliewi* will not enter a dark room. Dolmatova has reported that in Azerbaidzhan *Phlebotomus kandelakii, Phlebotomus perniciosus tobbi*, and *Phlebotomus chinensis* have often been taken in light traps, but in Uzbekistan *Sergentomyia sintoni* was not attracted to artificial light. The attraction of some of these species to artificial light may increase the transmission of *Leishmania.* In Africa, light traps tend to catch many *Sergentomyia squamipleuris*. *Phlebotomus l. orientalis* has occasionally been caught in lighted rooms in the Sudan, but this species may have been partly attracted to man, as in the case of South American sandflies in Shannon-type traps.

Feeding habits

Sugar-feeding. Most or all species probably feed on plant sugars (Lewis & Domoney, 1966). Dolmatova has reported that the crops of some *Phlebotomus papatasi* and *Phlebotomus major* in houses have been found to contain sugar, and it is possible that one function of the crop contents is to maintain the water balance of the fly. It would be interesting to know if sugar-feeding introduces into the gut bacteria that might be harmful to *Leishmania.*

Blood-sucking: host preference. Gut contents have seldom been analysed owing to the small size of the blood meal and the difficulty of obtaining enough gorged specimens of wild species of sandfly.

Some rodent-biters seem to be purely zoophilic; one example is *Lutzomyia flaviscutellata* at Belém, Brazil, which transmits rodent leishmaniasis (Lainson & Shaw, 1968). Garnham has reported that human cases are rare, and there is evidently a " closed circuit " infection in the rodents (Shaw & Lainson, 1968).

Disney (1966) used a rodent-baited oil trap in Belize and showed that *Lutzomyia olmeca* fed commonly on rodents although few bit man. This species was shown by Biagi et al. (1965) and Disney (1967) to be the vector of *Leishmania mexicana*, and Williams (1970) found that disturbing leaf litter shortly before dawn caused *Lutzomyia olmeca* to bite man.

Previously it had been thought that the vectors were species that often bite man and sometimes bite rodents, and according to Heyneman it is likely that human involvement in zoonotic leishmaniasis is sometimes caused by sandflies that occasionally bite the reservoir animal.

Distribution of man-biters: Phlebotomus *and* Lutzomyia. Many species of *Phlebotomus* suck mammalian blood and can bite man; some attack lizards as well. In the Old World, exophilic and endophilic man-biters are particularly common in the main area of *Phlebotomus*—namely, the south of the palaearctic region. Pervomajskij (1948) regarded sandflies as the dominant man-biting insects of northern Iran.

In much of the Ethiopian region, anthropophilic sandflies are scarce or absent, and the presence of some important man-biters in Kenya, southern Arabia, the Sudan, and the highlands of Ethiopia may perhaps be regarded as a southern extension of the palaearctic fauna. Even in the kala azar area of Kenya, however, man-biters are not conspicuous, being seasonal and local, and research was carried on for more than a year before one was discovered. One of the man-biting sandflies of north-eastern Africa, *Phlebotomus l. orientalis*, has been found in Niger (Abonnenc et al., 1964) and Chad (Lewis & Hitchcock, 1968), but very few other anthropophilic species were found in West Africa by Abonnenc & Larivière (1959), Lewis & McMillan (1961), or Lewis & Murphy (1965).

In the oriental region, *Phlebotomus argentipes* is primarily zoophilic and it is conceivable that an animal reservoir of *Leishmania donovani* exists in India (Barnett, 1962). According to Heyneman, there are several reasons for and against this hypothesis.

In the neotropical region, many species of *Lutzomyia*, including vectors of dermal leishmaniasis, bite man in forest country. In Belize, for instance, about half the species attack man, in contrast to the numerous zoophilic sandflies of West Africa. Garnham has suggested that the apparently great variety of neotropical vectors of leishmaniasis may have led to the profuse speciation of leishmanial parasites of man in that region.

Lutzomyia longipalpis in Venezuela attacks man when it is abundant (Torrealba, 1964). It has a wide range of hosts, and Pifano et al. (1962) attributed the low incidence of kala azar in Venezuela to this fact.

Distribution of man-biters: Sergentomyia. Some species of *Sergentomyia* attack man at times, but very rarely in Central Asia. *Sergentomyia sintoni* bites rodents in Turkmenia (Saf'janova, 1963). Dergačeva has expressed the view that in Uzbekistan *Phlebotomus papatasi* and *Sergentomyia sintoni* would be likely to bite man in equal numbers if the latter were several hundred times more numerous. In the Sudan, *Sergentomyia schwetzi* and *Sergentomyia clydei* bite people regularly (Quate, 1964), and Southgate and Minter have reported that the latter sometimes does so in Kenya. *Sergentomyia clydei*, like *Phlebotomus argentipes*, shows infraspecific variation in its habits, biting man in Africa but not in India. In Kenya, 8 species of sandfly attack man, at least occasionally, and *Sergentomyia garnhami* does so commonly (Wijers & Minter, 1962).

The site of bites on the human body. The site of bites determines the situation of primary lesions of dermal leishmaniasis. During the hot weather of the sandfly season in Iraq many people sleep out of doors with few bedclothes, and lesions develop on various parts of the body. In Belize, people are often bitten in the forest when wearing shirts and trousers, and lesions tend to develop on the face, particularly the ears. Two species of phlebotomid are noted for biting the ear, but one occurs in Kenya and one in Malaya. Williams (1966a) found that the common man-biters in Belize show no preference for the ears, and he thought that the main vector there might prove to be a zoophilic species that occasionally bites the human ear.

The infectivity of a sandfly depends partly on the type of infected tissue that it bites. For instance, the chance of a fly's becoming infected with *Leishmania tropica* from man is reduced if the lesions are ulcerated.

Numbers of bites by individual sandflies. Some sandfly species bite several times during a gonotrophic cycle, and this can have an important effect on transmission (Adler & Theodor, 1957).

Conditions in the alimentary canal in relation to Leishmania

Various physical and chemical factors affect *Leishmania* in the insect host, and some of these, such as the unidentified factor encountered by Hertig & McConnell (1963) during their efforts to transmit *L. brasiliensis* through sandflies to Panamanian mammals, are still unknown.

The peritrophic membrane. The nature of the peritrophic membrane evidently affects *Leishmania* (Lewis), but little is known about how and when flagellates avoid being trapped by it in different species of sandfly.

Chemical conditions. It is well known that sugar and salt, respectively, have an important effect on *Leishmania* in *Phlebotomus papatasi* and *Phlebotomus argentipes*, but sugar meals do not seem to be necessary for *Leishmania brasiliensis* to develop.

Adler & Theodor (1957) pointed out that some bacteria cause *Leishmania* to die, and that abnormal digestion of blood in *Phlebotomus major* could affect the parasite. *Leishmania brasiliensis* will grow in the presence of bacteria.

Position of Leishmania *in the gut*. Inspection of the gut of an infected sandfly to determine the exact position of promastigotes can give important information about the parasite. The midgut is differentiated into an anterior, thoracic, tubular part and a posterior, abdominal, expanding part (sometimes called the stomach), as in mosquitos (Snodgrass, 1959). The anterior part is often called the cardia, but is here termed the fore stomach because the word cardia should be reserved for the extreme anterior part of the midgut, according to Snodgrass (1935). The fore stomach contains numerous, minute, inwardly pointing rods (Adler & Theodor, 1926). When Old World leishmanial parasites of mammals develop in a sandfly they normally come to occupy the fore stomach, where promastigotes are mechanically attached by their flagella to the gut wall between the rods. Groups of the flagellates have been described by Garnham as rosettes and as clusters in a flower-like (chrysanthemum) pattern. Later, the promastigotes reach the oesophagus, pharynx, and mouth-parts. The term " anterior station " is often used for infections of the fore stomach and fore gut, as opposed to the " posterior station " in the hind gut, but these terms are regarded as misleading by Anderson & Ayala (1968).

Possible effect of gut conditions on the subsequent life of Leishmania. Barnett & Suyemoto (1961) suggested that particular species of sandfly confer pathogenic characteristics on *Leishmania* that infect them. Nothing definite is known about the possible physical or biochemical effects of passage through the insect host, but the matter is perhaps relevant to the puzzling question of the nature of *Leishmania tropica minor*. It is normally transmitted by *Phlebotomus papatasi* and may be derived from *Leishmania t. major*, which is often transmitted by an unrelated sandfly.

Reproduction

Autogeny. The capacity of a mosquito to lay its first batch of eggs without having sucked blood was discussed by Laurence (1964). Dolmatova has reported that *Phlebotomus papatasi* is facultatively autogenous in Egypt, and certain populations of it are autogenous in the USSR, where autogeny may be an advantage when hosts are scarce and bad weather prevents blood-sucking. *Lutzomyia cruciata* is autogenous in Belize, and *Lutzomyia gomezi* to some extent in Panama; and several other species may also be autogenous according to Lewis et al. (1970).

Autogeny may help a sandfly population to increase quickly, and thus bring a rapid onset of the maximum *Leishmania* transmission period. Autogeny makes it difficult to assess the age of wild-caught flies, and implies that a fly that becomes infected has already expended much of its life.

Numbers of sandflies

Population density is of fundamental importance in relation to leishmaniasis. *Phlebotomus l. orientalis* is the vector of *Leishmania donovani* in the Sudan, but is too rare in Kenya to be significant.

Reappearance after control. It takes some time for a sandfly population to reappear and recover after residual spraying. In some palaearctic areas it may take 3 years for sandflies to become fully re-established. In Kenya, Minter noted a 2-year period before the build-up of *Phlebotomus martini* after termite hills had been sprayed, but in India *Phlebotomus argentipes* reappeared 6 months after spraying stopped.

Seasonal changes. In the temperate palaearctic areas, the sandfly season is in summer. In Central Asia it begins when the average day temperature reaches 18–20°C. The sandfly season there varies according to altitude and latitude; Dolmatova reported that it may last 10 weeks (June–August) with one generation, or 8 months (April–November), sometimes with 3 generations. In some places there are two peaks of abundance, which probably correspond to two generations. Hibernation (diapause) sets in gradually, partly in larvae from the first generation, but mostly in those from the second. Asynchronous development occurs in single batches of eggs and is hard to explain. Some hatch and others remain dormant, and the latter may have a survival value for the species in abnormal years. Nadžafov et al. reported that in the Azerbaidzhan SSR, *Phlebotomus kandelakii* has one annual generation where *Phlebotomus papatasi* has two. According to Rahim, the sandfly season in Iraq does not correspond with the peak period (about December and January) for active lesions in man from which flies could ingest *Leishmania tropica.* According to Dolmatova this type of discordance must reduce transmission, as indicated by Moškovskij's counterpoint principle.

Sandflies in the tropics can flourish in the wet or the dry season, or they may occur throughout the year. In parts of the Sudan, most sandfly species flourish only in the dry season, probably because their breeding places are flooded by rain-water; however, certain species (Quate, 1964) are prevalent throughout the year. Minter (1964) studied the seasonal dynamics of the rainy-season and perennial species in Kenya. The former may show a bimodal pattern, according to rainfall, and their distribution is probably limited by the length of the dry season. Studies of parous rates suggested that this period is spent in larval diapause.

Sandfly seasons naturally affect the time of leishmaniasis outbreaks. Knowledge of the seasonal changes of Kenya sandflies in relation to kala azar drew attention to the species that proved to be the main vector (Wijers & Minter, 1962). It appears for a very short time after the rains; the incubation period of kala azar is about 5–8 months and the peak of the disease occurs about 6 months after the rains according to the report by Southgate & Minter. In India, *Phlebotomus argentipes* transmits *Leishmania donovani* from June to October, if outbreaks are in progress.

Man-biting sandflies in Belize are numerous in the rainy season; at this season, sap flows in the sapodilla trees and thus *chicleros,* who enter the forest to gather the material, may become infected with *Leishmania mexicana.* In Surinam, dermal leishmaniasis may be a seasonal disease of woodcutters, who are bitten by *Lutzomyia anduzei* in the rains (Wijers & Linger, 1966). Coelho reported that in Brazil some vector sandflies are most numerous in the rainy season, which differs from one area to another.

Year-to-year changes. The prevalence of Central Asian sandflies can depend on the temperature of a particular year (Petriščeva, 1965). Theodor & Mesghali (1964) stressed the need for studying sandflies continuously for several years in Iran. *Phlebotomus l. orientalis* was found at Wad Medani in the Sudan in 1936 and has not been reported there since; this may be due to long-term change or to irregular collecting. Quate (1964) found that the numbers of *Phlebotomus papatasi* and *Phlebotomus heischi* in the same country varied greatly from year to year. Certain sandflies in Belize are common in some years and rare in others, possibly in relation to changing edaphic factors. In south-western Brazil, the numbers of *Lutzomyia intermedia* vary from year to year (Forattini, 1954).

Sometimes fluctuations have been due to unusual events, such as an earthquake at Ashkhabad in Turkmenia (where *Phlebotomus papatasi* multiplied among the ruins), a Nile flood in the northern Sudan (where excessive silt was deposited and cracked during the next year, when numerous *Phlebotomus papatasi* appeared), and the severe West Indian hurricane of 1961, which affected the sandflies of Belize.

Relation with other organisms

Association with wild animals. Dergačeva has said that burrows of *Rhombomys opimus* in Central Asia are biocoenotic and epidemiological systems. In the burrows, the sandflies have suitable microclimates, breeding sites, and a supply of hosts—namely, the gerbils and their cohabitants, reptiles, birds, and certain other mammals. The colonies are sited according to features of the landscape.

Synanthropy. When road-building and land reclamation in Central Asia brought people into contact with the sandfly–gerbil association, the sandflies often became associated with the larger host, man. After agricultural development in Azerbaidzhan, natural biotopes became rare in cultivated land, and sandflies became concentrated in settlements. Dergačeva has shown (by counts of flies per sticky trap) that *Phlebotomus papatasi* may be found in gerbil burrows 2.5 km from settlements but is much more numerous in settlements. However, she regards this synanthropy as due, not so much to preference for man, as to similarity of the microclimate of gerbil burrows and houses.

Endophily. In contrast to " wild " sandflies, which live, like most insects, without any special association with man, some species, particularly some man-biters of the genus *Phlebotomus*, can be more or less endophilic. This term (World Health Organization, 1963) is a convenient one but, like " anthropophilic ", must be used in a rather indefinite way. There are various degrees of endophily. Some wild species may rest indoors if they are abundant and have no alternative shelter, and endophilic species can sometimes be found outdoors by day. Endophily may be due to a combination of factors. The initial presence of the flies in houses may be due to host preference, and to proximity of breeding places of short-range insects. The tendency for sandflies to remain in a house after a blood meal may depend on the sites where people sleep, the negative phototropism of the flies after biting, and, possibly, the absence of smoke (although, as Hoogstraal & Heyneman (1969) have pointed out, this has not been proved).

Petriščeva (1954a, 1954b) has described the rapid colonization of new settlements by sandflies from animal burrows in the surrounding desert. This sort of transference may often explain the presence of " domestic " species. In the palaearctic region, *Phlebotomus papatasi* and *Phlebotomus sergenti* are well-known endophilic species, but the latter is sometimes exophilic—e.g., in Kirovabad, as has been pointed out by Nadžafov et al. Dolmatova reported that the moisture-loving *Phlebotomus kandelakii* and *Phlebotomus p. tobbi*, which rest in certain Azerbaidzhan homesteads that are surrounded by vegetation, are among the moderately endophilic species. In the Azerbaidzhan SSR several members of the subgenus *Larroussius*, *Phlebotomus kandelakii*, *Phlebotomus p. tobbi*, and *Phlebotomus p. caucasicus* are exophilic but enter dwellings at night, according to Nadžafov et al. Maruašvili said that *Phlebotomus perfiliewi* is exophilic in Romania. However, a species may be endophilic in one area and not in another, possibly owing to genetic variation. For instance, Dolmatova reported that *Phlebotomus chinensis* is endophilic in North Kirghizia, Georgia, and the northern part of mainland China, and mainly exophilic in the Crimea and Tajikistan. Endophilic sandflies are often vectors of anthroponotic leishmaniasis—e.g., Old World urban dermal leishmaniasis, which had probably been associated with man for a long time and which is, according to Corradetti, probably transmitted regularly from man to man.

In the Sudan, *Phlebotomus papatasi* is rather endophilic but in one area Dietlein (1964) usually found it out-of-doors. *Phlebotomus guggisbergi*, which rests in caves and among trees in Kenya, is one of the few partially endophilic species of the Ethiopian region.

Most American species are exophilic and it is often impossible to find any in houses, whereas thousands can be collected in some Old World houses in a few hours. Most American man-biting sandflies live in forest, having little contact with man, and do not live in microhabitats of the type from which they might invade a domestic environment. Sandflies that enter houses to bite are not necessarily endophilic, and Barretto (1943) reported that some *Lutzomyia whitmani* near forests bit in dwellings but then left them. Garnham found that visceral leishmaniasis in America is much more a domestic disease than the dermal form, but *Lutzomyia longipalpis* is only partly endophilic, and this may explain why *Leishmania donovani* has not spread in epidemic form in America. Deane & Deane (1962) noted that this sandfly was often numerous in stables and houses but it did not appear to be strongly endophilic. It is sometimes common in caves, and this habit may have led to partial endophily. In Minas Gerais, *Lutzomyia longipalpis* is sylvatic or peridomestic and transmits leishmaniasis outdoors.

Parasites and predators. In many areas, parasites are few both in number and species, possibly because the larvae live in soil. According to Petriščeva, some old crumbled gerbil burrows in the southern USSR contain many beetles and ants that destroy larvae, pupae, and young sandflies.

RECOGNITION OF VECTORS OF LEISHMANIASIS

Much of the study of sandflies in relation to human leishmaniasis is designed to find out which species are vectors, from animal to animal, from animal to man, from man to man, or in a general sense. This is often very difficult except in parts of the Old World with only one commonly occurring man-biter. It is necessary to study both extrinsic and intrinsic factors, and, when a sandfly is recognized as a vector, it is necessary to consider quantitative and qualitative relations between *Leishmania* and the insect host. The relation of some sandfly species with *Leishmania* varies according to locality, and regional appraisals are necessary. Some sandflies may transmit leishmaniasis to man yet have negligible significance, not being habitual vectors (Rioux et al., 1968). Furthermore, the importance of some vectors alters with environmental changes.

Many of the factors mentioned above have a bearing on the recognition of vectors and the criteria that must usually be considered are as follows.

The taxonomic relations of leishmaniasis vectors

All, or most, Old World vectors of human leishmaniasis belong to the genus *Phlebotomus*, and most vectors of *Leishmania tropica* belong to the subgenera *Phlebotomus* and *Paraphlebotomus*. Most vectors of Old World kala azar belong to the subgenera *Synphlebotomus*, *Larroussius*, *Adlerius*, and *Euphlebotomus*. It follows that, in looking for a vector in the Old World, it is advisable to consider species related to known vectors.

In the New World, however, although several vectors belong to the subgenus *Nyssomyia*, vectors may be scattered among various subgeneric groups of *Lutzomyia*. Therefore, taxonomic position may not be a guide to a likely vector, and ecological studies are particularly important in the preliminary search for a vector (Williams, 1966b).

Theodor said that until 1967 only a few species had been proved to be vectors of human leishmaniasis according to the following criteria: infection in captured sandflies, infection of laboratory animals with promastigotes from sandflies, experimental infection of sandflies from the infected animals, typical behaviour of the flagellates in the sandfly, and serological identification of the parasite. The proved vectors of dermal leishmaniasis are *Phlebotomus papatasi* (western Asia), *Phlebotomus sergenti* (western Asia and India), and *Phlebotomus caucasicus* (which apparently transmits disease among rodents; although it has not been proved to transmit leishmaniasis to man). Proved vectors of visceral leishmaniasis are *Phlebotomus perniciosus*, *Phlebotomus major*, and *Phlebotomus longicuspis* (all around the Mediterranean area); *Phlebotomus langeroni orientalis* (the Sudan); *Phlebotomus martini* (Kenya); *Phlebotomus argentipes* (India); *Phlebotomus chinensis* (mainland China), and *Lutzomyia longipalpis* (South America). Saf'janova has carefully analysed the significance of these and other species.

The study of a vector usually takes many years and gives rise to much discussion about its significance. Furthermore, there is no sharp distinction between important vectors and minor or occasional vectors; some suspected vectors may be more important than some proved ones, the situation of one species varies from place to place, circumstances may alter, and opinions may alter and conflict. It is therefore impossible to draw up a clear-cut list of vectors, but a list of some proved and suspected vectors has a certain value, and information of this kind is accordingly presented in the accompanying table, for which the following works were sources of information or bibliographical references: vectorial significance of most species, Adler & Theodor (1957); *Phlebotomus duboscqi*, Larivière et al. (1961); *Phlebotomus papatasi* and kala azar in Iraq, Pringle (1956); *Phlebotomus vansomerenae*, Minter & Wijers (1963); *Phlebotomus ariasi*, Rioux & Golvan (1969); *Phlebotomus kandelakii*, Dolmatova (unpublished data); *Phlebotomus longipes* and disseminated dermal leishmaniasis, Lemma et al. (1969); *Phlebotomus perfiliewi*, Corradetti (1968); *Phlebotomus chinensis halepensis* and *Phlebotomus c. longiductus*, Petriščeva et al. (1966); *Phlebotomus simici*, Theodor (unpublished data); *Lutzomyia renei*, Coelho et al. (1967); *Lutzomyia anduzei*, Wijers & Linger (1966); *Lutzomyia flaviscutellata*, Lainson & Shaw (1968); *Lutzomyia olmeca*, Biagi et al. (1965), Disney (1967, 1968), and Williams (1970). Notes on distribution are adapted from Theodor (1958, 1970) and from other sources.

Some species may have to be added to the list when more is known about them; for instance, a series was studied by Coelho et al. (1967), who experimentally infected a number of species from different subgeneric groups, demonstrating lack of specificity in the sandfly–parasite relation in tropical America. Ecological studies may show how many of the sandflies are vectors. Courmes et al. (1966) reported visceral leishmaniasis from Guadeloupe and suspected the vector to be *Lutzomyia atroclavata*, a species that is not assigned to any subgenus.

Other species may have to be removed from the list because studies in recent years strongly suggest that the tropical American vectors of dermal leishmaniasis are members of the subgenus *Nyssomyia* (Williams, 1970).

The accompanying table shows that there are few " vectors " of dermal leishmaniasis and many of visceral leishmaniasis in the Old World, whereas the converse is true in the New World. The small number of Old World vectors of dermal leishmaniasis is presumably a result of the limited range of the main animal reservoir, and of the fact that the main domestic vector is a widespread species. The small number of vectors of visceral leishmaniasis in the New World may be associated with the disease possibly having arrived rather recently.

A species may transmit *Leishmania* in only part of its range (Adler & Theodor, 1957), and Heyneman (1963) observed variations in susceptibility. He was able to infect an Egyptian strain of *Phlebotomus papatasi* experimentally with *Leishmania donovani* more readily than a Sudanese strain. Pringle (1956) believed that a local form of *Phlebotomus papatasi* might be transmitting this species of *Leishmania* in Iraq.

Epidemiological evidence

The epidemiological and epizootiological significance of each species of sandfly depends on the particular conditions obtaining in the various biocoenoses; therefore, the significance must be assessed from a regional quantitative analysis of: (1) the prevalence and area distribution of the sandfly species, (2) its seasonal prevalence, (3) the degree of relationship (topical and feeding habits) with vertebrate hosts of *Leishmania*, including man, and (4) the degree of relationship of the sandfly species with a *Leishmania* species or strain circulating in a given focus.

As stressed by Saf'janova, many of the external and intrinsic factors affecting the development of *Leishmania* in their arthropod hosts need to be investigated in order to elucidate the process of mutual adaptation and the causes of specific relationships between these organisms.

Subjects to be considered include occurrence when sources of infection are present, phenology, circadian activity, host preference, and natural infection with promastigotes and their position in the gut. Garnham believes that in studying zoophilic sandflies in relation to *Leishmania* it is necessary to distinguish between true animal reservoirs and secondary reservoirs.

Natural infection rates of human parasites in sandflies tend to be low for visceral leishmaniasis and high for dermal leishmaniasis, especially the zoonotic form in the USSR. When possible, infection rates should be given as proportions, not only of the total sandfly population, but also of the parous population as far as it can be assessed.

Specific behaviour of Leishmania *flagellates in the gut*

In proved Old World vectors of leishmanial parasites of man, the flagellates normally develop first in the hind stomach of the sandfly and gradually move to the fore stomach and accumulate behind the oesophageal valve. After 5 days few are found in the hind stomach and very few or none in the hind gut. Flagellates pass into the pharynx and cibarium and finally into the tip of the proboscis about the eighth to tenth days; the infection may now be deposited in the wound made by a bite. In a good vector infection is progressive and strongly localized; in a poor one it is regressive.

Heyneman studied *Leishmania donovani* in *Phlebotomus l. orientalis* of the Sudan and observed that it always adopted the anterior position; in *Phlebotomus papatasi* it did not always reach this position and, even if it did so, it soon died. Findings of this kind yield important epidemiological information.

Leishmanial parasites of lizards migrate posteriorly in sandflies. Garnham has pointed out that in searching wild-caught sandflies for *Leishmania* of man much confusion can be caused by lizard *Leishmania*, certain *Leishmania* of mammals that have little effect on man, trypanosomes, or *Leptomonas* parasites of sandflies. In the New World some leishmanial parasites of man cause hindgut infections in sandflies (Johnson & Hertig, 1970).

It is possible that the relative susceptibility of sandflies to local strains of *Leishmania* may be useful in classifying or identifying forms of the parasites. For instance, *Leishmania tropica minor* will not infect *Sergentomyia* " *dentata* " but *Leishmania t. major* will, according to Belova.

The position of flagellates in the gut is of some use in xenodiagnosis but their numbers and position vary considerably. Quantitative records of distribution, with a time scale of movement for each *Leishmania*-sandfly complex, infection rate, and survival rate might be useful. So many factors are involved, however, that xenodiagnosis may not be practicable. Johnson & Hertig (1970) found that the position of flagellates in the gut would serve to separate from each other some American species or strains of *Leishmania*.

Vector specificity

A good vector is characterized by a high infection rate following the ingestion of relatively few parasites, as well as by the pattern of behaviour already described. Hindgut infections of sandflies are common when species of *Leishmania* are not in their normal host, and these infections have proved not to be transmissible by contamination.

Identification of promastigotes from sandflies

Promastigotes from wild-caught sandflies should be identified by development of the disease in animals or volunteers after inoculation and by serological methods, in the opinion of Saf'janova & Alekseev (1967a).

Quantitative studies by Saf'janova and other Russian workers have thrown light on the dynamics of vector–parasite relationships. Natural infection of sandflies with *Leishmania* was investigated by the application of Adler's test [1] to 36 strains of promastigotes isolated in leishmaniasis foci in Turkmenia and Uzbekistan—namely, 5 strains of *Leishmania tropica* from patients, 2 strains of *Leishmania tropica* from large gerbils, 1 strain of *Leishmania donovani* from a sick child, 4 strains from reptiles (*Gymnodactylus caspius*, *Agama sanguinolenta*, and *Eremias intermedia*), and 24 strains from sandflies (*Phlebotomus papatasi*, *Phlebotomus caucasicus*, and *Sergentomyia* " *dentata* "). All *Leishmania tropica* strains were related antigenically. The *Leishmania donovani* strain had common antigens with them, but it was possible to differentiate this species. Promastigotes from sandflies were either related to amastigotes of mammals or to promastigotes of reptiles. Thus, on the basis of antigenic relationships, two serologically distinct groups of parasites could be differentiated, namely mammal leishmaniae and promastigotes of reptiles.

[1] The method developed by Saf'janova is described by Garnham (1971)—see pages 486-487 of this issue.

Field and laboratory observations on natural infection were confirmed by laboratory studies on the susceptibility of sandflies to promastigotes from different serological groups. Alekseev reported that, using a modified pipette method of feeding sandflies with measured quantities of promastigote cultures, these studies showed that reptilian leishmaniae developed poorly in *Phlebotomus papatasi* but well in *Sergentomyia* " *dentata* ", and *vice versa* for the man–mammal *Leishmania tropica*.

Wallace & Hertig (1968) used the ultrastructure of promastigotes from wild-caught flies as an aid in distinguishing *Leishmania* from *Crithidia*.

Transmission by bite

The capacity of a sandfly to transmit *Leishmania* by bite to a volunteer or susceptible animal should be tested.

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RÉSUMÉ

LES PHLÉBOTOMINÉS

On connaît actuellement plus de 500 espèces de Phlébotominés dont la plupart appartiennent aux genres *Phlebotomus* et *Sergentomyia* dans l'Ancien Monde, et au genre *Lutzomyia* dans le Nouveau Monde.

Les Phlébotominés sont très répandus dans les régions tropicales et autres zones à climat chaud, et on les trouve jusque vers le 50° de latitude N. Le genre *Phlebotomus* prédomine dans la région paléoarctique et sa distribution s'étend aux autres régions de l'Ancien Monde où le genre principal est *Sergentomyia*. Dans les zones tempérées de l'Amérique du Nord, les Phlébotominés ne sont représentés que par quelques espèces. Dans les zones tropicales du continent, on rencontre surtout le genre *Lutzomyia*. La répartition des divers genres et sous-

genres détermine en grande partie la distribution de la leishmaniose cutanée et viscérale. Certaines espèces de *Phlebotomus* et de *Lutzomyia* transmettent la leishmaniose cutanée dans de vastes secteurs des régions paléoarctique et néotropicale. La leishmaniose viscérale est propagée par certaines espèces de *Phlebotomus* dans la majeure partie de la région paléoarctique — à l'exception de la zone désertique d'Afrique du Nord et de quelques régions d'Afrique et de l'Inde — et par une espèce de *Lutzomyia* dans le nord-est du Brésil.

Dans les zones forestières du Nouveau Monde, les Phlébotominés n'ont normalement que peu de contacts avec l'homme, mais ils peuvent occasionnellement lui transmettre la leishmaniose d'origine zoonotique. En terrain découvert, les risques d'infection sont beaucoup plus élevés. En certains endroits, la leishmaniose se présente en foyers localisés, dus à l'existence de microhabitats de Phlébotominés. C'est le cas en Asie centrale où les terriers de gerbilles et d'autres rongeurs servent d'abri au vecteur. La répartition des Phlébotominés et de la leishmaniose se modifie constamment et le danger d'extension de la maladie rend nécessaire une surveillance épidémiologique.

Après avoir décrit les particularités biologiques des Phlébotominés, l'auteur expose les critères qui conduisent à attribuer à certaines espèces un rôle certain dans la transmission de la leishmaniose. Il est actuellement impossible de dresser une liste complète et précise des vecteurs, mais on peut établir un inventaire des espèces dont la participation est reconnue ou suspectée. Les méthodes d'étude des relations vecteur-parasite sont brièvement mentionnées.

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