RIVERS STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY,
NKPOLU, PORT-HARCOURT

STUDIES ON FACTORS AFFECTING THE DISTRIBUTION AND ABUNDANCE OF PHLEBOTOMINE SANDFLIES IN A LEISHMANIASIS ENDEMIC FOCUS IN BARINGO DISTRICT, KENYA.

MULENDA BASIMIKE
(Gradué en Sciences, Université de Kisangani)
(Licencié en Sciences Biologiques, Université de Kisangani).

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DECLARATIONS

I certify that this is my original research work and all help has been dully acknowledged. This work has not been submitted for a degree in any other University.

MULENDA BASIMIKE

This thesis has been submitted for examination with our approval as Supervisors.

DR. MUTUKU J. MUTINGA
Principal Research Scientist and Programme Leader, Medical Vectors Research Programme, ICIPE/ Nairobi

PROF. R. KUMAR
Dean, School of Postgraduate Studies, RUST, Port-Harcourt, Nigeria

DR. C.M. MUTERO
Research Scientist
Medical Vectors Research Programme
(ICIPE)

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A B S T R A C T

Factors affecting the distribution and abundance of Phlebotomine sandflies were studied during the period 1985 to 1987, in the Marigat leishmaniasis endemic area, located in Baringo district, Kenya. It was found that the relative abundance of Phlebotomus species collected from burrows was 4-fold those from termite hills, whereas the Sergentomyia species recovered from termite hills was twice the number caught in animal burrows. Both termite hills and animal burrows were the main sandfly breeding and resting sites in the Marigat area. The Sergentomyia species were predominant in this area, representing 97 per cent of the total sandfly population, while the Phlebotomus constituted only 3 per cent of the population. Considerable seasonal variations were observed in both sites. However, sandfly relative abundance increased in the rainy season and decreased in the dry period. The Phlebotomine sandflies were grouped into perennial and seasonal species. Sergentomyia antennatus was the most collected sandfly species followed by S. bedfordi. Phlebotomus martini showed a high capture rate among the Phlebotomus species.

Fluctuations in the sandfly population from all breeding and resting sites are discussed, in relation to environmental conditions. The abiotic factors, particularly the rainfall, appeared to have important effects on the

distribution and abundance of sandflies. Two major peaks of sandfly abundance were observed in April and August, corresponding to high rainfall. Significant positive correlation coefficients obtained between rainfall and sandfly vectors of leishmaniases, showed that high incidence of the disease occurred mainly during the rainy season.

Collections of phlebotomine sandflies in differentes vegetation habitats demonstrated the existence of a high density of flies in large trees. Sergentomyia bedfordi seemed to be more closely associated with the vegetation habitats. The studies on sandfly vertical distribution in two different biotopes showed that only Sergentomyia bedfordi and S. antennatus reached a height of ten metres and beyond. Also, it was observed that two types of sandfly populations occur in the forested area: the lower species (Sergentomyia ingrami, S. affinis, S. adleri, S. africanus and S. clydei), mainly flying from the ground level up to five metres and the species flying beyond six metres (Sergentomyia bedfordi and S. antennatus). Relating the sandfly density and the height of flight, it was found that the number of both male and female sandflies significantly decreased with the height.

It was possible to relate the increase of phlebotomine sandflies in a particular habitat to the presence of a certain number of soil chemical and physical characteristics. It was found that the growth of the immature stages depended on parameters such as organic carbon, calcium, potassium, sand and clay. However, other features such as sodium were found to have detrimental effects on sandfly abundance.

The identification of bloodmeals, determined the range of possible hosts on which each sandfly feeds, and showed the degrees of anthropophily of the local sandflies. The bloodmeal analyses also provided the actual or potential sandfly hosts for the *Leishmania* parasite.

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GENERAL INTRODUCTION

The term sandfly refers to a group of insects (Diptera: Psychodidae) which transmit the disease known as leishmaniasis. Sandfly vectors transmit various forms of leishmaniasis such as the visceral leishmaniasis commonly known as kala-azar, the cutaneous leishmaniasis also called dermal leishmaniasis or the oriental sore, and the muco-cutaneous leishmaniasis, known as espundia or the American cutaneous leishmaniasis. Modern research on leishmaniasis dates from the discovery of the leishmanial parasite (Phylum of Protozoa, the Order of Kinetoplastida and the Family of Trypanosomatidae) in 1903 (Garnham, 1987). However, Leishman and Donovan were the first to observe and recognize the leishmanial parasites from a spleen biopsy of a patient (Lewis, 1976). Normally endemic in certain wild animal species forming the reservoir of the disease, the human leishmaniasis (kala-azar, the dermal leishmaniasis or the American leishmaniasis) is a zoonosis, in which man is the occasional or accidental host, but nevertheless a very vulnerable one (Disney, 1966; Shaw and Lainson, 1968). According to the World Health Organization, Leishmaniasis is one of the six major communicable diseases (Peters and Killick-Kendrick, 1987). Leishmaniases are among the important public health problems facing populations in the tropical and subtropical areas (Mutinga, 1986a).

The French workers in North Africa (Pressat, 1905; Sergent and Sergent, 1905) were the first to publish reports implicating the phlebotomine sandflies (*Phlebotomus*) as the likely potential vectors of leishmaniasis. The discovery of the insect vector, long suspected of being a sandfly, had to wait until workers in India (Swaminath, *et al*., 1942) succeeded in transmitting *Leishmania donovani* Laveran and Mensil to man by the bite of experimentally infected *Phlebotomus argentipes* Annandale and Brunetti, and in the Middle East, Adler and Theodor (1926, 1928, 1929a, and b) and Adler and Ber (1941) transmitted *L. tropica* Wright to man by the bite of *P. papatasi* Scopoli and *P. sergenti* Parrot and Martin. Sandflies are potential vectors of various other infections to man, such as bartonellosis or Carrion's disease, the sandfly fever or pappataci fever, the spirochetes, the vesicular stomatitis, and the dengue fever (Abonnenc, 1972; Chaniotis, 1978; Herrer and Christensen, 1975). Apart from their medical importance to man, sandflies also are responsible for transmitting the canine leishmaniasis to dogs and reptilian leishmaniasis to reptiles (Killick-Kendrick 1978).

Economically, leishmaniases are very important in the developing countries which already are involved in combating other public health problems. In Brazil, the cutaneous and muco-cutaneous leishmaniases constitute serious problems among labour workers engaged in the development of heavily forested areas. Trunks of trees serve as refuge or daytime resting sites for sandfly vectors of leishmaniasis. Once disturbed from their resting sites, these flies are attracted to forest workers, who receive the flies' bites.

In Kenya, visceral and cutaneous leishmaniases were introduced probably during the Second World War (Mutinga, 1980). The first outbreak occurred in 1940, among soldiers who were camped in the North of Lake Turkana in South West Ethiopia. After the war, sporadic cases were recorded in many places in the country and that was after the soldiers' departure. Piers (1947) stated that leishmaniasis was rare in the East Africa before the war, and the only area in which leishmaniasis was known to be endemic (before the war) was the Northern Frontier District, situated between the Uaso Ngisu river and the Abyssinian (Ethiopia) border. Therefore, he concluded, that cutaneous cases were obviously "imported " as infections were contracted in endemic areas outside Kenya and, only became manifest in East Africa. Throughout the World, and mainly in the Tropics and Subtropics, an estimated 400,000 new cases of leishmaniases are reported annually (W.H.O., 1984; Young and Lawyer, 1987). Lainson and Shaw (1978) and Lee et al. (1985) stated that of the diseases caused by protozoal parasites, leishmaniasis is probably second in importance only to malaria in many areas.

Before 1940, the tartar emetic (sodium antimonyl tartrate), the anthiomaline (an organic trivalent antimonial), the urea stibamine and an organic pentavalent antimonial were used in leishmaniasis treatment (Cole, 1944; W.H.O., 1984). Only the urea stibamine in adequate dosage gave successful results. In East Africa, Cole (1942) highlighted the use of stilbamidine in the treatment of leishmaniasis. Nowadays, the antimony gluconate, a pentavalent antimonial drug has been extensively used in leishmaniasis treatment. However, due to its high cost, toxicity, lower efficacy and adverse side-effects, its use has diminished (W.H.O., 1984). Also, patients treated with the antimony gluconate tend to relapse. For second-line treatment, the amphotericin B and pentamidine have been commonly used respectively in the New and Old Worlds (W.H.O., 1984; Were et al., 1986). The use of both drugs is limited to patients who are unresponsive to antimonials. Were et al. (1986), reported that due to significant drawbacks of drugs used in leishmaniasis treatment,(high toxicity, difficulty of drug administration, high cost and limited availability), it is not yet possible to make firm recommendations concerning the treatment of leishmaniases. Lainson and Shaw (1978) stated that, due to high toxicity of the antimonial drugs, their high rate of relapses after treatment, accompanied by their unsuccessful results and the absence of any vaccine against the disease, the control of leishmaniasis should depend on eliminating either the reservoirs or the insect vector, or both. Results from studies indicate that control measures of leishmaniasis could only succeed if essential environmental parameters regulating the sandfly vectors, the sandfly behaviour and the sandfly ecology are well understood.

Available literature indicates that a few applications of insecticides have been carried out on controlling sandflies. Killick-Kendrick (1978) and Ward (1977) stated that, the prolonged exposure of sandflies to insecticide might lead to the appearance of resistance. Sandflies had also shown resistance to chlorinated insecticides in some parts of USSR (Killick-Kendrick, 1978). Lainson and Shaw (1978) reported that, in the Peruvian Andes, Lutzomyia verrucarum (Townsend) vector of Leishmania peruviana Velez, responsible for "uta" (so-called tegumentary leishmaniasis), a form of American leishmaniasis and of human bartonellosis, was efficiently controlled by intensive spraying of DDT. Also, he stated that, in Brazil the American visceral leishmaniasis caused by L. chagasi Cunha and Chagas was efficiently controlled using insecticides. Currently in Latin America, the problem of controlling cutaneous and muco-cutaneous leishmaniases has not been overcome. The use of insecticide on a large scale in tropical rainforest is highly uneconomical. From a biological viewpoint, insecticides are dangerous because they cause destruction of small-mammal populations and also harm man. In 1968, limited applications of insecticide (2% aqueous DDT suspension) was utilized in Kitui area (Kenya), both in houses, in thorn bush enclosures and in termite hills of all types to control sandflies but with temporary success (Mutinga, 1985; Zahar, 1981).

The clearance of forest, in the continuing development of land for agriculture and other purposes, undoubtedly reduces leishmaniasis endemic areas (Lainson and Shaw, 1978), but alternatively, destroying the forest and establishing an open dry terrain may create new areas which are favourable for Lutzomyia longipalpis (Lutz and Nieva), vector of visceral leishmaniasis. Rutledge and Ellenwood (1975a), suggested that the effects of thinning and selective removal of plant species could greatly reduce or eliminate the sandfly breeding, and hence, its population density. Mutinga (1985) concluded that the use of insecticides in controlling sandflies, is feasible where there is a high population density of sandflies. In order to be effective, careful preliminary planning and studies on the bionomics and behaviour of the fly are essential. Therefore, control measures against sandflies should be based on knowledge of various essential parameters occurring in the environment. These parameters are: the sandfly population density in breeding and resting sites, the environmental factors and their effects on sandfly abundance, the microclimate (soil temperature and soil relative humidity), the sandfly density in the vegetation cover and their flight behaviour, and the sandfly host preferences, among others. Perfil'ev (1966), stated that " The control of arthropods (parasites of man and vectors of disease) cannot be achieved without a precise knowledge of their biology, i.e., their life cycle, duration of the stages of development, habitats, shelters, habits, food, reaction to environmental factors, sensitiveness to insecticides or other control measures, and so on...". Killick-Kendrick (1978), noted that long-term studies on the population dynamics of a vector species are of inestimable value in planning a control strategy.

It is evident that in Kenya as well as in many other countries, most of the previous investigations on phlebotomine sandflies, were concerned with compiling lists of sandfly species occurring in a region; they dealt with the disease transmission; the identification of the parasites isolated from leishmaniasis patients as well as from the animal reservoirs; the delimitation of zones of local transmission of leishmaniasis and the establishment of leishmaniasis endemic zones. Also the earlier investigators implicated the movement of people in the spread or the dissemination of the disease. The study of sandfly species in Kenya received a sudden impetus following the outbreak of a serious epidemic of kala-azar in Kitui District towards the end of 1952 (Heish, 1954; Mckinnon and Fendall, 1955), and the discovery of kala-azar in Baringo District in 1955 (Mckinnon and Fendall, 1956; Mckinnon, 1962; Mutinga and Ngoka, 1983). In recent years, detailed investigations on sandflies and their transmitted diseases have been initiated at the International Centre of Insect Physiology and Ecology/Nairobi (Mutinga and Odhiambo, 1986a,b; Mutinga and Kamau, 1986; Mutinga et al., 1986a,b; Mutinga, 1986a,b; Mutinga et al., 1987). Most of these studies are related to the epidemiology of leishmaniasis and the ecology of phlebotomine sandflies in various parts of Kenya. Studies on the relationship between termite hills and the presence of leishmaniasis in West Pokot, revealed that all homes afflicted with kala-azar had the sandfly breeding and resting sites within a 10-metres radius (Mutinga et al.,1984). They therefore, incriminated the termite hill as main breeding place of Phlebotomus martini Parrot, responsible for the transmission of L. donovani, causative organism of kala-azar, and considered dogs as reservoirs of the pathogens (Mutinga et al., 1984). Mutinga and Odhiambo (1986a), investigating the vectorial capacity of wild Phlebotomus species, determined the route of infection and the infection rates of P. pedifer in caves on Mount Elgon. Using various types of animal baits at burrow sites, Mutinga et al.(1986b) reported that the differences in host preferences by *Phlebotomus* and *Sergentomyia* species were significant. In the Marigat area, Mutinga and Kamau (1986), Mutinga *et al.*, (1986a), discovered the resting places of *Phlebotomus duboscqi* Neveu-Lemaire and *Sergentomyia ingrami* Newstead (both vectors of *Leishmania major* Yakimov and Schokhov) and *P. martini* (vector of *L.donovani*) by incubating and observing the daily adult sandfly emergence from soil samples collected from natural resting sites of sandflies.

Detailed factors controlling the distribution of sandflies are virtually unknown (Ashford, 1974; Minter, 1964a,b,c). However, apart from the epidemiological aspects of leishmaniasis and the ecology of phlebotomine sandflies, no studies have been undertaken on the microclimate of animal burrows and termite hills, main sandfly breeding and resting sites, on the soil characteristics (chemical and physical) prevailing inside both sandfly breeding and resting sites, on the vertical distribution of sandflies in a semi-arid area among many other aspects.

For this reason, the present study was undertaken with the following objectives in view:

1. To determine the species composition, the relative seasonal abundance and the fluctuations of sandflies in the Marigat area.

2. To study the relationship between general climatic factors and the sandfly population dynamics.

3. To study the microclimate in animal burrows and termite hills in relation to sandfly population dynamics.

4. To determine the chemical and the physical characteristics of the soil in sandfly breeding and resting sites.

5. To study the relationship between sandfly species distribution and the vegetation cover.

6. To study the vertical distribution of the local phlebotomine sandfly species.

CHAPTER ONE

LITERATURE REVIEW

1.1 Infections caused by sandflies

1.1.1 Leishmaniases

For nearly forty years, the transmission of *Leishmania* remained one of the fascinating unsolved problems of the tropical medicine. The fact that the parasites assumed the flagellate form in the bed bug and in the dog flea suggested that these insects might be natural transmitters of the infection; but extensive epidemiological and experimental studies did not confirm this view. Sinton (1925), studied the distribution of Indian sandflies and found that the distribution of kala-azar in India corresponded with that of *Phlebotomus argentipes* Annandale and Brunetti. Later on, it was shown that the distribution and incidence of leishmaniasis in various endemic areas was closely related to the distribution of specific sandflies as that of malaria to anopheline mosquitoes (Kirk and Lewis, 1955).

Sandflies of the *Phlebotomus* Rondani and Berte, the *Sergentomyia* Franca and Parrot (*S. garnhami* and *S.*

ingrami) and of Lutzomyia Franca groups are responsible for transmitting the protozoan parasites (Leishmania) to man and/or to animals (rodents and dogs) in the Old and New Worlds. There are six species of Leishmania infecting man in the Old and New Worlds (Molyneux and Ashford, 1983), Leishmania aethiopica Bray, Ashford and Bray, L. donovani Laveran and Mensil, L. major Yakimov and Schokhov, L. tropica Wright, L. braziliensis Vianna and L. mexicana Biagi. In natural hosts, there is usually a well balanced host-parasite relationship and parasites are scattered in small numbers, in macrophages of the skin, viscera, in blood, causing few or no pathological effects. However, in man and other unusual hosts, there may be violent host-cell reaction to the parasite, causing lesions on the skin, or severe pathological changes in the internal organs.

Human leishmaniasis occurs in three main clinical forms (Abonnenc, 1972; Kirk and Lewis, 1955; Lainson and Shaw, 1978; Mutinga, 1985), visceral leishmaniasis, cutaneous leishmaniasis and muco-cutaneous leishmaniasis. Leishmania donovani responsible for visceral leishmaniasis is transmitted by sandflies belonging to the Phlebotomus group. According to Lewis and Ward (1987), these sandflies are: Phlebotomus papatasi (Scopoli) for the Middle East; P. chinensis Newstead, P. caucasicus Marzinowsky and P. alexandri Sinton for China; P. pernicosus Newstead and P. ariasi Tonnoir for France; P. longicuspis Nitzulescu and P.

major Annandale for Algeria; P. orientalis Parrot for Sudan and Ethiopia; P. tobbi Adler and Theodor and P. simici Nitzulescu for the Mediterranean region and Central Asia. In the USSR, P. brevis Theodor and Mesghali and P. longiductus Parrot transmit the leishmaniasis parasites. In India, P. argentipes Annandale and Brunetti is the main vector of L. donovani. In the New World (South America), the leishmanial parasite, L. d. chagasi agent of the visceral leishmaniasis is transmitted by Lutzomyia longipalpis (Lutz and Nieva).

In East Africa, visceral leishmaniasis is transmitted to man by Phlebotomus martini Parrot a species of the Synphlebotomus group which also may infect animals as secondary hosts (e.g. wild canidae and dogs). P. celiae Minter and P. vansomerenae Heisch, Guggisberg and Teesdale are closely related to P. martini and are suspected to be vectors (Minter, 1981; Lewis and Ward, 1987). Sergentomyia garnhami Heisch, Guggisberg and Teesdale has been reported as a possible vector of kala-azar in some parts of Kenya (Mutinga and Odhiambo, 1982; Mutinga and Kyai, 1985).

Cutaneous leishmaniasis is caused by members of the Leishmania tropica group. This parasite is transmitted by sandfly species of the Phlebotomus group. Its wild hosts are rodents. This group of parasites comprises L. tropica major which infects man and rodents and L. tropica tropica which affects man and dogs. Leishmania major Yakimov and Schokhov occurs in areas with semi-arid to arid climate with a hot dry season lasting 6 or more months with high air temperature, while Leishmania tropica Wright is the agent of the cutaneous dry lesion known as the urban cutaneous leishmaniasis (Ashford and Bettini, 1987). In Ethiopia and Kenya (Mount Elgon), Leishmania aethiopica Bray, Ashford and Bray, the agent for human high land cutaneous leishmaniasis, is transmitted by P. longipes Parrot and Martin and P. pedifer Lewis, Mutinga and Ashford, closely associated to the hyrax, which is the animal reservoir (Ashford, 1974; Mutinga, 1971; W.H.O., 1984). Lewis and Ward (1987), incriminated the following sandflies as vectors and/or suspected vectors of Leishmania tropica in the Old World: Phlebotomus bergeroti Parrot (in the Sahara and Saudi Arabia), P. duboscqi Neveu-Lemaire (in Nigeria and Senegal), and P. saheli Meshgali and P. sergenti Parrot and Martin (in India and Iran). In Kenya, Mutinga (1975, 1986b) observed that L. major and L. aethiopica, agents of the cutaneous leishmaniasis are transmitted by P. duboscqi and P. pedifer respectively. In the New World, a diversity of leishmanial parasites have been identified as causing cutaneous leishmaniasis. These parasites fall into two natural groups upon their biological characteristics and are: the Leishmania mexicana Biagi, and L. braziliensis Vianna complexes. Walton (1987) reported that in the New World, the pattern of development of the cutaneous leishmanial lesion refers to the form of the causative parasite. Thus, L. mexicana mexicana Biagi is responsible of Chiclero's ulcer (ear mutilation), L. braziliensis panamensis Lainson and Shaw is responsible of Panamanian leishmaniasis, while L. b. guyanensis Floch is the agent of "Pian-bois" (Forest Yaws). L. peruviana Velez is the agent of Uta in mountainous areas of Peru (W.H.O., 1984). These parasites are transmitted by a large number of sandflies belonging to the genus Lutzomyia.

The muco-cutaneous leishmaniasis is undoubtedly caused by parasites native to the New World. Leishmania braziliensis the causative agent of this disease is transmitted by a sandfly belonging to Lutzomyia group, of New World sandflies. Herrer and Christensen (1975), reported the Spanish Colonial chronicles (of 16 and 17th centuries) as describing this disease as espundia and its cause was said to be the bite of the sandfly.

1.1.2 Other infections caused by sandflies

At the beginning of the twentieth century, interest in sandflies attracted the attention of both entomologists and physicians. Apart from the visceral and cutaneous leishmaniasis, sandflies also are suspected for transmitting the summer fever in Central Europe, the Mediterranean countries, South USSR, India and South China (Abonnenc, 1972). Later, it was proved that some sandfly species transmit Bartonella bacilliformis Barton, the causal agent of bartonellosis or Carrion's disease or Oroya fever in Peruvian Andes Vallies (Abonnenc, 1972; Herrer and Christensen, 1975; Perfil'ev, 1966), the dengue fever and Borrelia. In China Wuchereria bancrofti Cobbold, can also be transmitted by sandflies.

In the New World, phlebotomine sandflies have been found also to be potential vectors of numerous arboviruses. These, presumably animal viruses belong to three serological groups: Changuinola, the vesicular stomatitis and the phlebotomus fever (Chaniotis et al.,1971a, Chaniotis, 1978). In Uganda, a suspension of 133 sandflies of various species, innoculated into monkeys resulted in animals developing the yellow fever after 34 days. Smithburn et al.(1949) isolated the virus of yellow fever from Phlebotomus in Uganda. Sandfly bites are painful. It's saliva contains a toxin which may cause severe indisposition and which irritates the skin. In Palestine, this skin irritation or reaction is known as "Harara" (Abonnenc, 1972). Patients of leishmaniasis are sleepless, lose their appetite, feel exhausted and have headaches; their body temperatures rise periodically.

Apart from their medical importance, sandflies are also of veterinary importance as they are responsible for transmitting the canine leishmaniasis. However, Chaniotis (1978) stated that less is known on the role played by phlebotomine sandflies as vectors of trypanosomes of reptiles and amphibians (Trypanosoma), haemogregarines of lizards and snakes (Hepatozon sp) and acephaline gregarines (Lankesteria sp).

However, not all sandflies are vectors of the diseases; their role in the disease transmission is determined by their feeding habits, flight behaviour, survival rates among many others. Thus, some sandflies do not feed on man, but feed on animals and birds. Others feed on reptiles. Another fact is that all man-biters or feeders are not vectors of various sandfly-borne diseases, and the sandfly succeptibility to transmit the parasite is individual and not depending on the group. This susceptibility can differ from species to another within the same group.

1.2 Distribution of phlebotominae sandflies

Of approximately 600 species of phlebotomine sandflies described (Chaniotis, 1978; Service, 1986; W.H.O., 1984) the great majority are tropical and subtropical (Perfil'ev, 1966). These flies become progressively less abundant as climates become temperate (Abonnenc, 1972; Chaniotis, 1978; Lainson and Shaw, 1978; Perfil'ev, 1966).

Perfil'ev (1966), stated that large number of sandflies are present in Tropics and Muirhead-Thomson (1982) added that even some countries of Temperate zones and particularly the Mediterranean regions and the USSR also harbour a quite good number of phlebotomine sandflies.

Phlebotomine sandflies are grouped into five genera and include all the habitual mammal-biters and the vectors of human leishmaniasis (Lewis, 1982). In the Old World (Central Asia, India, Africa and some European countries), two genera of phlebotomine sandflies are present: the Phlebotomus Rondani and Berte group containning a number of sandfly species responsible for transmitting the visceral and cutaneous leishmaniasis to man and to rodents; and the Sergentomyia Franca and Parrot group consisting of a large variety of sandfly species, having a minor role in the transmission of leishmaniasis. In the New World (Central and South America), three groups of phlebotomine sandflies occur, namely: Warileya Hertig, Brumptomyia Franca and Parrot and Lutzomyia Franca. Species of Lutzomyia group seem to be more important as they are involved in the transmission of Leishmania braziliensis, the disease which is responsible for the transmission of the mutilating form of leishmaniasis.

1.2.1 Old world

In the Old World, twenty nine species and subspecies of sandflies are known or suspected to be vectors of leishmaniasis of man (Killick-Kendrick, 1978). Among them, Phlebotomus martini and P. argentipes transmit Leishmania donovani, while Phlebotomus sergenti, P. papatasi, P. duboscqi, P. pedifer and P. longipes are vectors of Leishmania tropica, L. major and L. aethiopica. Heisch (1955), Mutinga and Odhiambo (1982) and Mutinga and Kyai (1985), reported Sergentomyia garnhami as vector of human visceral leishmaniasis in Kenya. This species transmits Leishmania donovani. In Africa, the phlebotomine sandflies of the Afro-Tropical region have been extensively studied and constitute the bulk of the literature on african sandflies.

1.2.1.1 Distribution of sandflies in Kenya

Since the publication of the first papers on phlebotomine sandflies in Kenya by Sinton (in the early twentieth century), knowledge on sandflies has been accumulating steadily. Most of these papers dealt with epidemiology and taxonomy, and only a few papers were on the biology and ecology of the local sandflies.

Manteufel (1912) was the first investigator to notice sandflies in Kenya with emphasis on the presence of Phlebotomus species in the port of Mombasa. A large numbers of sandfly specimens collected in Mombasa were identified by Sinton in 1930 and 1932 (in India) as *P. symesi*(*P. schwetzi*), *P. africanus*, *P. yusafi*, *P. suberectus* (as *P. meilloni* var. *suberectus*). Sinton (1932) identified a number of sandflies collected at Taveta as *P. nairobiensis*, actually known as *S. bedfordi* var. *congolensis*. From sandfly collections made near Nairobi and at Jinja, Theodor (1931) identified the presence of *P. nairobiensis*. The two decades after these first attempts, recorded few studies on Kenyan sandflies. Kirk and Lewis(1951), published a monograph on the taxonomy of the Ethiopian Phlebotomines. This valuable work included keys to the known Ethiopian sandfly species as well as a simple classification. In 1953, the Division of Insect-Borne Diseases initiated investigations on sandflies in Kitui district. Heisch (1954 and 1955) and Heisch *et al*. (1956), revealed the existence of a complex fauna of Phlebotomine sandflies in Kitui and Baringo districts. Heisch (1954) found that *P. kirki* Parrot, *P. rosannae* Heisch, Guggisberg and Teesdale and *P. garnhami* Heisch, Guggisberg and Teesdale were man-biting. *P. clydei* Sinton was sometimes naturally infected with leptomonads and crithidiae in the Kitui. In 1955 and 1956, Mckinnon and Fendall reported the existence of a focus of kala-azar in the Baringo district of the Rift Valley Province.

The distribution of sandflies in Kenya has been documented (Kirk and Lewis, 1952; Heish and Guggisberg, 1953; Heisch, 1954; Minter, 1963). Later, the species distribution was compiled by Minter (1964a), raising the number to 36. Of these, two were collected from areas on the Western Kenya borders. The Phlebotomine sandflies are:

Phlebotomus sergenti Parrot and Martin (Southern Kenya)

P.martini Parrot (Lowland areas)

P.vansomerenae Heisch, Guggisberg and Teesdale (South-east Kenya)

P.celiae Minter (South-east Kenya)

P. orientalis Parrot (South Kenya)

P.heischi Kirk and Lewis (Kitui District of Kenya)

P.rodhaini Parrot (widely distributed in Kenya)

P. guggisbergi Kirk and Lewis (found on the slopes of mount Kenya, in caves, tree holes, bark of trees and in dense evergreen woodland.Also, this species is present in lowlands).

P.longipes Parrot and Martin (Western shore of Lake Naivasha)

Sergentomyia clydei Sinton and *S.adleri* Theodor (common and widespread african sandflies. They are found in Kenya lowlands).

S.affinis Theodor (not common species in Kenya).

S.meilloni Sintoni. (only found in Coastal areas of

Kenya)

S.*suberectus* Sinton, (was collected in Coastal and inland areas).

S.*graingeri* Heisch, Guggisberg and Teesdale (widespread distribution in inland areas of Kenya, below 4,000 feet).

S.*antennatus* Newstead (widely spread in Kenya).

S.*bedfordi* Newstead (associated with tree holes, widely spread).

S.*gracilis* Kirk and Lewis, (found on Coastal areas of Kenya).

S.*simillimus* Newstead (found in Western foothills of Mount Elgon(Uganda side), its is restricted to forested areas of high rainfall).

S.*yusafi* Sinton (uncommon species, found in the Coastal areas of Kenya)

S.*blossi* Kirk and Lewis, found in Kwale (Southern Kenya Coastal).

S.*schwetzi* Adler,Theodor and Parrot (common in Africa and is widely distributed in lowland areas of Kenya).

S.*africanus* Newstead (common in Africa, is widely distributed in lowland of Kenya).

S.*squamipleuris* Newstead (common African species, widespread in lowland areas of Kenya).

S.*multidens* Heisch,Guggisberg and Teedale (common during the rainy seasons in the Kitui district, occasionally this species is collected in other parts of Kenya).

S.garnhami Heisch, Guggisberg and Teesdale (found in South-Eastern Kenya and in Rift Valley. It has a very strictly seasonal incidence).

S.ingrami Newstead (widely distributed in lowlands of Kenya, but this species is seldom found in large numbers).

S.kirki Parrot (collected in South-eastern of Kenya during the rainy season)..

S.serratus Parrot and Malbrand (has been rarely recorded in Kenya).

S.teesdalei Minter (collected in the Kitui district of South-eastern Kenya. Also this species is rare).

S.dureni Parrot (uncommon species in Kenya, found in Kitui and Kisumu)

S.rosannae Heisch, Guggisberg and Teesdale (only collected in Kitui district. This species is a rainy-season species).

S.harveyi Heisch, Guggisberg and Teesdale (was collected in Kitui and has been found to be a rainy season species).

S.kitonyii Minter (had been collected near Kitui township. Collections were made from termite hills).

S.edwini Minter (collections of this species were made in Bufumbo area (Uganda), not far from the Kenya border. This species has not yet been recorded from Kenya).

S.decipiens Theodor (was collected near Kakamega, the only place in Kenya where this species has been recorded).

However, species such as *P.elgonensis* Ngoka, Madel and Mutinga, *P.pedifer* Lewis, Mutinga and Ashford, *P.duboscqi*, *S.waynnae* Watson were added to this long list later on (Mutinga *et al*.,1986c) followed by *S. christophersi* Sinton.

1.2.2 New World

The New World has three groups of phlebotomine sandflies namely, *Warileya*, *Brumptomyia* and *Lutzomyia*. All New World sandflies vectors of leishmaniasis belong to the *Lutzomyia* group.

Rutledge and Ellenwood (1975b), working on panamanian sandflies, recovered leishmanial organisms from wild caught sandflies. Killick-Kendrick (1978) reported twenty seven species and subspecies of sandflies so far known or suspected vectors of leishmaniasis of man in the New World. The major vectors were then, *Lutzomyia trapidoi* (Fairchild and Hertig), *Lu. panamensis* (Shannon), *Lu. gomezi* (Nitzulescu), *Lu. pessoana* Countinho and Barretto, *Lu.*

flaviscutellata (Mangabeira), *Lu*. *wellcomei* Fraiha, Shaw and Lainson, *Lu. umbratilis* Ward and Fraiha and *Lu*. *trapidoi* (Fairchild and Hertig) amongst other species of sandflies found to be vectors of *Leishmania mexicana* and *L. braziliensis* respectively and hence responsible of the cutaneous leishmaniasis in man. *Lu*. *cruciata* (Coquillett) and *Lu*. *olmeca* Fairchild and Theodor were found to have minor incidence on the transmission of the parasite.

1.3 Habitats of sandflies

Wherever sandflies occur, some research results have been reported on their habitats. In India, Howlett (1913) observed sandfly species breeding in cracks of walls in which lizards reside and in nests of termite hills. These sites provide suitable food for larvae of sandflies as well as favourable moisture and temperature for the adults.

In the USSR, Petrishcheva and Izyumskaya (1941) and Perfil'ev (1966) among others, studied extensively the sandfly breeding sites. They noted that burrows are the preferred biotope of sandflies in nature. They found that sandflies occur in burrows of ground squirrels, gerbils, jerboas, mouse-like rodents, porcupines, badgers, jackals, hedgehogs and tortoises, bee-eaters, rollers, pigeons and other vertebrates and birds. In the USSR, sandflies were also found in abandoned buildings and caves frequented by bats, lizards and snakes.

In British Honduras, few sandflies have been recorded from animal burrows, but this is mainly because burrows are difficult to locate (Disney, 1966). In this part of the New World, sandflies have been found concentrated in natural cavities (caves, rock crevices), in tree holes, on trunks of large trees and under leaves scattered over the forest floor (Hanson, 1961).

In Kenya, extensive studies on sandfly habitats were conducted by Heisch _et_ _al_.(1956); Minter (1964a,b,c); Mutinga and Kamau (1986) and Mutinga _et_ _al_.(1986a) and sandfly species were collected from different habitats which ranged from natural to artificial sites.

Natural sites: these include occupied or abandoned animal burrows, termite hills, tree holes and hallows, soil crevices, river banks and piles of stones.

Artificial habitats: identified as man-made habitats (Minter, 1964b), they comprise human habitations, animal enclosures or shelters, empty beehives made from hollowed logs, pit latrines, beer shops, tents, grain-stores, chicken coops and wells. Some habitats harbour a wide range of sandfly species, others have a more restricted or specialized sandfly fauna. Termite hills were classified into four ecological types of mounds (Minter, 1964b,c; Wijers and Minter, 1962): the castellated, the eroded, the closed and the pinnacled types. The castellated type consists of mounds of hardened earth, often 4 to 6 feet high, having multiple low-level ventilation shafts; these sites are favorable for resting sandflies. The shafts are generally up to five inches in diameter and lead into the depths of the termitary. The eroded mounds, derived from the castellated type by normal processes of weathering when building activities of the termite colony have declined or ceased. Both, the castellated and the eroded hills harbour the similar sandfly population, excepting only the Synphlebotomus species are added to sandfly population found in the eroded type. The closed termite hill, was unsuitable as a habitat for sandflies; although a few flies were collected on the wall of the mound. This type is a structure abandoned by the termites at an early stage in the formation of the mound. The pinnacled termite hill, mainly found in Western Kenya and in Marigat area, consisted of mound from which a single ventillation shafts rose like a pinnacle to heights up to 3.6 metres. In the Marigat area, all four types of termite hills are the work of Macrotermes bellicosus Smeathman. Minter (1964c) reported that in Kenya, breeding places of sandflies are still unknown, although the termite hills in which adult flies are found resting seem to offer suitable conditions for breeding. Animal burrows have been used as breeding sites for several species of sandflies (Abonnenc, 1972; Chaniotis and Anderson, 1968; Lewis and Kirk, 1951). Hanson (1961), working on Panamanian sandflies, listed the potential breeding places of phlebotomine sandflies. These were found in tree buttresses, on the forest floor, in burrows, tree hollows and holes, under overhanging roots, at the base of trees, under bark and logs, under rocks, on chicken-coop floors and cracks in the soil.

Petrishcheva and Izyumskaya (1941) in Russia recovered sandfly larvae from floors of inhabited houses and animal quarters, burrows of rodents, at the base of clay or stone walls and in sheep-pens.

In the Old World, extensive investigations were carried out to locate the breeding sites of sandfly vector species (W.H.O., 1979). These studies have shown that sandfly breeding places are so widely distributed that adequate coverage is difficult.

CHAPTER TWO

GENERAL MATERIALS AND METHODS

2.1 Study area

2.1.1 Location, topography and vegetation

Studies on ecology of sandflies were carried out in the Perkerra Irrigation Scheme, a few kilometres east of Marigat, a trading and administrative centre (Figure 1). The area lies approximately between the Latitude 0o 28' North and Longitude 35o 58' East (Minter, 1963) and is situated in Baringo district (Kenya). This area is located at an altitude of about 1067 metres above sea level on the floor of the Kenya Rift Valley (Minter, 1963; Zahar, 1981). Marigat area is situated between Lake Baringo to the North, and Lake Bogoria to the south. The Tugen hills form a large barrier in the West and Laikipia escarpment, large mountains which rise to over seven thousand feet in the East.

A semi-arid area, Marigat experiences high temperatures throughout the year, during both dry and rainy seasons. Its daily fluctuation of temperatures is high and the effects of alternate expansion and contraction are important in the breaking up of the soil and rocks.

Figure 1. Map showing the area of investigations

The alternation of long dry season and the intense heat even during the rainy season, is the dominant factor causing the soil erosion in the area. In his study on the geology of Kenya, Cole (1950), stated that " The Rift Valley is essentially a region of internal drainage; with rivers flowing into shallow lakes along its floor ". Wind constitutes an important eroding and transporting agent in the Marigat area, it takes away and scoops out the soft soil and rocks and polishes their surfaces. During the dry period as well as before any downpour, there is an accumulation of wind-borne dust mixed with sand, then at this time the land becomes brownish showing conditions of great aridity.

The Perkerra Irrigation Scheme lies in a valley, with soils deposited by heavy drainage of the slopes surrounding it. Studies undertaken on the texture of the soils showed that, they are principally light silt to clay loam, with considerable alkaline and neutral (soil) reactions approaching pH 7. These soils are poor in organic substances, but rich in calcium and available phosphorus. Marigat is a valuable agriculture area although the fluctuations and unreliable nature of its rainfall, constitute a major environmental constraint, which limits the growth of various plants in the area. The high lands (Laikipia mountains, Tugen hills) are characterized by upland evergreen forests and at their lower limits, there is an evergreen and semi-deciduous bushland and perennial grassland. In the lowlands, bushland is the major vegetation type, dominated by Acacia thorn trees, which have a height comprising between 8 and 13 metres. A number of plants grow under these trees. Along the larger drainage channels and on the old bed of the Perkerra river, Acacia seyal Del. dominates. On the rocky hills, Acacia thorn tree predominates and is associated with some members of graminae.

The vegetation of this area can be designated as tropical dry forest where Acacia thorn tree constitutes more than 90% of the total of tree species. An excessive cut down of trees for firewood, house construction and charcoal has led to excessive erosion and destruction of soil by both the wind and the rains.

2.1.2 Climate

Marigat area experiences two main seasons, a six-months rainy season (March to August) and the dry period, normally September to February. Occasionally, scattered showers occur in November. Average rainfall data from 1981-1986 showed a total of 653 mm per annum with a maximum in June (147.08 mm) and a minimum in January (0.56 mm). An average of 54.40 mm of rainfall was recorded per month

(Appendix 1a). Ashford and Bettini (1987) stated that in Kenya about 600 mm annual rainfall occur almost entirely in a rainy season which lasts about 6 months. Perkerra river is the only permanent river in the area. Due to water run-off from surrounding hills, its flow increases during the rainy season and goes down during the dry period. The river supplies water to both Marigat township and the Perkerra Irrigation Scheme. Confined in the Rift Valley System, and by its position near the Equator line, Marigat area has its maximum temperature (air) of 34.71 oC in January, corresponding to the driest month of the year. Also, high temperatures were recorded during the wet season (29.58 oC). A six-year average gave a value of 32.16 oC per month (Appendix 1a).

The outstanding feature of the mean monthly relative humidity (Appendix 1a) was the relative instability of the air moisture content during both periods of investigations. High relative humidity values were recorded during the wet period, while low values were monitored during the dry season. The highest relative humidity value was observed in July (69.18%) while the lowest was calculated in January (47.30%) corresponding to the wettest and the driest months of the year respectively.

2.2 Sampling methods

One of the principal objectives of this investigation was to determine the relative seasonal abundance of sandflies in relation to some environmental conditions in a particular area by comparing successive samples of sandflies taken in a standard way. To simplify the sampling procedure, and the identification of sandflies into species, only adult phlebotomines of both sexes were included in the examination and the analysis of seasonal variations. Attempts to collect immature stages did not produce sandflies despite the enormous effort. W.H.O. (1984) noted that immature stages of sandflies are difficult to study in the wild.

Wherever the sandflies occur, a large number of collecting methods have been used: fan-suction trap with or without light, mouth-aspirator, plastic or glass tubes and sticky traps amongst many others have been tried. The first device has given little success as many studies have proved that sandflies respond in different ways to light traps (Lainson and Shaw, 1972; Perfil'ev, 1966). Service (1976), while sampling resting mosquitoes found that traps employing attractants such as carbon dioxide, light or some other visual stimuli, attracted host-seeking mosquitoes. Moreover these traps are usually species selective. However, the fan-suction trap, the mouth-aspirator trap and the sticky or adhesive papers, using non attractants give less biased data and should sample all species more or less equally (Service, 1976). Thatcher (1968a) baited the castor oil traps with animals to collect phlebotomine sandflies in Panama. Chaniotis (1978) used various methods to catch both flying and biting panamanian sandflies. These methods were: light traps, oil trap or sticky traps, animal-baited traps, burrow-traps, smoke and suction tubes.

2.2.1 Sampling devices

Three devices were used during the present investigations on sandflies in the Marigat area, these were: mouth-aspirator trap or sucking tube, the mechanical aspirator or fan-suction trap and the sticky trap. For the long-term collections, only the standardized sticky trap, was used for sampling the sandflies (Dergacheva et.al., 1979; Disney, 1966; Mutinga, 1981). Other techniques, such as, mouth-aspirator and fan-suction traps served occasionally to collect live sandflies from where blood meals were taken for further analysis of host preferences.

The selection of sampling devices largely depends on the habits of the flies, the type of biotopes and the availability of man-power and ressources (W.H.O., 1979).

2.2.1.1 Sticky traps

In order to sample the maximum number of sandfly species, standardized sheets of polythene material covered with castor oil were used in natural and artificial habitats of sandflies in the Marigat area.

- In nature, a 20 by 30 cm sticky trap was placed at the entrance of animal burrow, at the opening of tree hole/hollow or inserted into the ventilation shafts of termite hills.
- In human settlements comprising human habitation and animal enclosures, a 1 by 1 m sticky polythene sheet, was used for sandfly collections.

Sticky traps were set up in breeding and resting places during evening hours, and left overnight. Caught sandflies were removed from traps in the early hours next morning. Flies were taken off the sticky trap with a spine, obtained from the thorn tree (Acacia) and preserved in 70% alcohol after they were washed in a dishwashing detergent instead of 95-96% alcohol, as used by earlier workers. The high concentration of alcohol dries up the sandfly specimens, making difficult their dissections). The detergent removed the castor oil solution in which flies were caught. Each sandfly was taken individually.

According to Dergacheva et al., (1979), data from sticky traps showed less variability than those from other capture methods, and were consequently more acceptable for statistical analyses. Also the sticky trap is believed to be the most effective and non-selective method of sampling sandflies. It is the most valid and unbiased sampling method of sandfly species, (Dergacheva et al., 1979) and was therefore, used during all the present investigations.

2.2.1.2 Mouth-aspirator trap

Sucking tubes, or the mouth-aspirator trap was used to collect resting sandflies from various surfaces. Sandflies resting on tree backs and/or buttresses, in tree holes/hollows, on rock crevices, on house walls and in holes made by birds on termite hills were usually collected by using this device. Service (1976) referred to hand-catchers the collections of flies using the mouth-aspirator traps.

A 140 x 5 mm plastic or glass tube was used in these sandfly collections. The inner end of the tube was closed with a piece of mosquito netting. This end also had a cork through which passed a long rubber or pliable plastic tube, which formed the mouth of the trap. The inner opening of the glass or plastic tube was also closed with a cork into which was inserted a 20 cm length of glass tube of small size (5 mm). This (glass or plastic tube of small size) formed the part from where flies entered the trap

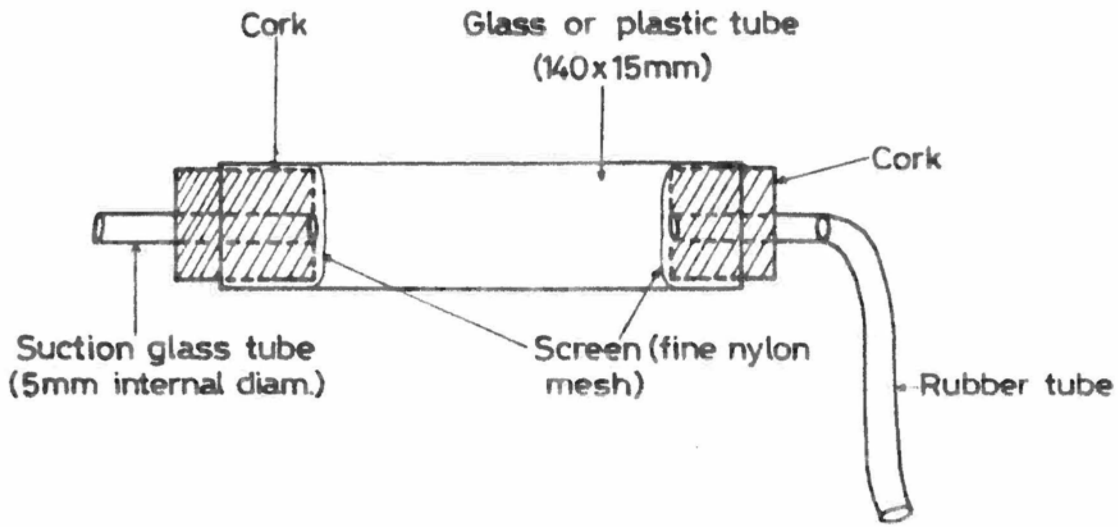

Figure 2a. Mouth-aspirator or suction tube for the collections of sandflies.

(Figure 2a). The piece of mosquito netting covering the cork, prevented the entry of the dust particles in the sucking tube and their inhalation by the collector. The small sized glass tube was closed with cotton wool to prevent the escape of flies. To kill the caught sandflies inside the aspirator, cotton wool moistened with ether or chloroform was inserted into the small sized glass tube.

2.2.1.3 The mechanical aspirator

The mechanical aspirator is a battery operated device using fan-suction to collect sandflies. It catches very large numbers of insects. This trap consisted of two main parts: the fan-suction, which is a rotor soldered inside a can (15 cm long and 10 cm diameter), open at both sides. The fan sucked up all flies passing beneath the tin, into the collecting chamber. The collecting chamber normally was made of a mosquito netting and placed on the top of the can. In order to prevent adult sandflies from escaping from the collecting chamber or the container, the fan-suction trap was operated throughout the night. It was disconnected from the main supplier source (four dry-cell batteries of 1.5 volts each) the following morning.

2.3 Sandfly collection sites

Twenty three sites were randomnly selected for the sandfly standardized long-term collection series in the area. These were five animal burrows, five termite hills, five tree holes/hollows, three animal enclosures, three human habitations and an open field. To provide sufficient data for meaningful analyses of sandfly population dynamics, weekly sandfly collections (four per month) were undertaken for a period of twelve months.

2.3.1 Animal burrow

Located along the old river bank of the Perkerra river, the burrows (Figure 2b) were occupied by rodents, birds, bats, squirrels, monitor lizards and porcupines. The "No.4" burrow was however situated in a land depression in an open field.

Sticky traps, 20 X 30 cm (Dergacheva et al., 1979) were placed at the entrances of burrows overnight, once every week for a period of twelve months. It was thus possible to collect a large number of sandflies of both sexes, making the assessment of seasonal variations and species composition possible throughout the year. The suction-traps were occasionally placed in burrows (Figure 3a) in order to collect live sandflies. The mouth-aspirator

Figure 2b. Animal burrow used by sandflies as breeding and resting site.

Figure 3a. Fan-suction trap collecting sandflies from animal burrow.

was not used for collecting sandflies from burrows.

2.3.2 Termite hills

Built by the *Macrotermes bellicosus* which is the predominant termite in the area, all investigated mounds were classified according to Minter (1964b,c). Thus, eroded (Figure 3b), closed, pinnacled and castellated hills were searched for sandflies.

For the sandfly collections, the 20 X 30 centimetres sticky traps were placed on the ventilation shafts of each of the five termite hills. Collections were done weekly at 1800 - 0700 hours (the following morning).

1. The castellated termite hill is a type of mound with multiple low-level ventilation shafts. Termite hills No.1 and No.5 belonged to this category. The clear polythene sheet covered with castor oil was placed on the ventilation shaft and then covered the termite hill opening.

2. The eroded termite hill. derived from the castellated type. This hill may or may not have a termite colony. The mound then becomes eroded due to the weathering conditions and animal activity (e.g. cows). Goats and sheep destroy large numbers of mounds. A sticky trap was placed on the top of each eroded hill and caught sandflies were removed the next day. Termite hill number 2 fell in this group.

Figure 3b. Eroded termite hill used by sandflies as breeding and resting site. The sticky trap collects sandflies coming in or going out the mound.

3. The closed termite hill.

Although this type of mound did not have any ventilation shaft, sticky trap was placed on the wall of the termite hill. Small clear polythene sheets measuring 20x30 cm were pinned on the mound's wall and caught all flies which came in search for a resting place. The investigated termite hill number 4 was found to fall into this group.

4. The pinnacled termite hill.

This type of termite hill consisted of a mound from which a single ventilation shaft arose like a pinnacle. On this type, sticky traps were placed on the top of the termite hill and covered the hole. All sandflies which were resting inside this termite hill and others which came in search for a hiding place were caught in this way. Termite hill number three belonged to this category.

2.3.3 Tree holes and hollows

Sticky traps were used for the sandfly collections in five randomnly chosen tree holes and hollows. Searches of holes and hollows on trees were carried out in the Perkerra forest where large trees were found having holes and hollows. Thus, Acacia thorn trees (*Acacia seyal* Del.) as well as the Fig trees (*Ficus capensis* Thunb.) predominantly growing in the area, were searched for hollows and holes. Investigated holes and hollows were between 0 and 5 metres above the ground. It was observed that tree holes and hollows, which constitute important sandfly breeding and resting sites, were made by woodcutters, who remove branches or cut roots from living trees.

Sticky traps measuring 20x30 cm were inserted into holes and hollows of trees, weekly, for a period of twelve months. Traps were left overnight at every collecting site. Occasionally, the mouth-aspirator trap was used to collect sandflies resting in these habitats.

2.3.4 Human habitation

In order to study the sandfly attraction to humans, sandfly sticky traps were placed in homesteads, surrounding inhabited houses. Collections of sandflies from three randomnly selected houses in three different homesteads were made over a 12-month period, with 1x1 metre sticky traps. Two traps were placed in every homestead.

The type of houses in the area, made it impossible to use either the fan-suction trap or the mouth-aspirator trap. These houses are thatched and once a sandfly landed on its wall it could never be detected. Collections of sandflies in this habitat helped to assess the sandfly species as attracted to humans and their seasonal variations in homesteads.

2.3.5 Animal enclosures

Sandfly species composition in animal enclosures and its variations over seasons were investigated for a period of one year (November 1985-October 86), using sticky traps, 1x1 metre. The sticky traps were suspended on branches and placed alongside the surrounding thorny fences (Figure 4). Three animal enclosures separated from each other by not less than eight hundred metres were randomnly selected in the area. Two traps were placed in every animal enclosure.

2.3.6 Open field

In order to avoid the interaction which may result between sandflies and the human and/or animals (cattle), the investigated open field was located far from human habitations and animal enclosures. Sticky traps were fastened to two branches at 1.5 m above ground level and placed randomnly in the field.

2.4 Identification of sandflies

Once removed from traps and processed as said earlier (2.2.1.1), sandflies were thereafter, mounted on slides for identification to species level. Gumchloral solution was used for the mounting of sandflies.

Figure 4. Sticky trap suspended alongside a thorny fence.

2.4.1 Mounting of sandflies

Washed sandflies were placed separately on slides and these steps were followed:

1. A drop of gumchloral (solution containing 50 ml of distilled water, 30 gm of gum arabic, 20 ml of glycerin and 50 gm of chloral hydrate) was placed in the middle of the slide and the sandfly specimen was left on it,

2. For the male and the female, the head was removed and turned upside down, the whole fly was thereafter covered with a coverslip.

2.4.2 Identification

The identification of sandflies into different species is known to have caused a lot of problems to earlier investigators involved in sandfly taxonomy (Abonnenc, 1972; Abonnenc and Minter, 1965; Kirk and Lewis, 1951). Service (1986) noted that the identification of adult phlebotomine sandflies to species is difficult and usually necessitates the examination of internal structures such as the arrangement of the teeth on the cibarial armature, the shape of the spermatheca in female, and in males the structure of the external genitalia. Mutinga (1972) reported that the difficulty in the identification of phlebotomine sandflies arises from the small size of the insects and from the fact that specific characteristics (e.g. spermatheca, pharynx, ...) are found only in the internal structures. Rogo (1985) stated that biochemical techniques are the most diagnostic and reliable tools to differentiate between closely related species of the same sandfly group. Lewis (1982), recognized the division of the phlebotomine sandflies into five genera: Phlebotomus and Sergentomyia (Old World) and Warileya, Brumptomyia and Lutzomyia (New World).

In this study, the classification of Lewis (1982) was used mostly. The classification of flies into different groups was based on the presence or absence of the erect hairs. For the male, the genitalia (pennis sheath), the size, number and arrangement of spines on the coxite and the head (cibarium and shape/size of the teeth) were the most used features for their identification. For the female, the spermatheca, cibarium and pharynx were carefully examined and served as valuable characters to identify the female sandfly into species. Sandflies in this work are treated as a sub-family (Kirk and Lewis, 1951; Theodor, 1948) and placed in the 2 Old World genera (Abonnenc, 1972; Lewis, 1982).

2.5 Data analyses

In entomological field studies, sampling occasionally yields erratic values (Chaniotis, 1978). Analysing the population structure, Chaniotis et al. (1971b) noted that it is common in insect sampling to have disparate results in successive samples for reasons other than the sampling technique. In order to minimize such abnormalities, it was necessary to transform the original data into logarithms. The data transformation was done in the following way (Parker, 1979; Snedecor and Cochran, 1980):

1. For low figures and zeroes, logarithm (n) transformation or logarithm (n+1) was employed respectively. Logarithms to base 10 were used.
2. For data recorded in percentages, these were transformed to arc sine $\sqrt{P}$

The analysis of variance (ANOVA model-1) was used for studying the sandfly prevalence in various investigated breeding and resting sites as well as their distribution in main breeding sites (animal burrow and termite hill), and resting places (vegetation sites) in relation to the soil characteristics (soil chemical and physical properties) and the microclimates as prevailing inside these sites.

To normalize the data for seasonal variations (e.g.

monthly sandfly relative abundance, rainfall, relative humidity, temperatures,...), the logarithmic transformation (log (n+1)) was applied (Williams, 1937). Statistical analysis system (SAS) was used to perform the correlation and analysis of variance for detecting the association or the relationship which could exist between sandflies and all investigated environmental and microclimatic factors. For this reason, continuous parameters such as monthly sandfly collections, the monitored environmental factors and the microclimate variables recorded inside burrows and termite hills were used for calculating the correlation coefficients.

CHAPTER THREE

SANDFLY POPULATION DYNAMICS

3.1 Introduction

Collections of sandflies from the randomnly selected sites such as termite hills, animal burrows, tree hollows, human habitations, animal enclosures and open field had shown that sandfly densities in both breeding and resting sites are characterized by a high species diversity, spatial heterogeneity and changes over seasons for both Phlebotomus and Sergentomyia groups. Killick-Kendrick (1978) and W.H.O. (1984) stated that the long-term studies on the population dynamics of phlebotomine sandflies, mainly the vector species are of inestimable value in understanding the epidemiology of the sandfly-transmitted diseases and in planning control strategies. The knowledge of the sandfly annual generations and the sandfly population peaks determine the most effective time to mount an attack. Also, the regular and representative population samples taken during an annual cycle in a standard way will reveal fluctuations in sandfly densities. One of the principle objectives of this study was to determine the relative seasonal abundance of the Sergentomyia and Phlebotomus species present in the Marigat area utilizing the sticky traps.

3.2 Materials and Methods

Collections of sandflies were carefully undertaken from the randomnly selected termite hills, animal burrows, tree holes/hollows, human habitations, animal enclosures, open field and tree trunks (see 2.3). The standardized sheets of polythene material coated with castor oil so called sticky traps were used in collecting sandflies from the selected sites. Traps measuring 20 by 30 cm were placed in the first three sites and on tree trunks, while a 1 by 1 metre sticky polythene sheets were placed in the human habitations and in animal enclosures. Collections were done once every week in each collecting site for a period of twelve months. This regular sampling from discovered sandfly breeding and resting places revealed the sandfly population densities during an annual cycle comprising both dry and wet periods. Also, this sampling carried throughout both seasons revealed the activity pattern of sandflies.

3.3 Results

3.3.1 Sandfly species composition

During the studies on sandfly relative abundance (1985/86), a total of 98574 specimens (49955 males and 48619 females) were collected in the area. After identification, 15 species belonging to the Phlebotomus and Sergentomyia sandfly genera were recorded in the area. The sandfly species present in the Marigat area, were therefore grouped into 5 Phlebotomus spp. and 10 Sergentomyia species:

1. Phlebotomus martini Parrot, 1936
2. Phlebotomus duboscqi Neveu-Lemaire, 1906
3. Phlebotomus rodhaini Parrot, 1930
4. Phlebotomus orientalis Parrot, 1936
5. Phlebotomus sergenti var.saevus Parrot and Martin, 1939
6. Sergentomyia bedfordi Newstead, 1914
7. Sergentomyia antennatus Newstead, 1912
8. Sergentomyia ingrami Newstead, 1912
9. Sergentomyia africanus Newstead, 1912
10. Sergentomyia affinis Theodor, 1933
11. Sergentomyia schwetzi Adler, Theodor and Parrot, 1929
12. Sergentomyia adleri Theodor, 1933
13. Sergentomyia clydei Sinton, 1928
14. Sergentomyia graingeri Heisch, Guggisberg, Teesdale, 1956
15. Sergentomyia squamipleuris Newstead,1912.

Studying the sandfly abundance in various trapping sites, it was shown that the common sandfly species were collected in large numbers from the different types of sites. There was a high occurrence of the 2 ubiquitous Sergentomyia species (S. antennatus,and S. bedfordi). Table 1 shows the capture rates (number per 100 collections expressed into log(n+1) transformation) of each sandfly species as taken by sticky traps in termite hills, animal burrows, tree hollows, human habitations, animal enclosures and in open fields. Phlebotomus martini was among the commonest sandflies in the area. Twelve species were collected from animal burrows and tree hollows, while the termite hills, human habitations and animal enclosures yielded eleven species. Ten species were recorded from the Open field (Table 2).

Animal burrow and tree hollow habitats yielded twelve different sandfly species. These were Phlebotomus martini, P. duboscqi, P. rodhaini, Sergentomyia antennatus, S. bedfordi, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri, S. clydei and S. graingeri. Apart from the difference in sandfly occurrence, the same species composition was found at both sites. Thus, Phlebotomus species occurred in animal burrows at a rate of 71.45% against 1.69% in tree hollows, and Sergentomyia species prevailed at 18.03% in animal burrows against 25.89% in tree hollows.

In the termite hill habitat, eleven species were recovered. These were Phlebotomus martini, P.duboscqi, P.rodhaini, S.antennatus, S.bedfordi, S.ingrami, S.africanus, S.affinis, S.schwetzi, S.adleri and S.clydei. Comparing both sandfly groups as collected from termite hills to the total sandflies recovered in the area, it was shown that 16.26% of Phlebotomus species against 31.89% of Sergentomyia species were collected from this habitat. Termite hills constituted therefore, an important collecting site for the Sergentomyia species in particular and for the phlebotomine sandflies (both groups) in general. The recovery of Phlebotomus species from termite hills comes into second position after animal burrows.

In both human dwellings and animal enclosures, eleven sandfly species were recoverd; among them were two Phlebotomus species and nine Sergentomyia species. These species were: Phlebotomus martini and P. duboscqi, Sergentomyia antennatus, S. bedfordi, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri, S. clydei and S. graingeri. Both groups of sandflies were collected at almost the same rate in human dwellings as well as in animal enclosures but with a slight increase in the last habitat. Therefore, it was seen that of the total sandflies collected in the area, 4.32% against 5.93% of Phlebotomus species were collected from human habitations and animal enclosures, while 8.45% against 10.30% of Sergentomyia species were recovered respectively from both sites. Investigating the sandfly attraction to human and animal lures, annual collections of sandflies showed that for the Phlebotomus group, Phlebotomus martini remained the main sandfly attracted to man in the study area. P. duboscqi was found to be much more attracted to animals than to humans. For the Sergentomyia group, S. bedfordi seemed to be more attracted to animals than to humans, while the S. antennatus was more attracted to humans than other members of the group.

In the open field, ten sandfly species were collected, amongst them, were 2 Phlebotomus and 8 Sergentomyia species. For the Phlebotomus group, P. martini and P. orientalis were present. The first species was collected in the Marigat area throughout the year, while the second was found to be a wet-season species. Although sandflies of the Phlebotomus group were present in the open field, they were rare. For the Sergentomyia group, S. antennatus was the main species followed by S. bedfordi, S. affinis and S. ingrami. A capture rate of 3.10, 2.99, 2.51 and 2.25 was observed for both species respectively.

Comparing both groups of sandflies in this habitat, it has been shown that 0.33% of Phlebotomus against 5.41% of Sergentomyia species of the total sandfly population recovered in the Marigat area were collected in the open field.

3.3.2 Relative abundance of sandflies

3.3.2.1 Termite hill and animal burrow

The relative abundance of sandflies in both animal burrows and termite hills, the main sandfly breeding sites, presented considerable seasonal variations (Figure 5 and Appendices 2, 5 and 6).

In the termite hills, a decrease in sandfly populations was observed during the dry season (December to February and September to October) and a month after the heavy rains (May). It was therefore, shown that heavy rains as well as the dryness of the breeding sites are the main factors contributing to the decrease of sandfly populations in this habitat. The increase of sandflies was observed during the rainy season and reached its peak in July.

In animal burrows, the trend of sandfly collections fluctuated from one month to another. Since these fluctuations occurred throughout the year it was not possible to pinpoint the month with the highest sandfly relative abundance in this habitat. Neverthless, the decrease in sandfly populations was observed during the month of May and July, corresponding to one month after heavy rains and a month before the end of the wet season

Table 1. Comparative distribution of the Phlebotomine sandflies in six biotopes. Data based on catches made by sticky traps. Marigat area, 1985/86.

Sandfly species	Termite hill	Animal burrow	Tree hollow	Human habitat	Animal enclos.	Open field	Average
P.martini	2.20	2.80	1.16	1.39	1.47	0.74	0.35
P.duboscqi	0.81	2.04	0.34	0.41	0.71	0.00	0.06
P.rodhaini	0.72	0.52	0.62	0.00	0.00	0.00	0.00
P.orientalis	0.00	0.00	0.00	0.00	0.00	0.19	0.00
S.bedfordi	3.40	2.80	3.79	2.76	3.00	2.99	1.26
S.antennatus	3.80	3.70	3.49	2.92	2.92	3.10	1.41
S.ingrami	3.33	2.79	2.40	2.22	1.97	2.25	0.77
S.africanus	2.53	2.21	2.28	1.22	1.40	1.50	0.31
S.affinis	1.58	1.22	1.36	1.35	1.35	2.51	0.17
S.schwetzi	2.63	2.08	2.03	1.57	1.39	1.73	0.32
S.adleri	1.95	1.87	1.48	1.65	1.55	1.88	0.18
S.graingeri	0.00	0.13	0.25	0.00	0.00	0.00	0.00
S.clydei	1.76	1.84	1.21	1.71	1.51	1.91	0.16
S.squam.	0.00	0.00	0.00	0.08	0.08	0.00	0.00
	4.08	3.87	3.99	3.25	3.32	3.47	
Percentage	33.20	20.70	27.16	4.88	5.80	8.23	

Values are expressed into log.(n+1) transformation
Percentages are calculated on the untransformed data.
S.squam.= *S.squamipleuris*.

Table 2. Shows the Phlebotomine sandfly groups as collected from various habitats. (Marigat area, 1985/86).

Collection site	Sandfly group				Total	
	<u>Phlebotomus</u> group		<u>Sergentomyia</u> group		%Collected sandflies	No.sp.
	No. sp.	%Sandfly	No.sp.	%Sandfly		
Termite hill	3	16.26	8	31.89	33.20	11
Animal burrow	3	71.45	9	18.03	20.70	12
Tree hollow	3	1.69	9	25.89	27.16	12
Human habitation	2	4.32	9	8.45	4.88	11
Animal enclosure	2	5.93	9	10.30	5.80	11
Open field	2	0.33	8	5.41	8.23	10
Total sandfly		2662		95910	98572	
Percentage		2.70		97.29		

No.sp.= number of sandfly species.

respectively.

During the dry season as well as the wet period, an increase of sandflies in one habitat corresponded to a decrease of sandflies in the other habitat and vice versa. The month of July corresponded to the highest population density of sandflies in termite hills, and conversely coincided with the lowest population of sandflies in burrows. Trends of sandfly fluctuations from both sites presented the same pattern in April, May and June.

Both important collecting sites, termite hills and animal burrows yielded respectively during the study period 33.20% and 20.70% of the total sandflies (Tables 1 and 2). Collections of sandflies during both seasons (1985/86), showed that in termite hills an average of 155.11 against 90.75 sandflies were collected during wet periods and the dry season respectively (Appendix 3). In animal burrows there was no major differences in sandfly collections during either seasons. An average of 75.29 sandflies against 75.83 sandflies were recorded during both wet and dry seasons respectively.

Statistical analysis of sandfly collections from both termite hill and animal burrow sites using Analysis of variance (Anova model-1) and SAS programme (Table 3), showed that:

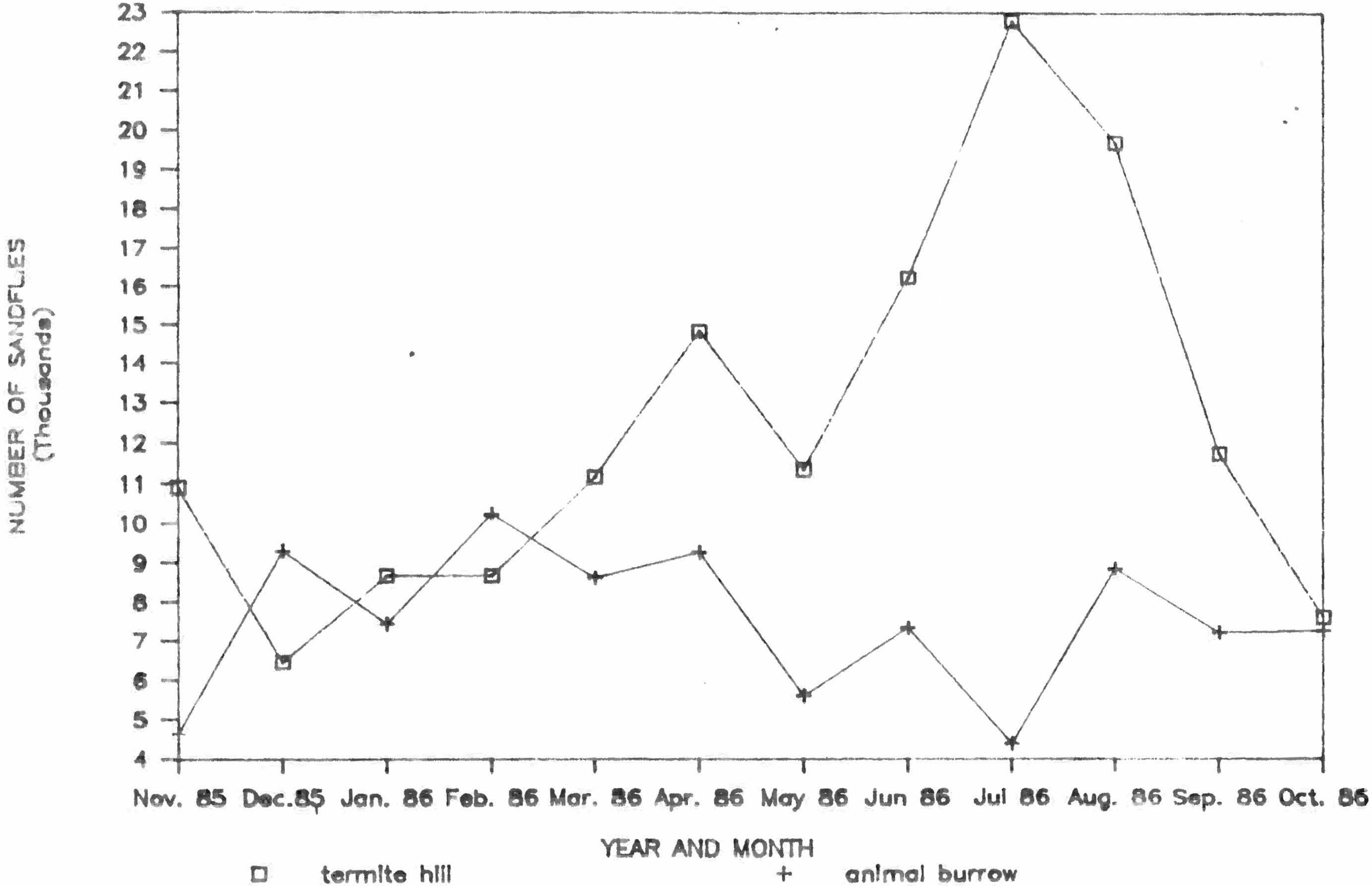

Figure 5. Seasonal variations of sandflies in Termite hills and Animal burrows. (Marigat area, 1985/86).

a) The difference between termite hill and animal burrow mean-sites was greater than the Least Significant Difference (LSD) at 5 percent level (0.20 greater than 0.12), indicating that both sites were significantly different (F-value= 7.01, P=0.009).

b) For the monthly collections of sandflies in termite hill and animal burrow, no difference was observed (F= 0.99, P= 0.462).

c) There was no interaction between termite hills and animal burrows; indicating that the number of collected sandflies behaved consistently the same way from month to month and site to site (F= 0.91, P= 0.530).

3.3.2.2 Human habitation and animal enclosures

The relative abundance of phlebotomine sandflies as collected from both human dwellings and animal enclosures (Figure 6 and Appendices 2, 7 and 8) was used to analyse the seasonal variations of sandflies attracted to human and animal lures. Collected data showed that:

a) In human habitation, the sandfly relative abundance decreased during the dry season and at the end of the wet period. The month of December, August and September presented a low sandfly population, with the lowest value in December. The increase in sandfly relative abundance in this habitat was observed during the wet period. Thus, the month of November (month with a few scattered rains), February April July, and October experienced an increase in sandfly populations with the peak appearing during the months with few rains (October and November).

b) In animal enclosures, the analysis of the sandfly population attracted to animals showed a decrease of sandflies during the dry season (January, September and October) and the wet season (March to May). The lowest sandfly relative abundance was recorded in January and May. An increase was seen at the end of the dry period (February) and during the wet season (June to August). High sandfly populations were then recorded at the end of the wet weather (July and August) and during the dry period with few rains (November).

In both human dwellings and animal enclosures, the sandfly relative abundance presented a "swamping" graph pattern from July to October. This shows that the increase of the sandfly population in one or both habitats (during that particular period) corresponded to the decrease of the sandfly population in the other habitat and vice versa. Collections of sandflies, showed a population of 18.91 against 16.73 sandflies from the human habitations during the dry and the wet season respectively. While from animal enclosures, a population of 22.03 against 20.34 sandflies was recorded during both dry and wet season respectively (Appendix 3). Both human habitations and animal enclosures yielded respectively 4.83% and 5.80% of the total sandflies.

Table 3. Analysis of variance for the sandfly population density as collected from termite hill and animal burrow sites.

Source of variation	Degree of freedom	Sum of square(SS)	Mean square(MS)	F value	Prob.
Sites (A)	1	0.815	0.815	7.01	0.0095*
Month (B)	11	1.264	0.114	0.99	0.4627
Month X Sites(AB)	11	1.169	0.106	0.91	0.5304
Error	96	11.167	0.116		

LSD= 0.12

Table: 4 Analysis of variance for the sandfly population density as collected from human habitation and animal enclosure.

Source of variat.	Degree of freedom	Sum of square(SS)	Mean square(MS)	F value	Prob.
Sites (A)	1	0.14	0.145	0.96	
Month (B)	11	2.89	0.262	1.75	0.091
Month X Sites (AB)	11	0.49	0.045	0.30	
Error	48	7.21	0.150		

* Significant at P= 0.05

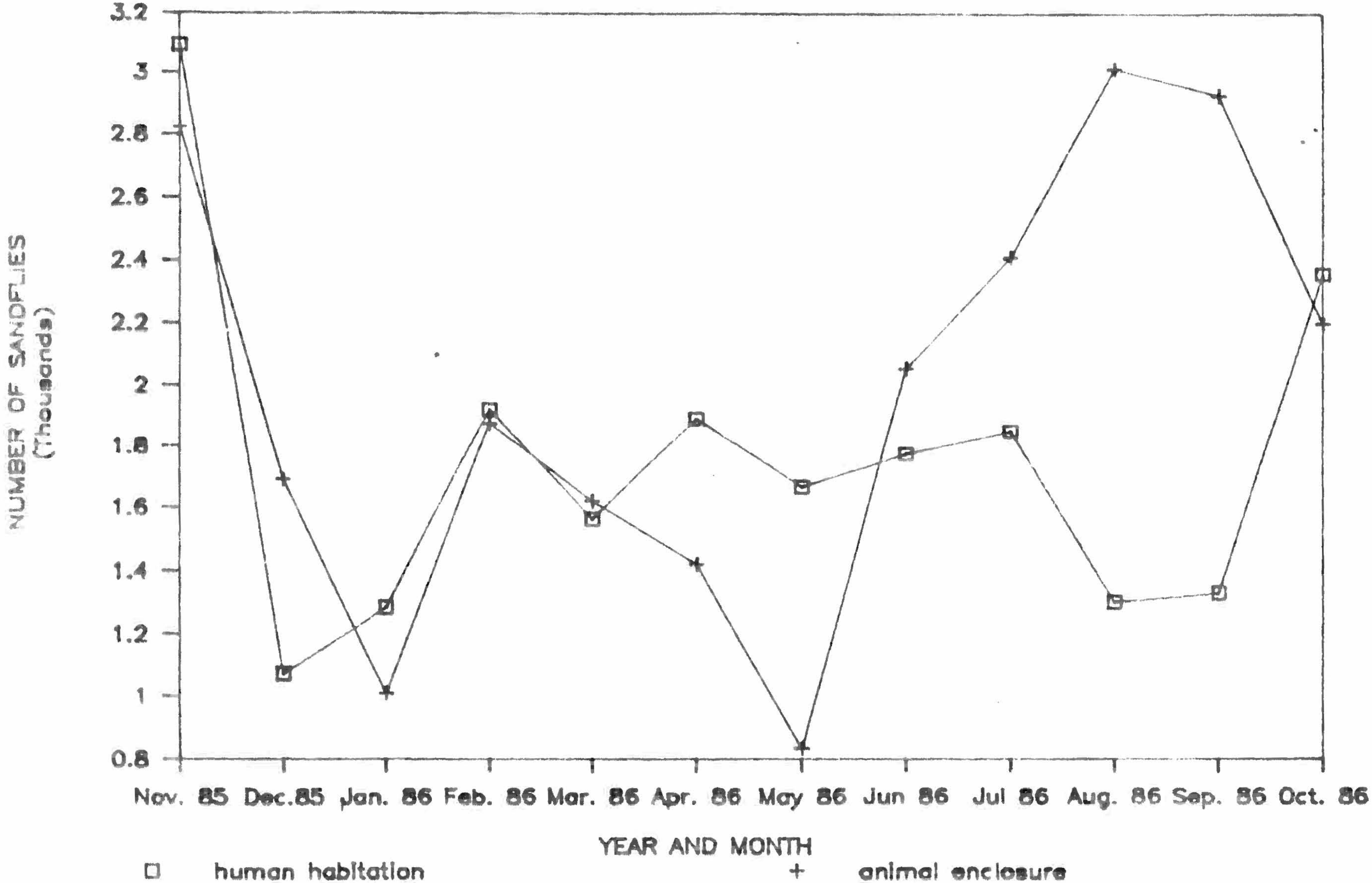

Figure 6. Seasonal variations of sandflies in human habitations and animal enclosures. (Marigat area, 1985/86).

Statistical analysis of the data collected from both sites (Tables 4 and 5), showed that:

a) The difference between human habitation and animal enclosure mean-sites was less than the Least Significant Difference at 5 percent level ($0.04<0.05$), indicating a no significant difference between both sites (F-value= 0.96).

b) No difference for the monthly sandfly collections was observed ($F= 1.75$, $P= 0.091$).

c) No difference in site interraction was observed, ($F= 0.30$).

3.3.2.3 Tree hollow and open field

Studies on seasonal variations of sandflies as collected from both sites (Figure 7 and Appendices 2, 9 and 10) have shown that:

a) In tree hollows, a decrease of sandfly relative abundance was observed during the month of December, February, May and September. Sandfly relative abundance increased during the dry period as well as during the wet season. The months of January, March, July and October marked an increase in sandfly abundance.

b) Observations carried out in the open field showed a decrease in sandfly relative abundance in December (corresponding to the dry season) and from May to August (corresponding to the wet period). An increase of sandfly

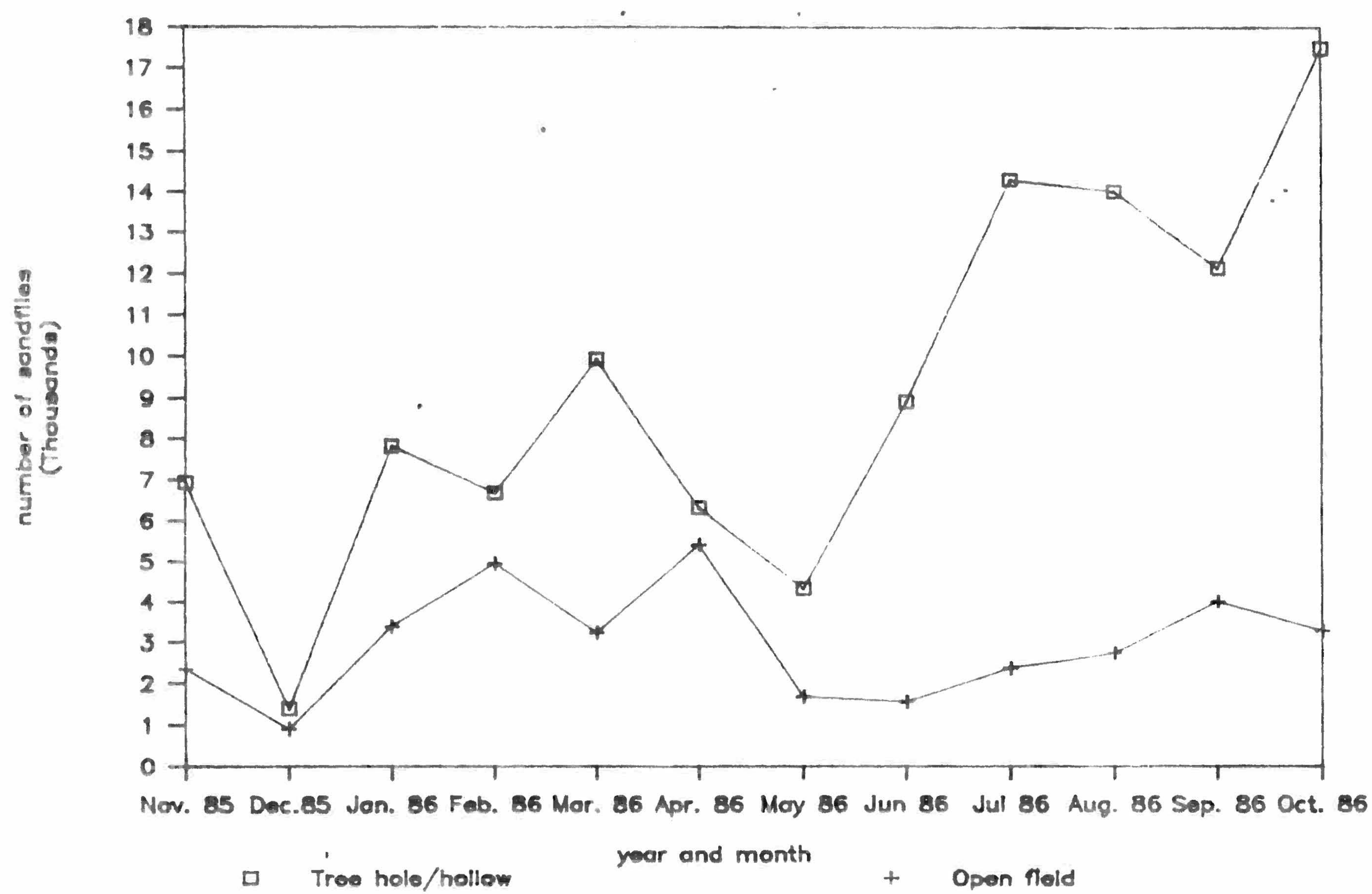

Figure 7. Seasonal variations of sandflies in Tree holes/hollows and in Open field. (Marigat area, 1985/86).

population in the open field habitat was observed in February, April and September.

Comparing the sandfly relative abundance in both sites, the following observations can be made:

1. The decrease in both sites was recorded during the months of December and May, corresponding to the dry and wet season respectively. This decrease could have been due to changes of microclimates, caused by the dryness and/or the dampness in resting sites during the rainy periods.
2. The increase of sandflies in both sites followed almost the same pattern, with the exception of March and September where an increase in one site was followed by a decrease in the other.
3. In both open field and tree hollow the highest sandfly relative abundance was monitored in April and October.
4. More sandflies were collected from tree hollows than from the open field. Collections of sandflies in both habitats during wet and dry seasons (1985/86), showed that 102.18 against 95.52 sandflies were collected from tree hollows during dry and wet seasons, while 33.53 against 27.21 sandflies were recorded from open fields during both dry and wet periods respectively (Appendix 3).

Although, there was no apparently major differences between sandfly occurrence in their various sites (Figure 8), the analysis of variance (using ANOVA-1 and SAS programme) carried out on the monthly total sandfly collections from every collecting place, showed that (Table 5):

The mean difference between collected sandflies from various habitats gave 0.09, 0.11, 0.45, 0.15 and 0.04 for termite hill and tree hollow, tree hollow and animal burrow, animal burrow and open field, open field and human habitation, human habitation and animal enclosure respectively.

Comparing both means, as shown in every pair of sites, the following observations were made:

1. Termite hills and tree hollows gave a difference mean-sites greater than the LSD (0.09>0.05). For this reason, both sites differed significantly.

2. Tree hollows and animal burrows showed a difference mean-sites greater than the LSD (0.11>0.05). Thus, both sites differed significantly.

3. Animal burrows and open fields gave a difference mean-sites greater than the LSD (0.45>0.05). Therefore, both sites differed significantly.

4. Open fields and human habitations presented a difference mean-sites greater than the LSD (0.15> 0.05), for this reason, both sites differed significantly.

5. Statistical analysis of sandfly collections from termite hills and animal burrows indicated that there was a significant difference between both sites. Their difference mean-sites was greater than their Least Significant Difference (LSD) (See 3.3.2.1 and Table 3).

Table 5. Analysis of variance for the sandfly population density as collected from various breeding and resting sites.

(Perkerra Irrigation Scheme, Marigat area, 1985/86).

Source of variation	df	SS	MS	F-value	Prob.
Sites	5	16.716	3.343	370.67**	0.0001
Month	11	0.872	0.079	8.79**	0.0001
Sites x Month	55	2.908	0.052	5.86**	0.0001
Error	55	0.496	0.009		

LSD on transformed
data (at 5% level)= 0.05

Transformed means.

Grouping	Means	Sites	No.
a	3.7500	Termite hill	1
b	3.6617	Tree hollow	3
c	3.5525	Animal burrow	2
d	3.1062	Open field	6
e	2.9550	Animal enclosure	5
e	2.9175	Human habitat.	4

** significant at 1 percent level.

Means with same letter (for significant F) are not significantly different at 5% level.

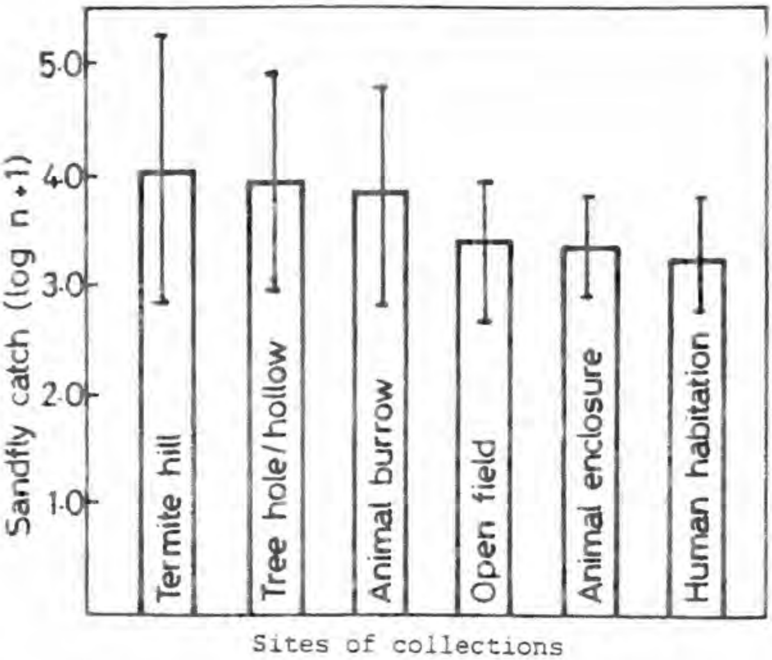

Figure 8. Prevalence of sandflies in six trapping sites. (Marigat area, 1985/86)

6. The difference mean-sites between human habitations and animal enclosures was less than their LSD at 5 percent level, this shows that there was no significant difference for the sandfly collections from both sites (See 3.3.2.2 and Table 4).

3.3.3 Seasonal incidence of sandfly species

It appears that in the Marigat area, two groups of sandfly species are present: the first group is composed of perennial species and the second of seasonal species (Appendix 3).

3.3.3.1 Perennial sandfly species

The perennial sandfly species, also called non-seasonal species, were collected throughout the year during both dry and wet seasons. These species were widely distributed and tolerated a wide range of conditions. Eleven sandfly species for both Phlebotomus and Sergentomyia groups belonged to this category. For the Phlebotomus group, they were Phlebotomus martini, P. duboscqi and P. rodhaini. It was observed that the majority of perennial species belong to the Sergentomyia group. These species were: Sergentomyia antennatus, S. bedfordi, S. ingrami, S. africanus, S. affinis, S. adleri, S. schwetzi and S. clydei.

For the Phlebotomus species (Figure 9), it was observed that Phlebotomus martini and P. duboscqi increased their densities in December a month after some isolated and scattered showers which were recorded in the area. Other increases in the Phlebotomus relative abundance were observed in April and August, corresponding to heavy rainfall. P. martini populations showed three peaks: the first in December, a month after scattered rainfall occurred in the area, the second in April, a month after the beginning of the rainy season and the third in August, corresponding to the end of rains. During the dry season (January and February), the P. martini populations decreased. Also, the month of July presented a fall off in P. martini's relative abundance. The same observation was true for P.duboscqi, its increase in numbers was observed during the month of December, April and August. The decrease was seen in January (dry season), June (wet month) and October.

Although a decrease in sandfly relative abundance was observed in one or other season for both P. martini and P. duboscqi, their presence in the area did not completely disappear and therefore, collections of these species were carried out throughout the year. P. martini was present in all investigated habitats, as was P. duboscqi with the exception of open fields (Table 1). P. rodhaini was present throughout the year but occurred in small numbers during both the dry and the wet seasons. However, the low population of *P. rodhaini* was recorded from July to October, while its high density was observed from November to February.

Comparing both *Phlebotomus* species, it has been observed that:

P. martini seemed to be well adapted species to the area as it was collected from various habitats and as it occurred in large numbers during both seasons. The high number of this species observed throughout the year determined its permanent contact with man and hence, the transmission of the parasite within the hosts. *P. duboscqi* was also always represented in the investigated breeding and resting sites, although its number did not reach the level of *P. martini*. *P. duboscqi* was absent from tree hollows and open fields during the dry season, while, its disappearance from open fields was seen only during the wet period (Appendix 3). Its collection in large number from burrows, is probably due to the presence of rodents living in these sites which serve as a source of food.

P. rodhaini was collected from termite hills, animal burrows and tree hollows during both seasons. It was absent from human habitations, animal enclosures and open fields.

Sergentomyia species form three quarters of the perennial sandfly population. The *Sergentomyia* group was

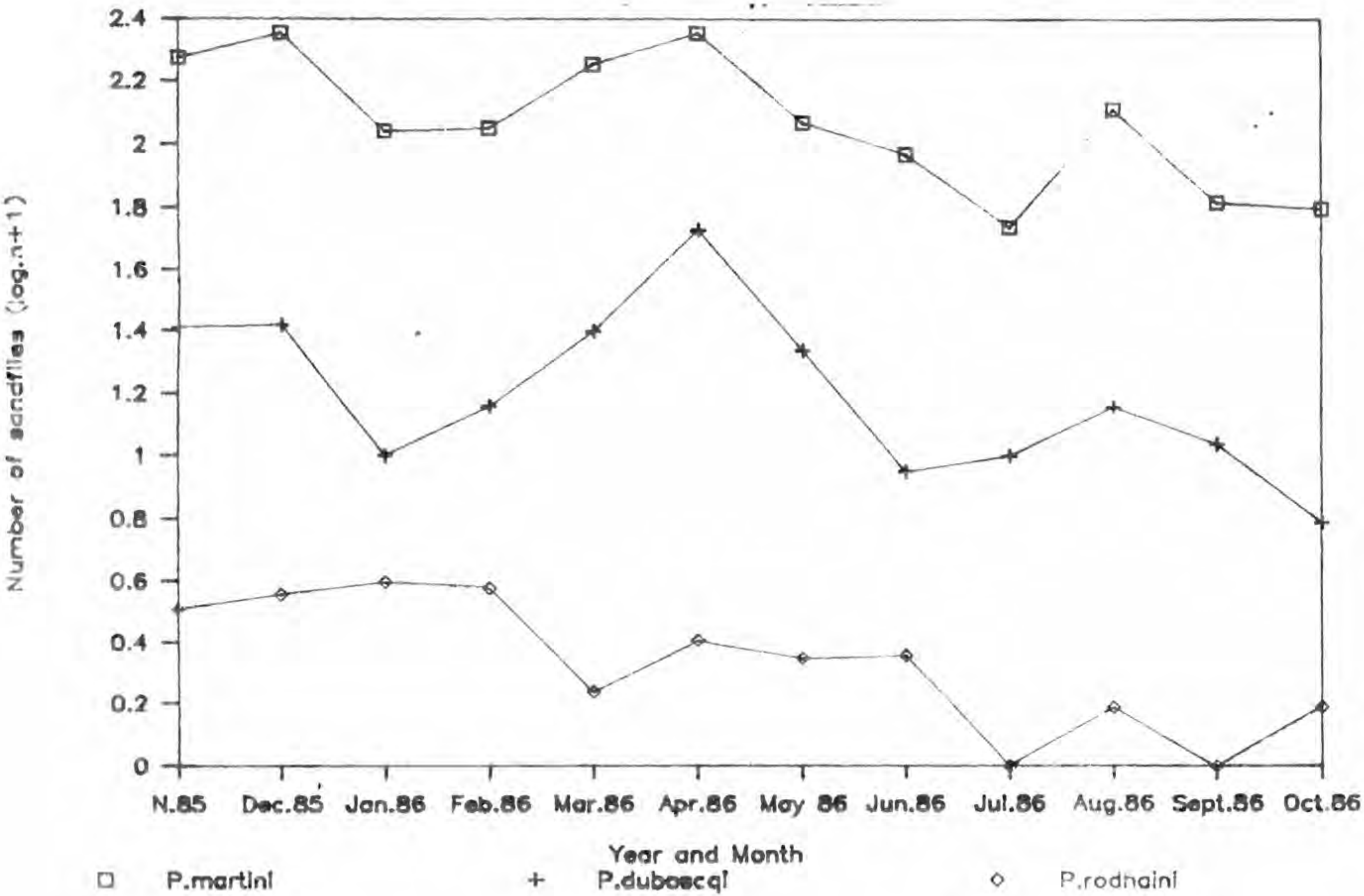

Figure 9. Seasonal variations of Phlebotomus martini, P. duboscqi and P. rodhaini. (Marigat area, 1985/86).

mainly composed of vigourous and robust species, which prevailed in the area throughout the year (Appendix 4). Eight sandfly species belonging to this group were found to inhabiting various breeding and resting sites in the area. These species were Sergentomyia antennatus, S. bedfordi, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri and S. clydei.

Despite the fluctuations of the Sergentomyia species in various habitats, none of them disappeared completely (Appendix 3). The robust and ubiquitous S. antennatus maintained high numbers during both dry and wet periods: S. bedfordi showed its highest density during the dry season, and then decreased during the months with high rainfall. The most common species in the area, S. antennatus and S. bedfordi seemed to be well adapted to various changes which occurred in the area during the study period. Their vigour and robustness resulted in their predominance in all investigated sites. It is possible that these species are more drought-resistant and therefore, showed fairly constant populations throughout the year.

S. antennatus.

The largest collected sandfly species in the area, S. antennatus showed high numbers during both dry and wet seasons. Although this species was collected in all investigated sites, it was most commonly found in termite hills. As shown in Figure 10, a slight decrease of S.antennatus relative abundance was monitored during both dry and wet seasons. The first decrease was recorded in November (month with scattered showers) and the second decrease was in May (wet period). Nevertheless, this species formed a high proportion of the total catch of sandflies; 46.43% and 48.97% of the total catch during both dry and wet period respectively. S. antennatus presented two peaks during its increase; the first peak was seen in February (end of the dry period) and the second in July (wet weather). Owing to these observations, the sudden increase of S. antennatus during the particular February (Figure 10) was unknown and probably exceptional, since there was no other species showing a peak in this month.

S. bedfordi

This species was relativly abundant throughout the study period, but was more sporadic in incidence than S. antennatus. Its population's fluctuations showed a decrease during May and July, corresponding to the wet period, while an increase was seen from August to October (Figure 10). The density during November and December remained high. Another increase was observed in March and June. The increase of S. bedfordi at the end of the wet weather and during the dry period helped to classify this species among the drought-resistant species. The high number collected from tree hollows shows that this species prefers to rest in

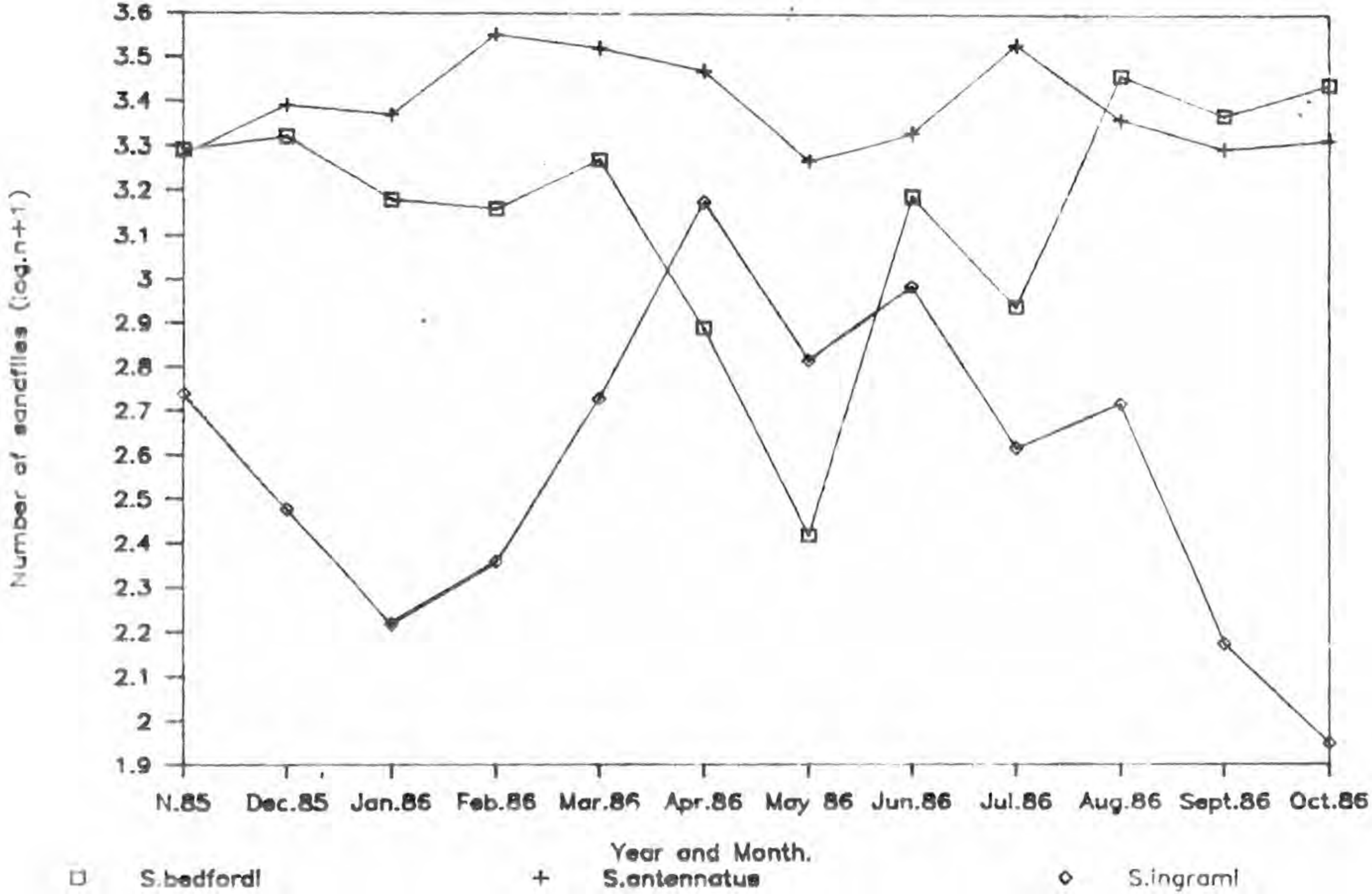

Figure 10. Seasonal variations of Sergentomyia bedfordi, S. antennatus and S. ingrami. (Marigat area, 1985/86).

shaded sites where temperatures are moderate and humidity is high. This species constituted 40.77% against 25.85% of the total sandfly catch during both dry and wet periods respectively.

The monthly incidence presented a tendency for both S. antennatus and S. bedfordi to follow a pattern similar to that of S. ingrami with increase and/or decrease of densities either in dry season and/or in wet period (Figure 10). Both Sergentomyia antennatus and S. bedfordi species seemed to be affected by rainfall. Thus, during May (a month after heavy rains) a decrease in both population was monitored. S. bedfordi seemed to be more affected by the wet weather than S. antennatus, which presented a little tendency of being affected by rains.

S. ingrami.

A common species at Perkerra Irrigation Scheme. S. ingrami was collected in large numbers from termite hills with fewer specimens recorded from animal enclosures. S. ingrami populations showed a decrease during the dry season (January and October) and the middle of the wet weather (May and July). An increase was recorded a month after the wet season had started (April) and at the end of the rainy period (August)(Figure 10).

S. africanus

Collected throughout the year in the Marigat area, this species seemed to be a regular inhabitant of termite hills. Tree hollows and animal burrows were used as secondary habitats. As for the other sandfly species, S. africanus population fluctuated with monthly weather variations (Figure 11). This species presented its highest population at the beginning and at the end of the rainy season, with the maximum numbers occurring late during the rainy season (August). Low populations were observed during the dry season and during the months immediately after heavy rains (May and July).

S. affinis

Mainly collected from open fields, this species seemed not to choose termite hills and animal burrows as the main breeding sites. Both sites were probably used as secondary habitats. Starting from April, S. affinis populations increased throughout the rainy period (Figure 11). The decline in numbers was observed during the dry season and reached the lowest value before the heavy rains had started.

S. schwetzi

Inhabitat of termite hills, S. schwetzi presented its maximum numbers during the rainy season. As indicated in Figure 11, its highest population was observed between March and August, reaching its peak in June (wet season). Its lowest population level was recorded during the dry

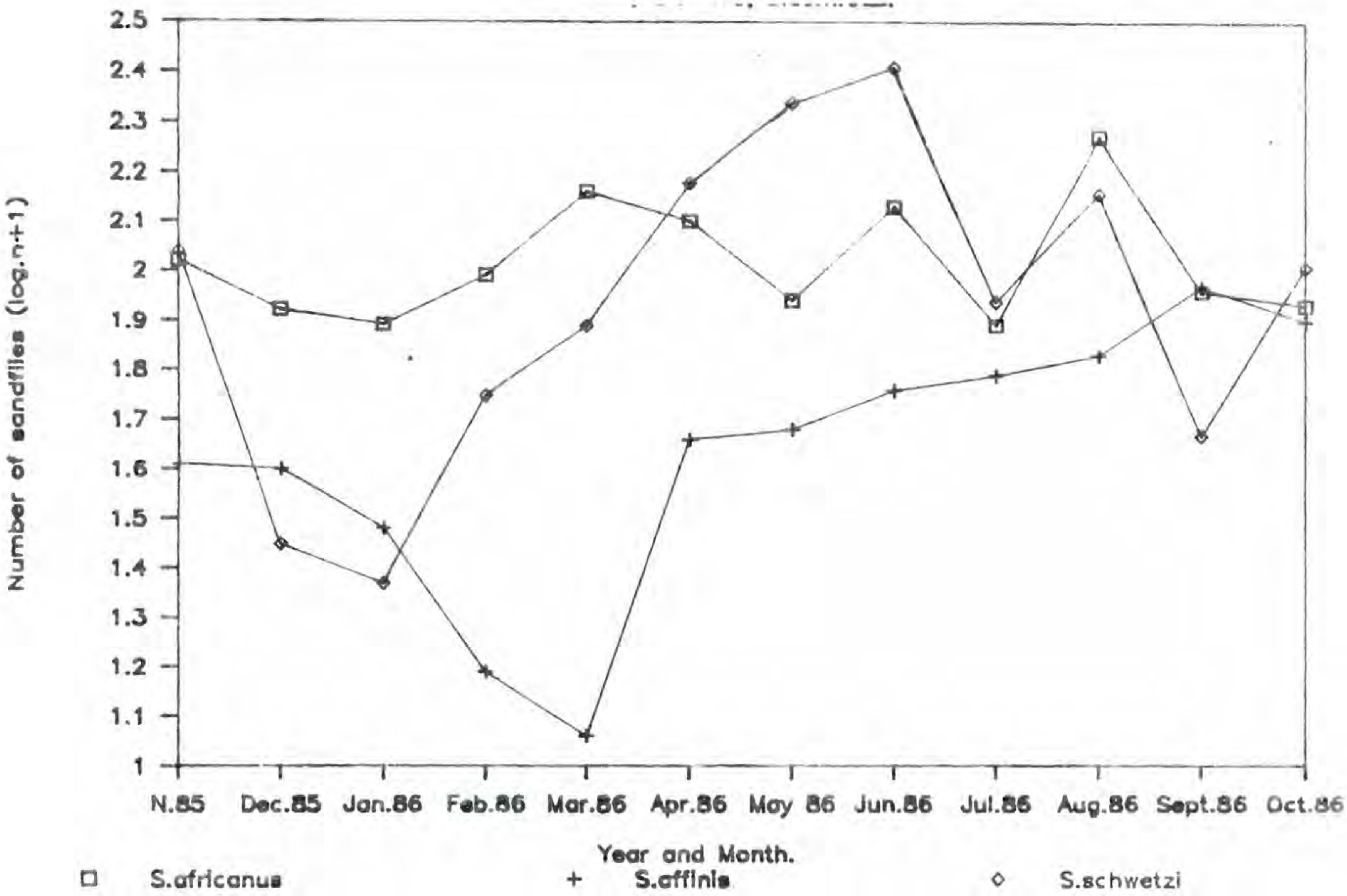

Figure 11. Seasonal variations of Sergentomyia africanus, S. affinis and S. schwetzi. (Marigat area, 1985/86).

period (December, January and September).

S. adleri and *S. clydei*

Analysing the monthly incidence of both species (Figure 12), it was found that:

a) the pattern of population's fluctuation for one species has a tendency to follow that of the other,

b) the maximum numbers for both species were recorded during the wetter months (March to August). Both species presented their peaks in April.

c) a decline in their relative abundance was monitored during the dry season. The months of November to February and September to October experienced low populations of both species.

Collected throughout the study period, each species (*S. adleri* and *S. clydei*) seemed to have a given preference for its breeding sites. *S. adleri* seemed to prefer breeding in termite hills, and used animal burrows as a secondary habitat. Conversely, *S. clydei* prefers breeding in animal burrows as primary habitats with termite hills as a secondary habitat.

3.3.3.2 Seasonal phlebotomine sandfly species

Analysing the sandfly collection data, it was shown that although the overwhelming majority of sandfly species

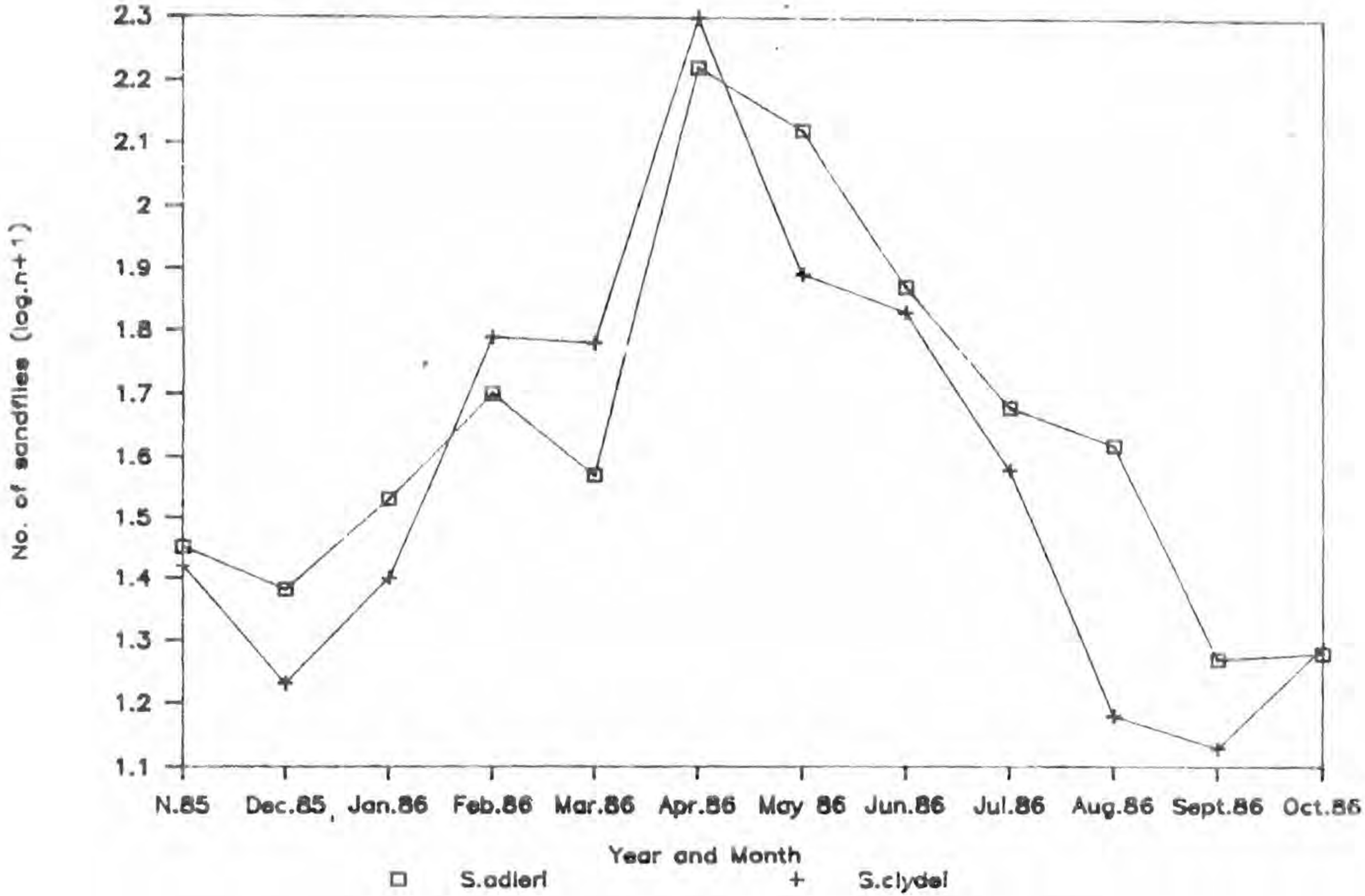

Figure 12. Seasonal variations of Sergentomyia adleri and S. clydei. (Marigat area, 1985/86).

occurred in the area throughout the year, other species emerged only at certain seasons of the year (Appendix 3: species included in this Appendix are the ones collected during our regular sampling of sandflies in the standardized long-term collection sites during the year 1985/86). 4 species among the 15 recovered in Perkerra Irrigation Scheme, were found to be either dry season or wet season species. These four species appear to be more sensitive, and have a limited distribution and a strictly seasonal incidence. Phlebotomus orientalis, P. sergenti, Sergentomyia graingeri and S. squamipleuris were found to belong to this category. P. orientalis and S. graingeri were restricted to the wet season and S. squamipleuris was found to be a dry season species. None of these species was collected during both seasons, showing that these species breed in an alternate habitats during the wet and/or the dry part of the year. P. orientalis was collected in an open field during August, while S. graingeri was recovered from burrows and tree hollows during June and July. S. squamipleuris was collected in human habitations during the month of October. P. sergenti was collected in September, a month corresponding to the dry period.

Collected during either the dry season or in the wet period, the seasonal species showed low populations during the period of investigation. Their presence did not make any great impact on the total sandfly population throughtout the year.

3.3.3.3 Occurrence of sandfly species

In Marigat area, recovered sandfly species seemed to be either perennial or seasonal species. Because of this, the analysis of the occurrence of sandflies in the study area was based on the common or non-seasonal sandflies which were collected in good numbers and present throughout the year.

Analysing Figure 13, the following observations may be made:

a) For the Phlebotomus group, P. martini was collected in large numbers, followed by P. duboscqi. P. rodhaini was collected throughout the year in the area, although it presented low populations in every searched site.

b) For the Sergentomyia group, the most common sandflies in the area, S. antennatus and S. bedfordi presented high populations. Both species were ubiquitous and utilized various habitats. However, S. adleri, S. affinis and S. clydei were collected at about the same rate with an average value of 0.18, 0.17 and 0.16 respectively.

Also, Figure 13 and Table 1 reveal that the perennial species prevailed in the following order of abundance: Sergentomyia antennatus, S. bedfordi, S. ingrami, *Phlebotomus martini*, *S. schwetzi*, *S. africanus*, *S. adleri*, *S. affinis*, *S. clydei*, *P. duboscqi* and *P. rodhaini*. Both *S. antennatus* and *S. bedfordi* represented 80.92% of the total sandfly population.

Because of the limitations of the sampling methods used in this study, some species were undoubtedly underrepresented in the catches.

Analysis carried out on the relative abundance of the common sandfly species in relation to seasonal changes (Table 6 and Appendix 4) showed that species such as *P. rodhaini* and *S. bedfordi* increased their populations during the dry season. The same period presented a slight increase in number of *P. martini* and *S. affinis*. However, an increase was monitored for *P. duboscqi*, *S. antennatus*, *S. ingrami*, *S. africanus*, *S. schwetzi*, *S. adleri* and *S. clydei* during the wet season.

An outstanding variation in seasonal relative abundance was observed for *S. bedfordi* (40.77% against 25.85% of the total sandfly population were recorded in dry and wet season respectively), while for *S. antennatus* a slight change in number was observed during both seasons (46.34% against 48.97% of the total sandfly population were monitored during the dry and the wet season respectively).

Table 6. Seasonal changes in sandfly composition.

(Marigat area, November 1985- October 1986).

Sandfly species	Percentage of the total catch		Total
	Dry season	Wet season	
Phlebotomus martini	2.36	2.33	2317
P. duboscqi	0.28	0.36	319
P. rodhaini	0.03	0.01	25
P. orientalis	0.00	0.001	1
Sergentomyia bedfordi	40.77	25.85	32729
S. antennatus	46.43	48.97	47043
S. ingrami	5.01	13.61	9247
S. africanus	1.77	2.29	2008
S. affinis	1.03	0.90	958
S. schwetzi	1.23	2.88	2045
S. adleri	0.54	1.45	990
S. clydei	0.50	1.28	887
S. graingeri	0.00	0.005	3
S. squamipleuris	0.004	0.00	2
Total sandflies	48542	50032	98574

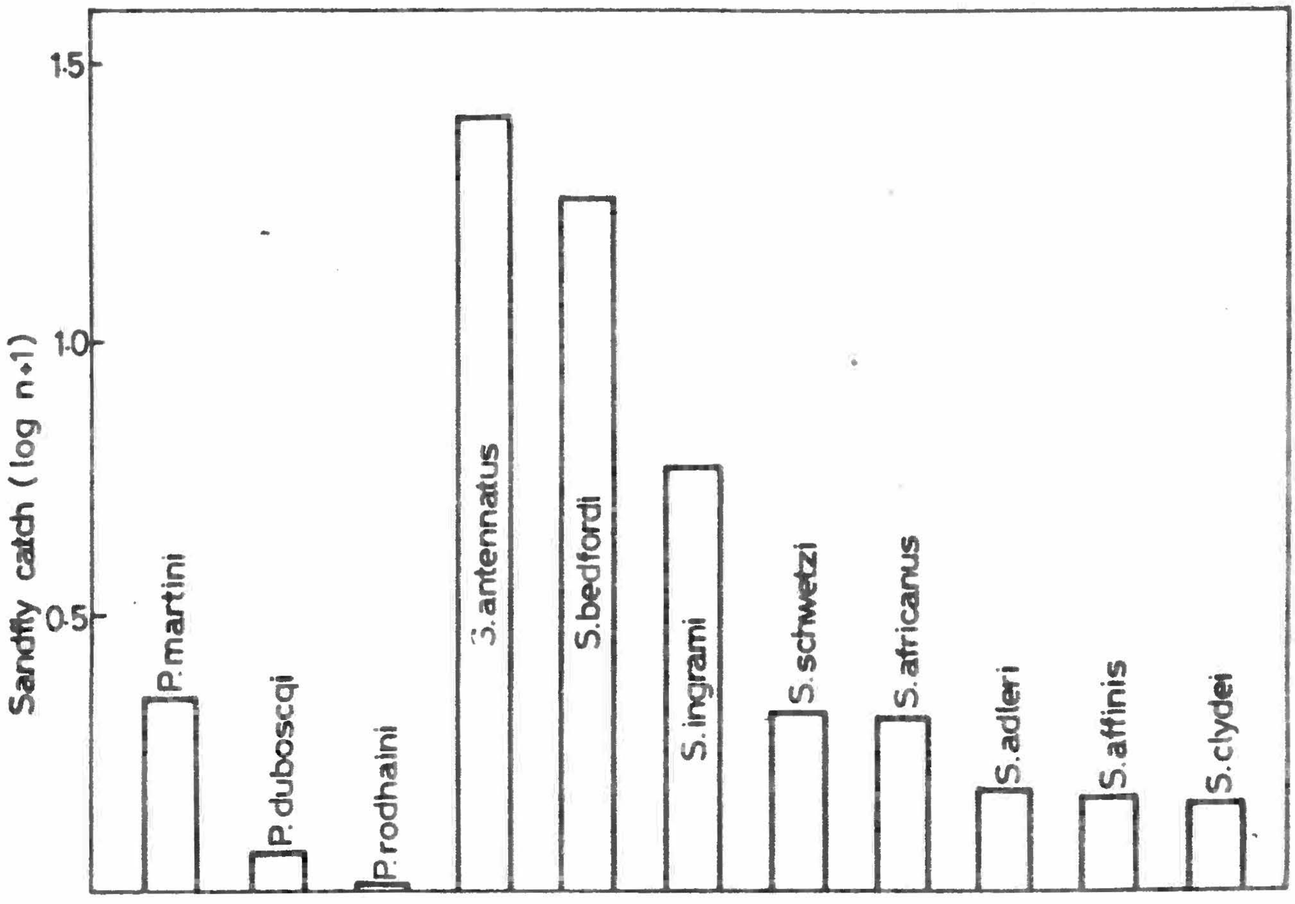

Figure 13. Prevalence of phlebotomine sandfly species in the Marigat area. (Marigat area, Baringo District, 1985/86).

3.3.4 The sex-ratio

Collections of both male and female sandflies were carried out from their breeding and resting sites during both dry and wet seasons (Table 7).

Studying the sex distribution in the standardized long-term collection sites, a sex-ratio of 1.12:1 (16457 males against 14564 females), 1.03:1 (9776 males/9419 females), 1.02:1 (4174 males/4053 females), 1.05:1 (3169 males/2032 females) were observed for termite hills, animal burrows, human habitations and open fields respectively, while a ratio of 1:1.07 (11989 males/12893 females) and 1:1.2 (4388 males/5658 females) were observed for tree hollows and animal enclosures respectively. For the first four sites, the sex-ratio was in favour of males, while for the last two, it favoured the females.

Analysing the variance of the sex distribution within the collecting sites, based on 3 criteria of classification (month, sex and collecting site), the following observations were made (Table 8):

1. The interaction between sex and site presented an F-value equal to 2.99. By testing the F-value at the 5 percent level corresponding to 5, 55 degrees of freedom, a value of 2.37 was observed, while the 1 percent level presented a value higher than the ones calculated (F5,55

degrees of freedom= 3.34 at 1%). Thus, this interaction can be ascribed as significant at the 1 per cent level and therefore, the significant difference observed between sex and collecting sites can be ascertained. It is suggested that the sandfly sex-ratios may be determined by the microclimatic conditions prevailing inside their breeding sites and/or the environmental factors occurring in the area. These factors may also have a physiological effect on one or the other sex during the immature stages.

2. The interaction between sex and month showed a F-value equal to 6.37. This interaction presented a highly significant difference since its variance ratio (calculated F-value) was higher than the ones observed at 5 and 1 percent level respectively. The 5 percent level corresponding to 11 and 55 degrees of freedom in that order is 1.92 (F11,55 df at 5 % level), while the 1 percent level is 2.50 (F11,55 df at 1% level). Thus, the highly significant difference between the sex (male and female) and the monthly collections of sandflies may be due to periodical climatic variations. These changes of environmental factors could bring changes of both male and female survival.

3. The interaction between site (total sandflies: male and female) and the month gave a F-value equal to 5.86. This interaction showed a highly significant difference since its variance ratio was higher than the ones observed at 5 and 1 percent level respectively. F(55,55)df= 1.53 at 5% and

Table 7. Distribution of the sex-ratio of sandflies within the collection site.

Period	TH		AB		th		Hh		Ae		OF	
	M	F	M	F	M	F	M	F	M	F	M	F
Nov.1985	1590	1241	699	553	741	1264	623	723	502	684	71	93
Dec.	490	734	789	886	845	1495	110	147	183	239	29	52
Jan.1986	667	1498	610	1097	799	1154	265	236	181	213	210	230
Feb.	741	1423	1320	1240	823	844	283	235	233	273	222	225
Mar.	1469	1322	1295	857	1243	1041	239	105	254	168	250	106
Apr.	1615	1496	1260	688	647	488	336	155	237	119	515	190
May	1374	897	673	446	464	363	334	333	186	139	193	94
June	2035	1210	755	710	875	908	339	300	378	424	153	81
Jul.	2303	1110	279	378	1512	636	589	464	603	726	316	164
Aug.	2342	1596	920	850	1458	1350	243	344	567	1000	309	214
Sept.	1100	1252	552	887	1102	1334	277	469	622	1078	547	341
Oct.	731	785	624	824	1480	2016	522	542	442	595	354	242

1. TH= termite hill
2. AB= animal burrow
3. th= tree hollow
4. Hh= human habitation
5. Ae= animal enclosure
6. OF= open field

M= male; F= female.

Table 8. Analysis of variance of the sandfly sex-ratio.

(Perkerra Irrigation Scheme, Marigat area, 1985/86).

Source of variation	df	SS	MS	F-value	Prob.
Sex	1	0.016	0.016	1.85	0.1794
Sites	5	16.716	3.343	370.67**	0.0001
Month	11	0.872	0.079	8.79**	0.0001
Sex x Sites	5	0.134	0.026	2.99**	0.0186
Sex x Month	11	0.631	0.057	6.37**	0.0001
Sites x Month	55	2.908	0.052	5.86**	0.0001
Error	55	0.496	0.009		

LSD on untransformed data (at 5% level)= 0.054.

$F_{(55,55df)}$ = 1.84 at 1%. Owing to this interaction value (F=5.86), the difference observed between site and month can be attributed to changes occurring in environmental conditions bringing a lot of changes in sandfly breeding and resting sites.

4. Comparing the treatment-means, no difference was observed between male and female sandflies (Table 8).

3.4 Discussion

3.4.1 Species composition

Fifteen species of sandflies belonging to the *Phlebotomus* and *Sergentomyia* groups were identified in the area during the period of investigations and these were: *Phlebotomus martini*, *P. duboscqi*, *P. rodhaini*, *P. orientalis*, *P. sergenti*, *Sergentomyia antennatus*, *S. bedfordi*, *S. ingrami*, *S. africanus*, *S. affinis*, *S. schwetzi*, *S. adleri*, *S. clydei*, *S. graingeri* and *S. squamipleuris*. Minter (1964b, and c) noted the same species of the *Sergentomyia* group in Marigat. For the *Phlebotomus* group, Minter (1964b and c) recovered only *P. martini* and *P. multidens*. Mutinga and Kamau (1986), identified the same sandfly species (for both groups) to which they added *S. wynae*.

Sandfly species such as *Phlebotomus martini*

Sergentomyia bedfordi, S. antennatus, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri and S. clydei were collected from all investigated sites, while Phlebotomus duboscqi was absent in the open field; P. rodhaini was recovered from the termite hills, the animal burrows and the tree hollows, but was absent the human habitations, the animal enclosures and the open field.

3.4.2 Relative abundance of sandflies

It has been thought that before the Marigat endemic leishmaniases focus became populated, phlebotomine sandflies were widely prevalent, and later, with the development of the area and the expansion of the Perkerra Irrigation Scheme, many sandfly habitats were eliminated. Nevertheless, the high populations of some sandfly species and their prevalence throughout the year have shown that, despite the improvement of the area, sandflies have become adapted to various new habitats. Foster (1972a and b) pointed out that some species of sandflies are highly adaptable even within a small area. Rutledge and Ellenwood (1975b) noted that each sandfly species is characterized by a particular pattern of local occurrence and population aggregation which reflect the species adaptation. The population dynamics of sandflies take into consideration of the more important habitats. Minter (1964b and c) observed a variety of sandfly breeding and resting habitats, which he divided into natural and man-made habitats. The natural habitats included: termite hills, animal burrows, bird holes, tree holes, caves, rocks and soil crevices, while the man-made sites comprised human habitations, shops and latrines, tents, chicken coops, grain stores, wells and beehives.

The present searches for sandflies were carried out from animal burrows, termite hills, tree hole/hollows, human habitations, animal enclosures and open fields. Collections were also undertaken from trunks and/ or buttresses of trees with light or huge canopies. Collections of adult sandflies from the investigated sites showed that the main breeding and resting habitats presented high population density variations. However, the results from the sticky traps, used for the sandfly collections, disclosed a capture rate order of termite hill, tree hollow, animal burrow, open field, animal enclosure and human habitation, with roughly 1 percent increase from one site to the next. Termite hills therefore, constitute important breeding sites for sandflies (Heish et al., 1956; Minter, 1964c) followed by tree hollows and animal burrows.

Phlebotomine sandfly species are associated with a given habitat. Thus, animal burrows and termite hills, the main sandfly breeding places in the Marigat leishmaniases endemic focus, showed an identical species composition but with marked quantitative differences for the Phlebotomus species. For the Sergentomyia group a slight difference in species composition for both sites was observed. The Phlebotomus species collected in burrows were 4 times in number than the ones found in termite hills, while Sergentomyia species recovered from termite hills represented twice the ones caught in animal burrrows. Contrary to Minter (1964b), who considered termite hills as the principal habitat of sandfly species of the Phlebotomus group and a secondary habitat for a large number of Sergentomyia species, the present observations have shown that species of the Phlebotomus group occur in large numbers in animal burrows and use termite hills as a secondary habitat. These observations corroborate the work of Mutinga and Kamu (1986); Mutinga et al.(1986a); Abonnenc (1972); Ashford (1974). For the Phlebotomus group, the only species to occur in large numbers in termite hills and tree hollows was P. rodhaini. Sergentomyia clydei pevailed in high density in the open field. Quate (1964) noted that in Paloich area (Sudan), all collected P. rodhaini were taken from tree trunks; while S. clydei on the other hand were numerous in grasslands. Minter (1964b) observed that P. rodhaini is a rare Kenyan sandfly that is found in termitaries.

Human habitation and animal enclosure yielded the same species composition for both sandfly groups; but with a slight difference in their population size.

The comparison between relative abundance of both Phlebotomus and Sergentomyia showed that, the second group predominated in the area. The Sergentomyia species represented ninety seven percent of the total sandfly population, while the Phlebotomus group gave only three percent. Perfil'ev (1966) pointed out that in the Ethiopian region, most sandfly species belong to the genus Sergentomyia, and about twenty to the genus Phlebotomus. In West Pokot, Mutinga et al. (1984) noted that Sergentomyia species represented a high population of Phlebotomine sandflies.

Analysing the relative abundance of every recovered sandfly species, Sergentomyia antennatus was the commonest collected fly in the area with a capture rate exceeding 1.41 and followed by S. bedfordi (1.26). In Iran, Sergentomyia antennatus was much more abundant than other species of the Sergentomyia group (Lewis et al., 1961). Mutinga and Kamau (1986), observed a large number of S. antennatus and S. bedordi emerging from soil samples taken from burrows and termite hills. In the Jordan Valley, Schlein et al.(1982), reported Sergentomyia antennatus as the common sandfly species. Phlebotomus martini and P. duboscqi were largelly collected from animal burrows: P. rodhaini showed its high number in termite hills. Sergentomyia species such as S. antennatus, S. bedfordi, S. ingrami, S. africanus, S. schwetzi and S. adleri were collected in large numbers from termite hills. _S. affinis_ and _S. clydei_ were commonly recovered in the open fields. Considering the attraction of sandflies to human and animal lures, it was shown that both _Phlebotomus martini_ and _P.duboscqi_ prevailed in high numbers in animal enclosures compared to human habitations, while _Sergentomyia antennatus_ showed an equal capture rate in both human habitations and animal enclosures. _Sergentomyia bedfordi_ was more collected from animal enclosures than human habitations.

3.4.3 Seasonal incidence of sandflies

The most obvious pattern that emerged from the analysis of seasonal variations of sandflies in the Marigat area is that some sandfly species are widely distributed and were collected all the year round or for most of the year, but with changes in monthly incidence, these species are perennial or non-seasonal. Other species appear to be more sensitive to climatic variations, they have a limited distribution and a strictly seasonal incidence and are called seasonal species.

The perennial sandfly species appear in large numbers and include species of both _Phlebotomus_ and _Sergentomyia_ groups. They form the overwhelming majority of sandfly species present in the study area. They are _Phlebotomus martini_, _P. duboscqi_, _P. rodhaini_, _Sergentomyia_ antennatus, S. bedfordi, S. ingrami, S. africanus, S. affinis, S. adleri, S. schwetzi and S. clydei. Wijers and Minter (1962) noted that "although the perennial sandfly species decrease considerably during the dry period, they do not disappear in the area". The population maxima of perennial species occurred during the month of December (P. martini), January (P. rodhaini), February (S. antennatus), April (P. martini, P. duboscqi, S. ingrami, S. adleri and S. clydei), June (S. schwetzi), August (S. bedfordi and S. africanus) and September (S. affinis). The majority of sandflies increased their numbers during the wet weather (April to August); with the exception of Phlebotomus rodhaini and Sergentomyia antennatus which reached their population maxima in the late dry period (January and February). At Kauriro, Minter (1964c) pointed out that the drought-resistant species, Sergentomyia antennatus was caught in the greatest numbers during the dry season. However, in the Paloich area, P. rodhaini was designated as dry-season species, as it was mainly collected during the dry periods of the year (Quate, 1964). Quate (1964) noted the same classification for sandflies present in Paloich area (Sudan). In Ethiopia, Foster (1972a) recovered various instars throughout the winter indicating that breeding probably continues all the year round and that adults shift from one habitat to another as angle of sun, temperature, relative humidity and other seasonal factor changes. Disney (1966), observed that in British Honduras, some species of sandflies occurred all the year round, while other seemed to be either wet season or dry season species.

The seasonal sandfly species formed the minority of species present in the Marigat endemic area. They have a limited distribution and a strictly seasonal incidence. In this category, species such as Phlebotomus orientalis, P. sergenti var. saevus, Sergentomyia graingeri and S. squamipleuris occur. P. orientalis and S. squamipleuris were found to be wet season species, while P. sergenti var. saevus and S. graingeri were collected only during the dry season. In the British Honduras, Disney (1966), pointed out that some sandfly species disappeared during the dry season and reappeared during the wet period. Wijers and Minter (1962) and Minter (1964c) stated that Kenyan sandflies fall readily into perennial and rainy season species.

3.4.4 The sandfly sex-ratio

It was at first thought that the proportion of males to females was equal, but the analysis of variance carried out on collections of both male and female sandflies in various breeding and resting sites showed that there is a significant difference between both sexes and their collecting sites (F= 2.99**, P= 0.01). The microclimates occurring inside the sandfly breeding and resting places may have an effect on one or the other sex during their immature stages and therefore determine the sandfly sexes. Rutledge and Ellenwood (1975b) suggested that sandfly sex-ratios may be partly determined by environmental factors perhaps physiologically or through differential mortality of the sexes in the immature stages. In termite hills and animal burrows there was predominance of males, whereas in tree hollows and animal enclosures, the sex-ratio was in favour of females. The predominance of males or females in one or other site cannot be fully assessed without further investigations in the field and in the laboratory. Chaniotis *et al*.(1971b), noted that differential sex mortality, genetic control of sex ratio as well as the fact that females resting fall prey easier than males are a number of possibilities which may have a bearing on the discrepancy between the 2 sexes. Gouteux and Laveissiere (1982), stated that the sex ratio value of *Glossina palpalis* depends upon the type of biotopes. Also it was shown that the sex-ratio value was highly significant between different periods of the year ($F= 6.37^{**}$, $P= 0.0001$).

CHAPTER FOUR

SANDFLY DENSITY IN THE VEGETATION HABITAT AND ITS VERTICAL DISTRIBUTION

4.1 Introduction

Sandflies spend most of the day-time resting and it is estimated that the daily activity period starts at sundown as well as at sunset and goes declining up to 2000 hours and 0700 hours a.m. respectively. Minter (1964b) reported that sandflies emerge from their day-time resting places at dusk and have returned shortly after dawn. Studies on the vegetation sites as sandfly resting places have been extensively carried out (Chaniotis et al., 1974; Christensen and De Vasquez et al., 1982; Rutledge and Ellenwood, 1975a; Thatcher and Hertig, 1966). These studies indicate that there are differences in resting behaviour between phlebotomine sandfly species.

Species of the Sergentomyia group seem to be arboreal (Disney, 1966; Hanson, 1961; Quate,1964), whereas the Phlebotomus species rarely occur in the vegetation sites. This last group of sandflies prefer to rest in termite hills and animal burrows. An understanding of the vegetation sites used as sandfly resting places is necessary in order to plan any control of these flies using residual insecticides within the forest or by the selective removal of particular plant species.

Sandfly species prevailing in the Marigat forested area are reported here in relation to three types of vegetation: the large trees, the open woodland and the bushy site. Investigations carried out in Perkerra Irrigation Scheme showed that its vegetation is frequently subjected to major changes during both dry and wet seasons. Observations undertaken during the dry season showed a lot of modifications in the vegetation composition. The grass turned brown and died, others became dormant and most of plants lost their foliage, except a few and scattered evergreen shrubs such as Euphorbia tirucalli L. Then, the grass cover lost its compactness as it dried up, and, was trampled by livestock, mainly cattle, sheep and goats, and finally blown off by the strong winds which occurred in the area. Besides the loss of their leaves during the dry weather, the thorn trees predominated this semi-arid area, together with other drought-resistant species such as Ficus capensis Thunb., Balanites aegyptica Del., Salvadora persica L. All graminae and the low flowering vegetation growing beneath high trees dried and disappeared completely during this period.

During the first rains of March grasses begin their growth, appearing as a green carpet and spread all over the area. Some graminaceous species grow up to about three metres. All deciduous trees regain their leaves during this period. Acacia seyal Del. with a greyish bark was the most abundant forest woody plant, it grows to about 13 metres and was followed by Balanites which grows to about eight to ten metres.

The vegetation of the Perkerra forested area is heterogeneous and has two distinct canopy levels:
1. The upper level, reaching about 13 metres high (with a range comprising between 10 and 13 metres) is mainly formed by four species of trees: Acacia seyal, Ficus capensis, Balanites aegyptica and Salvadora persica.
2. The lower level reaches about five metres high and consists of several species of seasonal plants. The ground flora is scanty due to the shading provided by the well-developed canopy.

4.2 Materials and Methods

4.2.1 Large trees

Twenty five polythene sheets, measuring 20 by 30 cm each, and coated with castor oil were used for sandfly collections during the period from February (end of dry season) to May 1986 (wet weather), while fourteen sticky traps were used during the dry period (September 1987). Drought-resistant plant species were randomnly selected during both periods of investigations and used for sandfly collections. These plants were mainly Ficus capensis Thunb., Balanites aegyptica Del., Acacia seyal Del. and Salvadora persica L. Both plants have huge canopies, which formed an obstacle to the sunlight to reach the soil.

4.2.2 Open woodland

As for the large tree habitat, standardized sticky traps were used during both dry and wet seasons.

4.2.3 Bushy area

The bushy area was mainly composed of Lantana camara L. which formed thickets with high humidity. Sticky traps measuring 20 by 30 cm were placed during the evening hours (1800 hours), surrounding the thicket and caught the sandflies were removed the next morning (0700 hours). In this site, collections of sandflies were carried out during both the wet season (February to May 1986) and the dry period (September 1987).

4.2.4 Sandfly density in the vegetation

In order to determine the sandfly density per trap in three different vegetation types, standardized sticky traps were used to collect sandflies on trunks of large trees (having huge canopies), on trunks of small-sized trees (having clear canopies) and in a bushy site. The density of sandflies per trap per site and per season was calculated (Tables 11 and 12), using the following formula:

$$\text{Fly density/trap/site} = \frac{\text{Number of collected sandflies}}{\text{No.collections} \times \text{No.traps} \times \text{Surface of trap}}$$

4.2.5 Sandfly vertical distribution

In order to study the sandfly species flight behaviour and their indirect impact on animals, lizards and birds living in tree canopies, investigations on the sandfly vertical distribution were carried out in two different habitats: a wooded area and an open field.

4.2.5.1 Wooded area

Flag-type sandfly sticky traps were placed in the wooded area at different heights (Figure 14a) ranging from the ground to eleven metres (0 to 11 metres) and caught ~~the~~ sandflies were removed the next morning. At this site, sandflies were collected during the dry period (January to February 1987) using sticky traps measuring 20x30 cm each, and placed at every metre. Traps were placed on wooden

Figure 14a. Flag-type sandfly sticky traps.

towers.

4.2.5.2 Open field

Investigations on sandfly vertical distribution in an open field were undertaken at the end of the dry season and the beginning of the wet period (February to March 1987). Flag-type sticky traps measuring 20x30 cm were used for overnight collections and caught sandflies were removed the next morning. Traps were set up at a distance of 0 to 9 metres.

Both, in the wooded area and the open field, the sticky traps were coated with castor oil, and traps were placed at every metre. No bait was used as a sandfly attractant during the experiments.

4.3 Results

4.3.1 Large trees

A total of 2791 sandflies were collected from twenty five sticky traps pinned on trunks of large trees during the wet season. After their identification, nine species were recovered, and these contained one Phlebotomus and eight Sergentomyia species These species were Phlebotomus martini, Sergentomyia bedfordi, S. antennatus

S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri and S. clydei (Table 9).

S. bedfordi predominated the sandfly collections and was followed by S. antennatus. Both species represented 60.08% and 29.81% of the total sandflies respectively. Phlebotomus martini and S. affinis were collected at a rate of 0.10% of each of the total collected flies in this site. Also, S. ingrami and S. schwetzi were collected in good numbers with a rate of 4.55% and 2.83% respectively. An average of 111.64 sandflies was recorded per trap.

Although an overall sex-ratio of 1:1 was recorded it was noted that more males than females were collected from this site, except for S. bedfordi, where more females than males were monitored. No P. martini female was recorded from tree trunks.

Collections of sandflies from large trees during the dry season yielded a total of 845 Old World phlebotomine sandflies. Thus, for the Phlebotomus group P. rodhaini was identified, while S bedfordi, S. antennatus, S. africanus, S. adleri and S. affinis were recovered for the Sergentomyia group (Table 10).
As during the wet season S.bedfordi predominated the sandfly collections. The analysis of the capture rates for every species, gave a prevalence of 55.62% and 42.36% for

S.bedfordi and S.antennatus respectively. P.rodhaini, S.affinis and S.adleri were collected at the same rate (0.11%). P.martini and S.ingrami were not collected during this period. An average of 60.35 sandflies was calculated for every sticky trap.

A slight predominance of females than males were recorded with a sex-ratio of 1:1.38 (354 males against 491 females). More males than females were recorded for Sergentomyia antennatus, S. adleri and S. affinis. Except for Phlebotomus rodhaini and Sergentomyia bedfordi where more females than males were observed. Sergentomyia africanus gave the same number of females and males.

4.3.2 Open woodland

From a total of 1573 sandflies collected during the wet weather, nine sandfly species were identified. These species are: Phlebotomus martini, Sergentomyia bedfordi, S. antennatus, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri and S. clydei.

Analysing the sandfly prevalence (Table 9), it was found that S. bedfordi and S. antennatus were the most common, representing 64.84% and 22.04% of the total sandfly population respectively. P.martini and S.affinis presented the same capture rate (0.12%). An average of 50.74

sandflies per trap was observed.

Studies carried out on the sandfly sex-ratio, showed that a ratio of 1.40:1 (918 males against 655 females) was recorded; showing a slight predominance of males than females. Exception was seen for S. africanus which presented more males than females.

A total of 753 sandflies were recovered in the open woodland habitat during the dry period. After identification, the following species were recovered: Phlebotomus martini, Sergentomyia bedfordi, S. antennatus, S. africanus, S. ingrami and S. squamipleuris. Analysing the prevalence of collected sandflies, it was noted that (Table 10):

1) S. bedfordi predominated the catches (84.32%) and was followed by S. antennatus (14.74%).
2) P. martini and S. squamipleuris were collected at the same rate (0.13%).
3) An average of 53.78 sandflies per trap was calculated.

4.3.3 Bushy habitat

4 sandfly species were identified from a total of 78 sandflies collected during the wet season. These species are: Sergentomyia antennatus, S. bedfordi, S. ingrami and S. affinis (Table 9).

Analysing the sandfly prevalence, the following observations may be made:

1) S. antennatus predominated the collections (50%) and was followed by S. bedfordi (41.02%).

2) S. ingrami and S. affinis were collected at a rate of 7.69% and 1.28% respectively.

3) An average of 9.75 sandflies per sticky trap was calculated.

A sex-ratio of 3:1 (58 males against 20 females) was recorded showing that this habitat harboured more males than females.

The scarcity of sandflies in this habitat was much pronounced during the dry season than the wet period. Only 18 sandflies were caught from 14 collections made during that period. Two species were identified from collected sandflies: Sergentomyia bedfordi and S. antennatus.
As indicated in Table 10, both species were collected at a rate of 83.33% for S. bedfordi and 16.66% for S. antennatus.
An average of 1.28 sandfly per sticky trap was recorded.
A ratio of 2:1 (11 males against 7 females) was obtained, showing that there was predominance of males over females.

Table 9. Comparative distribution of sandflies in three different biotopes: Large trees, Open woodland and the bushy area. Perkerra Irrigation Scheme, Marigat area, February 1986 to May 1986.

Sandfly species	Large trees				Open woodland				Bushy area				TOTAL			
	M.	F	TOT.	%	M.	F.	TOT.	%	M.	F.	TOT.	%	M.	F.	TOT.	%
P.martini	3	0	3	0.10	2	0	2	0.12	0	0	0	0.00	5	0	5	0.11
S.bedfordi	699	978	1677	60.08	549	471	1020	64.84	19	13	32	41.02	1276	1462	2729	61.43
S.antennatus	500	332	832	29.81	331	173	504	22.04	33	6	39	50.00	864	511	1375	30.95
S.ingrami	92	35	127	4.55	7	5	12	0.76	5	1	6	7.69	104	41	145	3.26
S.africanus	31	15	46	1.64	2	4	6	0.38	0	0	0	0.00	33	19	52	1.17
S.affinis	3	0	3	0.10	2	0	2	0.12	1	0	1	1.28	6	0	6	0.13
S.schwetzi	50	29	79	2.83	15	1	16	1.01	0	0	0	0.00	65	30	95	2.14
S.adleri	8	6	14	0.50	4	1	5	0.31	0	0	0	0.00	12	7	19	0.42
S.clydei	10	0	10	0.35	6	0	6	0.38	0	0	0	0.00	16	0	16	0.36
TOTAL	1396	1395	2791		918	655	1573		58	20	78		2372	2072	4442	
No.traps			25				31				8				64	
Average			111.64				50.74				9.75				69.40	

M= male, F= female, Tot.= total

Table 10. Comparative distribution of sandflies in three biotopes: Large trees, small trees with clear canopies and the bushy s
Perkerra Irrigation Scheme, Marigat area, September 1987.

Sandfly species	Large trees				Open woodland				Bushy area				TOTAL			
	M.	F.	TOT.	%	M.	F.	TOT.	%	M.	F.	TOT.	%	M.	F.	Tot.	%
P. martini	0	0	0	0.00	1	0	1	0.13	0	0	0	0.00	1	0	1	0.06
P. rodhaini	0	1	1	0.11	0	0	0	0.00	0	0	0	0.00	0	1	1	0.06
S. bedfordi	128	342	470	55.62	367	268	635	84.32	9	6	15	83.33	504	616	1120	69.30
S. antennat.	217	141	358	42.36	73	38	111	14.74	2	1	3	16.66	292	180	472	29.20
S. africanus	7	7	14	1.65	1	2	3	0.39	0	0	0	0.00	8	9	17	1.05
S. ingrami	0	0	0	0.00	1	1	2	0.26	0	0	0	0.00	1	1	2	0.12
S. adleri	1	0	1	0.11	0	0	0	0.00	0	0	0	0.00	1	0	1	0.06
S. affinis	1	0	1	0.11	0	0	0	0.00	0	0	0	0.00	1	0	1	0.06
S. squamipl.	0	0	0	0.00	0	1	1	0.13	0	0	0	0.00	0	1	1	0.06
TOTAL	354	491	845		443	310	755		11	7	18		808	808	1616	
No.trap			14				14				14				42	
Average			60.35				53.78				1.28				38.47	

M= male, F= female, Tot.= total.

4.3.4 Sandfly density in the vegetation

Analysing Tables 11 and 12, it emerges that:
1) The large trees presented high sandfly density/trap/cm2. A density of 0.010 fly/cm2 against 0.030 fly/cm2 was recorded during both wet and dry season respectively.
2) A density per trap/cm2 of 0.005 fly/cm2 against 0.020 fly/cm2 was observed in open woodland during both wet and dry season respectively.
3) A low sandfly density/trap/cm2 was monitored in the bushy habitat. Thus, 0.002 fly against 0.0007 fly/cm2 was recorded during the wet and the dry season respectively.

4.3.5 Sandfly vertical distribution

4.3.5.1 Wooded area

Six sandfly species belonging to the Sergentomyia group were recovered in this habitat. No Phlebotomus species was collected in the wooded area. Collected sandflies were: Sergentomyia bedfordi, S. antennatus, S. ingrami, S. africanus, S. schwetzi and S. squamipleuris.

As indicated in Table 13, the ubiquitous sandfly species, S. bedfordi and S. antennatus were collected at a height between 0 metre (ground level) and 11 metres high. Other species such as S. ingrami, S. africanus and S.

Table 11. Sandfly density in three different vegetation habitats. Perkerra Irrigation Scheme, Marigat area, Feb.1986 - May 1986.

	Number of			
	Collection (days)	Trap	Sandflies	Density per trap (Fly/cm^2)
Large trees	16	25	2791	0.010
Open woodland	16	31	1573	0.005
Bushy area	8	8	78	0.002

Table 12. Sandfly density in three different vegetation habitats. Perkerra Irrigation Scheme, Marigat area, September, 1987.

	Number of			
	Collection (days)	trap	sandflies	density per trap(Fly/cm^2)
Large trees	3	14	845	0.0300
Open woodland	3	14	753	0.0200
Bushy area	3	14	18	0.0007

schwetzi reached 7, 6 and 1 metres respectively. *S. squamipleuris* was collected at a height of 1 metre. *S. bedfordi* and *S.antennatus* were collected in large number and formed the overwhelming majority of collected sandflies (96.47%) in this habitat. Considering the density of both *S. bedfordi* and *S. antennatus* as collected per height, it was found that large numbers were collected up to eight metres, and then declined upwards. *S. ingrami*, one of the common species in the area, was mainly collected at the ground level (0 to 1 metre), while *S. africanus* and *S. schwetzi* presented high density in a zone comprising between 1 and 2 metres. A high density of the total sandflies was recorded between 1 and 2 metres (26.76%). However, it was observed that large numbers of sandflies were recorded between one and eight metres (Tables 13 and 14).

Analysing the average nightly catches (Table 17), it was observed that from 2 to 11 metres, the number of female sandflies was almost twice that of males. An exception was seen at 7 metres where the number of caught females was equal to the ones of males (1.43 sandflies per trap per night). Also between 0 and 2 metres, the number of male sandflies slightly predominated on the ones of females. This result also shows that both sexes (of *S. bedfordi* and *S. antennatus*) reached a height of eleven metres, indicating that in a wooded area, sandflies may fly at high height in search of bloodmeal and juice from various plants

Table 13. Vertical distribution of sandfly species in a wooded area. (Marigat, January - February 1897).

Sandfly species	Height (in m.)											
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	TOTAL
S. bedfordi	8	45	34	26	25	46	21	28	12	10	12	267
S. antennatus	32	63	9	1	4	8	2	17	5	2	1	144
S. ingrami	5	2	0	0	0	0	0	1	0	0	0	8
S. africanus	0	2	0	0	1	0	1	0	0	0	0	4
S. schwetzi	0	1	0	0	0	0	0	0	0	0	0	1
S. squamipleuris	0	1	1	0	0	0	0	0	0	0	0	2
	45	114	44	27	30	54	24	46	17	12	13	426

Table 14. Sandfly density and its vertical distribution in a wooded area.

(Marigat area, January - February 1987).

Height (in m.)	January 1987		February 1987		TOTAL
	19	22	12	16	
0-1	0	0	40	5	45
1-2	45	64	0	5	114
2-3	13	19	7	5	44
3-4	11	14	0	2	27
4-5	6	11	9	4	30
5-6	6	20	24	4	54
6-7	2	13	8	1	24
7-8	3	34	6	3	46
8-9	1	8	8	0	17
9-10	2	6	4	0	12
10-11	3	1	9	0	13
	92	190	115	29	
	282		144		

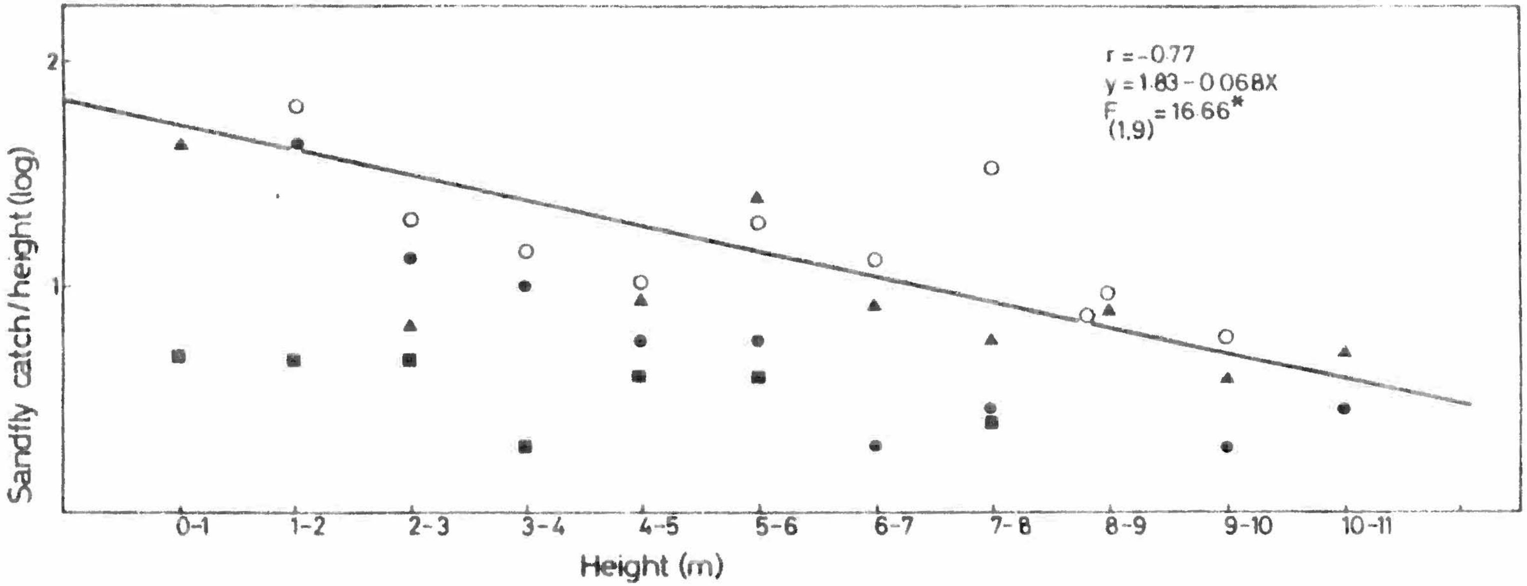

Figure 14b. Scatter diagram showing the relationships between phlebotomine sandflies and their flight heights in a wooden site. Collections of sandflies were made in January (represented by o and ●) and in February (represented by ▲ and ■). Marigat area, 1987.

Studying the relationships between the sandfly catches and their height of flight (Table 14 and Figure 14b), it was observed that :

a) a negative correlation coefficient was obtained ($r=-0.77$, $F(1,9)=16.66^*$),

b) the analysis of the regression line ($Y= 1.83-0.068X$), presented a highly significant variance ratio (F) at both 5 and 1 percent levels ($F= 16.66^*$).

4.3.5.2 Open field

In this habitat, nine sandfly species were identified, all belonged to the Sergentomyia group. These species were Sergentomyia bedfordi, S. antennatus, S. africanus, S. ingrami, S. adleri, S. affinis, S. clydei, S. schwetzi and S. squamipleuris.

Analysing the results as shown in Table 15, the two commonest species in the area, S. bedfordi and S. antennatus were collected at the highest height, corresponding to nine and seven metres respectively. On the other hand, S. ingrami, was not collected beyond two metres as was the case in the wooded area. S. adleri, S. clydei and S. schwetzi were collected at five metres while S. africanus was encountered at four metres. A single specimen of S. squamipleuris was collected at six metres. Studies on sandfly species densities, as collected at every height have shown that large number of sandflies were collected between zero and five metres, with the numbers decreasing upward to nine metres. The highest density of sandflies (40.29%) was recorded at the ground level (0 to 1 metre). Meanwhile, the collected data has shown that large numbers of sandflies were recorded between 0 and 5 metres (Tables 15 and 16).

Analysis of the nightly catches (Table 17) has shown that:

a) more males than females were collected at the height comprising between zero and three metres,

b) from four to nine metres, the population of female sandflies predominated on the male,

c) no male was collected from six metres in the open field,

d) no sandfly species was recorded from ten metres high in this site.

Studying the relationships between the sandfly densities and their height of flight (Table 16 and Figure 15) following observations can be made:

1. a negative correlation coefficient was established ($r= -0.92$, $F(1,7)= 40.66*$),

2. the analysis of the regression line ($Y= 1.678 - 0.202X$), showed a highly significant variance ratio at both 5 and 1 percent levels ($F= 40.66*$).

Table 15. Distribution of sandfly species in an open field.(Marigat area, February - March 1987).

Sandfly species	Height (in m.)									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	TOTAL
S. bedfordi	8	17	5	2	8	3	3	1	1	48
S. antennatus	22	4	5	3	7	4	1	0	0	46
S. africanus	0	0	0	1	0	0	0	0	0	1
S. ingrami	2	1	0	0	0	0	0	0	0	3
S. schwetzi	0	0	0	0	1	0	0	0	0	1
S. affinis	7	2	0	0	0	0	0	0	0	9
S. adleri	14	1	0	2	1	0	0	0	0	18
S. clydei	0	4	1	0	1	0	0	0	0	6
S. squamipleuris	1	0	0	0	0	1	0	0	0	2
	54	29	11	7	19	8	4	1	1	134

Table 16. Sandfly density as vertically distributed in an open field.

(Marigat area, February - March 1987).

Height (in metres)	February 1987		March 1987		TOTAL
	19	23	17	24	
0-1	21	4	0	29	54
1-2	21	2	0	6	29
2-3	6	2	1	2	11
3-4	2	0	1	4	7
4-5	6	5	6	2	19
5-6	2	1	2	3	8
6-7	4	0	0	0	4
7-8	1	0	0	0	1
8-9	1	0	0	0	1
9-10	0	0	0	0	0
	64	14	10	46	
	78		56		134

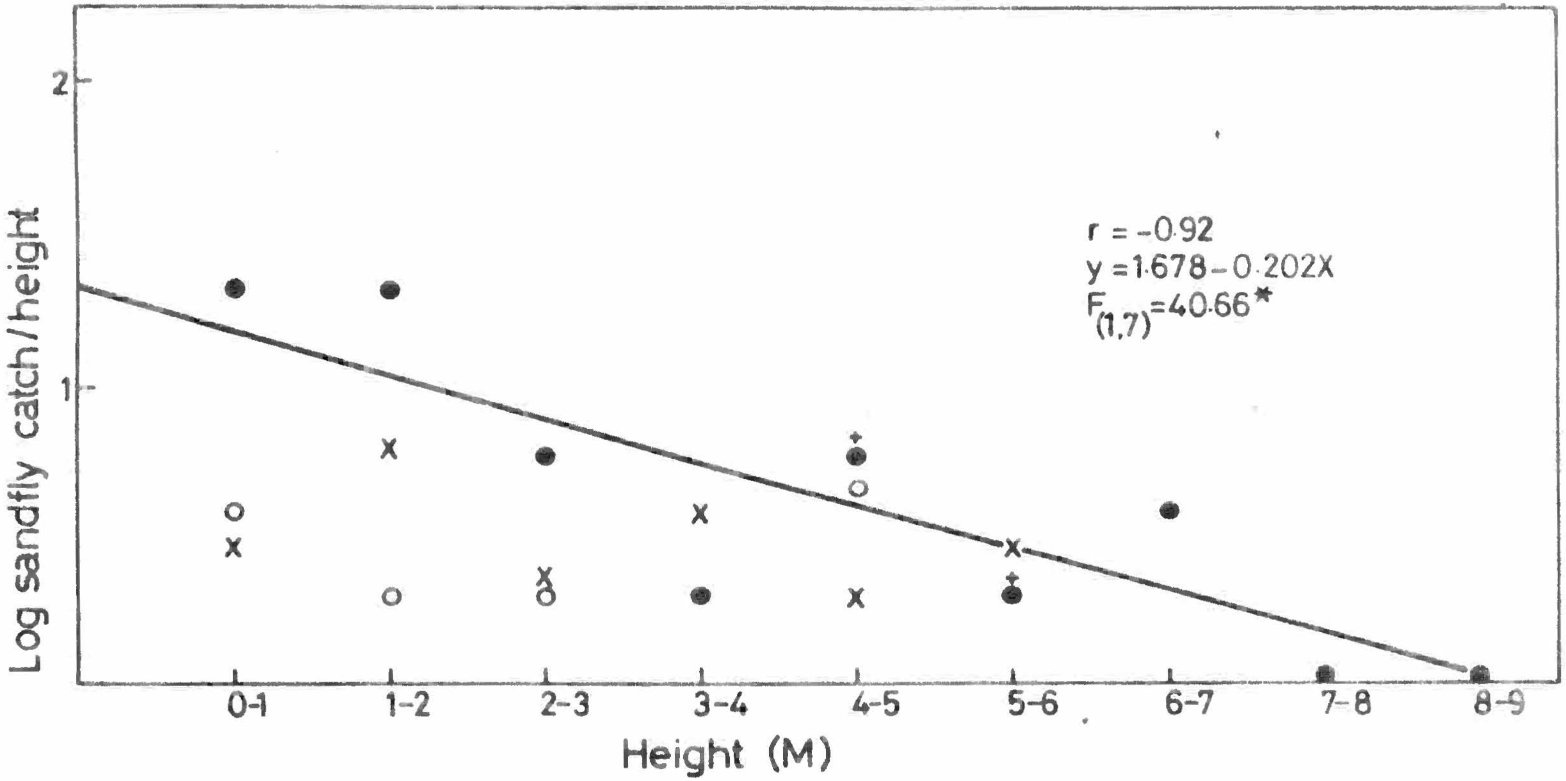

Figure 15. Scatter diagram showing the relationships between phlebotomine sandflies and their flight heights in an open field. Collections of sandflies were carried out in February (represented by O and ●) and in March (represented by + and X). Marigat area, 1987.

Table 17. The average nightly catches of sandflies caught on sticky traps set up at different heights in a wooded area and in an open field. (Perkerra Irrigation Scheme, Marigat area: 1987).

Height (in metres)	Wooden area		Open field	
	Average number of sandflies per trap per night		Average number of sandflies per trap per night	
	Males	Females	Males	Females
0-1	1.93	0.87	2.00	1.37
1-2	3.93	3.18	0.93	0.87
2-3	0.87	1.87	0.37	0.31
3-4	0.50	1.18	0.31	0.12
4-5	0.68	1.18	0.56	0.62
5-6	1.06	2.31	0.06	0.43
6-7	0.37	1.12	0.00	0.25
7-8	1.43	1.43	0.00	0.06
8-9	0.37	0.68	0.00	0.06
9-10	0.12	0.62	0.00	0.00
10-11	0.31	0.50	0.00	0.00

$$\text{Average nightly catch} = \frac{\text{No. sandflies caught(per one night)}}{\text{No. collections x No. traps.}}$$

4.4 Discussion

4.4.1 Large trees

Over a total of 3636 sandflies collected during both the wet and the dry seasons, ten species identified included two Phlebotomus species and eight Sergentomyia species. Collected species were Phlebotomus martini, P. rodhaini, Sergentomyia bedfordi, S. antennatus, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri, S. clydei. Druing both seasons, S. bedfordi predominated the sandfly collections and was followed by S. antennatus. For the Phlebotomus group, P. martini was collected during the wet season, whereas P. rodhaini was recovered in the dry period. S. ingrami disappeared in this site during the dry period.

However, a sex-ratio of 1:1 was observed during the wet season, although S. bedfordi showed high predominance of females over males. No P. martini female was collected from tree trunks. During the dry season, there was a predominance of female than male sandflies.

Analysing the average of sandflies per trap per season, it was shown that during the wet period the rate of collected flies was almost the double of the ones observed during the dry season.

4.4.2 Open woodland

A total of 2326 sandflies were collected during both the wet season and the dry period in the open woodland After identification, ten sandfly species were recovered. These species are Phlebotomus martini, Sergentomyia bedfordi, S. antennatus, S. africanus, S. ingrami, S. affinis, S. schwetzi, S. adleri, S. clydei and S. squamipleuris. The analysis of sandfly prevalence in this site has shown that S. bedfordi and S. antennatus were the most prevalent sandfly species during both seasons; while S. squamipleuris appeared during the dry season. Species such as S. schwetzi, S. affinis, S. adleri and S. clydei disappeared in this site during the dry season.

Studies carried out on the sandfly sex-ratio gave a ratio of 1:1, with a slight predominance of males during both the wet and the dry seasons. Thus, in the open woodland, it was observed that the number of male sandflies is greater than the number of females. Less female sandflies were recovered in this site, probably due to the lack of rodents, birds among many others which constitute hosts for female sandflies. Also, it was seen that in the open woodland, the environmental conditions such as strong wind. sunshine do not allow the sandflies to rest on tree trunks in this habitat. Dransfield et al. (1982) reported a greater proportion of the population of Glossina in the deciduous Pteleopsis woodland during the wet season.

The average sandfly per trap per season presented the same value during both the wet season and the dry period. Thus, 51 sandflies against 52 flies were observed during the wet season and the dry period respectively.

4.4.3 Bushy habitat

A low type habitat, the bushy area presented a vegetation growing up to about three metres and mainly was composed of Lantana camara. The humidity was too high and the sunlight could not even penetrate and reach the soil. The sandfly collections made during the wet season were not successful and therefore, the number of collection days was reduced and the study concentrated on the productive sites.

From a total of 96 sandflies collected in this site, four species were identified. These species are Sergentomyia antennatus, S. bedfordi, S. ingrami and S. affinis. No Phlebotomus species was recovered in this site. S. antennatus predominated the sandfly collections in this site during the wet season and was followed by S. bedfordi. S. bedfordi showed a high density during the dry season. S. affinis presented a low population density.

The sex-ratio was in favour of males during both

seasons. A ratio of 3:1 against 2:1 was observed during the wet season and the dry period respectively.
The analysis of the average collections has shown that 10 flies per trap per season were collected during the wet season, while 1 sandfly was caught per trap during the dry season.

4.4.4 Sandfly density in the vegetation

Mainly composed of drought-resistant tree species, the vegetation in the Marigat semi-arid area is heterogeneous. Acacia thorn tree predominates the area together with other species such as Ficus capensis (Fig tree), Balanites aegyptica, Salvadora persica and Euphorbia tirucalli. Some graminae species and the low flowering vegetation grow beneath these high trees.

Sandfly collections were undertaken in large trees with huge canopies, in the open woodland with trees having clear or light canopies and in a bushy area. Resting sandflies on standing vegetation were collected using sticky traps pinned on tree trunks or on buttresses. Two species of Phlebotomus group (P. martini and P. rodhaini) and nine species of Sergentomyia group (S. bedfordi, S. antennatus, S. ingrami, S. africanus, S. affinis, S. schwetzi, S. adleri, S. clydei and S. squamipleuris) were collected from both sites during the dry and wet weathers respectively.

None of Phlebotomus species was collected from the bushy area, they were only present on the trunks of large trees and in open woodland. Sergentomyia species were recovered in all investigated habitats. A high prevalence of sandflies was observed in large trees; this was probably due to high humidity provided by the huge canopy found in this habitat. The bushy habitat yielded a few sandflies during both seasons, showing that thickets do not constitute preferred habitats for sandflies. The excessive humidity could probably be the reason for sandflies not to breed and congregate in bushy areas.

Sergentomyia bedfordi seemed to be more closely associated with tree buttresses. This species was collected in large numbers in all searched habitats during both seasons; it was followed by S. antennatus. Exception was seen in the bushy site where Sergentomyia antennatus predominated over S. bedfordi. Mutinga (1972) reported a large number of both Sergentomyia bedfordi and S. antennatus collected from tree trunks. Phlebotomus martini and P. rodhaini seemed to be well adapted to the forested area as they were found in wooden habitats as well as in open woodland site. In large trees, the sex-ratio was equal; while it was in favour of male sandflies in open woodland and bushy area. Christensen and De Vasquez (1982), observed more male than female sandflies on tree buttresses in Panama. In Panama, Thatcher and Hertig (1966) collected a large numbers of phlebotomine sandflies of different species in a shallow hollow and in large buttress cavities of a fig tree (*Ficus sp*) inhabited by bats.

In order to determine the sandfly density per trap per habitat, it was observed that large trees presented a high density per trap compared to other investigated habitats. In both large trees and open woodland sites, high sandfly density per trap was recorded during the dry season, indicating that these habitats constitute the more important resting sites for sandflies during that period. Christensen and De Vasquez (1982) noted that buttresses of large trees constitute a resting site which provide stable microenvironment and optimal preferenda for sandflies and in which large numbers and a diversity of phlebotomines congregate. In Panama, Thatcher (1968b) pointed out that sandflies are attracted to natural cavities and hollows of trees constitute the best resting sites for sandflies. Hanson (1961) stated that tree buttresses have shown to be the richest in species of phlebotomine. In Sudan (Paloich area), Quate (1964) observed large numbers of sandflies on trunks of large trees. Nevertheless, due to high temperature present in the Marigat area, man as well as animals spend their evening hours under large trees, hiding the ambient heat, at this time both are subjected to sandfly bites.

The forest litter is the breeding habitat of the most sandfly species (Rutledge and Ellenwood, 1975a) and therefore it is evident that the large number of collected sandflies from large trees was due to high emergence of sandflies from deposited litter. On the other hand, there seems to be no particular breeding habitat in the bushy area which could lead to increase the sandfly collection in this site. Chaniotis _et al_.(1971b) pointed out that a few sandfly numbers observed in secondary growth is due to lack of large trees. _Acacia_ and _Ficus_ leaf deposits seemed to prevail, as these trees predominate in the area. Both plants determine therefore, the nature of the litter, source of nutrients of sandfly immature stages. Rutledge and Ellenwood (1975a) noted that the graminae and other plants of the undergrowth contribute relatively to the forest litter, because of their small size. The effects of the open woodland, mainly composed of small-sized trees on sandflies were similar to, but less substantial than those of large trees. Small-sized trees produced sparse litter and their deposits were relatively limited in extent. Also, the shading effect of small trees appeared to be likewise slight in comparison with those of larger trees. Rutledge and Ellenwood (1975a) pointed out that the shade of the forest vegetation is a major factor affecting conditions within the forest litter in that it acts to modulate soil temperature and to delay the evaporation of soil moisture. They therefore collected sandflies on particular plants .

Due to the fact that some sandfly species are mostly collected from given plants in the Marigat forested area (e.g. Ficus capensis and Acacia seyal), this could lead to plan for a control by treatment of selected areas within the forest. Also the selective removal of particular plant species will reduce the number of plants from where sandflies take the sugar juice for their feedings. Schlein and Warburg (1986) reported that all plants do not equally attract sandflies. They noted that Capparis spinosa (the Caper plant) attracts the highest proportion of sandflies in the Middle East. Ashford (1974) noted that some Ethiopian sandflies take plant juices by percing the leaves of plants. The sugar constitutes a source of energy for sandflies before dispersing to seek blood. Minter (1964b) reported that sandflies appeared to probe the undersides of the plant leaves and some apparently sucked the sap from the plant tissues.

4.4.5 Sandfly vertical distribution

Comparing the sandfly species composition as recovered in both the wooded area and the open field habitats, it was shown that the Sergentomyia species were the only identified phlebotomine sandflies. None of the Phlebotomus species was recorded. Both "termitophylic and burrowphylic" the Phlebotomus species (P. martini and P.

ḍuboscqi) seemed to be more closely associated with termite hills and animal burrows than with tree buttresses. It also might suggest that most of leishmaniasis transmission caused by sandflies would occur near termite hills (Heisch et al., 1956; Wijers and Minter, 1962 and Wijers, 1963) and animal burrows (Figure 16a) .

Comparison between both areas (Table 18, and Figure 16b), has shown that the wooded area seemed to be most likely preferred by sandflies. In this area, both sexes of sandflies were collected from 0 to 11 metres, with predominance of females. The lack of trees and the strong winds were thought to be the major factors for sandfly species not to fly too high in the open field. The main zone of sandfly flight in the open fiedl comprised between the ground level to five metres (0 to 5 m). It was noted that more flies were collected in the wooded area than in the open fied. All investigated heights in the first habitat yielded more sandflies than in the last ones. The only exception was seen at the ground level (0 to 1 m) where large number of sandflies were recorded in the open field than in the wooded area. It was obs rved that in the wooded area, the high density of sandflies reached 7 metres, with the highest number recorded between 1 to 2 metres; while in the open field large numbers of sandflies were monitored up to four metres with the highest population at the ground level.

Table 18. Vertical zonation of sandflies caught in traps erected one above the other in two different biotopes (A= wooded area and B= open field). (January 1987 - March 87).

	Height (in metres)																					
	0-1		1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-9		9-10		10-11	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
S. bedfordi	8	8	45	17	34	5	26	2	25	8	46	3	21	3	28	1	12	1	10	0	12	0
S. antennatus	32	22	63	4	9	5	1	3	4	7	8	4	2	1	17	0	5	0	2	0	1	0
S. africanus	0	0	2	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
S. ingrami	5	2	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
S. schwetzi	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S. affinis	0	7	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. adleri	0	14	0	1	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S. clydei	0	0	0	4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S. squamipl.	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	45	54	114	29	44	11	27	7	30	19	54	8	24	4	46	1	17	1	12	0	13	0

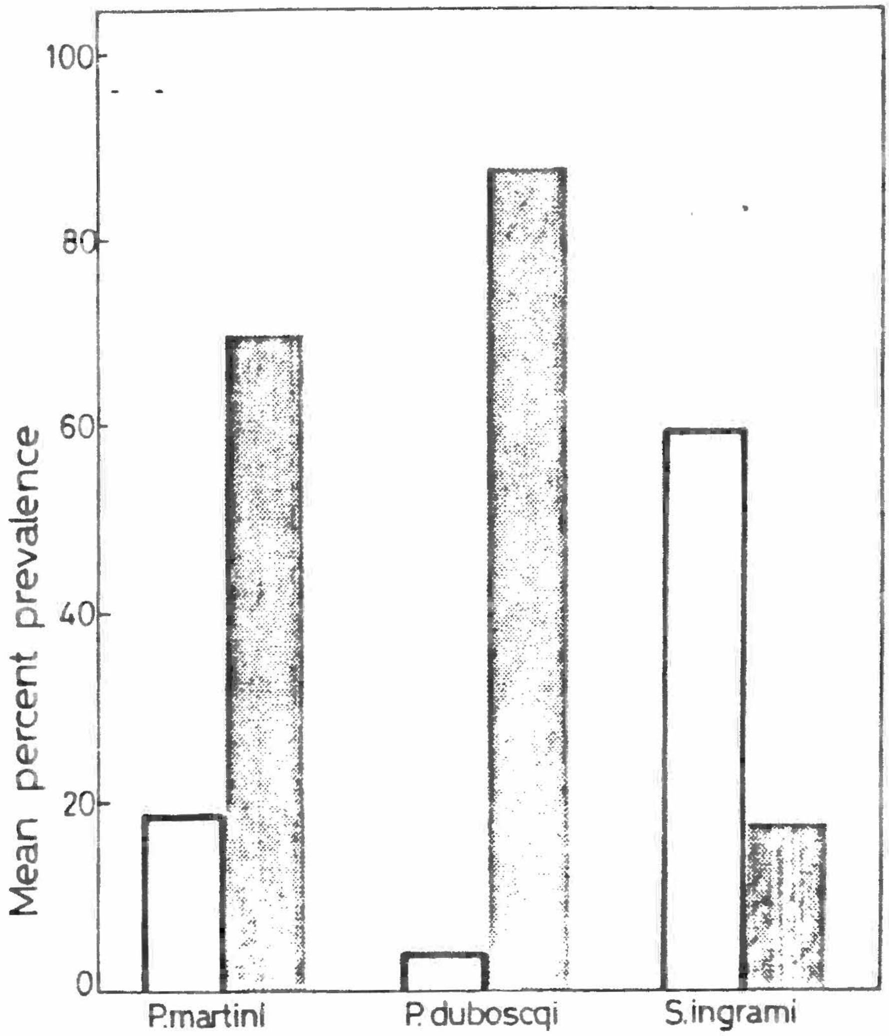

Figure 16a. Prevalence of sandfly vectors and suspected vectors of Leishmania in animal burrow and termite hill. Solid black bar represents the sandfly production in animal burrow and the white bar represents the sandfly production in termite hill. Marigat area, 1985/86.

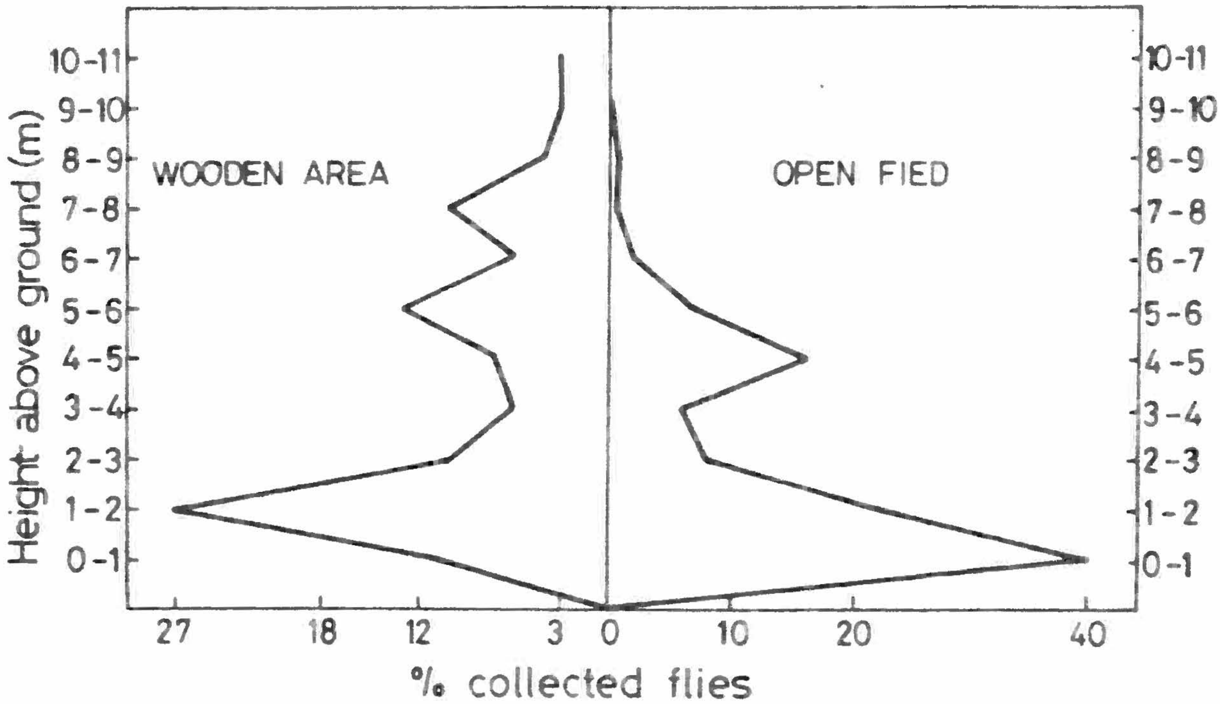

Figure 16b. Vertical zonation of phlebotomine sanflies in two different habitats: a wooden area and an open field. (Marigat area, 1987).

Analyses of Figure 17, pointed out that the ubiquitous species (*Sergentomyia bedfordi* and *S. antennatus*) occurred in both areas at different densities as well as they reached different heights. Both species reached the highest height in the wooded site, while in the open field, *S. bedfordi* seemed to reach up to nine metres and *S. antennatus* only reached six metres.

The average nightly sandfly catches showed that large number of female sandflies was collected from two to eleven metres (wooded area) and four to nine metres (open field). At each height in the forested area, the number of female sandflies was almost the double of males, the only exception was seen between 0 and 2 metres, where the number of male sandflies slightly predominated on the females. Williams (1970), observed the majority of male sandflies remaining near to the ground, though some rise well above the ground; whereas most females move towards the tops of the trees. Meanwhile, Shaw *et al.*(1972) noted a proportion of 1 male against 46 females reaching 1.2 metres.

There seemed to be a great deal of variation in the vertical distribution of different sandfly species in the Marigat forested area. Thus, *Sergentomyia antennatus* and *S. bedfordi* were the only species to reach a height of eleven metres corresponding to the canopy level in the wooded area.

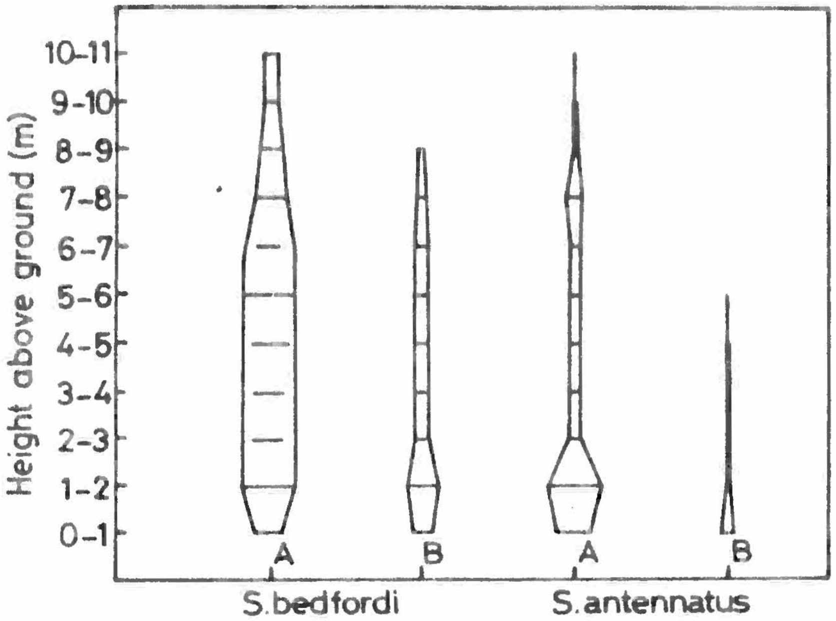

Figure 17. Diagram showing the vertical distribution of Sergentomyia bedfordi and S. antennatus in two different biotopes, a wooden area (A) and an open field (B). (Marigat area, 1987).

Thatcher (1968b), pointed out that the larvae of arboreal sandfly species were found in dead leaves deposited at 20, 36 and 40 feet above the ground, where a series of large limbs branched out. He suggested therefore that when sandfly control is attempted, arboreal breeding sites should be considered since some man-biting species may develop there. In the open field, both species reached nine metres. S. antennatus and S. bedfordi were the commonest sandflies at all heights. Their greatest densities were recorded between 1 and 2 metres in the wooded area and 0 to 1 metre in the open field. The high height of flight for both S. antennatus and S. bedfordi may indicate that these species are predominately tree-dwellers; their preferred source of blood meals are likely to be mammals (rodents), reptiles (lizards) and birds of arboreal habits. It has been observed that in the absence of preferred hosts in the preferred height zone, these flies readily descend to the floor and attack alternative hosts (ruminants, dogs). Mutinga and Ngoka (1981), noted that Sergentomyia antennatus and S. bedfordi among many others can be incriminated as lizard-feeders.

Species such as Sergentomyia ingrami, S. affinis and S. adleri feed mainly near or at the ground level. Both species, therefore can be designated as "lower zone species". They all are limited in their vertical distribution to a narrow zone just above the forest floor. S. africanus and S. clydei appear to search for food well above the ground, they prefer the middle-zone (2 to 5 metres). Disney (1966) observed that in British Honduras, some species of Lutzomyia appear to feed near to the ground, whereas others seem to bite at all levels, even reaching the canopy.

Furthermore, large numbers of sandflies was recorded between ground level and eight metres in the wooded area and between the ground level and five metres in the open field. The large numbers of sandflies caught at the ground level indicate that sandflies frequently fly close to the ground for searching of hosts as well as of resting sites. However, the discrepancy observed in the sandfly flight behaviour was due to the fact that in the wooded site, composed of large trees with huge canopies, sandfly species probably reached the high height for search of an acceptable microenvironment and for food, while in the open habitat the lack of trees and the presence of strong winds caused the flies to get confined in a lower zone. The female sandflies have a large ability to fly too high; they reach the canopy level of trees like Ficus and Acacia. In British Honduras, Disney (1966) stated that more female sandfly species reach the high level of flight (11 to 12 metres) and only a few males of Lutzomyia trinidadensis were found at higher heights. Okoth and Kapata (1987) studying the resting sites of Glossina f. fuscipes noted that female flies rest heigher than males.

Analysing the relationships between the height of flight and the sandfly population density as recorded at every height in both habitats: it was observed that the number of sandflies decreased with the height. Shaw _et al_.(1972) pointed out that in Brazil, the number of males and females of sandflies falls off with the height.

CHAPTER FIVE

ENVIRONMENTAL CONDITIONS AND THE SANDFLY DENSITY

5.1 Introduction

Most field entomologists are aware of the need to measure the environmental factors such as the rainfall, the atmospheric humidity, the temperature and the wind speed, and some have studied their independant or combined effect on insects. According to Ferro and Chapman (1979) few entomologists have been concerned with the interaction of humidity and temperature on insects. The temperature and humidity are critical factors in sandfly ecology (Theodor, 1936) yet the relationship of the interaction of these two factors has not been clearly demonstrated with respect to sandfly development. There have been few studies on the effect of varying humidities at a constant temperature or vice versa (Theodor, 1936), but none of these studies examined the interaction of both temperature and humidities on sandflies. Studies on the microclimates prevailing in sandfly breeding and resting sites are meagre, whilst their effects on sandfly production are of inestimable importance in understanding the relationships existing between sandfly and the microenvironment.

5.2 Materials and Methods

5.2.1 Ambient conditions

Physical data comprising rainfall, temperature, relative humidity and wind velocity were obtained each month from the Perkerra Agricultural Research Station (PARS), located within the study area. Excepting, the soil temperature values which were recorded from November 1985 to October 86. Appendix 1 gives a summary of the climatic conditions in Marigat area for a six-year period.

5.2.2 Microclimatic conditions

In order to assess the effects of soil temperature and soil relative humidity on sandfly variations and their species diversity, the temperature and the relative humidity measurements were taken at different periods of the day during both dry and wet seasons (from November 1986 to August 1987). At the same time, sandflies were collected from the investigated breeding places.

Soil temperature and soil moisture were detected and measured by burying the thermistor soil cells in the soils, permanently or semi-permanently, and taking both temperature and resistance readings directly from the Soiltestmeter MC 302 Celsius model, developed originally by the California Forest and Range Experimental Station. Dial temperature ranges were -10 oC to 44 oC and electrical resistance ranges for moisture readings were 0 Ohms to 20 millions Ohms. Moisture percentages were determined by relating resistance readings to a calibration curve (resistance versus moisture%) for the type of tested soil.

Four sites comprising two burrows and two termite hills were investigated. Cells were inserted as far as they could be pushed into the burrow opening and in termite hill ventilation shaft, and then, buried at a depth comprising between 0 and 10 centimetres.

5.3 Results

5.3.1 Ambient conditions

5.3.1.1 Rainfall

During the present study period (1985-87), zero millimetre of rainfall was recorded in the area in both January and February 1986. The area, then became dry and the soil was frequently blown off by the strong evening wind. April and June constituted the months with heavy rainfall, with an average of 163.50 and 103.90 mm respectively

(Appendix 1b).

Analysing the relationship between the average monthly rainfall and the mean of the total monthly sandfly collections (Figure 18), the following observations were made:

1. The decrease of the sandfly population can be ascribed to two main factors.

a) the dryness of the soil and

b) the dampness of the breeding sites.

It had been observed that a marked fall off of the sandfly relative abundance followed the lack of rains (dry season) and the waterlogging of the breeding sites. Thus, as indicated in Figure 18, the decrease of sandflies in January was due to the lack of water in the area and the one of May was caused by large amount of rains which had fallen in the area in April; modifying the soil microclimatic conditions in sandfly breeding and resting sites and hence, disrupting the sandfly's activities as well as their larval development.

2. The increase of the total sandfly population was attributed to the wet weather with moderate rains and, stable temperatures. Taking into account the Figure 18, it has been shown that the increase of sandfly relative abundance occurred at any time the rainfall has increased. The peak of sandflies observed in April was due to the first rains of March and the next recorded in August was related

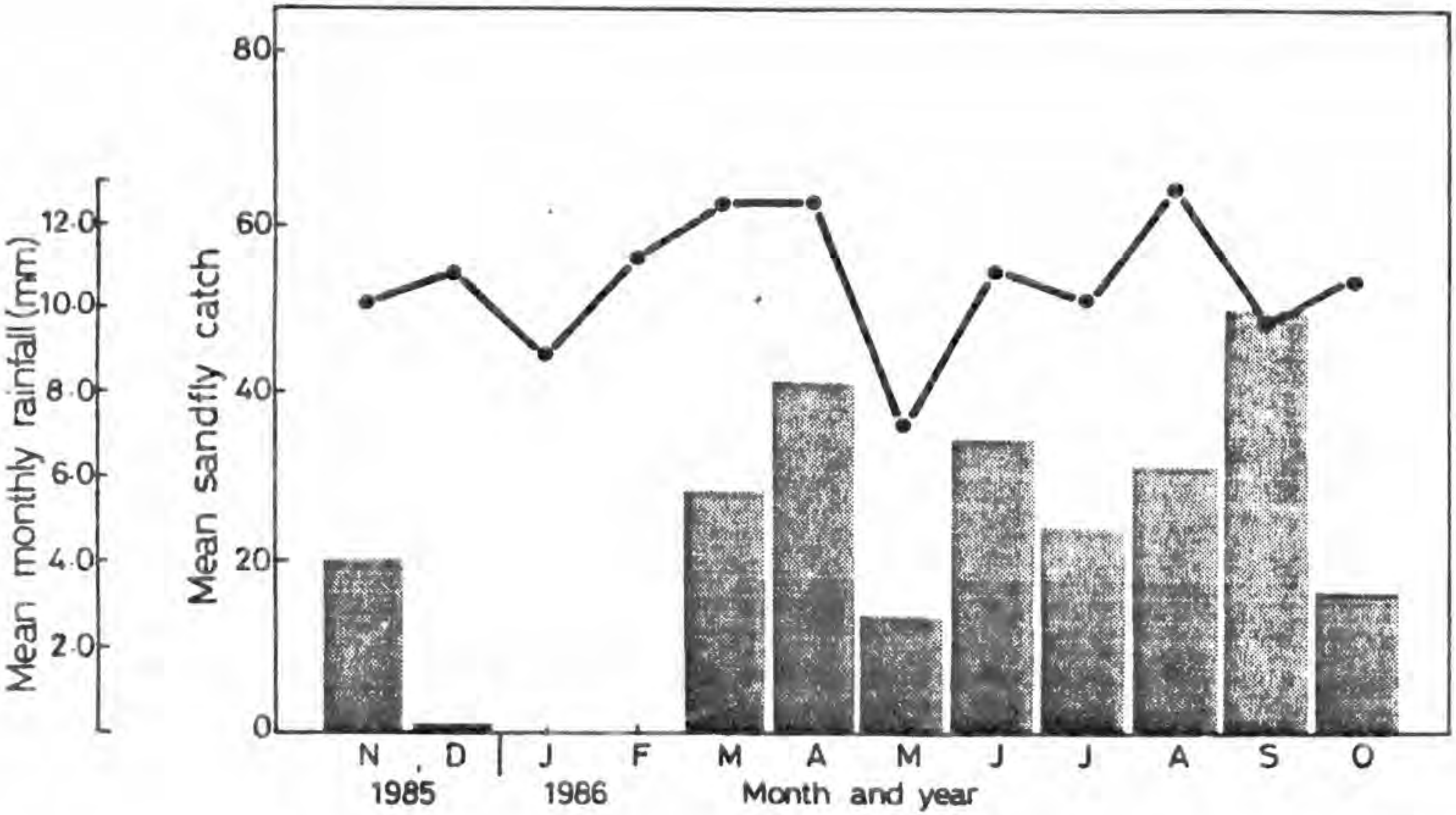

Figure 18. Mean monthly sandfly catch and the rainfall. The line represents the sandfly catches and the solid bars represent the average monthly rainfall. (Marigat area, 1985/86).

to the moderate rains which fell in July. Therefore, both sandfly peaks were due to the bimodal pattern of rainfall in the area.

Correlating both the total sandfly vectors and suspected vectors of leishmaniasis (P. martini, P. duboscqi and S. ingrami) with the rainfall (Figure 19), it was observed that a significant positive correlation coefficient was calculated ($r=0.60$, $P<0.05$), indicating that at any time moderate rains occurred, there was a sharp increase in sandfly vectors in the breeding sites.

Analysing the rainfall effects on the sandfly collections, it was found that the positive and significant correlation coefficient existed between the rainfall and the sandfly relative abundance in termite hill ($r=0.729$, $P<0.007$) (Table 19 and Figure 20). Although some sites presented positive correlation coefficients (r) (e.g. human habitations and animal enclosures) or showed negative correlation coefficients (e.g. animal burrows, tree hollows and open field); the analysis of the significance of r did not reach a significant level at both 1 and 5 percent levels of probability.

Table 19. Relationships between sandfly population density as collected from various habitats and the environmental factors. Perkerra Irrigation Scheme, Marigat area, 1985/86.

	Rainfall			Relative humidity			Air temperature			Soil temperature			Wind speed		
Site	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
TH	0.729	1.87a	3.365	0.694	-0.33	3.048	-0.669	9.77	2.840	-0.834	9.57	4.791	-0.327	2.35	1.095
		0.15b	P.007*		1.34	P.012		-5.06	P.017		-5.07	P.000		-0.23	P1.0
AB	-0.334	1.93	1.120	-0.325	2.67	1.087	0.611	-3.18	2.442	0.381	-0.60	1.304	0.041	1.88	0.130
		-0.05	P.288		-0.45	P.302		3.31	P.034*		1.66	P.221		0.04	P1.0
th	-0.093	2.00	0.297	-0.030	2.09	0.096	-0.144	3.81	0.461	-0.013	2.10	0.041	0.068	1.14	0.217
		-0.02	P1.0		-0.06	P1.0		-1.20	P1.0		-0.08	P1.0		0.05	P1.0
Hh	0.217	1.21	0.701	0.115	0.96	0.367	-0.160	2.59	0.511	-0.050	1.58	0.160	0.335	0.58	1.123
		0.03	P1.0		0.16	P1.0		-0.88	P1.0		-0.22	P1.0		0.34	P.287
Ae	0.248	1.22	0.810	0.040	1.15	0.127	-0.420	6.26	1.465	-0.284	3.91	0.936	0.110	1.15	0.350
		0.05	P1.0		0.08	P1.0		-3.26	P.173		-1.77	P1.0		0.14	P1.0
OF	-0.029	1.45	0.092	-0.220	2.43	0.714	0.424	-4.87	1.479	0.205	-0.94	0.662	-	-	-
		-0.008	P1.0		-0.55	P1.0		4.14	P.170		1.61	P1.0		-	

TH= termite hill   Hh= human habitation   (1)= Correlation coefficient (r)

AB= animal burrow   Ae= Animal enclosure   (2)= regression line (y) : a= intercept, b= slope

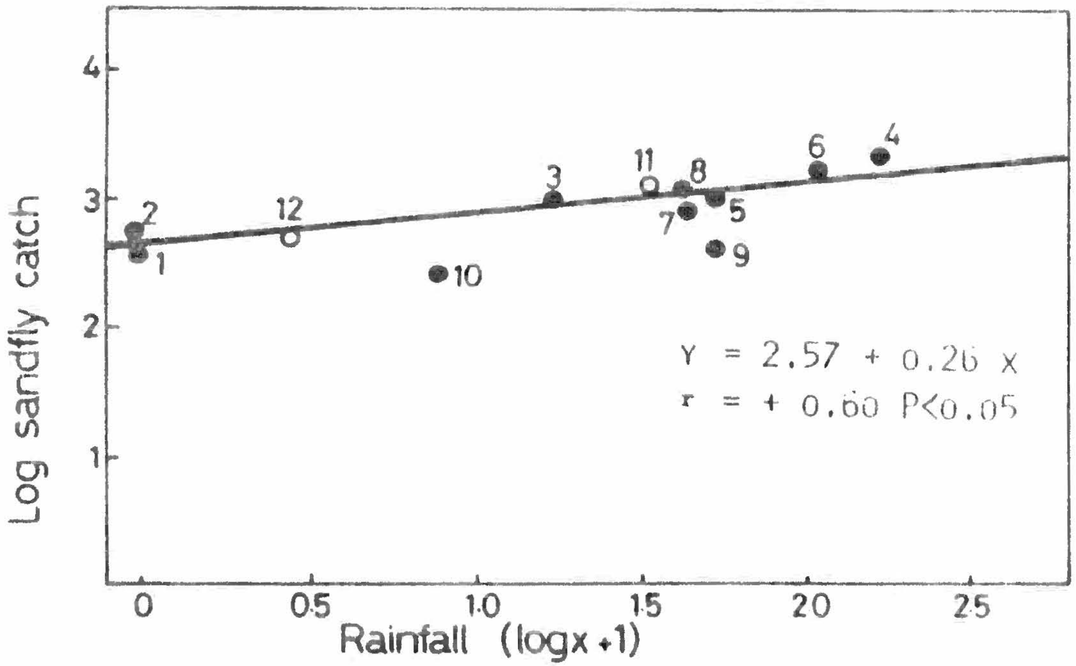

Figure 19. Relationships between the sandfly vectors of *Leishmania* and the rainfall. The numbers refer to the month of the year (○ = 1985, ● = 1986).

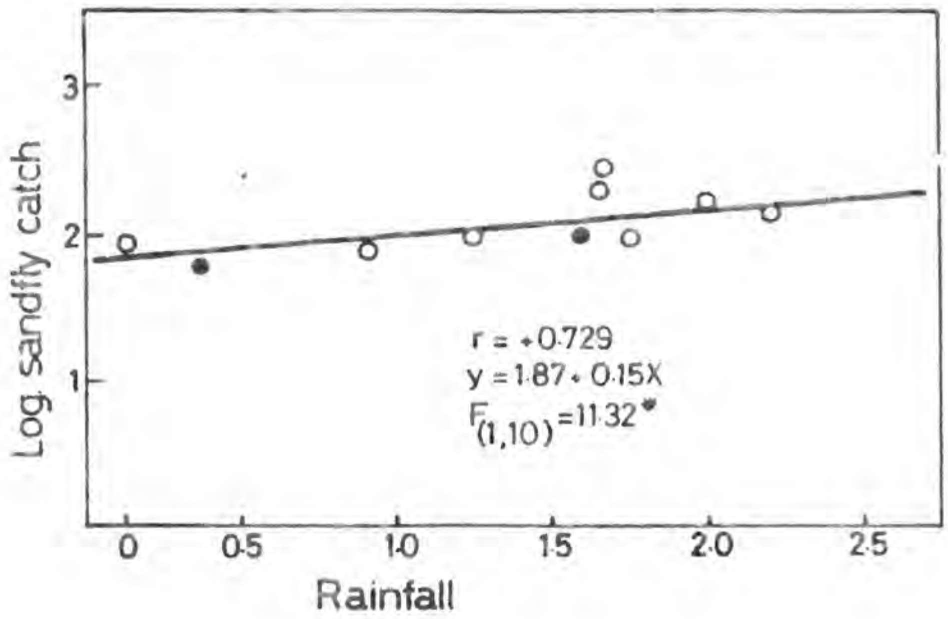

Figure 20. Scatter diagram showing the relationships between the sandfly density in termite hill and the rainfall. (Marigat area, 1985/86).

5.3.1.2 Relative humidity (RH)

The ambient relative humidity was recorded throughout the study period and their effects on sandfly collections were assessed. During the dry season, a decrease of relative humidity was observed and corresponded to 45.90% (maximum) and 28.80% (minimum) for January 1986 and 44.50% (maximum) and 31.40% (minimum) for February 1986. Meanwhile, in the wet period, the relative humidity increased; the months of April and June gave their relative humidity mean values of 73.20% and 83.90% respectively. Both months presented high rainfall values (163.50 mm for April and 103.90 mm for June). However, comparing the monitored relative humidity values to Tropical areas' values, it can be seen that in the semi-arid as well as in the arid areas, relative humidity values are too low. The observed low relative humidity was due to high temperatures occurring in the area.

Correlating the total monthly sandfly population (all sites) with the relative humidity, the negative correlation coefficients were observed for both the maximum and the minimum relative humidities (r=-0.068 for maximum and r=-0.202 for minimum). Despite the effects of this factor on the sandfly's activities the student's t test did not show any significant correlation coefficient.

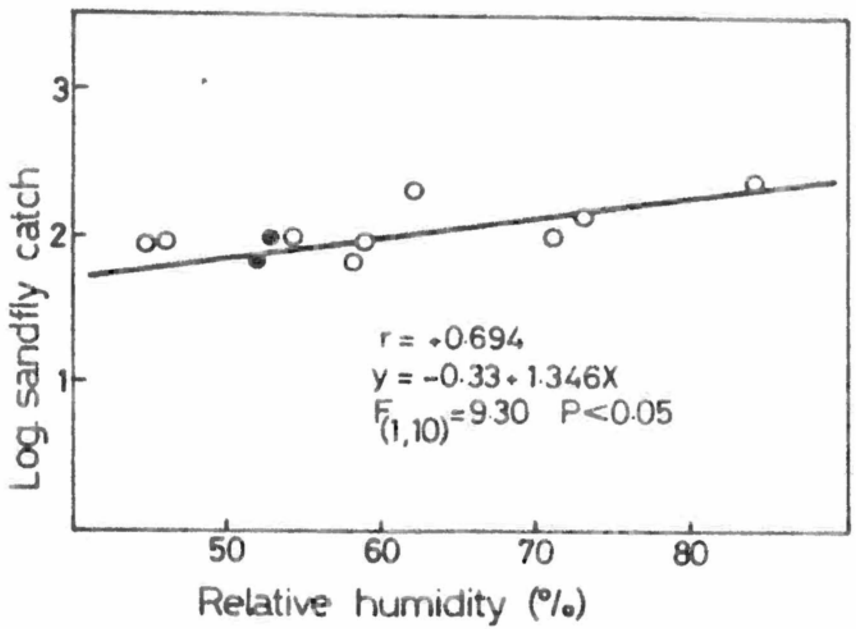

Figure 21. Scatter diagram showing the relationships between the sandfly density in termite hill and the ambient relative humidity. (Marigat area, 1985/86).

Analysing the effects of relative humidity on the sandfly catches in every searched site, the correlation coefficient analysis was carried out between the average monthly relative humidity (as monitored in the area) and the mean of the monthly total sandflies (as recorded from every investigated site). As indicated in Table 19, positive correlation coefficents were observed for termite hills (r= 0.694) (Figure 21), human habitations (r= 0.115) and animal enclosures (r= 0.040), while negative coefficients were calculated for animal burrows (r= -0.325), tree hollows (r=-0.003) and open field (r=-0.220). Studying the level of significance at both 5 and 1 percent levels of probability, none of the correlated parameters was significant.

5.3.1.3 Temperatures

Temperatures ranging from 30 to 35oC occurred throughout the year during the period 1985-86 in the Marigat area. The highest temperatures were recorded during the dry season (January and February) and the beginning of the wet weather (March). It also was found that during the dry period, temperatures ranged from 32.10 to 35.00oC, while in the wet season, they ranged from 30.20 to 35.00oC. Surprisingly, it was also observed that at the beginning of the wet weather high temperatures were monitored (35.10oC). These temperatures went decreasing with the frequency of rains. Thus, the lowest temperatures of 30.20 and 30.60oC were monitored in June and July, months corresponding to the wet period.

Correlating both the average monthly air temperature with the average of the total monthly sandfly collections (all sites), a negative correlation coefficient was calculated (r=-0.41), indicating a negative effect of air temperature on sandfly catches. The average monthly air temperature correlated with the average monthly sandfly densities as collected from every searched site presented the following deductions (Table 19):

1. a significant positive correlation coefficient was observed between air temperature and sandfly collections in animal burrows (r= 0.611, F(1,10)= 6.24, P<0.005)(Figure 22).
2. a positive correlation coefficient (but not significant) was calculated between air temperature and sandfly relative abundance in the open field (r= 0.424).
3. relationship between air temperature and sandfly relative abundance in termite hills, tree hollows, human habitations and animal enclosures presented negative correlation coefficients (r= -0.669, P= 0.017; r= -0.144, P= 1.0; r= -0.160, P= 1.0 and r= -0.420, P= 0.173 respectively). None of these r values was significant at both 5 and 1 percent levels.

Starting from September to February, the dry season

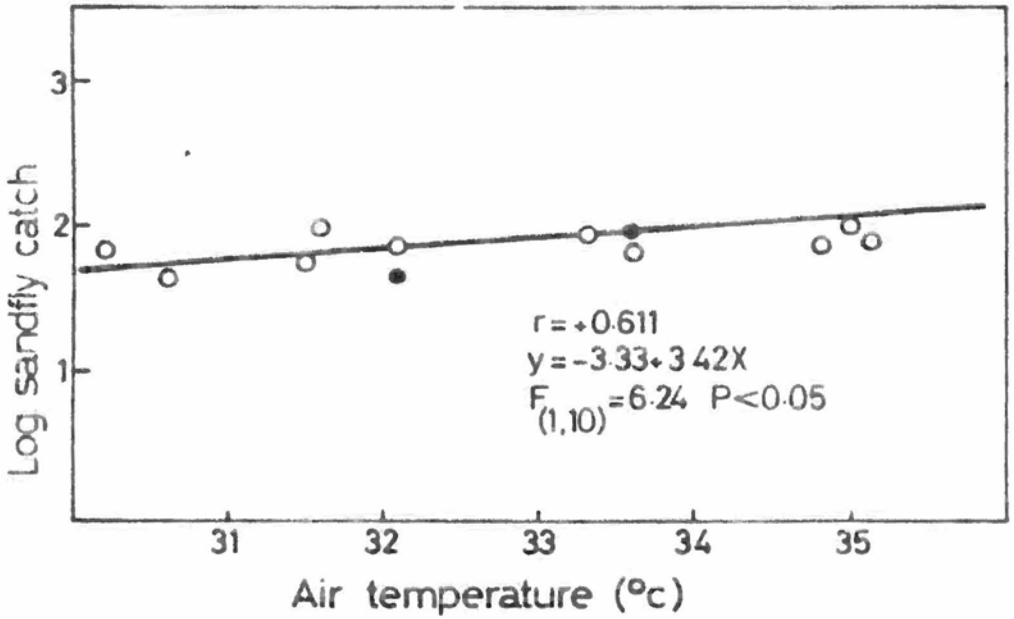

Figure 22. Scatter diagram showing the relationships between the sandfly density in animal burrow and the air temperature. (Marigat area, 1985/86).

experienced higher soil temperatures ranging from 28 to 32oC. The high soil temperatures of 32.20 and 32.65oC were recorded in January and February 1986. The lowest soil temperature (27.23oC) observed at the end of the rainy season was due to the dampness of the soil. Thus, the months of June, July and August experienced low soil temperatures corresponding to 27.63, 27.30 and 27.23oC respectively. Both air and soil temperatures presented graph curves showing the same pattern.

Correlating the average monthly soil temperatures with the average monthly total sandfly catches (all sites), a negative correlation coefficient was observed, indicating that the soil temperature is also one of the sandfly limiting factors (r=-0.66).

Studying the effect of soil temperature on sandfly relative abundance as observed in each investigated site, the following deductions may be made (Table 19):

1. a significant negative correlation coefficient was observed between soil temperature and sandfly population in termite hills (r= -0.834, $F(1,10)$= 25.75**)(Figure 23),
2. positive correlation coefficients were calculated between soil temperature and the sandfly population in animal burrows (r= 0.381) and open field (r= 0.205).
3. negative correlation coefficients were observed between soil temperature and sandfly population in tree hollows (r=

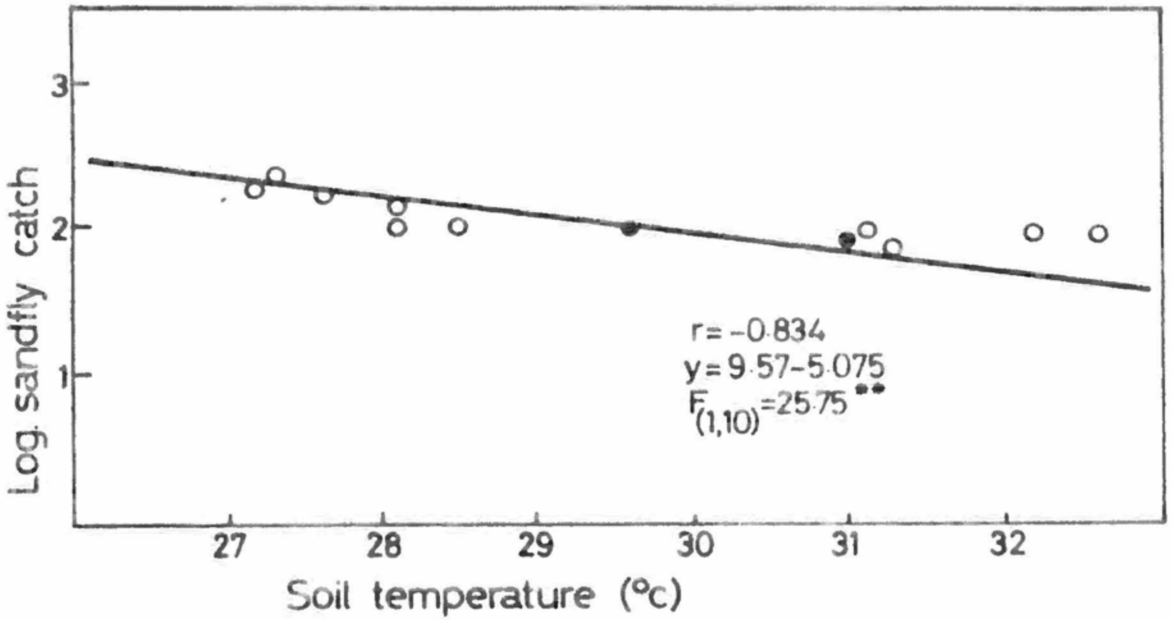

Figure 23. Scatter diagram showing the relationships between the sandfly density in termite hill and the soil temperature. (Marigat area, 1985/86).

-0.013), human habitations (r=-0.050) and animal enclosures (r=-0.284).

5.3.1.4 Wind velocity

A strong wind occurred in the area during the dry months of January and February and before the first rains of March. A wind speed of 78.03 miles per hour was observed in March. Meanwhile, the low wind speed values were recorded during the rainy season (April to August). The lowest wind speed value was monitored in August (48.73 miles per hour), month corresponding to the end of the rainfall (74.31 mm) in the area.

The correlation coefficients between the average monthly wind velocity and the monthly sandfly relative abundance as observed in each searched site (Table 19) may lead to the following deductions:

1. Negative correlation coefficient was observed between sandfly production in termite hills and the wind velocity,
2. No significant correlation was found between sandfly population and the wind velocity.

5.3.2 The microclimatic conditions

5.3.2.1 Soil temperature

Soil temperature occurring inside both the termite hills and animal burrows was the most stable parameter (Table 20). The monthly means ranged from 27.62oC to 30.23oC in termite hills and 22.42oC to 27.50oC in animal burrows, giving a difference (between the highest and the lowest temperatures) of 3oC for the termite hill and 5oC for the animal burrows.

In termite hills, the highest soil temperatures were recorded in March (30.13oC) and August (30.23oC); while the lowest were monitored in June (27.62oC). Analysing the Table 20, it may be observed that:

a) During the dry season (November to January), high soil temperatures were persistently recorded in termite hills, these ranged from 28.25oC to 28.56oC. The driest month in the area (January), presented the monthly mean of 28.50oC.

b) During the wet period (March to August), a few variations of temperatures were observed in termite hills. The beginning of the wet season (March) and its end (August) experienced the highest soil temperatures. The temperatures of 30.13oC and 30.23oC were recorded in March and August respectively. During this period, the soil temperature decreased and reached the lowest temperature value of

Table 20. Temperature and relative humidity recorded in Termite hills and Animal burrows.

(Perkerra Irrigation Scheme, Marigat area, 1986/87)

	Termite hill				Animal burrow				Rainfall
	Temperature (°C)		Relative humidity(%)		Temperature (°C)		Relative humidity(%)		(mm)
	Range	Aver.	Range	Aver.	Range	Aver.	Range	Aver.	
1986 Nov.	27.87-29.25	28.56	15.50-27.00	21.00	26.56-26.97	26.76	1.00- 5.00	3.50	22.40
Dec.	28.25-28.25	28.25	16.00-25.00	20.00	27.00-27.50	27.25	13.00-19.50	16.00	10.90
1987 Jan.	24.50-31.00	28.50	1.00-45.50	22.00	-	-	-	-	2.60
Mar.	28.50-31.00	30.13	19.50-28.50	23.00	26.00-30.00	27.50	1.00-19.50	8.00	19.80
Apr.	24.00-29.00	26.75	19.50-44.50	39.50	24.00-29.00	25.50	25.50-45.50	39.00	133.50
Jun.	27.50-27.75	27.62	44.50-47.50	47.00	24.00-25.00	24.33	46.50-48.50	48.00	127.30
Aug.	29.66-31.66	30.23	19.50-42.50	36.50	21.66-23.00	22.42	21.00-36.00	28.50	31.50
Average	27.18-29.70	28.58	19.50-37.50	30.00	24.87-26.91	25.62	18.00-29.00	24.00	49.71

26.75oC in April, a month with heavy rainfall (133.50 mm). In June a temperature of 27.62oC was recorded.

c) An average monthly soil temperature of 28.58oC was monitored from the termite hills.

In animal burrows, the highest soil temperatures were recorded in March (27.50oC) and its lowest were monitored in August (22.42oC). Analysing the means of monthly temperatures as recorded from this site (Table 20), the following observations may be made:

a) The high temperatures were observed during the dry season and the beginning of the wet period.

b) During the wet season, the soil temperatures decreased. The high rainfall which occurred in the area in April and June caused the soil to become wet and thus, influencing the soil temperature to decrease. Despite the decrease of the rainfall at the end of the rainy season (August), the lowest soil temperatures were still recorded (22.42oC). This was due to the high accumulation of the wetness into the soil of burrows.

c) An average monthly soil temperatures of 25.62oC was observed in animal burrows.

In general, the soil temperatures recorded from both termite hills and animal burrows, followed the same pattern as the one of air temperature. Since the low soil temperature in termite hills corresponded to the highest in animal burrows, termite hills therefore experienced high temperatures than animal burrows. A difference of 2.96oC was observed between the average monthly soil temperature from termite hills and the one recorded from animal burrows.

The large amount of water received by the soil caused the wetness of the breeding sites and hence the decrease of its temperature. Moderate rains, did not contribute to the soil temperature decrease, and inversely, it influenced its increase. An accuracy estimate of the soil temperature from the air temperature in this area, could be the mean monthly air temperature plus 3oC for the termite hills and the mean monthly air temperature plus 6oC for the animal burrow.

Comparing both rainfall data and soil temperatures as recorded from termite hills and animal burrows (Table 20 and Figure 24), the following observations may be made:

a) a decrease of rainfall was followed by an increase of soil temperatures in both habitats. The, high soil temperatures recorded in March, followed a decrease of rains in that particular month.

b) Conversely, an increase of rains in the area was followed by a decrease of soil temperatures. April experienced high rainfall, which was followed by a decrease of soil temperatures in termite hills as well as in animal burrows.

c) A sharp decrease of rainfall in August, was followed by

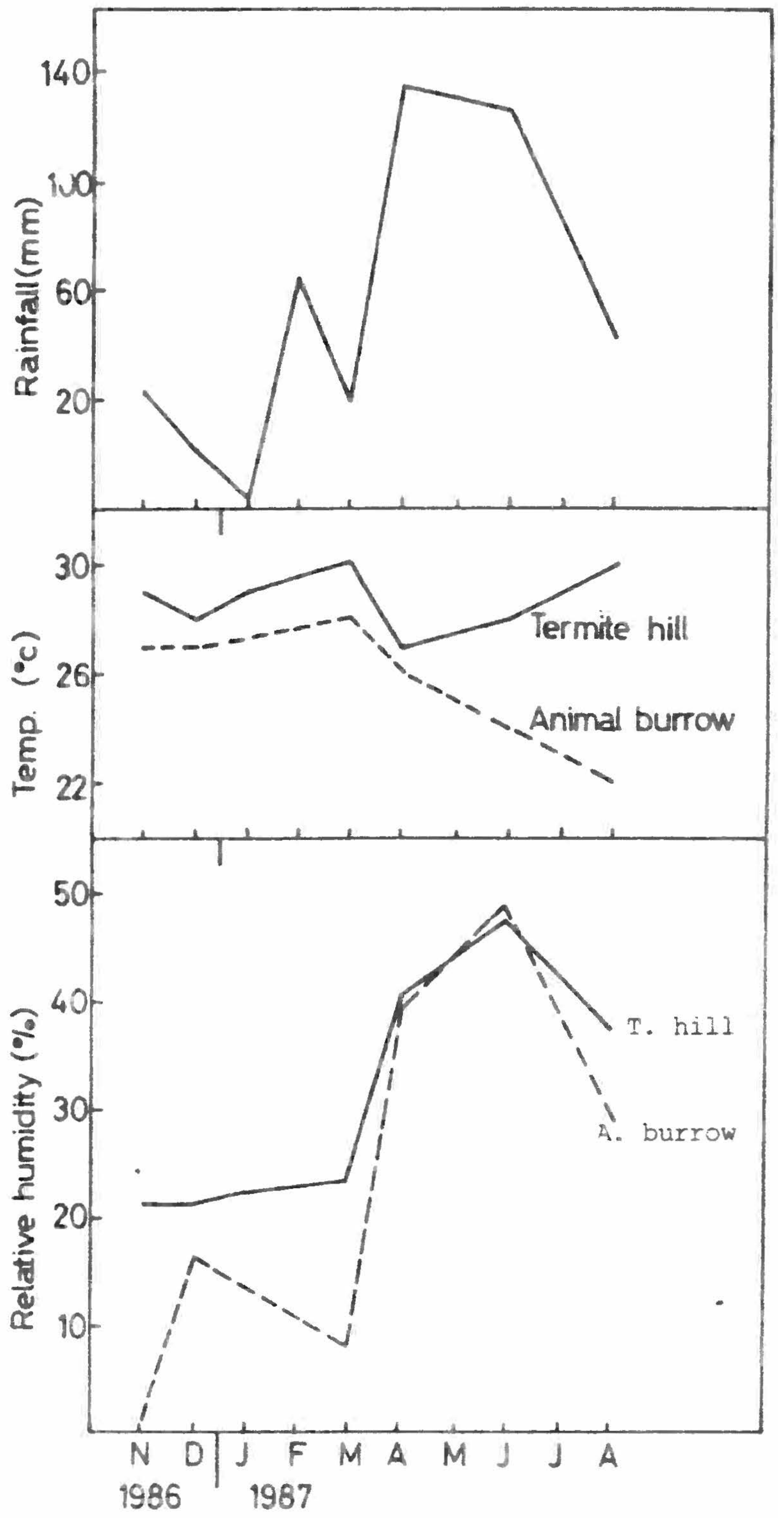

Figure 24. Monthly variations of soil temperatures and soil relative humidity inside termite hill and animal burrow in relation to rainfall (Marigat area, 1986-87).

an increase of soil temperature in termite hills, but with a soil temperature decrease in animal burrow.

5.3.2.2 Soil relative humidity

The relative humidity of the soil recorded in both the termite hills and the animal burrows were characterized by frequent instability during our recordings (Table 20). The average monthly relative humidity ranging from 20 to 47 percent in termite hills and 4 to 48 percent in animal burrows were observed respectively. These results show that in a semi-arid area, the percentage relative humidity in both sites did not exceed 50 percent, and therefore, the sites were not saturated during the present period of investigation.

The highest relative humidity recorded in termite hills was observed in June (47.00 percent), while the lowest was monitored in December (20.50 percent). As indicated in Table 20, the dry season presented low relative humidity values, while the wet period showed high percentages. Meanwhile, the month of November to March experienced low percentages of relative humidity ranging from 20 to 23 percent, and the one of April to August seemed to maintain good quantity of moisture content into the soil (36.50 to 47 percent relative humidity). The high increase of moisture content was due to the high amount of rains that fell on the exposed termite mounds. The slight decrease of relative humidity during August (36.50 percent) was due to the decrease of rains in the area. A difference of 26.50 percent was observed between the month with the highest and the lowest relative humidity. An average monthly relative humidity of 30 percent was monitored from the termite hills.

Relating the relative humidity recorded from termite hills to the rainfall (Figure 24), the following observations may be made:

a) The slight increase of relative humidity in termite hills (21 to 23 percent) was due to moderate rains, which occurred in the area,

b) The sharp increase of relative humidity observed in April and June were due to high increase of rains,

c) The pattern of the relative humidity curve followed the ones of the rainfall.

During the dry season the relative humidity values ranged from 3.50 to 16.00 percent, while during the wet period, values ranging from 39 to 48 percent were recorded. The lowest relative humidity value was recorded in November (3.50 percent), while the highest was observed in June (48 percent). Both, November and June corresponded to the dry and the wet season respectively.

In animal burrows, the difference of 44.50 percent was observed between the month with the highest and the lowest relative humidity. This value shows that, during the dry season, burrows dry up and regain their normal microclimate (relative humidity) during the wet period. Recordings in animal burrows covering both periods (November to August), presented a monthly mean soil relative humidity of 24.00 percent.

Analysing the relationship between the rainfall and the relative humidity as recorded from the animal burrows (Figure 24), the following observations may be made:

a) Except in November, both rainfall and relative humidity presented the curves showing the same trend,

b) The decrease of relative humidity during the dry season and at the end of the rainy season was due to a decrease of the rainfall,

c) The increase of relative humidity (from April) was attributed to high increase of rainfall.

5.3.2.3 Relationships between sandflies and soil microclimates

In order to study the relationship existing between sandflies and the microclimates (temperatures and relative humidity) occurring inside their breeding and resting sites, sandflies (of both *Phlebotomus* and *Sergentomyia* genera) were collected in both termite hills and animal burrows during the period the microclimates were recorded (Table 11).

Table 21. Phlebotomine sandflies as collected from termite hill and animal burrow and the microclimates as recorded from the same habitats. (Perkerra Irrigation Scheme, Marigat area, November to August 1987).

Period	Sandfly group (*)						Microclimates (*)				Rainfall(*)
	Termite hill			Animal burrow			Termite hill		An. burrow		
	P	S	Tot.	P	S	Tot.	T°C	RH(%)	T°C	RH(%)	
1986 Nov.	1.12	2.74	2.75	1.61	2.32	2.39	1.45	1.32	1.42	0.50	1.32
Dec.	0.91	2.37	2.38	1.64	2.46	2.52	1.45	1.31	1.43	1.20	1.03
1987 Jan.	1.04	2.62	2.63	-	-	-	1.45	1.34	-	-	0.41
Mar.	1.00	2.73	2.74	1.59	2.59	2.63	1.47	1.36	1.43	0.90	1.29
Apr	1.12	2.78	2.79	1.70	2.53	2.59	1.42	1.59	1.40	1.59	2.12
Jun.	0.60	2.80	2.81	1.38	2.42	2.46	1.44	1.67	1.38	1.68	2.10
Aug.	0.38	2.89	2.89	1.66	2.48	2.54	1.48	1.56	1.35	1.45	1.49
Average	0.88	2.70	2.71	1.59	2.46	2.52	1.45	1.45	1.40	1.22	1.39

(*) : Values are expressed into log. transformation (log n)

P= *Phlebotomus* group T= temperature

S= *Sergentomyia* group RH= relative humidity

Tot.= total sandflies.

Table 22. Correlation coefficient between sandfly density and the microclimates as recorded from sandfly breeding and resting sites (Marigat area, November 1986-August 1987).

	Termite hill		Animal burrow	
Sandfly group	Temperature	Rel.humidity	Temperature	Rel.humidity
Phlebotomus	r=-0.511 P=0.2409	r=-0.570 P=0.1813	r=0.140 P=0.7903	r=-0.216 P=0.6807
Sergentomyia	r=0.144 P=0.7566	r=0.663 P=0.1043	r=0.056 P=0.9157	r=0.339 P=0.5103
Total sandflies	r=0.131 P=0.7782	r=0.663 P=0.1044	r=0.063 P=0.9046	r=0.311 P=0.547

r= correlation coefficient

P= probability.

Correlating both sandfly relative abundance (Phlebotomus and Sergentomyia species) with the microclimates (temperatures and relative humidity): the following observations may be made (Table 22):
Correlation carried out between sandflies of the Phlebotomus group (P. martini and P. duboscqi) and the microclimates prevailing inside sandfly breeding and resting sites showed that:

a) In termite hills, the correlation coefficients presented negative values for both temperature (r=-0.511, P=0.241) and relative humdity (r=-0.570, P=0.181).

b) In animal burrows, a positive correlation coefficient was observed for temperature (r= +0.140, P= 0.790), while a negative correlation coefficient was calculated for the relative humidity (r= -0.216, P= 0.681).

Although, no significant correlation coefficient was observed between the Phlebotomus species and the microclimates occurring inside their breeding sites, soil temperature and soil relative humidity remain the factors regulating the sandfly population densities.
Also, besides its low population, the Phlebotomus species seemed to be highly collected in the animal burrows than in termite hills. Their monthly means (data transformed into logarithms) were 1.59 sandflies in animal burrows and 0.88 sandflies in termite hills (Table 21). These data show that

the number of Phlebotomus species in burrows was twice the number collected in termite hills.

The relative abundance of Sergentomyia species was correlated with the microclimates recorded in their breeding and resting sites. Analysing the results (Table 22), it has been shown that:

a) In termite hills, positive correlation coefficients (r) were observed for both temperature (r= +0.144, P= 0.757) and relative humidity (r=+0.663, P=0.104). Although, r was positive for both parameters, none of them presented a significant level.

b) In animal burrows, positive correlation coefficients for both temperature (r= 0.056, P= 0.916) and relative humidity (r= 0.339, P= 0.510) were observed, for temperature and for animal burrow.

Studying the level of significance of r in burrows; it was seen that besides both factors showed a positive correlation, none of them reached a significant level. The positive correlation confirmed that the temperature and the relative humidity regulate the population of the Sergentomyia species in their breeding and resting sites.

Correlating the total sandfly population (Phlebotomus and Sergentomyia species) and the microclimates, it was seen that positive but not significant correlation coefficients were calculated for temperature and relative humidity in both termite hills and animal burrows. Therefore, in termite hills; r= 0.131, P= 0.778; r= 0.663, P= 0.104 for temperature and relative humidity respectively and in animal burrows, r= 0.063, P= 0.905; r= 0.311, P= 0.547 for temperature and relative humidity respectively.

5.4 Discussion

5.4.1 Ambient conditions

5.4.1.1 Rainfall

The tendency for every sandfly species to increase in number during one or both seasons depends on its ability as well as on its adaptability to the local conditions. Thus, the density of species of the Phlebotomus group, increased during the wet weather, their population density declined during the dry period. The high population of both Phlebotomus martini and P. duboscqi was recorded in April, a month with heavy rainfall. Wijers and Minter (1962) stated that in Baringo area, a quite large numbers of P. martini were found during the wet seasons. For the Sergentomyia species the density increase was observed during the wet season and its decline could be seen during the dry period. The density decrease of some Sergentomyia species could also be expected during the middle of the wet weather. However, there was an increase in the relative abundance of <u>Sergentomyia</u> <u>antennatus</u> and <u>S</u>. <u>bedffordi</u> at the beginning and the end of the wet weather, with a decrease in the middle of the wet season and during the dry period. Wijers and Minter (1962) noted that most of sandflies decrease in numbers in the middle of the rains.

Climatic factors, particularly rainfall, appear to have important effects on the gross distribution and local abundance of sandflies (Minter, 1964c). Dransfield <u>et</u> <u>al</u>. (1982) noted that climatic factors and host availability are likely to determine the changing pattern of the distribution and the abundance of <u>Glossina</u>.

However, termite hill microhabitat produced large numbers of sandflies during the wet season, which decreased during the dry season. The animal burrows on the other hand, kept an equal capture rate during both dry and wet seasons. Tree hollows experienced high sandfly population during the dry season, which decreased during the wet weather. The relative abundance of sandflies in human habitations, animal enclosures and open field was higher during the dry season than the wet period. Foster (1972a), stated that the most protected sites (e.g. burrows, tree holes) present a limited decline or do not show a noticeable decline of sandflies at all during the spring. Meanwhile, Wijers and Minter (1962) pointed out that the climatic factors may influence the number of sandflies year by year.

Considering the total sandfly population, the two major peaks of abundance occurred in April and August, months corresponding to heavy and moderate rains respectively. Foster (1972b), observed the same trend of sandfly fluctuations in Ethiopia. Minter (1964b) pointed out that an increased incidence of sandflies corresponds with the period of maximum rainfall. The decrease of the sandfly population during the dry period and a month after heavy rains was probably due to changes caused by the dryness of the soil as well as by its dampness. Both factors (dryness and dampness) could produce changes in edaphic conditions by modifying the microenvironment occurring inside the sandfly breeding and resting sites and therefore, kill or wash away eggs, larvae and pupae. Sandfly larvae and pupae are known to be extremely susceptible to dryness as well as to excessive dampness (Chaniotis et al., 1971a). Although, there was a reduction of sandfly densities during the dry season, this did not bring any complete disappearance of sandflies indicating that breeding was continuous in well-protected sites (e.g. animal burrows), where evaporation of the soil moisture is slow. In Panama, Thatcher (1968b), noted that during the dry weather, sandfly breeding is reduced even on the forest floor (which usually retains enough moisture) but not eliminated. In British Honduras Disney (1966) noted that a heavy rainfall results in a brief but sharp fall in population density (possibly due to drowning), while, conversely, during the dry season a shower of rain led to a brief but sharp increase in population. In Panama, Chaniotis et al.(1971b) stated that the steadily decline of sandfly population density has resulted from heavy rainfall. He noted that the sandfly population was usually much lower in the dry season and reached a peak just before the wettest month of the year. Thatcher and Hertig (1966) pointed out that the sandfly population density declines gradually during the dry season.

The peak of abundance observed in April, a month after have started the rainfall may represent a dominant emergence rythms. This suggests that a preimaginal development time of four to five months, with two generations per year may well be correct for the Marigat area. Foster (1972b) observed two generations per year for sandflies present in Ethiopia. This situation can be related to all breeding sites, although some sites showed their peaks during different periods of the year.

To accurately estimate the apparent relationship between sandfly abundance and the macroclimates as well as the microclimates, the analysis of the correlation coefficient was carried out. Although a positive correlation coefficient was observed between the monthly rainfall and the mean monthly sandfly relative abundance, a significant level could not be reached. This suggested that the increase of the sandfly population was not directly seen during the month where an increase of rains occurred, but it was observed later on. Beach et al. (1983) noted that sandfly species accomplish their life span within a period ranging from 31-69 days (depending on the species). W.H.O. (1984), stated that the normal time from egg-laying to the emergence of adults ranges from 35 to 60 days. Nevertheless, the positive relationship between sandfly catch and rainfall indicated that a geometric increase in sandfly relative abundance accompanied a rise of rainfall. Haddow (1942) observed the same relationship between mosquitoes catches and rainfall in Kisumu. However, two species of sandfly vectors of leishmaniases (Lariviere et al., 1961; Minter and Wijers, 1963; Mutinga and Ngoka, 1978; Mutinga, 1986a and b), Phlebotomus martini and P. duboscqi presented a significant positive correlation coefficient once correlated with rainfall. This suggests that in the Marigat area, the high incidence of the diseases (leishmaniases) occurs during the rainy season. In Kenya, there is a close correlation between the spring rainfall, the increased population of sandflies (P. martini) and subsequent outbreak of visceral leishmaniasis (Mckinnon, 1962; Southgate, 1977; Lewis and Ward, 1987). Chaniotis et al. (1971a) noted that the seasonal sandfly density may have been related to the amount and distributional pattern of rainfall which acted by modifying the breeding conditions in the ground. In French Guyana, Le Pont (1982) reported that the dynamics of the man-biting flies (Lutzomyia umbratilis Ward and Fraiha) fluctuated in close correlation with rains. Rain was beneficial to the sandflies when it occurred in moderate amounts and was evenly distributed, but it became detrimental when it inundated the ground. Minter (1964c) stated that the pattern of rainfall distribution has more influence on the seasonal incidence and relative abundance of most sandfly species than the total amount of precipitation. He concluded that rainfall increases the length of life of adult flies and hence the reproductive turnover. The seasonal fluctuations of sandflies are closely associated with the rainfall and it would appear that a monthly rainfall above 200 to 250 mm is prejudicial to some species of sandflies (Shaw and Lainson, 1972).

5.4.1.2 Relative humidity

Due to high temperatures prevailing in the Marigat semi-arid area, low values of relative humidity were monitored. Although no significance level was found, the correlation coefficients between the sandfly catches in every investigated site and the average monthly relative humidity presented positive correlation for termite hills, human habitations and animal enclosures, whereas negative correlation coefficients were obtained for animal burrows tree hollows and open field. Killick-Kendrick (1987) reported that peridomestic sandfly species from both the Old and New Worlds are more tolerant to low humidity.

5.4.1.3 Temperatures

There was no evident correlation between ambient temperature and the total sandfly population (all investigated breeding and resting places). Quate (1964) reported similar observations while working on sandflies of the Paloich area. Although no significant correlation coefficient was observed between temperatures (of air) and the total sandfly population, its negative nature indicated that this parameter has a detrimental effect on the production of flies from their breeding sites. However, high ambient temperatures have negative effects on sandflies. Killick-Kendrick (1987) noted that the optimum temperatures in sandfly habitat will be similar to ambient temperatures in the range of 23-30oC.

Correlating both the air temperature and the sandfly population in the investigated sites, it was shown that this parameter has a positive effect on sandfly population in animal burrows and open field, while it presented a negative effect on sandflies in termite hills, tree hollows, human habitations and animal enclosures. Thus, the highly significant positive correlation coefficient was found between air temperature and sandfly relative abundance in the animal burrows.

5.4.1.4 Wind speed

Marigat semi-arid area experiences a high wind speed throughout the year. It was seen that in this area, the high wind speed occurred between 1500 and 1700 hours. At this time, sandflies were still in their resting sites and their flying activities started normally around 1800 hours. Therefore, it was observed that even during the month with strong wind, sandflies were still being caught in large numbers. This was due to the fact that the winds occurred in the area three hours before the sandflies started living their resting sites. The correlation between the wind speed and the sandfly collections in the investigated sites did not show any evident relationship. In Paloich area, Quate (1964) reported that there was no evident correlation between wind and sandfly activity.

5.4.2 Microclimatic conditions

5.4.2.1 Soil temperature

The outstanding feature for temperatures was the less variations observed in both sites during the wet and the dry periods. The temperature values were slightly higher in termite hills than in animal burrows. A range of 27 to 30oC was observed in termite hills, with a monthly average of 29oC, while in burrows, a range of 25 to 27oC was seen, with a monthly mean of 26oC. Thus, there were no marked differences between soil temperatures (3oC) in both microhabitats. The highest temperatures were observed at the end of the dry season and the beginning of the rainy period in both termite hills and animal burrows. The month of April presented a decrease in termite hill temperatures, which remained high for animal burrows. The lowest temperature value in burrows was monitored at the end of the rainy season. The decrease of the soil temperature in burrows at the end of the rainy period was probably due to the high accumulation of moisture in the investigated burrows. Temperatures in both termite hills and animal burrows therefore, do not vary greatly from that of the outside air. Longanecker and Burroughs (1952) and Mitchell (1971) noted that the mean monthly temperatures do not differ greatly inside and outside burrows. Mutinga (1972) stated that temperatures of between 24oC to 29oC were optimal for the development of intermediate stages of Phlebotomine sandflies. Foster _et al_. (1970) pointed out that the hatching time (egg to adult) of _Phlebotomus longipes_ is longer (100 days) when temperatures are low (18 to 20oC) and shorter (53 days) when temperatures are higher (28 to 30oC). Verma (1979) observed (in laboratory) that the mean incubation time for _P. martini_ eggs is 10.[illegible] days (range 8 to 13 days) at temperature of 26 to 28oC.

5.4.2.2 Soil relative humidity

The increase of relative humidity in June could be ascribed to the accumulation of moisture content in the sandfly breeding and resting places; its decrease was related to less rains which had fallen in the area. The slight decrease observed in August was due to the decrease of rainfall in the area. In general, these results (Table 27), have shown that in a semi-arid area, the percentage relative humidity in both termite hills and animal burrows has never saturated. A relative humidity of 90 to 100 percent was never recorded.

The relative humidity increase and/or decrease inside sandfly microhabitat was inversely proportional to the amount of rainfall which had fallen in the area. The percentage relative humidity values has shown that in both termite hills and animal burrows, moisture content has never been saturated. A range of 20 to 47 and 4 to 48 percent relative humidity were recorded in termite hills and animal burrows respectively. The relative humidity was found to be the microclimate variable most subject to marked changes. This is probably due to the air above the ground (ambient air temperature) which is very dry all round the year, and therefore influencing the termite hills and animal burrows to get much drier. Haas (1965) noted that in arid localities, air in burrows can be considerably drier than 95 percent. On the other hand, the ventilation of ambient air caused drying of air in termite hills and burrows (which remained unsealed) and hence reduced its soil moisture content. Haas (1965) pointed out that the air entering the burrow would be saturated at night and rarely as dry as 50 percent relative humidity during the warmest hour of the day.

Comparing the mean relative humidity of burrows and termite hills with the mean relative humidity of the atmosphere outside, it was observed that both sites presented lower values in most cases. This would lead one to expect that atmospheric relative humidity would affect both the relative humidity inside termite hills and animal burrows as well as the sandfly activity patterns.
The combination of both moderate soil temperature and soil relative humdity makes the termite hills as well as the animal burrows to harbour a large variety of small and large rodents, birds and lizards, and hence, stimulates the suitability of both habitats for continuous breeding by sandflies.

The recorded temperatures and relative humidity ranges remained well within the limits of tolerance known for a few sandfly species. Chaniotis and Anderson (1968).

and Chaniotis et al.(1971a) pointed out that sandflies were active over a wide spectrum of temperatures ranging from 12 to 28oC and of relative humidity ranging from 20 to 100 percent. They then, noted that high temperatures prevent early activation of sandflies. Meanwhile, lab-reared adult sandflies (Phlebotomus duboscqi) have been maintained at room temperature of 25oC and 80 percent relative humidity (Mutinga et al., 1987). Silverman et al.(1981) noted that longevity of adult of Ctenocephalides felis (Cat flea) was affected by conditions of temperature and relative humdity. They observed that longevity increased with increasing relative humidity and decreasing temperature and reported that cat flea has lower and upper temperature limits for development (egg to adult) ranging from 13 to 32oC, with a 50 to 92 percent relative humidity. However, Hussein and Mustafa (1987) studying the effects of different temperatures and relative humidity regimes on the reproduction development of ticks noted that Rhippicephalus simus proceed well at temperature ranging from 15 to 38oC, with 85 ± 2 percent relative humidity. Theodor (1936) stated that temperatures under 10oC or more than 40oC may be considered as definitely unfavourable for adult sandflies (Phlebotomus papatasii), although their larvae can stand lower temperatures. The larvae die at 42oC. Silverman et al.(1981) reported that temperatures above 35oC were lethal to the immature stages of the cat flea (Ctenocephalides felis) and low relative humidity was adverse to all stages except the pupa, suggesting this stage is most likely to survival extended periods in cool dry climates. Quate (1964), pointed out that sandflies do not become numerous until about March after the hot, dry weather has begun and the average maximum temperature exceeds 35oC. He then, noted that sandflies diminish or disappear as rains commence. Owing to Quate's observations, the Paloich situation is quitely different from the Marigat ones. During the present observations, days with hot morning and evening did not yield many sandflies. In Jerusalem, Theodor (1936) noted that in nature, at a temperature of 30oC, the whole cycle of developement from egg to egg takes about 36 days. He stated that larvae of sandflies are adapted to life in moist soil and are extremely sensitive to dessication. Rutledge and Mosser (1972), pointed out that in the rain forest soil of Panama, the average moisture content was 48 percent during the rainy season. Studying the life cycle of *Phlebotomus pedifer* in the laboratory, Mutinga (1972) pointed out that temperatures ranging from 24 to 27oC and relative humidity ranging from 52 to 75 percent are required. He noted also that in the caves of Mount Elgon, temperatures ranging from 18 to 19oC and relative humidity ranging from 72 to 92 percent were necessary for the development of *P. pedifer*. However, both temperatures and relative humidity inside sandfly breeding and resting habitats are more function or dependent on seasonal climatic characteristics than minor weather changes

5.4.2.3 Relationships between sandflies and the soil microclimates

Correlating the soil temperatures and soil relative humidity with the total sandfly population as prevailing in termite hills and animal burrows, positive correlation coefficients were noted. Although, the student's t test did not reveal any significant level, the observed positive correlation coefficients suggest that both temperature and relative humidity have positive effects on sandflies inside their microhabitats.

From our point of view, the data gathered indicate the remarkably flexible ability of Sergentomyia and Phlebotomus species to breed extensively in the diverse situations that occur in the Marigat semi-arid area, which may have been related to progressively increasing temperatures and low relative humidity in both termite hills and animal burrows. Theodor (1936), noted that the climatic conditions in sandfly breeding and resting sites during the day, will even in hot climates very rarely attain values unfavourable to sandflies, and the lower temperature and increased humidity at night provide tolerable conditions for sandflies even in the hottest and driest climates. Bettini and Melis (1988) reported that moisture and temperature are basic parameters which regulate larval development

CHAPTER SIX

SOIL CHARACTERISTICS AS FOUND INSIDE SANDFLY BREEDING AND RESTING SITES

6.1 Introduction

Studies on soil features occurring inside sandfly breeding and resting sites are scanty (Bettini and Melis, 1988) although soil chemical and physical characteristics could probably play major role in regulating sandfly population density. Hanson (1961) noted that sandflies have received much attention because of their transmission of *Leishmania* and other disease organisms, surprisingly little is known of their breeding places. However, W.H.O. (1984), emphasized the study of soil structure as a tool in understanding the epidemiology of leishmaniasis. In fact, immature stages of sandflies live in soils and usually are subject to the presence or absence of soil nutrients, soil moisture, soil reaction, organic compounds as well as to the soil texture. Schlein *et al.*, (1982) in his studies on the cutaneous leishmaniasis in the Jordan Valley, noted that the differences in sandfly populations might have resulted from larval breeding conditions, mainly the soil qualities occurring inside the breeding sites. In India, Rajagopal *et al.* (1982) reported that information on physical and chemical properties of termite mound soil and surrounding soils is meagre. Soil characteristics as found inside sandfly animal burrows, termite hills and under-vegetation in relation to the sandfly production from both sites are reported. The animal burrows and the termite hills constitute the most important sandfly breeding and resting places in the Marigat area and therefore, formed the basis of the present investigation.

6.2 Materials and Methods

6.2.1 Collections of soil samples

Soil samples were collected from termite hills, animal burrows and under-vegetation (comprising tree holes/hollows and the base of trees) at a depth ranging between 0 and 10 cm. This depth has been considered suitable for sandfly larvae as it contains the organic matters and other nutritive materials (Hanson, 1961; Perfil'ev,1966; Thatcher, 1968b; Rutledge and Mosser, 1972; Mutinga, 1972). Thirty soil samples with an average of ten samples per each type of site were examined, tested and analysed during the study period. Every sample was weighed, sealed in a polythene sheet and preserved in a dark place before being sent to the laboratory for examination and tests.

6.2.2 Analyses of soil samples

For the chemical analyses, the following determinations were carried out: soil reactions (pH), organic carbon (C), available phosphorus (P), total ions such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). The physical analyses comprised moisture content and texture (sand, silt and clay). Soil samples analyses were carried out by the National Agriculture Laboratory (NAL) of the Kenya Ministry of Agriculture.

6.3 Results

6.3.1 Chemical characteristics of the soil

Soil reaction (pH), organic carbon, calcium, magnesium, manganese, potassium, sodium and the phosphorus constituted the chemical characteristics examined and analysed in both investigated sites (Tables 23 and 24). Sodium and manganese (for the dry season soil samples) and calcium (for the wet season soil samples) showed highly significant differences between sites. The variance ratios (F) for the highly significant parameters were 9.27 (for sodium), 17.48 (for manganese) and 9.67 (for calcium). The 5 percent point corresponding to 2 and 12 degrees of freedom in that order is 3.89, while the 1 percent point is 6.93

Table 23. Analysis of variance of the transformed data of the chemical characteristics of soil samples collected from sandfly breeding and resting sites. (Marigat area, February 1986).

Source of variation	df	pH		Organic carbon		Calcium		Magnesium		Manganese		Potassium		Sodium		Phosphorus	
		MS $x10^{-3}$	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS $x10^{-3}$	F
Between sites	2	1.60	5.23*	16.45	0.91	10.63	3.34	4.12	2.45	3.17	17.48**	27.47	3.65	1.72	9.27**	4.20	1.35
Within sites	12	0.31		18.07		3.18		1.68		0.18		7.52		0.19		3.13	
LSD on transformed data (at 5%level)		0.78								0.58				0.58			
Untransformed means																	
Termite hill		6.90 a		1.53		12.72		4.14		0.87 a		1.19		0.77 a		240.80	
Animal burrow		7.71 a		0.75		14.64		4.91		0.99 a		1.90		0.90 a		261.00	
Vegetation site		7.20 a		3.26		11.36		3.66		0.54 b		3.98		0.56 b		277.60	

* Significant at 5 percent level
** Significant at 1 percent level
Means with same letter (for significant F) do not differ significantly at 5%level.
Test carried out on transformed means.
MS= mean square, F= variance-ratio.

Table 24. Analysis of variance of the transformed data of the chemical characteristics of soil samples collected from the sandly breeding and resting sites. (Marigat area, June 1986)

Source of variation	df	Soil reaction(pH)		Organic carbon		Calcium		Magnesium		Manganese		Potassium		Sodium		Phosphorus	
		MS $\times 10^{-3}$	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS $\times 10^{-3}$	F
Between sites	2	2.25	1.69	21.10	1.60	43.95	9.67**	1.36	2.61	0.07	0.19	10.87	1.94	0.85	1.92	0.20	1
Within sites	12	1.33		13.21		4.55		0.52		0.38		5.60		0.44		0.54	
LSD on transformed data (at 5% level)						2.93											
Untransformed means																	
Termite hill		6.44		0.99		16.56 a		2.78		0.56		1.16		0.70		24.80	
Animal burrow		7.16		0.42		22.00 b		3.50		0.51		1.77		1.00		24.50	
Vegetation site		7.08		2.63		24.72 b		3.20		0.47		2.88		0.90		37.80	

** Significant at 1 percent level
Means with same letter(for significant F) do not differ significantly at 5%.
Test carried out on transformed means.
MS= mean square, F= variance-ratio.

The soil reaction (pH), presented a significant difference between sites, with a variance ratio (F) of 5.23 (Table 23). The F (2,10) degrees of freedom at 5 percent level gave a value of 4.10 (lesser than the calculated), while the 1 percent level gave a value of 7.56 (higher than the ones calculated). Thus, the soil reaction (pH) can be described as significant between sites at 5 percent level (during the dry season). Testing its difference between pairs of sites using the Least Significant Difference (LSD), no significant difference was observed. For this reason, the soil reaction of samples collected from burrows, termite hills and under-vegetation did not differ significantly at the 5 percent level (Table 23).

From the analyses of the two highly significant parameters between sites, the following observations were made (Tables 23 and 24):

1. <u>SODIUM</u> (Na).

The treatment-means between termite hill and vegetation habitats differed by 0.76, a value greater than the least significant difference (LSD5%= 0.58). Thus, both termite hills and vegetation sites differed significantly at the 5% level of probability in sodium content. The mean-difference observed between animal burrows and the vegetation sites was 1.15, greater than 0.58. For this reason the animal burrows and the vegetation sites differed significantly at the 5% level. Testing the animal burrows and termite hills, a mean difference value of 0.39 lesser than the LSD at 5 per cent level corresponding to t(0.05, 12)= 0.58 was calculated . This showed that both sites did not differ significantly at the 5% level.

2. <u>MANGANESE</u> (Mn).

The mean difference between animal burrows and termite hills gave a value of less than the LSD at 5% level (0.38<0.58). For this reason, animal burrow and termite hill did not differ significantly at the 5% level.
The animal burrows and the vegetation sites presented a mean-difference value (1.53) greater than the LSD, confirming that both sites differed significantly at the 5% level of probability. The termite hills and the vegetation habitats differed by 1.15, a value greater than the LSD (0.58). It was concluded that both termite hills and vegetation sites differed significantly at 5% level.

3. <u>SOIL REACTION</u> (pH).

Testing the significance of the soil reaction (pH) between sites, using the least significant difference (LSD), a no significant difference was observed between mean-sites of all treatments and their respective LSDs. For this reason, the soil reaction (pH) as analysed from soil samples collected from burrows, termite hills and under-vegetation sites did not differ significantly (between themselves) at the 5 percent level

4. CALCIUM (Ca).

Differences between treatment-means gave 4.02, 5.82 and 1.80 for animal burrow and termite hill, vegetation site and termite hill and vegetation site and animal burrow respectively. The mean difference between animal burrows and termite hills gave a value greater than the LSD at the 5% level for t(0.05, 12df), LSD= 2.93. Thus, 4.02 was greater than 2.93, concluding that animal burrow and termite hill differed significantly at the 5% level. The vegetation site and the termite hill mean-sites differed by 5.82, a greater value than the LSD at 5% level. This leads to the conclusion that the under-vegetation and termite hill differed significantly at 5% level. The under-vegetation and the animal burrow sites however, gave their mean difference value lesser than the LSD (1.80 < 2.93). For this reason, both sites did not significantly differ. The other parameters such as organic carbon, magnesium, potassium and phosphorus had shown their respective calculated F-ratios being lesser than the tabulated at the 5 percent level of probability, indicating that their means of pairs of treatments being not significantly different.

6.3.2 Physical characteristics of the soil

The analysis of variance of different soil physical parameters was carried out and differences between sites were estimated (Table 25) .

Analysing all tested soil physical parameters, it was found that the clay showed highly significant difference between sites since its variance ratio was 7.41. F-distribution at 5% level for 2 and 12 degrees of freedom was 3.89. For the sand characteristics, a significant difference between sites was observed at 5% level only. The F-distribution at 1 percent level gave a higher value (6.93) than the ones calculated (3.93). The silt and the moisture content, did not present any significant difference between sites.

Analysing the mean-differences between treatments , for sand and clay, the Least Significant Difference (LSD) mainly was used. Thus, the following observations were pointed out:

1. CLAY.

For clay variable the mean difference between termite hills and animal burrows differed by 11.23, a greater value than the LSD (7.40) at 5% level for t(0.05,12df). This value makes both sites to differ at 5% level of probability. Comparing both termite hills and vegetation sites, a value greater than the LSD was observed, making both sites to differ.

Table 25. Analysis of variance of the transformed data of the physical characteristics of soil samples collected from sandfly breeding and resting sites. (Marigat area, June 1986).

Source of variation	df	Moisture content		Sand		Silt		Clay	
		MS	F	MS	F	MS	F	MS	F
Between sites	2	264.16	2.26	423.29	3.93*	58.98	0.94	214.22	7.41**
Within sites	12	116.92		107.64		62.98		28.90	
LSD on transformed data (at 5% level)				14.29				7.40	
Untransformed means									
Termite hill		17.84		20.80 b		44.80		34.40 a	
Animal burrow		13.27		47.00 a		34.80		18.20 b	
Vegetation site		34.92		46.20 a		36.20		17.60 b	

* significant at 5 percent level

** significant at 1 percent level

Means with same letter (for significant F) do not differ significantly at 5%.

Test carried out on transformed means.

2. SAND.

The mean differences between soil samples collected from sandfly breeding and resting sites gave 16.16, 0.44 and 15.72 for animal burrow and termite hills, animal burrows and vegetation sites and vegetation site and termite hills respectively. Comparing the mean-values as shown in every set of sites, the following observations were made:

1. The animal burrows and termite hills gave a difference mean-sites of 16.16. This value compared to the LSD (14.29) at 5% level was greater (16.16>14.29), for this reason, both sites differed significantly.

2. The animal burrows and vegetation sites did not present any difference between their mean-sites compared to the LSD at 5%. The mean-difference of 0.44 observed between animal burrows and vegetation sites was lesser than the LSD at 5% (LSD at 5% =14.29). Thus, both sites did not show any significant difference for the sand parameter.

3. The mean difference between vegetation site and termite hills differed by 15.72. This value was greater than the LSD at 5% (14.29) and therefore, both sites were significantly different at 5% level of probability.

6.3.3 Relationships between sandfly groups and the soil characteristics

Correlation carried out between both chemical and physical characterisitics and the sandfly relative abundance

as monitored from their breeding and resting sites during the period the soil samples were collected presented the following observations (Tables 26 and 27):
In termite hills, it was found that the chemical features such as the soil reaction and the scidum presented highly significant negative correlation coefficient at 1% level (r= -0.915 for the pH and r= -0.932 for Na). Except for the phosphorus, all analysed chemical features showed negative correlation coefficients and therefore, were limiting factors for the sandfly production in termite hills. Although some parameters (e.g. Ca, Mg, Mn, K and the organic carbon) presented negative correlation coefficients they cic not show any significant level of correlation.
Correlation coefficients between the sandfly relative abundance in termite hills and the physical characteristics showed that the moisture content presented a highly significant positive correlation at 1% level (r= +0.911). The silt variable gave a positive correlation coefficient (r= +0.287) which did not reach a significant level. A negative correlation coefficient was calculated for the sand parameter (r= -0.623). Moisture content therefore, can be taken as determining factor for the sandfly distribution in termite hills.

The correlation coefficient between the sandfly relative abundance in animal burrows and the values of tested soil parameters in the same habitats showed that the soil reaction, the organic carbon, the calcium and the potassium presented positive correlation coefficients corresponding to r= 0.060, 0.463, 0.171 and 0.468 respectively. The other parameters such as magnesium, manganese and the available phosphorus presented negative correlation coefficients. However, the correlation coefficient between the sodium and the sandfly relative abundance showed that a highly negative significant correlation coefficient at 1% level (r= -0.951). This parameter can be ascribed as limiting factor, having a detrimental effect on sandfly survival in burrows.

Analysing the correlation between both physical characteristics and the sandfly relative abundance in animal burrows, it was observed that parameters such as moisture content, sand and silt gave highly significant coefficients at 1% level.

1. The moisture content presented a highly negative correlation coefficient (r= -0.993),
2. Inversely, the soil texture showed highly significant positive correlation coefficients for sand (r= 0.986)and silt (r= 0.972). The moisture content seemed to have a detrimental effect, while sand, silt and clay have a positive effect on sandflies as produced from animal burrows.

As in the previous two sites, sandflies collected from the vegetation sites were correlated with the soil chemical and physical parameters (Tables 26 and 27). Correlation between sandflies and the organic carbon, soil reaction, calcium and potassium (as analysed during the period sandflies were collected) presented positive correlation coefficients, with r= 0.090, 0.196, 0.297 and 0.689 respectively. The parameters such as magnesium, manganese, sodium and phosphorus presented negative correlation coefficients. Nevertheless. it was observed that among all tested parameters, only sodium presented a highly significant negative correlation coefficient (r=-0.965) at 1% level.

Although there was no significant correlation between organic carbon and sandfly relative abundance, the positive value showed that any increase of the organic matter has an influence on the increase of sandfly population. The correlation between sandfly relative abundance in the under-vegetation sites and the physical parameters gave positive correlation coefficients for both moisture content, silt and clay. The clay factor showed a highly significant positive correlation coefficient at 1% level (r= 0.996), while a negative correlation coefficient was obtained between the sandfly relative abundance and the sand parameter.

Table 26. Correlation coefficient of sandfly density with the chemical characteristics of soil samples prevailing in sandfly breeding and resting sites. (Marigat area, June 1986).

Site	Soil react. (pH)	Organic carbon (%)	Total ions (me/100)					p. (ppm)
			Ca	Mg	Mn	K	Na	
	Correlation coefficient with sandfly density.							
TH	-0.915**	-0.491	-0.744	-0.872*	-0.719	-0.050	-0.932**	0.717
AB	0.060	0.463	0.171	-0.808	-0.865	0.468	-0.951**	-0.624
VEG.	0.196	0.090	0.297	-0.060	-0.871	0.689	-0.965**	-0.721

Table. 27 Correlation coefficient of sandfly density with the physical characterisitics of soil samples as collected from sandfly breeding sites. (Marigat area, June 1986).

Collection site	Moisture content(%)	Texture (%)		
		Sand	Silt	clay
	(Correlation coefficient with sandfly density).			
Termite hill	0.911*	-0.623	0.287	-
Animal burrow	-0.993**	0.986**	0.972**	0.955
Vegetation	0.036	-0.201	0.393	0.996**

** significant at 1 percent level, * significant at 5 percent level.

TH= termite hill, AB= animal burrow, VEG.= vegetation site, df= 3 (for n=5).

6.4 Discussion

6.4.1 Chemical characteristics of the soil

Analyses of soil parameters capable of influencing the sandfly population had demonstrated that the sandfly breeding and resting sites cannot be considered as homogeneous sites as their chemical and physical characteristics presented significant differences between sites. The sandfly breeding and resting places were different from one to the other by its chemical and/or its physical characteristics during both dry and wet seasons.

Differences in sandfly breeding and resting sites soil composition during both dry and wet seasons can therefore, be ascribed to the environmental effects. During the dry season, sodium, manganese and soil reaction presented high significant difference between sites than in the wet period. Also, due to food availability during the wet season, mainly composed of wild plants and some cultivated cereals (sorghum and maize) the number of rodents and other herbivorous got increased in the area. These small and large mammals ingest plant tissue and the excreted end products of digestion of the structural polysaccharides are mixed with soil, and therefore increasing its calcium content. The calcium is deposited into the soil by percolating waters. In general, calcium content was observed higher in animal burrow than in other sandfly collection sites. This increase might be derived from ingested plant tissue by herbivorous living in these habitats. The end products of ingested plants are rejected and deposited on the soil inside burrows, and therefore, increasing its contents in calcium.

During the dry season (February, 1986), few parameters such as sodium, manganese and soil reaction (pH) differed significantly within sites. However, comparing their mean differences between sites using the LSD at 5% level of probability (Clarke, 1980; Bailey, 1981), it was shown that:

For sodium, there was no significant difference between its observed values in termite hill with the ones in animal burrow; while a significant difference was observed between the first two sites and the vegetation sites. For manganese, the same observations as the ones of sodium could be made: termite hill and animal burrow did not differ significantly, whereas vegetation site presented a mean-value which differed significanlty with the termite hills and animal burrows.

Soil reaction (pH): although it was shown by the analysis of variance (F) that there was a significant difference between sites, the comparison of their treatment-means did not give any significant difference. For this reason differences observed between soil samples collected from termite hills, animal burrows and the vegetation sites were small and therefore, cannot imply any significant difference between investigated sites.

Analysis of variance carried out on soil samples collected during the wet season (June 86) gave calcium as the only highly significant among the examined and tested soil parameters. Comparing the mean differences of calcium using the LSD at 5 percent level, the following observations were made:

Comparing the mean differences as calculated between termite hill and animal burrow, there was a significant difference. For this reason, both sites differed significantly at 5% level. Mean difference between termite hill and vegetation site presented a significant difference and hence these sites differed significantly at 5% level. The comparison carried out between animal burrow and under-vegetation site mean differences, did not give any difference between both sites and hence, no significant difference can be described for burrow and termite hill sandfly breeding and resting sites.

Comparing the calcium content in both sites, it was found that this parameter presented higher value in animal burrows than in termite hills; whereas between animal burrows and under the vegetation sites non significant difference could be observed. The increase of calcium in animal burrows was due to the excreted end products of ingested plant tissue taken from wild plants and cultivated cereals which are rejected or deposited on the soil of burrow by rodents or other herbivorous. The increase of calcium on the forest floor can be attributed to plant leaf deposits. The organic carbon observed (ranged from 0.75 to 3.26 percent during the dry season and 0.42 to 2.63 percent during the wet period) did not show any difference between both sites. These values were lower than the ones monitored in sardinian soils (Italy), which ranged from 1.4 to 7.5 % (Bettini and Melis, 1988) and much lower than the ones observed in the panamanian rain forest (24 - 84%) (Rutledge and Mosser, 1972). In Saudi Arabia, Buttiker and Lewis (1979) reported that the sandy loam had extremely low organic content (0.5%). Other parameters, such as sodium and manganese did not show any differences between animal burrows and termite hills, while a significant difference could be seen between the under-vegetation and the first two sites. Although, considerable alkaline and neutral reaction (6.9 - 7.7) was monitored in both sites, the comparison of the treatment-means did not yield any significant difference. In East Africa, Hesse (1955) reported that the reactions of the mound soils range from pH 5 to 10. Rutledge and Mosser (1972), reported close average pH values ranging 6.8 to 7.9 for soil samples taken from sandfly breeding sites in Panama.

6.4.2 Physical characteristics of the soil

Generally, soils in the Marigat area are loose, light silt to sandy loam. Shortt et al.(1930) noted that loose soils admit the burrowing in of the larvae in the search for food. Comparison of physical features showed that clay and sand presented significant differences between sites, whereas the silt and the moisture content did not give any differences between investigated sites. Both the clay and the sand gave significant differences once their treatment-means were compared between termite hills, animal burrows and under-vegetation sites respectively (Table 25). Hesse (1955) noted that the percentage of clay and sand in different East african mounds was not of the same order.

Analysis of soil samples collected in the Marigat area has shown that sandfly animal burrow, termite hill and under-vegetation sites cannot be considered as homogeneous sites as their soil characteristics presented significant differences at both 5 and 1 percent levels. Both sites can therefore be taken as different from one to the other.

6.4.3 Relationships between sandflies and the soil characteristics

The sandfly abundance is related to a given soil, rich in certain elements, which would be necessary for the growth and the survival of the immature stages. In order to determine the soil features which may play a major role in sandfly abundance the correlation between sandflies as monitored from both sites and the soil characteristics (chemical and physical) as prevailing in the same places was applied.

In termite hills, the correlation between both the soil reaction and the sodium and the sandfly relative abundance presented highly significant negative correlation coefficients, whereas the moisture content gave a highly significant positive correlation coefficient. In this site, soils were found to be poor in organic substances.

In animal burrows, the sodium showed a highly negative correlation coefficient and conversely, the high population of sandflies could be related to the positive effect of organic carbon brought in by a high accumulation of nutrients. Bettini and Melis (1988) reported that in Sardinia (Italy), the high organic content of some soil samples may be due to differences in distribution of sheep urine and faeces. The organic content of the soils is important for larval development. Hanson (1961) pointed out that larvae of sandflies are numerous in the top 5 inches of soil rich in organic matter. In burrows, the moisture content presented a highly negative correlation coefficient as it affected the immature stages and the adult sandflies. The sand, the silt and the clay gave highly significant positive correlation coefficients.

In the under-vegetation sites, only the sodium presented a highly significant negative correlation coefficient. The other parameters such as the organic carbon, the calcium and the potassium gave positive correlation coefficients. Both the moisture content, the silt and the clay showed positive correlation coefficients. Hanson (1961) and Thatcher (1968b) noted that soils of the forest floor often contain considerable organic matter, caused by fallen leaves, insect fragments and mammal faeces, which make the forest to be an ideal habitat for the immature stages of phlebotomine sandflies. In Panama, Hanson (1961) observed sandfly larvae feeding on decaying leaves and litter on the ground. Mutinga (1972) reported that areas rich in decaying organic matter harbour large numbers of sandfly immature stages (eggs, larvae and pupae). He noted also, that sites soaked with urine of domesticated animals (cattle) are likely to be good breeding places for sandflies. Shortt _et al_.(1930) noted that the presence in the soil of organic debris is "a sine qua non" for the continuance of sandfly breeding.

Schlein _et al_., (1982) reported that sandfly breeding sites with low or high salinity value presented low population density of flies, indicating that the sodium is limiting factor for the sandfly production. In the Marigat

area, the organic carbon and the calcium content were found to have positive effect on sandflies as positive correlation coefficients were calculated.
The physical parameters (e.g. moisture content, silt and clay) have positive effects on the distribution of sandflies in the vegetation site.

Separate correlation for both sandfly groups (Phlebotomus and Sergentomyia) with the soil parameters (Tables 28 and 29), showed the following observations:
1. In the termite hills, the soil reaction (pH), the magnesium, and the sodium presented highly significant negative correlation coefficients at 1% level .
2. In the animal burrows as well as in the vegetation sites, only the sodium characteristic presented a highly significant negative correlation coefficient at 1% level.
The high increase of Phlebotomus species in animal burrows than in other site was probably due to the positive effect of organic carbon, calcium and soil reaction to the sandfly abundance. Positive correlation coefficients between Phlebotomus species as produced from burrows and the organic carbon, calcium and soil reaction were observed (Table 29). Conversely, a high increase of Sergentomyia species in termite hills than in animal burrows was probably due to the available phosphorous. The correlation coefficient between species of this group and the phosphorus parameter presented a positive correlation coefficient (r=0.712).

Table 28. Correlation coefficent between Sergentomyia species and the chemical characteristics of the soil samples as prevailing in sandfly breeding sites. (Marigat area, June 1986).

Site	Soil react. (pH)	Organic carbon (%)	Total ions (me/100) Ca	Mg	Mn	K	Na	P. (ppm)
			Correlation coefficent with sandfly density.					
TH	-0.943*	-0.540	-0.762	-0.907*	-0.763	-0.087	-0.953*	0.712
AB	0.073	0.463	0.171	-0.808	-0.865	0.468	-0.951*	-0.624
VEG.	0.196	0.090	0.297	-0.254	-0.871	0.689	-0.965**	-0.721

Table. 29 Correlation coefficient between the Phlebotomus species and the chemical characteristics as prevailing in sandfly breeding sites. (Marigat area, June 1986).

Site	Soil react. (pH)	Organic carbon	Total ions (me/100) Ca	Mg	Mn	K	Na	P.
			Correlation coefficient with sandfly density.					
TH	-0.943*	-0.540	-0.762	-0.907*	-0.763	-0.087	-0.953*	0.712
AB	0.073	0.463	0.171	-0.808	-0.865	-0.468	-0.951*	-0.624
VEG.	0.196	0.090	0.297	-0.060	-0.871	0.689	-0.965**	-0.721

TH= termite hill, AB= animal burrow, VEG.= vegetation site

* significant at 5 percent level.** significant at 1 percent level.

CHAPTER SEVEN

SANDFLY HOST PREFERENCES

7.1 Introduction

The Phlebotomine sandflies have been implicated as vectors of leishmaniasis, bartonellosis, and a number of diseases, yet little is known of their natural feeding habits (Tesh et al. 1971). The fact that sandfly species feed on man, reptiles, birds and many vertebrates (e.g. rodents and other small mammals) and its incrimination in the transmission of the diseases to man and animals has increased the interest of investigating their feeding behaviour. Studies on the biting habits of different sandfly species has shown that some species are likely to be efficient vectors of the disease to man and animals, other species do not have any incidence to humans because of their disinclination to bite man. A number of sandfly species had been reported to be less specific and can feed on various hosts, other species are found to be well specialized and depend on particular hosts. Due to this specialization, the first group of sandfly species seem to be widely distributed and are present in many types of habitats. They occur in large numbers in the area. Species of Sergentomyia group fall in this category. The second group seem to be well adapted to feed on a particular host and are few in numbers. They prefer to rest in particular sites where their hosts can be found. Rodents constitute their main hosts. Species of Phlebotomus group belong to this category. In Kenya as well as in many other countries, investigations on sandfly feeding habits were carried out by various workers (Disney, 1968; Minter, 1964b; Mutinga, 1980; Mutinga *et al.*, 1986b; Shaw and Lainson, 1968; Tesh *et al.*, 1971 and 1972).

In an effort to evaluate the importance of the sandfly feeding habits in the Marigat area; blood meal collections taken from wild sandflies were undertaken, after the identification, the host preferences for each group of sandflies as well as for the known local sandflies were revealed.

7.2 Materials and Methods

Fed female sandfies recovered from animal burrows, termite hills and tree holes/hollows (Table 30), were separated from the unfed ones for the blood meal collections. The engorged posterior midguts were then transferred to filter papers. The head and the rest of the body were used for the identification of the sandfly specimens. Collected blood meals were sealed in polythene bags and sent to Robert Von Ostergat-Institut (Institut fur Veterinarmedizin) in Berlin (Germany) for the

Table 30. Collection of fed sandflies from their breeding and resting sites. Perkerra Irrigation Scheme, Marigat area, 1987.

Sandfly species	Animal burrow	Termite hill	Tree hollow	Total
P. martini	10	-	-	10
P. duboscqi	9	-	-	9
S. bedfordi	-	6	35	41
S. antennatus	4	4	1	9
S. ingrami	10	38	6	54
S. africanus	2	4	-	6
S. schwetzi	-	32	-	32
S. affinis	-	1	-	1
Total	35	85	42	162

seroprecipitation analysis. The fan-suction traps, the modified CDC light traps and the mouth-aspirator traps or sucking tubes were used to collect fed sandflies. In order to obtain freshly engorged sandflies, traps were set up for the overnight and collections of caught sandflies were made in the earlier next morning.

7.3 Results

162 bloodmeal samples were collected from the common sandflies present in the area. Among them 143 specimens were collected from six sandfly species belonging to the Sergentomyia group and 19 samples were obtained from 2 species of the Phlebotomus group. It was found that the bloodmeals on screening reacted against three classes of antiserum. These were mammals, aves and reptiles.

7.3.1 The Sergentomyia species

A total of 143 bloodmeals taken from fed Sergentomyia species were tested and examined for feeding preferences. Analysing the results as shown in Table 31, the following observations were made:

1. Sergentomyia ingrami

The analysis of bloodmeal smears taken from S. ingrami showed that this species has a much wider range of

Table 31. Sandfly host preference as identified by bloodmeal analysis (Perkerra Irrigation Scheme, Marigat area, 1987).

Sandfly species	Host preference										
	1	2	3	4	5	6	7	3/7	4/2	n.i.	total
P.martini	0	1	0	2	0	0	0	0	0	7	10
P.duboscqi	0	0	1	0	0	0	0	0	0	8	9
S.antennatus	0	2	0	0	0	0	0	0	0	7	9
S.bedfordi	0	0	0	2	1	0	1	1	0	36	41
S.ingrami	1	2	1	17	2	9	0	0	0	22	54
S.africanus	0	0	0	0	0	0	0	0	0	6	6
S.affinis	0	0	0	0	0	0	0	0	0	1	1
S.schwetzi	0	0	0	15	0	7	0	0	1	9	32
Total	1	5	2	36	3	16	1	1	1	96	162

1= man
2= ruminant
3= rodent
4= bird
5= hippopotamus
6= monitor lizard
7= canidae
3/7= rodent/canidae
4/2= bird/ruminant
n.i.= not identified

natural hosts, with its high preference on birds and monitor lizards. The rate of feeding showed that this species feeds main'y on birds (53.13 %), monitor lizards (28.13%), ruminants (6.25%), hippopotamus (6.25%), rodents (3.13%) and man (3.13%). These observations tally with the presence of S. ingrami in termite hills, where both monitor lizard and birds prevail.

2. S. bedfordi

A number of bloodmeal samples were taken from fed S.bedfordi collected from tree hollows and termite hills. Analysing the results of this species host preferences, it was shown that it mainly feeds on birds (40%). Family Canidae (only dogs are present in the area) and hippopotamus presented a same rate of feeding (20%). A mixture of blood from rodent and Canidae was observed and represented 20% of the total hosts. The large numbers of this species in tree hollows can be related to its feeding habits. Tree hollows as well as tree canopies harbour a large variety of birds on which this species frequently feed.

3. S. schwetzi

Analysis of bloodmeals collected from fed S. schwetzi showed that, this species feeds on birds (65.22%) and monitor lizards (30.43%). A mixture of bird/ruminant bloodmeal, representing 4.34% was identified. The high percentage of bloodmeal from birds determined the main preference of wild sandfly (S. schwetzi) to feed on birds and its association with trees and termite hills.

4. S. antennatus

Despite its high density in the area, and its presence in various habitats, S. antennatus did not seem to have a wide range of hosts. Its only identified host during the observations was a ruminant. For this reason, its collections in large numbers from animal enclosures (cattle) was justified.

7.3.2 The Phlebotomus species

Due to lack of enough fed sandfly species of this group, only few bloodmeal samples were sent for identification. Phlebotomus martini and P. duboscqi represented the collected flies of this group. Analysing the results as indicated in Table 31, it was observed that:

1. In the Marigat area, P. martini showed its preference on birds (66.66%) and ruminants (33.33%). However, the association of P. martini with burrows and termite hills is clearly due to the presence of birds in both sites.
2. P. duboscqi seemed to be an exclusive rodent-feeder (100%). The close association of P. duboscqi with burrows can be attributed to the presence of rodents on which this species feeds.

The overall results (Table 32) show that:

1. Species of the Sergentomyia group feed preferentially on birds (54.83%) and reptiles (25.80%) and less frequently on dogs (Canidae)(1.62%). The feeding rates of 6.45 and 4.83 percent were observed for ruminant and hippopotamus respectively. Rodent/dog and bird/ruminant bloodmeal mixtures were identified. 1.62 percent of Sergentomyia species were found feeding on man. In Sergentomyia group, a crossing over to many other hosts can be expected.

2. The available information on the feeding preferences of Phlebotomus species showed that some species of this group feed exclusively on a given host; while others can diversify. Thus, P. duboscqi was found to feed on rodents and P. martini can feed on birds as well as on many other mammals.

Some species of sandflies seemed to be well specialized, depended on particular hosts and were therefore, more vulnerable than less specific species which were generally widely distributed, occurred in large numbers and fed on various hosts. Analysing the source of sandfly bloodmeals collected from various sites the following deductions were made (Table 33):

1. The large numbers of sandflies resting in termite hill had fed on bloodmeals taken from various hosts. The overwhelming majority of these flies had the blood of birds (31 over 55 specimens) and monitor lizards (16/55

Table 32. Percentages of identified hosts for both <u>Sergentomyia</u> and <u>Phlebotomus</u> groups. Marigat area, 1987.

Sandfly group	Host preference								
	1	2	3	4	5	6	7	3/7	4/2
<u>Sergentomyia</u> (N=62)	1.62 (1)	6.45 (4)	1.62 (1)	54.83 (34)	4.83 (3)	25.80 (16)	1.62 (1)	1.62 (1)	1.62 (1)
<u>Phlebotomus</u> (N=4)	0 (0)	25.00 (1)	25.00 (1)	50.00 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total identified(positive) (N=66)	1.52 (1)	7.57 (5)	3.03 (2)	54.54 (36)	4.54 (3)	24.24 (16)	1.52 (1)	1.52 (1)	1.52 (1)

in brackets are number of positive bloodmeal.

1= man
2= ruminant
3= rodent
4= bird
5= hippopotamus
6= monitor lizard
7= canidae
3/7= rodent/canidae
4/2= bird/ruminant
n.i.= not identified.

Table 33. Source of bloodmeals of phlebotomine sandflies.
Marigat area, 1987.

Source of bloodmeals	Number and percentage of bloodmeals				
	Site of collection			All sites	
	AB	TH	th	N	%
Man	-	1	-	1	1.51
Ruminant	2	3	-	5	7.58
Rodent	1	1	-	2	3.03
Bird	4	31	1	36	54.55
Hippopotamus	1	2	-	3	4.55
Monitor lizard	-	16	-	16	24.24
Canidae	-	-	1	1	1.51
Rodent/Canidae	-	-	1	1	1.51
Bird/Ruminant	-	1	-	1	1.51
Total	8	55	3	66	

AB= Animal burrow
TH= Termite hill
th= Tree hollow

N= number of identified bloodmeals
%= percentage of identified bloodmeals.

specimens).

2. In animal burrows, most of sandflies had fed on bloodmeal taken from birds (4/8 specimens) and ruminants (2/8). The blooda of rodent formed the lowest rate (1/8).

3. Resting sandflies in tree hollows had fed on the blood of birds and dogs.

Generally, it has been observed that 54.55 percent of sandflies had fed on birds, 24.24 percent on monitor lizards, 7.58 percent on ruminants, 4.35 percent on hippopotamus, 3.03 percent on rodents and 1.52 percent on dogs (Canidae). Among the examined bloodmeals, 1.51 percent derived from man.

7.4 Discussion

To study the feeding behaviour of the common sandflies in relation to animals, birds and reptiles prevailing in the Marigat kala-azar area, fed sandflies were collected from their breeding and resting places (Table 30). Thus, animal burrows, termite hills and tree hollows were investigated for sandflies. Although the present work on fed sandflies did not cover all types of sandfly breeding and resting sites, the available data indicated the feeding preference and the origins of the bloodmeals of both Sergentomyia and Phlebotomus species (Table 31). As the present collections of sandflies were not exhaustive, it was not possible to determine the host preference index (HPI); this requires a large number of fed sandflies of different species.

7.4.1 The Sergentomyia species

The study on feeding behaviour of the common sandflies was undertaken in an attempt to find out the natural feeding habitat, the range of hosts and the host preferences among species of sandflies present in the Marigat area. Thus, the Sergentomyia ingrami appeared to have much wider range of natural hosts, with high preference on birds and reptiles (monitor lizards). Christensen and De Vasquez (1982) found Lutzomyia trinidadensis, the second most common sandfly in Panama to feed preferentially on reptiles (lizards). It was also shown that S. ingrami was fed on ruminants, rodents and man. Its presence in large numbers in termite hills could be related to the prevalence of monitor lizards and to some species of birds. Sergentomyia bedfordi was found to be bird-feeder. The Canidae (dogs) were also observed to be used by this species for its feeding. Among the analysed blood-meal samples, a mixture of blood from rodent and Canidae was also identified. Collections in large numbers of S. ingrami in tree hollows and canopies could be associated with the presence of birds. Quate (1964) reported this species to be a reptile-feeder in the Paloich area, while Minter (1964b) noted that birds are among the preferred hosts of S. bedfordi, which also feeds on gekoes. No Sergentomyia bedfordi was found biting man during the present investigation. In West Pokot, Mutinga (1980) noted that S. bedfordi feeds readly on reptiles, but also, can feed on man.

Sergentomyia schwetzi like S. ingrami and S. bedfordi seemed to have a high preference on birds as well as on monitor lizards. Its double feeding on birds and ruminants was also observed. The high rate of bloodmeal from birds determined the main preference of both wild sandflies, S. ingrami and S. schwetzi and hence their association with trees and termite hills. In Ethiopia, Foster et al.(1972) observed unfed S. schwetzi feeding on exposed skinks. This species was seen to feed readily on man as well as it was found biting gekoes, chickens, tortoises, dogs and ground squirrels (Minter, 1964b). In Kenya, Heisch et al. (1956) noted the feeding of S. schwetzi on lizards.

Despite its large numbers in the area, the Sergentomyia antennatus did not seem to have a wide range of hosts. This species was found to feed on ruminants. This can probably justify its large collections from animal enclosures where the cattle (mainly composed of cows, goats and sheep) are being kept for the nights. Minter (1964) collected this species whilst feeding on gekoes in tree holes.

7.4.2 The *Phlebotomus* species

During these investigations, it was observed that *P. martini* was fed on birds and ruminants whereas, *P. duboscqi* seemed to be an exclusive rodent-feeder. In Senegal, precipitin tests of 4 bloodmeal smears of *P. duboscqi* gave positive reactions for birds (2 smears), for mammals (1 smear) and for reptiles (1 smear) (W.H.O., 1981). However, the close association of one or the other species of the *Phlebotomus* group with a given habitat can be correlated with the presence of hosts. Therefore, the collections of *P. duboscqi* in burrows can be attributed to rodents, while the presence of *P. martini* in burrows and termite hills is related to the presence of rodents and birds which rest in both sites. Minter (1964b) pointed out that *P. martini* feeds readily on man, dogs and ground squirrels, and noticed the presence of spiny mice (*Acomys sp*), schrew (*Crocidura sp*) and gerbils (*Tatera sp*) in termite hills inhabited by this sandfly species.

Though the samples were small, identified bloodmeals taken from fed sandflies were consistent as it was shown that the overwhelming majority of meals from the investigated area were derived from birds and lizards. From the small number of bloodmeals found to be of human origin, it was difficult to draw conclusions about the anthropophylic sandflies. This requires further investigations. However, it was observed that species of the Sergentomyia group feed preferentially on birds and reptiles (lizards) and less frequently on dogs. These observations corroborate those of Minter(1964b) who reported that species of this group feed readily on reptiles, birds and less frequently on small mammals. Mutinga et al. (1986b) reported that Sergentomyia species prefer to feed on reptilian hosts. Mixtures of blood meals were identified from species of the Sergentomyia group. In Panama, Christiansen and De Vasquez (1982) detected in one Lutzomyia panamensis specimen a feeding on both chicken and an unidentified mammal. Mutinga (1972 and 1980) observed a mixture of blood meals taken from sheep/goat (0.13%) in Phlebotomus pedifer collected from caves of Mount Elgon. Nevertheless, S. ingrami was only found to feed on man. The crossing over to many other hosts by members of this group can be expected. Biologically, such adaptability would seem to have obvious survival benefits for sandflies (Tesh et al. 1972) and epidemiologically, it also has important implications in the transmission of certain arthropod (sandfly)- borne diseases (Tesh et al. 1971, 1972). Quate (1964) noted a much overlapping of host and sandfly species of the Sergentomyia group.

The present information on feeding preferences of the Phlebotomus group showed that some species feed exclusively on determined hosts, they seem to be well specialized and therefore more vulnerable, while others can diversify and feed on various hosts. Minter (1964b) noted that the *Phlebotomus* species prefer to feed on mammals including man. Mutinga and Ngoka (1978) reported positive reaction of fed *P. martini* on a bovid. Judging from the meal identification and the exact collecting sites of freshly engorged females, it appears that sandflies remain in resting habitats to digest their meals (Foster, 1972a). However, it was observed that identified bloodmeals were derived from animals, birds and reptiles.

CHAPTER EIGHT

SUMMARY

1. Factors affecting the distribution and abundance of Phlebotomine sandflies were studied in a leishmaniasis endemic focus in Baringo district, Kenya.

2. In order to determine the main patterns of the seasonal dynamics and variations of the sandfly relative abundance, sticky traps were placed at the entrances of burrows, tree holes and hollows, at the openings of termite hills and also traps were fastened to branches in the open field. The sticky traps were weekly in place for 13 hours (from 1800 to 0700 hours), and the trapping remained in progress for 12 months.

3. The analysis of sandfly occurrence in the investigated breeding and resting sites seemed to appear in the following decreasing order of capture: termite hill, tree hollow, animal burrow, open field, animal enclosure and human habitation.

4. The seasonal variations of sandflies were studied in two different ways: 1) by considering the individual sandfly species and 2) by taking into account the

total sandfly population produced in each investigated site as a whole. It was found that *Sergentomyia antennatus* was the most abundant fly followed by *S. bedfordi*. *Phlebotomus martini* showed a high occurrence among the *Phlebotomus* species. The *Sergentomyia* species represented 97 percent, while the *Phlebotomus* species constituted only 3 percent of the total sandfly population.

5. At least 15 species of sandflies were found within the Marigat area. Among them 5 species belonged to the *Phlebotomus* group and 10 to the *Sergentomyia* group. The termite hills and animal burrows, the main sandfly breeding sites in the area presented identical species composition but with marked quantitative differences. The *Phlebotomus* species collected from burrows were 4 times in number than the ones found in termite hills, whereas the *Sergentomyia* species recovered from termite hills represented twice the ones caught in animal burrows.

6. The analysis of the seasonal incidence of sandflies showed that the perennial species were widely distributed and were present all the year round or for most of the year. They formed the overwhelming majority of sandflies present in the area. The other species appeared to be more sensitive to the climatic variations, with limited distribution and a strictly seasonal incidence. They formed the minority of sandfly species, and were called

seasonal species.

7. The analysis of variance of both collected male and female sandflies showed a significant difference between both sexes and their collecting sites. Termite hills and animal burrows presented a predominance of males, whereas tree hollows and animal enclosures gave a sex-ratio in favour of females. Also, it was shown that the sex-ratio varied with seasons of the year.

8. Collections of sandflies from three different vegetation types (large trees, open woodland and bushy area), showed that buttresses of large trees provided stable microenvironment for sandflies. The high occurrence of sandflies observed on trunks of large trees was due to moderate humidity provided by the huge canopies.

9. A high density of sandflies per trap was recovered in large trees. The bushy habitat composed of thickets yielded few sandflies during both seasons. Sergentomyia bedfordi seemed to be more closely associated with the vegetation habitats. This species was collected in large numbers in both searched habitats and was followed by S. antennatus. In the bushy site, S. antennatus predominated over S. bedfordi. Phlebotomus martini and P. rodhaini seemed to be well adapted to the open woodland situation.

10. The fact that sandflies were found to congregate in large numbers on particular plants (e.g. Ficus, Acacia) could lead to a planning of control measures by treatment of selected areas within the forest or by selective removal of these plants where sandflies rest or take the sugar juice for their feedings.

11. Studies on sandfly vertical distribution in the wooded area and the open field showed that the first site was most preferred by sandflies. Sandflies were collected from 0 metre (ground level) to 11 metres in wooded area with predominance of females, whereas in the open field, the main zone of sandfly flight height comprised between the ground level and five metres.

12. Sergentomyia bedfordi and S. antennatus were the only species to reach a height of ten metres, corresponding to the canopy level in the area. Also both species were the commonest sandflies at all investigated heights, with the greatest density between 1 and 2 metres in the wooded site and 0 to 1 metre in the open field.

13. Two types of sandfly populations were observed in the Marigat forested area, a population flying between the ground level and five metres and the second population occurring between six metres and upwards.

14. The analysis of the relationships between the height of flight and the sandfly relative abundance as recovered at each height showed that the number of males and females of sandflies falls off with height.

15. The environmental factors, particularly the rainfall, appeared to have important effects on the distribution and abundance of sandflies. The two major peaks of abundance of sandflies occurred in April and August. Relative abundance of both Sergentomyia and Phlebotomus species increased during the wet weather, their populations declined during the dry period.

16. The month of April with heavy rainfall experienced high population of both Phlebotomus martini and P. duboscqi. Sergentomyia antennatus and S. bedfordi presented high relative abundance at the beginning and the end of the wet weather, and their decreases were observed in the middle of the rainy period.

17. During the wet season, large numbers of sandflies were produced from termite hills. The animal burrows did not show any variations of sandfly relative abundance as an equal capture rate (during both dry and wet seasons) was kept.

18. Correlating both sandfly vectors (*Phlebotomus martini* and *P. duboscqi*) and rainfall, a significant positive correlation coefficient was obtained. This suggested that in the Marigat area, the high incidence of the diseases occurred during the rainy season.

19. Although the positive or negative correlation coefficients (r) were found when the monthly relative humidity, air temperature and wind speed were correlated with the sandfly relative abundance in each site, the test of significance (using t-Student) of both r did not reach a significant level. Nevertheless, this indicated that both abiotic factors had more or less favourable effects (when the correlation is positive) or detrimental action (when r is negative) on the production and abundance of these flies.

20. The outstanding features of soil temperatures were the less variations observed in both termite hills and animal burrows during the wet and the dry seasons. A mean-difference of 3oC was obtained between both sites.

21. Soil relative humidity was found to be the microclimate variable most subjected to marked changes. It was found to be influenced by the atmospheric (air) temperature which is very dry throughout the year in the study area.

22. The combination of both moderate soil temperature and soil relative humidity makes the termite hills as well as the animal burrows to harbour a large variety of small and large rodents, birds and lizards and hence, stimulate their suitability for continous breeding by sandflies.

23. Correlating the soil temperature and soil relative humidity with sandfly relative abundance as prevailing in termite hills and animal burrows habitat-types, positive correlation coefficients were noted.

24. Immature sandflies live in soils and usually are subject to the presence or absence of soil nutrients, soil moisture content, soil reaction, organic compounds and soil texture among many others. During the wet season and the dry period, the calcium content presented a high significant difference between sites. The comparison of the soil physical characteristics showed that clay and sand presented significant differences between sites, whereas silt and moisture content did not give any differences.

25. The correlation of soil reaction (pH) and sodium (Na) with the sandfly relative abundance in termite hills presented highly significant negative correlation coefficients, whereas the moisture content gave a highly significant positive correlation coefficient.

26. The correlations of sodium and moisture content with sandfly relative abundance in animal burrows showed a highly negative correlation coefficients. The sand and the clay parameters gave the highly significant positive correlation coefficients.

27. In the vegetation growing under the trees, only the sodium presented a highly significant negative correlation coefficient. The other parameters such as organic carbon, calcium and potassium presented positive correlation coefficients. Both moisture content, silt and clay showed positive correlation coefficients when correlated with the sandfly population as monitored in under-vegetation.

28. The increase of the *Phlebotomus* species in animal burrows was attributed to the positive effect of organic carbon, calcium and soil reaction; while for the *Sergentomyia* species, its high occurrence in termite hills was ascribed to the available phosphorus.

29. Bloodmeals of 162 phlebotomine sandflies (*Phlebotomus* and *Sergentomyia*) collected from animal burrows, termite hills and tree hollows were identified by seroprecipitation utilizing three order-specific antisera (mammal, aves and reptile). It was found that the frequency

of feedings varied with species and place of collection. The *Sergentomyia schwetzi* fed mainly on birds and monitor lizards, *S. antennatus* on ruminants, *Phlebotomus martini* on birds and *P. duboscqi* on rodents.

30. *Sergentomyia bedfordi* and *S. ingrami* demonstrated a much broader range of hosts. The first species showed a preference for birds, dogs and rodents; while the second was found to feed mainly on birds, monitor lizards, ruminants, rodents and man.

31. The identification of sandfly host preferences by bloodmeal analysis determined the epidemiological importance of each sandfly species in the transmission of *Leishmania* parasite. Also, it showed the degree of anthropophily as well as of zoophily of sandfly species present in the area of investigations.

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APPENDICES

Appendix 1a. Monthly average for rainfall, temperature, relative humidity and wind speed recorded at Perkerra Agricultural Research Station(PARS), Marigat area, 1981-1986.

MONTH	Rainfall (mm)	Temperature °C air	soil *	%RH	Wind speed (mph)
January	0.56	34.71	32.21	47.30	70.23
February	18.20	29.58	32.65	52.70	73.18
March	43.30	29.75	31.11	54.30	78.03
April	120.81	33.18	28.11	67.48	58.91
May	61.88	32.45	28.17	64.98	55.43
June	147.08	32.31	27.63	64.96	50.02
July	48.75	31.71	27.30	69.18	48.85
August	74.31	31.61	27.23	67.33	48.73
September	27.11	33.01	28.53	58.81	57.65
October	34.56	33.10	31.21	59.10	65.36
November	57.76	32.45	29.61	58.00	60.77
December	18.55	33.08	31.03	58.28	59.52
Average	54.40	32.16	29.56	60.20	60.55

* data recorded in 1985/1986.

Temperatures and Relative humidity (RH) were recorded in maximum values.

Appendix 1b. Monthly means for the environmental factors recorded at the Perkerra Agricultural Research Station (PARS), (Marigat area, 1985/86).

Period (Year and Month)		Rainfall (mm)	Temperature (°C) Air	soil	RH %	Wind speed (MPH)
1985	November	32.40	32.10	29.61	53.20	60.63
	December	1.80	33.60	31.03	51.60	64.24
1986	January	0.00	34.80	32.20	45.90	66.32
	February	0.00	35.00	32.65	44.50	71.95
	March	16.70	35.10	31.11	53.60	69.67
	April	163.50	33.30	28.11	73.20	51.56
	May	50.68	31.50	28.17	71.10	42.54
	June	103.90	30.20	27.63	83.90	30.06
	July	43.10	30.60	27.30	73.90	23.90
	August	42.70	31.60	27.23	62.00	35.90
	September	50.30	32.10	28.53	58.50	50.32
	October	6.50	33.60	31.21	58.10	68.71

Temperature and relative humidity(RH) were recorded in maximum values.

Appendix 2. Average monthly sandfly population as collected from the standardized long-term collection series. Perkerra Irrigation Scheme, Marigat area, 1985/86.

S.	Nov.85	Dec.85	Jan.86	Feb.86	Mar.86	Ap.86	May 86	June 86	July 86	August 86	Sep.86	Oct. 86
T.H	108.88+0.45	64.42+0.35	86.60+0.37	86.56+0.39	111.64+0.41	148.14+0.61	113.55+0.62	162.25+0.56	227.53+0.48	196.90+0.53	117.60+0.50	75.80 + 0.51
A.B	46.37+0.50	193.05+0.39	74.21+0.43	102.40+0.40	86.08+0.40	52.76+0.44	55.95+0.41	73.25+0.38	43.80+0.38	88.50+0.55	71.95+0.49	72.55 + 0.44
t.h	69.13+0.04	137.64+0.48	78.12+0.41	66.68+0.40	99.30+0.37	63.05+0.35	43.52+0.41	89.15+0.43	143.20+0.52	140.40+0.36	121.80+0.43	174.80 + 0.52
H.h	30.90+0.61	10.70+0.60	12.84+0.74	19.18+0.78	15.63+0.62	18.88+0.58	16.67+0.65	17.75+0.71	18.47+0.66	13.04+0.64	13.32+0.66	23.64 + 0.78
A.e	28.23+0.61	16.88+0.59	10.10+0.54	18.74+0.61	16.23+0.54	14.24+0.57	8.33+0.5[illegible]	20.56+0.62	24.16+0.58	30.13+0.68	29.31+0.67	22.06 + 0.64
O.f	21.42+0.85	9.00+0.89	33.84+0.92	49.66+0.88	32.66+0.90	54.23+0.92	16.88+0.94	15.60+0.93	24.00+0.95	27.52+0.94	40.36+0.95	33.11 + 0.94
Tot.	50.27+0.45	53.56+0.51	43.65+0.47	56.97+0.47	63.25+0.49	62.46+0.49	35.45+0.49	54.45+0.49	51.29+0.47	63.59+0.47	48.78+0.42	53.87 + 0.46

T.H.= termite hill, A.B.= aniaml burrow, t.h.= tree hollow

H.h = human habitation, A.e.= animal enclosur, O.f.= open field, S.= site.

Appendix 3. Seasonal variations of Phlebotomine sandflies based on the division of the year into 2 climatological periods.

Marigat area, Nov.1985 - Oct.1986.

	Dry period (Nov.85- Feb.and Sept.-Oct.86						Wet period(Mar.-Aug.86)						
	Termite hill	Animal burrow	Tree hollow	Human habitat.	Animal enclos.	Open field	Termite hill	Animal burrow	Tree hollow	Human habitat.	Animal enclos.	Open field	TOTAL
P.martini	228	740	28	70	78	6	180	879	6	40	60	2	2317
P.duboscqi	1	121	0	3	11	0	13	156	3	2	9	0	319
P.rodhaini	10	4	3	0	0	0	1	2	5	0	0	0	25
P.orientalis	0	0	0	0	0	0	0	0	0	0	0	1	1
S.bedfordi	3192	815	9978	1900	2778	1129	3303	790	5528	760	1991	566	32729
S.antennatus	7061	7336	3198	2022	1960	963	9104	5640	4570	1880	2064	1245	47043
S.ingrami	1124	640	247	195	144	84	4379	944	392	573	300	225	9247
S.africanus	312	176	232	36	74	30	553	242	250	37	43	23	2008
S.affinis	27	29	30	51	59	307	70	11	26	48	43	257	958
S.schwetzi	220	115	134	53	40	39	872	191	136	117	74	54	2045
S.adleri	50	60	34	51	43	25	176	130	41	152	123	105	990
S.clydei	28	50	13	64	57	33	118	125	26	172	94	107	887
S.graingeri	0	0	0	0	0	0	0	1	2	0	0	0	3
S.squamipl.	0	0	0	1	1	0	0	0	0	0	0	0	2
TOTAL	12252	10086	13897	4446	5245	2616	18769	9111	10985	3781	4801	2585	98574
No.collection	135	133	136	235	238	78	121	121	115	226	236	95	1869
Average	90.75	75.83	102.18	18.91	22.03	33.53	155.11	75.29	95.52	16.73	20.34	27.21	52.74
Tot.flies/season					48542			50032					
Tot.collection/season					955			914					
Average sandfly/collection/season					50.82			54.73					

Appendix 4. The common phlebotomine sandfly species as collected in the Marigat area during the period 1985/1986.

Sandfly	Nov.85	Dec.85	Jan.86	Feb.86	Mar.86	Apr.86	May.86	Jun.86	Jul.86	Aug.86	Sept.86	Oct.
P.martini	2.27	2.35	2.04	2.05	2.25	2.35	2.07	1.97	1.74	2.11	1.82	1.[illegible]
P.duboscqi	1.41	1.42	1.00	1.16	1.40	1.73	1.34	0.95	1.00	1.16	1.04	0.[illegible]
P.rodhaini	0.51	0.56	0.60	0.58	0.24	0.41	0.35	0.36	0.00	0.19	0.00	0.1[illegible]
S.bedfordi	3.29	3.32	3.18	3.16	3.27	2.89	2.42	3.19	2.94	3.46	3.37	3.[illegible]
S.antennatus	3.28	3.39	3.37	3.55	3.52	3.47	3.27	3.33	3.53	3.36	3.30	3.[illegible]
S.ingrami	2.74	2.48	2.22	2.36	2.73	3.18	2.82	2.99	2.62	2.72	2.18	1.[illegible]
S.africanus	2.02	1.92	1.89	1.99	2.16	2.10	1.94	2.13	1.89	2.27	1.96	1.[illegible]
S.affinis	1.61	1.60	1.48	1.19	1.06	1.66	1.68	1.76	1.79	1.83	1.97	1.[illegible]
S.schwetzi	2.04	1.45	1.37	1.75	1.89	2.18	2.34	2.41	1.94	2.16	1.67	2.[illegible]
S.adleri	1.45	1.38	1.53	1.70	1.57	2.22	2.12	1.87	1.68	1.62	1.27	1.[illegible]
S.clydei	1.42	1.23	1.40	1.79	1.78	2.30	1.89	1.83	1.58	1.18	1.13	1.[illegible]

Values are expressed into log(n+1) transformation.

Appendix 5. Monthly sandfly collections from termite hills.
(Marigat area,1985/86)

	November 1985			December 1985			January 1986			February 86			March 86			April 1986		
	Males	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1. P.martini	43	20	63	23	16	39	39	11	50	33	14	47	33	11	44	37	23	60
2. P.duboscqi	0	0	0	0	0	0	0	1	1	0	0	0	3	2	5	2	4	6
3. P.rodhaini	4	0	4	0	2	2	2	2	4	0	0	0	1	0	1	0	0	0
4. S.bedfordi	320	444	764	60	103	163	149	316	465	101	174	275	199	248	447	78	110	188
5. S.antenna.	622	473	1095	328	537	865	399	1085	1484	530	1138	1668	885	824	1709	707	584	1291
6. S.ingrami	476	240	716	56	48	104	40	41	81	33	31	64	234	138	372	622	692	1314
7. S.african.	25	33	58	9	19	28	19	35	57	25	49	74	45	74	119	30	44	74
8. S.affinis	3	2	5	0	2	2	4	3	7	2	0	2	2	4	6	6	4	10
9. S.schwetzi	85	25	110	6	5	11	8	4	12	10	7	17	37	10	47	90	21	111
10.S.adleri	7	4	11	6	2	8	3	0	3	3	8	11	15	8	23	18	14	32
11.S.clydei	5	0	5	2	0	2	4	0	4	4	2	6	15	3	18	25	0	25
TOTAL	1590	1241	2831	490	734	1224	667	1498	2165	741	1423	2164	1469	1322	2791	1615	1496	3111
NO. COLLECT.			26			19			25			25			25			21
AVERAGE			108.8			64.42			86.60			86.56			111.6			148.14

termite hills (continued).

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
28	10	38	12	7	19	6	1	7	11	1	12	12	1	13	12	4	16	289	119	40
1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	7	7	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	4	1
18	62	80	390	276	666	239	179	418	687	817	1504	350	671	1021	187	316	503	2778	3716	649
721	398	1119	676	476	1152	1584	745	2329	1041	463	1504	601	507	1108	436	405	841	8530	7635	1616
369	275	644	686	290	976	345	140	485	391	197	588	70	41	111	33	15	48	3355	2148	550
32	35	67	33	46	79	34	35	69	78	67	145	26	23	49	23	26	49	379	486	86
7	7	14	13	11	24	10	1	11	5	0	5	2	0	2	3	6	9	57	40	9
144	84	228	160	92	252	70	6	76	111	47	158	23	7	30	29	11	40	773	319	109
21	26	47	31	12	43	8	3	11	16	4	20	11	2	13	2	2	4	141	85	22
33	0	33	33	0	33	7	0	7	2	0	2	5	0	5	6	0	6	141	5	14
1374	897	2271	2035	1210	3245	2303	1110	3413	2342	1596	3938	1100	1252	2352	731	785	1516	16457	14564	3102
		20			20			15			20			20			20			25
		113.55			162.25			227.53			196.90			117.60			75.80			121.

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Appendix 6. Monthly sandfly collections from animal burrows.
(Marigat area, 1985/86).

	November 1985			December 1985			January 1986			February 1986			March 1986			April 1986		
	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1. P.martini	141	23	164	164	29	193	90	12	102	86	6	92	155	15	170	179	17	196
2. P.duboscqi	28	15	43	17	10	27	9	3	12	13	6	19	19	7	26	44	12	56
3. P.rodhaini	0	0	0	1	0	1	0	0	0	1	2	3	0	0	0	1	0	1
4. S.bedfordi	69	32	101	70	52	122	52	79	131	108	87	195	89	66	155	34	44	78
5. S.antenna.	389	424	813	459	710	1169	362	879	1240	926	1024	1950	837	655	1492	673	421	1094
6. S.ingrami	23	37	60	56	70	126	55	73	128	114	78	192	136	77	213	187	132	319
7. S.african.	13	18	31	6	15	21	5	21	26	8	18	26	15	24	39	25	23	48
8. S.affinis	12	2	14	0	0	0	5	1	6	0	2	2	0	0	0	1	0	1
9. S.schwetzi	21	2	23	10	0	10	8	2	10	32	12	44	19	7	26	30	9	39
10.S.adleri	2	0	2	3	0	3	4	28	32	10	5	15	5	6	11	22	30	52
11.S.clydei	1	0	1	3	0	3	20	0	20	22	0	22	20	0	20	64	0	64
12.S.graing.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	699	553	1252	789	886	1675	610	1097	1707	1320	1240	2560	1295	857	2152	1260	688	1948
NO. COLLECT.			27			18			23			25			25			21
AVERAGE			46.37			93.05			74.21			102.4			86.08			92.76

animal burrows (continued).

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
101	22	123	94	17	111	60	9	69	186	24	210	96	12	108	72	9	81	1424	195	1619
22	5	27	8	2	10	8	7	15	13	9	22	9	3	12	5	3	8	195	82	277
0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6
7	13	20	162	118	280	15	16	31	104	122	226	55	74	129	44	93	137	809	796	1605
381	304	685	338	492	830	162	314	476	464	599	1063	315	732	1047	446	671	1117	5752	7224	12976
72	40	112	83	45	128	18	18	36	83	53	136	53	31	86	27	21	48	907	675	1582
16	17	33	28	18	46	6	8	14	34	28	62	11	21	32	16	24	40	183	235	418
1	1	2	2	1	3	0	1	1	3	1	4	1	3	4	2	1	3	27	13	40
24	15	39	22	13	35	9	4	13	26	13	39	7	10	17	6	5	11	214	92	306
18	29	47	9	2	11	1	1	2	6	1	7	4	1	5	3	0	3	87	103	190
31	0	31	9	1	10	0	0	0	0	0	0	1	0	1	3	0	3	174	1	175
0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1
673	446	1119	755	710	1465	279	378	657	920	850	1770	552	887	1439	624	827	1451	9776	9419	19195
		20			20			15			20			20			20			254
		55.95			73.25			43.80			88.50			71.95			72.55			75.57

Appendix 7. Monthly sandfly collections from human habitations (Marigat area, 1985/86).

	November 1985			December 1985			January 1986			February 1986			March 1986			April 1986		
	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1. *P. martini*	24	18	42	4	1	5	8	5	13	2	4	6	8	2	10	4	2	6
2. *P. duboscqi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
3. *P. rodhaini*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. *S. bedfordi*	173	383	556	25	91	116	75	95	170	78	79	157	49	46	95	21	30	51
5. *S. antenn.*	328	232	560	64	46	110	169	124	293	177	133	310	144	41	185	167	50	217
6. *S. ingrami*	62	52	114	5	4	9	5	4	9	4	9	13	11	12	23	37	43	80
7. *S. african.*	5	9	14	1	1	2	1	3	4	2	1	3	2	1	3	4	2	6
8. *S. affinis*	5	12	17	2	4	6	2	2	4	0	3	3	0	2	2	2	2	4
9. *S. schwetzi*	14	5	19	2	0	2	0	2	2	1	2	3	8	0	8	8	1	9
10. *S. adleri*	8	12	20	2	0	2	3	1	4	7	3	10	2	1	3	23	25	48
11. *S. clydei*	18	0	18	5	0	5	2	0	2	12	1	13	15	0	15	69	0	69
12. *S. squami.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	637	723	1360	110	147	257	265	236	501	283	235	518	239	105	344	336	155	491
NO. COLLECT.			44			24			39			27			22			26
AVERAGE			30.90			10.70			12.84			19.18			15.63			18.88

human habitation (continued)

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
5	6	11	2	0	2	8	1	9	1	1	2	2	2	4	0	0	0	68	42	110
1	0	1	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	5	0	5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	24	42	50	106	156	63	86	149	80	187	267	72	233	305	236	360	596	940	1720	2660
190	142	332	131	84	215	400	299	699	127	105	232	156	204	360	234	155	389	2287	1615	3902
64	98	162	85	74	159	63	44	107	15	27	42	21	16	37	8	5	13	380	388	768
6	2	8	4	2	6	2	5	7	3	4	7	3	4	7	3	3	6	36	37	73
4	2	6	11	4	15	10	3	13	5	3	8	5	3	8	9	4	13	55	44	99
17	24	41	21	15	36	12	4	16	0	7	7	2	4	6	18	3	21	103	67	170
8	35	43	5	15	20	4	22	26	2	10	12	3	1	4	4	7	11	71	132	203
21	0	21	30	0	30	27	0	27	10	0	10	10	2	12	10	4	14	229	7	236
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
334	333	667	339	300	639	589	464	1053	243	344	587	277	469	746	522	542	1064	4174	4053	8227
		40			36			57			45			56			45			461
		16.67			17.75			18.47			13.04			13.32			23.64			17.84

Appendix 8. Monthly sandfly collections from animal enclosures (Marigat area, 1985/86).

	November 1985			December 1985			January 1986			February			March 1986			April 1986		
	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1. *P. martini*	37	5	42	5	1	6	9	2	11	6	0	6	12	3	15	7	7	14
2. *P. duboscqi*	1	0	1	1	1	2	1	1	2	0	0	0	1	0	1	0	0	0
3. *P. rodhaini*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. *S. bedfordi*	146	448	594	66	138	204	55	101	156	56	129	185	64	76	140	36	25	61
5. *S. antenn.*	255	190	445	74	79	153	93	95	188	127	113	240	145	65	210	114	40	154
6. *S. ingrami*	29	17	46	20	2	22	7	6	13	8	17	25	14	12	26	30	20	50
7. *S. african.*	18	12	30	3	4	7	4	1	5	2	4	6	2	1	3	3	1	4
8. *S. affinis*	3	3	6	7	12	19	1	3	4	0	1	1	1	2	3	0	4	4
9. *S. schwetzi*	4	6	10	1	0	1	0	2	2	3	1	4	3	5	8	7	2	9
10. *S. adleri*	4	3	7	3	2	5	2	2	4	6	7	13	4	4	8	9	20	29
11. *S. clydei*	5	0	5	3	0	3	9	0	9	25	1	26	8	0	8	31	0	31
12. *S. squam.*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	502	684	1186	183	239	422	181	213	394	233	273	506	254	168	422	237	119	356
NO. COLLECT.			42			25			39			27			26			25
AVERAGE			28.23			16.88			10.10			18.74			16.23			14.24

animal enclosures (continued)

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
7	2	9	5	2	7	10	1	11	3	1	4	4	0	4	8	1	9	113	25	138
4	0	4	1	0	1	1	0	1	2	0	2	5	0	5	1	0	1	18	2	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	27	45	100	234	334	107	278	385	288	738	1026	299	772	1071	169	399	568	1404	3365	4769
110	59	169	175	143	318	403	390	793	199	221	420	278	260	538	230	166	396	2203	1821	4024
19	23	42	50	23	73	27	31	58	28	23	51	7	19	26	6	6	12	245	199	444
1	1	2	6	2	8	8	4	12	12	2	14	7	7	14	3	9	12	69	48	117
2	3	5	4	1	5	5	4	9	12	5	17	14	8	22	5	2	7	54	48	102
8	3	11	17	7	24	12	3	15	4	3	7	2	5	7	11	5	16	72	42	114
8	21	29	6	12	18	8	15	23	9	7	16	1	6	7	3	4	7	63	103	166
9	0	9	14	0	14	22	0	22	10	0	10	5	1	6	6	2	8	147	4	151
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
186	139	325	378	424	802	603	726	1329	567	1000	1567	622	1078	1700	442	595	1037	4388	5658	10046
		39			39			55			52			58			47			474
		8.33			20.56			24.16			30.13			29.31			22.06			21.19

Appendix 9. Monthly sandfly collections from tree holes/hollows.
(Marigat area, 1985/86).

	November 1985			December 1985			January 1986			February 1986			March 1986			April 1986		
	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1.P.martini	12	2	14	5	4	9	2	0	2	3	0	3	1	1	2	1	0	1
2.P.duboscqi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
3.P.rodhaini	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	1	0	1
4.S.bedfordi	353	1024	1377	476	1241	1717	495	960	1455	430	632	1062	713	839	1552	207	299	506
5.S.antenn.	264	155	419	280	200	480	250	172	422	367	192	559	462	166	628	364	153	517
6.S.ingrami	45	61	106	35	36	71	12	4	16	6	3	9	43	13	56	34	20	54
7.S.african.	33	15	48	21	13	34	20	15	35	7	12	19	14	14	28	5	12	17
8.S.affinis	3	1	4	13	0	13	5	1	6	1	0	1	0	0	0	1	1	2
9.S.schwetzi	22	6	28	6	1	7	4	1	5	0	3	3	4	8	12	14	2	16
10.S.adleri	6	0	6	8	0	8	7	1	8	3	1	4	0	0	0	7	1	8
11.S.clydei	3	0	3	1	0	1	3	0	3	6	0	6	6	0	6	10	0	10
12.S.graing.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	741	1264	2005	845	1495	2340	799	1154	1953	823	844	1667	1243	1041	2284	647	488	1135
NO. COLLECT.			29			17			25			25			23			18
AVERAGE			69.13			137.6			78.12			66.68			99.30			63.05

tree holes/hollows (continued)

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	27	7	34
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
2	0	2	0	1	1	0	0	0	0	1	1	0	0	0	0	1	1	4	4	8
81	124	205	376	477	853	276	239	515	845	1052	1897	692	1041	1733	907	1727	2634	5851	9655	15506
316	211	527	354	345	699	1161	375	1536	434	229	663	340	243	583	469	266	735	5061	2707	7768
25	16	41	62	49	111	19	11	30	80	20	100	22	6	28	10	7	17	393	246	639
14	8	22	34	27	61	19	9	28	53	41	94	27	37	64	23	9	32	270	212	482
9	1	10	2	1	3	4	0	4	6	1	7	2	0	2	3	1	4	49	7	56
11	3	14	30	5	35	26	2	28	26	5	31	15	7	22	64	5	69	222	48	270
3	0	3	9	2	11	6	0	6	12	1	13	4	0	4	4	0	4	69	6	75
2	0	2	7	0	7	0	0	0	1	0	1	0	0	0	0	0	0	39	0	39
0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	2
464	363	827	875	908	1783	1512	636	2148	1458	1350	2808	1102	1334	2436	1480	2016	3496	11989	12893	24882
		19			20			15			20			20			20			251
		43.52			89.15			143.20			140.40			121.80			174.80			99.13

Appendix 10. Monthly sandfly collections from the open field.
(Marigat area, 1985/86).

	November 1985			December 1985			January 1986			February 1986			March 1986			April 1986		
	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
1.P.martini	0	0	0	1	0	1	0	1	1	2	1	3	2	0	2	0	0	0
2.P.duboscqi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.P.rodhaini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.P.oriental.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.S.bedfordi	15	49	64	11	38	49	70	86	156	56	91	147	52	37	89	49	46	95
6.S.antenn.	33	13	46	8	6	14	120	100	220	138	94	232	172	45	217	324	68	392
7.S.ingrami	4	3	7	5	2	7	7	20	27	4	11	15	7	19	26	33	40	73
8.S.african.	3	1	4	0	2	2	1	1	2	3	3	6	0	1	1	6	0	6
9.S.affinis	0	25	25	0	4	4	6	16	22	5	6	11	1	2	3	22	13	35
10.S.schwetzi	1	2	3	0	0	0	3	3	6	1	5	6	2	0	2	14	1	15
11.S.adleri	2	0	2	0	0	0	1	3	4	1	14	15	1	2	3	16	21	37
12.S.clydei	13	0	13	4	0	4	2	0	2	12	0	12	13	0	13	51	1	52
TOTAL	71	93	164	29	52	81	210	230	440	222	225	447	250	106	356	515	190	705
NO. COLLECT.			7			9			13			9			11			13
AVERAGE			23.42			9.00			33.84			49.66			32.66			54.23

open field (continued)

May 1986			June 1986			July 1986			August 1986			September 1986			October 1986			Total		
Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.	Male	Fem.	Tot.
0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	6	2	8
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1
12	10	22	34	32	66	27	38	65	84	145	229	148	218	366	184	163	347	742	953	1695
93	26	119	50	15	65	206	75	281	132	39	171	258	80	338	79	34	113	1613	595	2208
18	20	38	21	18	39	10	17	27	12	10	22	6	8	14	6	8	14	133	176	309
0	2	2	3	0	3	1	5	6	1	4	5	5	6	11	2	3	5	25	28	53
30	7	37	28	7	35	57	13	70	67	10	77	122	25	147	70	28	98	408	156	564
9	2	11	6	4	10	3	2	5	6	5	11	5	3	8	12	4	16	62	31	93
8	27	35	4	5	9	3	13	16	4	1	5	1	1	2	0	2	2	41	89	130
23	0	23	7	0	7	9	1	10	2	0	2	1	0	1	1	0	1	138	2	140
193	94	287	153	81	234	316	164	480	309	214	523	547	341	888	354	242	596	3169	2032	5201
		17			15			20			19			22			18			173
		16.88			15.60			24.00			27.52			40.36			33.11			30.06