ECOLOGY OF *SERGENTOMYIA GARNHAMI* HEISCH, GUGGISBERG AND TEESDALE (DIPTERA:PSYCHODIDAE) IN A KALA AZAR ENDEMIC AREA OF TSEIKURU, KITUI DISTRICT, KENYA

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DECLARATION

I declare that this is my own original research work and all assistance have been duly acknowledged

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CERTIFICATION

We certify that the work reported in this thesis was carried out under our supervision.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES .

LIST OF PLATES

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ABSTRACT

Ecological studies on *S.garnhami* in Tseikuru area of Kitui district, Kenya, were carried out from January 1989 to December 1990. This phlebotomine sandfly species had been shown to be economically important as a possible vector of *Leishmania donovani* and *L. major*. Experimental determination of the breeding sites of *S.garnhami* showed that this species was recovered from 14 out of 17 ecological habitats investigated. *S.garnhami* was also found to breed in domestic, peridomestic and sylvatic environments. Investigations on the day resting sites of *S.garnhami* showed that it has a wide distribution of day resting sites but prefers termite hills. Distribution studies within the different ecological sites showed that the flies were strongly aggregated within the sites. This study also revealed that *S.garnhami* and other phlebotomine sandflies encountered have a wide distribution of breeding and resting sites in Tseikuru area but prefer termite hills,animal burrows, rock crevices, treeholes,and treebases. Vertical zonation studies also showed that *S.garnhami* and other phlebotomine sandflies populations decreased with increased heights with most of the flies collected between 0-2m height. *S.garnhami* was not collected beyond 6-8m height. Studies on the seasonal population dynamics showed that *S.garnhami* has two annual peaks, one in May and the other in December.

The population peaks were observed within the temperature range of 28.5-31.5°C, relative humidity of range of 60-80% and rainfall of 0-40mm. The 3 climatic factors were considered complementary to one another in their effects. Under the optimal temperature conditions available in the area, the relative humidity was deemed an important factor in sustained population of *S.garnhami*.

Within the breeding habitats of *S.garnhami*, the immature stages thrived well within a temperature range of 19-24°C and moisture content of 80-100%. At a temperature range of 22-24°C both *S.garnhami* and other phlebotomine sandfly populations were significant to moisture. Moisture was considered to be an important factor in sustaining the population of *S.garnhami* immature stages within the sandfly breeding habitats. Studies on the edaphic factors in the microenvironments of *S.garnhami* showed that calcium, magnesium, and soil texture were positively correlated to *S garnhami* populations in both wet and dry seasons whereas sodium, potassium, carbon, phosphorus and capillarity were negatively correlated to *S.garnhami* populations in both seasons. Soil pH had non-significant negative correlation with wet season collections of *S.garnhami* and overall species collection of both seasons but showed non-significant positive correlation with the dry season populations of *S.garnhami*. The exchangeable

salts showed non-significant positive correlation with wet season populations of both *S.garnhami* and overall sandfly species but non-significant negative correlation to dry season populations of both *S.garnhami* and the overall sandfly species. Manganese had non-significant negative correlation with wet season populations of *S.garnhami* and the overall sandfly species but showed non-significant positive correlation to both populations in dry season.

Investigations on the hourly feeding pattern of *S.garnhami* revealed that this species was caught biting man throughout the hours of the night while sitting on or around the termite hills. The highest biting rate of 24-25 flies per man per hour was observed between 1800-2000hr. Occasional bites of one fly/hour were observed within and outside human homes. Few *S.garnhami* were caught from the animal baited cages placed near termite hills at different hours of the night. Identifications of the bloodmeals from wild-caught females of *S.garnhami* showed that it feeds on a wide range of hosts from reptiles to mammals including man but prefers lizards. Although the flies were collected from 11 ecological habitats, most of the hosts were associated with termite hills and animal burrows. Eighty-two (11.47%) out of 715 wild-caught females of *S.garnhami* dissected were infected with *Leishmania* promastigotes and 8 of them grew up in NNN-diphasic culture medium.

Investigations on the epidemiological role of *S.garnhami* showed that it satisfies the conditions of anthropophily, concordance of its distribution with the distribution of the disease in man and high percentage of natural infections. Further work is however required in the areas of parasite identifications and characterisation, laboratory studies of the parasite life cycle in the fly and experimental infections and infectivity

CHAPTER ONE

INTRODUCTION

Sandflies are small dipterous insects with the body, legs and wings covered with long hairs and scales. The legs are slender and prop-like. The wings are pear-shaped, covered with long hairs along the margin and venation is characteristically parallel (Plate 1.1)

Sandflies are very important as the only known insect vectors of leishmaniases-a complex of debilitating diseases caused by haemoflagellate protozoans of the genus *Leishmania*. Leishmanial diseases of man range in form from self-healing benign skin lesions called cutaneous leishmaniasis to permanently disfiguring and fatal muco-cutaneous leishmaniasis (espundia) which destroys the muco cutaneous membranes of the nose and throat of the patient. It also includes the quickly decimating form called visceral leishmaniasis which destroys the white blood cells and invades the internal organs like the spleen, liver and the bone marrow. Amongst the insect-borne diseases, leishmaniases only rank second to malaria in Kenya and probably the most debilitating in the endemic areas. The vectors, better known as sandflies, were unknown to Kenyans until 1912, when Manteufel (cited by Minter 1964a) collected some at the Port of Mombasa. The impact of the fly was unknown in

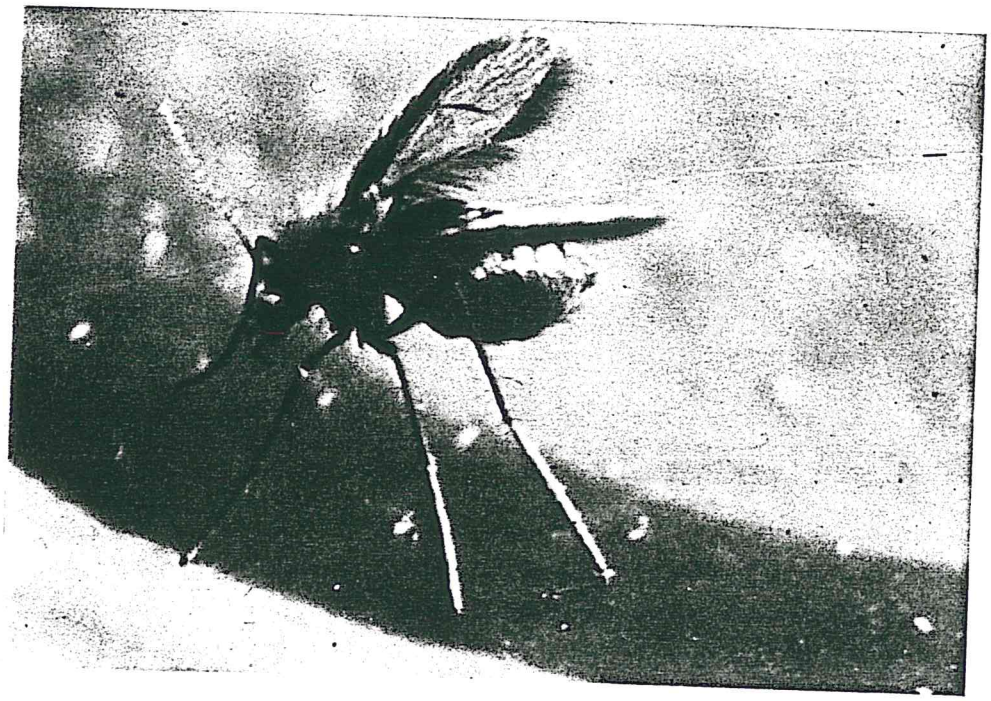


Plate 1.1 Bloodfed *Sergentomyia ingrami* female showing the characteristic features of phlebotomine sandflies

the health quarters as no case of leishmaniasis had at that time been reported, and therefore ecological studies were not pursued vigorously. The study of sandflies remained an academic exercise as there was no cause to link them with a disease outbreak. Sinton (1930, 1932) reported some species which were mainly *Sergentomyia* genus. Theodore (1931) described *S. bedfordi var congolensis* (formerly known as *P. nairobiensis).* From then on, the knowledge of sandflies of Kenya progressively increased as a result of collections made by a number of workers. The first case of leishmaniasis in Kenya was reported in 1941 (Fendal 1952). This was followed by sporadic cases reported in 1946 and an eventual epidemic outbreak in Kitui District notably Tseikuru in October 1952 to June 1953 (Heisch 1954). Subsequent to these, was the location of other endemic Kala-azar foci in Kenya (Minter 1964). These observations led to intensive research into the ecology of vectors and the epidemiology of leishmaniasis (Heisch 1954, Heisch et al 1956, Wijers 1963, Wijers and Minter 1962, 1966, Mutinga 1971, 1972, 1975a & b, 1981, 1986a & b, 1988. Mutinga et al 1983, 1989a, b & c, 1990).

From all these investigations, 41 species of sandflies have been presently reported in Kenya (Zahar 1981, Kaddu 1986, Basimike 1988). Initial investigations in Kitui (Heisch 1954 and Minter 1964) implicated Synphl*ebotomus, complex* (P *martini, P celiae,*

P. vansomerenae) as vectors of visceral leishmaniasis. P. mar*tini was* shown to be present in all visceral leishmaniasis endemic foci and has been considered the major vector. Later studies however showed that P celi*ae is p*resent in Ethiopia and in Sudan (Ayele and Mutinga 1989) in the disease endemic areas. For cutaneous leishmaniasis, *P. pedifer is s*hown to be a vector of *L.* aet*hiopica in th*e high altitude of Mt Elgon (Mutinga 1975), whereas *P.* dub*oscqi is s*hown to transmit *L. major (Muti*nga et al 1985). *P* or*ientalis known* to transmit leishmanial parasites of man in Ethiopia highlands and Sudan (Lewis et al 1974) has also been encountered in Kenya in some of the leishmaniasis foci but its role in disease transmission is still being investigated .

The role of the *Sergentomyia* as vectors of leishmaniases has been investigated and two species, S. ga*rnhami* (Mutinga and Odhiambo 1982) and *S.ingrami* (Mutinga et al 1986), were identified as potential vectors. *Sergentomyia ingrami* and *S.garnhami* have been reported to be secondary vectors of *L. major* and *L. donovani* respectively (Mutinga and Odhiambo 1982, 1986). Mutinga (1986), also reported that one of the leishmanial isolates from Tseikuru in Kitui district of Kenya produced *L major* type of sores in the nose and tail junctions when inoculated into experimental mice (Balb/c). He argued that although the strain has not

been typed biochemically and confirmed to be *L.major* the fact that it produced cutaneous lesions gave a strong indication that it was *L.major* He suggested that if biochemical investigations confirms this, *S. garnhami* could be a potential vector of zoonotic *L. major* in Kitui *District* of Kenya. Heisch (1954, 1955), Mutinga (1986) and Mutinga and Odhiambo (1982) have all reported the strong anthropophily exhibited by *S.garnhami* in Kitui and Machakos district respectively. Heisch (1954, 1955) had found 1.0% natural infection and 5.0% experimental infection in *S.garnhami* and concluded that *S.garnhami* was probably the vector of Kitui Kala-azar. Before these findings, species belonging to the *Sergentomyia* genus were generally not considered vectors of *Leishmania* of man. Because of the prevalence and anthropophily of *S garnhami* in cutaneous *and* visceral leishmaniases foci it was deemed important to investigate this species in greater detail in the oldest focus of the disease where *S garnhami* is most prevalent.

1.1 Objectives.

The main aim of the investigations was to study the ecology, bionomics and vector potential of *S. garnhami* in Kitui *district.* Specifically the following objectives were envisaged.

1. To study the distribution and seasonal population

dynamics of *S. garnhami* by investigating the breeding and resting sites and to establish the parameters which influence them including temperature, humidity, rainfall, soil factors, and altitude.

2. To study the natural infection rates of *S. garnhami* with *leishmania* parasites.

3. To determine the host preference of *S. garnhami* through bloodmeal identification.

1.2 Significance of the study.

The importance of this work was to clarify the ecological features of *S. garnhami*, and the possible role of *S. garnhami* in the epidemiology of leishmaniasis in kala-azar endemic focus of Kitui district. These studies would be able to show whether this species plays a role as a vector of *L. major* and therefore one of the species sustaining the endemicity of the infection in Kitui kala-azar focus.

1.3 Activities

A breakdown of the objectives showed that the

following activities should be undertaken:

1. Studies to locate the resting sites.
2 Studies to locate the breeding sites
3 Spatial distribution of *S. garnhami*.
4. *Vertical* distribution of *S garnhami*.
5. *Seasonal* population changes of *S. garnhami* with reference to the climatic factors influencing them.
6. Microclimatic factors influencing *S. garnhami* population in their breeding habitats
7. Edaphic factors influencing *S. garnhami* population in their breeding habitats
8. Feeding habits of *S. garnhami*.
9. Host preference studies and.
10. The determination of the natural infection rates of *S. garnhami*

CHAPTER TWO

LITERATURE REVIEW

2.1 Distribution

2.1.1 Global Distribution

The phlebotomine sandflies are found throughout the world mainly within the tropics and subtropics. The greatest numbers are found within the tropics (Perfile'v 1966). The northern limits of distribution in Europe and Asia lies between 45° and 50°N latitude, whereas the southern limits in the Old World is 40°S latitude. The *Phlebotominae* comprises five genera (*Phlebotomus, Sergentomyia, Lutzomyia, Warileya and Brumptomyia*) which are widely recognized (WHO 1984). *Phlebotomus* and *Sergentomyia* are found in the Old World whereas *Lutzomyia, Warileya* and *Brumptomyia* are found in the New World (Lewis 1974). Most species of the Ethiopian region belong to the genus *Sergentomyia*. Only very few species belong to *Phlebotomus* (Lewis 1974 & Perfile'v 1966).

Zahar (1981) reported that 41 species of sandflies are found in Kenya, 9 of which belong to *Phlebotomus* whereas 32 belong to *Sergentomyia*. Heisch et al (1965) and Minter (1964 a & b) have respectively reported on the distribution of sandflies in Kenya. *S. garnhami* was

previously thought to be restricted in distribution to Kitui district of Kenya where it is widespread. It has now been reported in Machakos district (Mutinga and Odhiambo 1982), in Loboi, Baringo District by Mutinga (1985), in Gonja in Tanzania (Pringle 1980, Abonnenc 1972), and in Kutaber area in Ethiopia (Aschford et al 1973).

2.1.2 Vertical Distribution

Vertical distribution studies are usually undertaken to investigate the distribution of man-biting species at different heights above the ground. Disney (1968) working in British Honduras showed that there was marked vertical zonation of phlebotomine sandflies attracted to small forest mammals. In a similar studies in British Honduras, Williams (1970) captured 19 species of sandflies most of which, notably *Lutzomyia permia*, were predominantly arboreal. He also noted that *L. panamensis* and *L. bispinosa* live amongst the foliage but descend to the forest floor to seek bloodmeals.

Vertical distribution studies have been carried out on the mosquitoes of Ethiopian region to investigate the mosquitoes involved in sylvan yellow fever (Corbet 1941, Haddow et al 1947, Mattingly 1949 and Snow 1975). Information on the vertical distribution of sandflies of the Ethiopian region is still very scanty. In a study

of the flight behaviour of sandflies of the Paloich area of Sudan, Quate (1964) noted that sandflies hardly fly over 2m above the ground level. Basimike (1988) studying the sandfly density of forested areas in Marigat Kenya, observed the existence of high density of sandflies in large trees with *S. bedfordi* predominating in abundance. He grouped the flies into lower level group and high level group. The lower level group flew below 5m above the ground level and comprised such flies as *S. ingrami*, *S. affinis*, *S. adleri*, *S. africanus* and *S. clydei*. The high level group includes *S. bedfordi* and *S. antennatus*, and usually flew beyond 6m above the ground.

2.1.3 Spatial Distribution

Southwood (1978) has noted in his book " Ecological Methods" that the distribution of organisms in space is of considerable ecological significance. He showed that not only was it valuable in designing sampling programmes and selecting methods of data analysis but also in describing the population size and condition as well as designing control programmes in case of pests.

Information on the spatial distribution of sandflies is found in scattered literature. WHO (1984) showed that sylvatic species are found during the day time resting in treeholes and tree trunks, animal burrows, termite hills, leaf litters, rocks and soil

cracks. The peridomestic species rest on the walls of homes and at the hot times of the day they retreat into cracks and crevices

In Kenya, sandflies have been found resting in termite hills, animal burrows, rock crevices, treeholes, plant bases, and tree trunks, walls of homes and caves (Heisch 1954; Heisch et al, 1956; Minter 1964b; Mutinga 1986; Kapur and Mutinga 1985; Basimike 1988)

2.2 Dispersal

Freshly emerged sandflies disperse from their breeding sites to find sugar or bloodmeal or mate. Engorged females move to a resting place and later to an oviposition site (WHO 1984). Kirk and Lewis (1951) noted that engorged female sandflies rarely move more than a few feet from where she had fed, but seek the nearest place of refuge which offers suitable conditions of darkness, still air and humidity.

Sandflies move in a characteristic short hop flights and therefore fly over limited distances from their breeding sites. The general dispersal trend of adult sandflies has been studied by means capture/mark /release/recapture methods in Ethiopia, France, Panama, Sudan and USSR WHO (1984). It has been found that the flight range of sandflies differs according to species and habitat. In neotropical forests, sandflies rarely

move much more than 200m. In USSR, *P. papatasi* was observed to move as far as 1,500m but these distances was not achieved by the engorged and gravid females. In France, *P ariasi* has frequently been shown to fly over 1,000m even when engorged or gravid and occasionally as far as 2,300m. Meteorological observations showed that these sandflies were not assisted by wind in their dispersal flights (Killick-Kendrick 1972). This shows that they disperse by active flights and movements irrespective of the wind direction.

2.3 Description of *Sergentomyia garnhami*

S. garnhami Heisch, Guggisberg and Teesdale was first described by Heisch et al (1956). It is a fairly large dark-brown fly with marked seasonal cycles. The female could easily be identified by the appearance of the pigmented plate on the ventral part of the head capsule. The plate is usually cross-like in shape, brown in colour and with about 10 posterior teeth and one row of anterior teeth. The terminalia of the male bears a pair of long coxites which are about double the length of the styles attached to them at their distal ends. Each style bears 4 spines, two of which are subterminal whereas the other two are terminal.

2.4 Biting habits

S. garnhami was first collected by Heisch (1954) in Tseikuru while biting human volunteers sitting round a termite hill between 7.00 and 9.30 (Kenya local time), in the evening. He noted that for the sandflies to bite in large numbers, the conditions had to be just right and the most suitable being warm humid and still evening weather. Further studies showed that quite a good majority were caught biting near termitaries, a fair number in millet fields and occasional specimens in houses (Heisch et al 1965). He conducted a study of biting cycle of *S. garnhami* for 2 hourly periods on seven 24-hour catches in January 1955 and 16 catches in May. The results revealed *S. garnhami* to be strongly anthropophilic, having 2 marked peaks of activity, one in the morning and the other in the evening with very little happening in between. Wijers and Minter (1962), however, could not find *S. garnhami* so and concluded that it rarely bites man. Mutinga and Odhiambo (1982), Mutinga (1986) showed *S. garnhami* to be strongly anthropophilic both indoor and outdoors.

2.5 Host preference

Many and probably all species of *Sergentomyia* feed mainly on lizards or other cold-blooded animals (Lewis 1973, Mutinga et al 1986). However, an experimental host preference studies using various animal models in laboratory showed that *S. garnhami* preferred mammalian hosts (Mutinga et al 1986). In nature, Heisch (1954, 1955, 1956), Mutinga 1981 and Odhiambo (1982), and Mutinga (1986) have respectively found *S. garnhami* to be strongly anthropophilic though it could bite a number of hosts including lizards and mammals inhabiting termite hills. Heisch (1954) also tested 37 bloodsmears from *S. garnhami* captured in the wild by precipitin test and found that only 8 were positive for human blood. Microscopic examination of blood from the gut of wild caught flies nearly always contain nucleated red cells suspected to be from geckos numerous in the termite hills.

2.6 Infection rates of *S. garnhami*

Because of the undetermined vectorial status of *S. garnhami* only little has been done on the study of their infection rates in nature. Heisch (1954) dissected 200 *S. garnhami* caught in the wild and found that only 2 (or 1%) contained promastigotes in the anterior station of

the gut. Heisch (1955) fed 75 wild caught flies on a Kala-azar patient and only 4 (or 5%) became infected. Kaddu and Mutinga (1984) dissected 112 *S. garnhami* from Tseikuru and found that 12 had leishmanial parasites in their guts but 5 of the 12 had their leishmanial parasites in the malpighian tubules. In an artificial feeding experiment, Kaddu et al (1986) found that five *Sergentomyia* species, including *S. garnhami* were able to feed on rat, rabbit and hamster blood through a 1-day old cockerel skin membrane but none of the *S. garnhami* had demonstrable parasitaemia after 5 days post-feeding. Mutinga and Odhiambo (1982), working in Machakos district dissected all flies that came to bite man and found that amongst others, *S. garnhami* had an infection rate of 16.4% whereas *S. bedfordi, and S. antennatus*, hitherto regarded as vectors of reptilian leishmaniasis had infection rates of 7.6% and 1.0% respectively. Mutinga (1986a) also reported that one of the leishmanial isolates from Tseikuru in Kitui District of Kenya produced *L. major* type of sores in the nose and tail junctions of experimental mice (Balb/c).

2.7 Breeding sites

Sandflies generally breed in damp soil that is rich in humus such places as dark and damp cellars, caves, dug-outs, piles of rubbles stones, bricks and tiles,

crevices in damp stone walls, drains and banks of streams, cracks and fissures in the soil and in animal burrows (Kirk and Lewis 1951, Hanson 1961, Quate 1964, Perfile'v 1966 and WHO 1984).

In U.S.S.R., Perfile'v (1966) showed that animal burrows were characteristic biotope of sandflies in nature, they remained in them during the day, the most common type of burrows being those of ground squirrels, gerbils and jerboas. Others include burrows of mouse-like rodents, porcupines, badgers, jackals, hedgehogs and tortoises, burrow-nests of bee-eaters, rollers pigeons, other vertebrates and birds. Sandflies of U.S.S.R. also inhabit abandoned buildings and man-made natural environments and caves that shelter bats, lizards and snakes which constitute source of food for the sandflies.

In Kenya, termitaria, animal burrows, rock crevices, treeholes and plant bases have been reported as the major breeding sites of sandflies. However, animal burrows and termitaria are the preferred sites (Heisch 1954).

2.8 Resting sites

Sandflies do not fly far from their breeding places and consequently most of them are collected at or very close to their breeding sites. In his book, Lewis (1973), classified the resting sites of sandflies into natural and artificial shelters. The day time natural resting sites include treeholes, spaces between root buttresses of trees, foliage of forest undergrowth, animal burrows, termite hills, rock crevices in the caves and elsewhere, cavities amongst boulders and soil cracks. The artificial shelters include human habitations and animal pens.

In Marigat, Baringo District of Kenya, Mutinga et al (1986b) found that animal burrows proved to be the major resting sites for adult *S. antennatus*, *S. bedfordi* and *S. ingrami*. Other species included *P. martini*, *P. duboscqi*, *P. rodhaini*, *S. africanus*, *S. clydei*, *S. schwetzi*, *S. adleri*, *S. affinis* and *S. wynnae*. They suggested that this probably indicated that these flies were likely to be breeding inside these animal burrows. In West Pokot District of Kenya, Mutinga (1986) reported 10 species of *Sergentomyia* and only 1 species of *Phlebotomus* rested in termite hills. In Machakos District of Kenya, Mutinga (1986a) also found that the primary source of *P. martini* and *S. garnhami* were termite hills and that the closer the termite hills were

to human habitations, the greater were the numbers of *P. martini* and *S. garnhami* resting indoors. At Tseikuru, Kitui District of Kenya, seven species of *Sergentomyia* including *S. garnhami* and one species of *Phlebotomus* - *P. martini* - were captured from termite hills and houses with *S. garnhami* topping the list in abundance (Mutinga 1986). Earlier Minter (1964b) and Heisch (1954) have captured various species of sandflies in treeholes, animal burrows and clefts in the rocks in Tseikuru. Heisch (1954) observed that termite hills were a prominent feature in the Kala-azar areas of Kitui and that during certain periods of the year they were full of sandflies.

2.9 Seasonal abundance of sandflies

In a review of the phlebotominae of the Ethiopian region, Kirk and Lewis (1951) have shown that in most places where sandflies are prevalent, they exhibit a more or less marked seasonal variation in numbers. They reported that in some regions there was a well-defined sandfly season of a few months of the year. For instance, Heisch, Guggisberg and Teesdale (1956) showed that some species of sandflies in Kitui District of Kenya such as *Phlebotomus martini*, *P. vansomerenae*, *S. affinis*, *S. clydei*, *S. graingeri*, *S. antennatus*, *S. bedfordi*, *S. schwetzi* and *S. squamipleuris* were found

throughout the year but *S. garnhami*, *S. kirki*, and *S. multidens* were restricted to the rainy months. Wijers and Minters (1962), discussed the seasonal incidence of some species in the northern part of Kitui, dividing them into perennial and rainy season groups. Minter (1964b) has shown that with the exception of *P. celiae* and *P. vansomerenae*, all the perennial sandflies of Kitui District were also common at Marigat in Baringo District and that the rainy season group were generally absent from Marigat. He ascribed this to the unimodal rainfall pattern in Marigat area which makes survival difficult for rainy season species during the long interval between the prolonged rains and dry season.

2.10 Climatic factors and sandfly population

Seasonal variation in numbers of different species of sandflies in different places is closely correlated with meteorological conditions and thus varies in different areas according to the climate. The dominating factors are temperature, humidity, rainfall, insolation and wind (Kirk & Lewis 1951). The optimum physical conditions for sandflies are still air, darkness, a constant temperature of approximately 28°C and a high relative humidity (approximately saturation). Theodore (1936) has shown that at 30°C and a relative humidity of 40 per cent, the mean life of a fed female

P. papatasi was 3-5 days while the thermal death point in a 1-hour exposure was 41°C. Condensation of water vapour from the atmosphere is regarded harmful as they readily become entangled and drowned in the water so formed. Kirk and Lewis (1947) pointed out that the survival of sandflies in some arid areas is due in large measure to their exploitation of a vast subterranean environment, consisting of animal burrows and cracks in the soil in which equable conditions of temperature (27°C) and relative humidity (approximately 100%) exist in spite of wide fluctuations above ground. From this subterranean environment they emerge in search of food only after darkness when temperature falls and relative humidity in consequence rises, thus providing suitable climatic conditions for them. Heavy rains seem to have adverse effects on the sandfly populations. Kirk & Lewis (1951) have shown that in most places sandflies disappear during the heavy rains, as has been noticed in Sudan, Kirk & Lewis (1940), Ethiopia (Martin 1938) and Zaire (Wanson 1942), but appear in large numbers just before and shortly after rains.

In Kenya, Heisch (1954) found that some species including *S. garnhami* appear in large numbers about 6 weeks after rains. Minter (1964b) revealed that the annual pattern or rainfall distributions is of greater importance than the total precipitation in influencing the gross distribution and local abundance of a number

of phlebotomine sandflies. He also suggested that rainfall probably operates by changing the humidity of resting and breeding sites.

A series of laboratory studies in U.S.S.R. (Perfile'v 1966) on the development of the pre-imaginal stages of sandflies and their relation to temperature and humidity revealed that the optimal temperature for the development of the pre-imaginal stages of sandflies is 28-30°C. If the temperature is more or less uniform, the development of eggs of various species of sandfly lasts about 10 days. Sandfly eggs can stand neither desiccation nor immersion in water and never hatch under these conditions. These studies also showed that the different larval stages show a different resistance to adverse environmental factors. The 1st-stage larvae being most sensitive and the 4th stage larvae the most resistant.

2.11 Sandfly collection

General methods for the detection, collection and handling of sandflies have been described elsewhere (Kirk and Lewis 1951, Perfile'v 1966, Lewis 1973, Chaniotis, 1978). All these methods could be divided into 3 major groups, according to their application. These are (a) techniques for the location of breeding sites (b) techniques for collection of day resting

adults and (c) techniques for collection of flying insects

2.11.1 Techniques for location of breeding sites

The techniques used in location of breeding sites could be sub-divided again into (i) those used for collection of immature stages and (ii) those used for collection of adult stages from the breeding sites

2.11.2 Methods used for collection of immature stages

The methods employed in the collection of immature stages include (i) direct examination of soil samples under a stereomicroscope (ii) Macfadyen's method and (iii) flotation technique.

2.11.2.1 Direct examination of soil samples under stereomicroscope

Samples of soil from the suspected breeding grounds are taken with a small trowel, sealed in plastic bags and carried to the laboratory in heat insulators (e.g. cold boxes) for processing. Small aliquots of the sample are carefully examined under the stereomicroscope until the whole sample is examined. This method was employed by earlier workers in USSR (Perfile'v 1966).

It is time consuming, tedious and only few sandfly larvae could be obtained compared with tons of soil examined.

2.11.2.2 Macfadyen's method

This method is based on the repellent action of desiccation produced by incandescent lamp. It is a modification of Berlese funnel used by soil biologist and acarologists to extract mites and other soil organisms from the soil samples as well as from bird and nest materials. Seyedi and Nadim (1972) employed Macfadyen's method to collect sandfly larvae from soil samples in Iran, and reported excellent results.

The instrument consist basically of an incandescent lamp placed over a wooden box with enamel pans containing water or alcohol at the bottom. The top lid are perforated and funnels with screens to retain soil samples are placed in them. As the soil samples in the funnel heat up, larvae move down until they fall into the enamel pans at the bottom of the box. Although this has been considered very excellent it cannot be used to collect eggs and pupae - the immobile stages.

2.11.2.3 Flotation technique

This was first introduced by McCombie-Young et al (1926), although their method has undergone many modifications. The method involves the use of saturated solutions of salt or sugar to float the immature stages. It is the most commonly used method and has been effectively used by Hanson (1961), and Quate (1964). The soil samples are washed through several sieves, one below the other, and each with a smaller mesh. Saturated sugar solution is poured over the residue collected from the last sieve. When the residue contains larvae or pupae of insects, they float to the surface after some time and they could be detected with a magnifying lens.

2.11.3 Techniques for collecting of adult flies from breeding sites

Two basic techniques, emergence traps and soil incubation have been employed for the collection of adult flies from the suspected breeding sites.

2.11.3.1 Emergence traps

An emergence trap consists essentially of wire frames with the inner walls lined with sticky material to trap emerging adult sandflies. Many of these traps are placed over the surface of the investigated areas. The traps are so arranged that there are no spaces between the base of the traps and the soil. If the traps are difficult to arrange, their bases may be covered with sand to prevent emerging sandflies from escaping. Traps are usually left on the same spot for one month or longer but are examined daily. It has been noted that soil from a part of the ground that has given negative results earlier may yield hundreds of flies one or several days after. The idea behind this method is that if there are immature stages (eggs, larvae and pupae) they will undergo their normal life cycle and the emerging adult sandflies will be caught in the traps.

There are now many modifications of this trap. One form is that the wire frames are made of fine mesh wire netting and the sticky traps are not necessary. Alternatively the traps are made of wooden boxes with sticky papers on the inside walls. Further modifications of the wooden type is that used by Dipeolu (1977) which consists essentially of a cone of light wood 32cm diameter at the base, 32cm high and with a 2.8cm diameter opening at the top lid. The opening at

the top is surmounted with universal bottle coated with castor-oil inside. At intervals suitable to the investigator, the universal bottle is removed and examined for the presence of adult flies. It has the advantage of confirming the breeding sites with relative ease to those of collecting immature stages. However, it could be applied only during the appropriate sandfly seasons.

2.11.3.2 Soil incubation technique

This method was first described by Dedet et al (1980) and later modified and employed by Mutinga and Kamau (1986), and Mutinga et al 1986, 1989). Soil samples from suspected sandfly breeding areas are collected into rectangular containers of about 660 cm^2, vigorously agitated to search for adult flies. The samples are wetted thoroughly but not waterlogged, covered with fine mesh cotton or nylon netting held tightly on the sides with elastic rubber bands to prevent any escape of emerging sandflies during incubation. In order to maintain high relative humidity and provide minimal light conditions, the whole arrangement is enclosed (wrapped up) in dark polythene sheets, maintained on raised wood planks inside laboratory and also wetted regularly during checks.

The temperature of the soil samples is taken at sites and again 3 times a day at 0630, 1200 and 1500 hours. Room or laboratory temperatures are also recorded the same time. The soil samples are checked twice daily at 0600 and 1800 hours. A fine net mesh is hung over the person checking for emerging adult flies to prevent accidental escape of flies. All flies collected are to be washed in 0.1% of detergent saline, slide mounted using gum chloral as mountant and later identified. This method is an efficient one and could be employed even when the sandfly populations are low in the field. However, it is labour intensive and does not provide the opportunity of seeing the immature stages.

2.11.4 Techniques for collecting day resting adult sandflies

The methods employed in the collection of day-resting adult sandflies are aspirator method and smoke and sticky trap method.

2.11.4.1 Aspirator method

The day resting adult flies can often be obtained with suction catchers (or aspirators) or tubes from darkened parts of houses, stables, latrines, treeholes and cellars. They may often be driven out from their

resting sites in animal burrows, caves, termite hills, rock crevices or clefts in the soil by tobacco or cigarette smoke, twigs or a handful of dust.

2.11.4.2 Smoke and sticky trap method

Oiled polythene sheets placed in cleft sticks are stuck near the entrance of animal burrows, or placed at the ventilation shafts of termite hills, treeholes, crevices on plants, plant bases etc. and smoke blown to drive out resting sandflies which got trapped in the oil papers. Mutinga (1986) used bee-keeper smoker trap to pump smoke into animal burrows in order to drive out resting sandflies. This yielded nice results.

2.11.5 Techniques for collecting flying adult sandflies

Four methods, light traps, sticky traps, animal baits and human baits, are usually employed in the collection of flying adult sandflies.

2.11.5.1 Light Traps

Many forms of light traps have been employed in the collection of sandflies. The preferred version is the C.D.C. light traps. It is light weight, and operates on dry cell batteries. The major problem with this is that

the sample so collected is not representative as light trap is selective in their catches. Most of the insect catches are mutilated by fan blades or may escape because of their tendency to fly upwards when the motor ceases to function or because of human interference, battery failure or motor malfunction. It is also costly on long time studies.

2.11.5 2. Oil (sticky) traps

This usually consists of a piece of transparent polythene paper, plastic, tin or enamel smeared with adhesive oil and placed in a horizontal, vertical or inclined position in places where sandfly activity is suspected such as near animal burrows, soil crevices, rock piles, ventilation shafts of termite hills, treeholes and so on. The advantage of oil trap is that it does not attract and therefore not selective, but sandflies which move in short hops tend to alight on a nearby object on their path and are trapped.

The size of oil traps have varied from individual workers, the general rule is that the larger the surface the more effective but practical considerations impose limitations.

Also the type of oil has varied. Engine oils, castor oil, a mixture of castor oil and calophony, and different vegetable oils have been used. Castor oil has

proved an effective adhesive and has been employed frequently. It is sufficiently viscous and weather resistant. It lacks repellent properties though Quate (1964) reported that *Phlebotomus orientalis* Parrot was repelled by it in Sudan.

A thin film of oil is adequate to produce good results for small flies like sandflies, however, more oil than just a film provides better adhesion and also preserves the flies in a fresh state for several hours. Traps are left in the field for about 12 hours (over night). Trapped flies are removed individually with fine probes e.g fine brush, acacia thorns or sticks sharpened to pencil points, washed briefly (1-2 minutes) in saline solution containing 1.0% commercial dish washing detergent. Flies collected in this way remain fresh for several hours of their capture and can be dissected for studies of leishmaniasis or pooled for virus isolation in arbovirus studies.

Oil traps have been proved very effective in open and dry habitats. In humid tropical areas they are to be supplemented with animal bait.

2.11.5.3 Animal baited traps

This is an important method for sampling haematophagous insects. One or more animals are constrained in a wire mesh cage and set appropriately in the field. Hungry female flies are attracted as are some males either accidentally or for the purpose of mating. Flies that have approached or alighted on the host(s) and those which have already fed on the hosts are collected by one of the several ways described.

These include (1) by aspiration of alighting flies with suction tube, (2) by placing a moat of oil, e.g. oiled paper, plastic or tin, around the caged animal to capture flies that hop towards or away from the animal bait, (3) by placing a mechanical suction trap over the caged animal, (4) by stretching a rectangular or cuboidal tent, like white muslin or fine nylon mesh with the lower end higher than the bottom of the animal cage. Sandflies alighting to bite the animal are trapped and collected with suction tube, and (5) by direct exposure of large domestic animals, preferably horses or cows, to host- seeking female flies. One or more collectors equipped with suction tubes and flashlights aspirate alighting flies individually from the skin of the animal as they begin probing.

2.11.5.4 Human Bait Methods

This method is used mainly for the collection of anthropophilic species in which case man acts as both bait and collector.

One or more people provided with test tubes or suction tubes and flashlights can collect or aspirate flies from each other as the flies alight on exposed areas of their bodies in search of bloodmeal.

The major shortcoming of this method is the danger of contracting disease, the inflammation and irritation produced by the bite and the limitation of the catch to few species with a propensity to bite man. However, it has the advantage that flies are captured alive and are virtually females. Thus the catch off humans and animals is particularly valuable for isolating infective agents and in assessing parity and vector potential of the various species.

2.12 Processing of sandflies

This involves washing, preservation in 70.0% ethanol and mounting for identification.

2.12.1 Washing and preservation

Trapped flies from oil traps are washed briefly (1-2 minutes) in saline solution containing 1.0% commercial dishwashing detergent, rinsed in normal physiological saline and preserved in 70.0% alcohol in specimen bottles. Using adhesive papers and pencil, specimen bottles containing the flies are appropriately labelled indicating locality and site of collection, date and time. Sometimes the adhesive papers wear out quickly, ordinary papers are cut into label sizes, appropriately labelled with pencil and inserted into the bottles with the samples.

Specimens collected from other sources not using sticky oil or other adhesives can be preserved directly in 70% alcohol and properly labelled. However, washing in detergent saline before preservation has the advantage of wetting the flies and removing the hairs.

Living specimens are wetted and killed in the detergent saline contained in a petri dish. They are washed using fine brush to move the insects gently in the detergent saline, then rinsed in normal saline from where they are either transferred into 70.0% alcohol for preservation or picked individually and slide mounted under stereomicroscope.

2.12.2 Mounting

Fresh specimen are picked individually from physiological saline and mounted in a drop of Puri's chloral-gum mountant. Each insect is placed in a drop of the mountant and using a pair of dissecting pins fitted in applicator sticks, the head is severed from the body under a stereomicroscope, the head is inverted such that the dorsal surface lies on the slide and the ventral surface upwards. The wings, the body, the legs and the terminalia, in case of the males, are straightened. The whole specimen is covered with a coverslip and left under room temperature to dry. Drying is gradual and may take upto a month to completely dry, but within two days the edges harden and the slides could be packed into slide boxes where they will completely dry. It is advisable not to mount more than one specimen under one coverslip as there may be need to remount a specimen during identification or heads of confusing specimens could not easily be matched with their bodies leading to wrong identification or still new or rare specimens requiring preservation or further studies could be placed with other species making identification and isolation difficult.

2.12.3 Identification

Sandflies are tiny, delicate insects and usually morphologically identical to an unaided eye. They can only be identified under a compound microscope. Even with the aid of a microscope, some species (especially females of related species) are still difficult to identify. Earlier identifications depended largely on Phlebotometry, i.e. measurement of various parts of phlebotomine sandflies. Today phlebotometry is the last resort for identical and even new species. More recent identifications combine the use of certain distinguishable characters. Some of these characters include:

(a) The distribution of erect hairs on the abdominal tergites (for grouping into genera)
(b) The nature of the pigmented plate and the number of the cibarial teeth.
(c) The nature of spermatheca, in case of females, and
(d) The nature of the male terminalia - the coxite and their processes, the style and the attached spines, the penile sheath and sometimes the parameres and the hairs attached to them.

The combination of characters a, b, and c are very useful for female identifications whereas the combination of a, b and d is good for the males.

Other useful identification guides include those of Kirk & Lewis (1951), Abonnenc (1972), Heisch et al (1956), Minter (1964), Quate (1964), Mutinga (1988 unpublished guide). Charts for the identification of males and females of various species are shown in appendices 2-4.

CHAPTER THREE

DETERMINATION OF THE BREEDING SITES OF *S. GARNHAMI*

3.1 Introduction

Sandflies generally breed in damp soils that are rich in humus (WHO 1984). Kirk and Lewis (1951) showed that they breed in such places as dark and damp cellars, caves, dug-outs, piles of rubbles of bricks, tiles and stones, crevices in damp stone walls, drains and banks of streams, cracks and fissures in the soil. Inspite of this information, it is extremely difficult to collect the eggs and other immature stages of sandflies in nature. This is because of their microscopic size, delicate nature and colour blending with the environment. Various authors have used direct microscopic examination of soil samples and sugar or salt floatation methods to isolate the immature stages of phlebotomine sandflies from soil samples collected from their suspected breeding sites. While these methods are sometimes cumbersome and time consuming, they also might not be satisfactory because of the individual ecological niches preferred by different species of sandflies. Moreso, most of the immature stages were recovered in distorted forms which made identifications difficult. This work was aimed at

investigating the breeding sites of *S. garnhami* at Tseikuru using soil incubation technique.

3.2 Study area

This study was carried out at Tseikuru Area in Kitui District of Kenya (fig 3.1). Kitui District is located in the Eastern Province with Kitui as the District Headquarters. Tseikuru is in the far North East of Kitui town with a distance of about 175km from the headquarters. Tseikuru is about 25km away from Usueni which is the northmost boundary town of Kitui District. It lies approximately within latitude 0° 20" S and 38° 10" E. It is a low-lying countryside about 500m above sea level. The soil is generally of red sandy type but patches of stony farmlands and rocky outcrops (tors) may be encountered. Also patches of bare soil due to combined effects of erosion, weathering and overgrazing could be seen in some areas.

The climate of the area could be described as hot and dry throughout the year. Hence Kitui district is synonymous with hot area to most Kenyans. Average daily temperature range is about 25-38°C throughout the year with February, September and October being the hottest months. The windy period between June and August have some cold spells especially in the evening and morning hours.

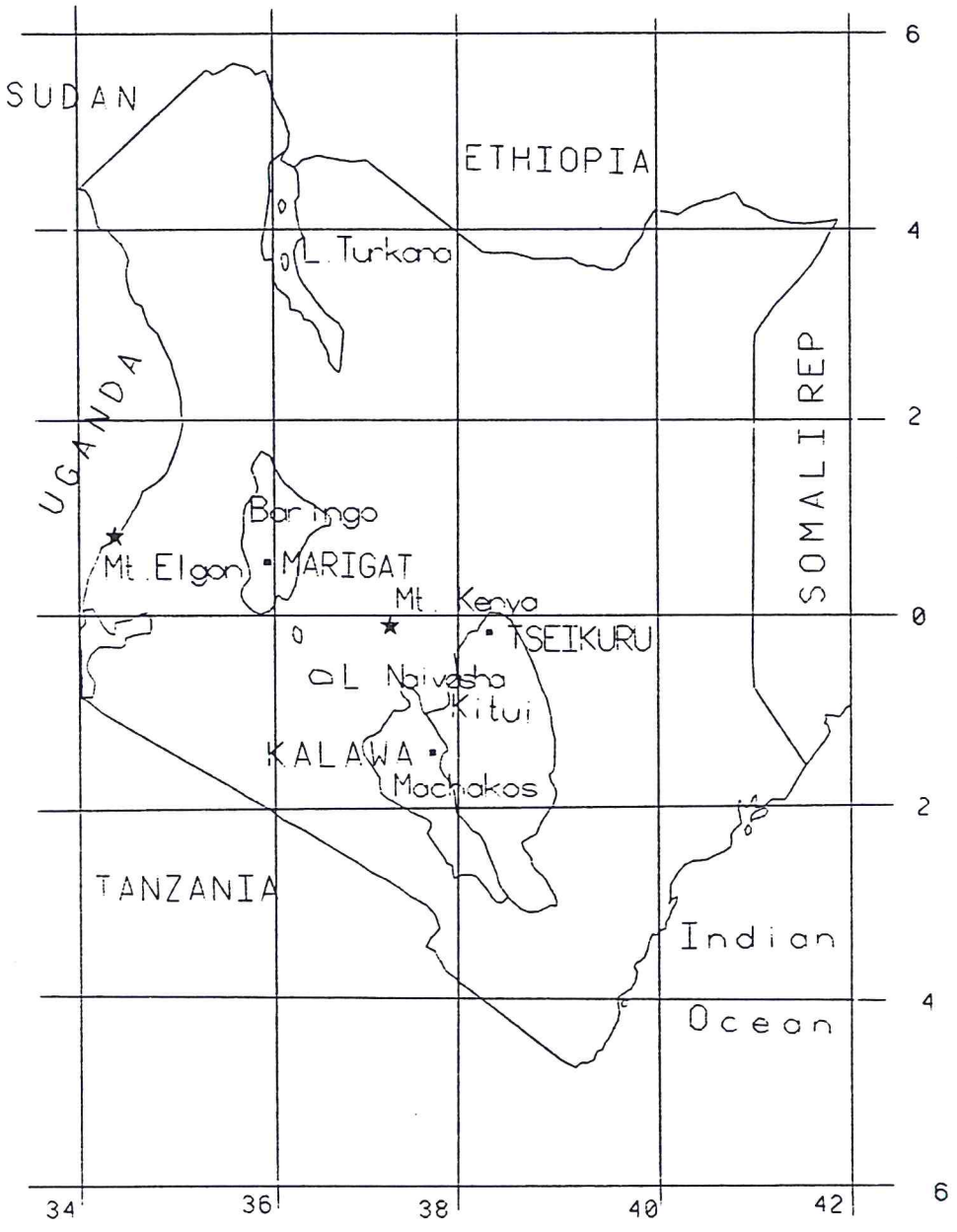


Fig 3.1 Map of Kenya showing Tseikuru in Kitui District and other leishmaniases endemic foci (Baringo and Machakos Districts).

There are two rainy and two dry seasons. The dry seasons occur from January to March and June to October whereas the rainy seasons are March-May and late October-December. The rains of March-May are light and unreliable for agricultural purposes. The October-December rains are heavier and more reliable for agricultural purposes. The average total annual rainfall obtained during the two years of study was 845 ± 124.31mm.

Drainage system is by numerous large water courses, River Nziitu, Muuna and Kyandani (fig 3.1a). These water courses are generally dry throughout the year though in some moments during the rains, raging torrents of erosion water from distant places, notably overflowing River Tana at Usueni, may be observed along these watercourses usually for a few hours. However, some of the watercourses may be regarded as subterranean rivers as they serve as permanent sources of drinking and domestic water to the inhabitants throughout the year. Water is collected just by scooping out sand to the depth of 0.5-3m depending on the season.

Tseikuru is a semi-arid rural area (Plate 3.1). The vegetation is generally sparse and consists mainly of thorny bush type with acacia trees being very dominant. Giant Baobab trees usually intersperse the thorny vegetation (Plate 3.2).

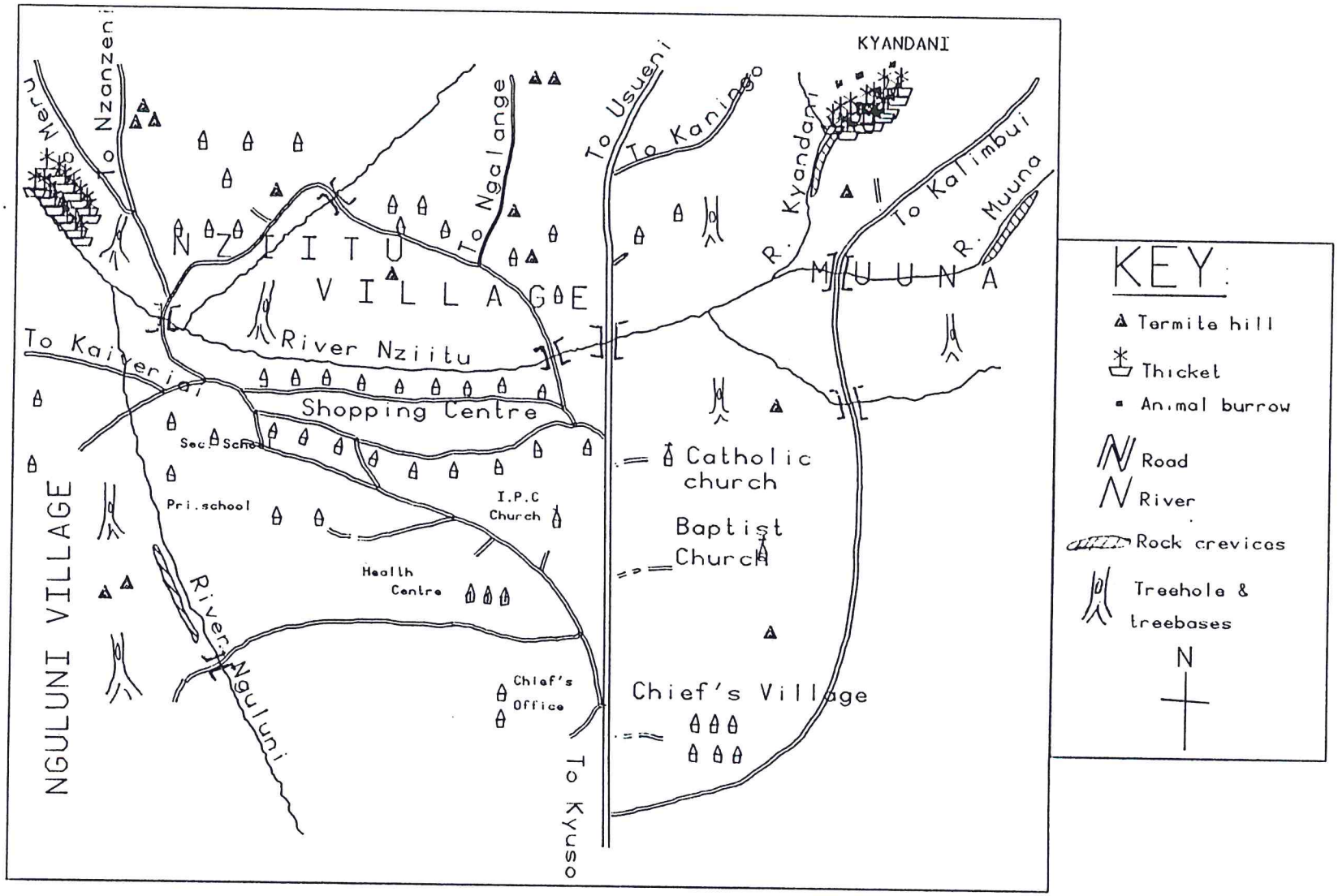


Fig. 3.1a: Map of Tseikuru Locality showing sites of study

Plate 3.1 Part of Tseikuru village

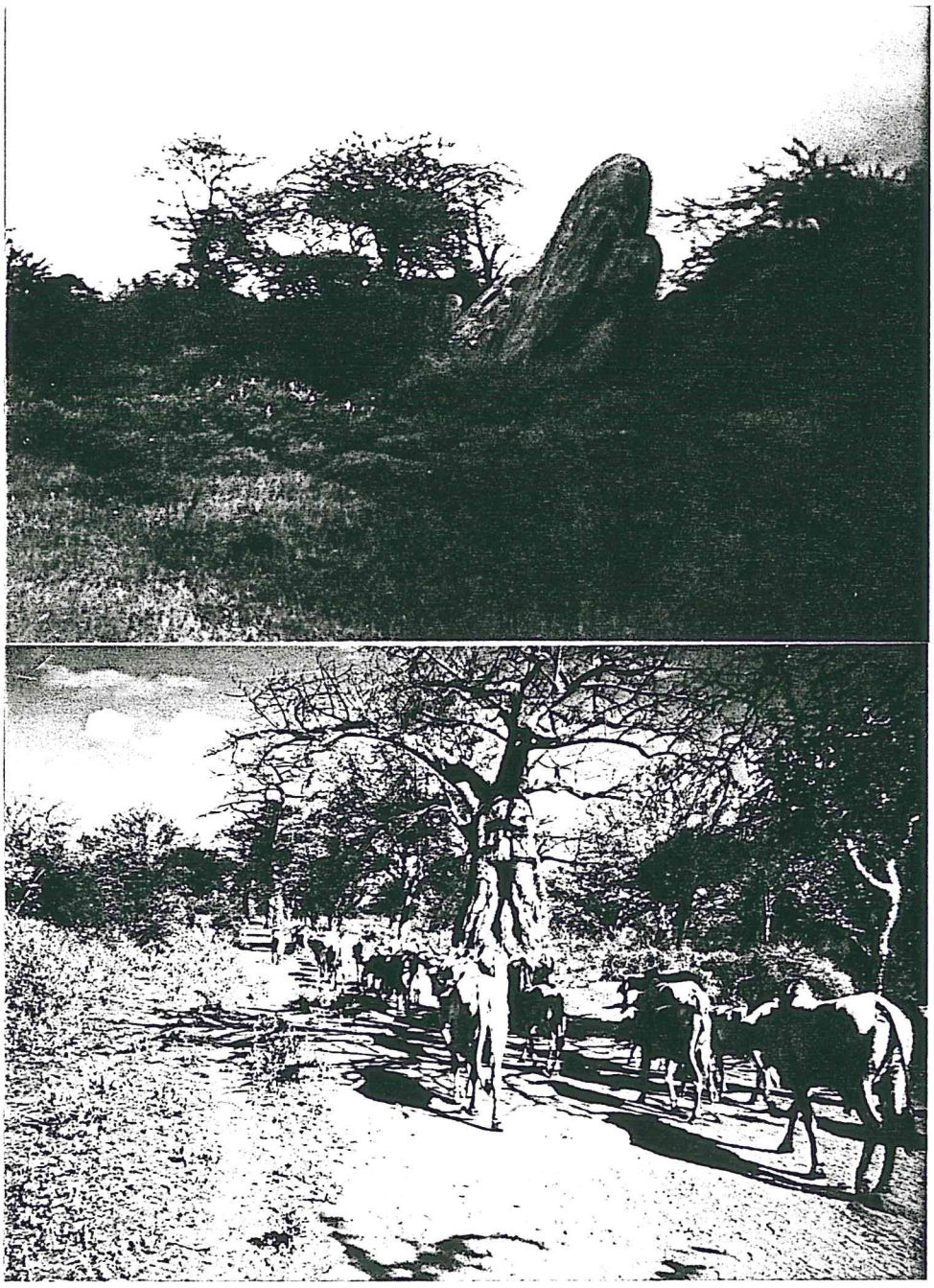


Plate 3.2 Aspects of vegetation and livestock of Tseikuru

Along the watercourses, dense discrete thickets of thorny bushes may be observed. Adjoining areas may be open woodland made up of shrubs with ground vegetation of grasses and herbs. Open woodlands further away from the watercourses have little or no undergrowth vegetation perhaps due to intense erosion, weathering and overgrazing by livestock.

During the dry seasons (January-March and June-November) most of the trees shade their leaves while the undergrowths including grasses and herbs wither and die. Intense heat and regular trampling by animals and humans cause them to break into tiny pieces that may be easily blown away by wind, and some of the dry herbs and grasses eaten up by the numerous livestock. This further exposes the soil to further erosion by weathering, water erosion and overgrazing. In the course of my stay I have personally witnessed strong windy period from June to August. This wind fills the air with dust particles and organic debris.

The inhabitants of Tseikuru and perhaps the whole North-Eastern province are known as Wakamba. They live in homesteads of 5-10 huts. Their buildings are mainly round huts of mud walls and thatched roof. Sometimes this could be a round hut of thatched roof and a framework of stick, (wooden fence). Around shopping centres (townships), rectangular buildings of mud bricks

or cement with corrugated iron roofs are now replacing the huts.

During the October-December agricultural period, millets, cow-pea beans and green grams are planted with millet being the staple crop. Bulls and donkeys are used as beasts of burden to plough the land. Manual cultivation with local hoes is also practised. The people also keep livestock mainly goats, cattle and sheep. These are usually herd by young boys and girls of 5-16 years and also young wives.

3.3 Materials and methods

3.3.1 Soil sampling procedure

Soil samples used for this study were collected from seventeen different ecological habitats namely:-

1. Rodent and small animal burrows (Rbu)
2. Large animal burrows (Ab)
3. Treeholes (Ht)
4. Treeshades(Ts)
5. Tree bases (Pb)
6. Grass vegetation (Gr)
7. Animal enclosures (Ae)
8. Termite hills fungus garden (Fg)
9. Termite hills ventilation shafts (Vs)

10. Soil from inside houses (Hse-in)
11. Soil from outside house (Hse-out)
12. Rock crevices soil from Kyandani area (Rck)
13. Rock crevices soil from Muuna (Rcm)
14. Rock crevices soil from Ngiluni (Rcg)
15. Soil from thicket floor (Thic)
16. Soil from riverbed (watercourse) (W)
17. Soil from chicken coop. (C)

3.3.1.1 Rodent and small animal burrows (Rbu)

Soil from rodent and small animal burrows was collected by carefully digging the burrow with digging tools such as hoe, fork and spade to the resting site of the animal (Plate 3.3). Soil from the walls and floor of the burrow was carefully scrapped and collected using either a spade or desert spoon or both. The soil was put in a plastic basin or a rectangular metal pan, covered with a fine-mesh of nylon net held tightly over the surface by an elastic rubber band on the sides and edges of the container. Then it was transported to the temporary laboratory.

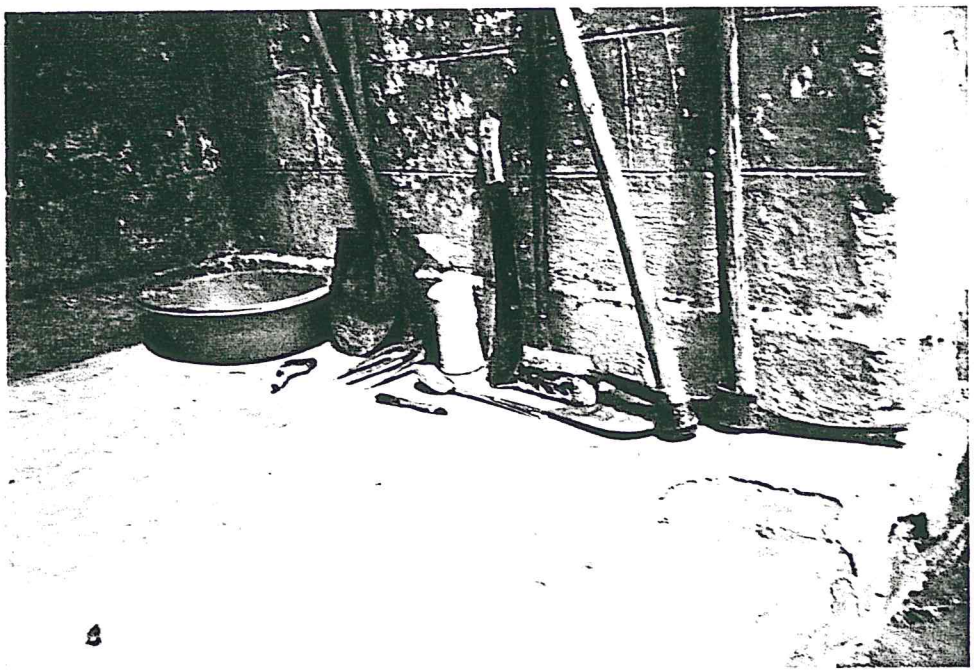


Plate 3.3 Implements for soil collection and processing

3.3.1.2 Large animal burrows (Ab)

Large animal burrows suspected to harbour such animals as Ant-deer (Aardavaak sp) were dug on a horizontal length of about 6 ft, the soil from the walls and floor of the tunnel was collected with spade into pails, covered with fine mesh nylon net and transported to the laboratory.

3.3.1.3 Treeholes (Ht)

Soil in the treeholes were either scooped out with the aid of desert spoon or were swept out with a broom or painters brush into a container, covered with the nylon net and transported to the laboratory (Plate 3.4).

3.3.1.4 Tree bases (Pb)

Top soil from the bases of big trees were carefully collected using spade, desert or table spoon. The soil were put in a container, covered with nylon mesh and transported to the laboratory (Plate 3.5).

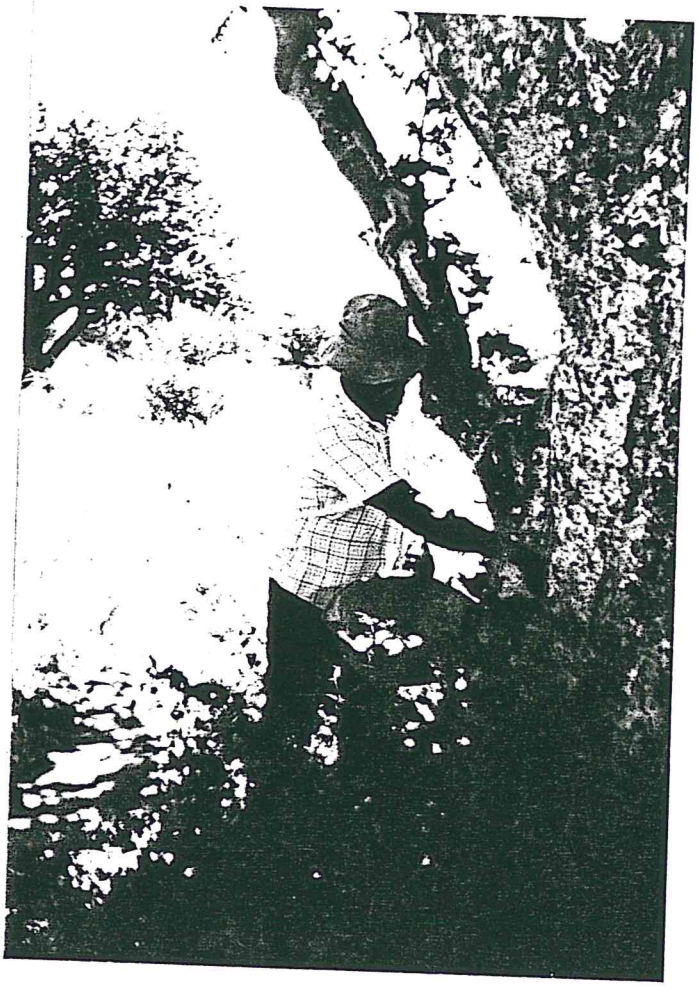


Plate 3.4 Scooping out soil from treehole using desert spoon

Plate 3.5 Collection of soil from tree bases

3.3.1.5 Grass Vegetation (Gr)

Grasses and herbs from a grass vegetation were cleared and the top soil not exceeding 10cm depth was collected into the container, covered with the nylon net and transported to the laboratory.

3.3.1.6 Animal Enclosures (Ae)

Animal enclosures are areas fenced with thorny twigs where animals (cattle, goats sheep and donkeys) are kept mainly in the night. Soil from the areas with thorough mixture of soil and animal dung as well as such areas with attractive dampness for sandflies to lay eggs was collected, prepared and sent to the laboratory.

3.3.1.7 Termite Hills (Fg & Vs)

During each experiment a selected sandfly-productive termite hill was dug to fungus garden level, following one or two prominent ventilation shaft(s). Digging was carefully carried out from one side and the ventilation shaft was gently cut open from that side (Plate 3.6). Loose soil accumulating in the shafts was swept into the container using brush. Top one centimetre of the surface soil of the walls of the ventilation shafts was scrapped with spade into the

container. Soil from the ventilation shafts were prepared and transported to the laboratory. Soil samples from the fungus garden of the same termite hill were prepared as separate samples.

3.3.1.8 Soil from inside and outside houses

Loose soil on the inside walls of houses were swept down with broom or brush. These were swept together with soil within one foot from the base of the walls and collected into a basin using desert spoon (Plate 3.7). Similarly loose soil on the outside walls were swept down and collected together with those within one foot from the base of the walls. Two to three huts were swept at each occasion to get enough soil for the experiment.

3.3.1.9 Rock crevices soil

Soil collections in crevices and spaces between rocks were scooped using spoons or swept together using brush or broom (Plate 3.8). The soil were put together in a plastic or metal basin and transported to our temporary laboratory in Tseikuru Health Centre for incubation.

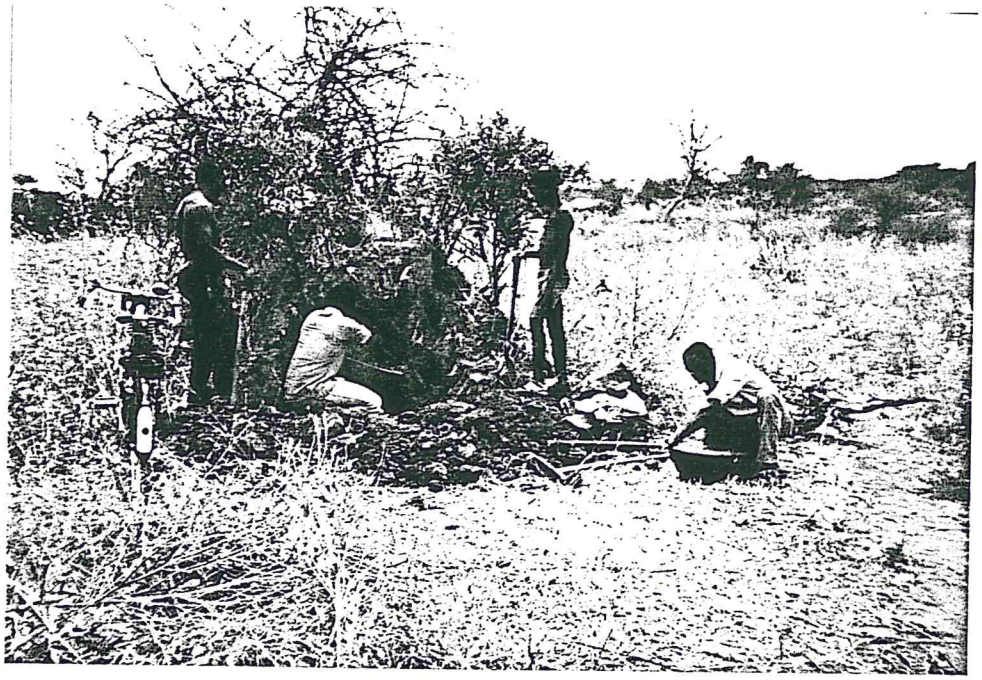


Plate 3.6 Collection of soil from termite hills

Plate 3.7 Collection of soil from outside walls of human dwellings

Plate 3.8 Collection of soil from rock crevices

3.3.1.10 Thicket floor Soil

Litters from the forest floor were cleared, top soil not deeper than 10cm was collected using spade, and or desert spoon into the containers, covered with nylon mesh and transported to the laboratory. Collection area was about 10m into the forest.

3.3.1.11 Chicken houses/coop (C)

The chicken coops were made of specially woven baskets, huts and earthen pots half burried into the soil to enhance stability (Plate 3.9). Soil and chicken droppings found in the pots were collected into a container using desert spoons or by turning the contents of the earthen pot right into a container, the sample was covered with nylon net and transported to the laboratory.

3.3.1.12 River bed Soil (W)

River bed soil was collected from selected corners of the large watercourse. About 10cm deep top soil was collected, covered with nylon net and transported to the laboratory.

An average of 15kg of soil sample per site were collected from various suspected breeding habitats of S.

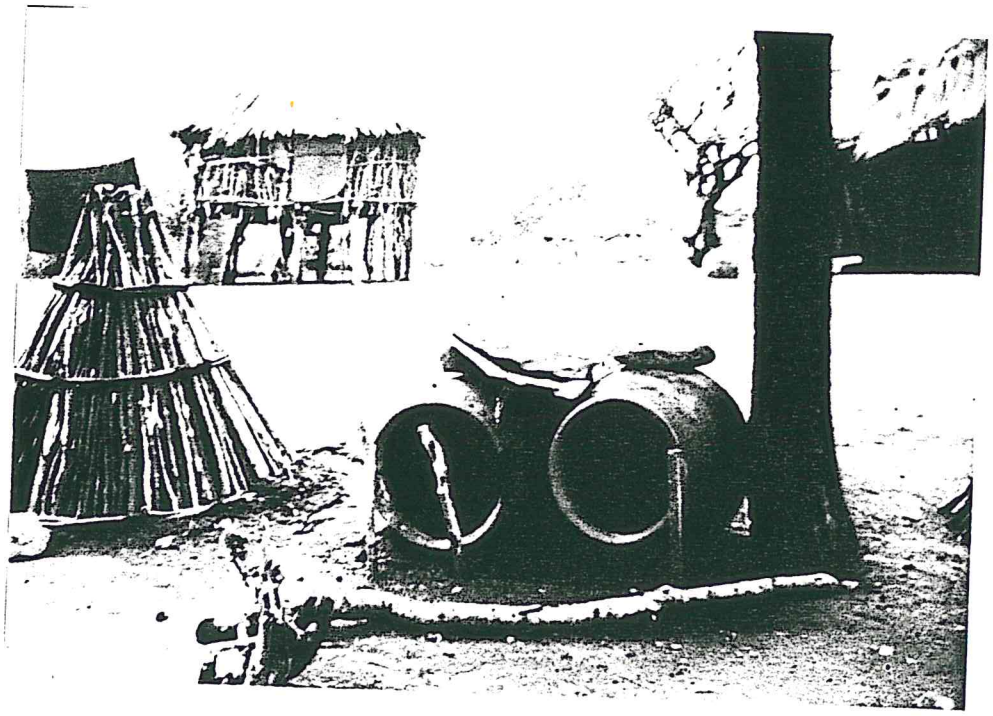


Plate 3.9 Chicken coops

garnhami and other phlebotomine sandflies and incubated in the laboratory for a minimum period of 90 days for the emergence of sandflies. Before incubation, each soil sample was vigorously shaken to remove debris and any adult flies collected in the field with the soil.

3.3.2. Laboratory processing of the soil samples

In the laboratory all the soil samples were weighed and an average of 15kg of each soil sample was used in the experiment except for the treehole samples which were between 10-12kg. The soil samples were shaken vigorously to remove debris and adult flies collected with the soil. All the soil samples were put in a rectangular metal basin about 660 cm^2. The samples were wetted thoroughly using insecticide spray bottles (pump). Water was released from the pumps in tiny jets and this gradually wetted the soil (Plate 3.10). Minimal light conditions and high relative humidity, were maintaned by covering all the soil samples with nylon netting and totally wrapped up in dark polythene sheets. The soil samples were kept at room temperature in the laboratory (Plate 3.11) for a minimum of 90 days.

The soil samples were checked twice daily between 0600-0700 hours and 1700-1800 hours. A fine net was hung over the checker to prevent escape of sandflies when each soil sample was opened (3.12). The soil

samples were wetted regularly during checks to replace water lost by evaporation and also to keep the condition of the experiment fairly constant.

The sandflies that emerged from the samples were washed in 1.0% detergent saline, rinsed in normal saline and mounted onto a microscopic slide with the aid of stereomicroscope using gum chloral mountant. The sandflies were identified under the compound microscope using x10 or x40 objectives. The identification parameters employed included the distribution of the erect hairs on the abdominal tergites, the stucture of cibarium and number of cibarial teeth and spermatheca for the females or the terminalia for the males. Plates 3.13 and 3.14 show the identification parameters *S.garnhami*.

3.3.3 Experimental design.

The study was carried out in bits of four experiments designed to locate the natural breeding sites of this species and also to study the events in the seasonality of *S garnhami*.

Experiment 1 was carried out from the third week of February 1989 to the second week of June the same year. It was intended to study the events in the life cycle of *S garnhami* immediately after the peak period of this species which is between November and January.

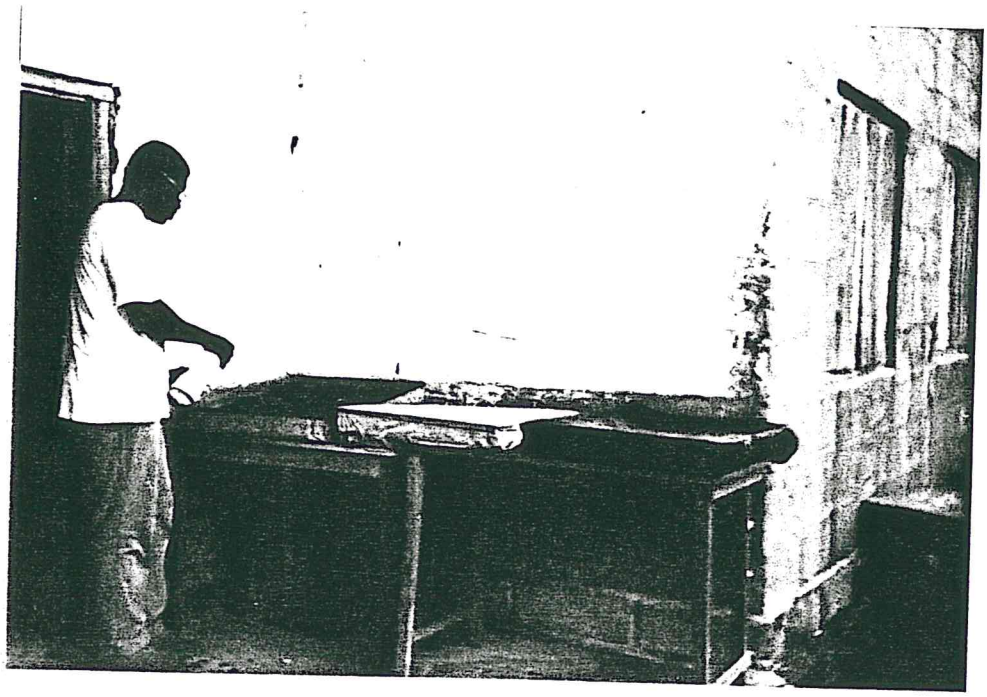


Plate 3.10 Preparation of soils for incubation in the laboratory for emergence of sandflies

Plate 3.11 Prepared soil samples wrapped in dark polythene sheets and incubated inside the laboratory at room temperature. The dark sheets were to provide darkness and maintain moisture.

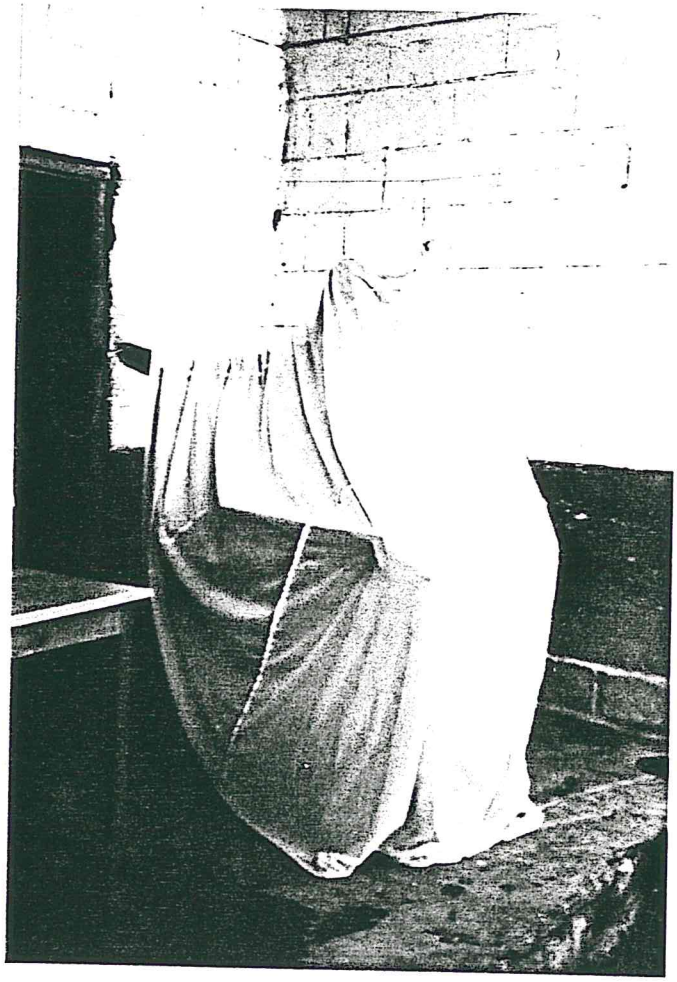


Plate 3.12 Checking soil samples for sandfly emergence with fine netting hung over the checker

Plate 3.13 Identification parameters of a female *S.garnhami*. 1. The head (h) showing the pharynx (p), and cibarial teeth (c). 2. The abdominal tergites (t) showing the spermatheca (s).

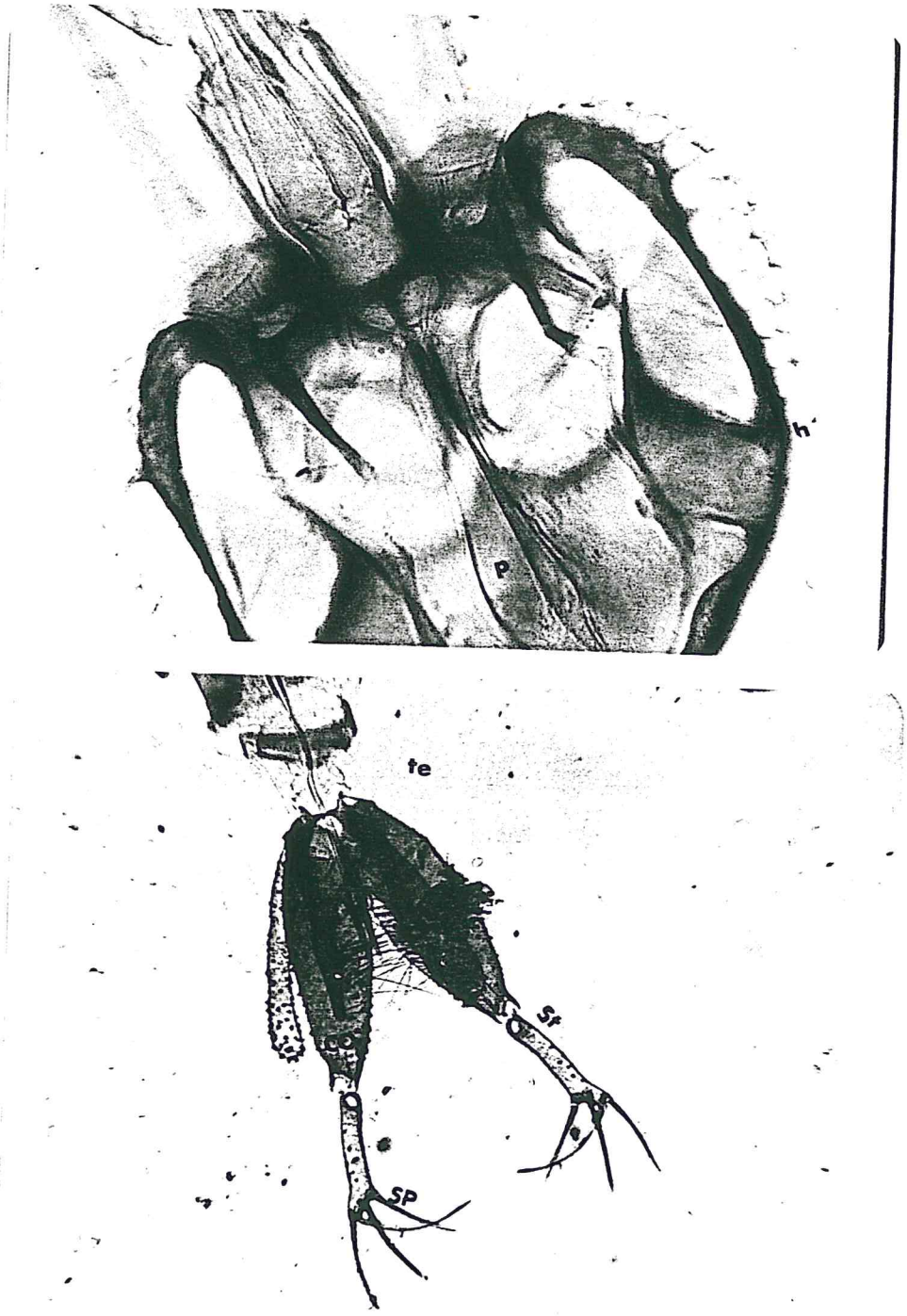


Plate 3.14 Identification parameters of a male *S.garnhami*. 1. The head (h) showing the pharynx (p), and the cibarial teeth (c). 2. The terminalia (te) comprising the coxite (co), the styles (st) and the spines (sp).

Experiment 2 was carried out between June and September 1989. It was meant to understand what happened from June when *S. garnhami* population is declining from the April-June peak period.

Experiment 3 was carried out from September 1989, the hottest period of the year and kept uptil December. It is a period when *S. garnhami* is presumably under diapause due to prolonged adverse hot weather conditons. It was meant to investigate if the provision of moisture would break diapause in the fly.

Experiment 4 was carried out from March to June 1990. It was intended to confirm the results of the first experiment (February-June 1989). All the experiments lasted for a minimum of 90 days.

3.4 Results

3.4.1 Experiment 1 (Feb-June)

Table 3.1 shows the data collected from the first experiment. A total of 665 sandflies were recovered from this investigation. 208 (or 31.28%) sandflies were recovered from soil sample of the termite hill fungus garden, 72 (or 10.83%) from treeshades and from rock crevices sample from Ngiluni area respectively, while 61 sandflies (or 9.17%) emerged from soil sample from animal enclosures and 43 (or 6.47%) from the inside

houses soil. Others included ventilation shafts of termite hills 27 (or 4.06%), rock crevices at Kyandani area 25 (or 3.78%), rock crevices at Muuna area and rodents and small animal burrows 24 (or 3.61%) respectively, large animal burrows 23 (or 3.46%), tree bases 22 (or 3.31%), outside houses 21 (or 3.16%), tree holes 19 (or 2.86%) grass vegetation 17 (or 2.56%) and thicket floor 7 (or 1.05%). No flies emerged from soils of the river bed and chicken houses. Analysis of variance showed that the sites were significantly different from one another (df = 14, F-value = 1.93, P = 0.028). Duncan's multiple range test also showed that fungus garden of the termite hills was significantly different from other sites (table 3.2).

A plot of *S.garnhami* numbers in relation to other phlebotomine sandflies that emerged from the differnt soil samples is shown in fig 3.2. *S.garnhami* was recovered in 9 soil samples. These were large animal burrows, animal enclosures,fungus garden and ventilation shafts of termite hills, treeholes, rock crevices from Ngilunu and Muuna areas, thickets and tree shades. Between one and three *S. garnhami* were recovered from each of the samples.

Thirteen sandfly species emerged from the soil samples studied (table 3.3). Total *S. bedfordi* recovered were 426 (or 64.06%) it was the most abundant species recovered. This was followed by *S. antennatus*

97 (or 14.57%), *S. schwetzi* 55 (or 8.27%) and *P. martini* 14 (or 2.11%). Because of the difficulty in morphological identification of the females of the *Synphlebotomus* species (*P.celiae, P.martini* and *P.vansomerenae*) the females were grouped under *Synphlebotomus*. This constituted 11 (or 1.65%) of the total species collected. Other species recovered included *S clydei* and *S.garnhami* 13 each (or 1.95%) *S.affinis* 8 (or 1.20%) *S.ingrami* 10 (or 1.50%), *S.kirki* and *S.squamipleuris* were 6 (or 0.90%) each, *P.vansomerenae* 3 (or 0.45%), *S.adleri* 2 (or 0.30%) and *S.christophersi* 1 (or 0.15%). No male of *P.celiae* was recovered from any of the soil samples (fig 3.3). Analysis of variance showed that the species were not significantly different from one another (df = 12, F-value =1.20, P= 0.2667) but the sandfly sexes significantly differed from each other (df = 1, F-value = 145.72, P = 0.0001***). Duncan's Multiple range test showed that significantly more females (mean = 0.32945, N = 479) than males (mean =0.28038, N = 479) emerged from the experiments. The period of sandfly emergence (day or night) was not significant (df = 1 , F-value = 2.02 P = 0.1557).

Figure 3.4 is a plot of the daily pattern of emergence of flies from experiment 1. Emergence of the first sandfly was observed on the 8th day from the start of incubation. This was followed by intermitent periods

Table 3.1 The number and percentage of sandflies recovered from the soil samples of various sites in experiment 1.

Site	No of sandflies recovered	Percent
Fungus garden	208	31.28
Treeshades	72	10.83
Rock crevices(Ngiluni)	72	10.83
Animal enclosure	61	9.17
Inside houses	43	6.47
Ventilation shaft	27	4.06
Rock crevices (Kyandani)	25	3.78
Rock crevices (Muuna)	24	3.61
Rodent burrows	24	3.61
Large animal burrows	23	3.46
Treebases	22	3.31
Outside houses	21	3.16
Treeholes	19	2.86
Grass vegetation	17	2.56
Thicket	7	1.05
River bed	0	0
Chicken coop	0	0
Total	665	100

Table 3.2 Comparison of sites by Duncans' Multiple Range Test (Experiment 1)

Duncan grouping		Mean	Site
	A	0.3238	Fungus garden
B	A	0.3043	Tree base
B	A	0.3039	Animal enclosure
B	A	0.3038	Tree shade
B	A	0.3006	Rock crevices Ngiluni
B	A	0.3004	Rock crevices Muuna
B	A	0.3000	Rodent burrows
B	A	0.2995	Rock crevice Kyandani
B	A	0.2988	Inside houses
B	A	0.2974	Tree holes
B	A	0.2959	Animal burrows
B	A	0.2945	Outside houses
B	A	0.2934	Grass vegetation
B	A	0.2920	Ventilation shaft
B		0.2898	Thicket floor

Table 3.3 Sandfly species recovered from the soil samples of various sites in experiment 1

Species	No of sandflies recovered	Percent
P.martini	14	2.11
P.vansomerenae	3	0.45
Synphlebotomus females	11	1.65
S.adleri	2	0.30
S.affinis	8	1.20
S.antennatus	97	2.11
S.bedfordi	426	64.06
S.christophersi	1	0.15
S.clydei	13	1.95
S.garnhami	13	1.95
S.ingrami	10	1.50
S.kirki	6	0.90
S.schwetzi	55	8.27
S.squamipleuris	6	0.90

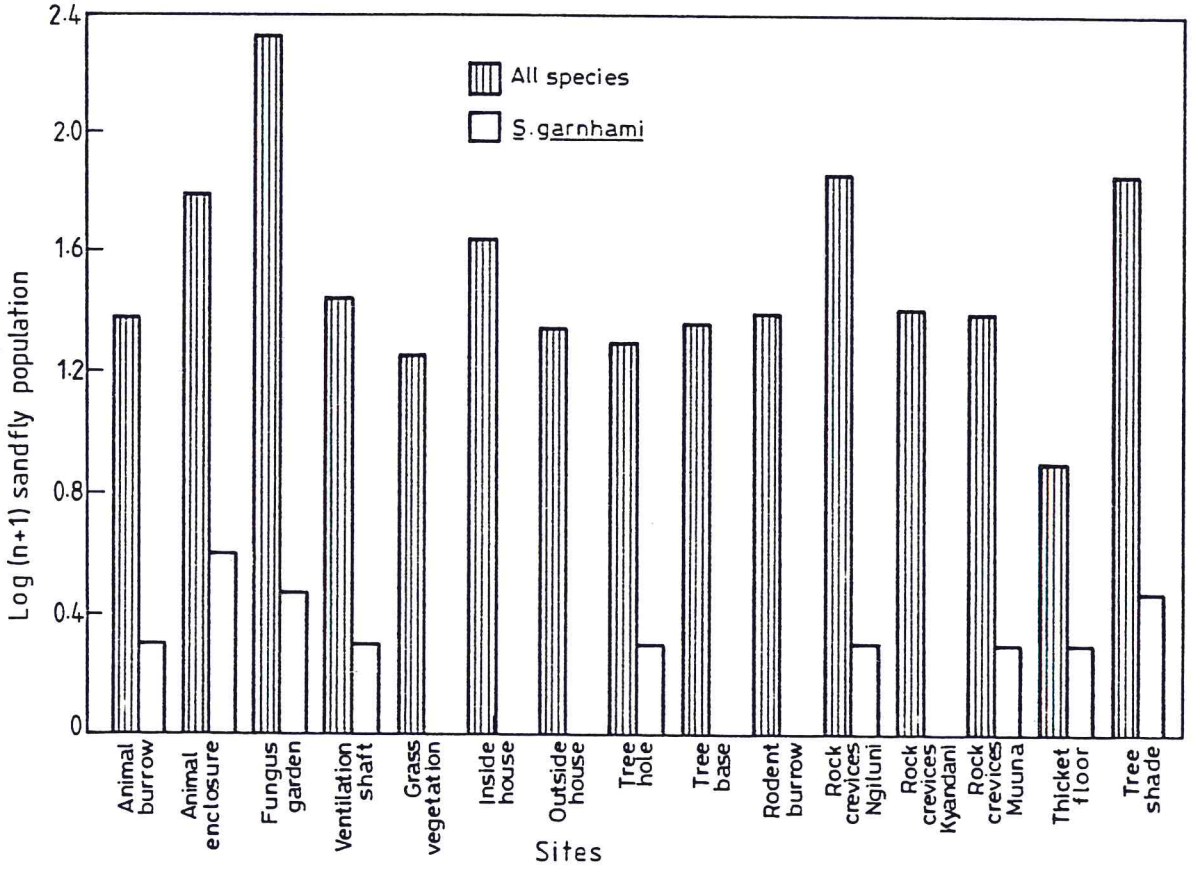


Fig 3.2 *S. garnhami* and other phlebotomine sandfly species recovered from soil samples of various sites (experiment 1, Feb–June 1989)

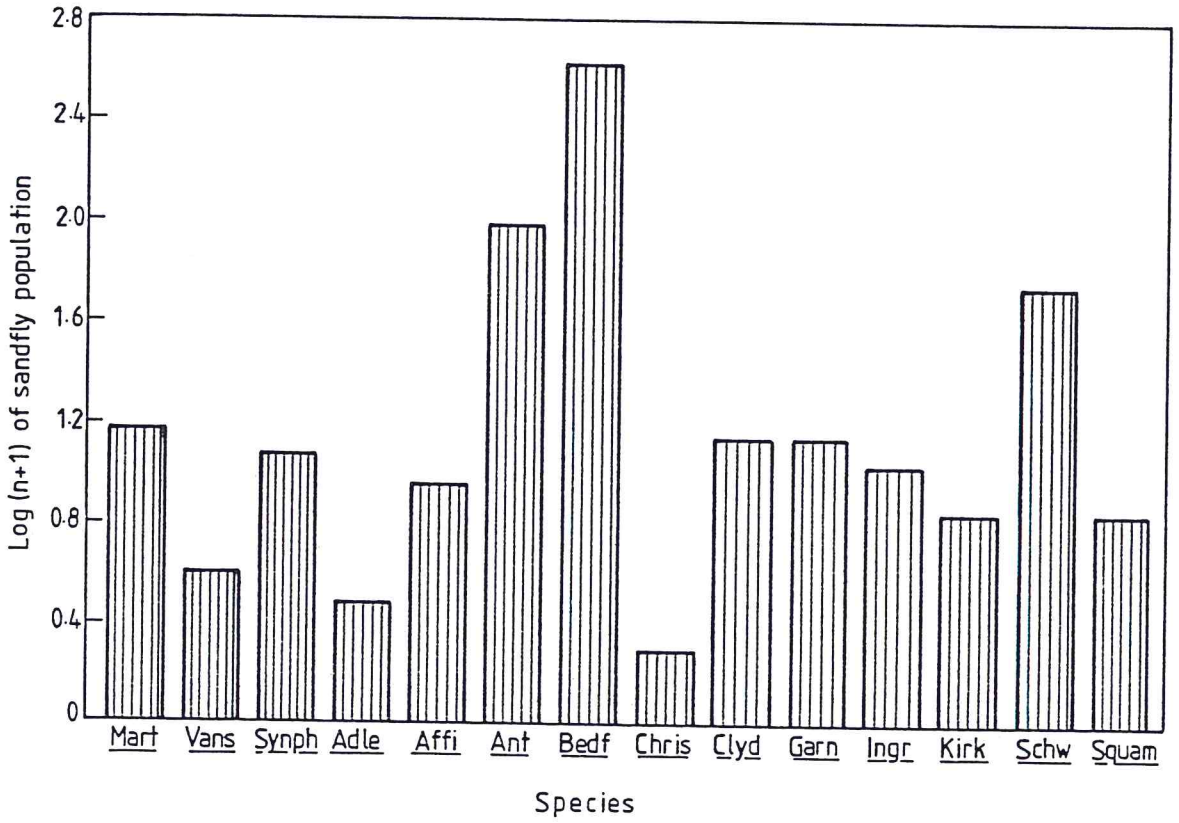


Fig 3.3 Phlebotomine sandfly species recovered from soil samples of various sites (experiment 1, Feb–June 1989)

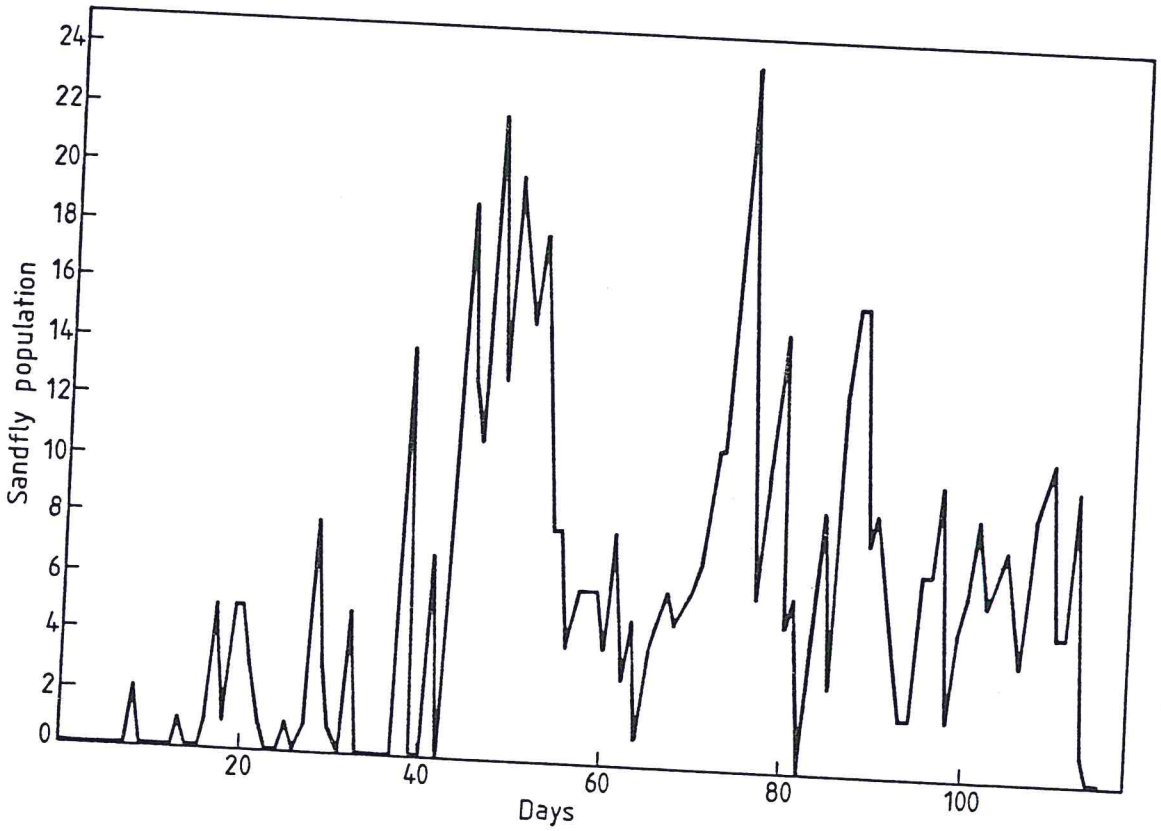


Fig 3.4 Daily pattern emergence of sandflies from various soil samples incubated (experiment 1, Feb–June 1989)

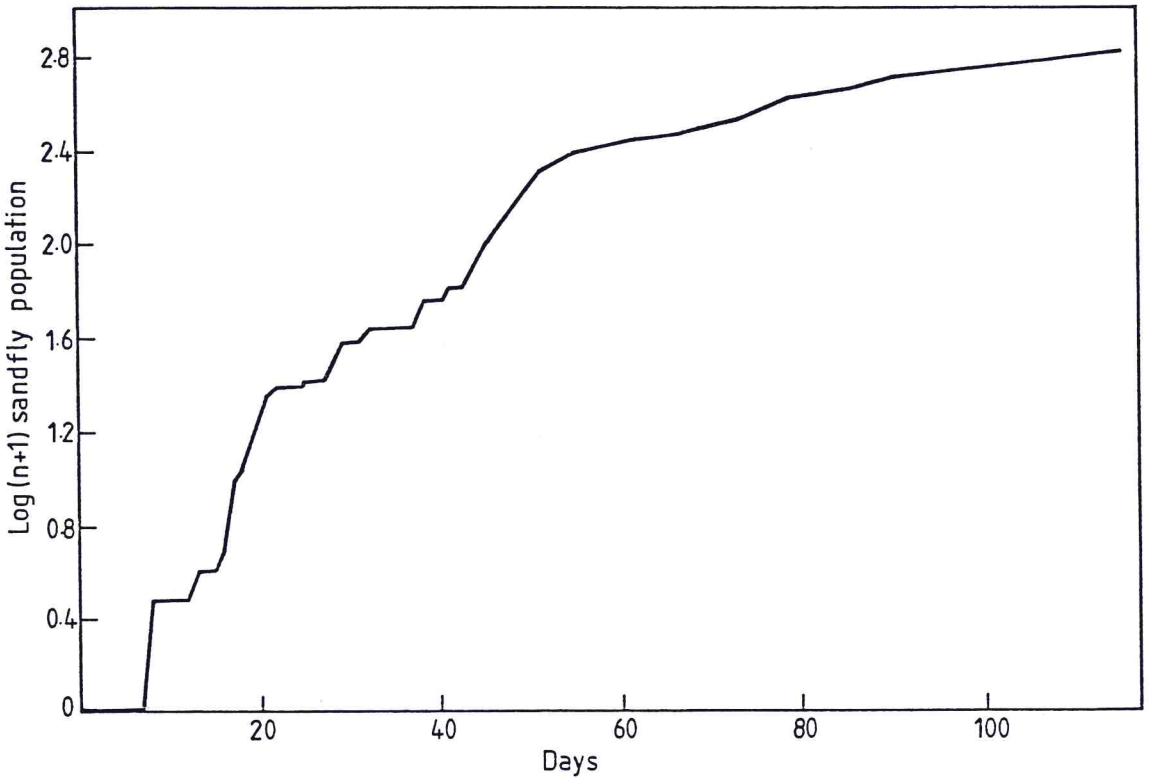


Fig 3.5 Daily cumulative emergence of sandflies from various soil samples incubated (experiment 1, Feb–June 1989)

of emergence and non-emegence of sandflies until day 40 to day 80 when most of the flies emerged. After, there was continued fluctuatons and declining emergence of the sandflies until the end of the study. Sandflies continued to emerge from the soil samples uptil 115th day when the study was stopped. The first *S. garnhami* emerged on the 61st day whereas the last was on the 83rd day. A plot of log(n+1) of sandfly daily cumulative emergence against days (fig 3.5) revealed an initial delay after incubation followed by a rapid increase in sandfly emergence which gradually started to level from day 60 A calculation of 50% (333 out of 665) emergence showed this to be on the 72nd day (log 333+1=2.52375).

3.4.2. Experiment 2 (June-Sept)

Table 3.4 shows the number and percentage of sandflies that emerged from this experiment. A hundred and twenty phlebotomine sandflies were recovered. No sandflies emerged from the soil samples from the large animal burrows, chicken coops and river beds. 24 (or 20.0%) were recovered from the tree shades soil, 19 (or 15.83%) from tree bases and 16 (or 13.33%) from rock crevices from Muuna area. Other soil samples from which sandflies were recovered included thicket floor soil 14 (or 11.67%), inside houses 8 (or 6.67%), fungus garden 7 (or 59.83%), and rodent and small animal burrows 6 (or

5.00%). Termite hill ventilation shaft, grass vegetation and rock crevices from Kyandani area each yielded 5 flies (or 4.17%). Soil from treeholes yielded 4 (or 3.33%), outside houses soil and those of rock crevices from Ngilunu yielded 3 (or 2.5%) each. One sandfly (or 0.83%) emerged from the soil collected from animal enclosures. Analysis of variance showed that the sites were not significantly different from one another (df = 13, F-value = 0.11, P = 1.000).

Fig 3.6 is a plot *S.garnhami* numbers in relation to other phlebotomine sandflies recoverd from each soil sample. No *S. garnhami* emerged from any of the samples.

Six species were collected from the samples (table 3.5). Again all the females of the *Synphlebotomus* species were grouped under *Synphlebotomus*. The species were *S.bedfordi* 103 (or 85.83%), *S.antennatus* 10 (or 8.3%), *P.martini* 3 (or 2.5%), *Synphlebotomus* females 2 (or 1.67%), *S.affinis* and *S.schwetzi* 1 (or 0.83%) respectively. Figure 3.7 shows all the sandflies that emerged from different soil samples in this experiment. Analysis of variance showed that the species were not significantly different from one another (df = 5, F-value =0.06, P= 0.9976) but the sandfly sexes significantly differed from each other (df = 1, F-value = 25.81, P = 0.0001***). Duncan's Multiple range test showed that significantly more females (mean = 0.31679, N = 105) than males (mean =0.27402, N = 105) emerged

Table 3.4 The number and percentage of sandflies recovered from the soil samples of various sites in experiment 2

Site	No of sandflies recovered	Percent
Fungus garden	7	5.9
Treeshades	24	20.0
Rock crevices (Ngiluni)	3	2.5
Animal enclosure	1	0.83
Inside houses	8	6.6
Ventilation shaft	5	4.17
Rock crevices (Kyandani)	5	4.17
Rock crevices (Muuna)	16	13.33
Rodent burrows	6	5.00
Large animal burrows	0	0
Treebases	19	15.83
Outside houses	3	2.5
Treeholes	4	3.33
Grass vegetation	5	4.17
Thicket	14	11.6
River bed	0	0
Chicken coop	0	0
Total	120	100

Table 3.5 Sandfly species recovered from the soil samples of various sites in experiment 2.

Species	No of sandflies recovered	Percent
P.martini	3	2.5
Synphlebotomus females	2	1.6
S.affinis	1	0.83
S.antennatus	10	8.3
S.bedfordi	103	85.83
S.schwetzi	1	0.83

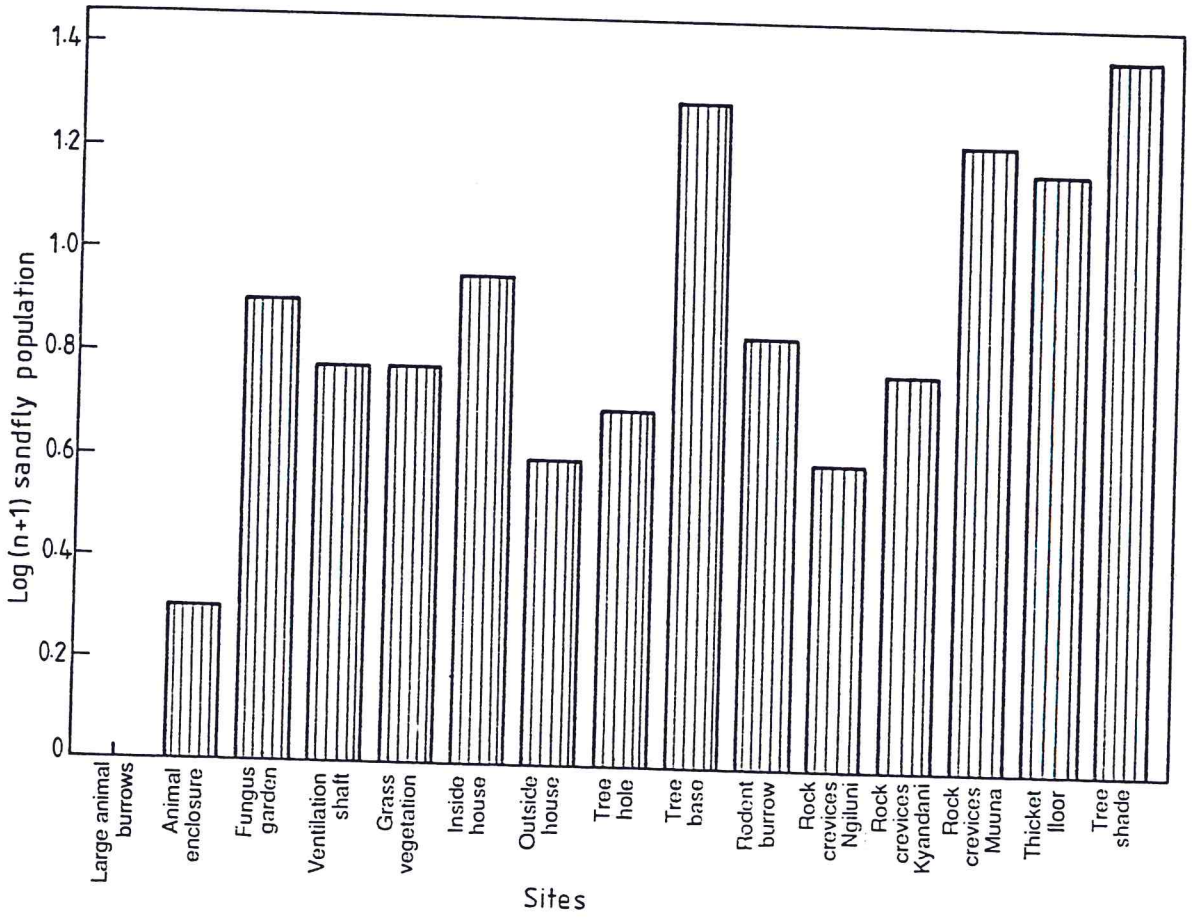


Fig 3.6 *S. garnhami* and other phlebotomine sandfly species recovered from soil samples of various sites (experiment 2, June–Sept 1989)

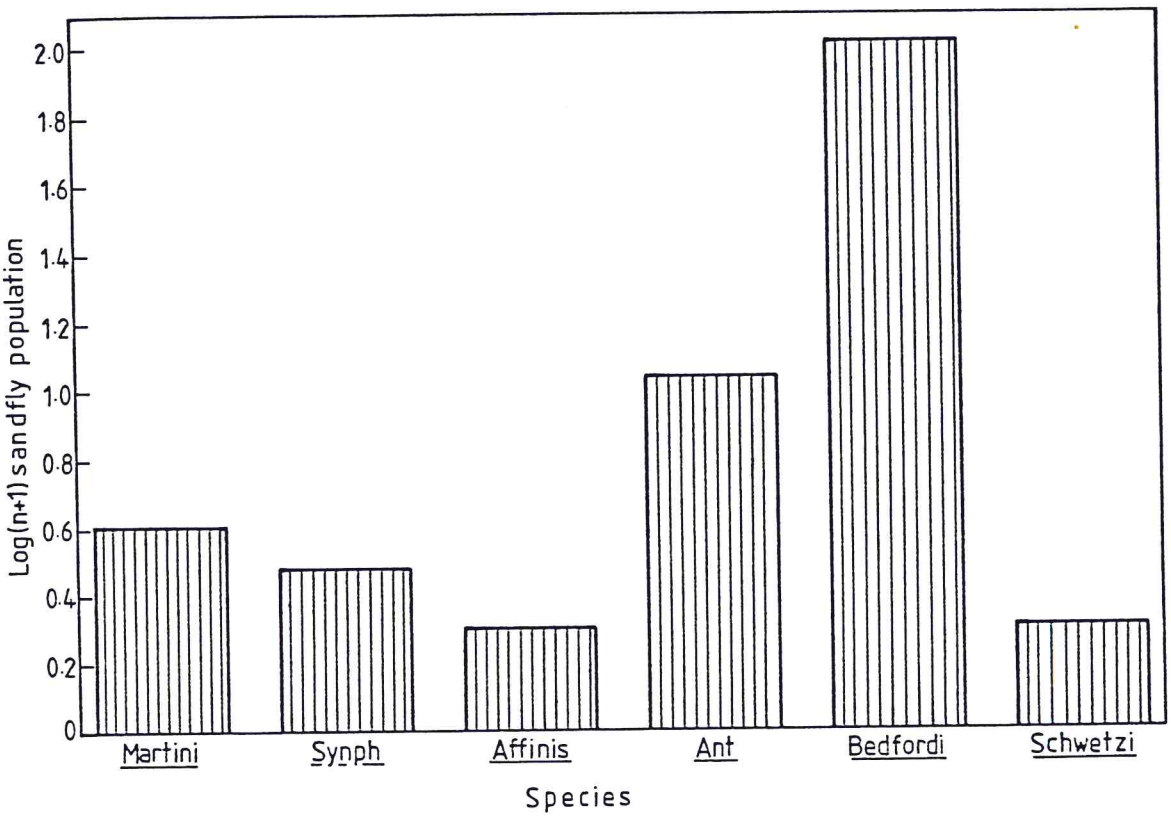


Fig 3.7 Phlebotomine sandfly species recovered from soil samples of various sites (experiment 2, June–Sept 1989)

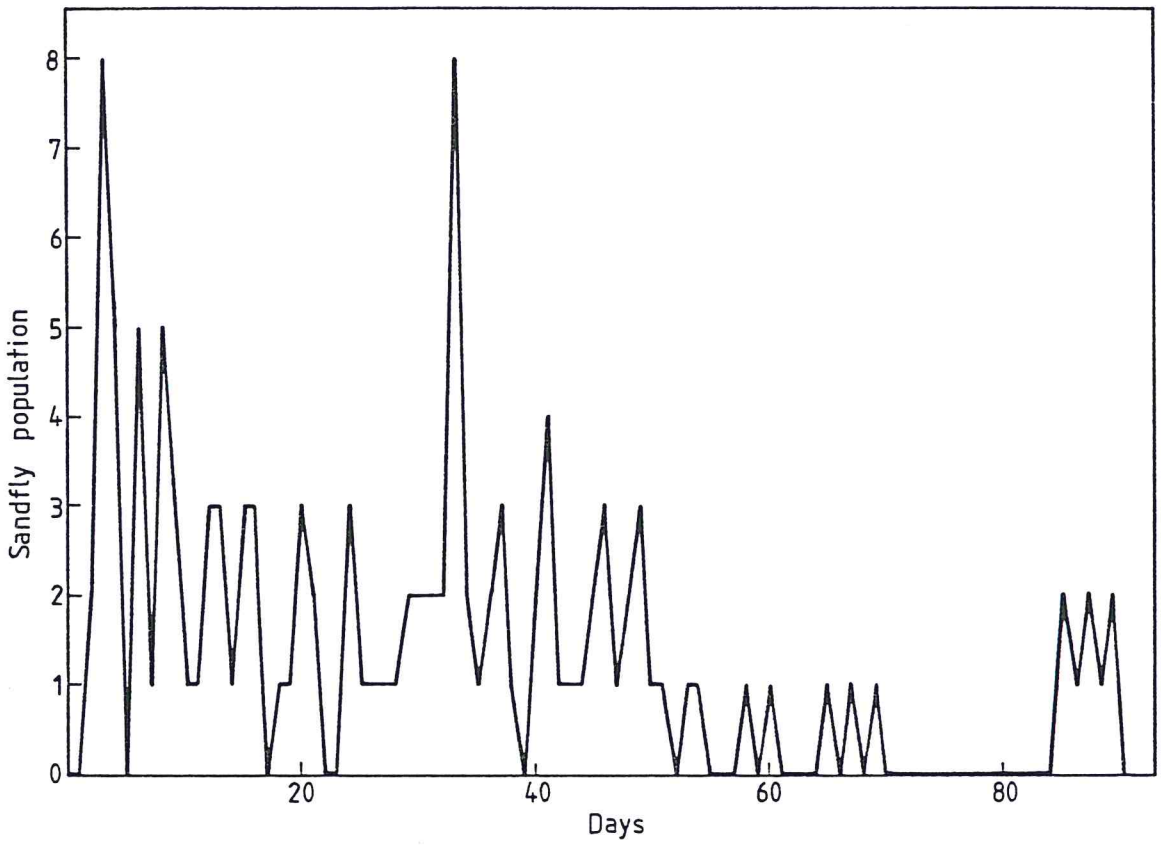


Fig 3.8 Daily pattern emergence of sandflies from various soil samples incubated (experiment 2, June–Sept 1989)

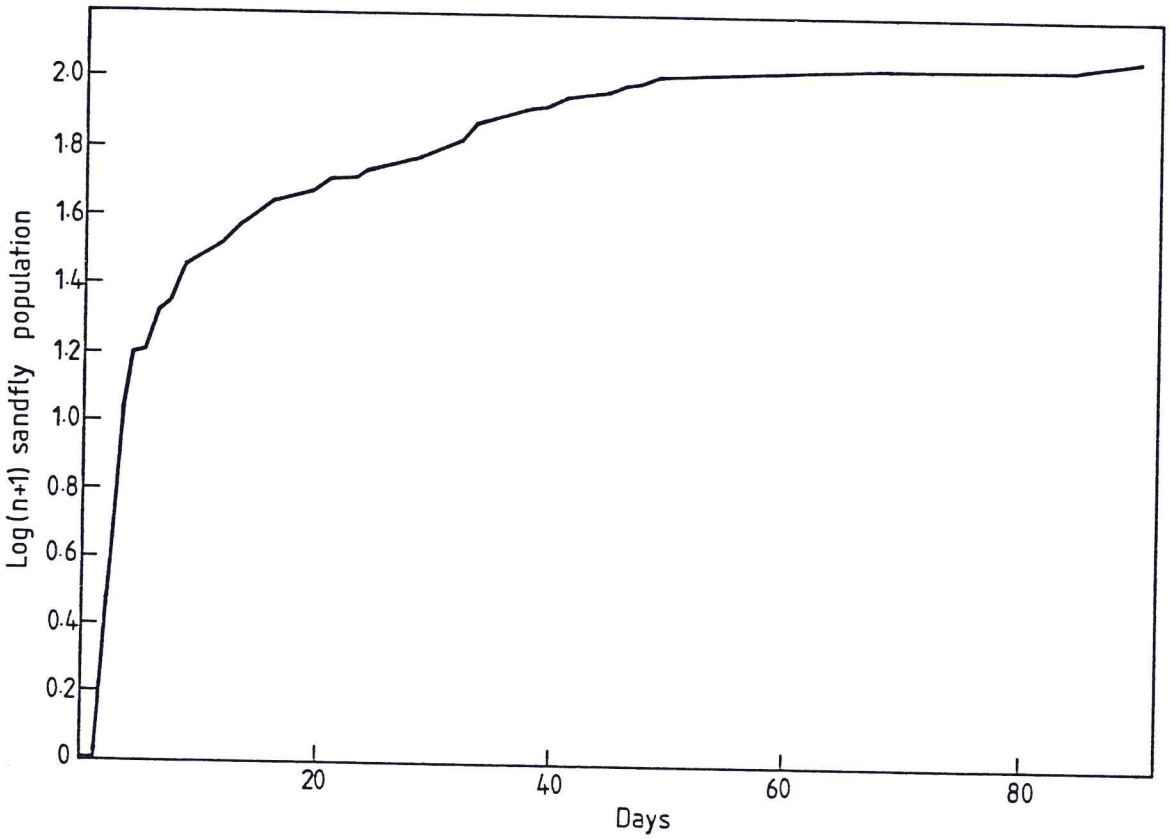


Fig 3.9 Daily cumulative emergence of sandflies from various soil samples incubated (experiment 2, June–Sept 1989)

from the experiments. The period of sandfly emergence (day or night) was not significant (df = 1 , F-value = 0.39, P = 0.5506).

A plot of sandfly daily emergence pattern (fig 3.8) showed that sandflies started emerging from the 2nd day of the experiment and continued progressively uptil day 50. Most of the sandflies emerged during this period. After there was a fluctuating decline in sandfly emergence until the end of the study in September . A plot of log(n+1) of sandfly daily cumulative emergence (Fig 3.9) also showed a trend of rapid emergence of many sandflies from the start of the experiment. This continued until about day 40 when it started to level off . A calculation of 50% (or 60 out of 120) sandfly emergence showed this to have occured on day 35 (log 60+1=1.7853).

3.4.3 Experiment 3 (Sept Dec)

Table 3.6 shows the number and percentage of sandflies recovered from various soil samples. A total of 137 sandflies emerged from all the soil samples investigated. 27 (or 19.71%) emerged from thicket floor soil, 22 (or 16.06%) from rock crevices soil from Muuna area, 13 (or 9.49%) from inside houses soil, and 11 (or 8.03%) from soil samples of grass vegetation and tree holes respectively. 10 (or 7.30%) emerged from big

animal burrow soil, 8 (or 5.84%) from termite hill fungus garden and rock crevices soil sample from Kyandani area respectively. Other samples from which sandflies emerged included rock crevices soil from Ngilunu area 7 (or 5.12%), outside houses soil and rodent and small animal burrows 5 (or 3.65%) respectively, ventilation shafts and tree bases 4 (or 2.92%) each. Tree shades yielded 2 (or 1.46%). Analysis of variance showed that the sites were not significantly different from one another (df = 13, F-value = 0.09, P = 1.000).

Fig 3.10 is a plot of *S.garnhami* in relation to other phlebotomine sandflies recoverd from various soil samples *S.garnhami* was recovered from 10 sites. These were the big animal burrows, grass vegetation, inside houses, outside houses, rodent and small animal burrows and the rock crevices samples from Kyandani, Muuna and Ngilunu areas. The other sites were thicket floor and tree shade soil samples .

Nine sandfly species were recovered from this experiment (table 3.7). These were *S.bedfordi* 75 (or 54.74%), *S.antennatus* 22 (or 16.06%), *S. garnhami* 15 (or 10.95%), *S.schwetzi* 9 (or 6.57%), *S.kirki* 5 (or 3.65%), *S.clydei* 4 (or 2.92%), *S.affinis* 3 (or 2.19%). Other species included *P.martini* and *S ingrami* 2 (or 1.46%) respectively (fig 3.11). No females of the *Synphlebotomus* species were recovered. Analysis of

variance showed that the species were not significantly different from one another (df = 5, F-value =0.06, P= 0.9976) but the sandfly sexes significantly differed from each other (df = 1, F-value = 13.89, P = 0.0002***). Duncan's Multiple range test showed that significantly more females (mean = 0.30770, N = 126) than males (mean =0.27893, N = 126) emerged from the experiments. The period of sandfly emergence (day or night) was not significant (df = 1 , F-value = 0.00, P = 0.9966).

Figure 3.12 is a daily sandfly emergence pattern plot. It showed that an initial delay of about 10 days from the beginning of the study before the first fly emerged. There was no emergence for another 20 days after which emergence of many flies started in earnest. However, most of the flies emerged between day 50 and 100 when the study was stopped. The first *S.garnhami* emerged on the the 73rd day and more continued to emerge uptil the 85th day. A log (n+1) plot of sandflies daily cumulative emergence also showed the initial delays until the 27th day when many flies started emerging. This continued until the 40th day when high but [illegible] number of flies continued to emerge uptil the end of the study (fig 3.13). A calculation of 50% emergence (69 out of 137 sandflies) showed that this occured on the 65th day (log 69+1= 1.8451).

Table 3.6 The number and percentage of sandflies recovered from the soil samples of various sites in experiment 3

Site	No of sandflies recovered	Percent
Fungus garden	8	5.84
Treeshades	2	1.46
Rock crevices(Ngiluni)	7	5.12
Animal enclosure	0	0
Inside houses	13	9.49
Ventilation shaft	4	2.92
Rock crevices (Kyandani)	8	5.84
Rock crevices (Muuna)	22	16.06
Rodent burrows	5	3.65
Large animal burrows	10	7.30
Treebases	4	2.92
Outside houses	5	3.65
Treeholes	11	8.03
Grass vegetation	11	8.03
Thicket	27	19.71
River bed	0	0
Chicken coop	0	0
Total	137	100

Table 3.7 Sandfly species recovered from the different soil samples in experiment 3

Species	No of sandflies recovered	Percent
P.martini	2	1.46
S.affinis	3	2.19
S.antennatus	22	16.06
S.bedfordi	75	54.74
S.clydei	4	2.92
S.garnhami	15	10.95
S.ingrami	2	1.46
S.kirki	5	3.65
S.schwetzi	9	6.57

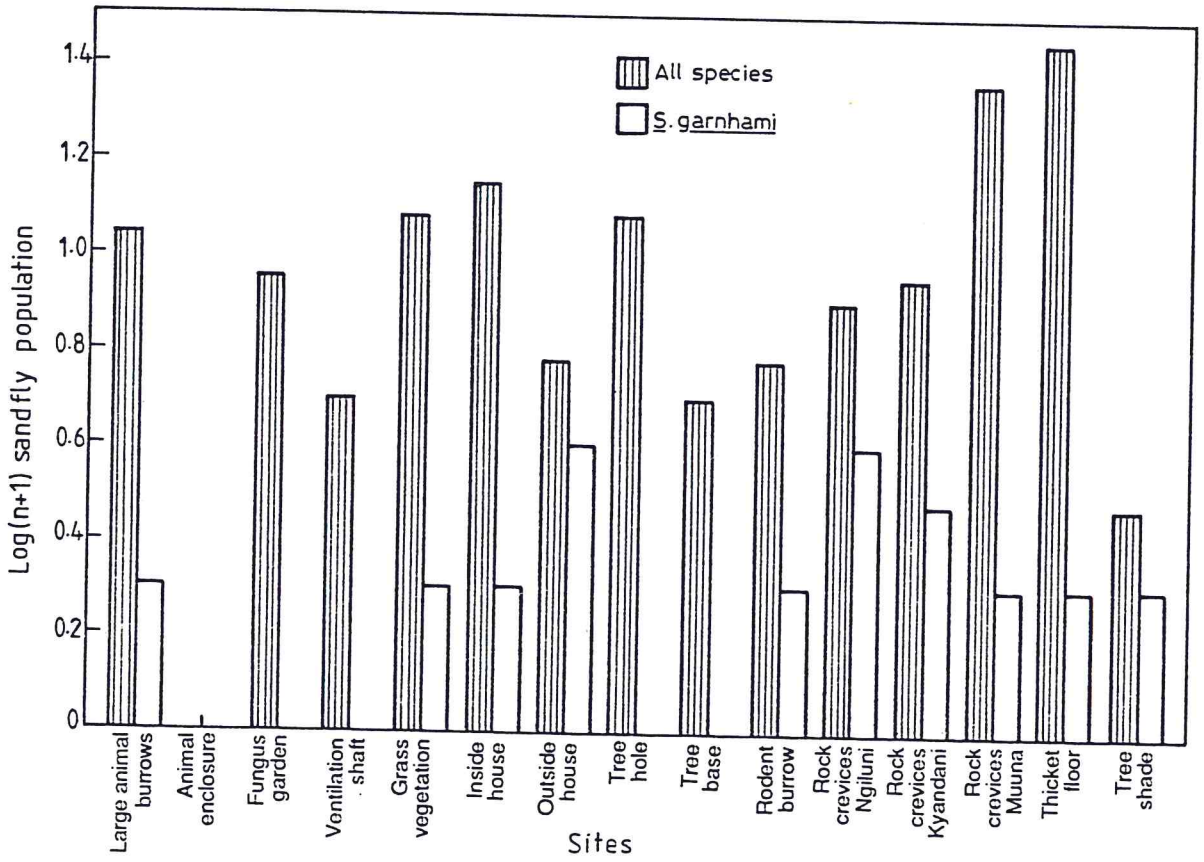


Fig 3.10 *S. garnhami* and other phlebotomine sandfly species recovered from soil samples of various sites (experiment 3, Sept–Dec 1989)

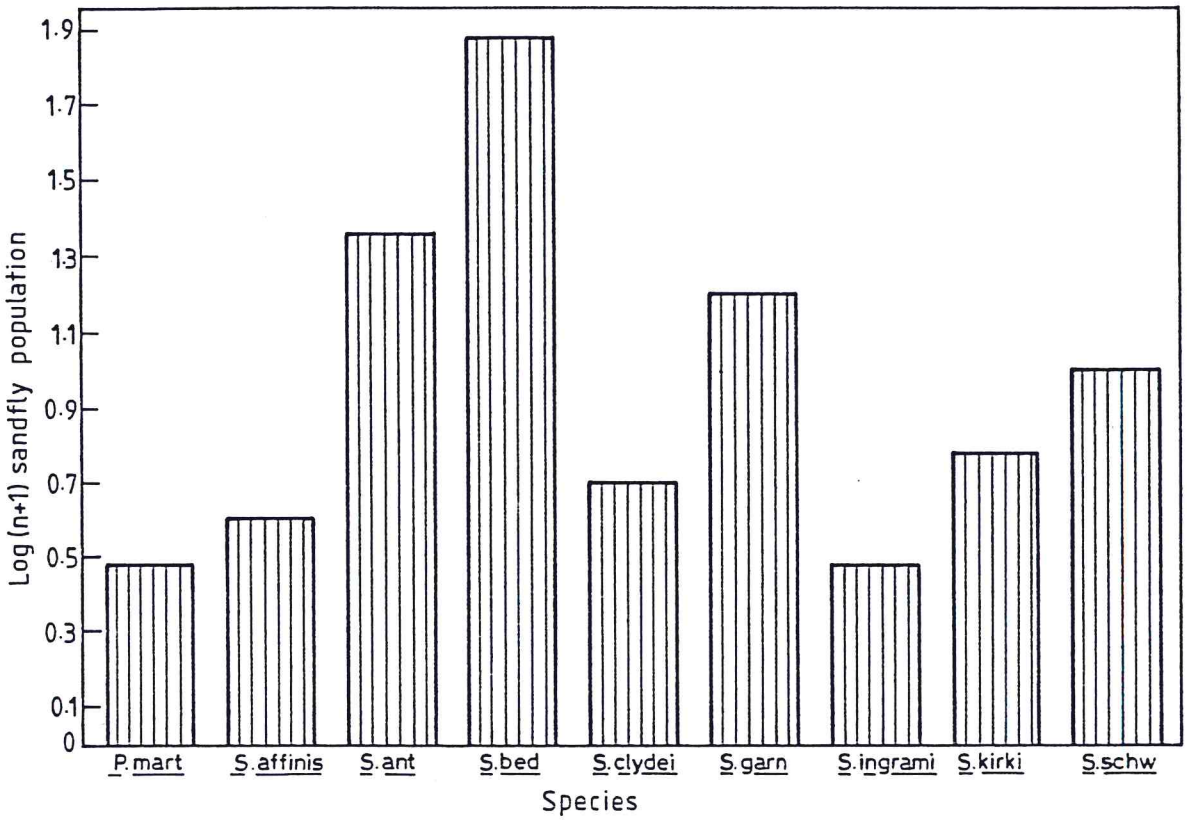


Fig 3.11 Phlebotomine sandfly species recovered from soil samples of various sites (experiment 3, Sept–Dec 1989)

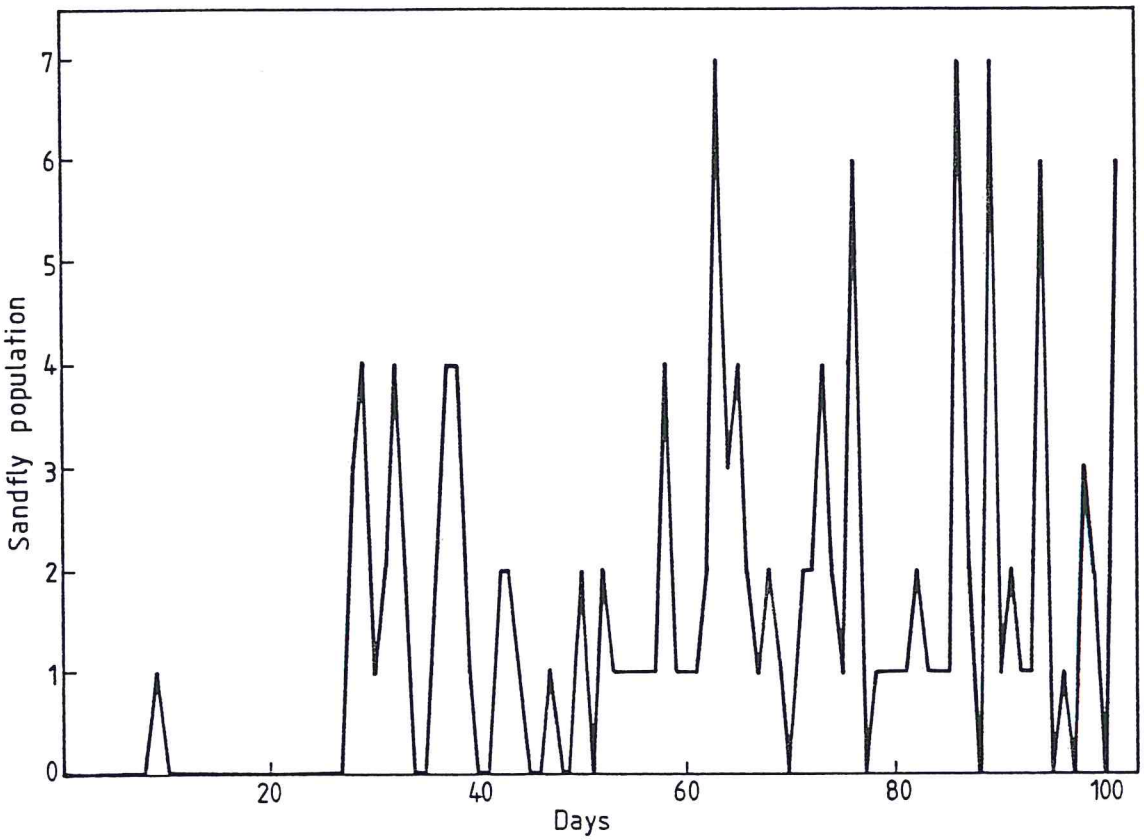


Fig 3.12 Daily pattern emergence of sandflies from various soil samples incubated (experiment 3, Sept–Dec 1989)

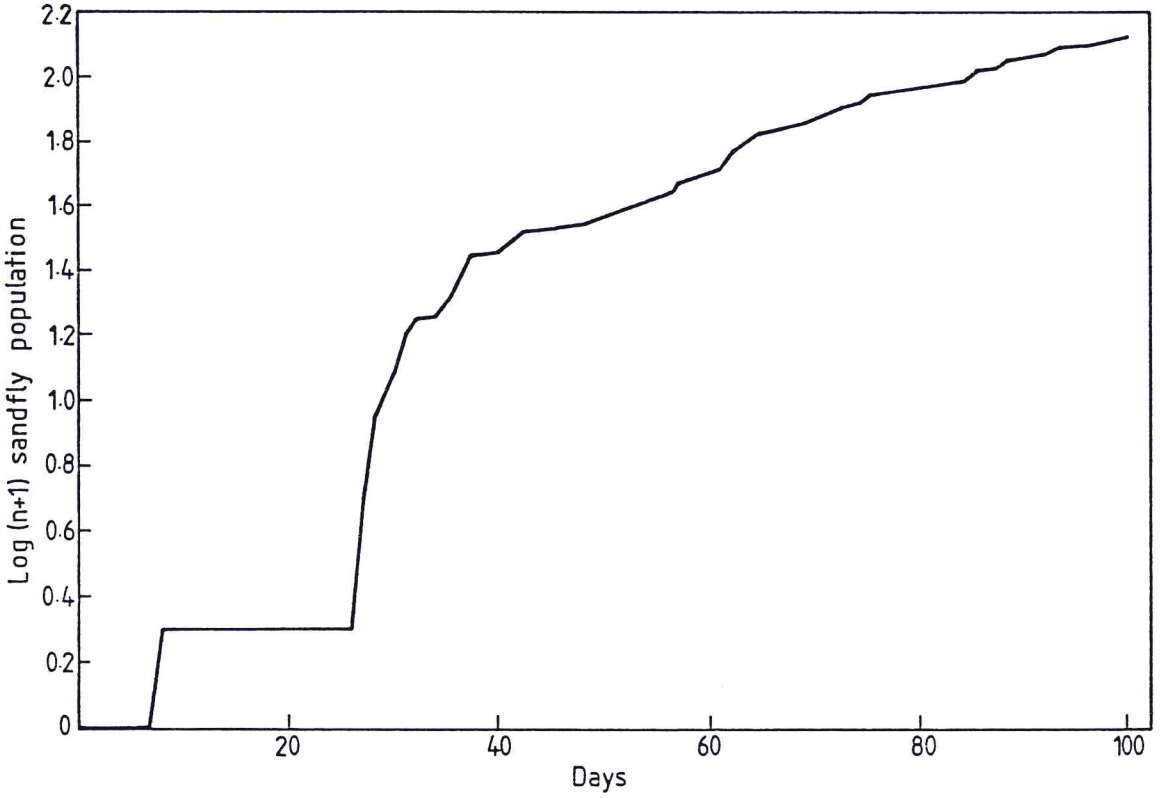


Fig 3.13 Daily cumulative emergence of sandflies from various soil samples incubated (experiment 3, Sept–Dec 1989)

3.4.4 Experiment 4 (March-June)

Table 3.8 shows the number and percentage of phlebotomine sandflies that emerged from this study. A total of 273 sandflies emerged from the various soil sample investigated. 47 (or 17.22%) emerged from rodent and small animal burrows 33 (or 12.09%) from outside houses and termite hill fungus garden soil samples respectively. Other sites were termite hill ventillation shaft 29 (or 10.62%) inside houses and tree shades 27 (or 9.89%) each, large aninmal burrows 23 (or 8.42%), tree holes 21 (or 7.69 %) treebases 20 (or 7.33%) and rock crevices 13 (or 4.76%). No flies emerged from soil samples from animal enclosures, grass vegetation and thicket floor riverbed, and chicken coops Analysis of variance showed that the sites were not significantly different from one another (df = 13, F-value = 0.33, P = 0.9998).

Figure 3.14 is a plot of *S. garnhami* in relation to other sandflies recovered from this experiment. Only One *S.garnhami* was recovered from this study. Analysis of variance showed there was no significant difference between sites (df=14, F=value=0.16 P=0.9968).

Eight sandfly species were recovered (table 3.9). They were *S.bedfordi* 227 (or 83.46%), *S.antennatus* 28 (or 10.26%), *S.clydei* 7 (or 2.56%), *S.schwetzi* 6 (or 2.20%) and *S.kirki* 2 (or 0.73%). *S.affinis*, *S.garnhami*

and *S.squamipleuris* were 1 each (or 0.37%). Figure 3.15 shows all sandfly species that emerged from this experiment. Analysis of variance showed there was no significant difference differences between species numbers (df=7, F-value =0.04 P= 0.999). Neither females nor the males of the *Synphlebotomus* species were recovered. Analysis of variance showed that the species were not significantly different from one another (df = 7, F-value =0.05, P= 0.9998) but the sandfly sexes significantly differed from each other (df = 1, F-value = 45.29, P = 0.0001***). Duncan's Multiple range test showed that significantly more females (mean = 0.31446, N = 236) than males (mean =0.27634, N = 236) emerged from the experiments. The period of sandfly emergence (day or night) was not significant (df = 1, F-value = 0.68, P = 0.4097).

A plot of sandflies daily emergence pattern (Fig 3.16) showed that emergence was recorded from the second day of incubation. There were low number of flies emerging until the 20th day. Many flies emerged from the 20th day until when a peak of 12 flies was recorded on the 97th day Flies continued to emerge until the end of study in June 1990. The first and the only *S.garnhami* from this study emerged on the 98th day. A log (n+1) plot (fig 3.17) of the daily cumulative emergence showed increased fly emergence starting from the beginning of the study. This was however punctuated

Table 3.8 The number and percentage of sandflies recovered from the soil samples of various sites in experiment 4

Site	No of sandflies recovered	Percent
Fungus garden	33	12.09
Treeshades	27	9.89
Animal enclosure	0	0
Inside houses	27	9.89
Ventilation shaft	29	10.62
Rock crevices	13	4.7
Rodent burrows	47	17.22
Large animal burrows	23	8.42
Treebases	20	7.33
Outside houses	33	12.09
Treeholes	21	7.69
Grass vegetation	0	0
Thicket	0	0
River bed	0	0
Chicken coop	0	0
Total	273	100

Table 3.9 Sandfly species recovered from the soil samples of various sites in experiment.4

Species	No of sandflies recovered	Percent
S.affinis	1	0.37
S.antennatus	28	10.26
S.bedfordi	227	83.46
S.clydei	7	2.56
S.garnhami	1	0.37
S.kirki	2	0.73
S.schwetzi	6	2.20
S.squamipleuris	1	0.37

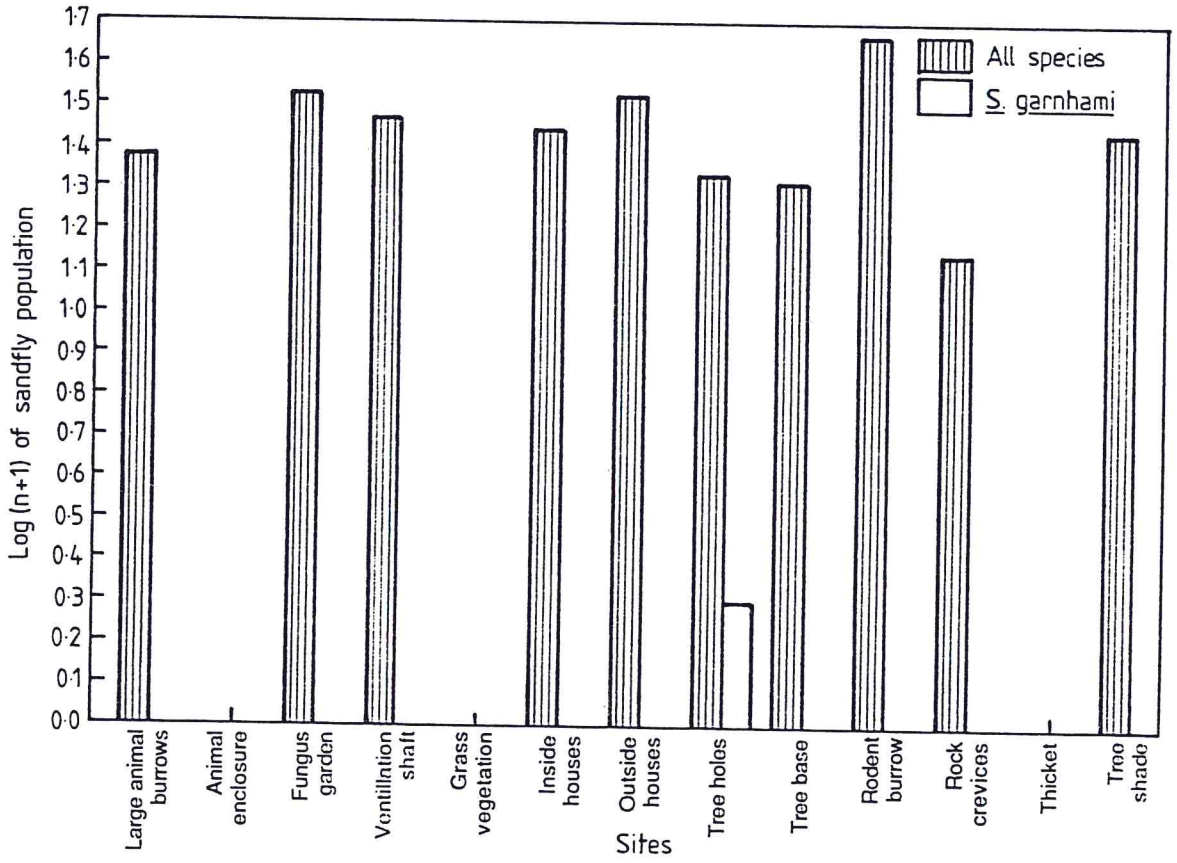


Fig 3.14 *S. garnhami* and other phlebotomine sandfly species recovered from soil samples of various sites (experiment 4, March–June 1989)

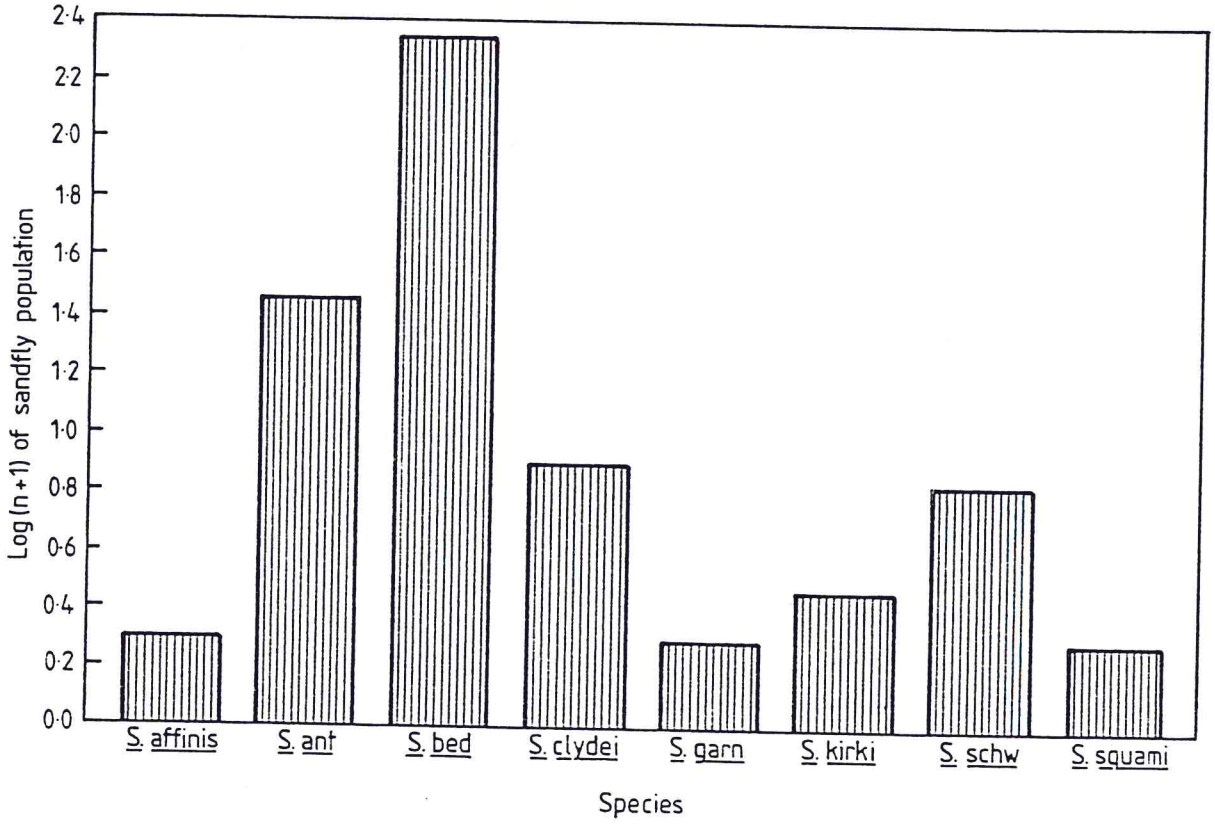


Fig 3.15 Phlebotomine sandfly species recovered from soil samples of various sites (experiment 4, March–June 1989)

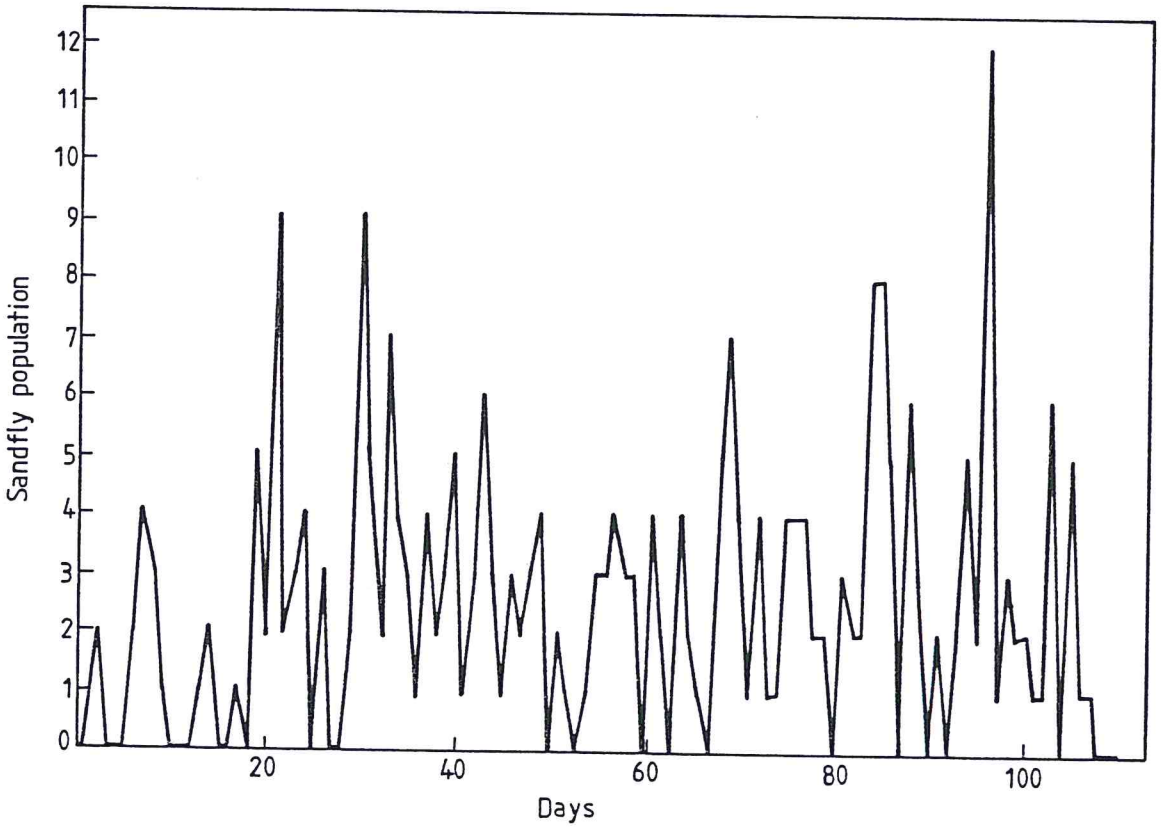


Fig 3.16 Daily pattern emergence of sandflies from various soil samples incubated (experiment 4, March–June 1989)

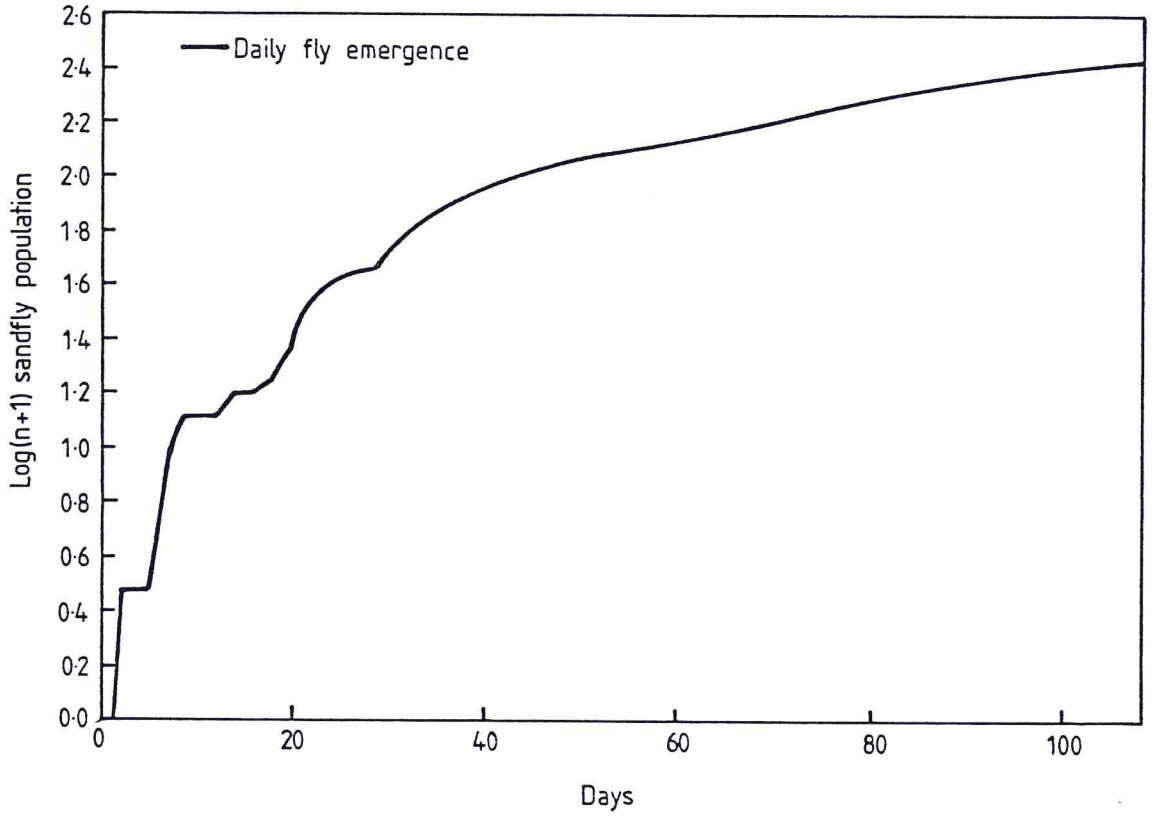


Fig 3.17 Daily cumulative emergence of sandflies from various soil samples incubated (experiment 4, March–June 1989)

by short delays until the 40th day when emergence per day was fairly constant .

3.4.5 Pooled data

Pooled data from the 4 experiments (table 3.10) showed that 1195 sandflies were recovered from the experiments. 256 sandflies (or 23.99%) emerged from the termite hill fungus garden, 125 (or 11.25%) from tree shades and 91 (or 8.53%) from inside houses soil samples. Others were rodent and small animal burrrows 82 (or 7.69%), rock crevices 73 (or 6.84%), termite hill ventilation shafts and tree bases 65 sandflies each (or 6.09%). Animal enclosures and outside houses yielded 62 (or 5.81%) each, large animal burrows 56 (or 5.25%), treeholes 55 (or 5.15%), thicket floor samples 42 (or 3.94%) and grass vegetation 33 (or 3.09%). In the 4 experiments, no flies were recovered from soil samples from chicken coops and riverbeds. Analysis of variance showed that the experiments were significantly different from one another (df=3, F-value = 4.29, P = 0.0050**). The sites were not significantly different from one another (df= 16, F-value=1.28, P = 0.2031) at 5% significant level but Duncan's multiple range test indicated that fungus garden of the termite hills was significantly different from other sites (table 3.11).

A plot of *S.garnhami* numbers in relation to other species recovered from the various soil samples (fig 3.18) shows that *S. garnhami* was recovered from 14 out of the 17 sites investigated. The sites included large animal burrows, animal enclosures, ventilation shafts and fungus gardens of termite hills, grass vegetation, inside and outside houses samples, treeholes, rodents and small animal burrows, all the rock crevices, thicket floor samples and tree shades. These results showed that *S.garnhami* and other sandflies in Tseikuru have a wide distribution of breeding sites with termite hills fungus garden having most of the emergents.

Fourteen species were altogether recovered from the various experiments (table 3.12). They were *S.bedfordi* 831 (or 69.54%), *S.antennatus* 157 (or 13.14%), *S.schwetzi* 71 (or 5.94%), *S.garnhami* 29 (or 2.43%), *S.clydei* 24 or 2.01%), *P. martini* 19 (or 1.59%), *Synphlebotomus* females, *S affinis* and *S.kirki* were 13 each (or 1.09%), *S.ingrami* 12 (or 1.00%), *S.squamipleuris* 7 (or 0.59%), *P.vansomerenae* 3 (or 0.25%), *S.adleri* 2 (or 0.17%) and *S.christophersi* 1 (or 0.08%) Figure 3 19 shows all the sandfly species collected from this experiment. Analysis of variance showed that the species were not significantly different from one another (df = 12, F-value =0.94, P= 0.5158) but the sandfly sexes significantly differed from each other (df = 1, F-value = 229.89, P = 0.0001***). Duncan's

Table 3.10 The number and percentage of sandflies recovered from the soil samples of various sites of the 4 experiments.

Site	No of sandflies recovered	Percent
Fungus garden	256	23.99
Treeshades	125	11.25
Animal enclosure	62	5.81
Inside houses	91	8.53
Ventilation shaft	65	6.09
Rodent burrows	82	7.69
Rock crevices	73	6.84
Large animal burrows	56	5.25
Treebases	65	6.09
Outside houses	62	5.81
Treeholes	55	5.15
Grass vegetation	33	3.09
Thicket	48	3.94
River bed	0	0
Chicken coop	0	0
Total	1195	100

Table 3.11 Sandflies species recovered from all the experiments

Species	No of sandflies recovered	Percent
P.*martini*	19	1.6
P.*vansomerenae*	6	0.5
Synphlebotomus females	13	1.1
S.*adleri*	2	0.2
S.*affinis*	13	1.1
S.*antennatus*	157	13.1
S.*bedfordi*	831	69.5
S.*christophersi*	5	0.4
S.*clydei*	20	1.7
S.*garnhami*	29	2.4
S.*ingrami*	12	1.0
S.*kirki*	13	1.1
S.*schwetzi*	71	5.9
S.*squamipleuris*	7	0.6

Table 3.12 Comparison of sites by Duncans' Multiple Range Test (Pooled data)

Duncan grouping		Mean	Site
	A	0.31556	Fungus garden
B	A	0.30363	Animal enclosure
B	A	0.30046	Tree shade
B	A	0.29898	Rock crevices Ngiluni
B	A	0.29888	Rodent burrows
B	A	0.29835	Rock crevices Muuna
B	A	0.29756	Animal burrows
B	A	0.297695	Rock crevices Kyandani
B	A	0.29683	Grass vegetation
B	A	0.29500	Inside houses
B	A	0.29466	Tree base
B	A	0.29413	Outside houses
B	A	0.29405	Tree holes
B	A	0.29391	Ventilation shaft
B	A	0.29328	Thicket floor

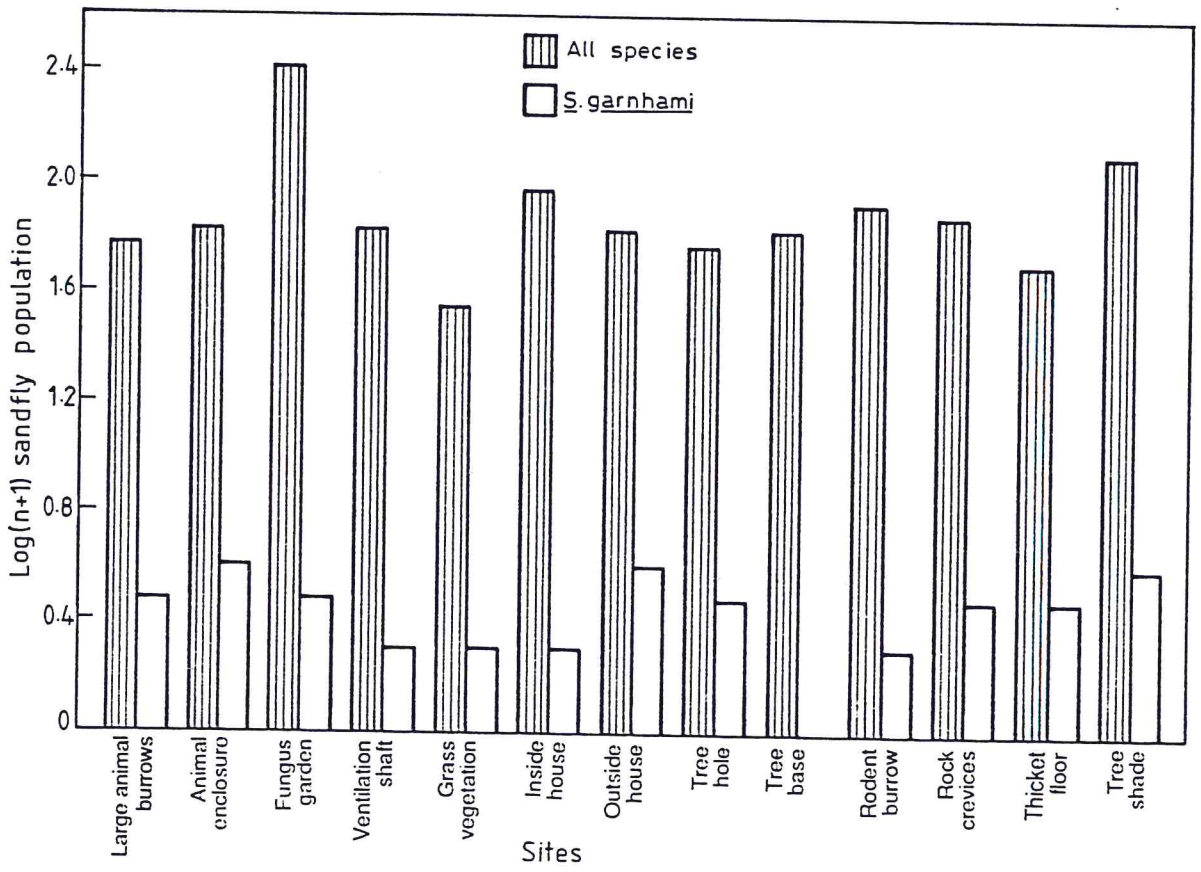


Fig 3.18 *S. garnhami* and other phlebotomine sandfly species recovered from soil samples of various sites (Pooled data)

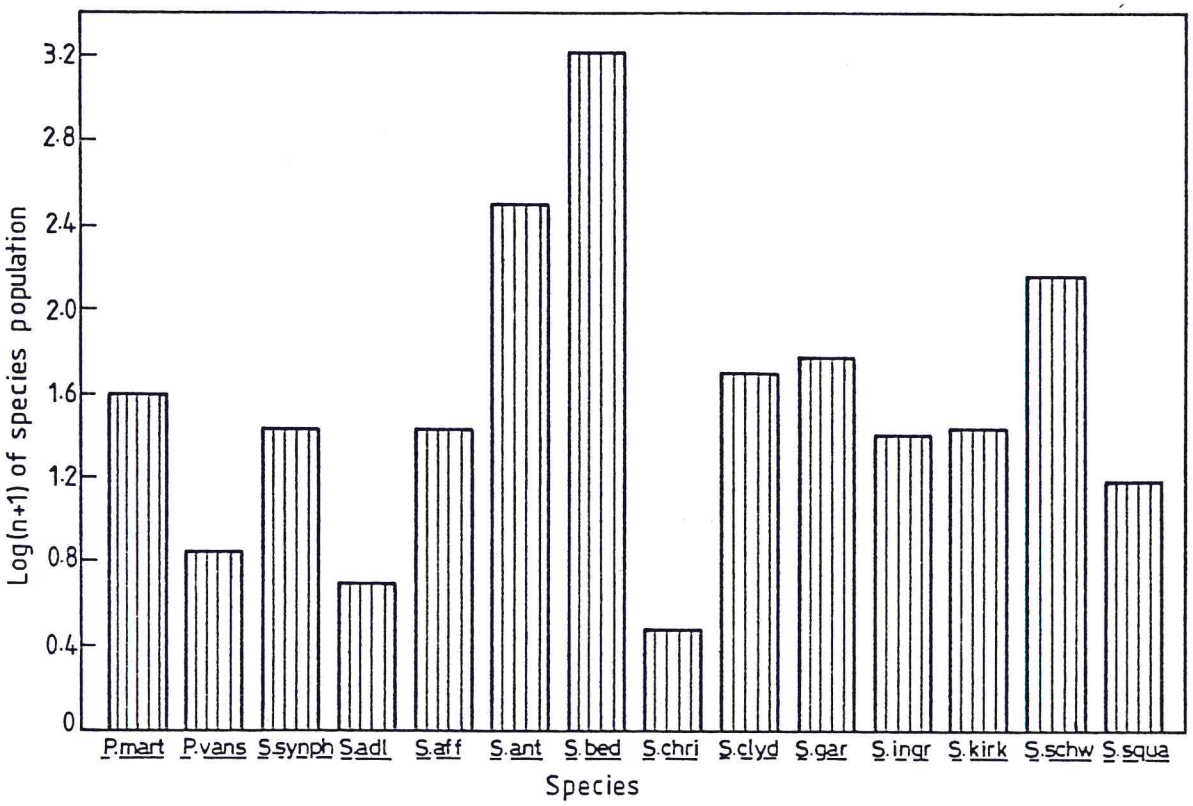


Fig 3.19 Phlebotomine sandfly species recovered from soil samples of various sites (Pooled data)

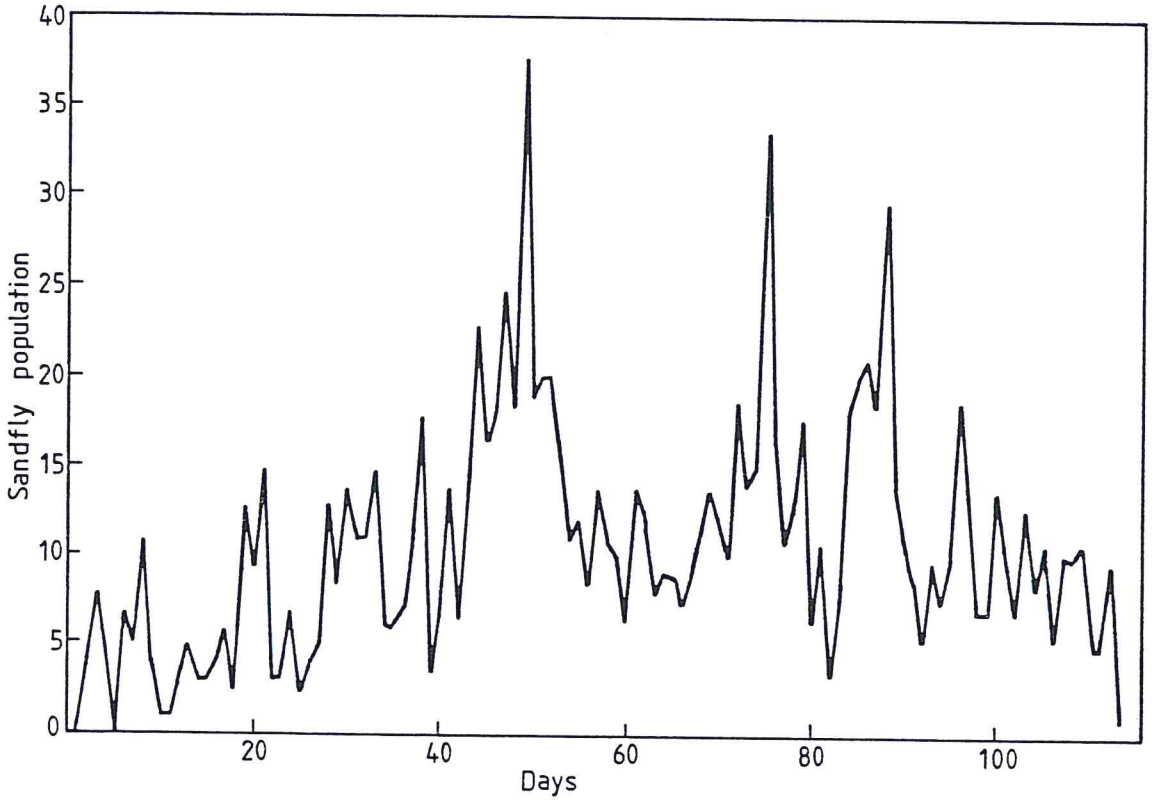


Fig 3.20 Daily pattern emergence of sandflies from various soil samples incubated (Pooled data)

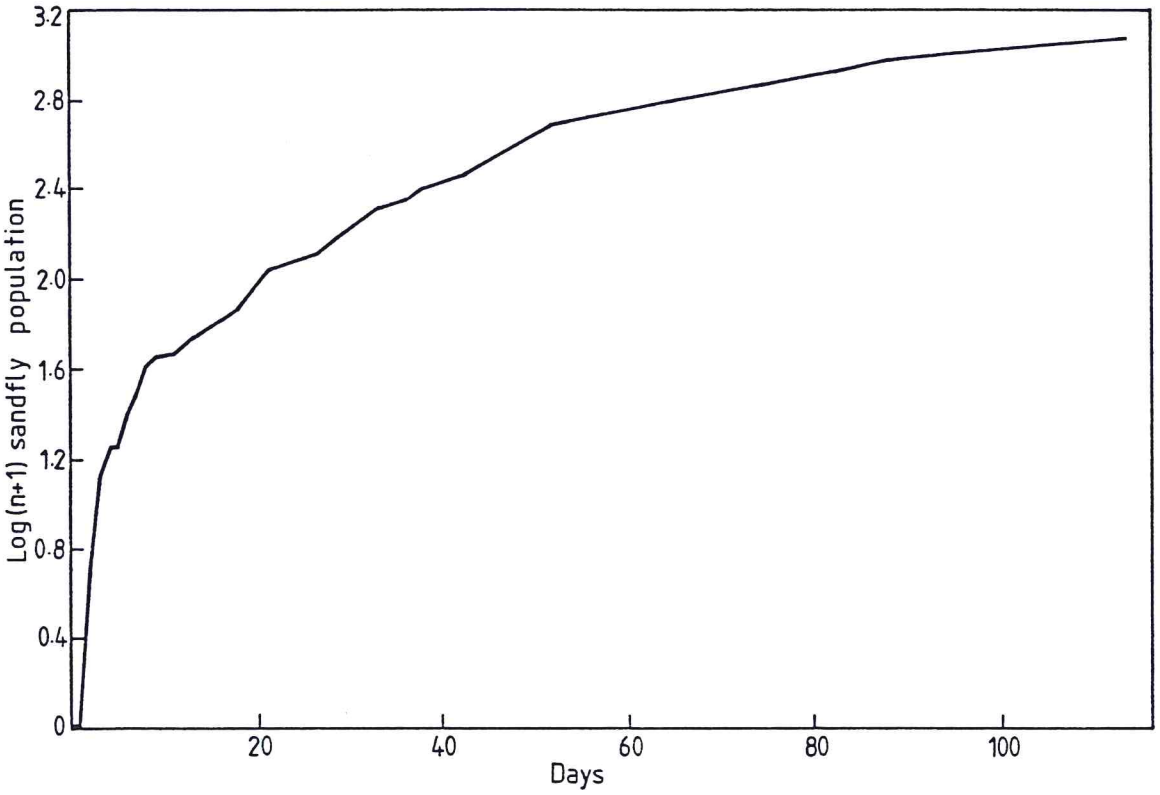


Fig 3.21 Daily cumulative emergence of sandflies from various soil samples incubated (Pooled data)

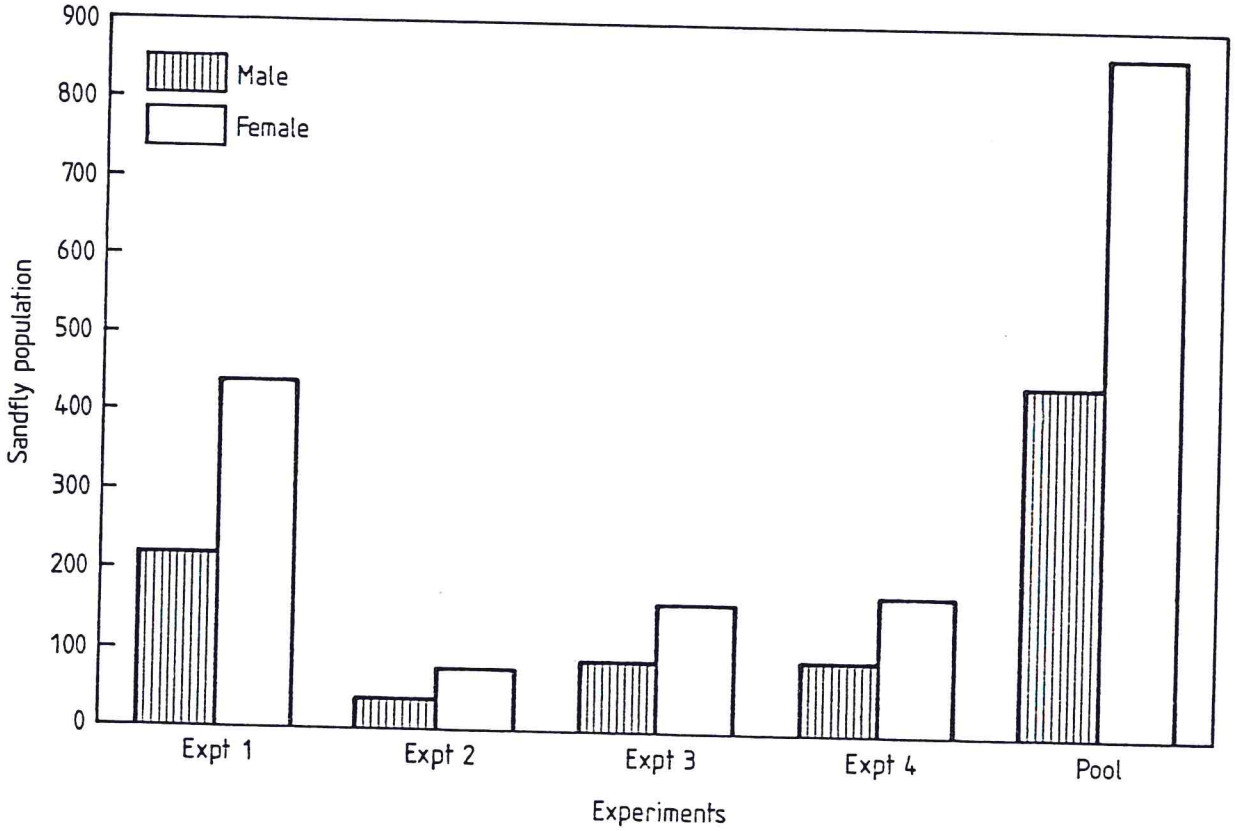


Fig.3.22 Emergence of different sexes of phlebotomine sandfly species from various experiments.

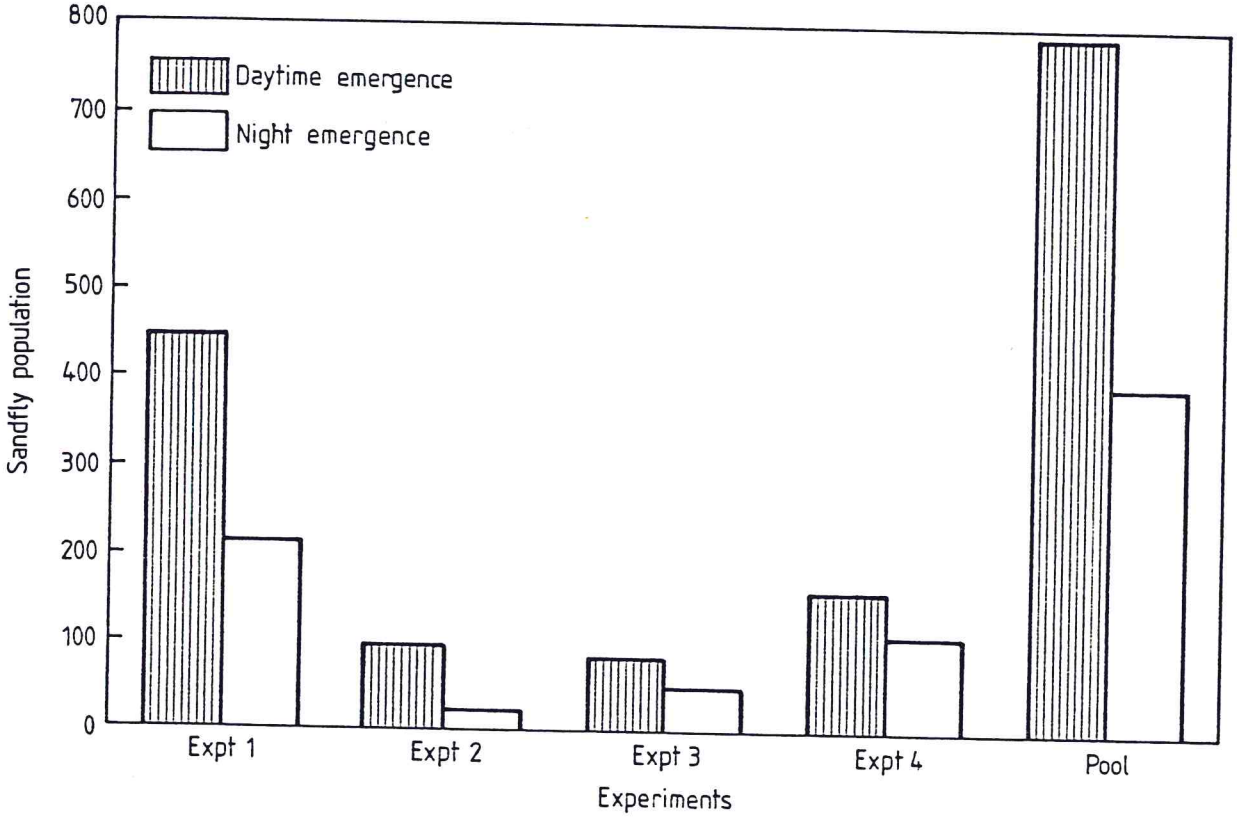


Fig.3.23 Day and night emergence of phlebotomine sandfly species from various experiments

Multiple range test showed that significantly more females (mean = 0.32141, N = 946) than males (mean =0.27847, N = 946) emerged from the experiments.

A plot of sandflies daily emergence pattern showed that most flies emerged between day 40 and 90 (fig 3.20). All the *S. garnhami* emerged between the 61st and 98th day from the start of the experiments. A log (n+1) plot of the sandflies daily cumulative emergence showed 50% emergence occured on the 52nd day (fig 21).

Figure 22 shows the emergence of sandfly sexes from various experimerints. This also showed that more females than males emerged from all the experiments. Although more sandlies emerged during the day between 0600 and 1800 hours (fig 23), statistical analysis showed that the period is not significant (df = 1 , F-value = 2.67 P = 0.1027).

3.5 Discussion

A baseline information on the breeding ecology of any insect vector of human and animal diseases is necessary in the selection, application, frequency and timing of anti-vector control measures directed against the immature stages. The results showed clearly that *S garnhami* and other sandflies in Tseikuru have a wide distribution of breeding haitats. Although termite hills were the preferred breeding sites for most

sandflies it is difficult from the results to identify the preferred sites of *S garnhami* as only between one and three flies emerged from each site.

In contrast to nature where *S. garnhami* were collected in hundreds or even thousands with sticky traps during its peak periods in May and December months, relatively few *S. garnhami* were recovered from these experiments. It could be that adequate natural conditions for the fly to emerge in large numbers were not met in the laboratory. Heisch (1954) noted during a biting cycle studies that for *S garnhami* to come out and bite in large numbers, the conditons must just be right He also observed that warm humid enviroment with more or less still air was adequate.

S garnhami was found to breed in both domestic and sylvatic environments. Similar results have been reported by several authors (Foster 1971, Mutinga and Kamau 1986, Mutinga and Odhiambo 1986, Mutinga et al 1986). The breeding of *S. garnhami* or any other vector species within or in the proximity of human dwellings has the imminent potential of increasing the man-fly contact to a dangerous level of increased disease transmission and consequent epidemics. This trend could be enhanced by some cultural habits as noticed in Tseikuru whereby people living in houses without concrete floors bath or regularly poor water on the floors to put down dust. This habit provides adequate

breeding conditons for the fly such that a fly which probably came from outside in search of blood meal eventually rests and oviposits in one of the cool dark corners of the house.

S garnhami was collected in experiments 1, 3 and 4 conducted in February, Semptember and March periods respectively. This showed that during the period between January and April *S garnhami* probably goes into quiescence and could be discontinued by reversing the conditions of the environment The absence of the fly from the soil collected and incubated in June when the fly population was declining suggested that the immature stages from the samples had probably gone into diapause and could not be reversed. This probably explains the seasonality of the fly (Minter 1964). The daily cumulative emergence pattern plots have practical implications. The results showed how long the soil could be incubated to yield a substantial number of sandflies. This was about 60 days for most sandflies but not less than 100 days for *S garnhami*. This could be longer during dry periods. The long periods taken for the *S. garnhami* to emerge from the samples lent credence to the above point.

The non-emergence of *S. garnhami* and other sandflies from the soil samples of chicken coops and riverbeds might not be that the sandflies do not lay their eggs in these sites but probably due to the

unstable and chemical nature of these sites which affected the survival of the immature stages to the adult stage. The riverbeds consisted of sandy soil which were subject to intense heat during the long dry season when no water flowed through them. Alternatively, during the wet season it was subject to violent torrential floodings. In addition there were immense human and animal activities going on in the riverbeds daily. The overall impact could be damaging on the eggs and other immature stages of sandflies. Soil samples from chicken coops, on the other hand, generated intense choking and pungent smell of ammonia gas when incubated. This could be deleterious to the developping embryos within the eggs or the larval and pupal stages given the laboratory conditons where the experimental set up were wrapped in polythene sheets.

CHAPTER FOUR

DAY RESTING SITES OF *S. GARNHAMI*

4.1 Introduction

Generally sandflies are minute delicate insects known to breed and rest under conditions of moist and dark environments. They are nocturnal in habit, being very active at dusk and early hours of the morning when the humidity of the environment is relatively favourable. They rest during the day in areas where they are protected from excessive heat, cold and wind. Lewis (1973) classified the day resting sites of sandflies into natural and artificial shelters. The natural shelters included treeholes, spaces between root buttresses of trees, foliage of forest undergrowths, animal burrows, termite hills, rock crevices in caves and elsewhere, cavities amongst boulders and soil cracks. The artificial shelters included human habitations and animal pens. Despite being the oldest focus of leishmaniasis in Kenya, the day resting sites of *S. garnhami* and other sandflies in Kitui District have not been studied. This study was aimed at investigating the day resting sites of *S garnhami* and other sandflies in Tseikuru, Kitui District.

4.2 Materials and Methods

Ten biotopes namely: termite hills (Th), treeholes (Ht), animal burrows (Ab), rock crevices (Rc), plant bases (Pb), tree stems (Ts), inside houses (Hin), spaces within packed mud and cement bricks (Brk), toilets (Tlt) and bathrooms (Ba) were studied. Ten sites of each were investigated. All the sandflies found in each site were collected using twig and aspirator method (Plate 4.1).

Suspected day resting sites of sandflies were disturbed using plant twigs. The escaping sandflies were collected with an aspirator. The flies were transferred into perspex cages and sent to the field laboratory at Tseikuru for identification. Searches were conducted between 0800 and 1200 hours and between 1400 and 1600 hours at weekly intervals. Because of the difficulty in locating the day resting sandflies inside houses and within the spaces in the packed mud and cements bricks, these were collected using castor oil coated polythene sheets measuring 1 x 1m (Plate 4.2). The traps were set once weekly between 0800 and 1600hr. At 1600hr the sandflies from each trap were harvested using acacia thorns. The collections were placed in well labelled specimen

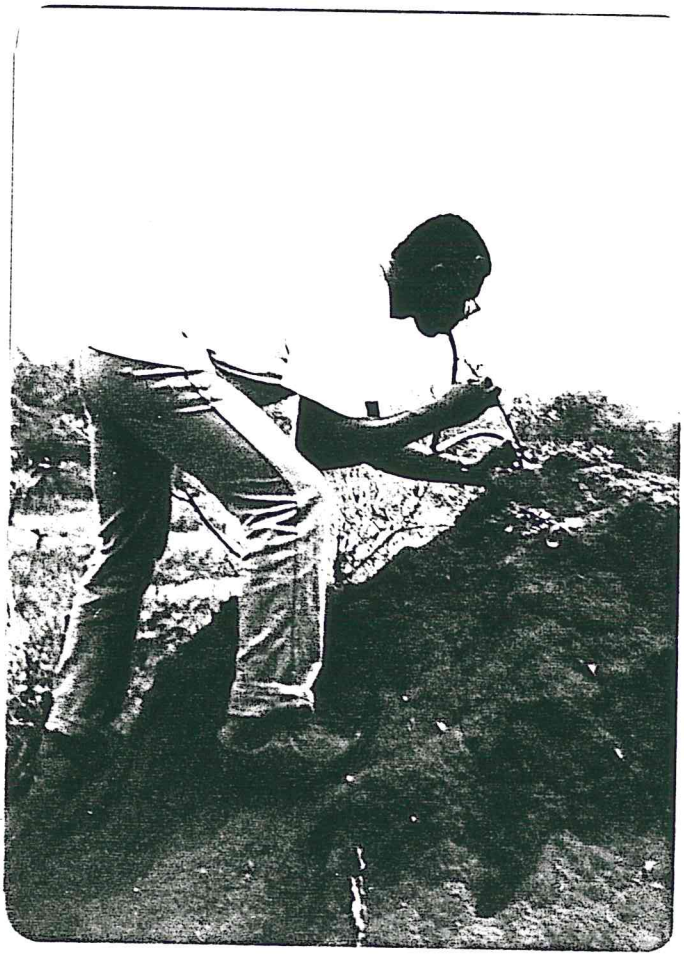


Plate 4.1 Collection of day resting sandflies from termite hills using Aspirator

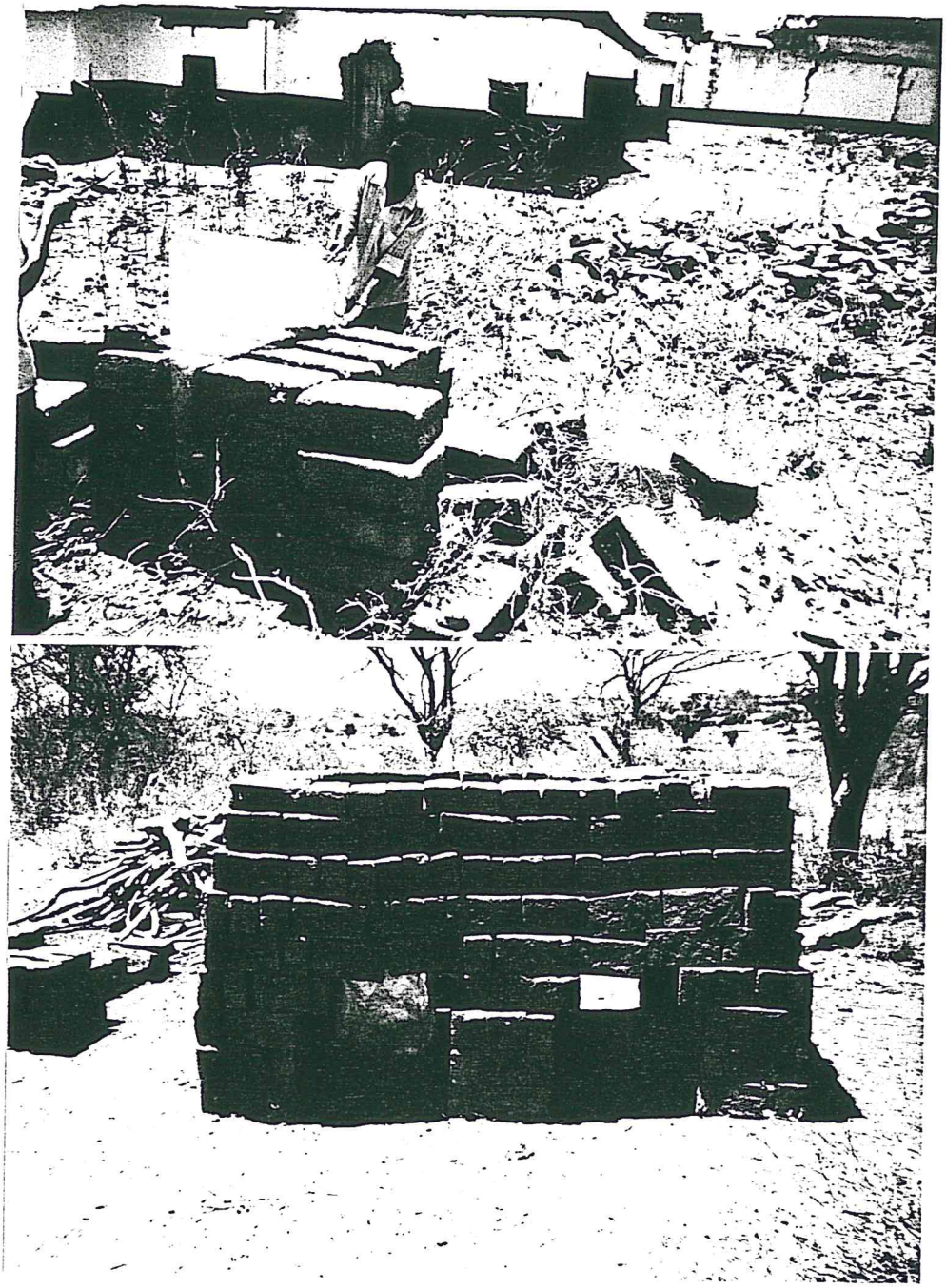


Plate 4.2 Collection of day resting sandflies from parked bricks using sticky traps

bottles for subsequent processing and identifications. The studies were carried out for 8 weeks covering the months of November and December 1990 - a period when *S garnhami* and other sandflies occur in large numbers (Heisch 1954 and Minter 1964). The bricks, toilets and the bathrooms were located around the village square (shopping centre). Because of constant supervision by the Public Health Department the toilets and the bathrooms were all plastered with cement and sometimes white washed. This made it easy to collect sandflies resting on the walls using aspirators. Most of the termite hills, treeholes, tree stems and tree bases were found scattered mainly within Nziitu and Ngiluni areas of Tseikuru. The rock crevices were located as stretches along the banks of Ngiluni, Kyandani and Muuna rivers or watercourses.

4.3 Results

Table 4.1 is the data on the distribution of *S.garnhami* and other sandflies in different day-resting sites. A total of 3,358 phlebotomine sandflies was collected from the 10 ecological habitats investigated. 596 (or 17.75%) were collected from inside houses, 535 (or 15.93%) from

toilets, 452 (or 13.46%) from bathrooms, 404 (or 12.03%) from rock crevices and 368 (or 10.96%) from termite hills. Others were 355 (or 10.57%) from spaces within bricks, 240 (or 7.15%) from treeholes, 149 (or 4.44%) from tree stems, 148 (or 4.41%) from treebases and 111 (or 3.31%) from animal burrows. Analysis of variance (Anova) between sites showed that the sites were significantly different from one another (df = 9, F-value=2.88 P= 0.0027). Duncan's Multiple range test showed that for the overall sandfly collections, the toilets were significantly different from other sights (table 4.2)

S. garnhami collected were 784 (or 23.35%). A total of 281 (or 35.84%) were from termite hills, 142 or (18.11%) from rock crevices, 76 (or 9.69 from tree bases, 71 (or 9.06%) from animal burrows and 67 (or 8.55%) treeholes. Others were 62 (or 7.91%) from tree stems, 41 (or 5.23%) from spaces between mud and cement bricks, 38 (or 4.85%) from toilets, 6 (or 0.77%) from inside houses and none from bathrooms. For *S garnhami* populations, statistical analysis using Anova, showed that the sites were significantly different from one another. Duncan's Multiple range test showed that termite hills and rock crevices were significantly

Table 4.1 Distribution of day-resting sandflies in the various ecological sites

Site	All species		*S.garnhami*	
	No collected	Percent	No collected	Percent
Termite hills	368	10.96	281	35.84
Treeholes	240	7.15	67	8.55
Animal burrows	111	3.31	71	9.06
Rock crevices	404	12.03	142	18.11
Treestems	149	4.44	62	7.91
Treebases	148	4.41	76	9.69
Inside houses	596	17.75	6	0.77
Bricks	355	10.57	41	5.23
Toilets	535	15.93	38	4.85
Bathrooms	452	13.46	0	0
Totals	3,358	100	784	100

Table 4.2 Comparison of sites using Duncan's Multiple Range Test for the overall sandfly population

Duncan grouping			Mean	Site
	A		0.9517	Toilet
B	A		0.9130	Bricks
B	A		0.9111	Inside houses
B	A		0.9086	Termite hill
B	A	C	0.8822	Tree hole
B	A	C	0.8727	Bathroom
B	A	C	0.8721	Rock crevices
B		C	0.8488	Tree stem
B		C	0.8406	Tree base
		C	0.7996	Animal burrow

Table 4.3 Comparison of sites using Duncan's Multiple Range Test for the *S.garnhami* population

Duncan grouping		Mean	Site
	A	2.119	Termite hill
	A	1.848	Rock crevices
	A	1.535	Animal burrow
	B	1.525	Tree base
	B	1.502	Tree hole
C	B	1.398	Tree stem
C	B	1.329	Bricks
C		1.155	Toilet
	D	0.540	Inside houses
	E	0.000	Bathroom

different from other sites (table 4.3)

The distribution of the different sexes of *S. garnhami* and other species in the various day resting sites is given in table 4.4. For all the species put together, more females (1850) than males (1508) were collected whereas slightly more males (434) than females (350) of *S.garnhami* were collected. Statistical analysis of sandfly sexes distribution in the various day resting sites showedv that sandfly sexes were not significantly different from each other in the overall sandfly collections but differed signficantly with S. garnhami populations (df = 1, F-value 0.34 P=0.5579 for overall sandfly population df = 1, F-value 21.07 P=0.0.0001 for *S.garnhami* populations). Duncan's Multiple range test showed that more males (mean 1.4336, N= 20) than females (mean =1.1563, N= 20) of *S.garnhami* were collected.

Table 4.5 is the sandfly species composition of the different sites. Fourteen species were collected, 3 species belonged to the genus *Phlebotomus* and 11 to *the Sergentomyia* genus. The *Phlebotomus* species put together were 32 (or 0.95%) whereas the *Sergentomyia* 3,326 (or 99.05%) formed the bulk of the catch. *S bedfordi* 1597 (or 47.56%) were the most abundant sandfly species collected.

Table 4.4: Distribution of sandfly species sexes in various day resting sites

Sites	All species		S. garnhami	
	Females	Males	Females	Males
Termite hills	225	143	193	88
Treeholes	62	178	20	47
Animal burrows	33	78	23	48
Rock crevices	160	244	56	86
Treestems	31	118	11	51
Treebases	34	114	18	58
Inside houses	537	59	1	5
Bricks	233	122	23	18
Toilets	281	254	5	33
Bathrooms	254	198	0	0
Totals	1850	1508	350	434

Table 4.5: Sandfly species distribution in various day-resting sites

Species	Sites											
	Th.	Ht	ab	Rc	Ts	Pb	Hin	Brk	Tlt	Ba	Tot	%
P.celiae	2	0	0	0	0	0	1	0	18	4	25	0.74
P.martini	0	0	0	1	0	0	1	0	0	0	2	0.06
P.vansomerenae	1	0	0	1	0	0	0	0	1	2	5	0.15
S.affinis	1	1	0	0	0	0	1	0	3	1	7	0.21
S.antennatus	7	1	0	2	1	1	38	20	79	36	185	5.51
S.bedfordi	21	46	2	137	12	16	497	159	341	366	1597	47.56
S.clydei	1	0	0	0	0	0	18	5	4	3	31	0.92
S.garnhami	281	67	71	142	62	76	6	41	38	0	784	23.35
S.graingeri	2	0	0	0	0	0	0	0	2	2	6	0.18
S.harveyi	0	12	0	0	5	5	0	0	0	0	22	0.66
S.ingrami	0	0	0	0	2	0	4	2	1	0	9	0.27
S.kirki	46	96	37	120	66	50	18	124	41	36	634	18.88
S.multidens	2	1	0	1	0	0	0	0	4	0	8	0.24
S.schwetzi	4	16	1	0	1	0	12	4	3	2	43	1.28
Total	368	240	111	404	149	148	596	355	535	452	3358	100

They also formed the bulk of the sandflies resting indoors (497 out of 596). Statistical analysis using Anova, showed that species from the various sites were significantly different from one another (df = 16, F-value = 44.38, P = 0.0001). Duncan's Multiple range test showed that *S.bedfordi* and *S.kirki* and *S.garnhami* were significantly higher than than other species (table 4.6)

Figures 4.1-10 show the species collected from the various resting sites and the relative position of *S. garnhami* amongst these species. Figure 4.11 shows *S.garnhami* only as collected from different sites.

Table 4.7 shows the weekly record of *S.garnhami* collections starting from the first week of November. No *S. garnhami* was collected in the first week. 72 were collected in the second week, 80 in the third week, 86 in the fourth , 86 in the fifth, 126 in the sixth, 164 in the 7th and 187 in the 8th week. The weekly trend of collection is shown in fig 4.12. This showed that *S.garnhami* emerged about 3 weeks from the first rain of the season which occurred on the 19th day of October. Its number gradually increased until the time we stopped the study at the fourth week of December 1990.

Table 4.6 Comparison of species predominance in the day resting sites using Duncan's Multiple Range test

Duncan grouping			Mean	Species
	A		1.3589	*S.bedfordi*
	A		1.3231	*S.kirki*
	A		1.3159	*S.garnhami*
	B		1.0122	*S.antennatus*
	C		0.8657	*S.schwetzi*
D	C		0.8328	*S.clydei*
D	C	E	0.8066	*P.celiae*
D	C	E	0.8003	*S.harveyi*
D	C	E	0.7682	*S.affinis*
D	C	E	0.7640	*S.ingrami*
D	C	E	0.7594	*S.multidens*
D		E	0.7494	*P.vansomerenae*
D		E	0.7400	*S.graingeri*
D		E	0.7259	*P. martini*
		E	0.7071	*S.christophersi*
		E	0.7071	*S.squamipleuris*
		E	0.7071	*S.adleri*

Table 4.7: Weekly collections of *S. garnhami* in various resting sites

Site	Week							
	1	2	3	4	5	6	7	8
Termite hills	0	34	53	70	15	38	24	47
Treeholes	0	0	0	7	0	12	45	3
Animal burrows	0	0	0	0	7	7	28	29
Rock crevices	0	0	11	1	35	30	52	13
Treestems	0	1	0	0	8	10	6	37
Treebases	0	0	1	0	11	5	5	54
Inside houses	0	0	2	2	0	1	0	1
Bricks	0	0	2	0	10	23	4	2
Toilets	0	37	0	0	0	0	0	1
Bathrooms	0	0	0	0	0	0	0	0
Totals	0	72	69	80	86	126	164	187

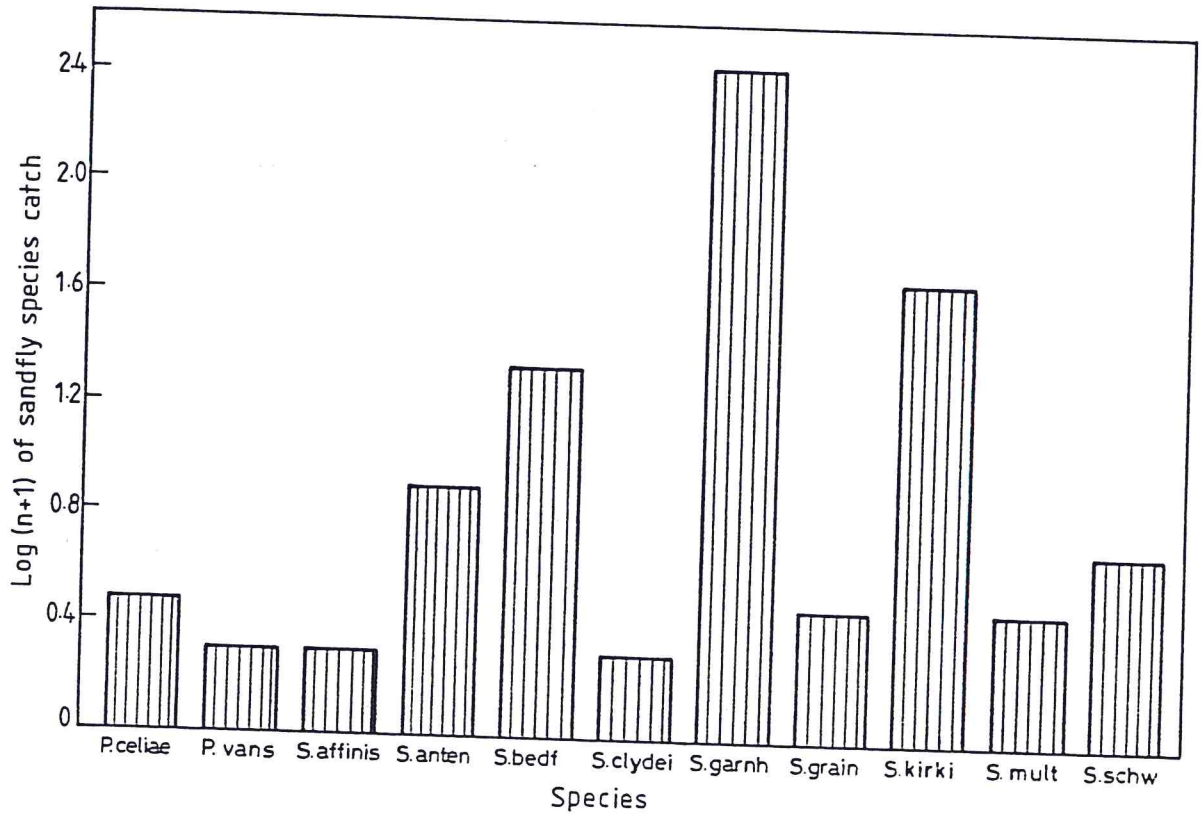


Fig 4.1 Day resting sandfly species in termite hill ventillation shafts

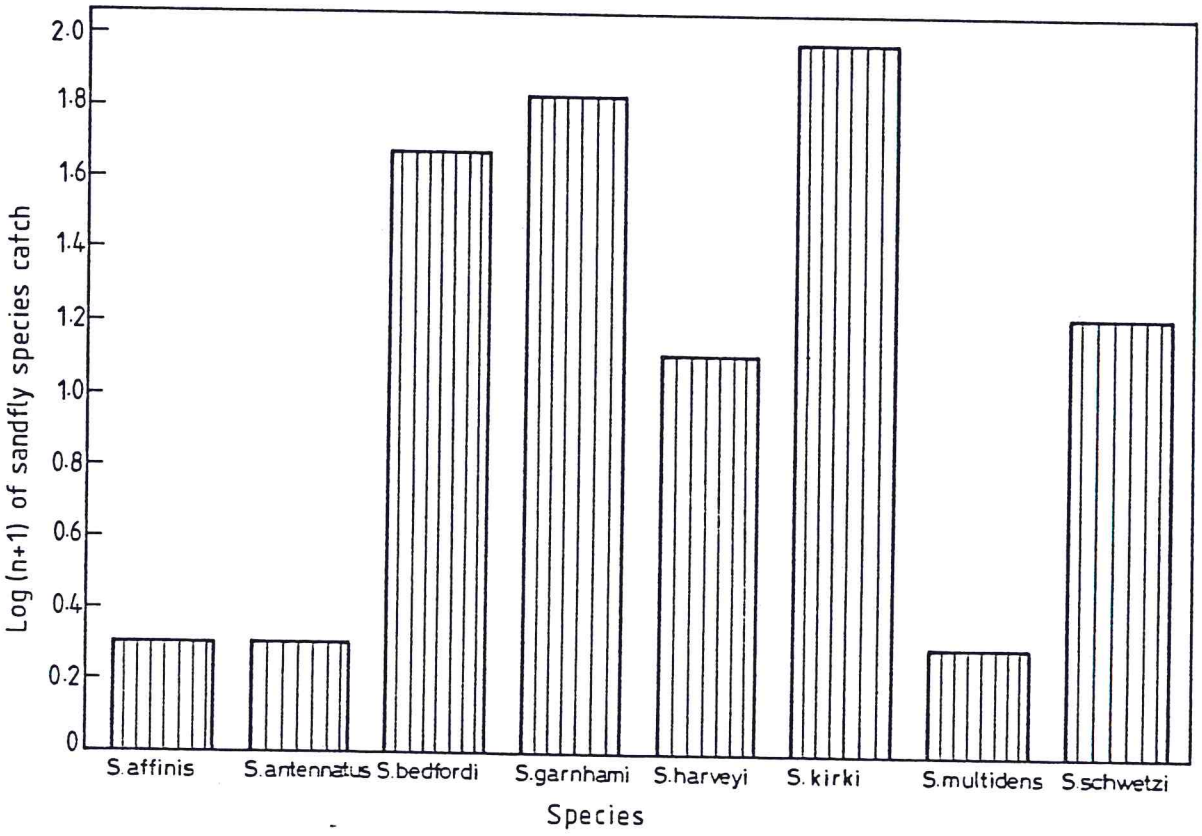


Fig 4.2 Day resting sandfly species in treeholes

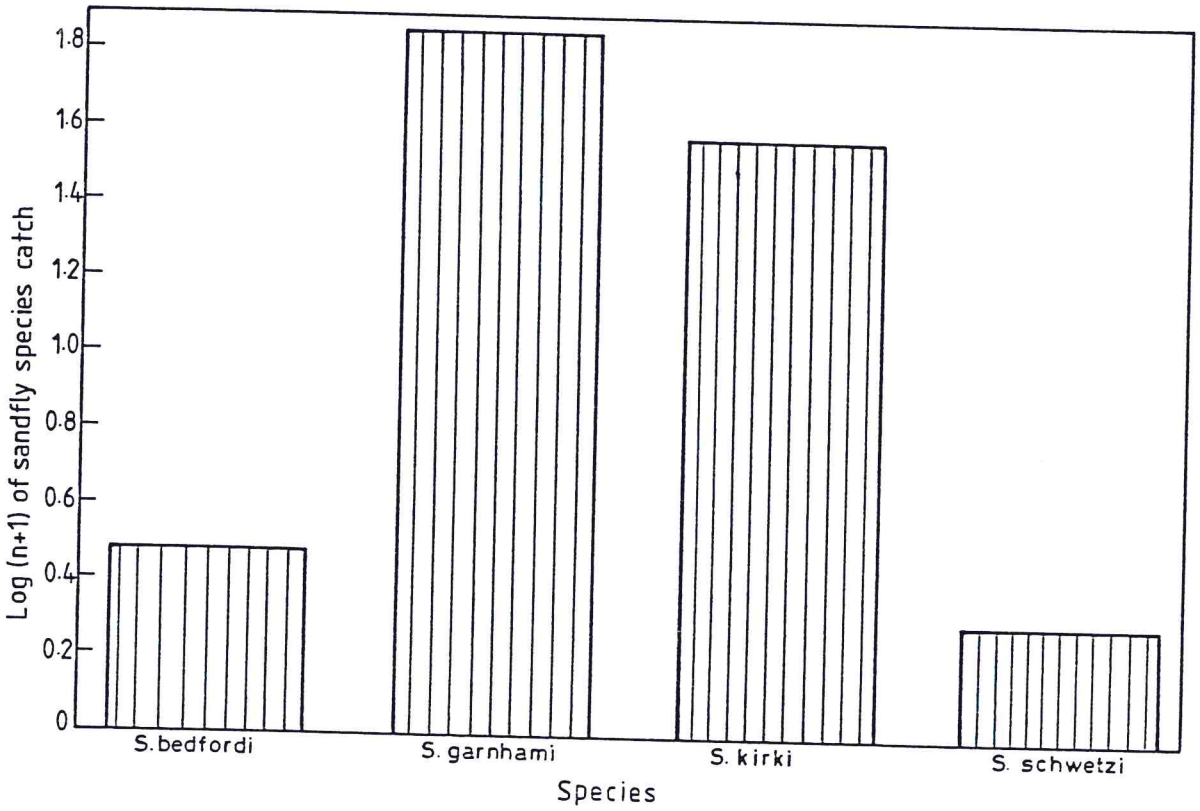


Fig 4.3 Day resting sandfly species in animal burrows

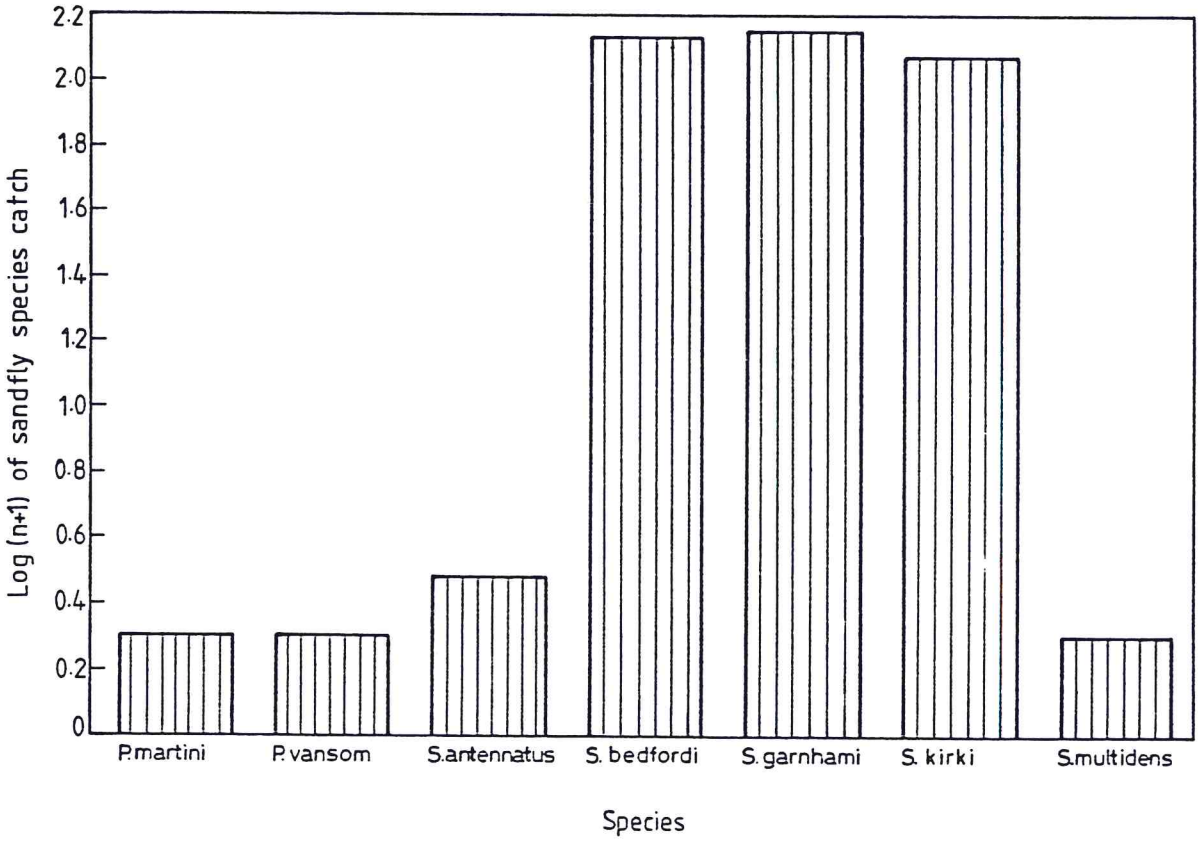


Fig 4.4 Day resting sandfly species in rock crevices

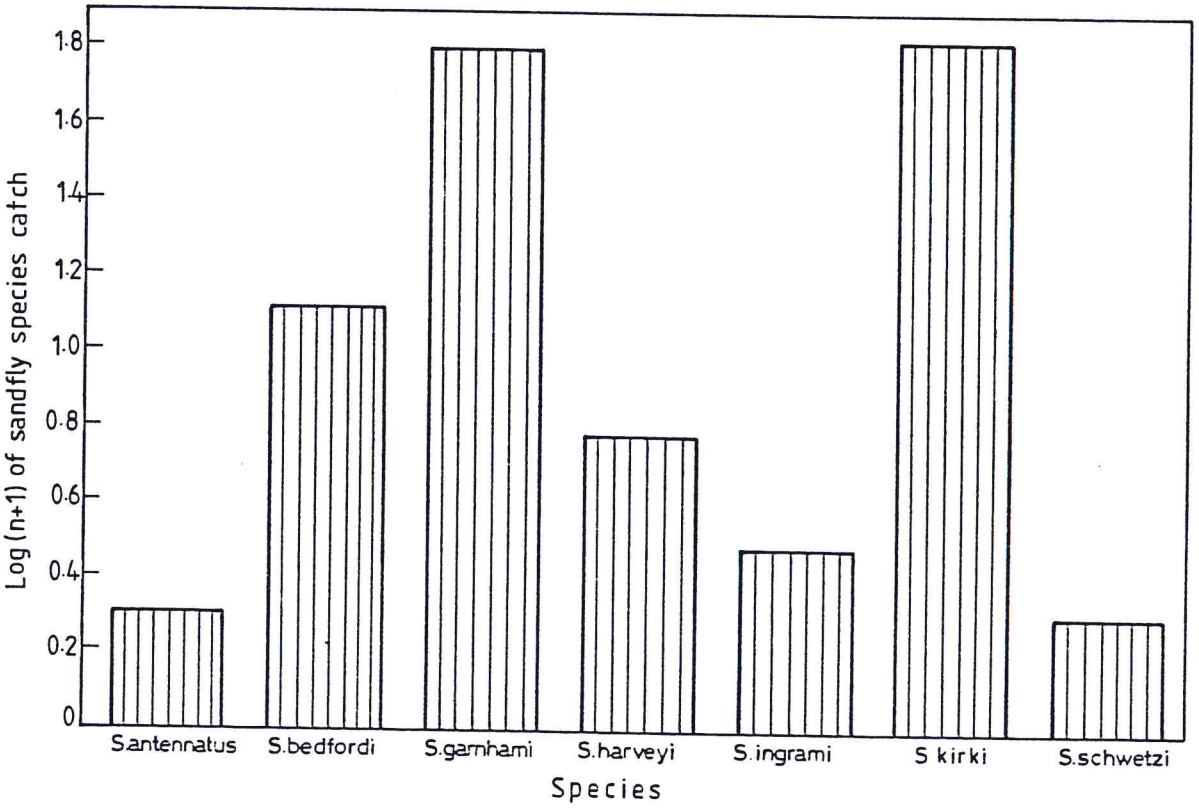


Fig 4.5 Day resting sandfly species on tree stems

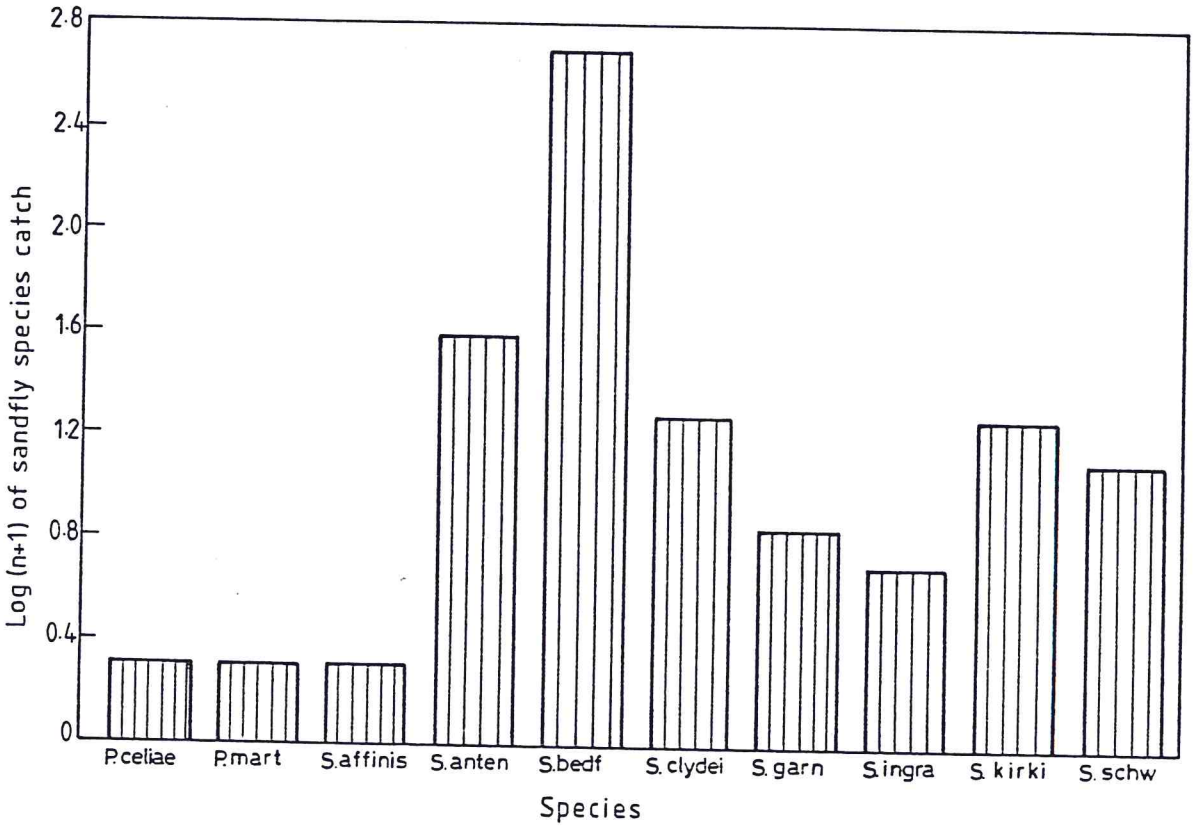


Fig 4.7 Day resting sandfly species in human homes

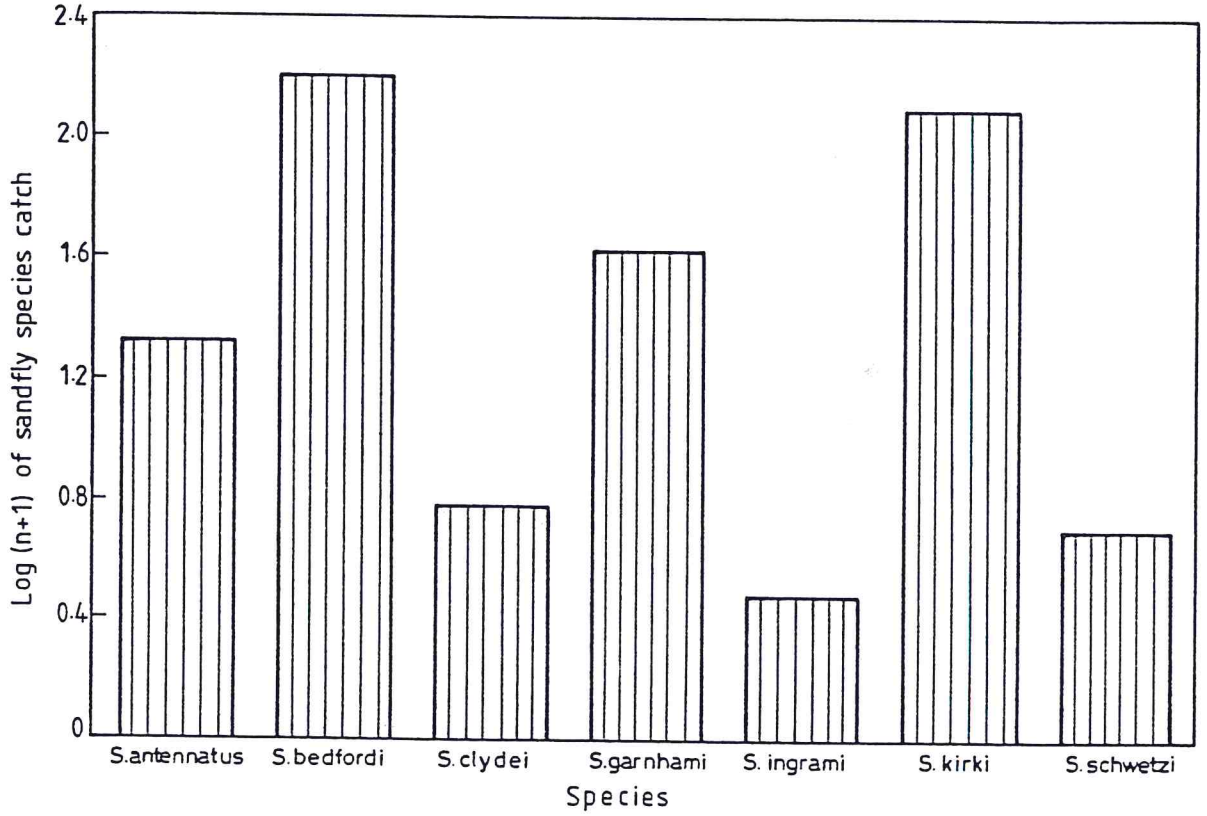


Fig 4.8 Day resting sandfly species within packed bricks

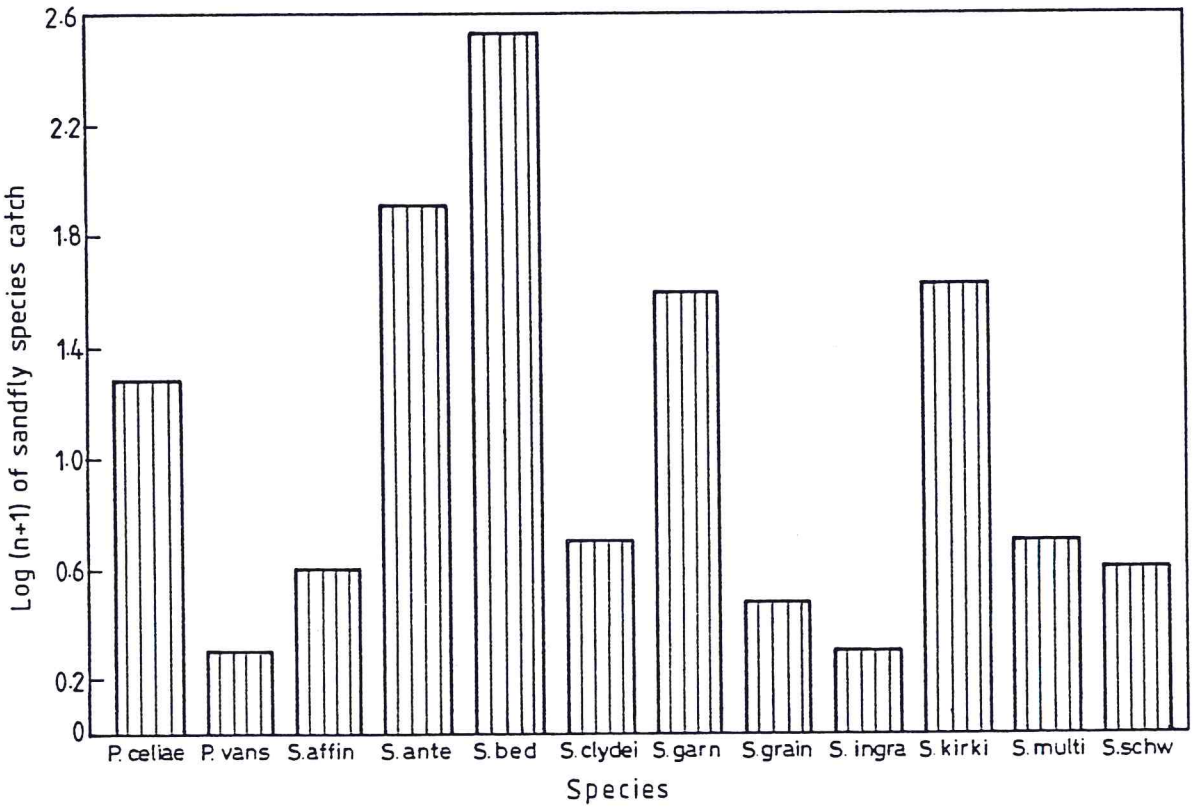


Fig 4.9 Day resting sandfly species on the inside walls of toilets

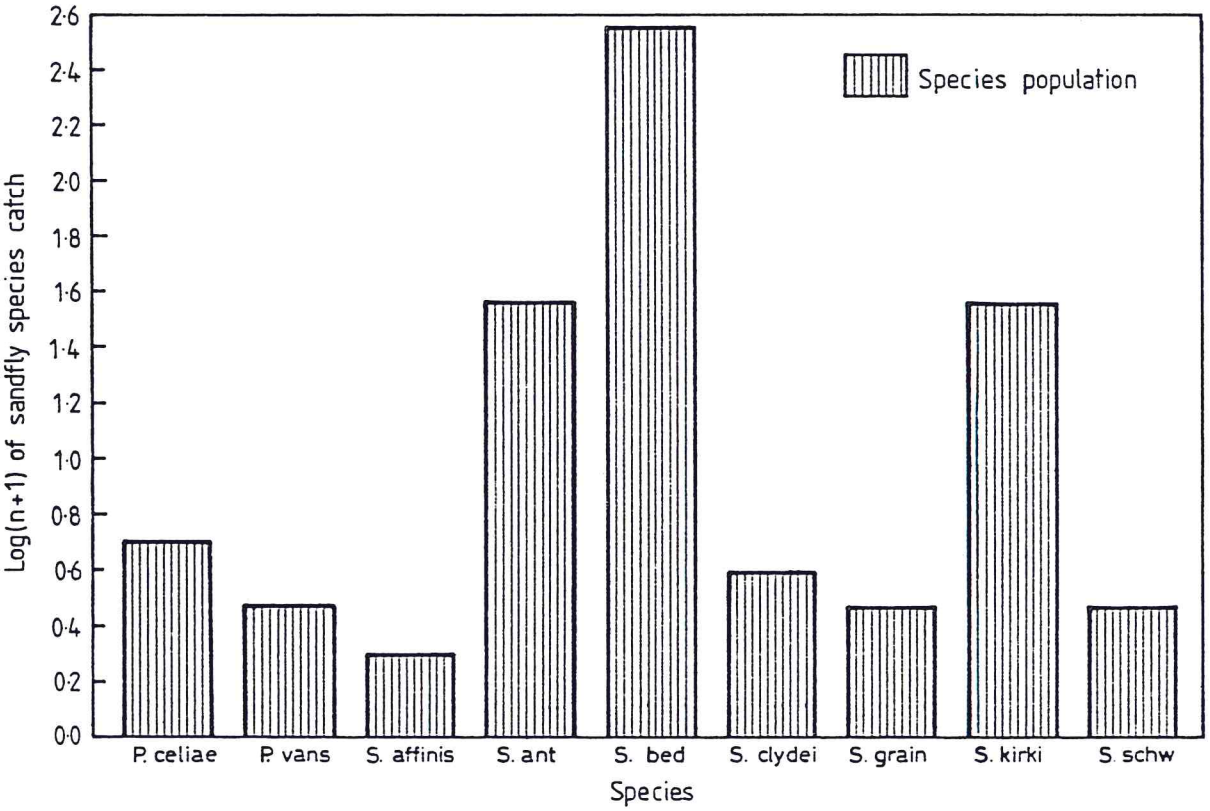


Fig 4.10 Day resting sandfly species on the inside walls of bathrooms

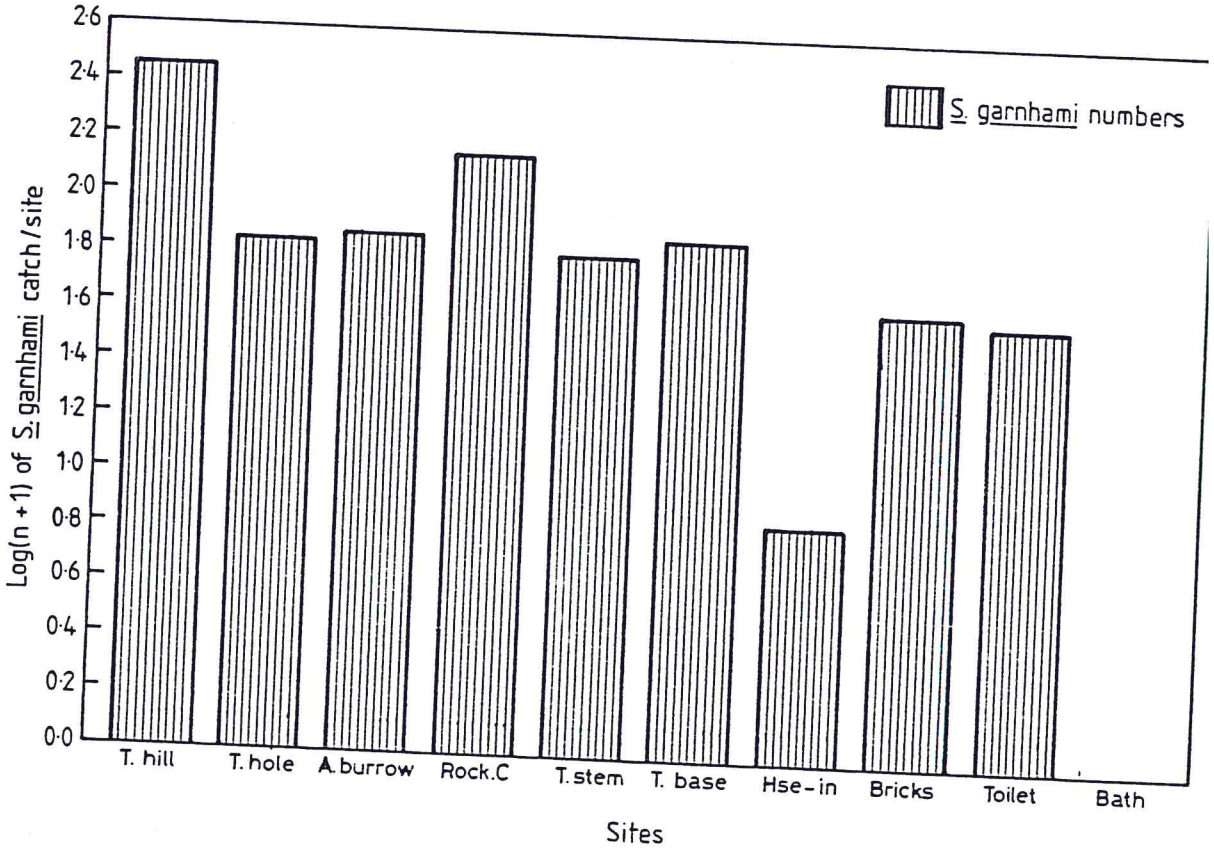


Fig 4.11 Day resting *S. garnhami* populations in various sites

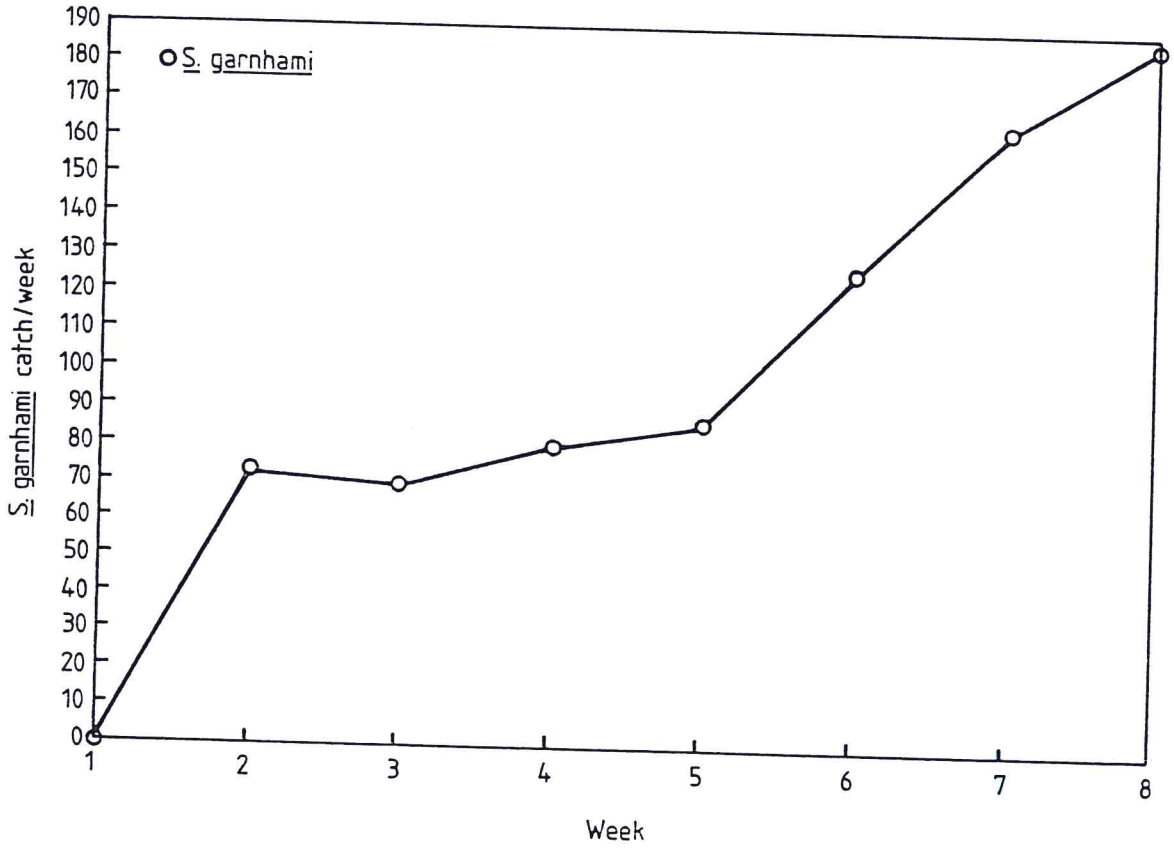


Fig 4.12 Weekly collections of *S. garnhami* from its day resting sites

4.4 Discussion

Search for the day resting sites of *Sergentomyia garnhami* and other sandflies was carried out during the months of November and December when these flies are known to appear in relatively large numbers (Heisch 1954, Minter 1964b). *S. garnhami* was collected in all the possible resting sites searched and in some cases in proportions greater than those of other sandflies. This does not only reveal the preponderance of this fly within this period but also its ability to exploit various alternative habitats for its resting and breeding sites. This feature of wide distribution no doubt provides it the opportunity of being in contact regularly with a number of host animals more especially rodents, canids, lizards, geckos, and skinks that were found hiding in the areas searched. Kirk and Lewis (1951) noted that the majority of sandflies derive their bloodmeal from the animal fauna living within or near their breeding grounds and thereafter seek for both oviposition and resting sites within the same sites. This probably explains why the majority of the sandflies were collected from termite hills, animal burrows and rock crevices already proven to be their breeding sites.

The highest numbers of day resting sandflies were collected from inside houses (596), toilets (535), and bathrooms (452). This is probably due to the relatively

favourable humidity condition existing in these areas and the existence of large numbers of geckos and lizards sheltering in them. This is understandable as the bulk of the catches in these areas were mostly *Sergentomyia* species known to have a host preference for lizards (Mutinga et al 1990). Examination of bloodmeals from some sandflies collected from the toilets revealed the red blood cells to be nucleated. Heisch (1954) reported similar observations. This was also an indication that the flies must have fed on lizards and geckos hiding in the toilets. The toilets and bathrooms studied belonged to commercial residential houses and hotels and were therefore frequently used to provide enough moisture to attract the flies. The traditional houses of the people were mainly huts of mud walls with thatched roof of grass straws. This alone has very high insulatory capacity to the daily heat of the sun. In addition, the need to conserve water has made the people wash inside their houses and sometimes even waste water were poured on the mud floor to contain the dust. This made the houses cool with relatively favourable humidity conditions for sandflies to rest in.

The highest number of *S. garnhami* were collected from the termite hills indicating that termite hills were the most preferred day resting sites of *S. garnhami*. Other sites where considerably large numbers were collected were rock

crevices, tree bases, animal burrows, and treeholes. It appears *S. garnhami* derives most of its bloodmeals as well as its sugar requirements around its breeding grounds since a lot of animals were found associated with where they were collected most. These animals ranged from geckos, other lizards to rats and canids especially mongooses. Heisch (1954) also made similar observations while working in the area. In a host preference studies in Machakos district using animal baited traps Mutinga and colleagues (1986) found that *S. garnhami* was attracted to both mammals and reptiles and also birds. Bloodmeal analysis has also proved this observation (see section on host preference of this work).

From the weekly collections *S.garnhami* was collected about 3 weeks after the first rain of the season. This observation differed slightly from laboratory finding of Mutinga et al (1989) in which the developmental period from egg to adult was 78 $\pm$ 39.2 days. It also differed slightly from on our laboratory breeding experiments in this study (see section on breeding sites). However our observations on the breeding experiments tallied with those of Mutinga et al (1989). This raises the question as to what stage of this fly goes into diapause or is there a case of rapid development

with the return of favourable weather conditions after diapause?. Another question is how long is the diapause?. Hopefully, further studies will elucidate the events.

CHAPTER FIVE

DISTRIBUTION OF *S. GARNHAMI* IN VARIOUS ECOLOGICAL HABITATS

5.1 Introduction

Distribution studies of haematophagous insect pests are usually undertaken to acquire full knowledge of spread of the pest species in a given area. A proper understanding of this is very important in the determination of inter-relationships between the vector and the host, epidemiology of disease and transmission in the focus. Distribution studies are also of utmost necessity in planning and execution of control programmes. This study is aimed at understanding the distribution of *S. garnhami* in the semi-arid region of Tseikuru in Kitui District.

5.2 Materials and Methods

This study was carried out for a period of 14 months (Jan 1989-Feb 1990). Ten ecological sites and 16 subsites were used for the study. It was carried out in two phases. In the first phase, the primary design, eight sites and ten subsites were used. It lasted from January 1989 to January 1990 (13 months). The second phase was designed latter to incorporate sites not

included in the original plan. It lasted from September 1989 to February 1990 (6 months). Two sites and six subsites were used. All the sites and subsites used were listed in the study plan (table 5.1).

Ten replicate sites of each biotope, except termite hills, were used. Twenty termite hills were used to enable equitable distribution of the subsites. Amongst the subsites, all the subsites of termite hills had 10 replicates each. The termite hills under shades and those exposed to light and other daily weather changes were nested within those near and far from human homes. Eight of the animal burrows were small types and 2 were large animal burrows. Plant bodies and open spaces subsites had 5 replicates each, whereas tree stems and foliage were 10 each. The thicket floors and foliage had 10 replicates each but the study was carried out in two thickets and the replicates were subdivided to 5 per subsite per thicket.

Sandflies were captured using sticky traps (oil-coated polythene sheets), placed horizontally, vertically or inclined to the site, depending on the nature of the site (Plates. 5.1-10) A trap per site per night was placed at biweekly intervals twice a month at each site. The traps were set between 1600 and 1800 hours (Kenya local time) and collected between 0600 and 0800 hours the following morning. Two trap sizes were used. A trap size of $1m^2$ was used for rock crevices,

open spaces, animal enclosures, inside and outside walls of human dwellings, tree stems and foliage and thicket floors and foliage. Sandflies of termite hills, animal burrows, treeholes and tree bases were trapped with a trap size of 30cm^2 (1 ft^2). Resulting sandfly catches were standardized by multiplying with 10.8 (10.8ft^2 = 1m^2).

Trapped sandflies were harvested individually using fine probes like acacia and balanite thorns or twigs cut to a fine pencil point (Plate 5.11). The sandflies were put in well labelled specimen bottles and sent to our temporary laboratory at Tseikuru Health Centre for processing.

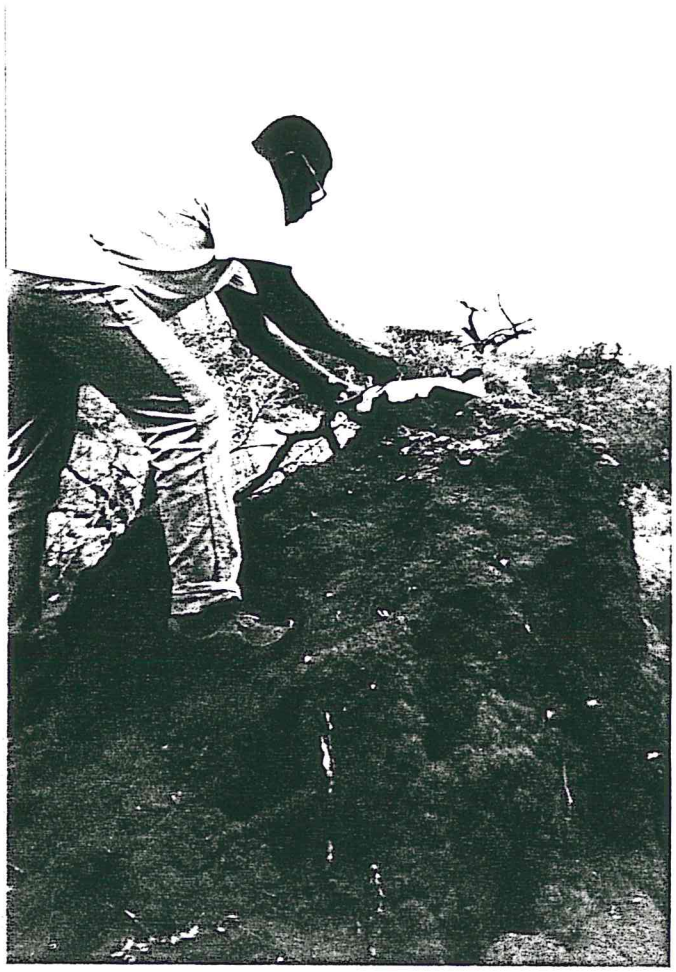
In the laboratory, the sandflies were washed in 1.0% detergent saline, rinsed in normal saline and transferred individually into a drop of gum chloral mountant on a clean microscope glass slide. With the aid of a pair of dissecting pins mounted on wooden handles and a stereomicroscope, the head of each fly was severed and inverted dorso-ventrally, thereby, exposing the ventral aspect for identification. Each fly body and the head were together separately covered with a coverslip, air-dried for 48 hours before identification or packed into slide boxes pending time for identification. Identifications were done under x10 or x40 objectives lens of a compound microscope, depending on the species. Characters used in the identification

Table 5.1:- The Study Plan.

Sites	Subsites
Phase 1	
Termite hills	Termite hills near human homes+
	Termite hills far from human homes++
	Exposed termite hills
	Shaded termite hills
Animal burrows	Rodent and small animal burrows
	Large animal burrows)
Plant bodies	Treeholes
	Treebases and buttresses
Open spaces	With vegetation
	Without vegetation
Rock crevices	
Animal enclosures	
Inside walls of houses	
Outside walls of houses	
Phase 2	
Trees	Tree stems
	Tree foliages
Thickets	Kyandani thicket floor
	Kyandani thicket foliage
	Nziitu thicket floor
	Nziitu thicket foliage

\+ Termite hills within 500 m from homes

++ Termite hills beyond 500 m from homes



Plates 5.1 Sampling of sandflies from a termite hill using sticky trap

Plate 5.2 Animal burrows along the bank of Kyandani river from where sandflies were sampled

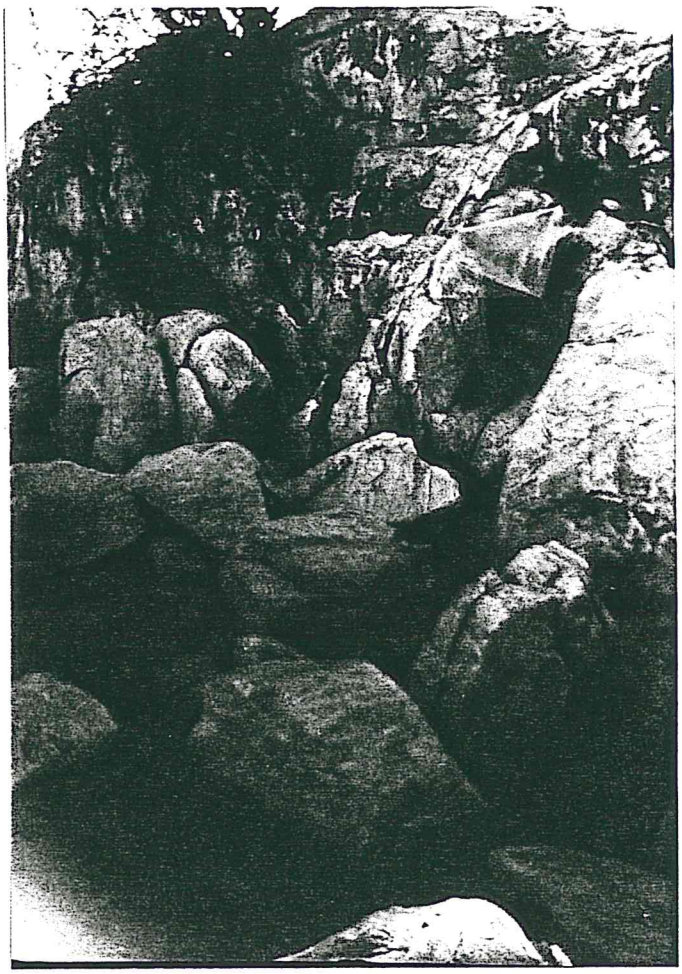


Plate 5.3 Sampling of sandflies from rock crevices

Plate 5.4 Tree hole in a boab tree from where sandflies were sampled

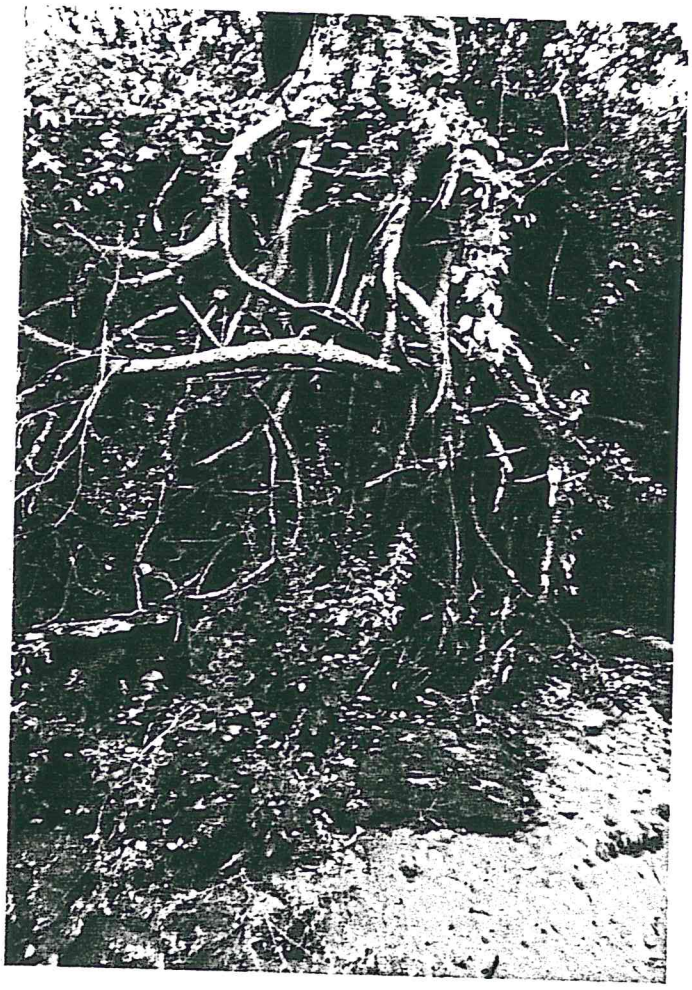


Plate 5.5 A tree base from where sandflies were sampled.

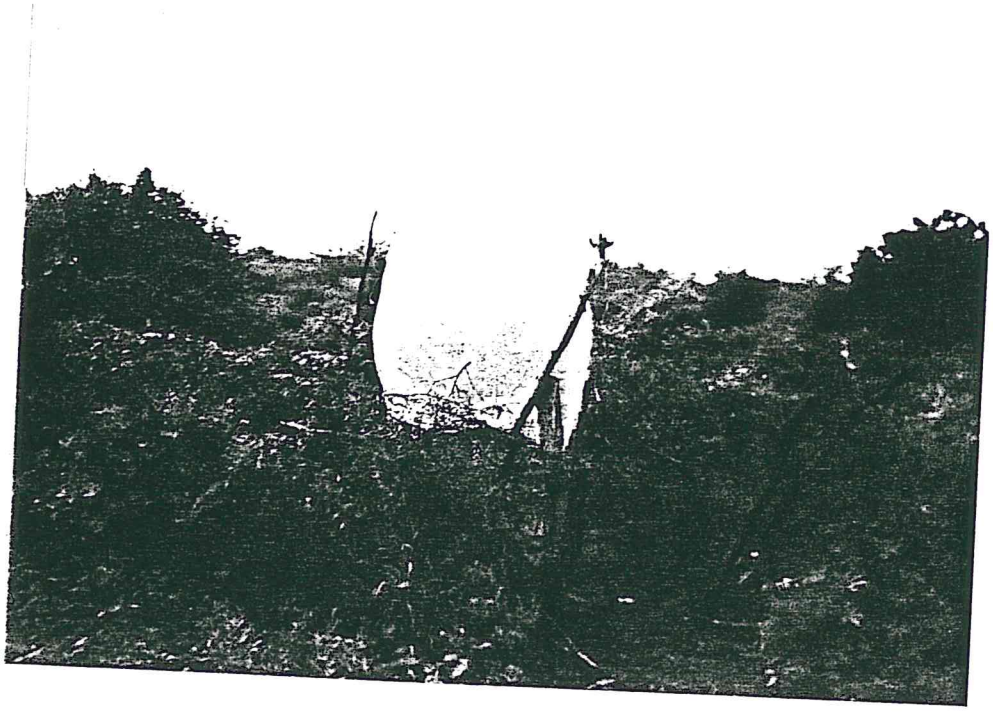


Plate 5.6 Sampling of sandflies from an animal enclosure

Plate 5.7 Sampling of sandflies fron open field without vegetation

Plate 5.8 Sampling of sandflies from open field with vegetation

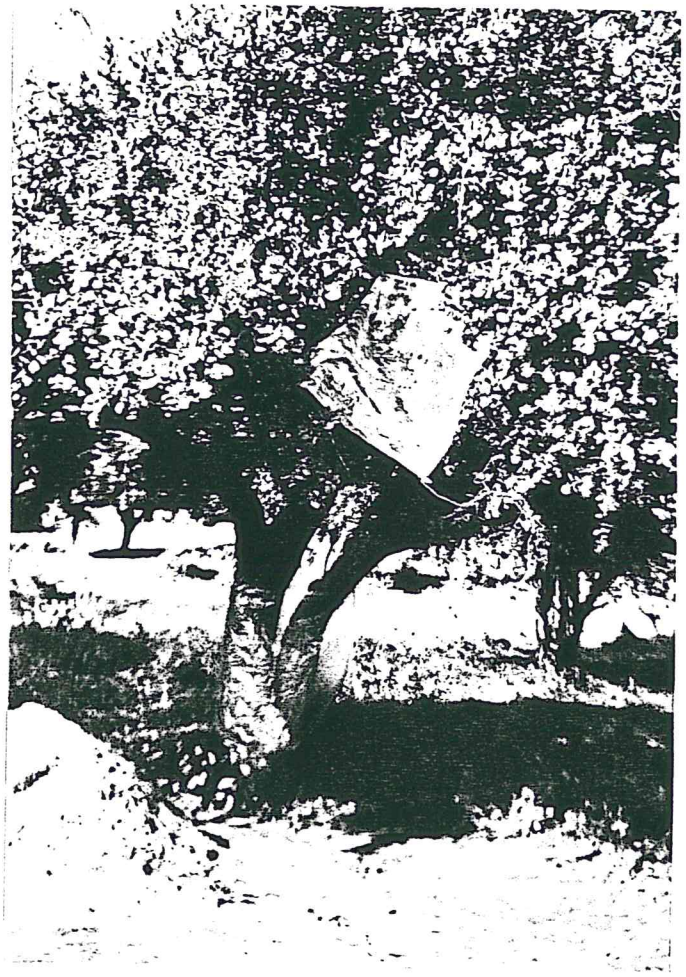


Plate 5.9 Sampling of sandflies from a tree stem and foliage

Plate 5.10 Aspect of Kyandani thicket from where sandflies were sampled.

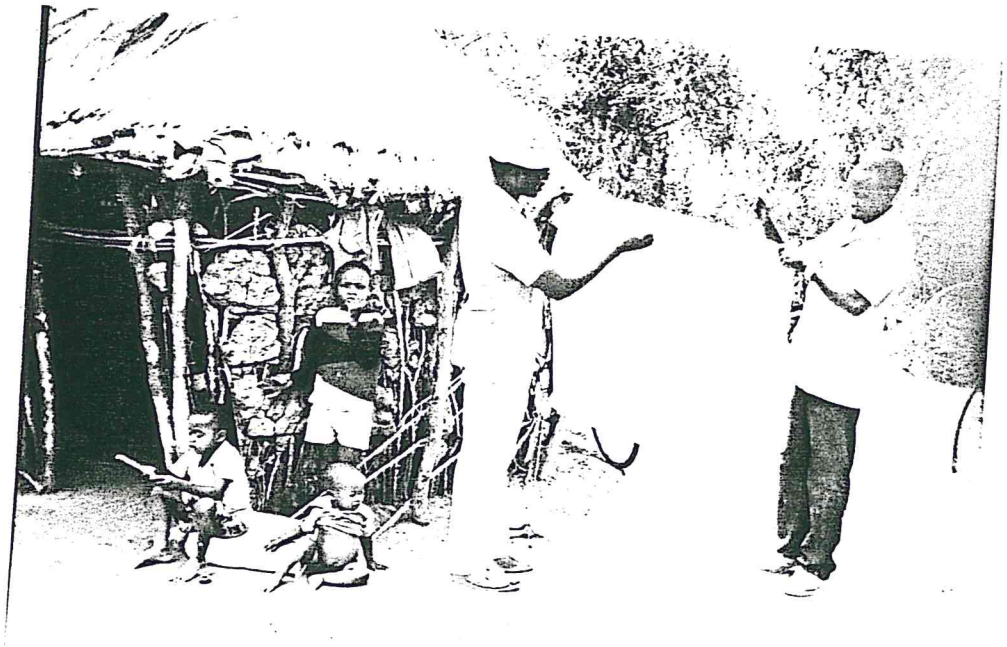


Plate 5.11 Removal of sandflies from a sticky trap

of species included the disposition of erect hairs on the abdominal tergites, the structure of the pigmented plate and pharynx, the spermatheca of the females and the terminalia of the males.

5.3 Results

5.3.1 Sites

The results of phlebotomine sandflies caught from various sites were presented in table 5.2. Altogether a total of 70106 sandflies were collected from all the sites. 67954 (or 96.93%) were collected from phase 1 of the studies while 2152 (or 3.07%) were collected from phase 2. In phase 1, 31669 (or 46.60%) were collected from termite hills. The collections from other sites were 12232 (or 18.00%) from rock crevices, 9418 (or 13.86%) from animal burrows, 4986 (or 7.34%) from plant bodies (treeholes and tree bases), 3796 (or 5.59%) from inside walls of human dwellings, 4208 (or 6.19 %) from outside walls of human homes, 1032 (or 1.52%) from open spaces and 613 (or 0.90%) animal enclosures. In phase 2, 1741 (or 80.90%) were collected from trees while 411 (or 19.10 %) were from thickets.

The distribution of *S. garnhami* in the various sites is also shown in table 5.2. A total of 33761 S.garnhami were collected from all the sites

investigated. 33695 or 99.80% were from phase one of the studies while 66 or 0.20% were from the second phase. In phase 1 17065 or 75.0% were collected from termite hills. Other sites with significant collections included animal burrows 4090 (or 12.14%), rock crevices 1909 (or 5.67%) and plant bodies 1793 (or 5.32%). collections from other sites were less than one percent of total sandflies from phase 1. In phase 2, 42 (or 63.64 %) were collected from trees whereas 24 (or 36.36%) were from thickets. Analysis of variance (Anova) showed that there was significant difference between sites (df = 9, F-value = 78.12, P = 0.0001***). Duncan's Multiple Range tests using Statistcal Analysis Systems programme (SAS) showed that both *S.garnhami* and other phlebotomine sandflies preferred termite hills amongst other sites. Animal burrows, rock crevices and plant bodies were in the order of next preferred sites (table 5.3).

Figures 5.1 and 5.2 are trends of distribution of *S. garnhami* in the various sites investigated. Figure 1 compared this with other species put together whereas figure 5.2 is *S. garnhami* only.

Table 5.2 Percentage distribution of phlebotomine sandfllies in various ecological habitats

Sites	All species		S. garnhami	
	Total	Percent	Total	Percent
Phase 1				
Termite hills	31669	46.60	17065	75
Rock crevices	12232	18.00	1909	5.67.
Animal burrows	9418	13.86	4090	12.14
Plant bodies	4986	7.34	1793	5.32
Inside houses	3796	5.59	94	0.28
Outside house	4208	6.19	77	0.23
Open spaces	1032	1.52	107	0.32
Animal enclosure	613	0.90	36	0.11
Total	67954	100	33695	100
Phase 2				
Tree	1741	80.90	42	63.64
Thickets	411	19.10	24	36.36
Total	2152	100	66	100

Table 5.3 Comparison of sites by Duncan's Multiple Range Test

Duncan grouping	Mean	Site
A	83.074	Termite hills
A	71.953	Rock crevices
B	55.400	Animal burrows
C	27.700	Plant bodies
C	24.753	Outside houses
C	22.329	Inside houses
D	6.071	Open spaces
D	3.606	Animal enclosure
Phase 2		
A	6.071	Tree
B	2.390	Thickets

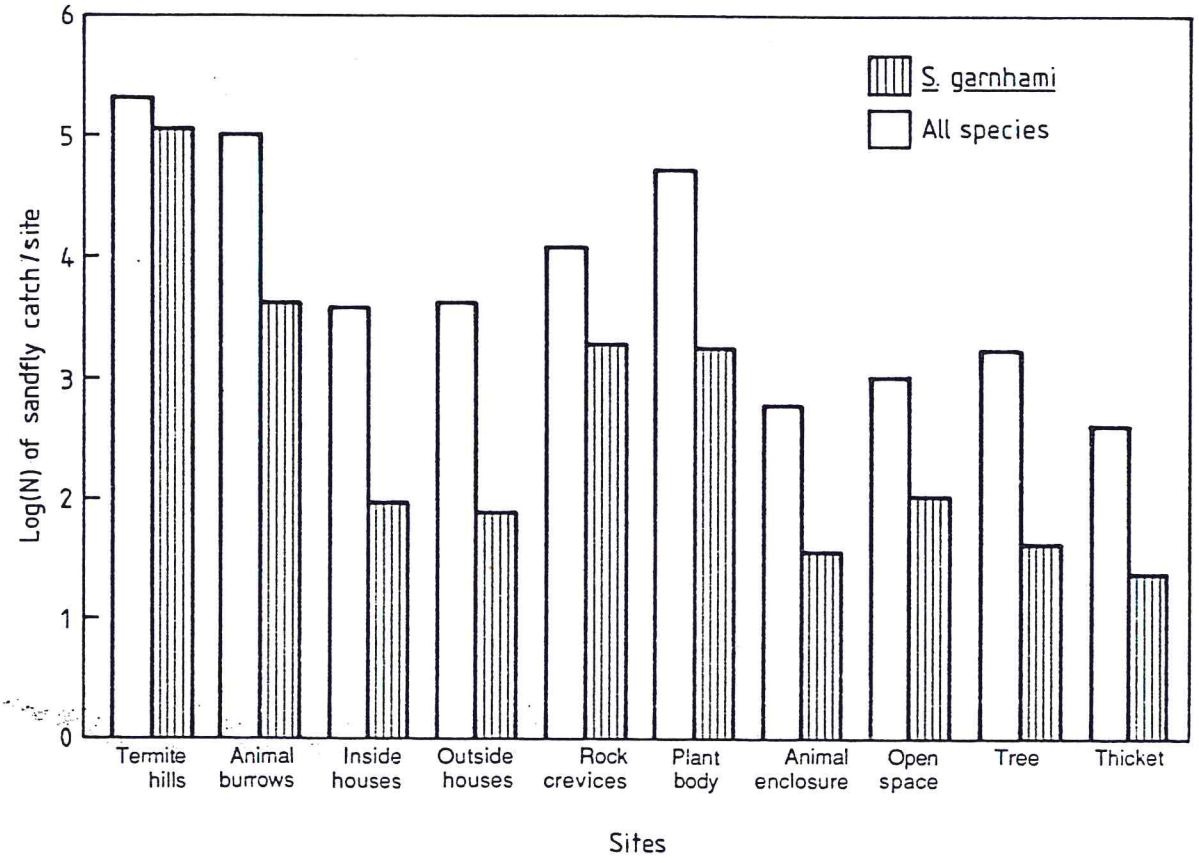


Fig 5.1 Spatial distribution of *S. garnhami* and other phlebotomine sandflies in various sites (Jan 1989– Jan 1990)

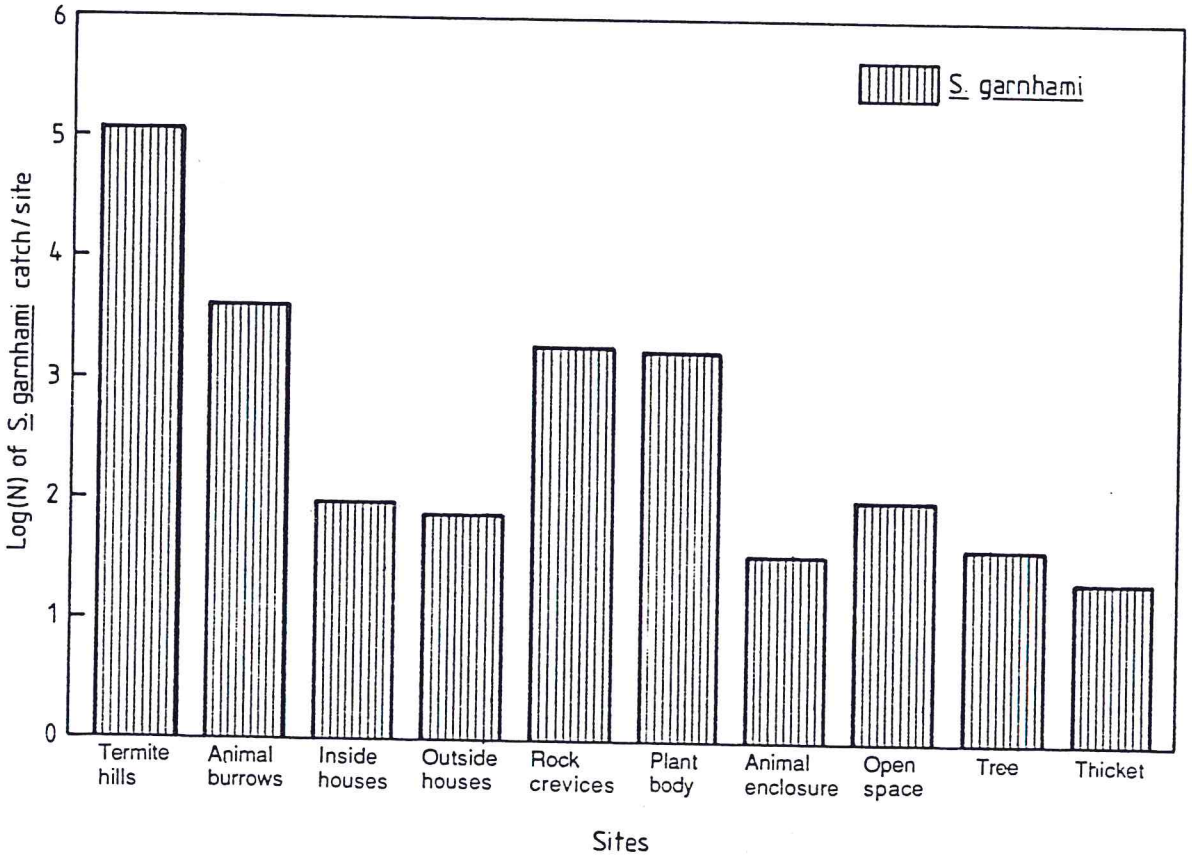


Fig 5.2 Spatial distribution of *S. garnhami* only in various sites (Jan 1989–Jan 1990)

5.3.2 Subsites

Table 5.4 shows the distribution of phlebotomine sandflies in the various subsites investigated. A total of 49257 sandflies were collected. 47105 (or 95.63%) were collected from the first phase while 2152 (or 4.37%) were collected from phase two of the studies. Relatively large numbers of phlebotomine sandflies were collected from the subsites of termite hills with termite hills exposed to daily sun rays and weather changes having the highest yield of 19488 (or 41.37%). The next to this were termite hills near human homes with a yield of 19109 (or 40.57%). Other subsites with significant yields were small animal burrows 8459 (or 17.96%), tree bases 3152 (or 6.69%), and treeholes 1834 (or 3.89%). In phase 2, most of the collections were from tree stems 1402 (or 65.15%) and foliage 339 (or 15.75%).

The distribution of *S. garnhami* in the various subsites is also given in table 5.4. A total of 23121 was collected from all the subsites. 23055 (or 99.71%) were collected from the first phase whereas 66 (or 0.29%) were from the second phase. Again most of the *S.garnhami* were collected from the subsites of the termite hills. Termite hills near human homes had the highest yield of 10585 (or 45.91%) followed by exposed termite hills with a yield of 10340 (or 44.85%). Other

subsites of importance include small animal burrows 3671 (or 15.92%), treebases 1123 (4.87%) treeholes 670 (or 2.91%) and large animal burrows 419 (or 1.82%). Analysis of variance (Anova) showed that there was significant difference between subsites (df = 15, F-value = 57.38, P = 0.0001***). Duncan's Multiple Range tests using Statistcal Analysis Systems programme (SAS) showed that the collections from exposed termite hills and termite hills near human homes were significantly different to those of other subsites but not significant to each other (table 5.5). Collections from termite hills far from homes were not signficantly different from those of termite hills under shade and small animal burrows. Small animal burrows were significant to big animal burrows and treebases. Tree bases were not significantly different to treeholes. Open spaces with vegetation were not significantly different to ope spaces wthiout vegetation. In phase two, collections from tree stems were significantly different from those of tree foliage, thicket foliage and floor.

Figures 5.3, 5.4, 5.5, and 5.6 are trends of distribution of *S. garnhami* in the various subsites investigated. Figure 5.3 and 5.4 compared this with other species put together whereas figures 5.5 and 5.6 presented *S. garnhami* only, in the various subsites investigated.

Table 5.4 Percentage distribution of phlebotomine sandflies in various subsites.

	All species		*S.garnhami*	
Subsite	Total	Percent	Total	Percent
Phase 1				
Termite hills near homes	19109	40.57	10585	45.91
Termite hills far from homes	12560	26.66	6480	28.12
Termite hills exposed	19488	41.37	10340	44.85
Termite hills under shades	11979	25.43	6725	29.17
Small animal burrows	8459	17.96	3671	15.92
Large animal burrows	959	2.04	419	1.82
Treeholes	1834	3.89	670	2.91
Treebases	3152	6.69	1123	4.87
Open space with vegetation	728	1.55	99	0.43
Open space without vegetation	304	0.65	8	0.03
Total	47105	100		100
Phase 2				
Tree stems	1402	65.15	22	33.33
Tree foliage	339	15.75	20	30.30
Kyandani thicket floor	59	2.74	9	13.64
Kyandani thicket foliage	113	5.25	8	12.12
Nziitu thicket floor	129	5.99	2	3.03
Nziitu thicket foliage	110	5.11	57	7.58
Total	2152	100		100

Table 5.5 Comparison of subsites by Duncan's Multiple Range Test

Duncan grouping		Mean	Sub-site
A		102.568	Exposed termite hills
A		100.574	Termite hills near homes
B		66.105	Termite hills far from homes
B		63.047	Shaded termite hills
B		62.199	Small animal burrows
	C	35.022	Treeholes
	C	28.206	Big animal burrows
D	C	20.378	Treeholes
D	E	8.565	Open space with vegetation
D	E	3.576	Open space without vegetation

Phase 2

A		10.014	Tree stem
B		2.421	Tree foliage
B		2.230	Forest foliage
B		1.880	Forest floor

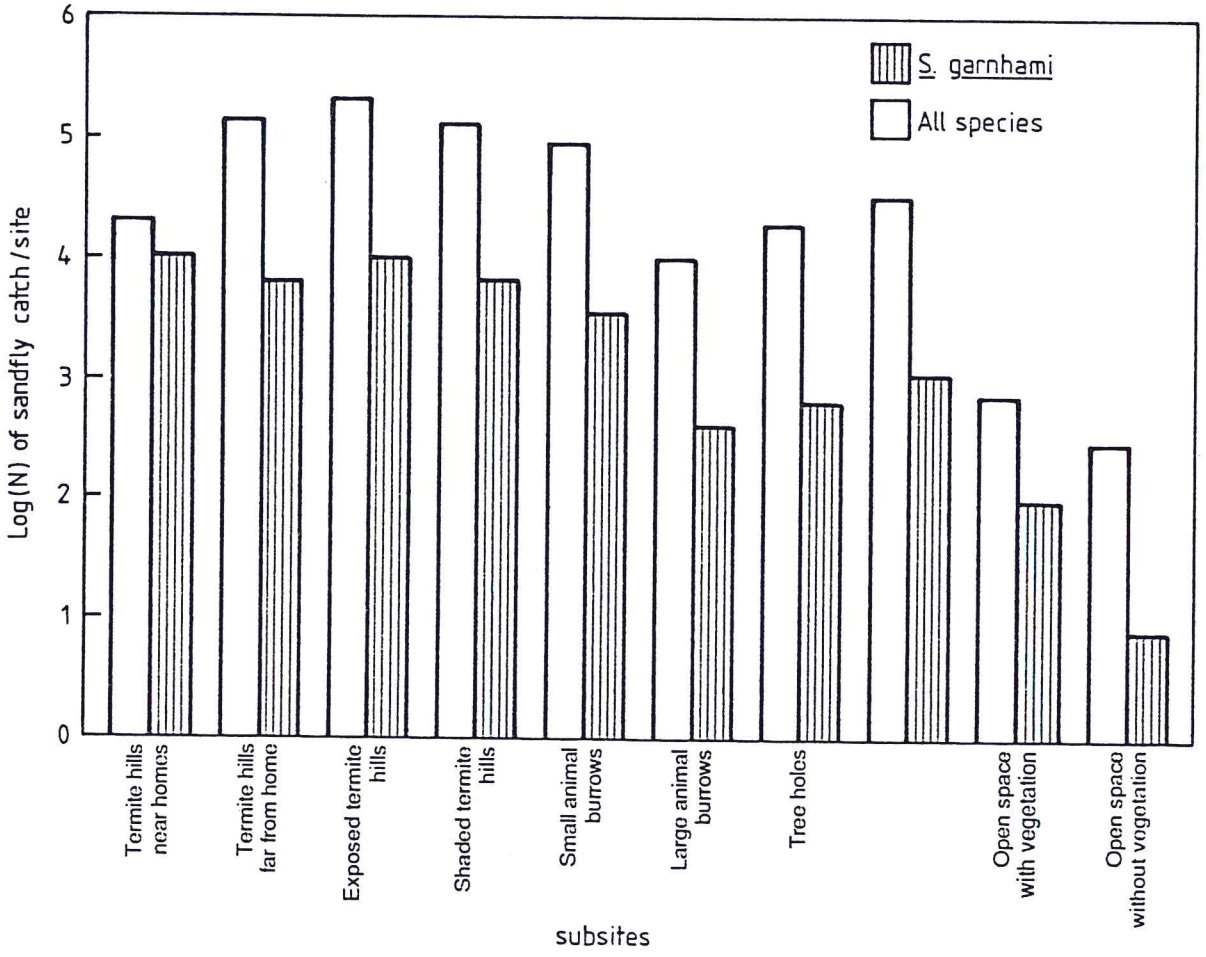


Fig 5.3 Spatial distribution of *S. garnhami* and other phlebotomine sandflies in various subsites (Phase 1, Jan 1989–Jan 1990)

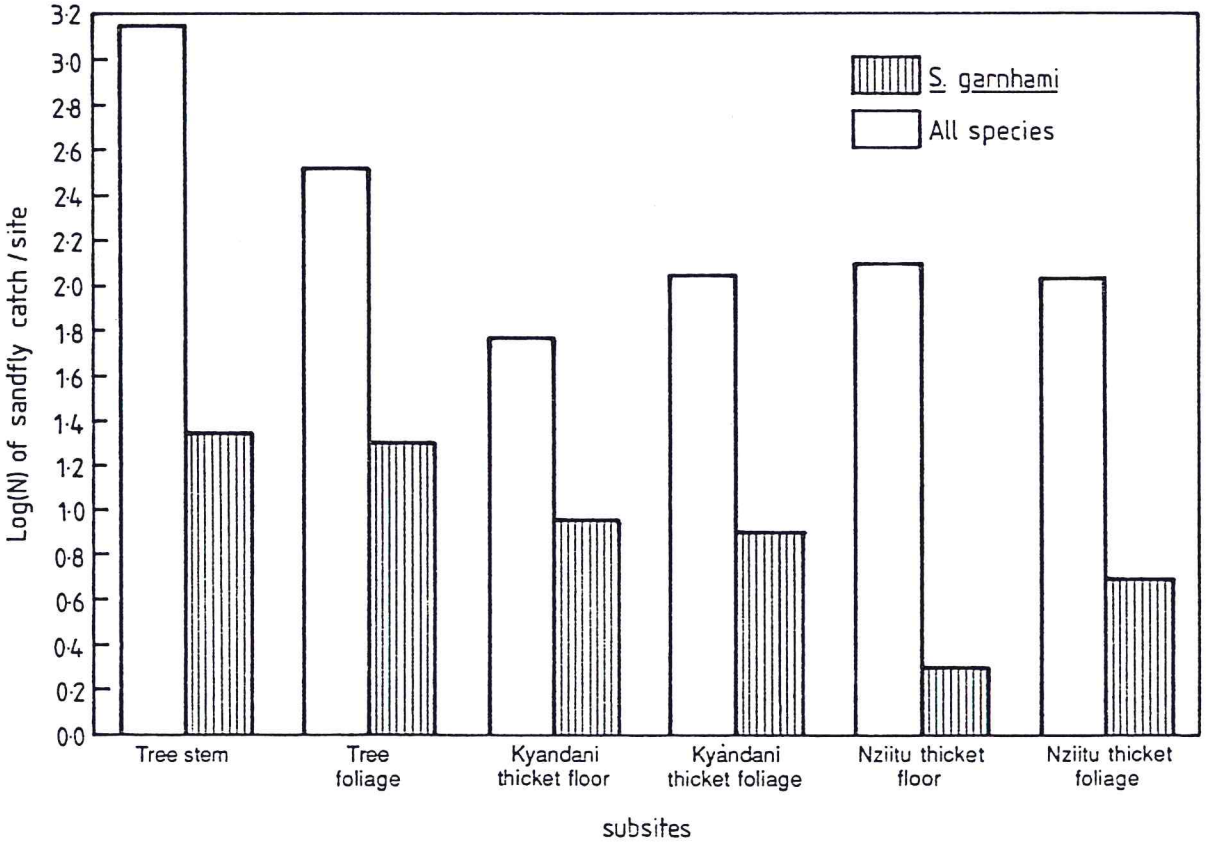


Fig 5.4 Spatial distribution of *S. garnhami* and other phlebotomine sandflies in various subsites (Phase 2, Sept.1989–Jan. 1990)

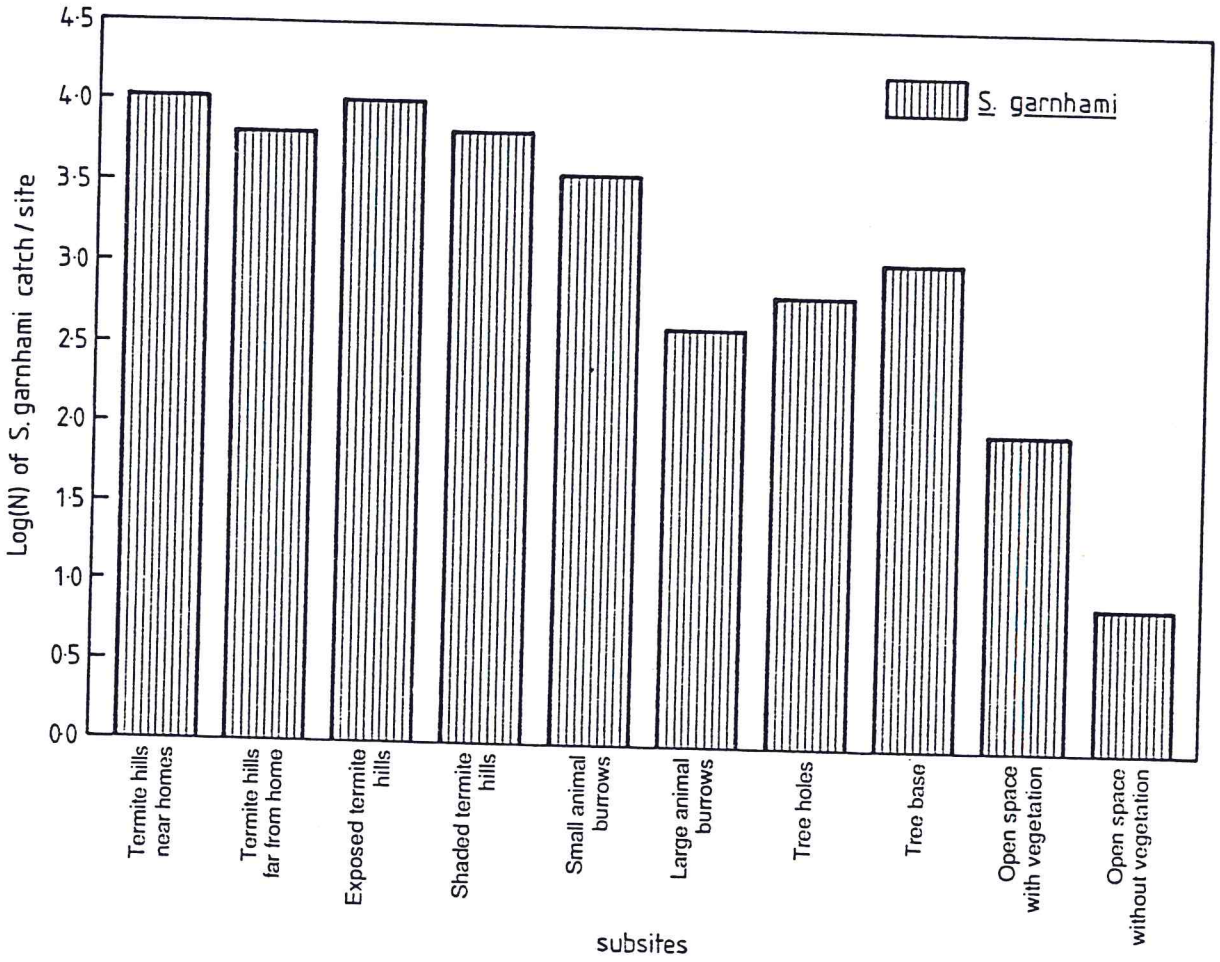


Fig 5.5 Spatial distribution of *S. garnhami* only in various subsites (Phase 1, Jan 1989–Jan 1990)

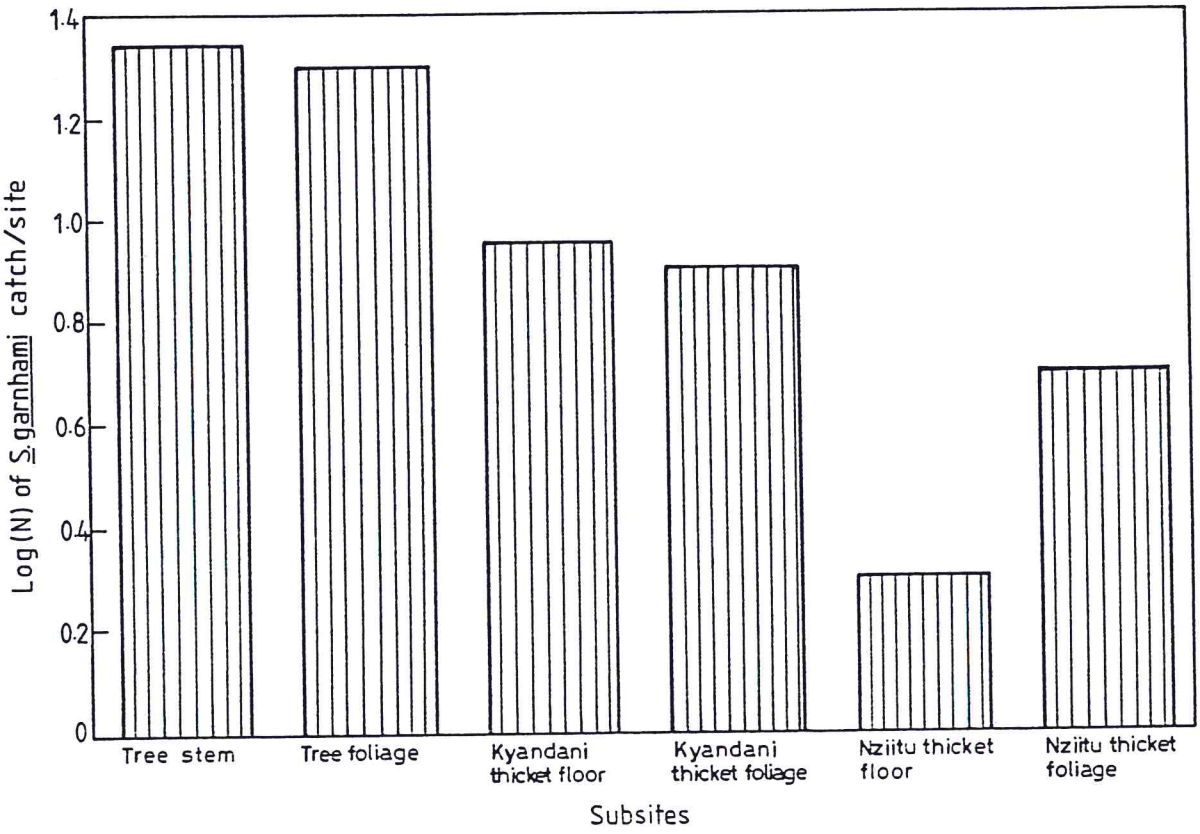


Fig 5.6 Spatial distribution of *S. garnhami* and other phlebotomine sandflies in various subsites (Phase 2, Sept 1989–Jan 1990)

5.3.3. Species distribution

Detailed information on the sandfly species distribution in the various sites and subsites is given in sections on various sites. Altogether 19 species comprising 3 species of the *Phlebotomus* genus and 16 species of *Sergentomyia* genus were collected. Analysis of variance (Anova) showed that there was significant difference between species (df = 18, F-value = 232.48, P= 0.001***). Duncan's Multiple Range tests using Statistcal Analysis Systems programme (SAS) showed that *S. garnhami* was significantly higher to *S. bedfordi* and other species (table 5.6).

5.3.4 Dispersion

Tables 5.7-10 contain data describing the dispersion or pattern of the distribution of *S.garnhami* and other phlebotomine sandflies in the various sites and subsites. In all the sites and the subsites the variance was considerably greater than the means indicating contagious or clumped distribution. Also the dispersion parameter (K) which measures the amount of clumping (i.e the index of aggregation) is less than 8 in most sites and subsites indicating strong aggregation. In most sites and subsites the value of K is less than 1 (i e they are fractions), illustrating a

Table 5.6 Comparison of species predominance by Duncan's Multiple Range Test.

Duncan grouping		Mean	Species
	A	282.013	*S.garnhami*
	B	218.240	*S.bedfordi*
	C	46.607	*S.kirki*
D	C	41.527	*S.affinis*
D	C	29.667	*S.antennatus*
D	E	13.773	*P.celiae*
	E	12.038	*S.ingrami*
	E	9.047	*S.schwetzi*
	E	6.223	*S.multidens*
	E	5.987	*P.martini*
	E	4.554	*S.graingeri*
	E	4.047	*S.clydei*
	E	2.353	*S.harveyi*
	E	2.236	*P.vansomerenae*
	E	1.562	*S.squamipleuris*
	E	0.840	*S.suberectus*
	E	0.709	*S.adleri*
	E	0.409	*S.christophersi*
	E	0.100	*S.rosannae*

Table 5.7 Distribution pattern of phlebotomine sandflies in different sites

Sites	No of sites	Total	Mean	Variance	K	CV
Phase 1						
Termite hills	20	31669	1583.5	1017468	0.25	0.64
Rock crevices	10	12232	1223.2	2423151	0.62	1.27
Animal burrows	10	9418	941.8	496912	1.79	0.74
Plant bodies	10	4986	498.1	291906	0.85	1.08
Inside houses	10	3796	379.6	27604	5.29	0.44
Outside house	10	4208	420.8	19495	9.28	0.33
Open spaces	10	1032	103.2	19452	0.55	1.34
Animal enclosur	10	e 613	61.3	327	14.1	0.29
Phase 2						
Tree	10	1741	174.1	43415	0.70	1.20
Thickets	20	411	20.55	183.42	2.59	0.66

Table 5.8: Distribution pattern of *S.garnhami* in different sites.

Sites	No of sites	Total	Mean	Variance	K	CV
Phase 1						
Termite hills	20	17065	853.25	391921.6	1.80	0.73
Rock crevices	10	1909	190.9	109198.8	0.33	1.73
Animal burrows	10	4090	409	127886	1.31	0.87
Plant bodies	10	1793	179.3	81814.7	0.39	0.50
Inside houses	10	94	9.4	69.6	1.46	0.88
Outside house	10	77	7.7	71.57	0.92	1.10
Open spaces	10	107	10.7	686.01	0.17	2.44
Animal enclosure	10	36	3.6	14.04	1.25	1.03
Phase 2						
Tree	10	42	4.2	44.4	0.44	1.60
Thickets	20	24	1.2	1.96	1.89	1.17

Table 5.9 Distribution pattern of phlebotomine sandflies in different subsites.

Subsite	No of sites	Total caught	Mean	Variance	K	CV
Phase 1						
Termite hills near homes	10	19109	1910.9	1132161	3.23	0.56
Termite hills far from homes	10	12560	1256	777552	2.03	0.70
Termite hills exposed	10	19488	1948.8	939816	4.05	0.50
Termite hills under shades	10	11979	1197.9	855705	1.68	0.77
Small animal burrows	8	8459	1057.4	562387	1.99	0.71
Large animal burrows	2	959	479.5	1201	319	0.07
Treeholes	5	1834	366.8	75364	1.79	0.74
Treebases	5	3152	630.4	537995	0.74	1.16
Open space with vegetation	5	728	145.6	39184	0.54	1.36
Open space without vegetation	5	304	60.8	89	1.5	0.15
Phase 2						
Tree stems	10	1402	140.2	27308	0.72	1.18
Tree foliage	10	339	33.9	2087	0.56	1.36
Kyandani thicket floor	5	59	11.8	75	2.20	0.76
Kyandani thicket foliage	5	113	22.6	210	2.73	0.62
Nziitu thicket floor	5	129	25.8	175	4.46	0.50
Nziitu thicket foliage	5	110	22	274	1.92	0.77

Table 5.10 Distribution pattern of *S.garnhami* in different subsites.

Subsite	No of sites	Total caught	Mean	Variance	K	CV
Phase 1						
Termite hills near homes	10	10585	1059	488919	2.30	0.66
Termite hills far from homes	10	6480	648	244852	1.72	0.76
Termite hills exposed	10	10340	1034	343802	3.12	0.57
Termite hills under shades	10	6725	673	410986	1.10	0.95
Small animal burrows	8	3671	459	149482	1.41	0.84
Large animal burrows	2	419	209	5101	24	0.34
Treeholes	5	670	134	60853	0.30	1.84
Treebases	5	1123	225	118100	0.43	1.53
Open space with vegetation	5	99	19.8	1333	67	1.83
Open space without vegetation	5	8	1.6	3.8	2	1.19
Phase 2						
Tree stems	10	22	2.2	31.73	0.16	2.54
Tree foliage	10	20	2.0	22.44	0.20	2.35
Kyandani thicket floor	5	9	1.8	3.7	1.71	1.05.
Kyandani thicket foliage	5	8	1.6	1.3	8.5	0.69
Nziitu thicket floor	5	2	0.4	0.8	0.4	2.23
Nziitu thicket foliage	5	5	1.0	2.00	1.0	1.4

distribution approaching logarithmic form in which the value of K is zero. The coefficient of variation or dispersion from unity (CV) is also high in most sites and subsites. CV is related to K and is usually larger the smaller the value of K.

5.3.5 Sandfly distribution in termite hills

Table 5.11 shows data on the sandfly species distribution in termite hills. A total of 31669 (or 46.60%) of all the sandflies from phase 1 studies was collected from all the termite hills. Nineteen species of sandflies comprising 3 species of genus *Phlebotomus* and 16 species of genus *Sergentomyia* were collected from the termite hills. *Sergentomyia garnhami* were 17065 (or 53.89%). All the 19 sandfly species were collected from the four subsites of the termite hills.

Table 5.12 is on sandfly species distribution in termite hills near human homes. 19109 (or 60.34%) of 31669 sandflies were collected from this subsite. 10585 (or 55.39%) were *S. garnhami* with female:male sex ratio of 2:1. The *Synphlebotomus* species were altogether 566 (or 2.97%). The breakdown of the *Synphlebotomus* complex was *P. celiae* 393 (or 2.06%), *P. martini* 139 (or 0.73%) and *P. vansomerenae* 34 (or 0.18%). This shows that

Sergentomyia species constituted 97.03% of the catches from this subsite.

Table 5.13 shows the sandfly distribution in termite hills far away from human homes. A total of 12560 (39.66%) sandflies were collected and *S. garnhami* were 6480 (or 51.59%) with female:male sex ratio of 2:1. The *Synphlebotomus* complex put together were 910 (or 7.24%) and comprised *P. celiae* 605 (or 4.8%), *P. martini* 224 (or 1.78%) and *P.vansomerenae* 81 (or 0.81%). *Sergentomyia* species put together were 11650 (or 92.76%).

19488 (61.54%) were caught from termite hills exposed to light and the daily weather changes (table 5.14). *S. garnhami* was 10340 (or 53.06%) with female:male sex ratio of 2:1. The *Synphlebotomus* species put together were 1215 (or 6.24%). The *Sergentomyia* species constituted 93.76%.

11979 (37.83%) were collected from the termite hills under shades (table 5.15). *S .garnhami* collected were 6725 (or 56.14%) with female:male sex ratio of 1:1. The *Synphlebotomus* species put together were 261 (or 2.18%). The *Sergentomyia* species put together were 97.82%.

Table 5.11: Sandfly species distribution in termite hills

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	998	3.15	1 : 3
P.martini	363	1.15	1 : 4
P.vansomerenae	115	0.36	1 : 11
S.adleri	17	0.05	1 : 1
S.affinis	2910	9.19	1 : 2
S.antennatus	906	2.86	2 : 1
S.bedfordi	4826	15.24	1 : 3
S.christophersi	6	0.02	5 : 1
S.clydei	184	0.58	1 : 1
S.garnhami	17065	53.89	2 : 1
S.graingeri	272	0.86	2 : 1
S.harveyi	45	0.14	45 : 0
S.ingrami	559	1.77	6 : 1
S.kirki	2621	8.28	1 : 3
S.multidens	399	1.26	1 : 2
S.rosanoffi	2	0.01	2 : 0
S.schwetzi	361	1.14	2 : 1
S.squamipleuris	4	0.01	1 : 1
S.suberectus	18	0.06	2 : 1

NB: Calculations done with pooled data from 20 termite hills

Table 5.12:- Species distribution in termite hills near homes

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	393	2.06	1 : 3
P.martini	139	0.73	1 : 3
P.vansomerenae	34	0.18	1 : 3
S.adleri	11	0.06	1 : 0.6
S.affinis	1635	8.56	1 : 1.5
S.antennatus	654	3.42	1 : 0.50
S.bedfordi	3408	17.83	1 : 3
S.christophersi	3	0.02	1 : 0.5
S.clydei	108	0.57	1 : 1
S.garnhami	10585	55.39	1 : 0.5
S.graingeri	156	0.82	1 : 0.5
S.harveyi	27	0.14	27 : 0
S.ingrami	37	1.95	1 : 02
S.kirki	1206	6.31	1 : 3
S.multidens	158	0.83	1 : 2
S.rosannae	1	0.01	1 : 0
S.schwetzi	206	1.08	1 : 0.7
S.squamipleuris	3	0.02	1 : 2
S.suberectus	10	0.05	1 : 2

Table:5.13:- Species distribution in termite hills far from human homes

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	605	4.82	1 : 2
P.martini	224	1.78	1 : 3
P.vansomerenae	81	0.64	1 : 8
S.adleri	6	0.05	1 : 1
S.affinis	1275	10.15	1 : 2
S.antennatus	252	2.01	1 : 0.5
S.bedfordi	1418	11.29	1 : 3
S.christophersi	3	0.02	3 : 0
S.clydei	76	0.61	1 : 1
S.garnhami	6480	51.59	1 : 0.6
S.graingeri	116	0.92	1 : 0.5
S.harveyi	18	0.14	18 : 0
S.ingrami	187	1.49	1 : 0.7
S.kirki	1415	11.27	1 : 3
S.multidens	239	1.90	1 : 3
S.rosannae	1	0.01	1 : 0
S.schwetzi	155	1.23	1 : 0.2
S.squamipleuris	1	0.01	1 : 0
S.suberectus	8	0.06	8 : 0

Table 5.14: Sandfly species distribution in exposed termite hills

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	859	4.41	1 : 3
P.martini	270	1.39	1 : 3
P.vansomerenae	86	0.44	1 : 9
S.adleri	13	0.07	1 : 1
S.affinis	2031	10.42	1 : 2
S.antennatus	619	3.18	1 : 0.6
S.bedfordi	2501	12.83	1 : 3.7
S.christophersi	2	0.01	1 : 1
S.clydei	126	0.65	1 : 1
S.garnhami	10340	53.06	1 : 0.4
S.graingeri	202	1.04	1 : 0.5
S.harveyi	27	0.14	27 : 0
S.ingrami	413	2.12	1 : 0.2
S.kirki	1446	7.42	1 : 3
S.multidens	265	1.36	1 : 2
S.rosannae	1	0.005	1 : 0
S.schwetzi	269	1.38	1 : 0.5
S.squamipleuris	3	0.015	1 : 0.5
S.suberectus	15	0.08	1 : 0.5

Table 5.15:- Sandfly species distribution in termite hills under shade

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	139	1.16	1 : 3
P.martini	93	0.78	1 : 6
P.vansomerenae	29	0.24	1 : 28
S.adleri	4	0.03	1 : 1
S.affinis	677	5.65	1 : 2
S.antennatus	287	2.40	1 : 0.5
S.bedfordi	2325	19.41	1 : 3
S.christophersi	4	0.03	4 : 0
S.clydei	58	0.48	1 : 1
S.garnhami	6725	56.14	1 : 1
S.graingeri	70	0.58	1 : 1
S.harveyi	18	0.15	18 : 0
S.ingrami	146	1.22	1 : 0.1
S.kirki	1175	9.81	1 : 3
S.multidens	132	1.10	1 : 3
S.rosannae	1	0.01	1 : 0
S.schwetzi	92	0.77	1 : 0.4
S.squamipleuris	1	0.01	0 : 1
S.suberectus	3	0.03	1 : 2

5.3.6 Sandfly distribution in rock crevices

A total of 12232 (or 22.06%) of the total sandflies collection of phase 1 were from the rock crevices (table 5.16). Seventeen species comprising 3 species of *Phlebotomus* genus and 14 species of *Sergentomyia* genus were caught. 1909 (or 15.61%) of all the collections from the rock crevices were *S. garnhami*. The *Synphlebotomus* species (*P.martini*, *P. celiae* and *P. vansomerenae*) put together were 30 (or 0.25%).

5.3.7 Sandfly distribution in animal burrows

9418 sandflies were collected from all the animal burrows (table 5.17) and this constituted 13.85% of all the collections from phase 1 sites investigated. Seventeen species were collected comprising 3 species of *Phlebotomus* genus and 14 species of *Sergentomyia* genus . *S garnhami* collected were 4090 (or 43.43%) of all the collections from the animal burrows. The *Synphlebotomus* complex put together were 149 (or 1.63%).

A total of 8459 sandflies (or 89.82%) of all the collections from animal burrows was from small animal burrows (table 5.18). All the 17 species of sandflies reported above were also collected in the small animal burrows but *S garnhami* constituted 3671 (or 43.40%). Sex ratio analysis showed that twice more males than

females of *S garnhami* were collected. The *Synphlebotomus* species put together were 64 (0.76%).

A total of 959 (or 10.18%) of all the sandfly collections from the animal burrows investigated was from the 2 large animal burrows used in this study (table 5.19). 419 (or 43.69%) were *S. garnhami* with a sex ratio of 1:2. The *Synphlebotomus* species were 85 (or 8.86%). This figure is significantly higher than 64 collected from 8 small animal burrows. 14 out of 17 sandfly species were collected and the missing species were *S. adleri, S squamipleuris* and *S multidens.*

5.3.8 Sandfly distribution on plant bodies

Table 5.20 shows the sandfly species collected from plant bodies (tree holes and tree bases).. 4986 (or 7.34%) out of the total sandfly collections from phase 1 study were from this site. 18 species comprising 3 species of the *Synphlebotomus* complex group and 15 species of *Sergentomyia* were caught in all the tree holes and tree bases investigated. 1793 (or 35.96%) were *S garnhami* with a female:male sex ratio of 1:2. The *Synphlebotomus* species collected were 37 (or 0.74%).

1834 (or 36.86%) of the total collections from plant bodies were from tree holes (table 5.21). *S garnhami* caught were 670 (or 36.53%) with female:male ratio of 3:1. 15 sandfly species were collected, the

Table 5.16:- Sandfly species distribution in rock crevices

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	10	0.08	9 : 1
P.martini	19	0.16	1 : 2
P.vansomerenae	1	0.008	0 : 1
S.adleri	5	0.04	0 : 5
S.affinis	163	1.33	3 : 1
S.antennatus	587	4.80	4 : 1
S.bedfordi	8432	68.93	2 : 1
S.christophersi	25	0.20	3 : 1
S.clydei	48	0.39	4 : 1
S.garnhami	1909	15.61	1 : 2
S.graingeri	15	0.12	14 : 1
S.harveyi	25	0.20	2 : 1
S.ingrami	23	0.18	2 : 1
S.kirki	795	6.50	1 : 2
S.multidens	3	0.02	3 : 0
S.schwetzi	70	0.57	34 : 1
S.squamipleuris	102	0.83	1 : 1

Table 5.17:-Sandfly species distribution in animal burrows

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	26	0.27	2 : 1
P.martini	112	1.19	1 : 11
P.vansomerenae	11	0.12	0 : 11
S.adleri	9	0.10	1 : 4
S.affinis	299	3.17	1 : 4
S.antennatus	237	2.52	7 : 1
S.bedfordi	4306	45.72	1 : 2
S.christophersi	4	0.04	4 : 0
S.clydei	14	0.15	1 : 1
S.garnhami	4090	43.43	1 : 2
S.graingeri	18	0.19	3 : 1
S.harveyi	64	0.68	2 : 1
S.ingrami	22	0.23	10 : 2
S.kirki	164	1.74	1 : 3
S.multidens	4	0.04	4 : 0
S.schwetzi	36	0.38	5 : 1
S.squamipleuris	2	0.02	2 : 0

Table 5.18: Sandfly species distribution in small animal burrows

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	17	0.20	1 : 1
P.martini	43	0.51	1 : 1
P.vansomerenae	4	0.05	1 : 8
S.adleri	9	0.11	0 : 4
S.affinis	263	3.11	2 : 1
S.antennatus	215	2.54	1 : 4
S.bedfordi	3954	46.74	3 : 1
S.christophersi	1	0.01	1 : 3
S.clydei	12	0.14	1 : 1
S.garnhami	3671	43.40	1 : 2
S.graingeri	15	0.18	1 : 2
S.harveyi	47	0.56	2 : 1
S.ingrami	19	0.22	1 : 9
S.kirki	151	1.79	1 : 3
S.multidens	4	0.05	4 : 0
S.schwetzi	32	0.38	5 : 1
S.squamipleuris	2	0.02	2 : 0

Table 5.19: Sandfly species distribution in big animal burrows

Species	Total collected	Percent	Sex ratio Female:Male
P.ocliae	9	0.94	1 : 3
P.martini	69	7.19	1 : 16
P.vansomerenae	7	0.73	0 : 7
S.affinis	36	3.75	1 : 6
S.antennatus	22	2.29	22 : 0
S.bedfordi	352	36.70	1 : 2
S.christophersi	3	0.31	1 : 2
S.clydei	2	0.21	2 : 0
S.garnhami	419	43.69	1 : 2
S.graingeri	3	0.31	3 : 0
S.harveyi	17	1.77	1 : 1
S.ingrami	3	0.31	3 : 0
S.kirki	13	1.36	1 : 2
S.schwetzi	4	0.42	3 : 1

Table 5.20:- Sandfly species distribution in treeholes and treebases combined.

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	14	0.28	1 : 4
P.martini	21	0.42	1 : 20
P.vansomerenae	2	0.04	0 : 2
S.adleri	6	0.12	0 : 6
S.affinis	83	1.66	1 : 1
S.antennatus	356	7.14	3 : 1
S.bedfordi	1619	32.47	1 : 2
S.christophersi	2	0.04	2 : 0
S.clydei	16	0.32	1 : 1
S.garnhami	1793	35.96	1 : 2
S.graingeri	3	0.06	0 : 3
S.harveyi	76	1.52	1 : 6
S.ingrami	308	6.17	6 : 1
S.kirki	323	6.48	1 : 3
S.multidens	2	0.04	1 : 1
S.schwetzi	352	6.48	3 : 1
S.squamipleuris	4	0.08	3 : 1
S.suberectus	6	0.12	1 : 1

Table 5.21: Sandfly species distribution in treeholes only

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	4	0.22	1 : 3
P.martini	8	0.44	1 : 7
P.vansomerenae	1	0.05	0 : 1
S.adleri	5	0.27	0 : 5
S.affinis	31	1.69	2 : 1
S.antennatus	177	9.65	3 : 1
S.bedfordi	420	22.90	1 : 2
S.christophersi	2	0.12	2 : 0
S.clydei	14	0.76	1 : 1
S.garnhami	670	36.53	3 : 1
S.graingeri	1	0.05	0 : 1
S.harveyi	48	2.62	11 : 1
S.ingrami	147	8.02	4 : 1
S.kirki	237	12.92	1 : 4
S.schwetzi	68	3.71	22 : 1
S.squamipleuris	1	0.05	0 : 1

Note: No *S.multidens* and *S.suberectus*

Table 5.22:- Sandfly species distribution under treebases

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	10	0.32	1 : 4
P.martini	13	0.41	0 : 13
P.vansomerenae	1	0.03	0 : 1
S.adleri	1	0.03	0 : 1
S.affinis	52	1.65	1 : 2
S.antennatus	179	5.68	3 : 1
S.bedfordi	1199	38.04	2 : 1
S.clydei	2	0.06	0 : 2
S.garnhami	1123	35.63	1 : 1
S.graingeri	2	0.06	0 : 2
S.harveyi	28	0.89	4 : 1
S.ingrami	161	5.11	14 : 1
S.kirki	86	2.73	1 : 2
S.multidens	2	0.06	1 : 1
S.schwetzi	284	9.01	3 : 1
S.squamipleuris	3	0.10	3 : 0
S.suberectus	6	0.19	1 : 1

Synphlebotomus complex were 13 (or 0.71%). *S. multidens and S. suberectus* were not collected.

3152 (or 63.22%) of all the sandflies from plant bodies were from under tree bases and spaces between root buttresses (table 5.22). *S. garnhami* caught were 1123 (or 35.63%) with female:male sex ratio of 1:1. Eighteen out of 19 species from this biotope were collected from tree bases. *S. christophersi* was not collected under the tree bases. The *Synphlebotomus* species were 24 (or 0.76%).

5.3.9 Sandfly distribution in inside walls of human homes

3796 (or 5.59%) of all the sandflies collected from the phase 1 of this investigation were from inside walls of houses (table 5.23). This consisted of two species of the *Synphlebotomus* complex (*P. celiae* and *P. martini*) and 13 species of *Sergentomyia* species. *S. bedfordi and S. antennatus* dominated the catches from the inside human homes. 94 (or 2.48%) were *S. garnhami* with a female:male sex ratio of 3:1. The *Synphlebotomus* complex species were 5 (or 0.13%) of the inside houses sandfly species population.

5.3.10 Sandfly distribution in outside walls of human homes

4208 (or 6.19%) of all the phlebotomine sandflies from phase 1 of this study were from outside walls of human habitations (table 5.24). This was composed of 2 species of the Synphlebotomus complex (P. celiae and P. martini) and 14 species of the *Sergentomyia* genus. 77 (or 1.83%) were *S. garnhami* with a female:male sex ratio of 2:1. The *Synphlebotomus* complex were 9 (or 0.22%). Again the catches were dominated by *S. bedfordi* and *S. antennatus*.

5.3.11 Sandfly distribution in animal enclosures

613 (or 0.90%) of all the sandflies from phase 1 of this investigation were caught from animal enclosures (table 5.25). 17 sandfly species were caught consisting of the 3 species of the *Synphlebotomus* complex and 14 species of the *Sergentomyia* genus. *S garnhami* caught were 36 (or 5.65%) of this population with a female:male sex ratio of 2:1. The *Synphlebotomus* complex were 5 (or 0.82%).

Table 5.23: Sandfly species distribution on the inside walls of human homes

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	3	0.08	2 : 1
P.martini	2	0.05	0 : 2
S.adleri	6	0.16	1 : 2
S.affinis	11	0.29	1 : 2
S.antennatus	432	11.38	5 : 1
S.bedfordi	3088	81.35	3 : 1
S.clydei	25	0.66	1 : 1
S.garnhami	94	2.48	3 : 1
S.graingeri	1	0.03	1 : 0
S.harveyi	1	0.03	1 : 0
S.ingrami	25	0.66	24 : 1
S.kirki	56	1.48	1 : 1
S.multidens	1	0.03	1 : 0
S.schwetzi	45	1.19	7 : 1
S.squamipleuris	6	0.16	5 : 1

Table 5.24 Sandflies species distribution on the outside walls of human homes

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	4	0.10	3 : 1
P.martini	5	0.12	1 : 2
S.adleri	5	0.12	5 : 0
S.affinis	18	0.43	1 : 2
S.antennatus	643	15.28	2 : 1
S.bedfordi	3143	74.69	2 : 1
S.christophersi	1	0.02	0 : 1
S.clydei	32	0.76	1 : 1
S.garnhami	77	1.83	2 : 1
S.graingeri	1	0.02	2 : 1
S.harveyi	4	0.10	3 : 1
S.ingrami	18	0.43	18 : 0
S.kirki	220	5.23	1 : 1
S.multidens	2	0.05	0 : 2
S.schwetzi	33	0.78	10 : 1
S.squamipleuris	2	0.05	2 : 0

Table 5.25: Sandfly species distribution in animal enclosures

Species	Total collected	Percent	Sex ratio Female : Male
P.celiae	2	0.33	2 : 0
P.martini	2	0.33	0 : 2
P.vansomerenae	1	0.16	0 : 1
S.adleri	8	1.31	1 : 7
S.affinis	6	0.98	0 : 6
S.antennatus	131	21.37	2 : 1
S.bedfordi	300	48.93	1 : 1
S.christophersi	1	0.16	1 : 0
S.clydei	40	6.53	2 : 1
S.garnhami	36	5.87	2 : 1
S.graingeri	4	0.65	1 : 1
S.harveyi	12	1.96	1 : 5
S.ingrami	4	0.65	1 : 1
S.kirki	53	8.65	1 : 1
S.schwetzi	5	0.82	1 : 1
S.squamipleuris	2	0.33	2 : 0

5.3.12 Sandfly distribution in open spaces

1032 (1.52%) of all the sandflies caught in phase 1 of this study were from open spaces (table 5.26). This comprised the 3 species of the *Synphlebotomus* complex and 13 species of the *Sergentomyia* genus. *S garnhami* caught were 107 (or 10.37%) of this population with a female:male sex ratio of 1:1. The *Synphlebotomus* complex species were 10 (or 0.97%). *S. bedfordi* dominated the catches.

304 (or 29.46%) out of 1032 sandflie from open spaces were from open spaces without vegetation (table 5.27). 14 out 16 species from the open spaces were collected from this subsite. *S. garnhami* caught were 8 (or 2.63%) with a female:male sex ratio of 1:1 . *S. bedfordi* and *S antennatus* were the most abundant flies caught. *S. graingeri* and *S multidens* were not collected. The *Synphlebotomus* complex caught were 3 (or 0.99%).

728 (or 70.54%) of the sandflies from the open spaces were from open spaces with vegetation (table 5.28). Fifteen species out of 16 were caught from this subsite comprising 2 species of the *Synphlebotomus* complex and 13 species of the *Sergentomyia* genus. 99 (or 13.60%) were *S. garnhami* with a female:male sex ratio of 1:1. *S. bedfordi* and *S antennatus* were also the most abundant flies collected. *P vansomerenae* was

Table 5.26: Sandfly species distribution in all the open spaces

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	5	0.48	4 : 1
P.martini	4	0.39	0 : 4
P.vansomerenae	1	0.10	0 : 1
S.adleri	5	0.48	1 : 2
S.affinis	23	2.23	1 : 2
S.antennatus	161	15.60	2 : 1
S.bedfordi	546	52.91	1 : 1
S.clydei	41	3.97	1 : 2
S.garnhami	107	10.37	1 : 1
S.graingeri	4	0.39	4 : 0
S.harveyi	4	0.39	1 : 3
S.ingrami	8	0.78	8 : 0
S.kirki	26	2.52	1 : 2
S.multidens	2	0.19	1 : 1
S.schwetzi	25	2.42	5 : 1
S.squamipleuris	70	6.78	5 : 1

Table 5.27: Sandfly species distribution in open spaces without vegetation

Species	Total collected	Percent	Sex ratio Female:Male
P.ceciliae	1	0.33	0 : 1
P.martini	1	0.33	1 : 0
P.vansomerenae	1	0.33	0 : 1
S.adleri	4	1.32	1 : 1
S.affinis	8	2.63	1 : 7
S.antennatus	60	19.74	2 : 1
S.bedfordi	114	37.50	1 : 1
S.clydei	20	6.58	1 : 2
S.garnhami	8	2.63	1 : 1
S.harveyi	3	0.99	1 : 2
S.ingrami	1	0.33	1 : 0
S.kirki	6	1.98	0 : 3
S.schwetzi	9	2.97	7 : 1
S.squamipleuris	68	22.44	1 : 1

Table 5.28 Sandfly species distribution in open spaces with vegetation

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	4	0.55	4 : 0
P.martini	3	0.41	0 : 3
S.adleri	1	0.14	0 : 1
S.affinis	15	2.06	1 : 2
S.antennatus	101	13.87	2 : 1
S.bedfordi	432	59.34	1 : 1
S.clydei	21	2.88	1 : 1
S.garnhami	99	13.60	1 : 1
S.graingeri	4	0.55	4 : 0
S.harveyi	1	0.14	1 : 0
S.ingrami	7	0.96	7 : 0
S.kirki	20	2.75	1 : 2
S.multidens	2	0.27	1 : 2
S.schwetzi	16	2.20	7 : 1
S.squamipleuris	2	0.27	1 : 1

not collected. *P. celiae and P. martini* put together were 7 (or 0.96%).

5.3.13 Sandfly distribution on trees

1741 (or 80.90%) out of 2152 sandflies (table 5.29) collected in this phase were from trees (tree stems and foliage). This consisted of 2 species of the *Synphlebotomus* complex and 12 species of the *Sergentomyia* genus. 42 (or 2.41%) were *S. garnhami*. *P. celiae* were 5 (or 0.29%) and *P martini* were 3 (or 0.17%). *S. bedfordi* was the most abundant species.

1402 (or 80.53%) out of 1741 sandflies were collected from tree stems (table 5.30). 13 out of 14 species were collected from this subsite. *S. garnhami* were 22 (or 1.57%) with a female:male ratio of 1:1. No *S. multidens* was caught. *P. celiae* and *P. martini* put together were 3 (or 0.21%). *S. bedfordi* were 1142 (or 81.46%)

339 (or 19.47%) of the sandflies caught were from the tree foliage (table 5.31). All the 14 species (2 species of *Synphlebotomus* complex and 12 species of *Sergentomyia* genus) were collected in this subsite. *S. garnhami* were 20 (or 5.90%) with female:male sex ratio of 1:3. *S. bedfordi* were 252 (or 77.29%) whereas *P. celiae* and *P. martini* put together were 5 (or 1.47%).

Table 5.29 Sandfly species distribution on trees

Species	Total collected	Percent	Sex ratio Female:Male
P. celiae	5	0.29	2:1
P. martini	3	0.17	1:2
S. affinis	5	0.29	0:5
S. antennatus	70	4.02	1:1
S. bedfordi	1404	80.64	1:3
S. clydei	18	1.03	1:2
S. garnhami	42	2.41	1:2
S. graingeri	2	0.11	2:0
S. harveyi	59	3.39	1:2
S. ingrami	39	2.24	38:1
S. kirki	31	1.78	1:1
S. multidens	1	0.06	1:0
S.schwetzi	55	3.16	54:1
S.squamipleuris	7	0.40	1:1

Percentages calculated from pooled data from 10 trees.

Table 5.30:- Sandfly species distribution on tree stems

Species	Total collected	Percent	Sex ratio Female:Male
P.celiae	2	0.14	2 : 0
P.martini	1	0.07	0 : 1
S.affinis	4	0.29	0 : 4
S.antennatus	58	4.14	1 : 1
S.bedfordi	1142	81.46	1 : 2
S.clydei	16	1.14	1 : 2
S.garnhami	22	1.57	1 : 1
S.graingeri	1	0.07	1 : 0
S.harveyi	50	3.57	1 : 1
S.ingrami	33	2.35	32 : 1
S.kirki	22	1.57	1 : 1
S.schwetzi	48	3.42	48 : 0
S.squamipleuris	3	0.21	2 : 1

Note: Calculations done with pooled data from ten different trees

Table 5.31: Sandfly species distribution on tree foliages

Species	Total collected	Percent	Sex ratio Female : Male
P.celiae	3	0.88	1 : 2
P.martini	2	0.59	1 : 1
S.affinis	1	0.29	0 : 1
S.antennatus	12	3.54	1 : 1
S.bedfordi	262	77.29	1 : 4
S.clydei	2	0.59	1 : 1
S.garnhami	20	5.90	1 : 3
S.graingeri	1	0.29	1 : 0
S.harveyi	9	2.65	1 : 3
S.ingrami	6	1.77	6 : 0
S.kirki	9	2.65	2 : 1
S.multidens	1	0.29	1 : 0
S.schwetzi	7	2.06	6 : 1
S.squamipleuris	4	1.18	1 : 1

Note: Calculations were done with pooled data from 10 different trees

5.3.14 Sandfly distribution in thickets

411 (or 19.10%) of the sandflies from the phase 2 of the whole investigation were from the thickets (table 5.32). Ten sandfly species were collected, two species of which were the *Synphlebotomus* complex (*P. celiae* and *P. martini*) and 8 species were of *Sergentomyia* genus. *S. garnhami* collected were 24 (or 5.84%) with male to female sex ratio of 1:1. *S. bedfordi* 246 (or 59.85%) and *S. kirki* 81 (or 19.71%) were the most abundant species collected. The *Synphlebotomus* species put together were 5 (or 1.21%).

59 (or 14.36%) of 411 sandflies from the thickets were from Kyandani thicket floor (table 5.33). Nine out of the ten species from the thickets were collected from Kyandani thicket floor. *S. garnhami* caught were 9 (or 15.25%) with female:male ratio of 1:1. *S. bedfordi* 30 (or 50.84%) was the most abundant fly collected. *P. celiae* was 1 (or 1.69%) and *P. martini* 3 (or 5.08%).

113 (or 27.49%) of all the flies from the thickets were from Kyandani thicket foliage subsite (table 5.34). Seven out of ten species from the thickets were collected from this subsite. *S. garnhami* caught were 8 (or 7.08%) with female:male ratio of 1:3. *S. bedfordi* 54 (or 47.79%) and *S. kirki* 43 (or 38.05%) were the most abundant flies collected.

Table 5.32: Sandfly species distribution in thickets

Species	Total collected	Percent	Sex ratio Female:male
P. celiae	1	0.24	0:1
P. martini	4	0.97	1:3
S. affinis	3	0.73	2.:1
S. antennatus	21	5.11	6:1
S. bedfordi	246	59.85	1:1
S. clydei	5	1.22	2:1
S. garnhami	24	5.84	1:1
S. harveyi	18	4.37	1:1
S. kirki	81	19.71	1:7
S. schwetzi	8	1.92	8:0

Percentages calculated from pooled data from the 2 thickets

Table 5.33 Sandfly species distribution in Kyandani thicket floor

Species	Total collected	Percent	Sex ratio Female:male
P. celiae	1	1.69	0:1
P. martini	3	5.08	1:2
S. affinis	2	3.39	2:0
S. antennatus	2	3.39	1:1
S. bedfordi	30	50.85	1:2
S. clydei	2	3.39	2:0
S. garnhami	9	15.25	1:1
S. harveyi	9	15.25	1:2
S. schwetzi	1	1.69	1:0

Percentages calculated from pooled data of 5 traps.

Table 5.34:- Sandfly species composition of Kyandani thicket foliage

Species	Total collected	Percent	Sex ratio Female:Male
P. martini	1	0.88	0:1
S. antennatus	2	2:0	1.77
S. bedfordi	54	47.79	2:1
S. garnhami	8	7.08	1:3
S. harveyi	2	1.77	0:2
S. kirki	43	38.05	1:5
S. schwetzi	3	2.65	3:0

Percentages calculated from pooled data of 5 traps.

Table 5.35:- Species composition of Nziitu thicket floor

Species	Total collected	Percent	Sex ratio Female:Male
S. antennatus	11	8.53	0:1
S.hedfordi	98	75.97	2:1
S.clydei	3	2.33	1:2
S.garnhami	2	1.55	2:0
S. harveyi	4	3.10	1:3
S .kirki	10	7.75	1:9
S.schwetzi	1	0.78	1:0

Calculations done with pooled data of 5 traps.

Table 5.36:- Sandfly species composition of Nziitu thicket foliage

Species	Total collected	Percent	Sex ratio Female:Male
S.affinis	1	0.91	0:1
S antennatus	6	5.45	5:1
S bedfordi	64	58.18	2:1
S garnhami	5	4.55	5:0
S.harveyi	3	2.73	3:0
S.kirki	28	25.45	2:13
S.schwetzi	3	2.73	3:0

Calculations done with pooled data of 5 traps.

129 (or 31.39%) of the sandflies caught from the thickets were from Nziitu thicket floor (table 5.35). Seven species, all *Sergentomyia*, were collected. *S. garnhami* caught were 2 (or 1.55%), all females, were collected. *S. bedfordi* 98 (or 75.97%) dominated the catches from this subsite. The collections differed from the foliage fauna by the absence of *S. affinis*.

110 (or 26.76%) of the sandflies from the thickets were from the Nziitu thicket foliage subsite(table 5.36). Seven species, all *Sergentomyia*, were collected. This differed from the thicket floor by the absence of *S. clydei*. *S. garnhami* caught were 5 (or 4.55%) and all were females. *S. bedfordi* 64 (or 58.18%) and *S. kirki* 28 (or 25.45%) were the most abundant species collected from this subsite.

5.4 Discussions

S. garnhami is very abundant and widespread in Tseikuru Location of Kitui district. This is partly due to the ability of this fly to colonise and effectively utilise resources in a very wide range of habitats. It may also be partly due to its high reproductive capacity since this fly were collected in large numbers from different sites almost as pure cultures during its population peaks in May and December months. The high reproductive capacity of these flies coupled with their

breeding in protected habitats probably explained the clumped distribution of this fly in the various sites and subsites (Southwood 1978).

Although *S. garnhami* was collected in all the sites investigated termite hills, animal burrows, rock crevices, treeholes and treebases were the most preferred sites. Similar observations have been made elsewhere (Heisch 1954, Heisch et al 1956, Minter 1964 a & b, Kapur and Mutinga 1985, Mutinga 1985 and Basimike 1988). Termite hills consist of subterranean chambers whose walls were constructed to resist erosion by flood and weather (Richards and Davies 1977). This probably provides protection to both the adult sandflies and their immature stages thriving within the termite hills. Through the existence of termites and termitophilous insects including mites in the termite hills (Richards and Davies 1977), termiteria probably provide both food and refuge to other animals such as lizards, geckos rats, snakes and even mongooses usually found thriving inside the termite hills in Tseikuru. This association probably creates a condition of regular and even multiple host-fly contact, providing immediate food source to various sandfly species. The resultant is that fed flies seek both the resting and oviposition sites within the dark cool chambers of the termiteria (Kirk and Lewis 1951). The preference of termite hills by sandflies has serious epidemiological significance.

Termiteria are numerous in the semi arid region of Tseikuru being widely distributed within farm lands far and near from human homes and along foot paths such that inhabitants working late in their farms or trekking to their homes during dusk hours are likely to be bitten by infected sandflies. It also poses a serious threat of being regular source of infection and epidemics to the community. Mutinga et al (1984) observed that in West Pokot District of Kenya, there was a direct correlation between the location of sandflies near homes and kala azar incidence. Mutinga and Ngoka (1978) observed similar results in Machakos District of Kenya. Heisch (1954) found *S. rosannae* and *S. garnhami* biting humans who were sitting near termite hills between 1900 an 2100 hours. Heisch et al (1962) found many *P. martini* biting man indoors and also outdoors near termitaries. Southgate and Oriedo (1962) observed a positive correlation between the proximity of termite hills incidence of visceral leishmaniasis. Wijers (1963) and Wijers and Kiilu (1984) associated high kala azar infections in males to human activities near termite hills.

The situation in animal burrows and rock crevices are similar but unlike termite hills they are subject to regular washings by flooding since most of them were located along the river banks (Basimike 1988). This probably have suppressive effects on the population

numbers of the various sandfly species breeding and resting in them. In the case of treeholes and treebases they are insulated from external environments by the plant body parts but unfortunately most of them were shallow and can only support small populations.
On the part of the subsites, exposed and partially exposed termite hills produced significantly higher number of *S. garnhami* and other sandflies than the intensively shaded ones. This is probably due to some intrinsic factors existing within the sites such as warmth and larval nutrients. Warmth probably attracts the animals to take refuge within these termite hills which in the process deposit their wastes that may serve as sandfly larval food (Kapur and Mutinga 1981 and Mutinga et al 1989). This may explain the similarity in sandfly productivity of those termite hills within 500m from human dwellings and the termite hills exposed to light and the daily weather changes contrary to our expectations that sandfly distributions may be influenced by the domestic odours (human and livestock odours from human dwellings). The arrangement of subsites in termite hills was a nested randomized design type in which exposed and shaded termite hills were nested into those far and near from homes and this has probably influenced the results.

Small animal burrows were preferred to big ones to the ones belonging to the Aadavaark wolves (Ant deer).

Sergentomyia species are known to primarily feed on lizards and other reptiles (Kirk and Lewis 1951, Lewis 1973, Mutinga et al 1986 and 1990) and since even the abandoned rodent burrows were usually occupied by lizards or snakes it is likely to be due to the regular fly-host contact existing in these burrows. The preponderance of the *Synphlebotomus* complex species in large animal burrows may be due to the natural preference of these species to mammals (Mutinga et al 1986, 1990).

CHAPTER SIX

VERTICAL DISTRIBUTION OF *S. GARNHAMI*

6.1 Introduction

Some insect-borne diseases are known to be acquired by man at different heights in the woods while in pursuit of some of his daily socio-economic activities. Vertical distribution studies is usually undertaken to investigate the spread of a vector species in the forest and its involvement in a sylvan disease transmission. Disney (1968) and Williams (1970), have successfully, in British Houndras, investigated the vertical zonation of the phlebotomine sandflies. Quate (1964), did similar work in Sudan and Basimike (1989), carried out such studies in Marigat, Baringo District, Kenya. Corbet (1941), Haddow et. al (1947), Mattingly (1949) and Snow (1975), have variously employed vertical zonation studies to investigate the mosquitoes of Ethiopian region involved in sylvan yellow fever transmission. This work was aimed at investigating the vertical zonation of *S. garnhami* in Tseikuru, Kitui District, Kenya.

6.2 Materials and Methods

An open field without vegetation and an open woodland interspersed with few trees and shrubs were chosen for this study. Three 10-meter long wooden ladders were constructed and used for this work. Each was divided into five 2-metre sections with timber crossbars. At the ends of each crossbar a 3-inch long nail was half-hammered into the ladder, the other half was curved to serve as a pulley system. A nylon twine (manila strings), double the length of the height was attached to the curved nails at both ends of each crossbar. During sampling, castor oil coated polythene sheets (sticky traps), of $1m^2$ each were tied at the four ends with the manila strings and pulled up to the appropriate heights of the ladder. Five traps were set at 2-metre intervals in each ladder. Trappings were done biweekly. Traps were set between 1700hr and 1800hr, left overnight and collected the next morning between 0700hr and 0800hr for the examination of the presence or absence of sandflies.

The open fields without vegetation were represented by the wide river beds at Muuna and Kyandani areas and the ladders were supported on the rocky escarpments along their banks (Plate 6.1). The woodlands were located at Nziitu area. The ladders were supported on selected trees (Plate 6.2). Altogether four trees in

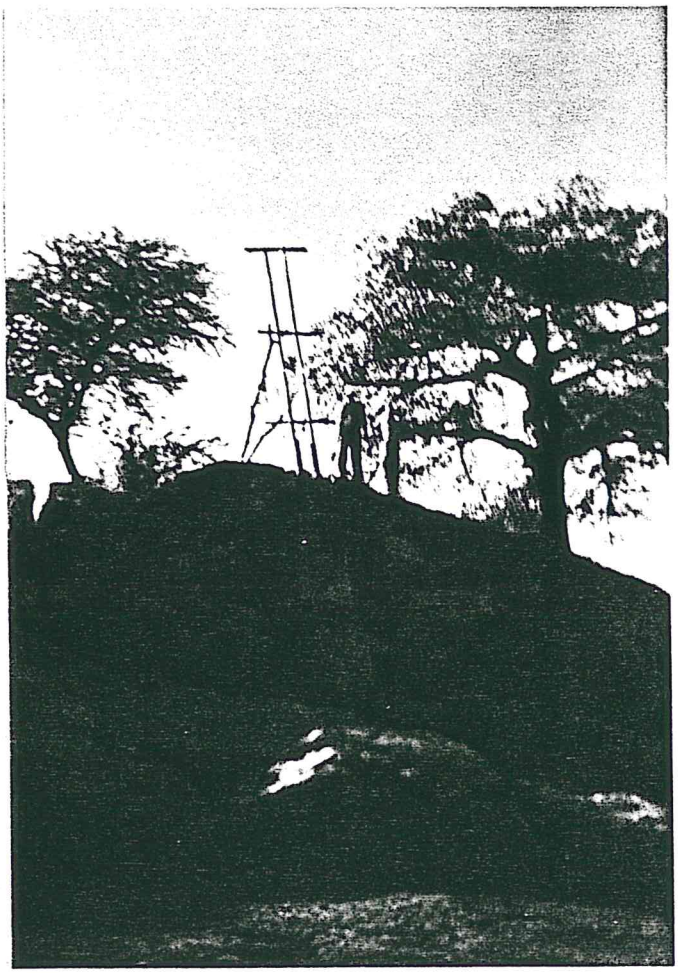


Plate 6.1 Sampling of sandflies at determined heights using sticky traps set at 2m intervals on a 10m long wooden ladder in an open field.

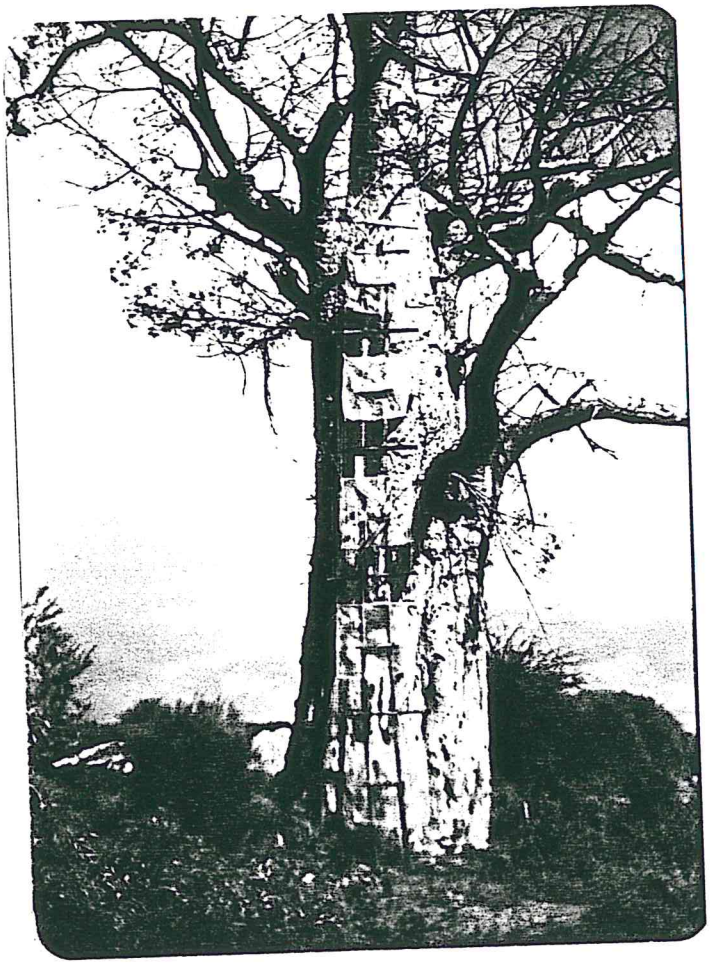


Plate 6.2 Sampling of sandflies at determined heights using sticky traps set at 2m intervals on a 10m long wooden ladder in a woodland

the woodland and two places in the open space without vegetation were used in this study. The studies were carried out in two shifts of 7 months each, from July 1989 to January 1990 and from February 1990 to August 1990. Each shift passed through a peak period of *S. garnhami* and other sandfly species (April-June or November-January).

6.3 Results.

Table 6.1 is pooled data from both woodland and open field studies. Altogether a total of 3272 phlebotomine sandflies was collected at various heights ranging from 0-2m to 8-10m. The flies were collected in the following order, 1453 (or 44.41%) from 0-2m, 702 (or 21.45%) from 2-4m, 600 (or 18.34%) from 4-6m, 267 (or 8.16%) from 6-8m, and 250 (or 7.64%) from 8-10m. The whole data showed a trend of decreasing sandfly population with the increasing height with the highest number caught between 0-2m height. Correlation analysis showed that the overall sandfly population was negatively and significantly correlated with height ($r = -0.8471$, $P = 0.0019^*$) at 5% significant level.

S. garnhami collected from both sites were 85 (or 2.60%) out of 3272 sandflies collected from the whole studies. The order of collection was 42 (or 49.4%) from 0-2m height, 24 (or 28.24%) from 2-4m, 17 (or 20%) from

4-6m, 2 (or 2.3%) from 6-8m, and 0 from 8-10m. This also showed a decreasing population with the increasing height. Correlation analysis showed that *S garnhami* populations were negatively and significantly correlated with heights (r = -0.85602, P= 0.0016**).

Table 6.2 is a pooled data on sex distribution of *S.garnhami* and other phlebotomine sandflies at various heights. From the overall sandfly catches, the males showed a consistent trend of decrease in number with increase in heights. The females were less consistent. More females (386) were collected between 4-6m than between 2-4m (317) and also between 8-10m (182) than between 6-8m (167). Altogether slightly more males (1661) than females (1611) were collected from the whole studies. Correlation analysis showed that both male and female of the overall sandfly populations were negatively and signifcantly correlated to heights (r = -0.88681, P= 0.0449 for the females, r = -0.90699, P= 0.0336for males).

From *S. garnhami* catches, the males also showed consistent decrease in numbers with the increase in heights. No male was collected beyond 8m. More females (14) were collected between 4-6m than between 2-4m (9). No female was collected beyond 6m. Altogether more females (49) than males (36) were collected. Correlation analysis showed that both male and female *S.garnhami* populations were also negatively and signifcantly

Table 6.1: Distribution of *S garnhami* and other phlebotomine sandflies at different heights (Pooled data from woodland and open field studies)

	All species		*S.garnhami*	
Height(m)	Total	Percent	Total	Percent
0-2	1493	44.41	42	49.41
2-4	702	21.45	24	28.24
4-6	600	18.34	17	20.00
6-8	267	8.16	2	2.35
8-10	250	7.64	0	0
Total		3272 100	85	100

Table 6.2: Distribution of *S garnhami* and other phlebotomine sandfly sexes at different heights (Pooled data from woodland and open field studies)

	All species			*S.garnhami*		
Height(m)	Total	Females	Males	Total	Females	Males
0-2	1453	559	894	42	26	16
2-4	702	317	385	24	9	15
4-6	600	386	214	17	14	3
6-8	267	167	100	2	0	2
8-10	250	182	68	0	0	0
Total	3272	1611	1661	85	49	36

correlated to heights (r = -0.94763, P= 0.0143 for the females, r = -0.91720, P= 0.0282 for males).

6.3.1 Species composition

Detailed information on the species composition of woodland and open field habitats were given in their respective sections. More flies were trapped from the woodland (2198 or 67.18%) than from the open field (1074 or 32.82%). The catch comprised 16 species, 2 of which belonged to the *Phlebotomus* genus and 14 to *Sergentomyia* genus. Surprisingly 15 species out of 16 were collected from the open field as opposed to 10 collected from the woodland. Only one female of the Synphlebotomus species was collected and this was ascribed to P. martini for record purposes. Two males of *P. vansomerenae* were caught from the woodland habitat but no male of *P. celiae* was caught from both habitat. *S. affinis*, *S. christophersi*, *S. graingeri*, *S. harveyi* and *S. multidens* caught from the open fields were not caught from the woodlands.

6.3.2 Woodland

Table 6.3 shows data on the distribution of *S.garnhami* and other phlebotomine sandflies in the woodland habitat. A total of 2198 phlebotomine sandflies was collected from this habitat. 1070 sandflies (or 48.68%) were collected from 0-2m height, 343 (or 15.61%) were from 2-4m height, 318 (or 14.47%) from 4-6m height, 242 (or 11.01%) from 6-8m height and 225 (or 10.24%) from 8-10m height. A graphic illustration of the general trend for the vertical zonation of all sandfly species and *S. garnhami* in the woodland is shown in figure 6.1. More sandflies were collected from 0-2m height than from others. Correlation analysis showed that the overall sandfly population from the woodland habitat was negatively and significantly correlated with height ($r = -0.73759$, $P = 0.0149^*$) at 5% significant level. Correlation of the overall sandfly sexes to heights in this habitat showed that the sexes were negatively but not significantly correlated to heights ($r = -0.75757$, $P = 0.1380$ for females, $r = -0.80549$, $P = 0.999$ for the males).

S. garnhami collected were 10 in number (or 0.45%). Six (or 60%) were collected from 0-2m height, nothing from 2-4m height, and 2 (or 20%) each were from heights 4-6m and 6-8m respectively. Also nothing was collected from 8-10m height (table 6.3). More females than males

were collected except at 6-8m height where only 2 males and no females were caught (table 6.4). Correlation analysis showed that *S.garnhami* population from the woodland habitat was negatively but not significantly correlated with height ($r = -0.52705$, $P = 0.1175$) at 5% significant level. Correlation of *S.garnhami* sexes to heights in this habitat showed that the sexes were negatively but not significantly correlated to heights ($r = -0.70711$, $P = 0.1817$ for females, $r = -0.28868$, $P = 0.6376$ for the males).

Scatter diagram plots of both *S. garnhami* and all the sandfly species population against determined heights, using regression programme of Lotus 123, release 2.1 version, showed that $r^2 = 0.757268$, $Y = 3.012546 - 0.07500X$ for all the species put together. For *S. garnhami* only, $r^2 = 0.281930$, and $Y = 0.723790 - 0.06065X$. This showed inverse linear relationships in which the sandfly populations decreased with the increasing heights with the highest population density caught at 0-2m height (fig 6.2-3).

Ten species comprising 2 species of the *Phlebotomus* genus and 8 of *Sergentomyia* genus were collected (table 6.5). *S. bedfordi* was the dominant species in all the heights and it constituted 93.13% of the collections from the woodland biotope. More females than males were collected (table 6.4).

Table 6.3: Distribution of *S garnhami* and other phlebotomine sandflies at different heights in the woodland and open field without vegetation

	All species		*S.garnhami*	
Height(m)	Total	Percent	Total	Percent
Woodland				
0-2	1070	48.68	6	60
2-4	343	15.61	0	0
4-6	318	14.47	2	20
6-8	242	11.01	2	20
8-10	225	10.24	0	0
Total		2198 100	10	100
Open field				
0-2	383	35.66	36	48
2-4	359	33.43	24	32
4-6	282	26.26	15	20
6-8	25	2.33	0	0
8-10	25	2.33	0	0
	1074	100	75	100

Table 6.4 Distribution of *S garnhami* and other phlebotomine sandfly species at different heights in the woodland and open field without vegetation

	All species			*S.garnhami*		
Height(m)	Total	Females	Males	Total	Females	Males
Woodland						
0-2	1070	416	654	6	4	2
2-4	343	174	169	0	0	0
4-6	318	214	104	2	2	0
6-8	242	151	91	2	0	2
8-10	225	164	61	0	0	0
Total	2198	1119	1079	10	6	4
Open field						
0-2	383	143	240	36	22	14
2-4	359	143	216	24	9	15
4-6	282	172	110	15	12	3
6-8	25	16	9	0	0	0
8-10	25	18	7	0	0	0
Total	1074	492	582	75	43	32

Table 6.5 Species composition of the open woodland at different heights

Species	Heights (m)					
	0-2	2-4	4-6	6-8	8-10	Total
P.martini	0	0	1	0	0	1
P.vansomerenae	0	0	1	0	1	2
S.adleri	0	1	0	0	0	1
S.affinis	0	0	0	0	0	0
S.antennatus	32	18	14	17	12	93
S.bedfordi	1012	315	296	217	207	2047
S.christophersi	0	0	0	0	0	0
S.clydei	2	0	0	1	2	5
S.garnhami.	6	0	2	2	0	10
S.grairgeri	0	0	0	0	0	0
S.harveyi	0	0	0	0	0	0
S.ingrami	6	4	2	3	1	16
S.kirki	7	1	0	1	0	9
S.multidens	0	0	0	0	0	0
S.schwetzi	1	1	1	0	1	4.
S.squamipleuris	4	3	1	1	1	10
Height total	1070	343	318	242	225	2198

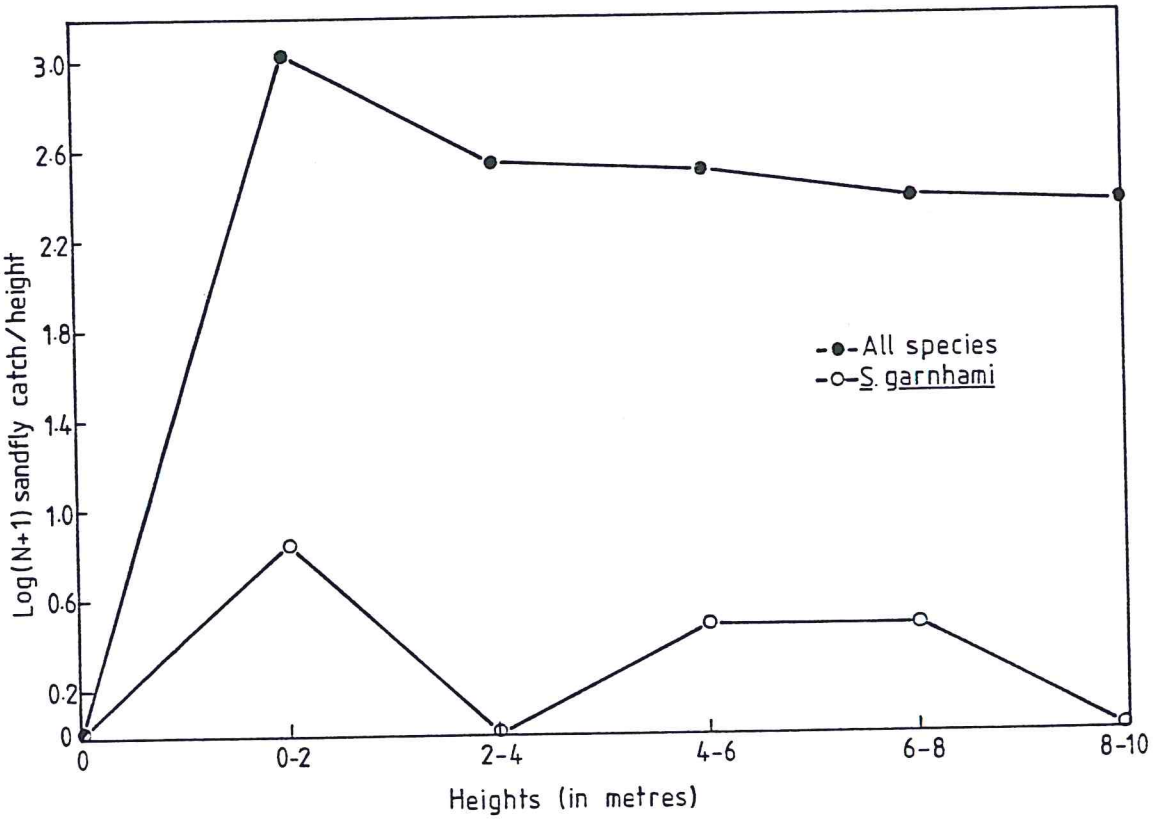


Fig 6.1 Vertical distribution of *S. garnhami* and other sandfly species in the open woodland

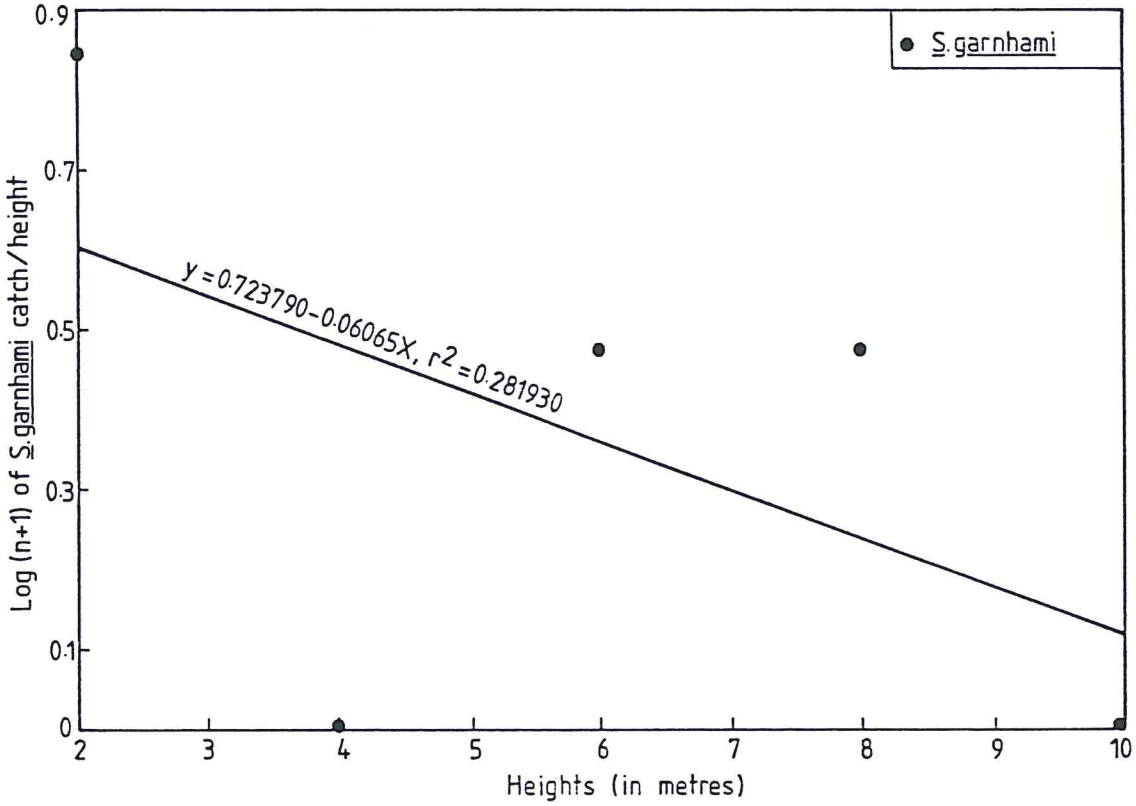


Fig 6.2 Relationship between *S. garnhami* and its flight heights in the open woodland

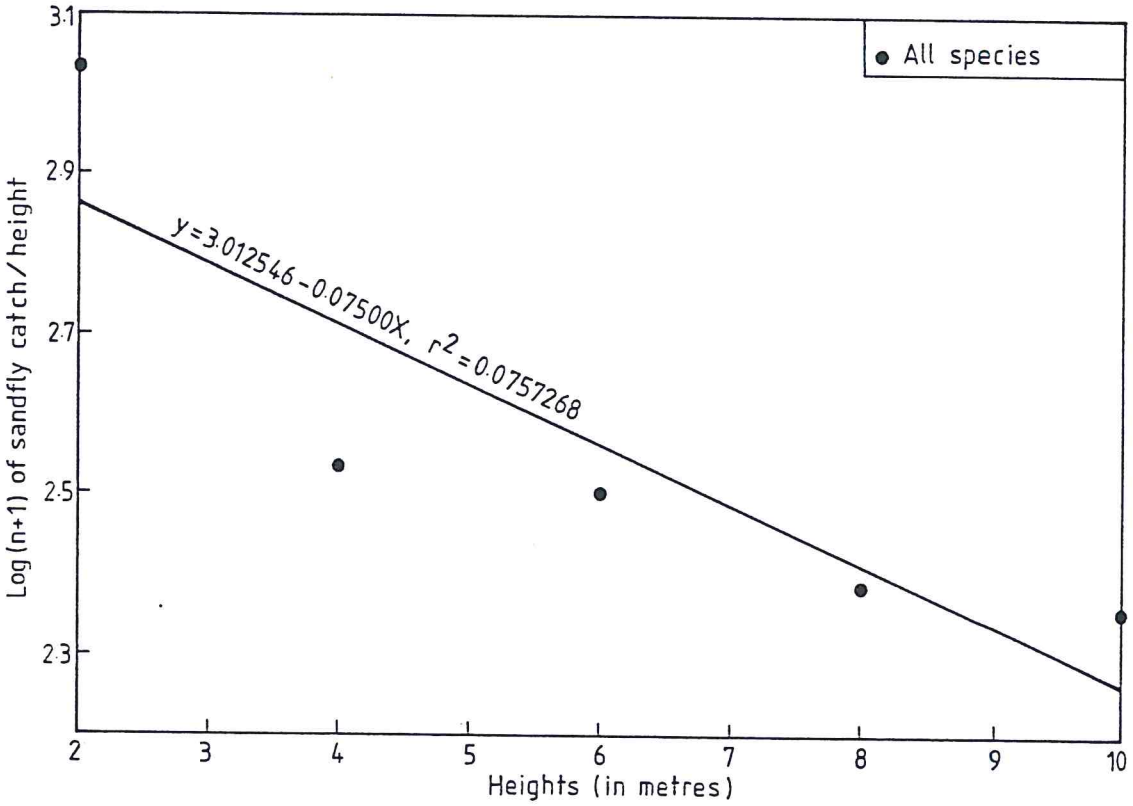


Fig 6.3 Relationship between overall sandfly species and their flight heights in the open woodland

6.3.3 Open field

Table 6.3 shows the data on the vertical distribution of *S.garnhami* and other phlebotomine sandflies in the open field habitat. A total of 1074 phlebotomine sandflies were collected from this site. 383 (or 35.66%) were collected from 0-2m height, 359 (or 33.43%) from 2-4m height 282 (or 26.26%) from 4-6m height 25 (or 2.33%) from 6-8 and 8-10m heights respectively. A trend of vertical zonation of the phlebotomine sandflies in this habitat is shown in fig 6.4. The highest number of sandflies were caught at 0-2m height. Correlation analysis showed that the overall sandfly population from the open field habitat was negatively and significantly correlated with height ($r = -0.87378$, $P = 0.0010^*$) at 5% significant level. Correlation of the overall sandfly sexes to heights in this habitat showed that the females were negatively but not significantly correlated to height[illegible] ($P = 0.1101$) whereas the males were significantly correlated ($r = -0.96398$, $P = 0.0082$).

S. garnhami collected in this biotope were 75 in number (or 6.98%). They were collected as follows 36 (or 48%) from 0-2m height, 24 (or 32%) from 2-4m height, 15 (or 20%) from 4-6m height, and none from 6-8m and 8-10m heights respectively (table 6.3). *S. garnhami* was not collected beyond 6m height. More females than males

were collected in 0-2m and 4-6m heights. Altogether more females than males were collected except at 2-4m height where more males than females were caught (table 6.4). Correlation analysis showed that *S.garnhami* population from the woodland habitat was negatively but not significantly correlated with height ($r = -0.83831$, $P = 0.0024$) at 5% significant level. Correlation of *S.garnhami* sexes to heights in this habitat showed that the sexes were negatively and significantly correlated to heights ($r = -0.92468$, $P = 0.0245$ for females, $r = -0.88195$, $P = 0.0478$ for the males).

Scatter diagram plots of *S. garnhami* and other sandfly species populations against their flight heights showed that $r^2 = 0.802011$, $Y = 3.100424 - 0.17096X$ for the overall species and for *S. garnhami* only, $r^2 = 0.862000$, and $Y = 2.194355 - 0.22671X$. This also showed inverse linear relationships in which the sandfly populations decreased with the increased heights (fig 6.5-6.6).

Fifteen sandfly species comprising 1 species of the *Phlebotomus* genus and 14 of *Sergentomyia* genus were collected (table 6.6). *S. bedfordi* 593 (or 55.21%) and S. kirki 235 (or 21.88%) were the dominant species from the open field without vegetation. Most species were collected between 0-6m high. Only 6 species namely *S. antennatus*, *S. bedfordi*, *S. harveyi*, *S.ingrami*, *S. kirki* and *S. schwetzi* were collected beyond 6m. Five of them

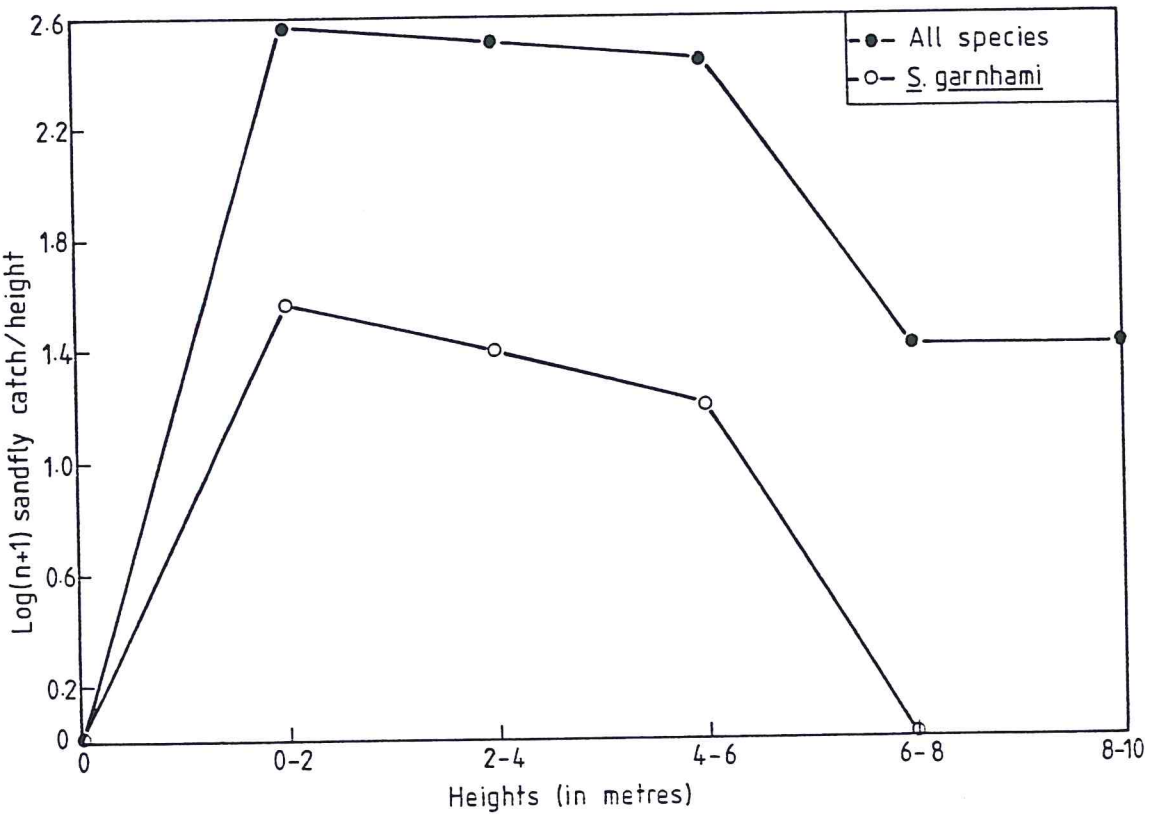


Fig 6.4 Vertical distribution of *S. garnhami* and other sandfly species in the open field without vegetation

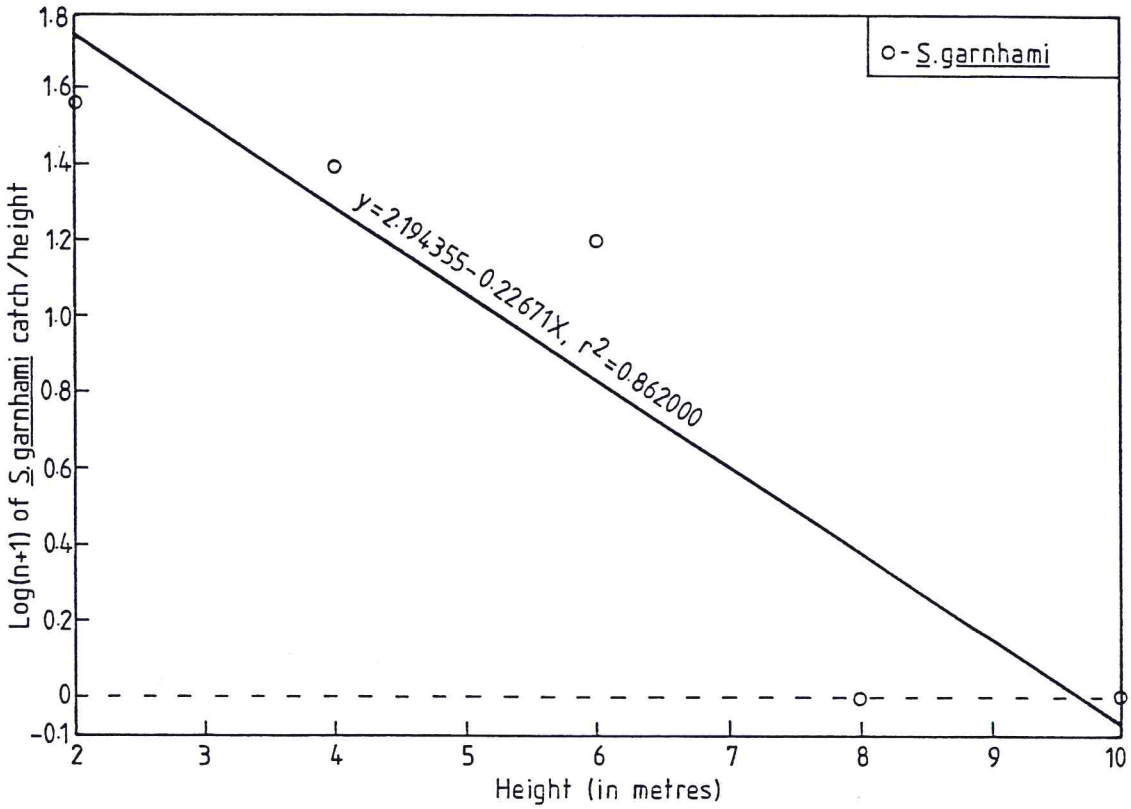


Fig 6.5 Relationship between *S. garnhami* and its flight heights in the open field without vegetation

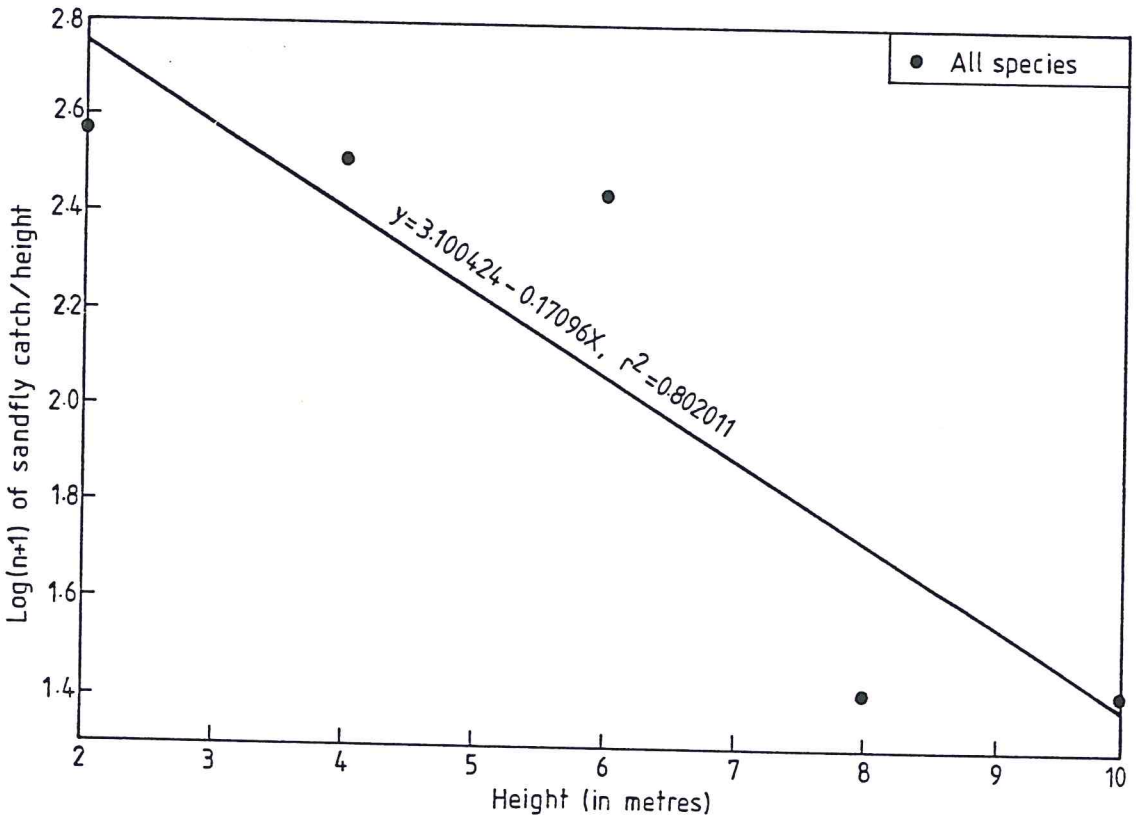


Fig 6.6 Relationship between overall sandfly species and their flight heights in the open field without vegetation

Table 6.6:- Species composition of open field without vegetation at different heights.

Species	Heights(m)					
	0-2	2-4	4-6	6-8	8-10	Total
P.celiae	1	0	0	0	0	1
P.martini	0	1	0	0	0	1
P.vansomerenae	0	0	0	0	0	0
S.adleri.	2	1	3	0	0	6
S.affinis	6	3	26	0	0	35
S.antennatus	23	17	14	4	1	59
S.bedfordi	212	166	193	16	6	593
S.christophersi	0	0	2	0	0	2
S.clydei	1	1	1	0	0	3
S.garnhami	36	24	15	0	0	75
S.graingeri	0	2	0	0	0	2
S.harveyi	1	10	7	1	0	19
S.ingrami	1	1	3	2	15	22
S.kirki	92	126	15	0	2	235
S.multidens	0	0	1	0	0	1
S.schwetzi	5	7	2	2	1	17
S.squamipleuris	3	0	0	0	0	3
Height total	383	359	282	25	25	1074

excluding *S. harveyi* were collected between 8-10m (table 6.3). More males than female flies were collected in the open field (table 6.4).

6.4 Discussion

This study has revealed the abundance of many sandfly species at various heights above the ground. Two species (*P. martini* and *P. vansomerenae*) belong to the *Synphlebotomus* complex. Earlier workers (Heisch 1954, Heisch et al 1955 1956, 1962 and Wijers and Minter 1962) have implicated *P. martini* as the main vector of leishmaniasis in Kitui District and in Kenya and same proved to the vector elsewhere (Mutinga and Ngoka 1978 and Mutinga et al 1984). . This fly was caught at the heights of 0-2m and 2-4m in the open field and at the heights of 4-6m and 8-10m in the open woodland, a level corresponding to tree canopies with the their branches. The implications of this finding could be related to the traditional occupation of the Wakamba people of Tseikuru and Kitui district as a whole where apiculture is a major alternative source of income to livestock keeping. Crop production-wise, the land in the area is marginally productive and may fail when the annual rainfall is below average subjecting the people to drought. Because of the need to buy most of their essentials from the market and the readily rewarding market for the honey

there are many emergent co-operative groups venturing into this business. Apiculture business is usually a night affair to avoid painful attacks of the bees and this corresponds to the biting activities of *P. martini* and many other sandflies. Interestingly it is a common practice that the adults usually go to harvest the honey with children (usually of school age) and while the children sat at a corner, one adult climbs the tree, pulls the beehive down with a rope and the other harvests it near a central fire. As the children are sitted waiting for the honey combs they are likely to be bitten by sandflies especially *P. martini* and other blood-sucking insects. This may explain more about the findings of Wijers and Kiilu (1962) that school children were much more affected with kala azar than adults. Mutinga and Ngoka (1978) and Mutinga et al (1984) had earlier shown that *P. martini* bites indoors at a time when children are sleeping and outdoors near termitaries between 1900 and 2100 hours. If the distribution in this study is in keeping throughout the district, it is likely that apiculture practice is one of the socio-economic ventures that has a good chance of exposing youths to sandfly bites and consequent infections with *Leishmania* parasites.

Most of the *S. garnhami* were collected below 6m height. This could be expected because the fly also breeds in tree holes usually found in tree trunks. Only

few trees in such semi-arid environments could tower beyond this height with considerably large trunks to accommodate tree holes. It is possible that this fly does not forage over a long distance for its meals. Within this height considerably high number of lizards, chickens and other birds, some mammals and host plants abound for its source of bloodmeal and sugar meal. The phlebotomine sandflies, like most other insects, are attracted to plants for shelter, food and breeding sites (Price 1984).

The propensity of the other *Sergentomyia* species to be collected at higher levels could be interpreted to mean that they have stronger flight capacity and can go after their hosts as well as mate seeking. Also some may be driven out of their hiding places by strong wind characteristic of the area and may be carried to greater heights than expected. Strong winds are known to affect the activities of sandflies (Basimike et al 1989). Killick-Kendrick (1981) noted that the activity of sandflies is reduced or suppressed by excessive heat, cold, rain, and most importantly wind. Quate (1964) showed that wind speeds of 1.5 to 2.5m/sec adversely affected the activity of sandflies and at 4m/sec all activity ceased. Chaniotis and Anderson (1968) observed that wind speeds of 2.5 to 3m/sec completely prevented the activity of sandflies in California. Rioux and Golvan (1969) noted that the optimal wind speed for the

activity of *P ariasi* in France was < 2m/sec. This might be the case in the open field but in the woodland it is likely that with alternate short flights and hopping on the tree trunks, they might reach great heights more especially if there is an attractant stimulus from a nearby host.

The collection of a wider range of species from the open field in contrast to the woodland may be explained by the positioning of the traps. The traps in the open field were in a relatively nearer position to the breeding grounds than those in the wooded environment. As mentioned earlier, the open fields were represented by the riverbeds and sometimes with rocky escarpments that were equally sandfly breeding grounds on both banks. This is relatively narrower than the vast expanse of land from which few trees were selected. Also rock crevices is a breeding ground for a wider range of sandfly species than tree bases and treeholes.

CHAPTER SEVEN

SEASONAL POPULATION CHANGES OF *S. GARNHAMI* IN RELATION TO CLIMATIC FACTORS

7.1 Introduction

Weather and climate are known to have profound effects on the numbers of insects present at any given time. Henson (1968), distinguished two sorts of climatic effects on population numbers of insects. He classified these into (i) those due to catastrophic changes leading to widespread mortality such as the impact of an unusual winter cold or desiccation and (ii) those which are expressed in the mode and tempo of development, fecundity, behaviour and selective changes on the genetic make up of the population.

The impact of climate on the insect populations has led to several adaptations including seasonal population fluctuations. Kirk and Lewis (1951), noticed that in most places where sandflies are prevalent, they show more or less marked seasonal variations. Heisch et. al.(1956), showed that some species of sandflies in Kitui District of Kenya have marked seasonal incidence. Wijers and Minters (1962), discussed the seasonal incidence of some species of sandflies in the northern part of Kitui District, and divided them into perennial and rainy season groups. Their observations in Kitui

District have not been represented quantitatively. This study covers the impacts of measured observations of some climatic factors on the seasonal population changes of *S. garnhami*.

7.2 Materials and Methods

Three basic methods have been employed by Scientists of biometeorology to study the effects of weather and climate on insect populations. These are by field observations and census, laboratory experimentation simulating environmental conditions and/or by a combination of both methods. Field observations and census method is the most commonly employed and is also adopted in this study.

Based on information from our preliminary survey at Tseikuru, the underlisted sites were selected for seasonal monitoring of *S. garnhami* population. These were:-

Inside walls of human homes

Outside walls of human homes

Termite hills

Animal burrows

Rock crevices

Treeholes

Plant bases

Animal enclosures

Open spaces

The study was carried out for 24 months (January 1989-December 1990). Studies in animal enclosures and open spaces were dropped in the second year (Jan-Dec 1990).

7.2.1 Location of sites

All the termite hills being used were located within Ngiluni and Nziitu areas. Animal burrows were located along the flanks of thorny thicket on the banks of Kyandani river. Rock crevices were located along the stretches of bed rock along the banks of Kyandani, Nziitu and Ngiluni watercourses. All the houses, were located at Nziitu area. Tree holes and plant bases were distributed between Nziitu and Ngiluni areas.

7.2.2 Trapping of sandflies

Biweekly collections of sandflies were made from each site using castor oil coated transparent polythene sheets.

Trap size of $1m^2$ were used for sandfly collections on the inside and outside walls of human homes, open spaces, animal enclosures and rock crevices whereas trap size of 30x30 cm (or $1ft^2$) was used to collect sandflies

from treeholes, animal burrows, plant bases and a selected ventilation shaft of each of the termite hills.

Traps were placed either horizontally, inclined or vertically, depending on the nature of the site and were secured to position by either fastening it with ropes, sticks, stones or even twigs. Acacia thorns were sometimes used as tacks to put traps for treeholes in position.

The traps were set between 1700-1800 hours and collected in the morning between 0630-0830 hours. Because different sandfly species breed in a common habitat and the difficulty in morphological identification with the naked eyes, all the sandflies breeding the same habitat were trapped and taken to the laboratory for processing (See Chapter 5).

7.2.3 Measurement of climatic data

Rainfall data were collected from the Kenya Ministry of Agriculture meteorological station at Tseikuru health centre. We measured the temperature data using maximum and minimum thermometer in 1989 but changed to Mason's wet and dry bulb thermometer (hygrometer) in 1990 to obtain the relative humidity data. Temperature readings were recorded twice daily at 0600 and 1500 hours. Mean temperatures were obtained by averaging the values of the minimum and maximum temperature values at monthly

intervals. Relative humidity values were obtained by reading the differences between wet and dry bulb thermometers over the corresponding dry bulb value in a table supplied by the manufacturers. Mean relative humidity values were obtained by averaging the morning and afternoon values.

7.3 Results

7.3.1 Overall sandfly population

Tables 7.1-7.4 show monthly collections of *S.garnhami* and other phlebotomine sandflies in 1989 and 1990. Phebotomine sandflies were collected from the field in every month of the year in both 1989 and 1990.

A total of 111,067 sandflies were trapped and processed in both years. 59,709 (53.76%) sandflies were collected in 1989 while 51,358 (46.24%) sandflies were collected in 1990. The highest numbers of phlebotomine sandflies were collected in May and December months of both years (tables 7.1 and 7.2).

Altogether 32,631 (or 29.37%) *S. garnhami* were collected in 1989 and 1990. 20,765 (or 34.78%) *S. garnhami* were collected in 1989 but in 1990, 11866 (or 23.10%) were *S. garnhami*. Adult *S garnhami* were present in the field only between April and early July and between November and early February with the highest

Table 7.1: Monthly distribution of phlebotomine sandflies in different ecological habitats (Jan-Dec 1989)

Month	Site									
	Th	Ab	Rc	Ht	Pb	Hin	Hout	Os	Ae	Total
Jan	1879	783	1174	129	384	278	407	92	59	5185
Feb	1244	658	929	70	250	381	523	124	57	4236
Mar	533	425	761	63	110	295	489	83	36	2795
Apr	1350	214	578	58	118	146	117	101	33	2715
May	7080	745	2048	422	313	488	430	278	94	11898
Jun	1684	1800	1730	169	415	352	372	103	60	6685
Jul	591	861	678	29	47	136	109	29	39	2519
Aug	284	873	702	20	47	209	175	15	24	2349
Sep	195	567	561	12	25	119	205	24	15	1723
Oct	166	897	520	18	28	140	226	28	15	2038
Nov	1739	167	159	36	24	73	114	49	17	2378
Dec	11404	284	1196	359	493	261	202	29	11	15188
Total	28149	8274	11036	1385	2354	3308	3699	987	517	59709

Th = Termite hills
Ab = Animal burrows,
Rc = Rock crevices,
Ht = Tree holes,
Pb = Treebases,
Hin = Inside human homes,
Hout = Outside human homes,
Os = Open spaces,
Ae = Animal enclosures,

Table 7.2: Monthly distribution of phlebotomine sandflies in different ecological habitats (Jan-Dec 1990)

Month	Site						
	Th	Ab	Rc	Ht	Pb	Hin	Hout	Total
Jan	2534	1147	1196	513	792	485	510	7177
Feb	690	547	552	47	135	369	272	2612
Mar	922	312	863	51	366	448	631	3593
Apr	1645	4	204	124	223	318	374	2892
May	4490	1411	2615	337	432	430	542	10257
Jun	1206	840	1595	136	379	383	539	5078
Jul	518	611	1633	58	183	333	430	3766
Aug	366	837	968	44	121	195	223	2754
Sep	200	1283	582	34	86	94	143	2422
Oct	224	1010	646	11	56	87	182	2216
Nov	1289	31	706	65	96	79	122	2388
Dec	2417	196	2095	255	254	435	376	6028
Total	16501	8229	13655	1675	3123	3656	4344	51183

Th = Termite hills
Ab = Animal burrows,
Rc = Rock crevices,
Ht = Tree holes,
Pb = Treebases,
Hin = Inside human homes,
Hout = Outside human homes,
Os = Open spaces,
Ae = Animal enclosures,

Table 7.3: Monthly distribution of *S garnhami* in different ecological habitats (Jan-Dec 1989)

Month	Site								
	Th	Ab	Rc	Ht	Pb	Hin	Hout	Os	Ae	Total
Jan	1239	684	276	12	204	2	8	4	1	2426
Feb	252	332	29	0	21	1	25	2	0	660
Mar	0	12	0	0	0	0	0	0	0	12
Apr	640	2	12	8	1	18	5	2	1	687
May	4767	648	650	18	137	38	15	77	12	6485
Jun	380	270	208	9	117	0	2	4	2	1988
Jul	1	33	3	0	0	0	0	0	0	37
Aug	0	0	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0	0	0
Nov	414	0	0	14	4	1	2	9	2	437
Dec	7097	111	261	96	279	2	3	2	1	7927
Total	14790	3092	1439	357	779	94	72	106	36	20659

Th = Termite hills
Ab = Animal burrows,
Rc = Rock crevices,
Ht = Tree holes,
Pb = Treebases,
Hin = Inside human homes,
Hout = Outside human homes,
Os = Open spaces,
Ae = Animal enclosures,

Table 7.4: Monthly distribution of *S garnhami* in different ecological habitats (Jan-Dec 1990)

Month	Site							
	Th	Ab	Rc	Ht	Pb	Hin	Hout	Total
Jan	1691	998	470	316	344	0	5	3824
Feb	136	231	29	12	12	1	1	422
Mar	8	3	0	0	0	0	1	12
Apr	371	2	0	46	0	1	1	421
May	2678	239	523	188	74	3	1	4706
Jun	154	310	12	4	0	3	3	486
Jul	0	41	1	1	0	2	1	46
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0
Nov	407	0	1	13	4	7	7	439
Dec	944	98	381	55	32	1	1	1512
Total	6389	2922	1417	635	466	18	21	11868

Th = Termite hills
Ab = Animal burrows,
Rc = Rock crevices,
Ht = Tree holes,
Pb = Treebases,
Hin = Inside human homes,
Hout = Outside human homes,
Os = Open spaces,
Ae = Animal enclosures,

numbers collected in May and December months. In all the sites *S. garnhami* adults were trapped in the field at virtually the same time except in the animal burrows where it appeared slightly latter. Also in the animal burrows, residual populations were maintained a little longer than was observed in other sites.

The seasonal trend of the overall sandfly species population of various habitats were plotted together with those of *S. garnhami* (Figs 7.1-16) and related to climatic data on rainfall, humidity, and temperature. The sandfly population graph consists of an outer graph of overall sandfly population/site/month and an inner one of *S. garnhami*/site/month. Two annual peaks were observed in May and in December months corresponding to late wet and early dry seasons periods with *S. garnhami* populations seemingly dictating their sizes. January and February points on the graphs represented the falling peaks of November-January populations.

S. garnhami populations together with other phlebotomine sandfly populations from different habitats were statistically correlated with climatic factors (table 7.5) using Statistical Analysis Systems Programme (SAS). In 1989 the mean temperatures (Avg T) were negatively correlated to both *S.garnhami* and other species populations in all the sites except in rock crevices, open spaces, and animal enclosures where it was positively correlated. In 1990 the mean temperatures

Table 7.5: Correlation Analysis
Correlation of *S. garnhami* and other phlebotomine sandfly populations of different ecological habitats with climatic factors

Climatic factor	Correlation with	Sites								
		Th	Ab	Rc	Ht	Pb	Hin	Hout	Os	Ae
1989										
Avg T	All species	-0.28 P=0.23	-0.05 P=0.84	0.06 P=0.80	-0.09 P=0.71	-0.16 P=0.49	-0.07 P=0.76	0.30 P=0.20	0.29 P=0.22	0.01 P=0.96
Rain		0.11 P=0.62	-0.39 P=0.06	-0.41 P=0.05	-0.08 P=0.7	-0.28 P=0.19	-0.15 P=0.48	-0.18 P=0.41	0.08 P=0.70	-0.34 P=0.10
Avg T	*S.garnhami*	-0.25 P=0.29	-0.01 P=0.98	-0.01 P=0.97	-0.02 P=0.92	-0.22 P=0.35	-0.06 P=0.80	-0.14 P=0.56	0.09 P=0.70	-0.23 P=0.33
Rain		0.03 P=0.8	-0.21 P=0.33	-0.15 P=0.49	0.07 P=0.75	-0.24 P=0.27	-0.00 P=0.99	-0.11 P=0.62	0.09 P=0.67	0.75 P=0.0001**
1990										
Avg T	All species	0.19 P=0.38	-0.19 P=0.36	-0.24 P=0.26	-0.07 P=0.73	-0.04 P=0.87	-0.07 P=0.73	-0.04 P=0.87		
Rain		0.06 P=0.78	-0.45 P=0.03*	-0.16 P=0.46	-0.17 P=0.42.	-0.02 P=0.90	-0.19 P=0.36	-0.02 P=0.93		
Avg Rh		0.27 P=0.21	-0.38 P=0.07	-0.04 P=0.83	0.03 P=0.90	-0.05 P=0.83	-0.07 P=0.73	-0.20 P=0.35		
Avg T	*S.garnhami*	0.17 P=0.42	-0.01 P=0.97	0.08 P=0.70	0.03 P=0.89	0.04 P=0.85	-0.05 P=0.83	0.002 P=0.99		
Rain		-0.03 P=0.89	-0.16 P=0.45	-0.13 P=0.53	-0.15 P=0.49	-0.17 P=0.42	0.11 P=0.62	0.08 P=0.70		
Avg Rh		0.19 P=0.36	-0.039 P=0.89	0.13 P=0.55	0.03 P=0.89	0.01 P=0.98	0.19 P=0.37	0.16 P=0.45		

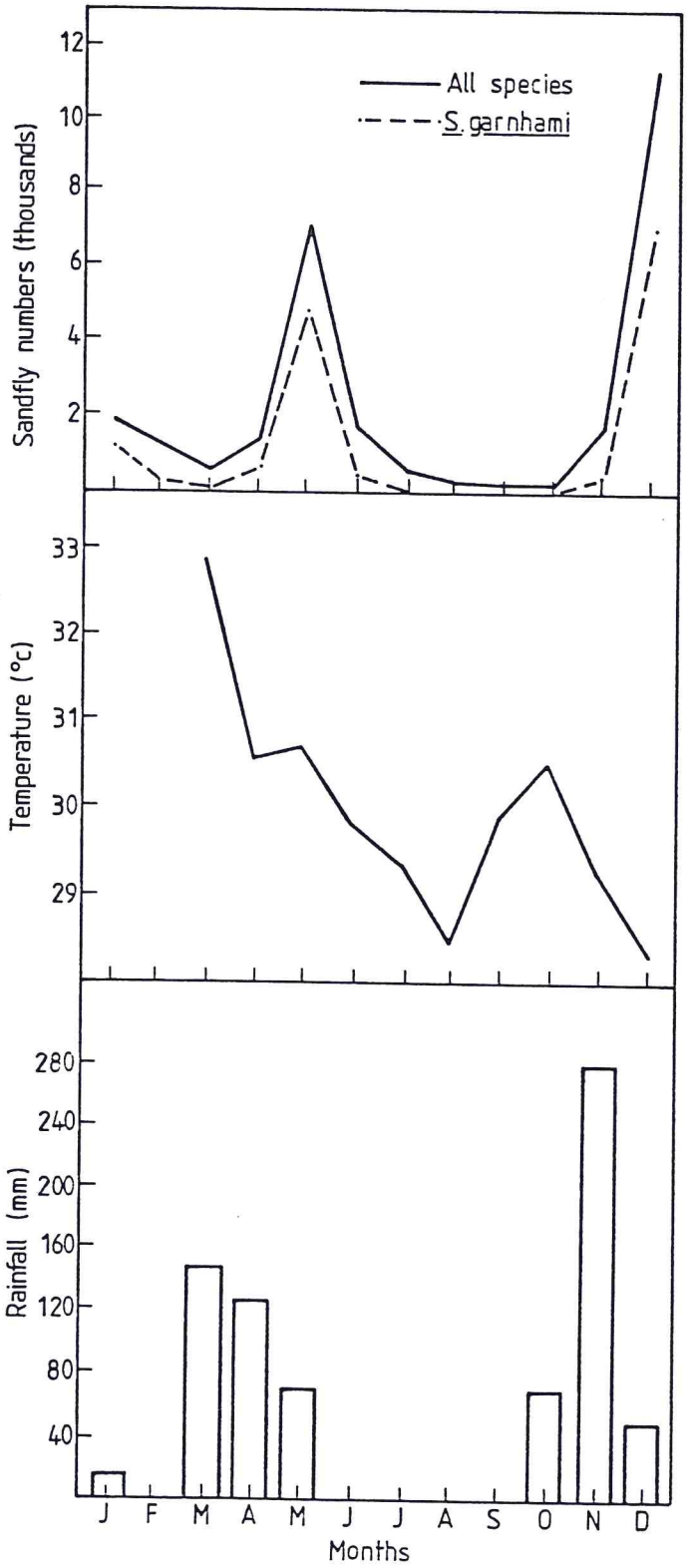


Fig 7.1. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in termite hills in relation to climatic factors (Jan–Dec 1989).

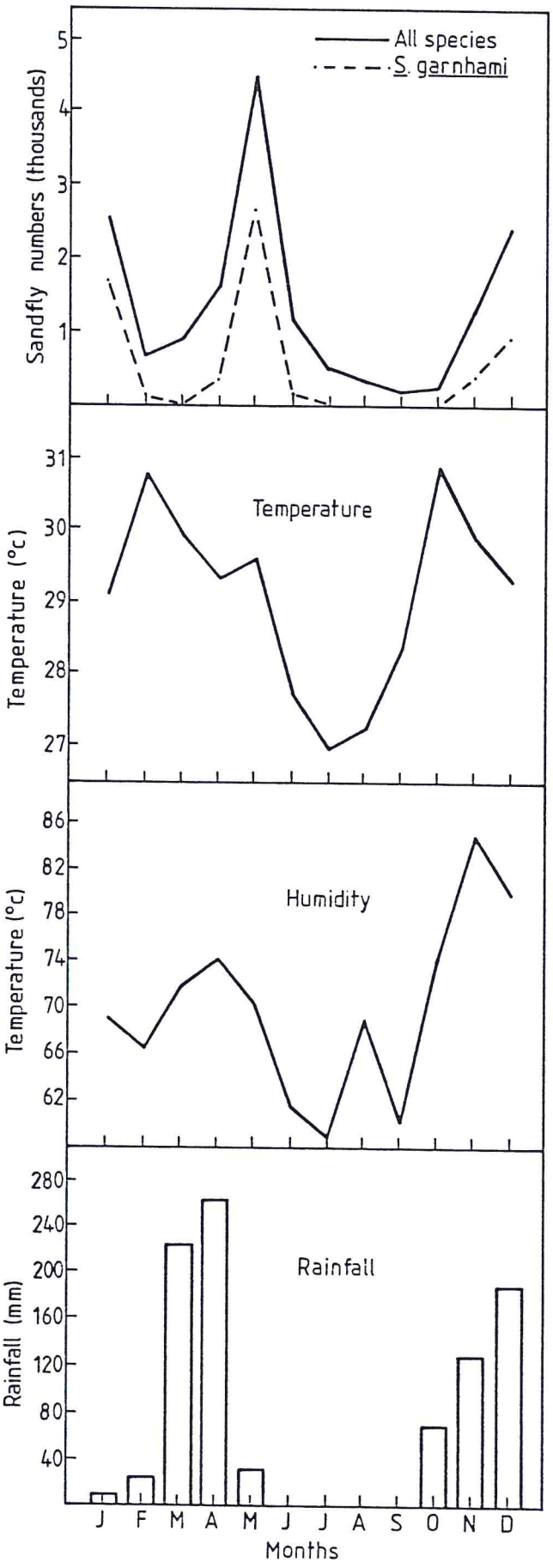


Fig 7.2. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in termite hills in relation to climatic factors (Jan–Dec 1990).

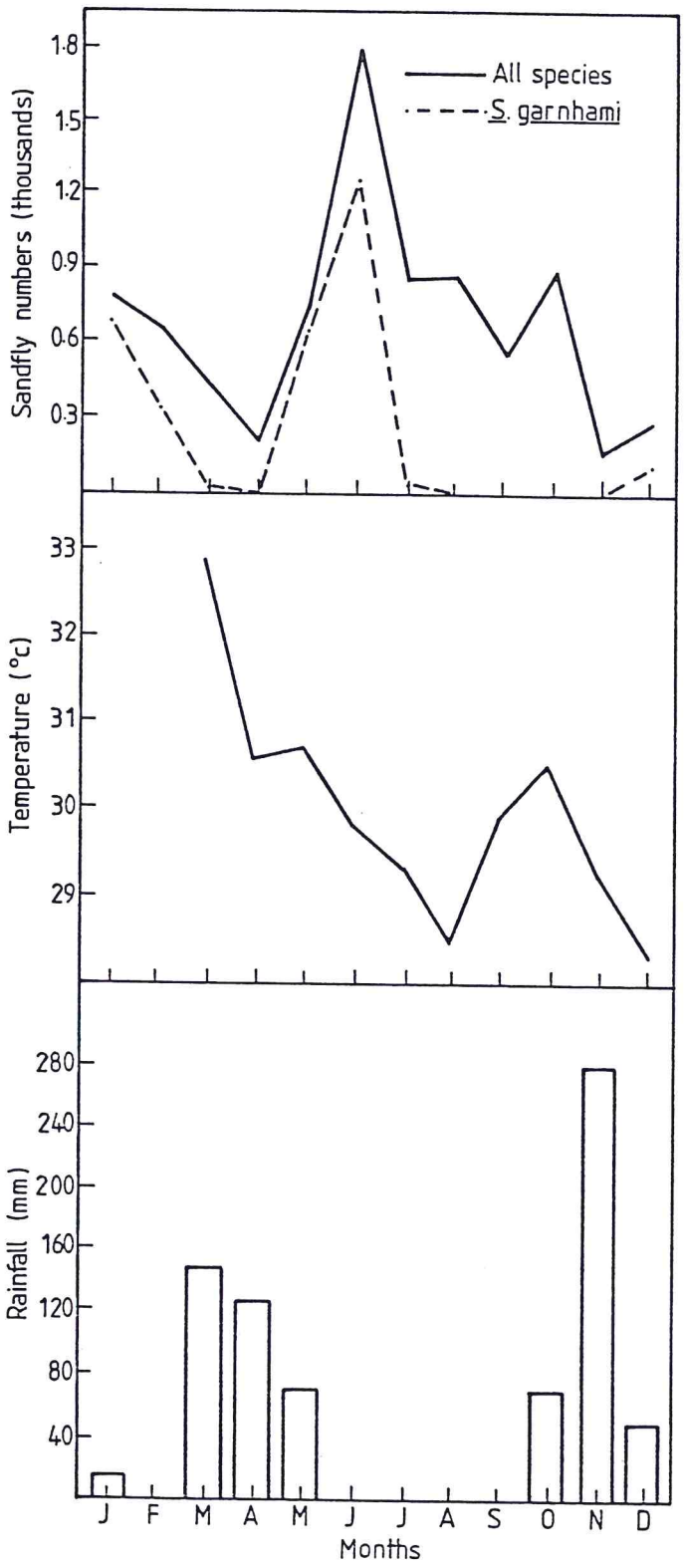


Fig 7.3. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in animal burrows in relation to climatic factors (Jan–Dec 1989).

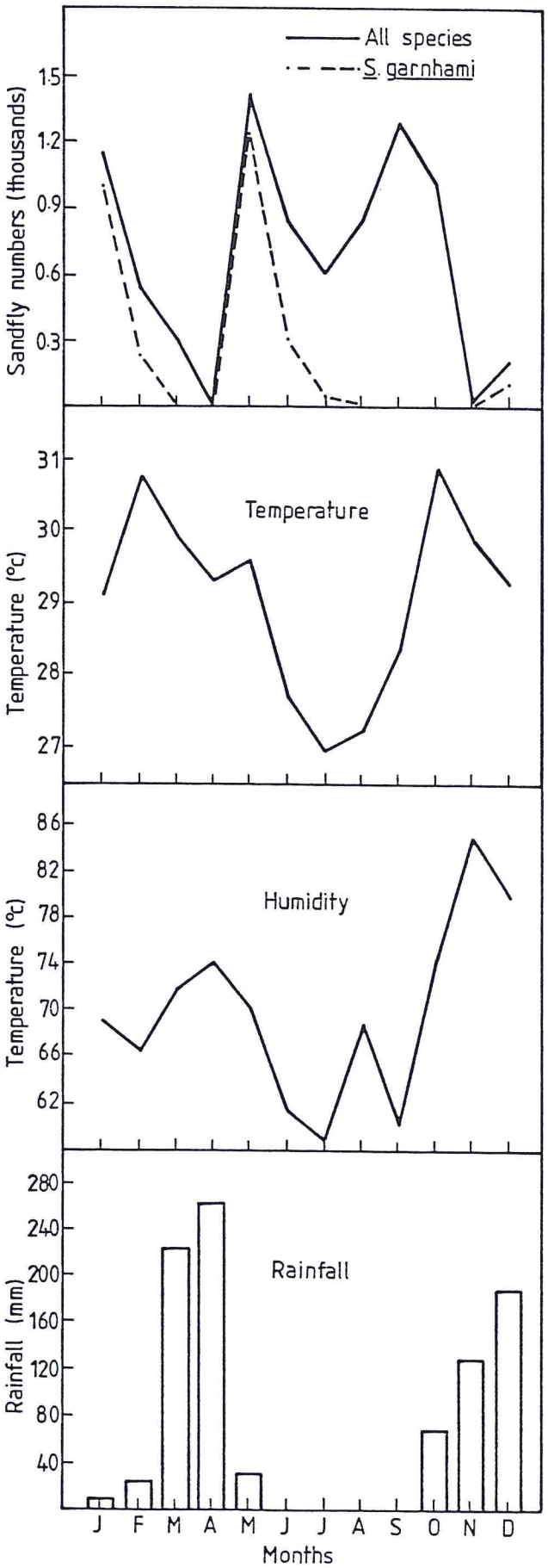


Fig 7.4. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in animal burrows in relation to climatic factors (Jan–Dec 1990).

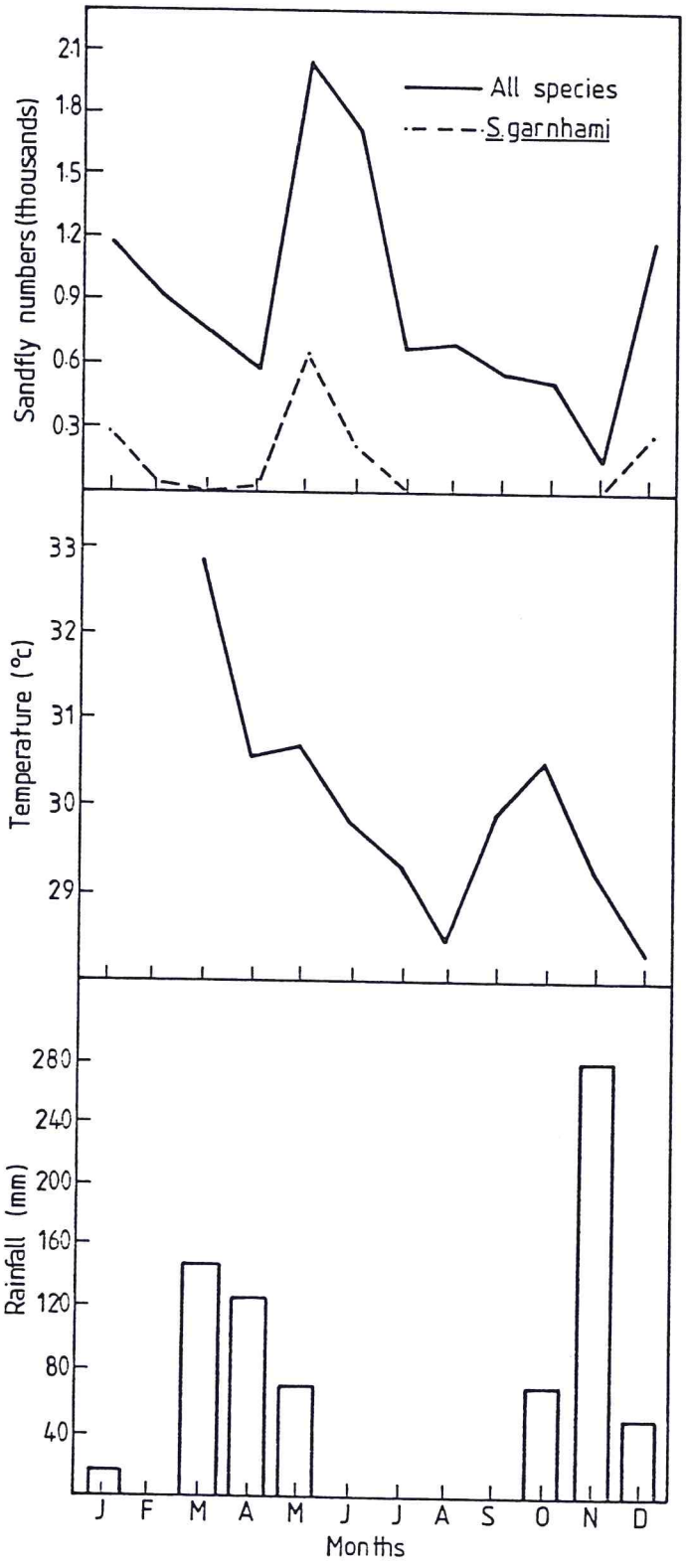


Fig 7.5. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in rock crevices in relation to climatic factors (Jan–Dec 1989).

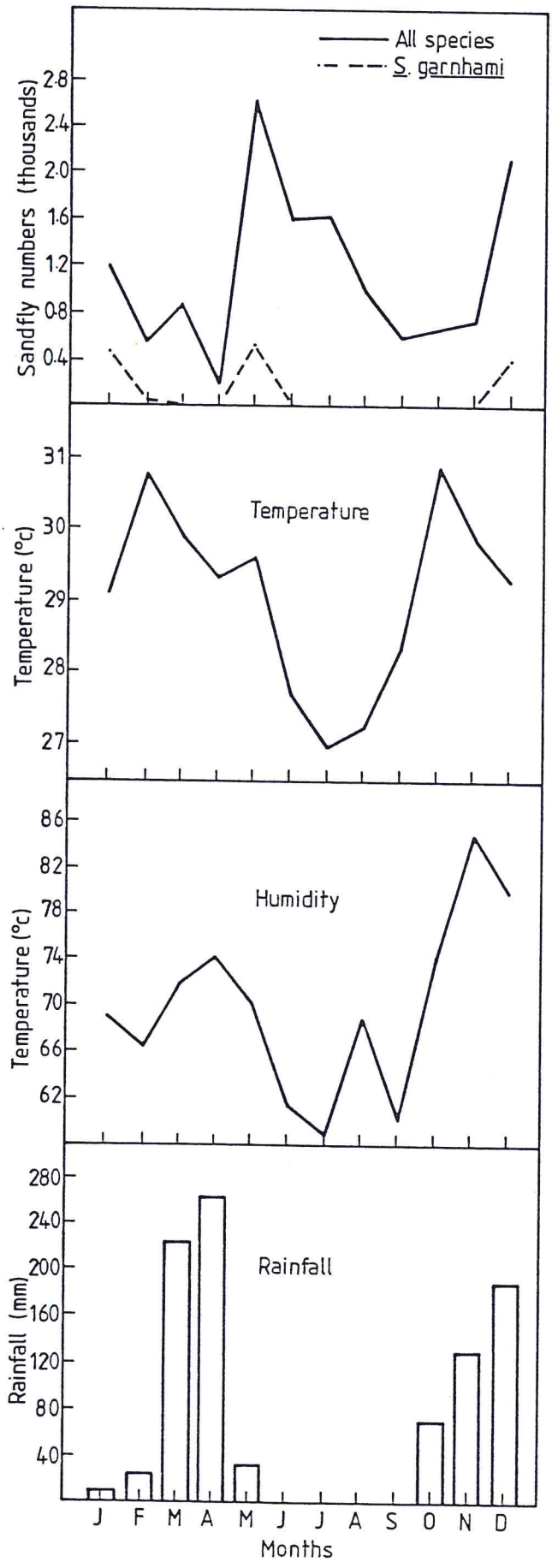


Fig 7.6. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in rock crevices in relation to climatic factors (Jan–Dec 1990).

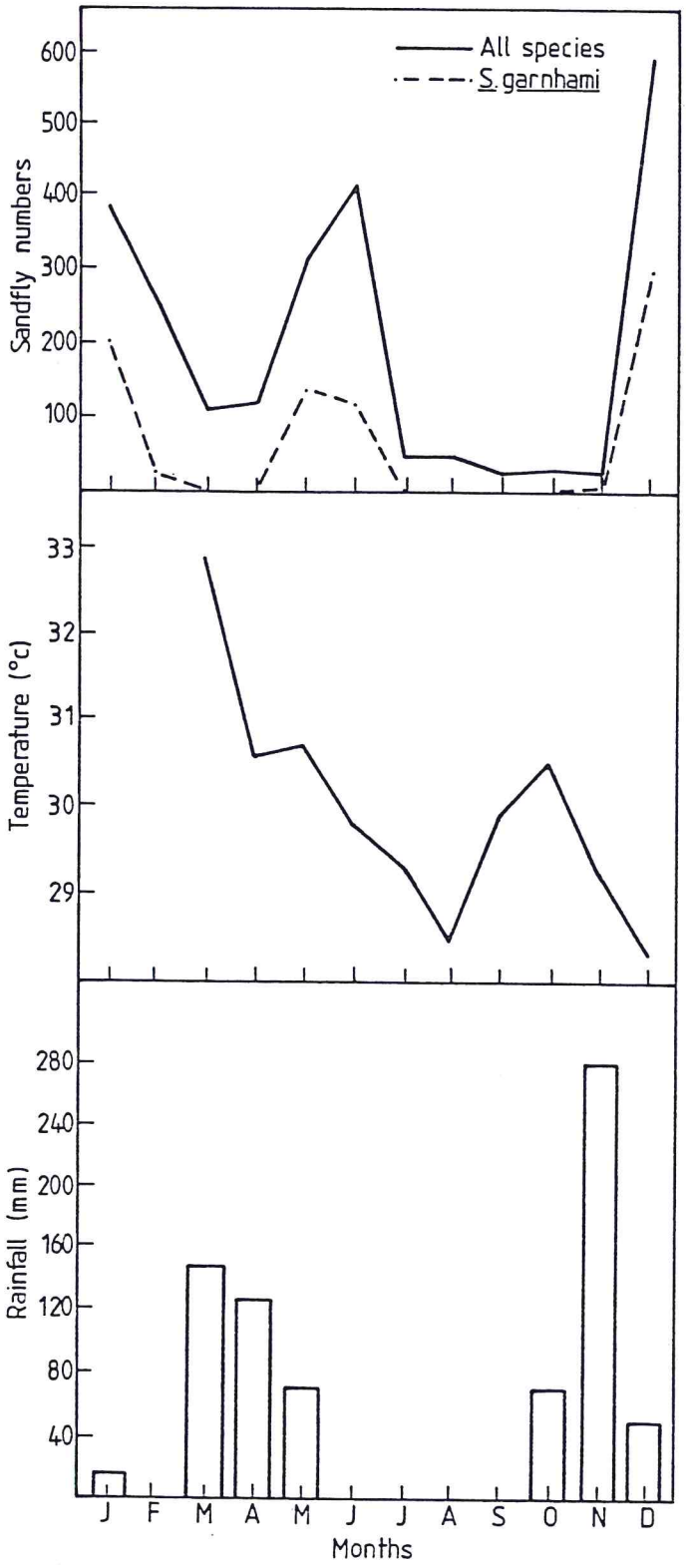


Fig 7.7. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species under tree bases in relation to climatic factors (Jan–Dec 1989).

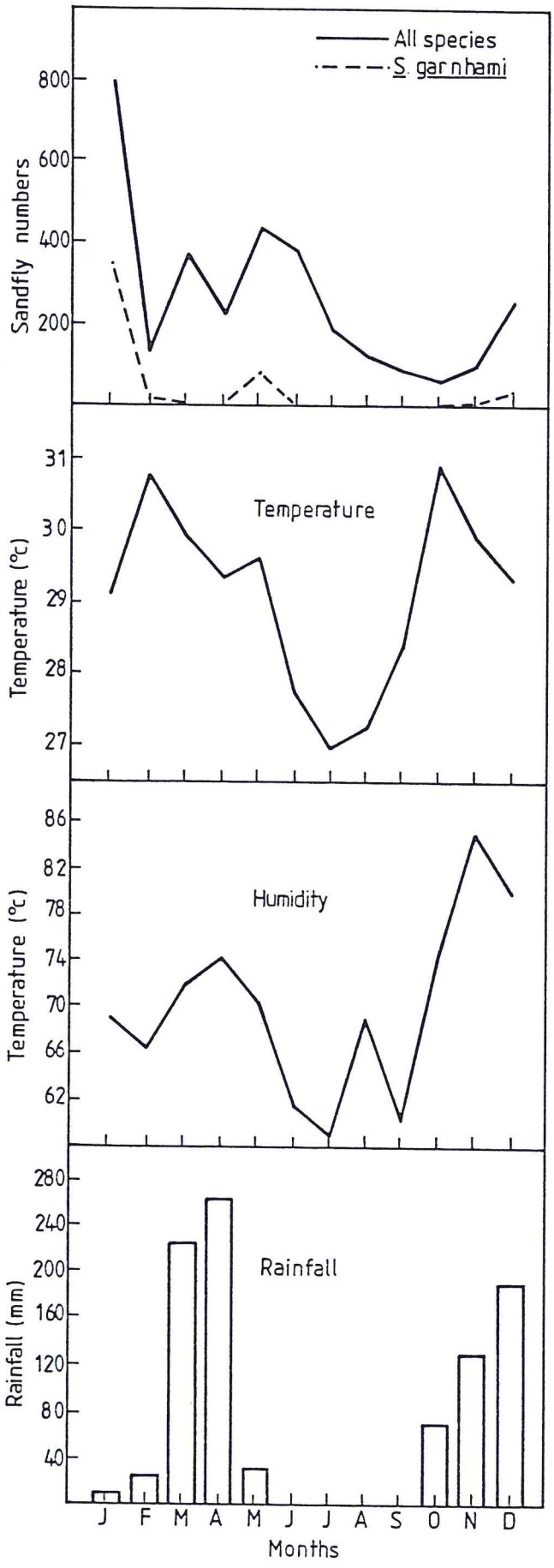


Fig 7.8. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species under tree bases in relation to climatic factors (Jan–Dec 1990).

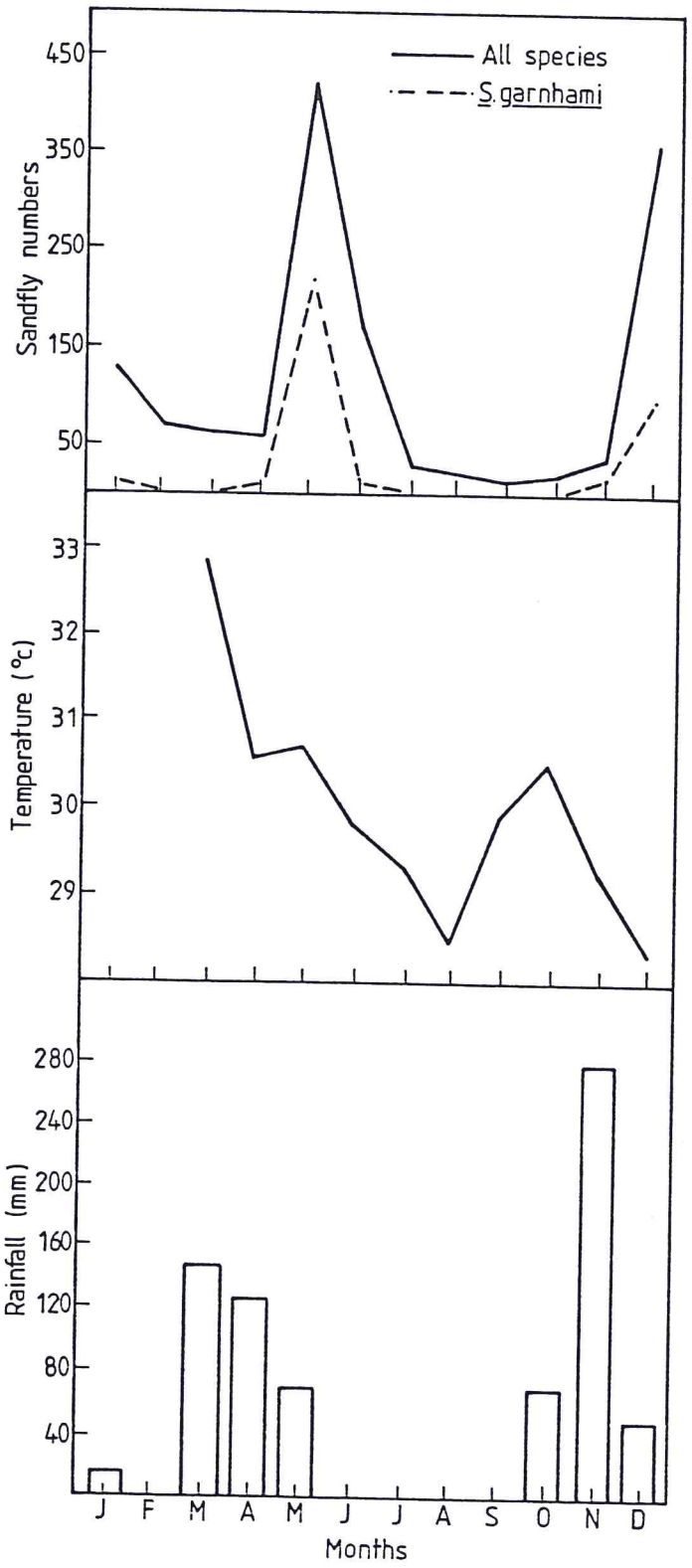


Fig 7.9. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in tree holes in relation to climatic factors (Jan–Dec 1989).

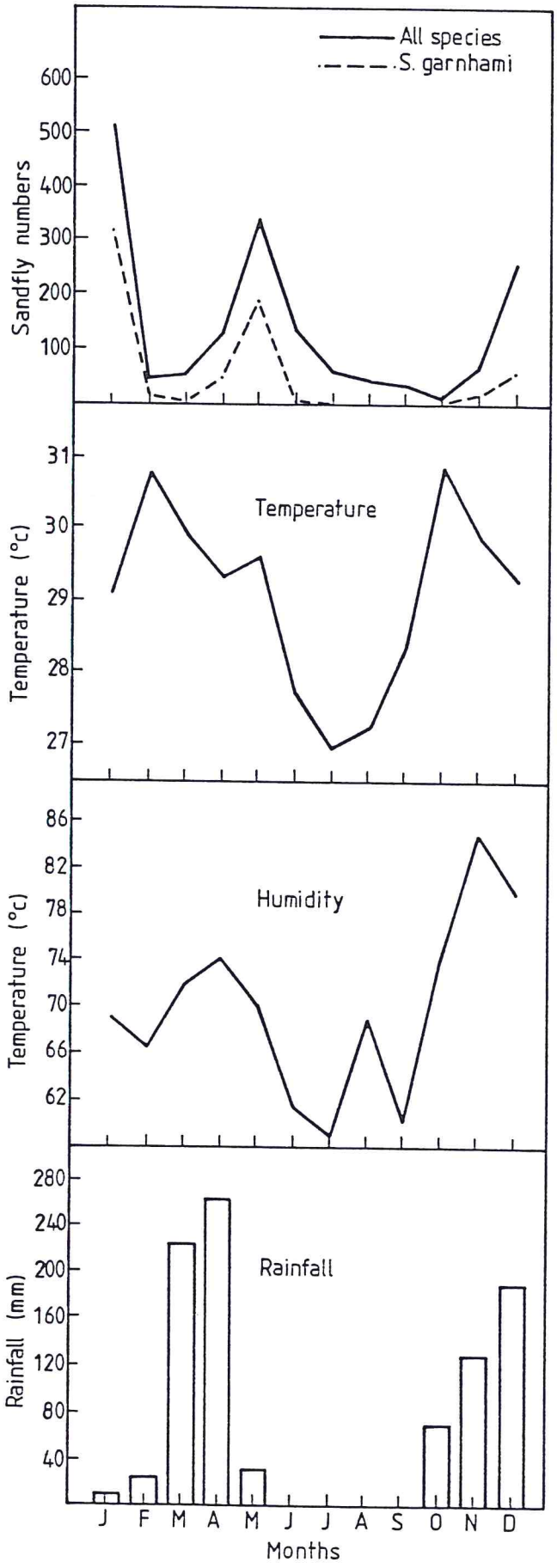


Fig 7.10. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in tree holes in relation to climatic factors (Jan–Dec 1990).

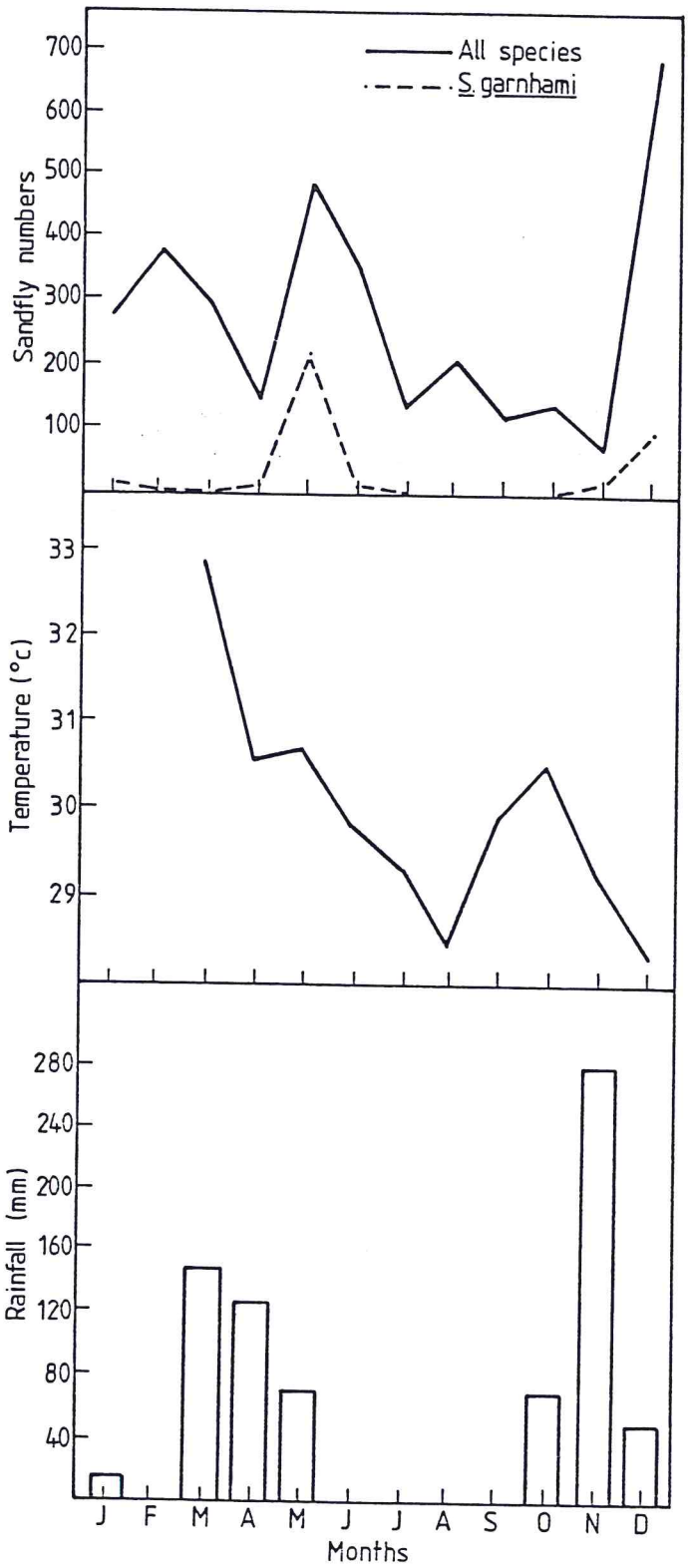


Fig 7.11. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species on the inside walls of human dwellings in relation to climatic factors (Jan–Dec 1989).

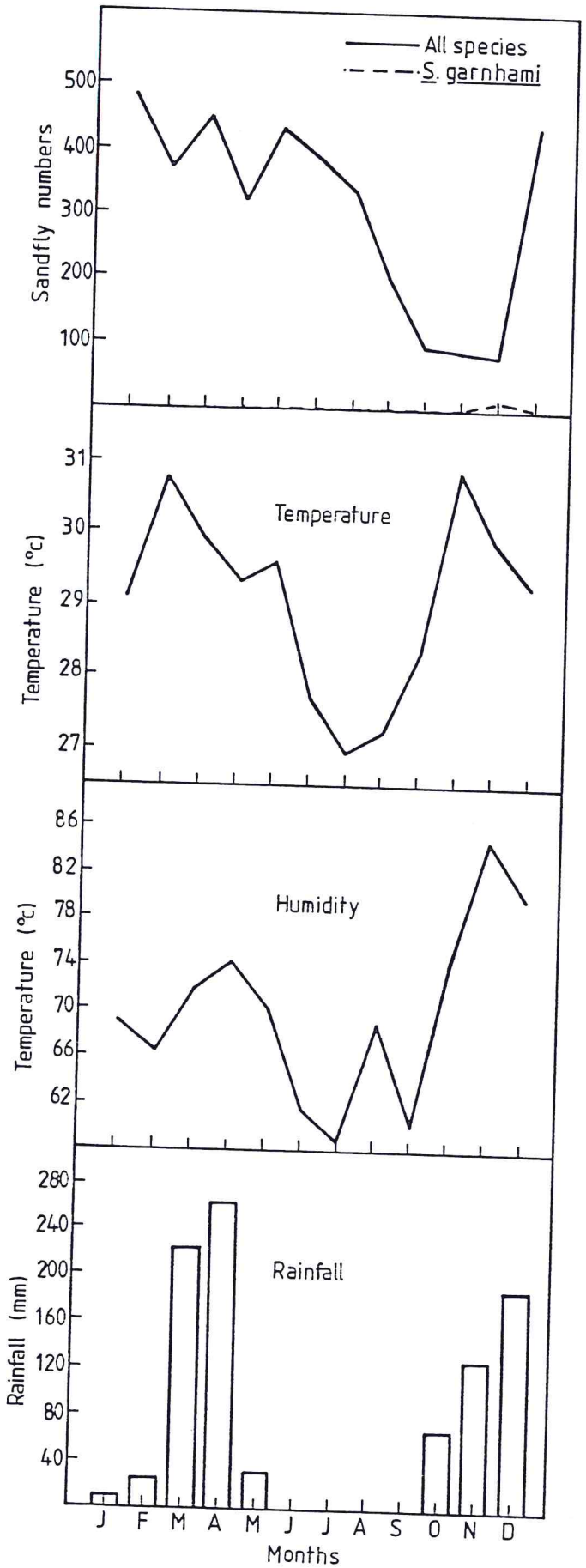


Fig 7.12. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species on the inside walls of human dwellings in relation to climatic factors (Jan–Dec 1990).

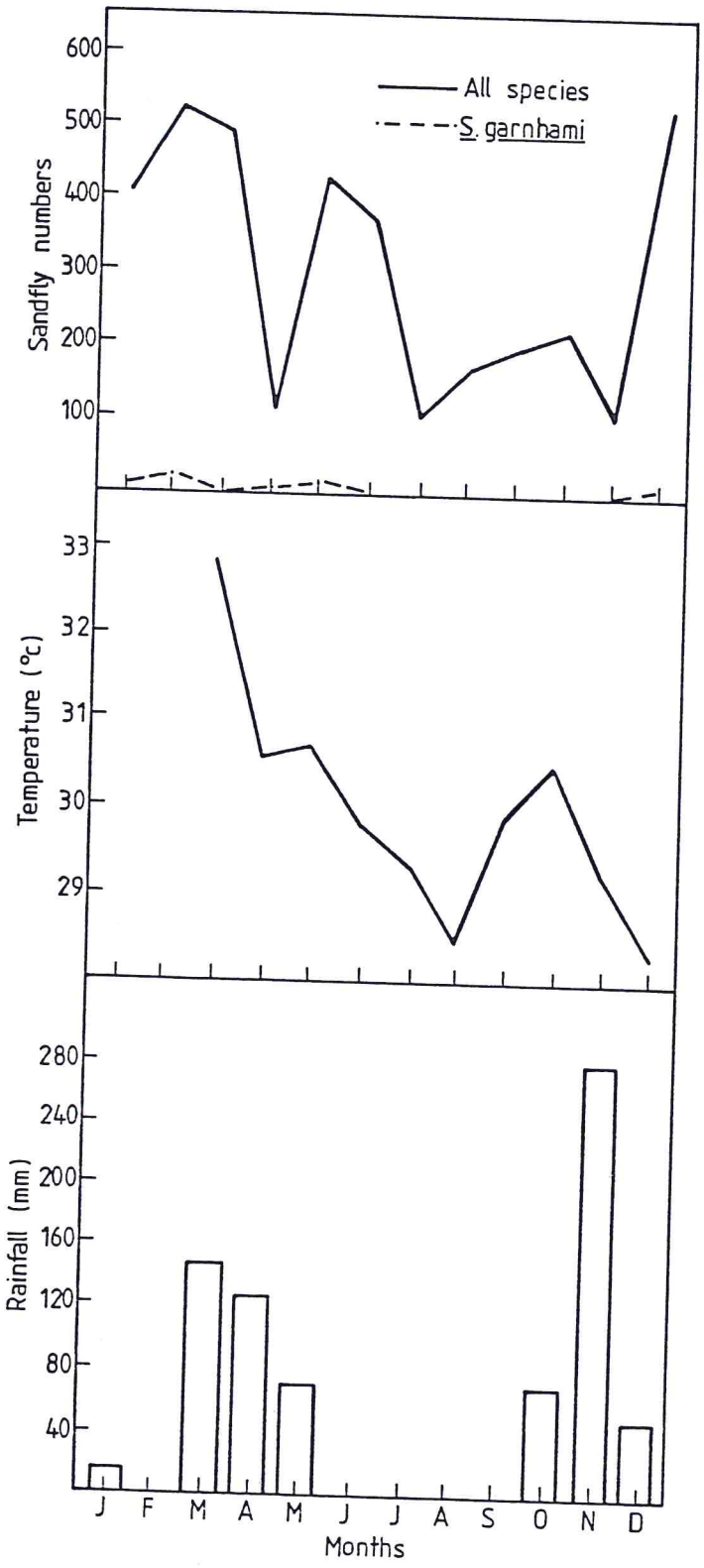


Fig 7.13. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species on the outside walls of human dwellings in relation to climatic factors (Jan–Dec 1989).

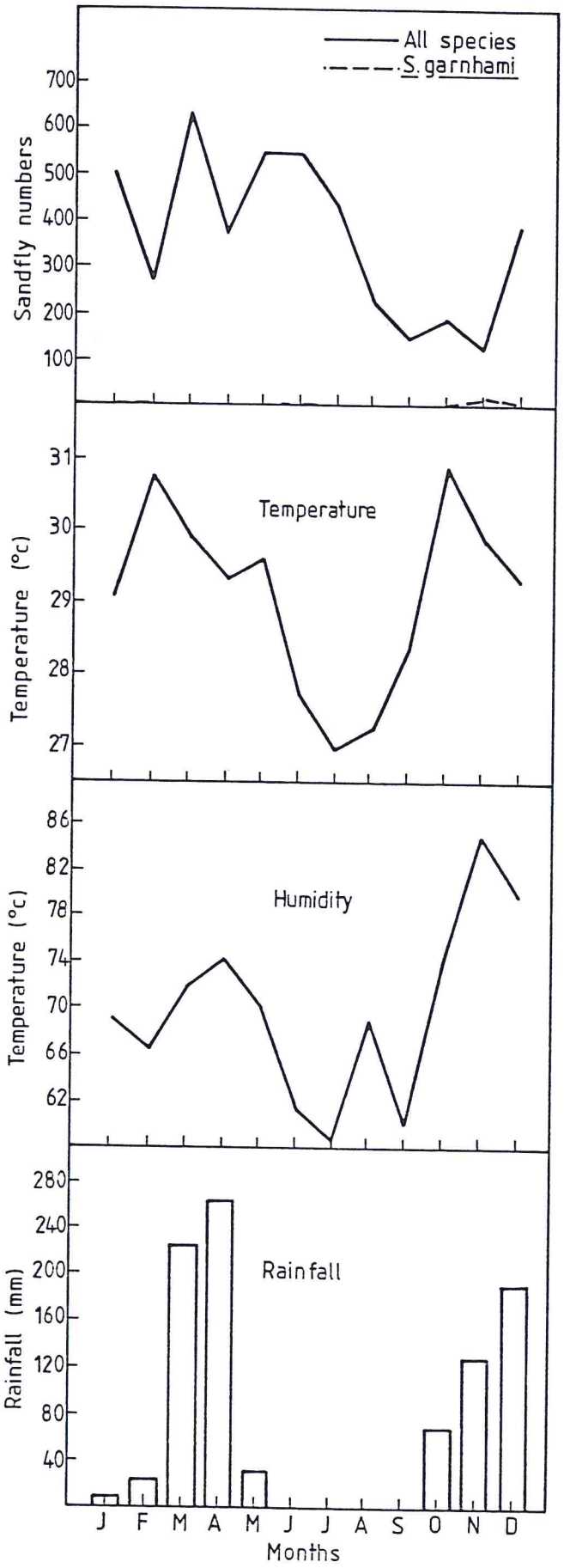


Fig 7.14. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species on the outside walls of human dwellings in relation to climatic factors (Jan–Dec 1990).

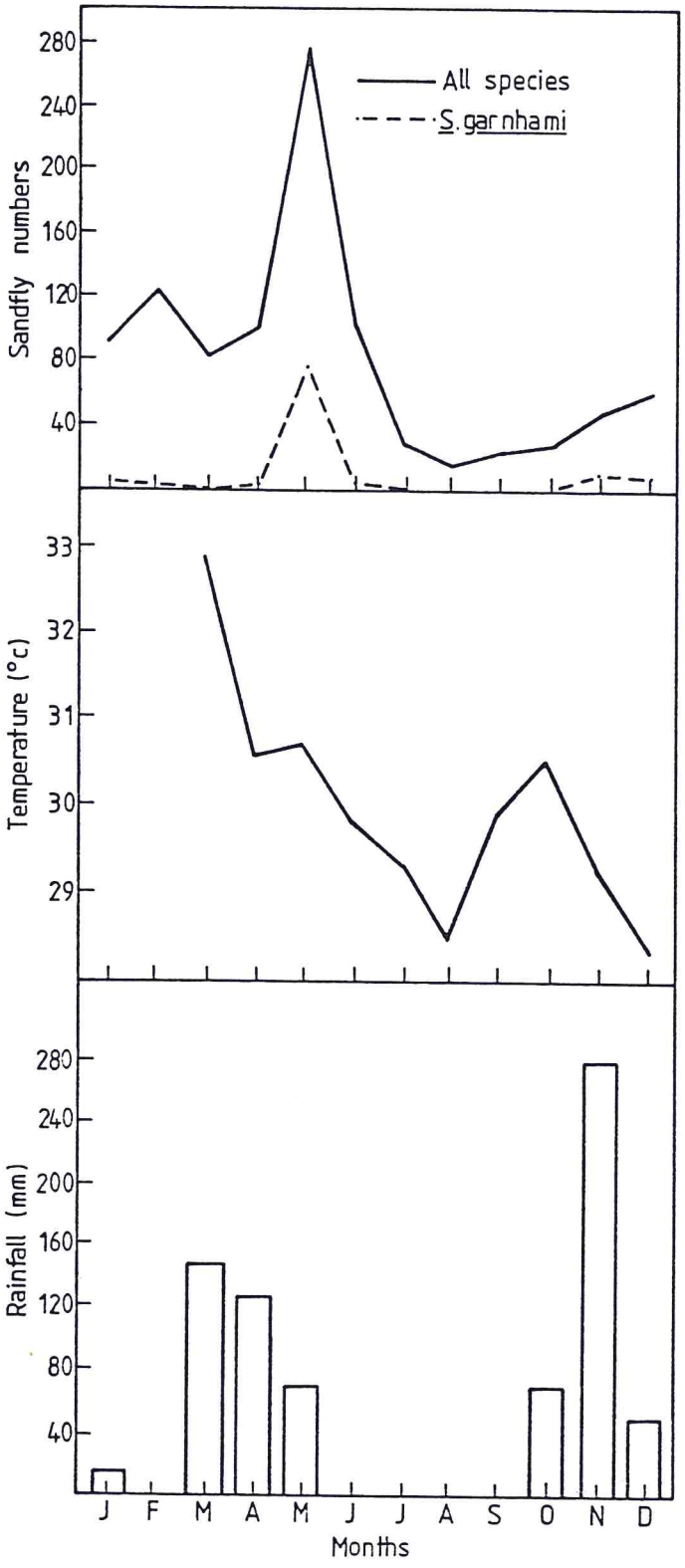


Fig 7.16. Monthly distribution of *S. garnhami* and other phlebotomine sandfly species in open spaces in relation to climatic factors (Jan–Dec 1989).

were positively correlated to the overall sandfly populations in termite hills but negatively correlated with them in other sites. Also in 1990, mean temperatures positively correlated with *S. garnhami* populations in all the sites except in animal burrows and inside human homes. In both years all the mean temperature correlations were not significant.

Total monthly rainfalls were positively correlated to *S garnhami* and overall sandfly populations in termite hills in 1989 and 1990 but negatively correlated to their populations in other sites.

Mean monthly relative humidity values were positively correlated to *S.garnhami* and overall sandfly populations in termite hills but showed negative correlation to their populations in other sites.

7.3.2 Species composition of various sites

A total of nineteen sandfly species were collected in both years comprising 3 species of the *Synphlebotomus* complex and 16 species of the *Sergentomyia* genus. Only 17 species were encountered in 1990. All the sandflies collected in 1989 formed part of the data on spatial distribution and were not further discussed in this section. The species composition and percentage distribution of various sandfly species in the different

ecological habitats in 1990 were given in table 7.6. It was again observed that the collections from the termite hills were considerably higher than those of other biotopes (see also chapter five).

7.3.3 Temperature

Tables 7.7 and 7.8 show the climatic data obtained in 1989 and 1990. Average monthly temperatures (AVGI) ranged from 28.34 - 32.89 °C. in 1989 with March and October being the warmest months. No data were collected in January and February months. In 1990 the average monthly temperature range was 26.96-30.90 °C with February and October being the warmest months.

In both years, the mean temperature graphs showed little fluctuations (1-4.6°C in 1989 and 1-3.94°C in 1990). A rise in temperature from January to early March (dry season periods) reaching a mean of 32.89°C in February 1989 and 30.8°C in 1990 were observed. Following the start of rainfall in March the temperature dropped to 30.60°C in 1989 and 28.93°C in 1990. In 1989 there was a gradual drop to 28.45°C August after which it rose again to a mean of 30.52°C in October. The temperature dropped again gradually to a mean of 28.33°C until the end of the year. Following the onset of rains in March 1990, the temperature dropped gradually to 26.96°C in July, then a rise to a mean of 30.91°C in

Table 7.6: Sandflies species composition and percentage distribution in the various ecological habitats

Species	Total caught	Percentage distribution per habitat						
		Termite hill	Animal burrow	Rock crevices	Tree base	Tree hole	Inside house	Outside house
P.celiae	1293	97.21	0.15	0.08	0.93	1.62	0	0
P.martini	562	83.45	8.36	1.60	4.27	1.25	0.71	0.36
P.vansomerenae	355	95.49	0.56	0	0.56	2.54	0.28	0.56
S.adleri	8	37.5	0	0	0	62.5	0	0
S.affinis	1231	81.07	5.52	10.97	0.73	1.14	0.16	0.41
S.antennatus	2158	29.47	15.71	19.69	4.03	2.64	10.52	17.93
S.bedfordi	29222	13.64	16.18	36.90	7.49	2.15	11.28	12.35
S.christophers	17	0	0	100	0	0	0	0
S.clydei	185	36.22	4.32	9.19	0	2.70	14.05	33.51
S.garnhami	11866	53.81	24.64	11.94	3.93	5.35	0.15	0.17
S.graingeri	153	97.39	2.61	0	0	0	0	0
S.harveyi	100	15	31	16	12	22	2	2
S.ingrami	198	32.83	11.62	3.03	23.2	19.7	3.54	6.06
S.kirki	3073	55.91	5.99	24.50	2.21	5.30	0.49	5.60
S.multidens	153	97.39	0	0	1.96	0.65	0	0
S.schwetzi	624	40.38	4.17	7.37	32.85	9.29	2.72	3.21
S.squamipleuris	160	0.625	6.88	79.38	0.63	0	2.5	10
Total	51358							

Table 7.7 Climatic data of Tseikuru Area (1989)

Month	Min T	Max T	Avg T	Rain
Jan	.	.	.	16.6
Feb	.	.	.	0
Mar	27.29	38.49	32.89	147.3
Apr	25.6	35.43	30.52	126
May	25.86	35.51	30.68	69.6
Jun	25.54	34.07	29.8	0
Jul	25.41	33.37	29.38	0
Aug	24.92	31.98	28.45	0
Sep	25.65	34.1	29.88	0
Oct	25.97	35.07	30.52	69.4
Nov	25.55	32.95	29.25	279.5
Dec	25.64	31.04	28.34	48.8

Min T = Minimum temperature
Max T = Maximum temperature
Avg T = Average temprature
Rh M = Relative humidity at 0600hr
Rh N = Relative humidity at 1500hr
Avg Rh = Mean daily relative humidity
Rain = Total monthly rainfall

Table 7.8: Climatic data of Tseikuru Area (1990)

Month	Min T	Max T	Avg T	Rh M	Rh N	Avg Rh	Rain
Jan	26.00	32.22	29.11	75.84	61.94	68.89	7.5
Feb	27.64	33.95	30.79	73.93	58.88	66.4	24
Mar	27.11	32.7	29.90	78.45	65.06	71.75	222.7
Apr	26.3	32.33	29.32	82.37	65.9	74.13	261
May	26.63	32.56	29.59	76.02	64.84	70.43	30.6
Jun	24.94	30.55	27.74	69.97	52.98	61.47	0
Jul	24.45	29.47	26.96	65.58	52.29	58.94	0
Aug	24.62	29.87	27.24	75.9	61.92	68.91	0
Sep	24.5	32.19	28.34	68.84	51.5	60.17	0
Oct	28.22	33.6	30.91	79.72	68.48	74.10	70.1
Nov	26.94	32.82	29.88	87.9	82.17	85.03	128.3
Dec	26.67	31.95	29.31	84.61	75.44	80.02	188.8

Min T = Minimum temperature
Max T = Maximum temperature
Avg T = Average temprature
Rh M = Relative humidity at 0600hr
Rh N = Relative humidity at 1500hr
Avg Rh = Mean daily relative humidity
Rain = Total monthly rainfall

early October, and a drop to 29.30°C by the end of December.

During the April-June sandfly population peaks, *S. garnhami* was first collected in the field from April and it lasted upto the end of June. This corresponded to a temperature range of 29.8-30.68 °C with a mean of 30.24 ± 0.62 °C in 1989 and a range of 27.74- 29.32 °C with a mean of 28.53 ± 1.12 °C in 1990. During this period, *S. garnhami* population peaks in all the sites except animal burrows were observed in May when the mean temperatures in both years were 30.68°C and 29.59°C respectively. In 1989, the population peak of *S. garnhami* in animal burrows occurred in June when the mean temperature was 29.8°C. In 1990 *S.garnhami* peak in animal burrows was in May as in other sites investigated with the mean temperature 29.59°C.

During the November-January sandfly population peaks, *S. garnhami* was trapped from termite hills and other sites from November to January when the mean temperature ranges were 28.34-29.25°C with a mean of 28.80°C ± 0.64°C in 1989 and 29.30-29.88°C with a mean of 29.59 ± 0.41°C in 1990. The peaks occurred in December when the mean temperatures were 28.34°C and 29.31°C respectively in both years. Collections from animal burrows were from December to early February when the mean temperature were between 28.34-30.79 °C in both years. The peaks were not observable from the graphs

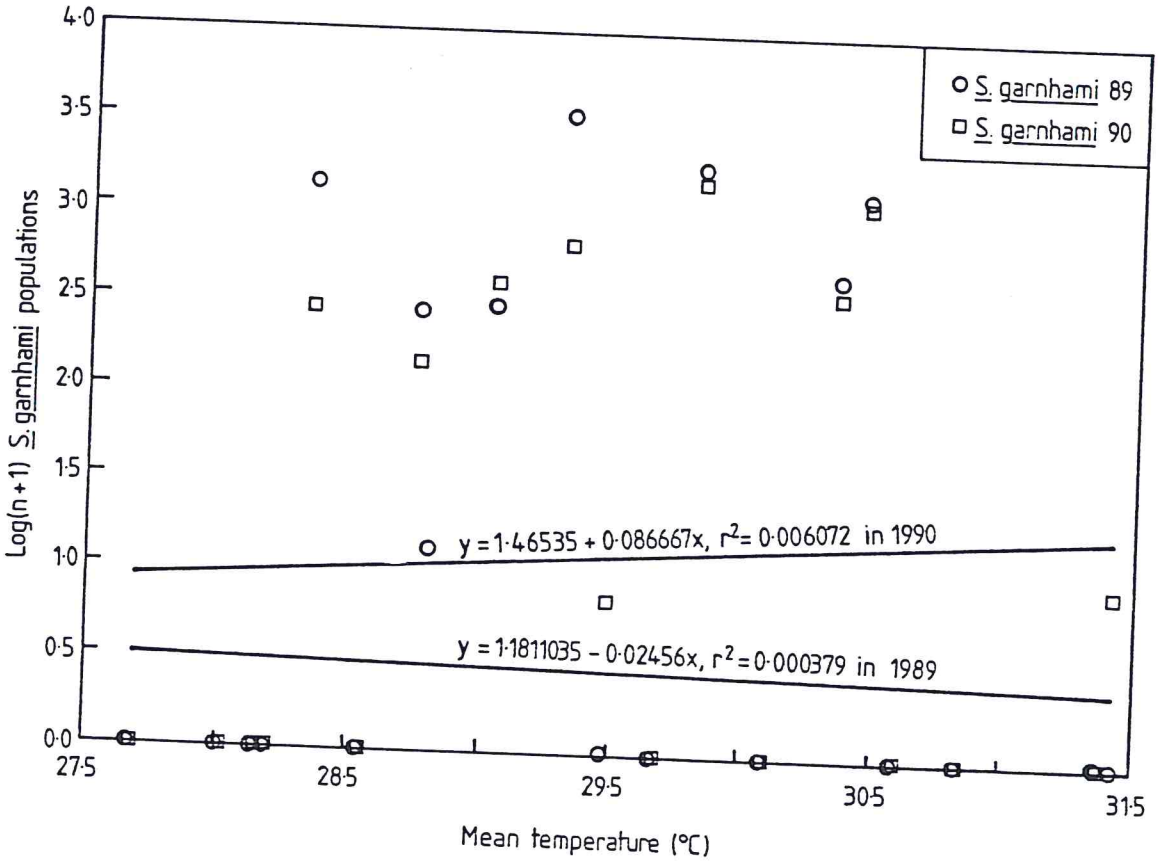


Fig 7.17 Scatter plots of *S. garnhami* catches against temperature (1989 and 1990)

(figs 7.3 and 7.4) but occrred in January in both years (tables 7.3 and 7.4). *S.garnhami* was collected from the field when the minimum and maximum temperatures were between 25.6 and 35.5°C in both years. These results showed that *S. garnhami* thrived in the field under a wide temperature range of 25.6-35.5°C but optimally at a temperature of 29.48 ± 0.96 °C (average of peak period temperatures). Scatter plots of *S. garnhami* catches against temperature using collections from termite hills showed non-significant linear relationships between *S. garnhami* populations and temperature in both years ($Y = 1.1811035 - 0.02456X$, $r^2 = 0.000379$ in 1989 and $Y = -1.46535 + 0.086667X$, $r^2 = 0.006072$ in 1990). In both years most *S. garnhami* were collected at temperatures between 28·5°C and 31·5°C (fig 7.17), and these temperature conditions were available throughout the period of study.

7.3.4 Relative humidity

Table 4 contains the relative humidity data for 1990. No data was collected in 1989. The mean monthly relative humidity (AVRH) ranged from 58.91-85.03% with March to May and October to December being the most moist months of the year. These periods corresponded with the wet sesaon periods.

The relative humidity graph showed that the relative humidity remained below 70% until March when it rose to 70% following the onset of rainy season. It continued to rise until a mean relative humidity of 74.5% was reached in April after which there was a gradual decline to 58.94% in July. It gradually rose again to 74.10% in October following the onset of another rainy season.It continued to rise until a peak of 85.03% was reached in November. This fell to 80% in December when this study was stopped. *S. garnhami* was collected from the field between April and June and from November to December when the mean relative humidity ranged from 61.17-74.43% with mean a of 68.68% and 74.10-85.03% with a of mean 79.72%) respctively. The peaks were observed in May and December when the mean relative humidity were 70.43% and 80.02% respectively. During the November-December period a minor peak in contrast to that of May was observed in December when the relative humidity was over 80%. The relative humidity recordings in the morning(RHM) and in the afternoon (RHN) showed that *S.garnhami* thrived in the field within the relative humidity range of 52.98-87.9%. These results showed that adult *S. garnhami* existed over a relative humidity range of 52.73-87.67% but thrived optimally at a relative humidity of 75.23% (average of relative humidity of peak periods). Scatter plots of *S. garnhami* populations against relative humidity revealed

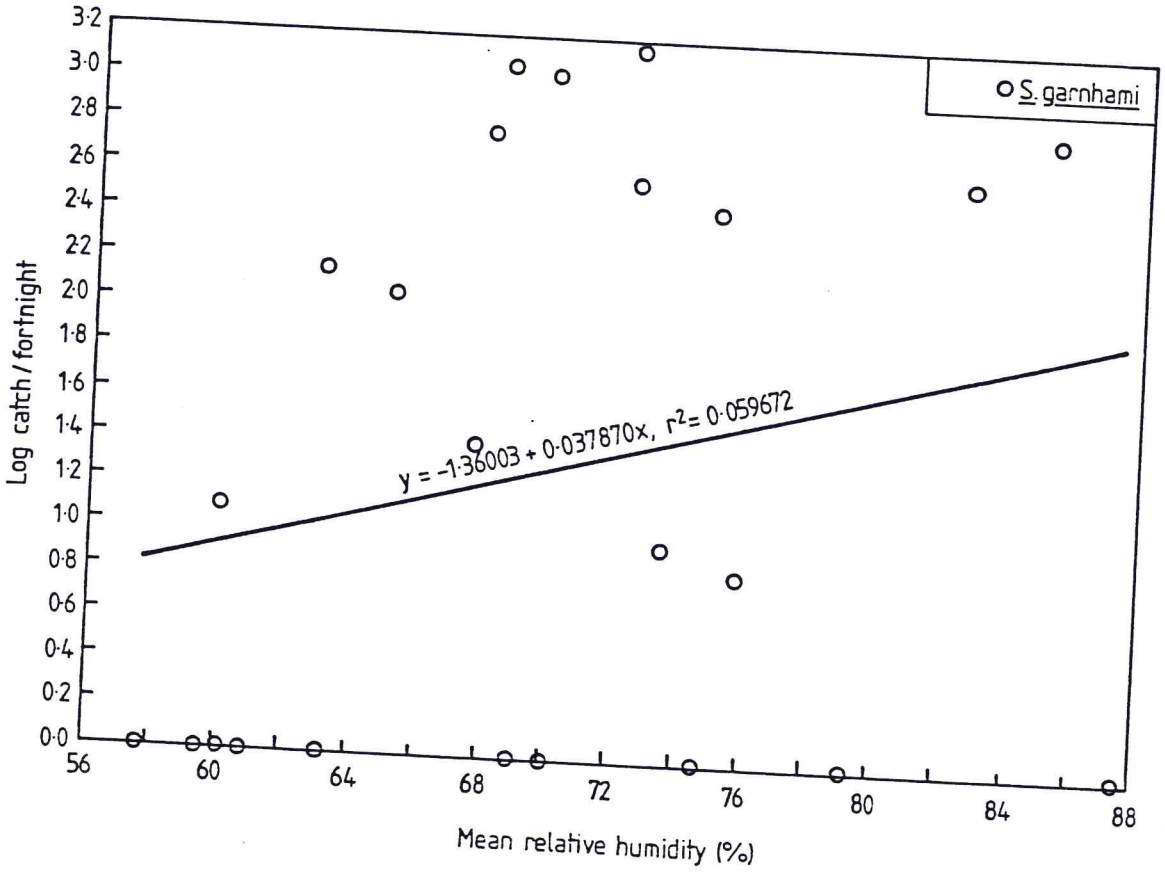


Fig 7.18 Scatter plots of *S. garnhami* catches against relative humidity (Jan–Dec 1990)

a positive linear relationship (fig 7.18). It also showed that most *S. garnhami* were collected between 60 and 80% relative humidity with a mean of 70%. This could be achieved only during rain periods in a natural environment.

7.3.5 Rainfall

Total monthly rainfall data were also shown in tables 7.7 and 7.8. There were two rainy seasons March-May and October to December. In 1989 there were no rainfalls in February and from June to September in both years. In the 1989 March and November were the peaks of rains while April and December were the peaks in 1990.

In both years the rainfall graphs were based on total monthly rains. Rainfalls in both years occurred at virtually the same period but differred in pattern and distribution. In 1989 there were less rainfall during the March-May rain period than during the October-December time. In 1990, the rainfall pattern was the reverse. There were more rains during March-May period. Rains in January and February months were small.

During the sandfly population peaks in both years *S. garnhami* population peaks were observed after the peaks of the rains except during the November-December period in 1990 when it corresponded with the rainfall

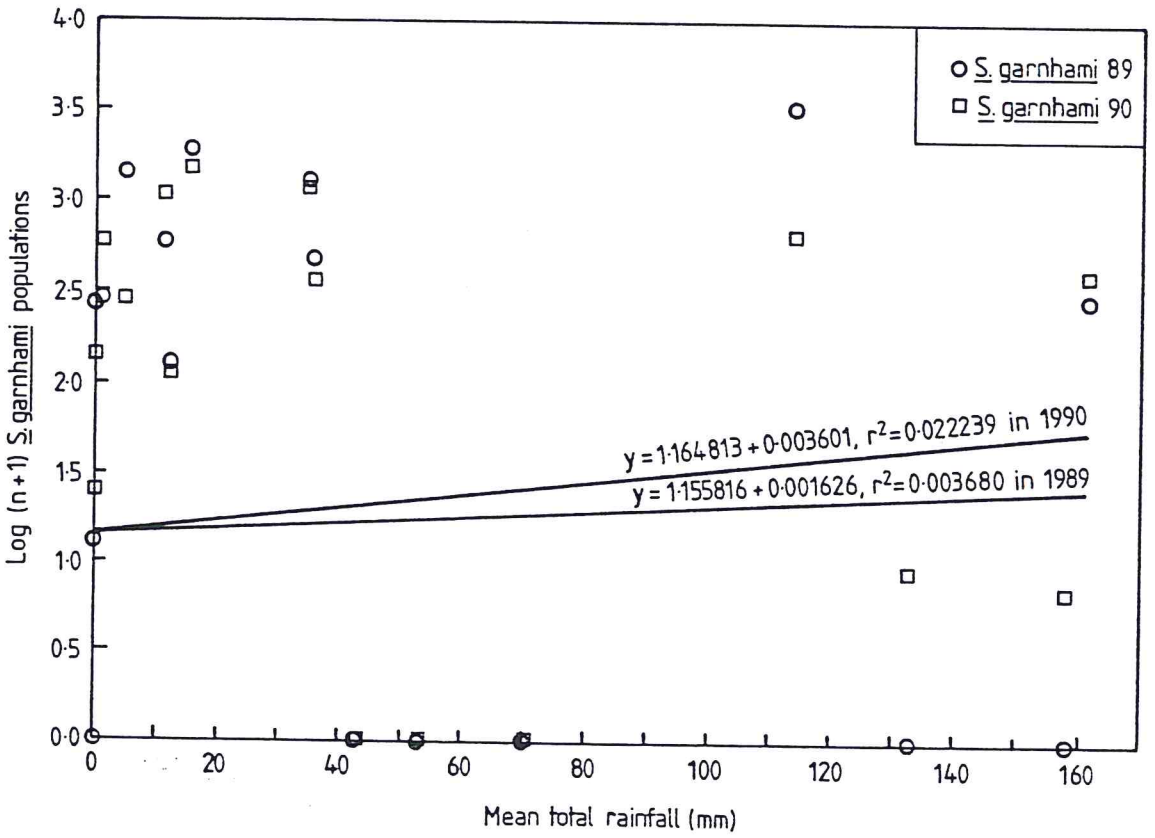


Fig 7.19 Scatter plots of *S. garnhami* catches against rainfall (1989 and 1990)

peak. *S.garnhami* was also collected in the field one month after the of rainfall (June-July). The time lapse were even longer in animal burrows as shown in the graphs. There was a striking synchrony in the time of first collection of *S. garnhami* from the sites and the commencement of rains. For example despite the starting of rains earlier during March-May period in 1990 than it was in 1989, it was observed that initial *S. garnhami* collections were at the same time. Rainfall periods were very short (about 2-2.5 months) and *S. garnhami* started emerging when over 50% of the rains have fallen and finally peaked at the nick of the end of the rains when there were alternating short rains and dry periods. Heavy rains at the end of rain periods seemed to have suppressing effect on the population size (see 1990 graphs). These results showed that *S. garnhami* started emerging from mid rainy season periods and reached population peaks when there were less rains (0-69.4mm) alternating with sunny periods. Scatter plots of *S. garnhami* catches against rainfall using collections from termite hills showed a non-significant linear relationships in both years ($Y = 1.155816 + 0.001626$, $r^2 = 0.003680$ for 1989, and $Y = 1.164813 + 0.003601$, $r2 = 0.022239$ for 1990). Most *S. garnhami* were collected between 0 and 40mm of rainfall in both 1989 and 1990 (fig 7.19).

7.4 Discussion

7.4.1 *S. garnhami* populations

From the above results *S. garnhami* appear to be strictly a seasonal fly with two peaks in the year. Similar observations have been made in Kenya (Heisch 1954, 1955, Heisch et al 1956, Wijers and Minter 1962, Minter 1964 and Basimike 1988), in Sudan (Quate 1964) and in Ethiopia (Foster 1972). Kirk and Lewis (1951) had earlier shown that sandflies of the ethiopian region had marked seasonal variations.

7.4.2 Temperature

S. garnhami existed in the field within a wide temperature variation but thrived optimally at mean temperature of 29.20 $\pm$ 3.77°C. The mean monthly temperatures of Tseikuru rarely fell below 29°C. This means that all the warmth requirements of *S. garnhami* is available all the time of the year. Since *S. garnhami* does not have uniform prevalence throughout the year there must be another factor acting in combination with temperature which influences the species predominance in a particular season. WHO (1984) showed that of all the climatic factors influencing the sandfly distribution in

the world the most reliable is temperature. They showed that a mean temperature of 20°C is required for existence of sandflies in an area. Theodore (1936) showed that in nature the cycle of development of *P. papatasi* was about 36 days at a temperature of 30°C. He also observed that temperatures under 10°C or more than 40°C were unfavourable to adult *P. papatasi* although the larvae could withstand lower temperatures. Killick-Kendrick (1987) noted that the optimum temperatures in the sandfly breeding habitats will be similar to the ambient temperatures in the range of 20-30°C.

7.4.3 Relative humidity

Adult *S. garnhami* existed in the field over a wide range of relative humidity but thrived best at a mean of 71.11 ± 7.66%. This could be achieved at a period of light to moderate rainfalls alternating with sunny periods. This was necessary to prevent drenching and killing of the delicate insects and such a situation was probably overcome by the long developmental period of the moisture loving immature stages. The results therefore showed that moderately high moisture (63.45-78.77%) in the environment is necessary for the adult survival. This fact is buttressed by the minor peaks of *S. garnhami* in January after light rains and also the low population density of *S.garnhami* and other sandflies

during heavy rains in November -December period of 1990. Also the differences in peak periods of *S. garnhami* and even late emergence in animal burrows could be explained in terms of the availability of moisture, adequate temperature and rainfall. The burrows were located in dense thorny thickets flanking the banks of river Kyandani. Coupled with the fact that these were subterranean habitats sheltered by thickets, it is apparent they had more moisture than other sites but they were relatively cooler than the other sites. This means that the difference in temperature caused delayed development of immature stages and therefore late emergence. Similarly the difference in evaporation rate led to the difference in the peak period in these burrows. Foster et al (1970) noted that the developmental period from egg to adult of *Phlebotomus longipes* was longer (100 days) when the temperatures were low (18-20°C) and shorter (53 days) when the temperatures were higher (28-30°C). Verma (1979) also observed that the incubation time for *P.martini* eggs was 8-13 days at temperatures of 26-28°C

7.4.4 Rainfall

S. garnhami existed from mid-rainy season period and did not reach the peak until towards the end of rains with alternating light rains (less than 50 mm) and sunny

period. The population declined sharply with the end of the rains existing only within the early dry season when moisture is still available in the soil. These facts show that rainfall is an important source of moisture to the habitat and water vapour to the atmosphere but there is probably a significant interplay between the 3 climatic factors and the sandfly population (rainfall, humidity and temperature). This is because:

1. Rainfalls were few, erratic and comparatively little
2. There was a good time lapse between the first rainfall and the emergence of *S. garnhami*. This suggests that the initial rains might have been a source of moisture stimulating the development of the immature stages and the time lapse being the developmental period from eggs to adults in nature.
3. At the peak of the rains little or no *S. garnhami* were collected and the overall sandfly population was low.
4. Prior to the rainfalls the mean daily maximum temperature was within the death thermal range (35°C-40°C).
5. The general environment was dry implying very low humidity in the atmosphere.
6. Sandflies were collected in large numbers only during the alternating dry periods between rains.
7. The peaking of *S. garnhami* population in the [illegible]imal

burrows in June was probably due to the differential evaporation rates in the subterranean habitats in comparison to those habitats near or on the surface of the soil.

Most *S. garnhami* and other sandfly species were collected towards the end of rains when there were alternating light rains (0-40mm) with sunny periods. This suggests that light to moderate rains are conducive for the adult *S. garnhami* and other sandfly populations. In Panama, Chaniotis et al (1971) noted a steady decline in sandfly population due to heavy rainfall. He also observed that sandfly populations were lower during the dry seasons but reached peak populations just before the wettest month of the year. Similar observations have been made by various workers elsewhere (Wijers and Minter 1965, Thatcher and Hertig 1966, Thatcher 1968, Disney,1966, 1968 1966, Le Pont 1982, Shaw and Lainson 1972). Basimike (1988) noted that rain was beneficial to the sandflies when it occurred in moderate amounts and was evenly distributed but detrimental to them when the ground is inundated. Minter (1964) showed that the 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 the adult flies.

It is evident from the results that there is a significant interplay between the 3 climatic factors

(rainfall, temperature and relative humidity). Temperature conditions were fulfilled in most part of the year. The relative humidity of the atmosphere as well as moisture content of the sandfly breeding habitats were low during the dry months when *S. garnhami* adults are absent from the environment. Precipitation is the primary source of moisture to the atmosphere and the breeding habitats. It is most likely that rainfall has an indirect influence on *S. garnhami* and other sandflies populations by supplying moisture to the habitats for the development of immature stages (eggs, larvae and pupae). It also a factor of increased relative humidity of the atmosphere which thereby brings down the temperature from the death thermal range of 35-40°C to the optimal range of 25°C-35°C, consequently enhancing adult survival and subsequent increases in the population of *S. garnhami* adults and other sandflies. Under optimal conditions of temperature, moisture is therefore is a factor of sustained adult survival. Rainfall also exerted negative influence on sandfly population through flooding and erosion of the breeding habitats of sandflies as was observed in our 1990 December populations. Hence rainfall showed negative correlation to *S.garnhami* and overall sandfly populations in most sites.

CHAPTER EIGHT

MICROCLIMATIC FACTORS INFLUENCING *S. GARNHAMI POPULATION* IN THEIR BREEDING HABITATS

8.1 Introduction

Temperature and moisture are major limiting climatic factors in the distribution and survival of organisms (Krebs 1981). Even at the regions and places of occurrence of a species, certain sites are much more favoured due to the differences in moisture and temperature conditions (Odum 1971). The knowledge of an organisms micro-environmental conditions helps in understanding why the species prefers certain habitats to others in a given area. In vector biology investigations, the studies are of practical value in successful laboratory colonization of the insect vector species for further studies into the biology, genetics, vector potentials as well as its susceptibility and resistance to control arsenals (WHO 1976, Killick-Kendrick 1981). Furthermore, it could be harnessed inthe field in the trapping and population ecology studies including the prediction of population models and in the planning and execution of control programmes. Inspite of these obvious values of the study, relatively little information is available on the natural microclimatic conditions existing in the sandfly resting

and breeding sites (WHO 1984, Bettini and Melis 1988, Basimike and Mutinga 1990). This study was aimed at investigating the influence of microclimatic factors on *S. garnhami* populations in their breeding habitats.

8.2 Materials and Methods

This study was carried out with a soil moisture/temperature metre and soil moisture/temperature cells (EL514-070 and EL514-074,-076, -078, Plate 8.1)

The soil metre is a portable, battery operated device that can monitor variations in moisture content of the soil with temperature, by having both resistance and temperature readings on a dual dial. The electrical resistance range for moisture readings is 0-20 milliohms and this is related to a calibration curve for each soil tested to obtain percentage soil moisture. The unit is housed in a compact aluminium case 178 x 140 x 120 mm.

The cells comprise 2 plates of stainless and corrosion resistant steel separated by a processed glass fibre binding which provides an electrical coupling. A small thermistor completes the two-circuit 3-wire system Each cell is approximately 25 x 38 x 3 mm and can be obtained in 3 different forms based on the length of the lead wire.

The cells were buried permanently to a depth of 5-10cm, for the period of study, into the soils of five

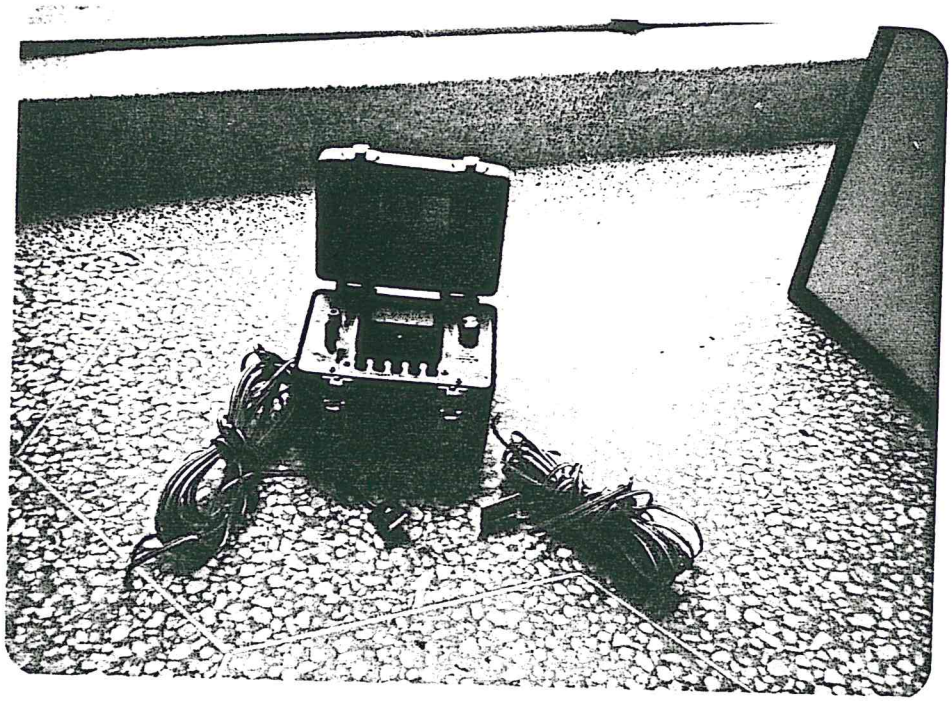


Plate 8.1 Soil moisture/temperature meter and cells used for measuring soil moisture and temperature

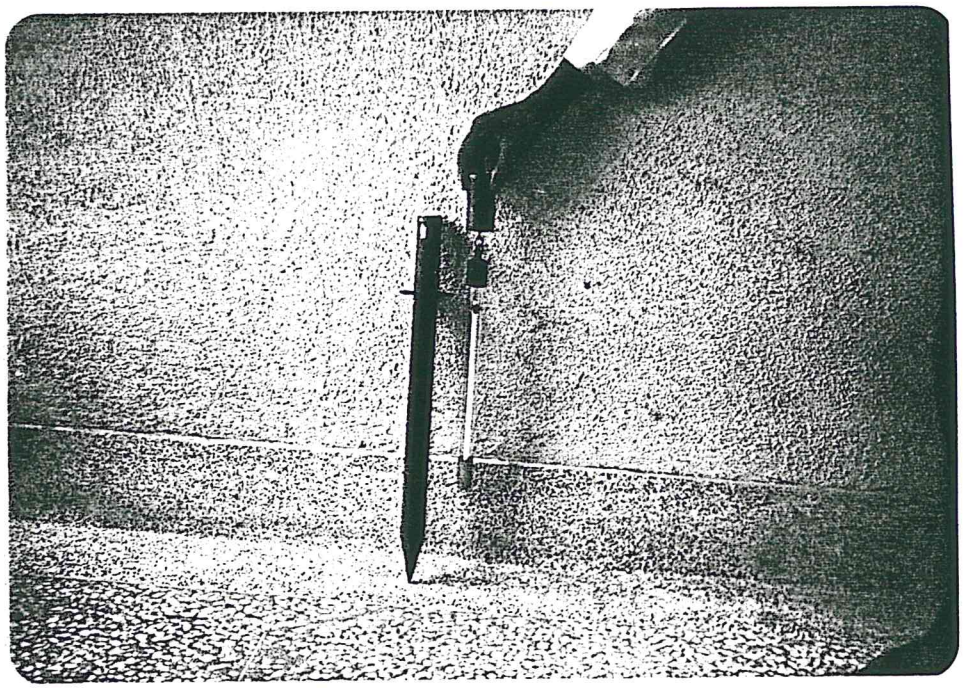


Plate 8.2 Sheathed earth thermometer for measuring soil temperatures at various depths

biotopes selected for this investigation. The sites were termite hills, treeholes, plant bases, rock crevices and animal burrows. Only one cell was used for each site. For the initial reading, an interval of at least 3 hours was allowed for the cells to adapt to the soil. Subsequent readings were taken between 6.00-8.00 am and 2.00-3.00 pm three times a week.

Soil temperatures at 45cm depth and ground surface were measured simultaneously with those of the five ecological sites. Due to the insufficiency of temperature/moisture cells, measurements of soil temperature at 45cm depth were done with sheathed earth thermometer (Plate 8.2) and at ground surface with ordinary thermometer.

8.3 Results

8.3.1 Termite hills

The data on soil moisture and temperature of termite hills were shown in table 8.1. Soil temperatures in termite hills ranged from 19-28°C with an overall mean of 22.71 + 2.09°C. The lowest temperature values were recorded in May and December corresponding to the periods of heavy rainfall. High temperature values were observed from January through March, and from September

Table 8.1: Soil temperature and moisture in termite hills

	Temperature		Moisture			
Month	Range	Mean	Range	Mean	Species	*S.garnhami*
Jan	21-27	24.425	50-99	81.96	468	344
Feb	23-27	26.33	20-95	75.64	25	4
Mar	25-28	26.71	50-92	80.94	12	1
Apr	20-24	21.14	85-100	98.6	282	69
May	19-22	20.54	50-100	5.32	1426	1008
Jun	20-22	20.835	50-95	55.66	168	83
Jul	20-22	21.175	25-75	36.71	50	0
Aug	20-24	22.66	25-63	18.75	37	0
Sep	21-25	23.87	12.5-25	48.31	32	0
Oct	21-26	24.295	12.5-100	97.02	33	0
Nov	21-26	21.39	87-100	94	129	60
Dec	19-23	21	99-100	99.67	575	232

through November. These periods were within the dry and early rainy seasons.

Soil moisture values varied from 12.5-100% with an overall mean of 72.81 + 27.89%. Low moisture readings were obtained from July to October when there were no rains. High moisture values were obtained in January through June and October through December when there were rains.

8.3.2 Animal burrows

Table 8.2 shows the data on soil moisture and temperature from animal burrows. Soil temperatures in the animal burrows varied from 18-26°C with a mean of 21.12 + 1.8°C. Low temperature readings were obtained in April, May through June and from November through the December when there were rains. High temperatures were recorded in January through March corresponding to dry and early rainy seasons. The temperature dropped in April and fluctuated between 19-21°C following the onset of rains until July when it improved and fluctuated between 20-22°C uptil October. July to October period is the long dry season with alternating cold mornings and evenings with hot afternoons. The burrows were located in the fringe of thorny thickets flanking the Kyandani river. The overall impacts of temperature fluctuations were buffered by the thicket shades and the sub-

Table 8.2: Soil temperature and moisture in animal burrows

Biweekly periods	Temperature Range	Temperature Mean	Moisture Range	Moisture Mean	Species	*S.garnhami*
Jan	22-26	24.545	10-99	81.29	100	82
Feb	23-26	25.115	63-99	98.49	19	12
Mar	24-26	22.5	94-99	99.44	11	0
Apr	19-22	20.3	99-100	99.72	0	0
May	19-21	20	92-100	72.01	106	94
Jun	19-21	20.085	15-90	39.16	19	11
Jul	20-21	20.465	25-25	25	33	0
Aug	20-22	20.59	12.5-25	18.75	41	0
Sep	20-22	20.61	25-25	25	62	0
Oct	20-22	20.715	25-25	88.43	50	0
Nov	19-22	20.02	90-100	89.95	3	0
Dec	18-22	19.42	65-100	86.75	8	4

terranean environment of the animal burrows. Hence the relatively constant mean temperatures from April to November.

The soil moisture within the animal burrows varied from 10-100% with an overall mean of 66.30 + 33.37%. Low moisture values were observed in January and from June through October when there were no rains (dry season periods). High moisture values were obtained from February through May and from late October through the whole December when there were rains.

8.3.3 Treeholes

Table 8.3 shows soil moisture and temperature data from treeholes. Soil temperature in the treeholes varied from 18-29°C with an overall mean of 21.75 + 2.27°C. Low temperatures were recorded during in April, August and December. Apart from August, these periods were within the rainy seasons. June to August months had cold and windy mornings and evenings alternating with hot afternoons and this could affect the small habitats as treeholes. High temperatures were recorded from January through March and in September through November. The mean temperature readings from the treeholes were more or less constant from the last two weeks of April to August inspite of the windy and relatively cold weather during this period.

Table 8.3: Soil temperature and moisture in treeholes

	Temperature		Moisture			
Month	Range	Mean	Range	Mean	Species	*S.garnhami*
Jan	22-28	25.07	92-99	97.21	330	269
Feb	24-29	26.035	92-94	93.07	5	3
Mar	26-27	26.55	85-90	88.36	3	0
Apr	18-22	20.205	94-100	99.54	49	44
May	20-21	20.47	87-100	97.47	197	169
Jun	20-21	20.5	5-85	45.59	10	3
Jul	20-21	20.5	25-50	31.25	10	0
Aug	19-21	20.61	25-50	28.75	10	0
Sep	20-22	21.04	10-25	12.5	10	0
Oct	20-24	21.93	0-100	35.5	1	0
Nov	20-22	21.04	99-100	99.91	41	9
Dec	18-20	19.5	92-100	99.62	63	29

Soil moisture values of the treeholes ranged from 0-100% with an overall mean of 67.16 + 38.65%. Low moisture values were obtained from June through October corresponding to the period of dry season. It was equally observable with the naked eyes and texture to the hands that these soils were dry. High moisture values were recorded from January through May and from the last two weeks of October through the whole December corresponding to periods when there were rains.

8.3.4 Tree bases

Investigations in this site were started in April due to some delays in the acquisition of soil temperature and moisture cells. Soil temperatures under tree bases varied from 18-23°C with an overall mean of 20.49°C (table 8.4). High temperature values were obtained in September through October while low temperature values were recorded from April through July and from November through December.

Soil moisture readings under treebases ranged from 0-100% with an overall mean of 36.25%.
Low moisture values were recorded from June through October when there were no rains. High moisture values were obtained from April through May and from the late October through December corresponding to the rainy seasons.

Table 8.4: Soil temperature and moisture under treebases

	Temperature		Moisture			
Month	Range	Mean	Range	Mean	Species	*S.garnhami*
Apr	18-22	20.335	50-100	75.95	71	0
May	18-22	20.475	25-99	53.77	131	18
Jun	19-21	20.405	0-80	15	31	0
Jul	19-21	20.415	0	0	44	0
Aug	20-21	20.465	0	0	6	0
Sep	20-22	21	0	0	8	0
Oct	20-23	21.82	0-95	31.07	1	0
Nov	18-21	20.235	50-99	68.75	1	0
Dec	18-21	19.25	25-100	81.70	59	16

8.3.5 Rock crevices

Soil temperature and moisture investigations in this site was also started in April due to delays in the acquisition of soil moisture and temperature cells. The temperature values ranged from 20-26°C with an overall mean of 22.90 + 0.95°C (table 8.5). High temperature values were obtained in September through early November corresponding to the dry and early rainy season periods. The temperature readings were more or less constant from May to August. This was within the dry season period.

The moisture readings ranged from 0-100% with a mean of 36.33 + 40.73%. High moisture values were recorded from April through May and from late October through December corresponding to the rainy season months. Low moisture readings were obtained from June through early October corresponding to the long dry season period.

8.3.6 Soil temperatures at 45cm depth and at the ground surface

Table 8.6 shows the data on soil temperatures at 45cm depth and at the ground surface. The soil temperatures at the ground surface level varied from 14-53oC with a mean of 30.59 + 1.84°C (table 8.6). The low

Table 8.5: Soil temperature and moisture in rock crevices

	Temperature		Moisture			
Month	Range	Mean	Range	Mean	Species	*S.garnhami*
Apr	20-25	22.085	50-99	88.79	40	0
May	22-23	22.5	0-98	53.87	173	18
Jun	21-24	22.82	0-25	12.5	107	0
Jul	22-24	22.88	0	0	42	0
Aug	21-24	22.855	0	0	8	0
Sep	22-25	23.915	0	0	11	0
Oct	23-26	24.57	0-99	29.7	3	0
Nov	22-26	22.895	25-99	77.75	14	0
Dec	20-23	21.54	0-100	76.87	144	3

Table 8.6: Soil temperatures at 45cm depth and at the ground surface level

Month	Ground surface Temperature Range	Mean	45cm soil depth Temperature Range	Mean
Jan	14-46	28.515	22-33	30.225
Feb	15-50	30.915	26-38	31.29
Mar	18-49	29.82	27-35	29.26
Apr	21-42	29.63	27-39	29.06
May	21-45	31.34	28-31	29.44
Jun	21-47	31.805	28-32	30.305
Jul	19-45	30.695	30-32	30.73
Aug	21-50	32.3	30-33	31.295
Sep	21-50	32.02	32-35	33.73
Oct	21-53	32.175	25-36	33.595
Nov	21-45	29.93	8-34	30.545
Dec	19-42	27.875	26-29	27.66

temperatures were early morning temperatures and were obtained from January through March, and in July and December. High temperature values were afternoon readings with highest values obtained from February to March and from August to October corresponding to late dry season and early rainy season periods. The ground surface temperatures in the afternoon were generally high throught the year.

The temperatures of the 45cm soil depth varied from 22-39°C with a mean of 30.59 + 1.94°C. Except in February when an early morning temperature of 22°C was observed the early morning temperatures of not less than 25°C were recorded throughout the year. High afternoon temperatures of above 30°C were observed throughout the year except April and December when there were heavy rainfalls. These results showed a comparatively very wide temperature variations at the ground surface level as opposed to narrow variations in the soil depth of 45cm although their overall mean were the same.

In the above 5 ecological sites, the results seem to follow the same trend. They indicated very large variations in the soil moisture contents in line with the rainfall patterns and in contrast to the temperature values with very narrow variations in both rainy and dry season periods. However the presence or absence of rainfall were reflected in slight depressions and/or increases in the ambient temperature values. Prolonged

dry periods noticed from June-October resulted in complete drying up of small and shallow habitats as were noticed in treeholes, rock crevices and under treebases. The wide fluctuations in moisture values were indicative of the soil nature which dries up quickly with the onset of dry seasons and easily saturated with little rainfall characteristic of the area.

8.3.7 Microclimate and *S.garnhami* populations

In all the sites, the monthly populations of *S. garnhami* and those of all the sandfly species collected were related to the soil moisture and temperature operating in each site. Phlebotomine sandflies were collected throughout the months of the investigation but *S.garnhami* were caught in the traps only during April-June and November-January periods when the soil moisture values were high and temperatures moderate (figs 8.1-5). These periods corresponded to the end of rainy and early dry seasons. Although other sandfly species were collected in large numbers during these high moisture periods, they showed a general trend of decreased populations or total disappearance during the low moisture periods of the dry season months. The bulk of the collections during the low moisture content of the habitats was constituted by *S. bedfordi and S. antennatus* punctuated with few species of *Phlebotomus*

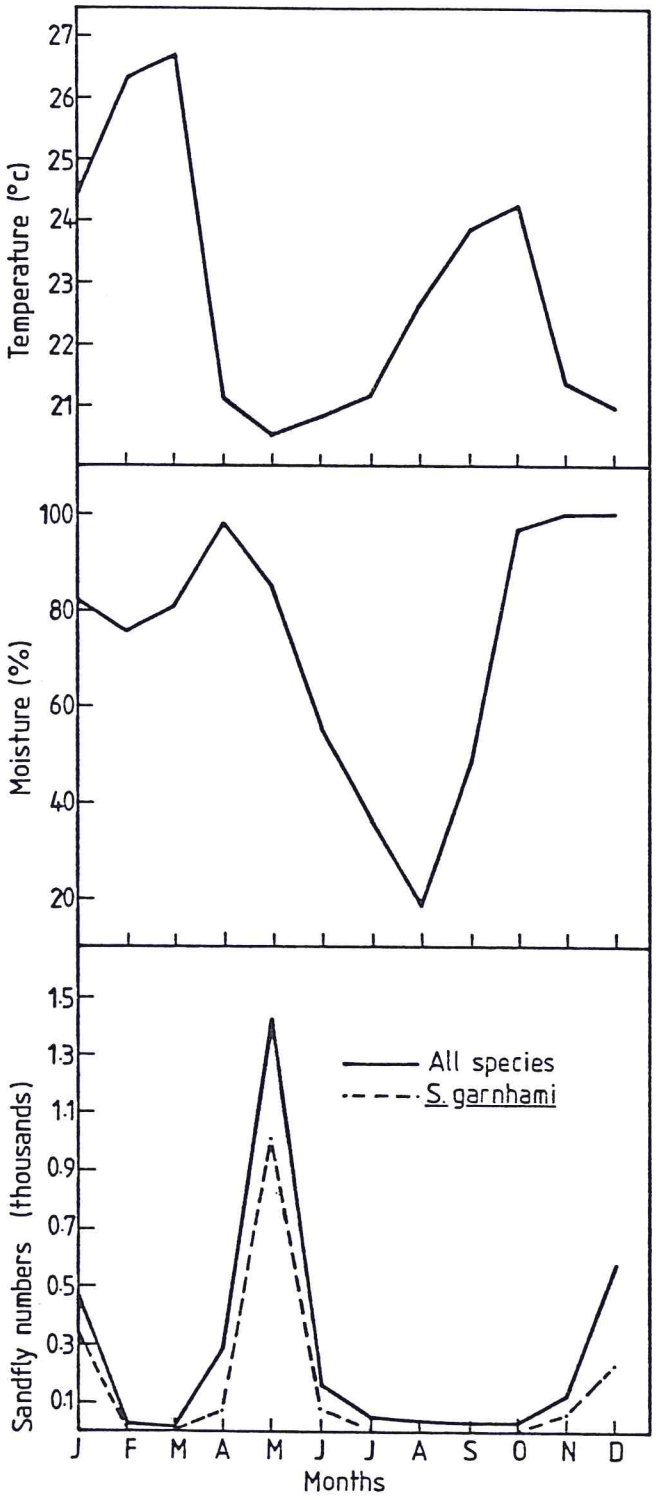


Fig 8.1. Relationship between microclimatic factors, *S. garnhami* and other sandfly species populations in termite hills (Jan–Dec 1990).

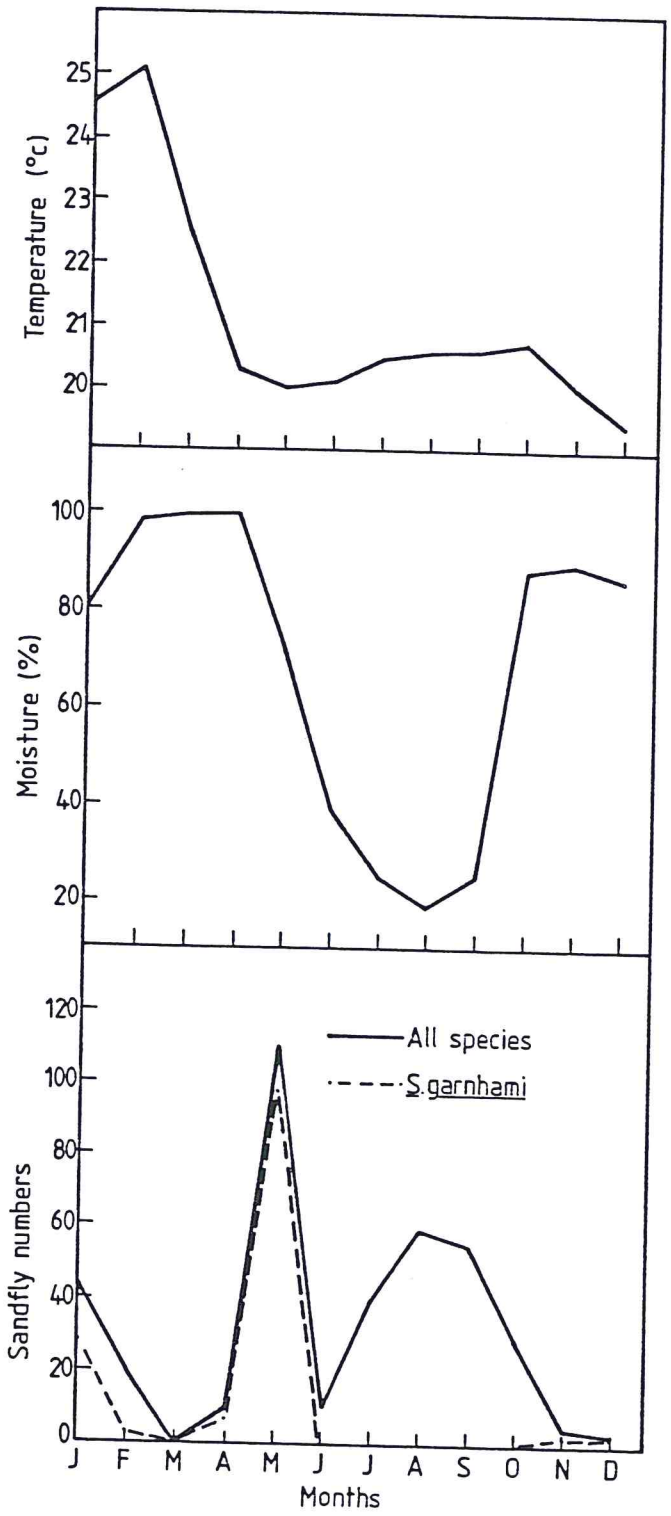


Fig 8.2. Relationship between microclimatic factors, *S. garnhami* and other sandfly species populations in animal burrows (Jan–Dec 1990).

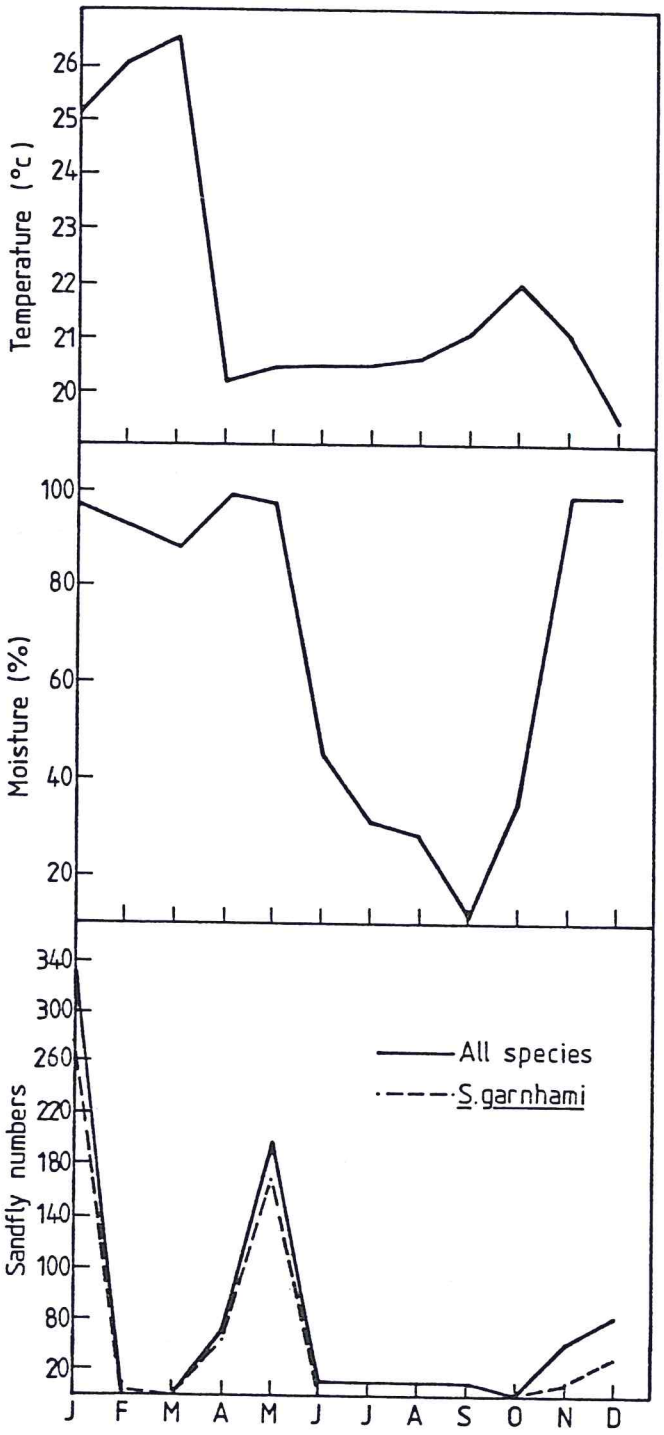


Fig 8.3. Relationship between microclimatic factors, *S. garnhami* and other sandfly species populations in treeholes (Jan–Dec 1990).

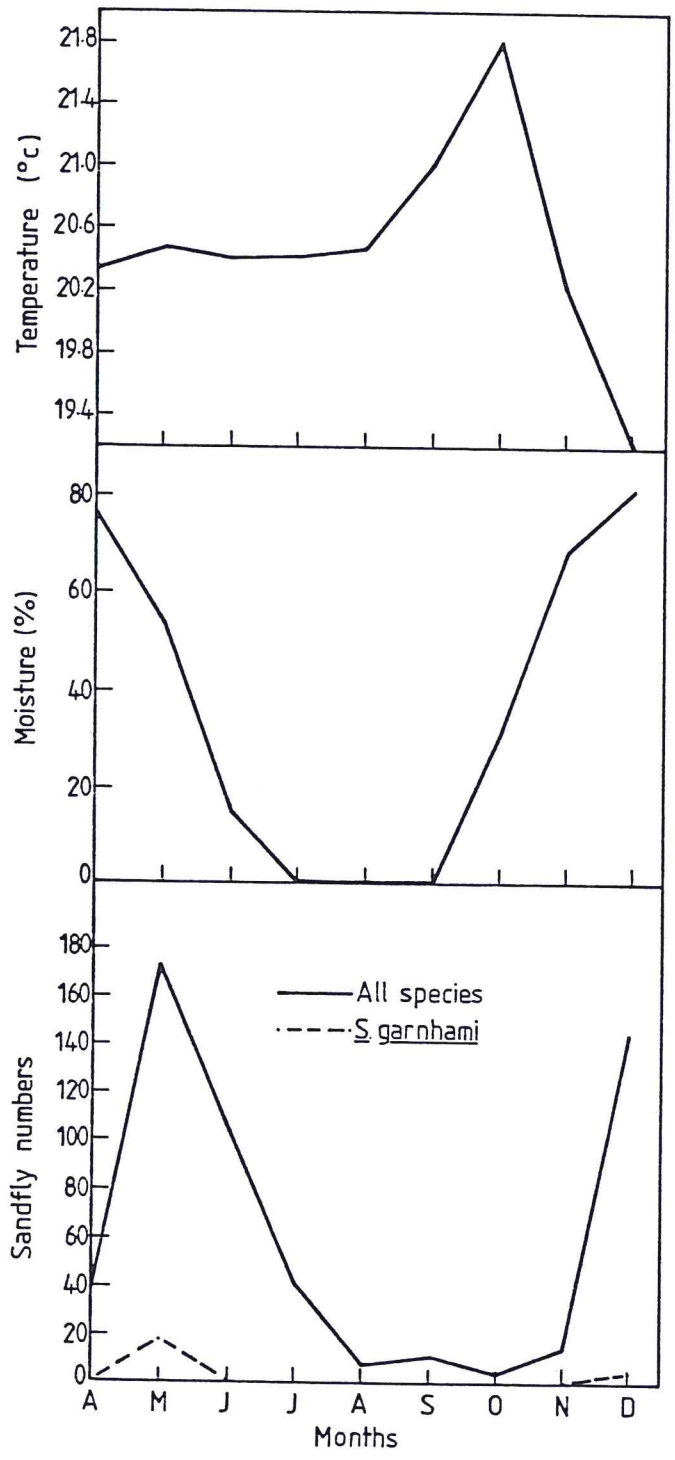


Fig 8.4. Relationship between microclimatic factors, *S. garnhami* and other sandfly species populations under tree bases (Jan–Dec 1990).

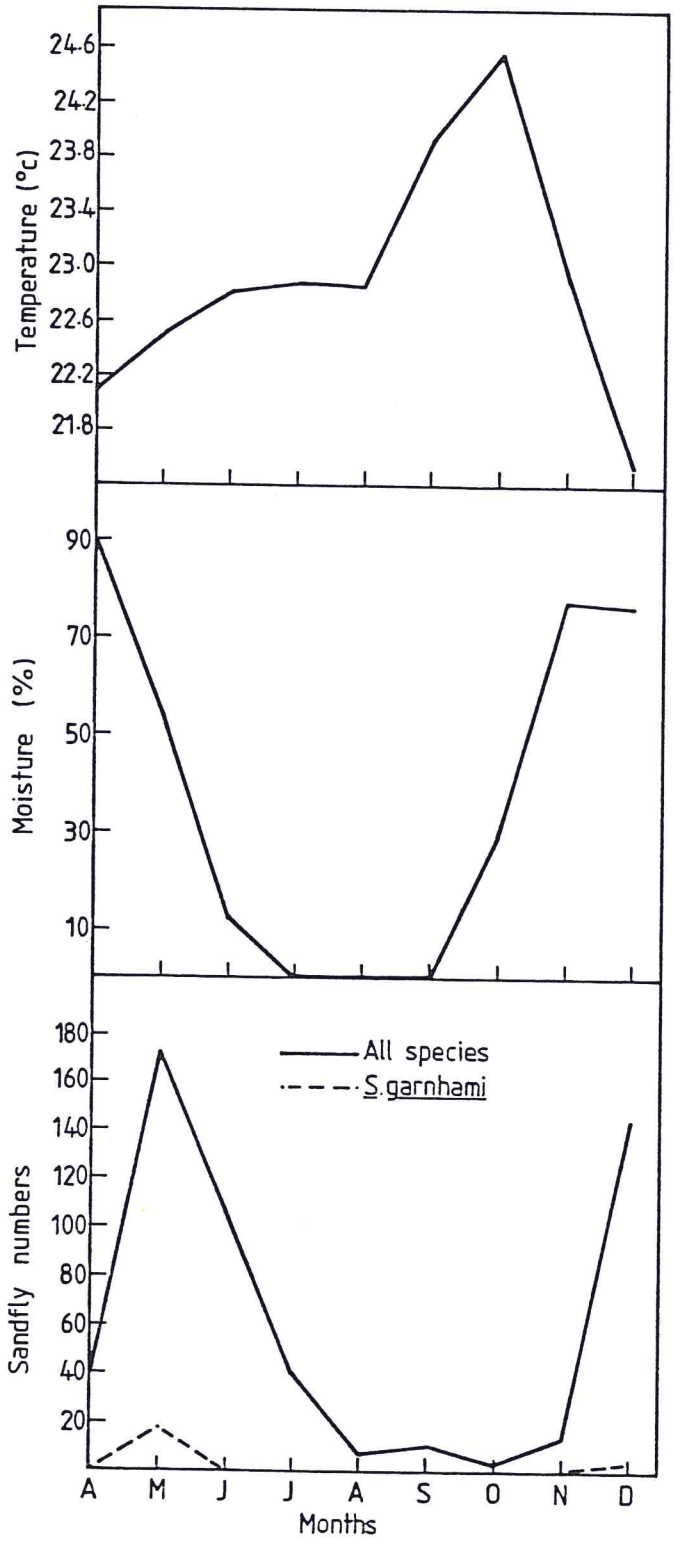


Fig 8.5. Relationship between microclimatic factors, *S. garnhami* and other sandfly species populations in rock crevices (Jan–Dec 1990).

genus. Statistical correlation (table 8.7) of *S.garnhami* and the overall sandfly populations of various sites with the mean monthly soil moisture and temperature values indicated that the mean temperatures were negatively correlated to both *S.garnhami* and overall sandfly populations in all the sites except in animal burrows and treeholes where temperatures were positively correlated with *S.garnhami* populations only. These correlations were significant to the overall sandfly populations in termite hills and *S.garnhami* populations in rock crevices. The mean soil moisture values were positively correlated to both *S.garnhami* and overall sandfly population in all the sites except in animal burrows where there was negative correlation with overall sandfly population only. Again moisture was significant to overall sandfly population in termite hills.

Correlation of various soil moisture and temperature ranges of various sites (table 8.8) with *S.garnhami* and overall sandfly populations of various sites showed that the overall sandfly population but not *S.garnhami*, was significantly and negatively correlated to moisture at a temperature range of 18-22°C. At a temperature range of 20-22°C the overall sandfly population was positively and significantly correlated with moisture but at a temperature range of 21-24°C both *S.garnhami* and the overall sandfly populations were

Table 8.7 Correlation Analysis

Correlation of *S.garnhami* and other phlebotomine sandfly populations of different sites with soil moisture and temperature values of the respective sites

Microclimate factor	Correlation with	Sites: Termite hill	Animal burrow	Tree hole	Tree base	Rock crevices
Temperature	All species	-0.43	-0.004	0.17	-0.40	-0.47
		P=0.04*	P=0.99	P=0.44	P=0.10	P=0.046*
Moisture		0.42	-0.22	0.38	0.34	0.27
		P=0.04*	P=0.33	P=0.07	P=0.16	P=0.29
Temperature	*S.garnhami*	-0.34	0.006	0.19	-0.47	-0.15
		P=0.11	P=0.98	P=0.39	P=0.047*	P=0.06
Moisture		0.37	0.198	0.37	0.28	0.03
		P=0.08	P=0.38	P=0.09	P=0.27	P=0.92

Table 8.8 Correlation analysis

Various temperature ranges at which sandfly populations were significantly correlated with either moisture or temperature

Temperature range	All species	*S.garnhami*	Remarks
18-22	-0.997	-0.85	
	P=0.040*	P=0.36	Significant to moisture
20-22	0.52	0.28	
	P=0.041*	P=0.29	Significant to moisture
21-24	0.80	0.98	
	P=0.031*	P=0.0002***	Significant to moisture
22-23	-0.99	-0.54	
	P=0.006**	P=0.63	Significant to temperature

positively and significantly correlated to moisture. At a temperature range of 22-23°C, the overall sandfly population was negatively and significantly correlated temperature.

Scatter plots of *S. garnhami* populations against temperature or moisture using Lotus 2.1 release, showed that there was positive linear relationship between temperature and *S. garnhami* population in animal burrows (fig 8.7), no relationship in treeholes (fig 8.8), and negative linear relationships in termite hills (fig 6), rock crevices (fig 8.9) and under treebases (fig 8.10). There were positive linear relationships between *S. garnhami* populations and moisture in the five ecological sites (figs 8.11-15). From the scatter plots also, large numbers of *S garnhami* were collected under the following temperature and moisture ranges, 21-23°C and moisture 60-100% in termite hills, 19-21°C and moisture 80-100% in animal burrows, 20-22°C and moisture 80-100% in treeholes, 22-23°C and moisture 80-100% in rock crevices and 19.5-21.5°C with moisture 60-85% under treebases. These results showed that the immature stages of *S. garnhami* could develop optimally at a temperature range of 19-23°C with a mean of 21.1°C, and a moisture range of 60-100% with a mean of 84.5%, depending on the site. Correlation analysis using SAS showed that *S. garnhami* populations were positively significant to moisture at 5% significant level (r =

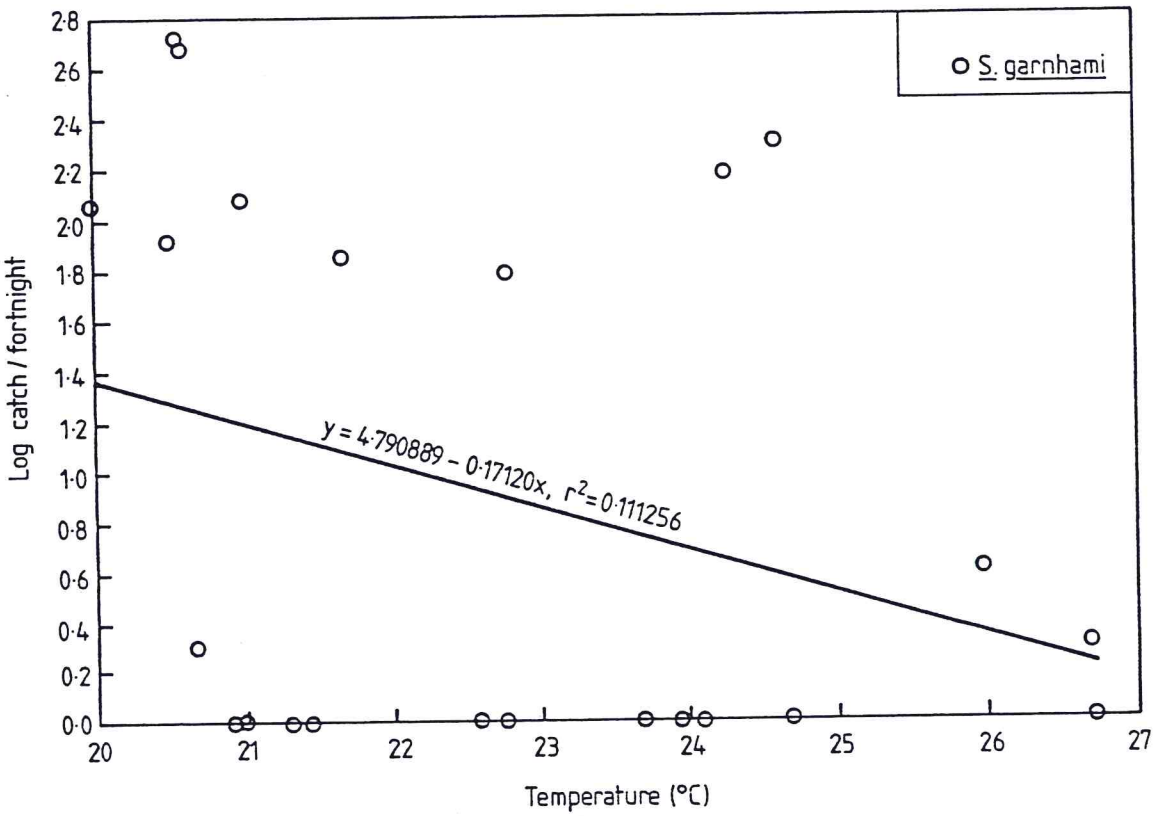


Fig 8.6 Scatter plots of *S. garnhami* populations against soil temperature in termite hills (Jan–Dec 1990)

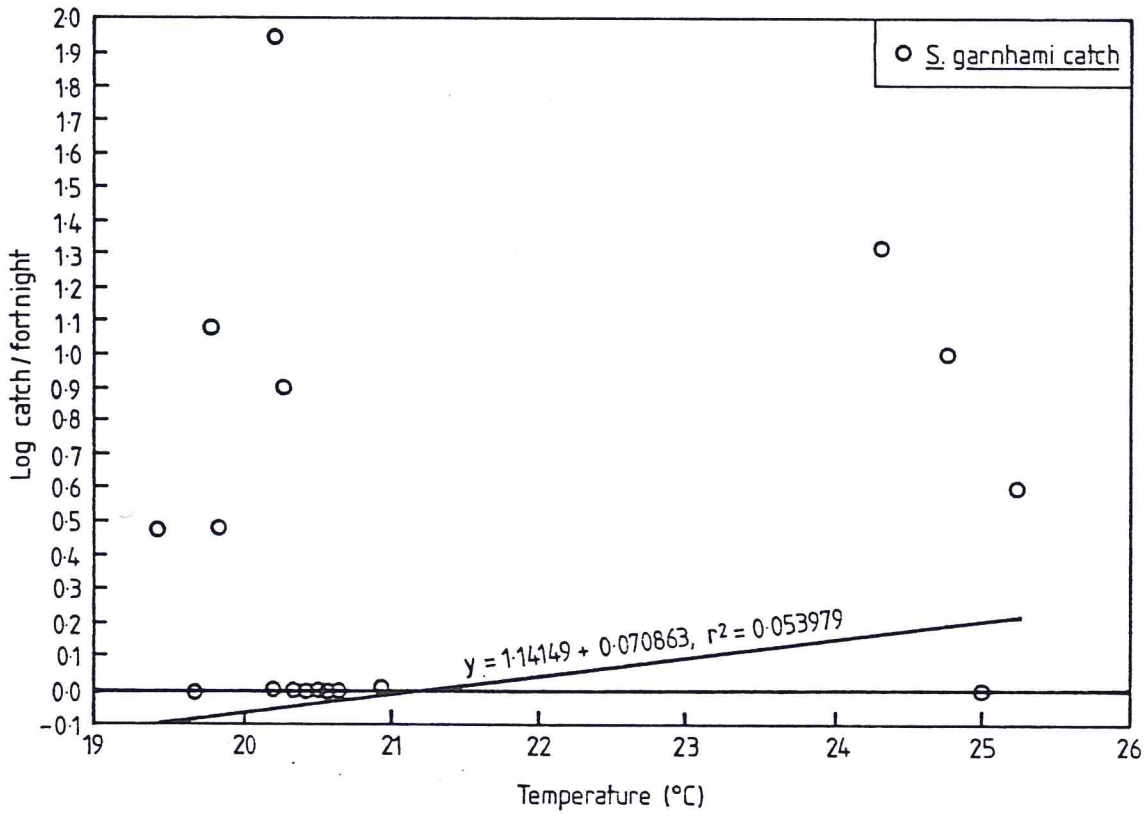


Fig 8.7 Scatter plots of *S. garnhami* populations against soil temperature in animal burrows (Jan–Dec 1990)

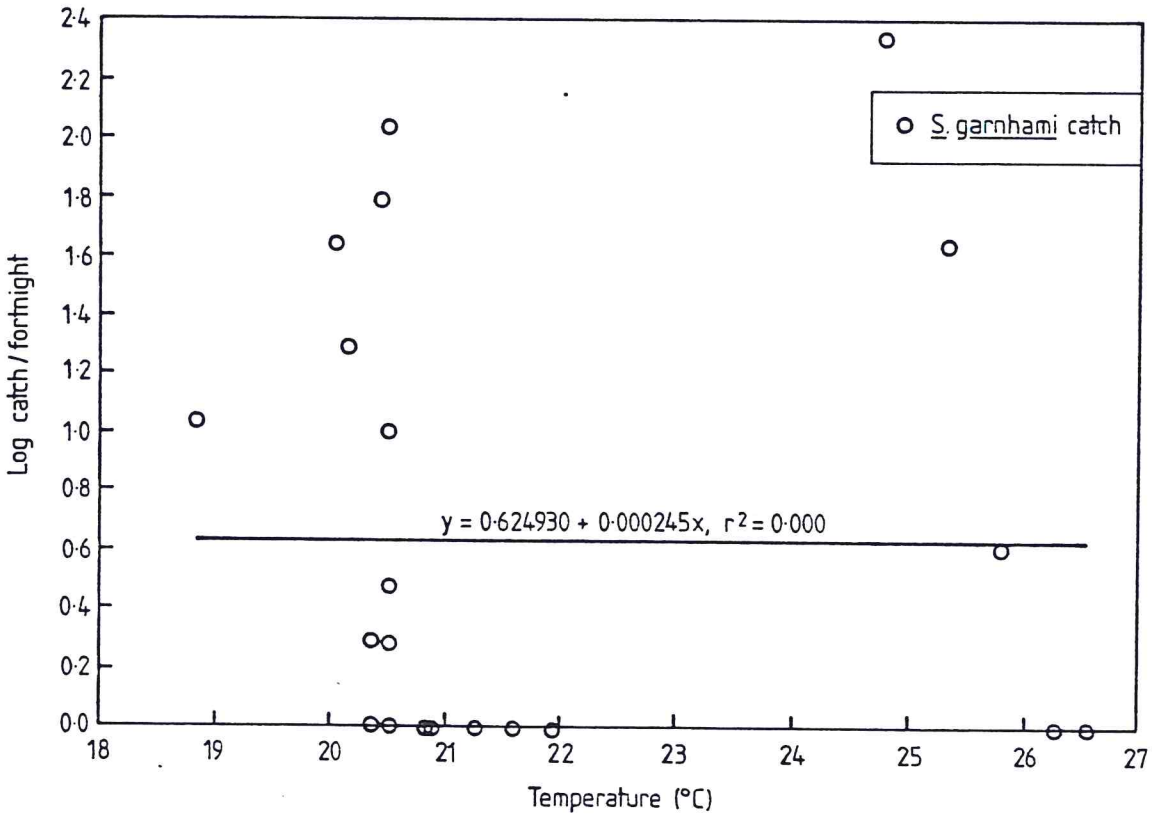


Fig 8.8 Scatter plots of *S. garnhami* populations against soil temperature inside treeholes (Jan–Dec 1990)

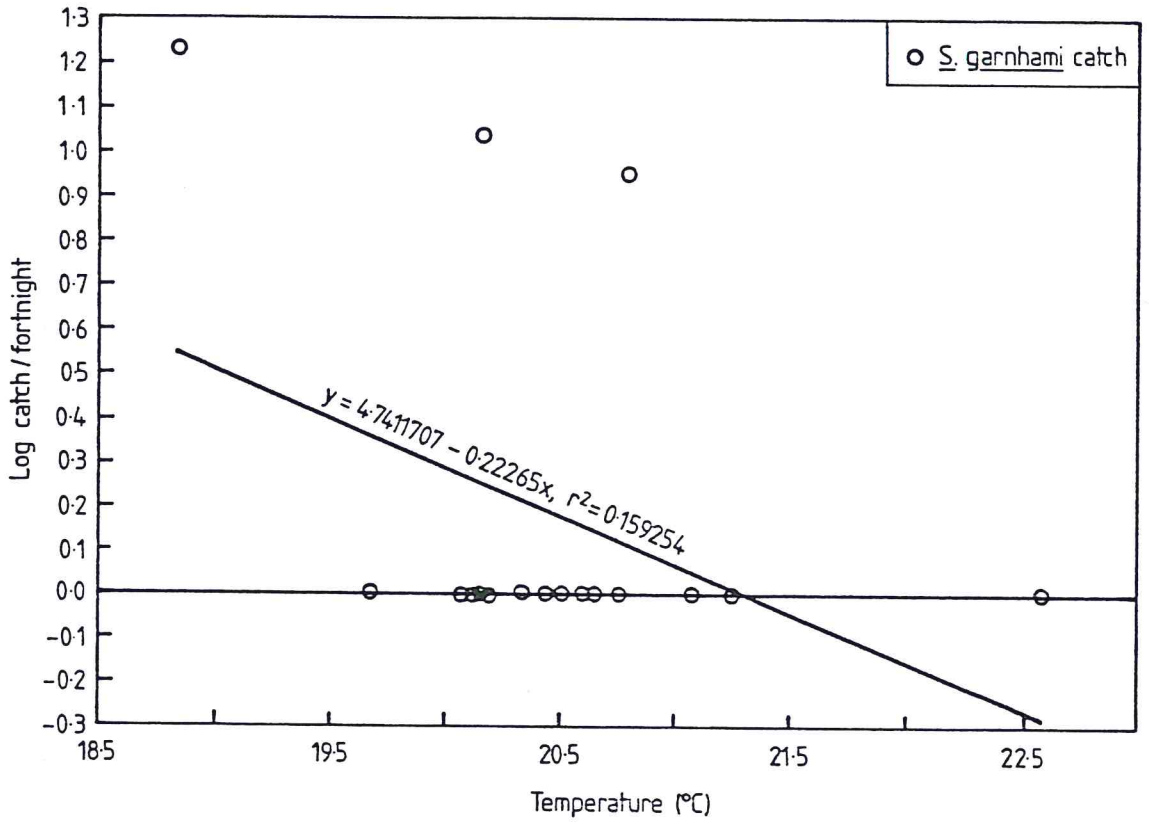


Fig 8.9 Scatter plots of *S. garnhami* populations against soil temperature under tree bases (Jan–Dec 1990)

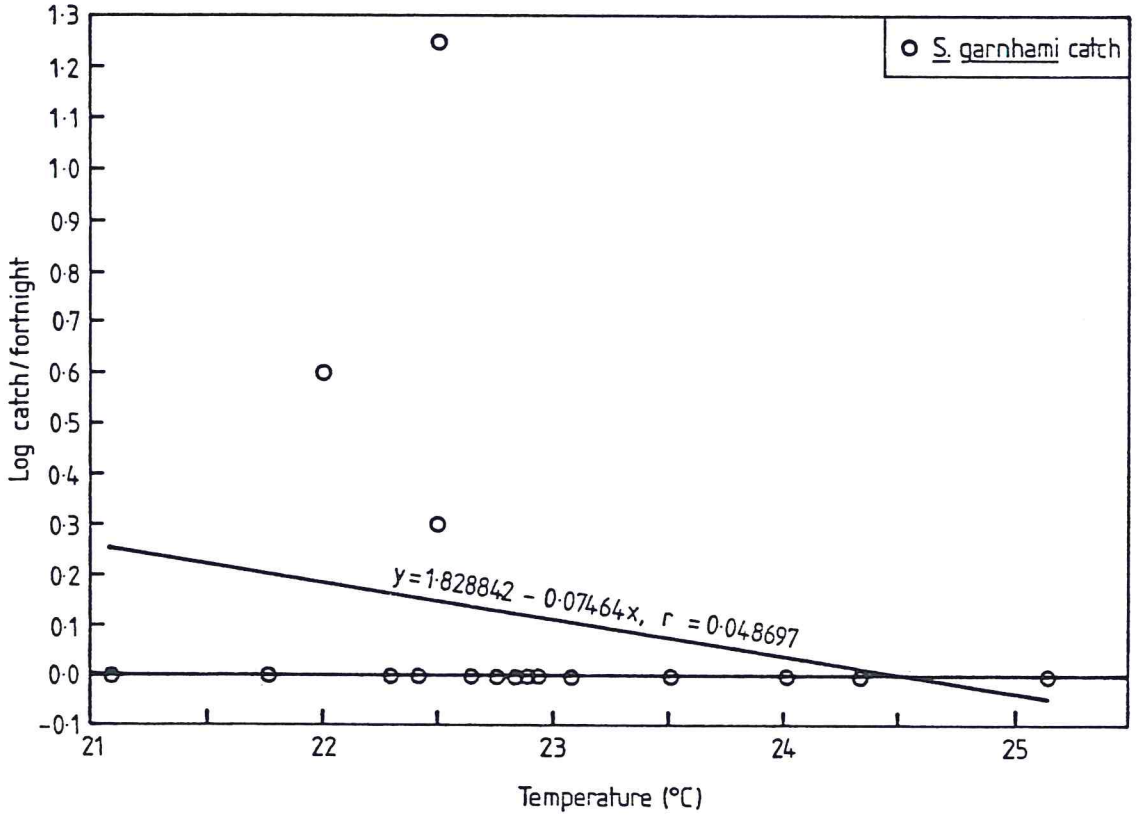


Fig 8.10 Scatter plots of *S. garnhami* populations against soil temperature inside rock crevices (Jan–Dec 1990)

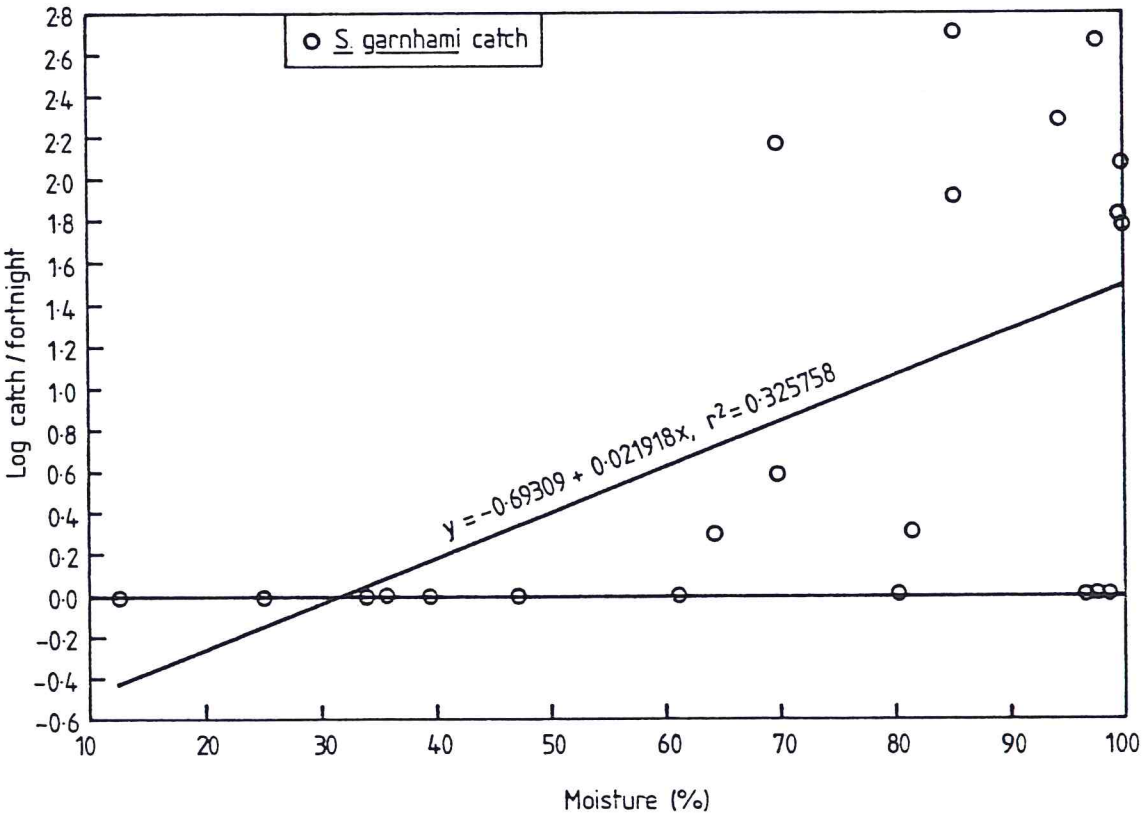


Fig 8.11 Scatter plots of *S. garnhami* populations against soil moisture in termite hills (Jan–Dec 1990)

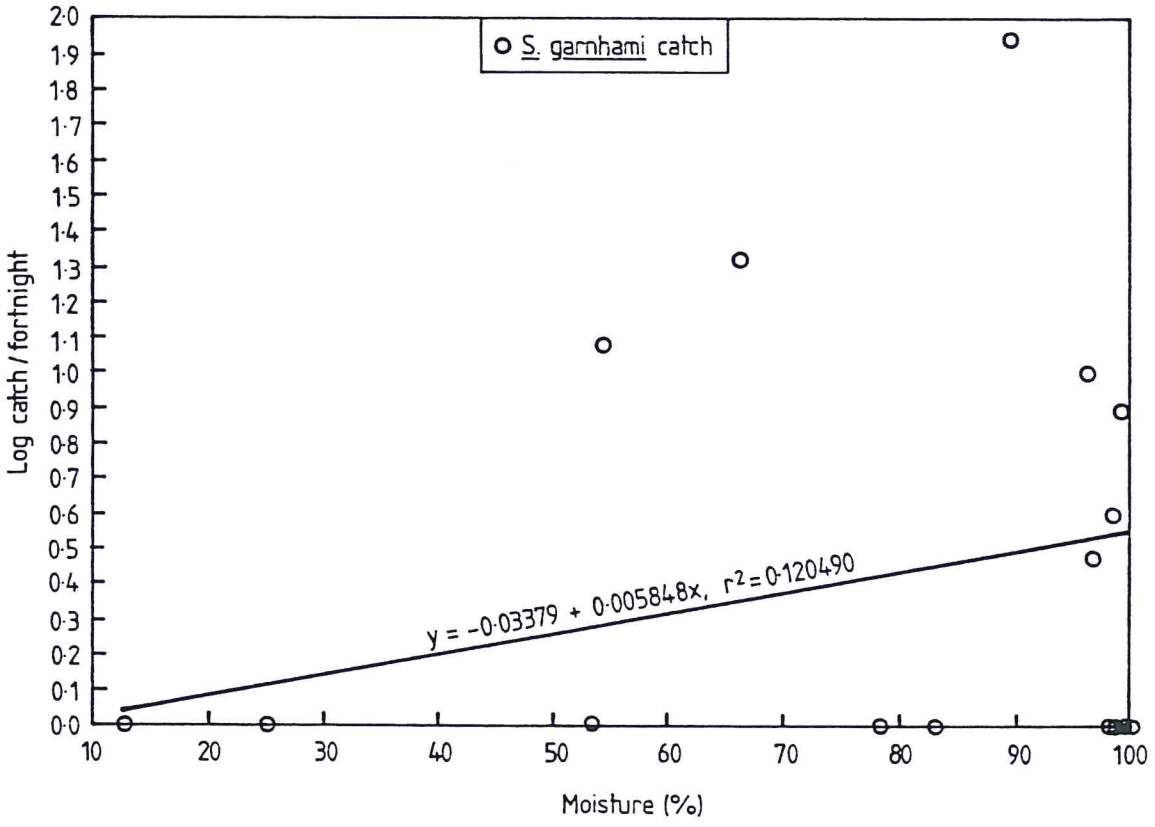


Fig 8.12 Scatter plots of *S. garnhami* populations against soil moisture in animal burrows (Jan–Dec 1990)

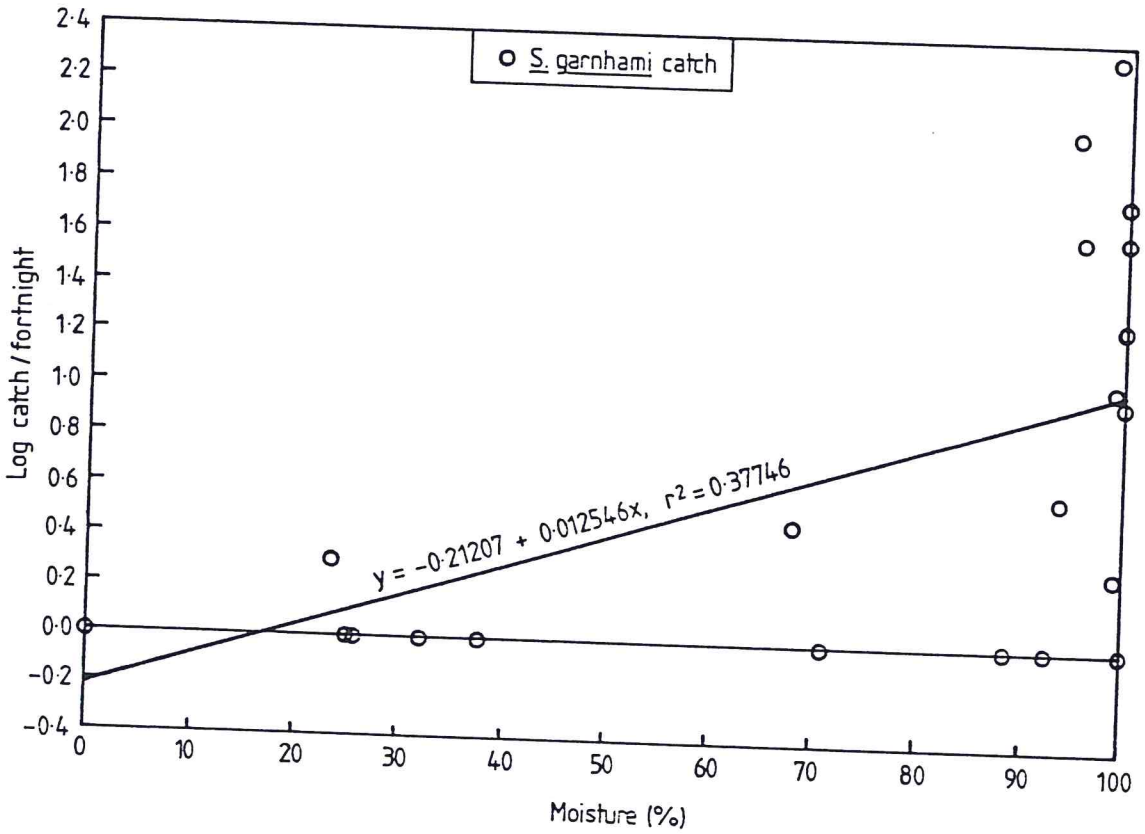


Fig 8.13 Scatter plots of *S. garnhami* populations against soil moisture inside tree holes (Jan–Dec 1990)

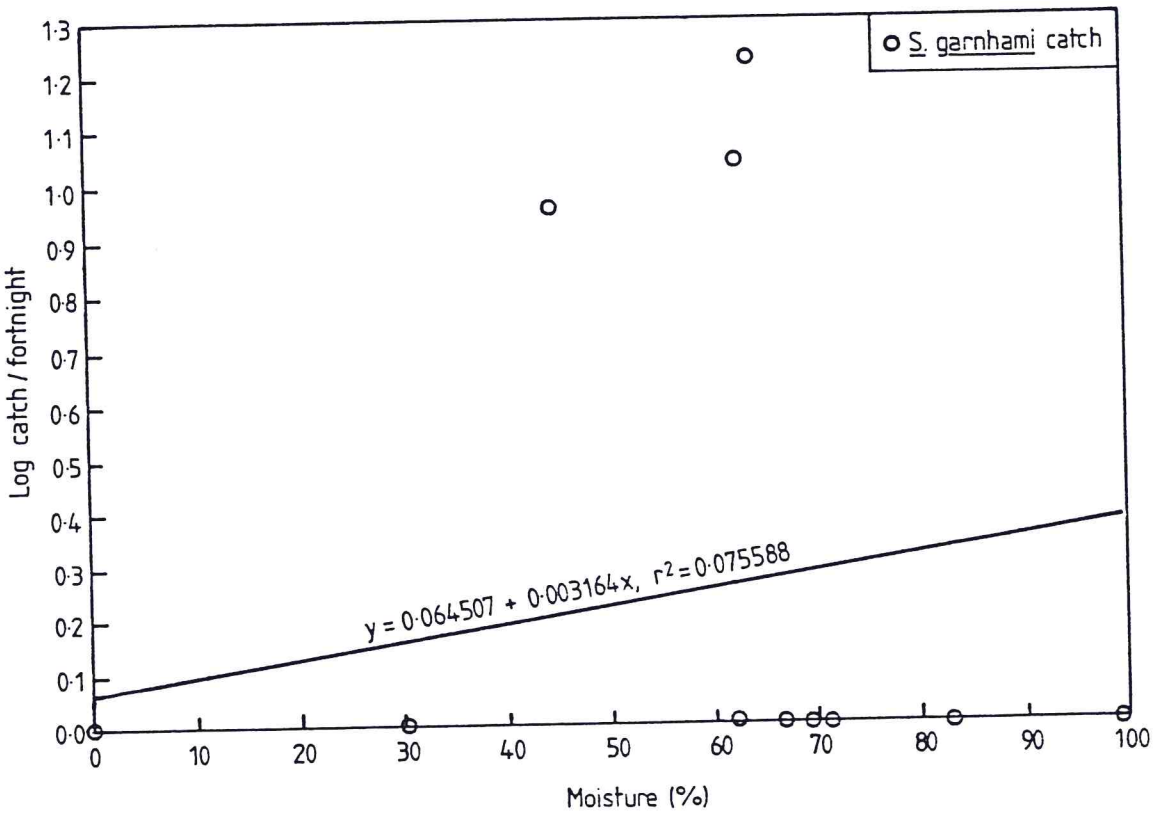


Fig 8.14 Scatter plots of *S. garnhami* populations against soil moisture under tree bases (Jan–Dec 1990)

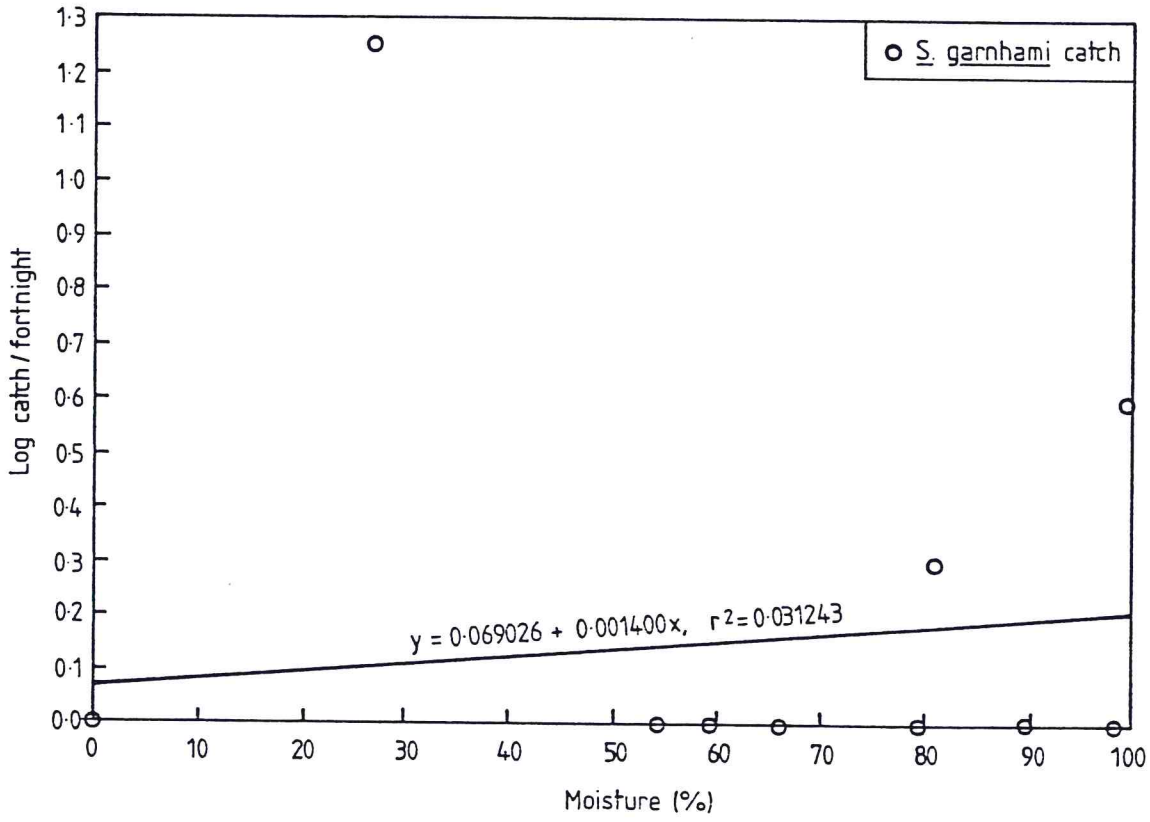


Fig 8.15 Scatter plots of *S. garnhami* populations against soil moisture inside rock crevices (Jan–Dec 1990)

0.27780, P = 0.0043) and not temperature. Correlation of both temperature and moisture ranges showed that *S.garnhami* populations were significant at 5% level to moisture at a temperature range of 21-24°C (r = 0.9764, P = 0.0002). No moisture range recorded were however found significant. Averaging both the temperature and moisture means in this range, a temperature mean of 22.44 + 0.44°C and a moisture mean of 37.89 + 44.04% (or -7.04 to 81.93%) were obtained. This shows that the moisture content of the soil above 80% is not significant for the development of the immature stages of *S. garnhami* at a temperature of 22°C.

8.3.8 Sandfly species composition of the five ecological habitats

Altogether 58242 phlebotomine sandflies were collected from the 5 habitats. Seventeen species composed of 4 species of *Phlebotomus* genus and 13 species of *Sergentomyia* genus were collected (table 8.9). Total *S.garnhami* collected were 2623 (or 44.90%)

A total of 3262 sandflies were collected from the termite hill. *S. garnhami* were 1801 (or 55.21%). The *Synphlebotomus* species (*P. celiae, P. martini, P. vansomerenae*) put together were 140 (or 4.29%). The remaining 40% were all *Sergentomyia* species with *S. bedfordi* forming the bulk.

Table 8.9 Sandfly species composition of the five ecological habitats

Species	Total	Sites				
		Termite hill	Animal burrow	Tree hole	Tree base	Rock crevices
S.affinis	153	2	11	1	60	227
S.antennatus	40	7	14	11	15	87
S.bedfordi	705	213	80	504	608	2110
S.christophersi	0	0	0	0	13	13
S.clydei	8	1	0	0	4	13
S.gardiani	1801	203	526	60	33	2623
S.graingeri	26	0	0	0	0	26
S harveyi	9	3	0	3	2	17
S.ingrami	28	0	5	3	1	37
S.kirki	280	11	61	17	2	371
S.multidens	22	0	1	1	0	24
S.schwetzi	50	0	5	16	3	74
S.squamipleuris	0	2	0	0	39	41
P.celiae	49	0	17	0	0	66
P.martini	24	7	1	0	1	33
P.vansomerenae	33	2	4	1	0	40
Synphlebotomus	34	1	4	0	0	39
P.sergenti	0	0	0	0	1	1
Total	3262	452	729	617	782	5842

A total of 452 sandflies were collected from the animal burrows. The *Synphlebotomus* complex put together were 10 (or 2.21%) whereas *S. garnhami* collected were 203 (or 44.91%). Others were Sergentomyia species with S. bedfordi topping the least in abundance.

A total of 729 sandflies were collected from the treeholes. The *Synphlebotomus* complex put together were 26 (or 3.57%). *S. garnhami* caught were 526 (or 72.15%). Others were *Sergentomyia* species.

The sandflies collected from under the treebases were altogether 617. *S. garnhami* collected were 60 (or 9.72%). Only one *P. vansomerenae* was collected amongst the *Phlebotomus* species. *S. bedfordi* caught were 504 (or 81.69%). The remainders were also *Sergentomyia* species.

A total of 782 sandflies were collected from rock crevices. Amongst the *Synphlebotomus* complex species, only one *P. martini* was collected. A female of a rare species in Kenya, *P.sergenti*, was also collected. This is probably the first report of this species in Kitui District. *S. garnhami* caught were 33 (or 4.22%). The rest were also *Sergentomyia* species with *S. bedfordi* topping the list in abundance.

8.4 Discussion

The observations indicated that the soil temperatures within the breeding and resting habitats of *S. garnhami* and other phlebotomine sandflies were relatively stable with narrow range of variations during cold and hot months whereas the soil moisture values varied widely according to rainfall. The observation also showed that *S. garnhami* were not collected during the dry months when the soil moisture values were low. A general decrease in the overall sandfly population and species diversity were recorded during the dry season. This meant that only those sandfly species that could tolerate wide variations in moisture levels of the soil for a period of about 4 months survived as adults and bred during the dry months. Alternatively, others adopted survival strategies including diapause (Kirk and Lewis 1951, Perfile'v 1966, Killick-Kendrick 1981). Bettini and Melis (1988) reported that moisture and temperature were the basic parameters which regulate larval development. Theodore (1936) noted that the larvae of sandflies are adapted to life in moist environment and are extremely sensitive to desiccation. He also noted that temperatures under 10oC or more than 40oC may be considered unfavorable for adult *P. papatasi*. Mutinga (1972) showed that temperatures

ranging from 24-27°C and a relative humidity of 52-75% were required for laboratory rearing of P. pedifer. Mutinga et al (1987) colonised *P. duboscqi* in the laboratory under room temperature of 25°C and relative humidity of 80%. Mutinga et al (1989) successfully maintained the immature stages of many sandfly species in the laboratory at a temperature of 27°C and relative humidity of 70-90%. They also maintained the adults of *Sergentomyia* species at temperatures of 20-25°C and relative humidity of 40-60%. The adult *Phlebotomus* species were maintained at a temperature of 25oC and relative humidity of 70-90%. Basimike and Mutinga (1990) noted that the sandfly populations correlated positively with microclimatic data. They also noted that temperature and moisture content of the soil were the basic parameters regulating the sandfly population dynamics.

All these observations clearly showed that under favourable conditions of temperature, moisture is necessary for the development of the immature stages and the survival of the adult. The temperature and moisture requirements of the individual or group of species may vary. This probably explained why *S. garnhami* and some other phlebotomine sandflies were abundant during the periods of high soil moisture contents of the year but decreased or completely disappeared with the decreased moisture values of the dry season months. It has been

reported that the only factor that tallies well with the distribution of the phlebotomine sandflies of the world is temperature of not less than 20oC (WHO 1984). This condition is a constant in the tropical semi-arid area of Tseikuru in the Kitui District of Kenya. Hence both *S. garnhami* and overall sandfly populations were positively correlated to moisture at a temperature range of 21-24. It is concluded that the factor in sustained sandfly population is moisture which was always supplied by the rainfall hence *S. garnhami* abundance whenever the adequate moisture conditions were met in nature. The complete absence of the fly during dry months may be because it survives adverse conditions through diapausing immature stages especially the eggs (Killick-Kendrick 1981). Statistical analysis results and scatter plots revealed that moisture is a significant factor in the development of *S. garnhami* immature stages under optimal temperature conditions

CHAPTER NINE

EDAPHIC FACTORS INFLUENCING *S.GARNHAMI* POPULATIONS IN THEIR BREEDING SITES

9.1 Introduction

Odum (1971) noted that soil is an important factor in th environment of organisms. He pointed out that the texture and porosity of the soil are highly important characteristics which determine the availability of nutrienets to plants and soil animals. Schlein et al (1982) attributed the differences in sandfly populations to soil quality of the sandfly breeding habitats. Price (1973) and Price and Benham (1977) showed that soil microarthropods are usually most abundant near the soil surface in a zone of about 10 cm depth characterised by adequate living space, favourable moisture conditions, aeration rates and accumulations of organic debris. A depth of 0-10 cm has been considered suitable for sandfly larvae as it contains organic matters and other nutritive materials (Hanson 1961, Mutinga 1972, Rutledge and Mosser 1972).

These larvae live at some distances below the surface of the soil where they are protected from such adverse climatic conditions as heat and intense cold (Kirk and Lewis 1951, Perfile'v 1966). Thatcher (1968) and Mutinga (1972) have reported the collection of sandfly

larvae at various depths in the soil. Information on the impact of edaphic factors on sandfly population is still scanty (Hanson 1961, WHO 1984, Bettini and Melis 1988). WHO (1984) stressed the need to study soil structure as a tool for the understanding of the epidemiology of leishmaniasis. This study is aimed at reporting investigations on the influence of chemical and physical properties of soils from the breeding habitats of *S. garnhami* on its population numbers.

9.2 Materials and methods

Seventeen biotopes were selected for this study. These included :

river bed soil
termite hill fungus garden soil
termite hill ventilation shaft soil
soil near termite hill
large animal burrow soil
small animal burrow soil
soil near large animal burrow
soil near small animal burrow
rock crevices soil
treehole soil
plant base soil
thicket floor soil
grass vegetation soil

chicken coop soil

animal enclosures soil

inside houses soil and

outside houses soil

Dry and rainy season soil samples from the above sites were collected at a depth of 0-10 cm and sent to the National Agricultural laboratories (NAL) at Nairobi for analysis for both chemical and physical properties. In each occasion five replicates of soil sample from each biotope were collected. Each sample weighed about 500g. A total of 85 samples were sent in each occasion and a grand total of 170 soil samples weighing about 85kg were sent for both the dry and rainy seasons between June and December 1989. The process of soil collection involved excavation with shovels, picks and hoes in termite hills and animal burrows, sweeping with brooms and brushes in and around houses, and rock crevices. Scooping using table or desert spoons was employed in tree holes and similar sites. Combinations of the above methods were employed where necessary. The soil samples were carried in standard paper packets supplied by the National Agricultural Laboratories, Nairobi.

9.3 Results

A total of 170 soil samples collected from the 17 ecological habitats during the wet and dry season periods was analysed for both chemical and physical properties. The chemical properties investigated were soil reaction (pH), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Manganese (Mn), available Phosphorus (P-olsen), Carbon (C), and exchangeable salts (EC). The physical properties were soil texture and capillarity.

9.3.1 Soil reaction (pH)

Table 9.1 is the mean pH values of various sites. During the wet season the mean soil pH of various sites varied from 7.1-8.55 with a mean of 7.72 $\pm$ 0.42 and from 5.9-9.0 with a mean of 7.63 $\pm$ 0.69 in the dry season. Except the dry season (pH) from outside the houses soil which averaged 5.9, all the other values were above 7.0. The highest values were obtained from river bed soil, animal burrows, soils near animal burrows and rock crevices while the lowest values were from treeholes, plant bases and termite hills. These results showed that soil reactions varied from neutral (7.0) to strongly alkaline (9.0). Statistical correlation of pH of both seasons with *S. garnhami* and the overall

Table 9.1: Soil reactions (pH) of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	pH			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	8.02	7.97	7.995	6	20.22	39.6	81.56
ABS	7.9	8.28	8.09	39.6	269.3	312.4	933.7
AE	8.55	8.22	8.385	8	0.44	36.8	32.44
FG	7.38	7.39	7.385	3004.4	84.67	5294	628.4
VS	7.32	7.63	7.475	3004.4	84.67	5294	628.4
GR	7.57	7.48	7.525	6	0.89	34.8	28.22
RIV	8.58	9	8.79	0.8	0	14.4	12.89
HIN	7.53	7.19	7.36	14	0	331.2	198.2
HOUT	7.77	5.9	6.835	6.8	0.44	296.4	220.4
RB	7.1	7.28	7.19	119.6	26	255.6	120
HT	7.23	7.02	7.125	44	2.44	161.6	64.22
NABL	7.65	8.3	7.975	6	20.22	39.6	81.56
NABS	8	8.02	8.01	39.6	269.3	312.4	933
NTH	7.98	8	7.99	3004.	84.67	5294	628.4
RC	7.75	7.35	7.55	104	46.88	668.4	861.1
THIC	7.4	7.35	7.375	0.67	1.67	20.67	58.33
CC	7.43	7.3	7.37	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

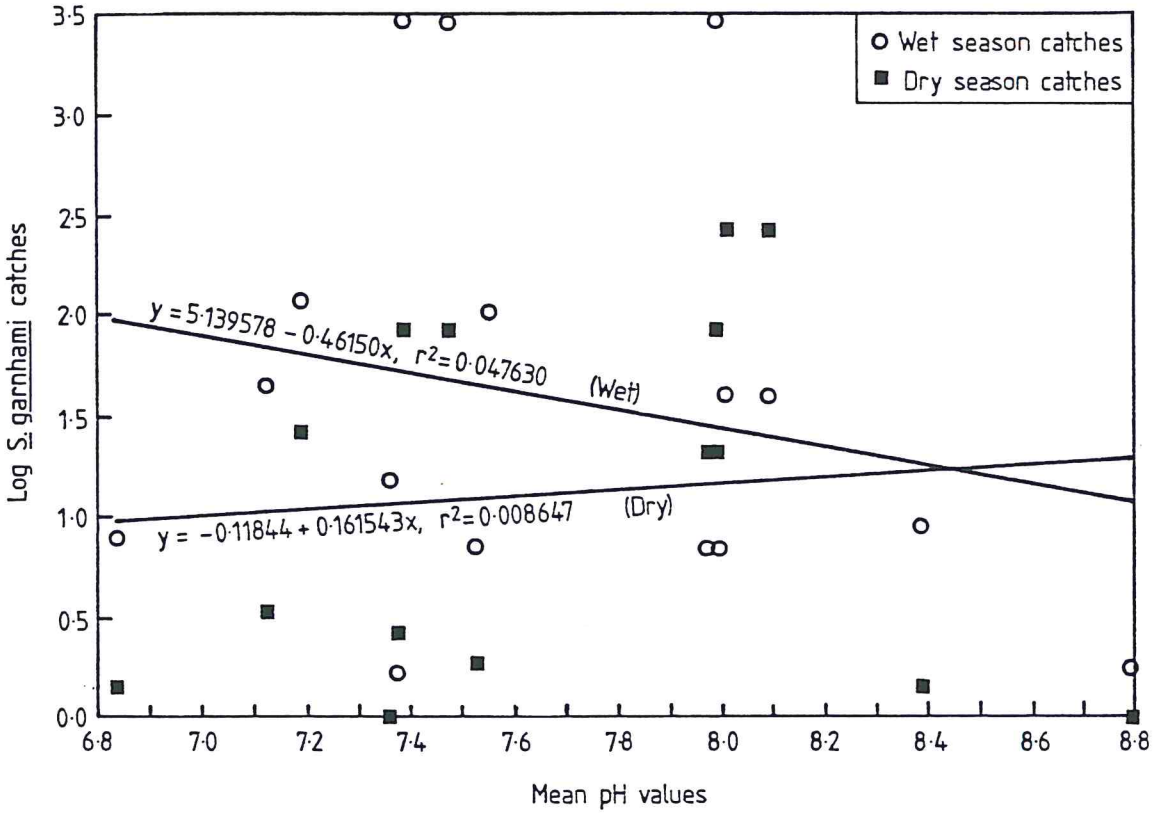


Fig 9.1 Relationship between soil pH and *S. garnhami* populations

phlebotomine sandfly populations from various sites in both wet and dry seasons showed that except for *S garnhami* populations during the dry season which showed non-significant positive correlation with dry season pH, wet season populations of *S. garnhami* and the overall sandfly populations of both seasons had non-significant negative correlations with pH (table 9.12). Correlation between the pH values of both seasons showed that wet and dry seasons pH values showed positive significant correlation with one another ($r = 0.60530^*$, $P = 0.0130$). Scatter diagrams of *S. garnhami* against mean pH values showed that wet season catches has an inverse linear relationship in which *S. garnhami* decreased with increased pH values whereas dry season catches had slight positive relationship in which *S. garnhami* populations increased with increased pH value (fig 9.1). Most of the *S. garnhami* were collected within pH range of 7.0 - 8.1 indicating optimal pH range tolerance for the immature stages of *S. garnhami*.

9.3.2 Sodium (Na)

Table 9.2 shows data on the soil sodium values of different sites. The mean values of the soil sodium from various sites ranged from 0.19-3.92 m.e. % with a mean of 1.13 $\pm$ 1.10 m.e % in wet season and from 0.22-4.07 m.e.% with a mean of 1.32 $\pm$ 1.27 m.e % in the dry

Table 9.2: Sodium contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Na			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	0.36	0.54	0.45	6	20.22	39.6	81.56
ABS	0.55	0.41	0.48	39.6	269.3	312.4	933.7
AE	3.92	4.07	3.995	8	0.44	36.8	32.44
FG	0.46	0.57	0.515	3004.4	84.67	5294	628.4
VS	0.44	0.74	0.59	3004.4	84.67	5294	628.4
GR	0.34	0.49	0.415	6	0.89	34.8	28.22
RIV	0.19	0.22	0.205	0.8	0	14.4	12.89
HIN	3.01	2.69	2.85	14	0	331.2	198.2
HOUT	2.04	1.96	2	6.8	0.44	296.4	220.4
RB	0.81	1.44	1.125	119.6	26	255.6	120
HT	1.75	2.42	2.085	44	2.44	161.6	64.22
NABL	0.16	0.29	0.225	6	20.22	39.6	81.56
NABS	0.3	0.35	0.325	39.6	269.3	312.4	933
NTH	0.3	0.71	0.505	3004.4	84.67	5294	628.4
RC	1.33	1.18	1.255	104	46.88	668.4	861.1
THIC	1.16	0.39	0.775	0.67	1.67	20.67	58.33
CC	2.08	4.01	3.05	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

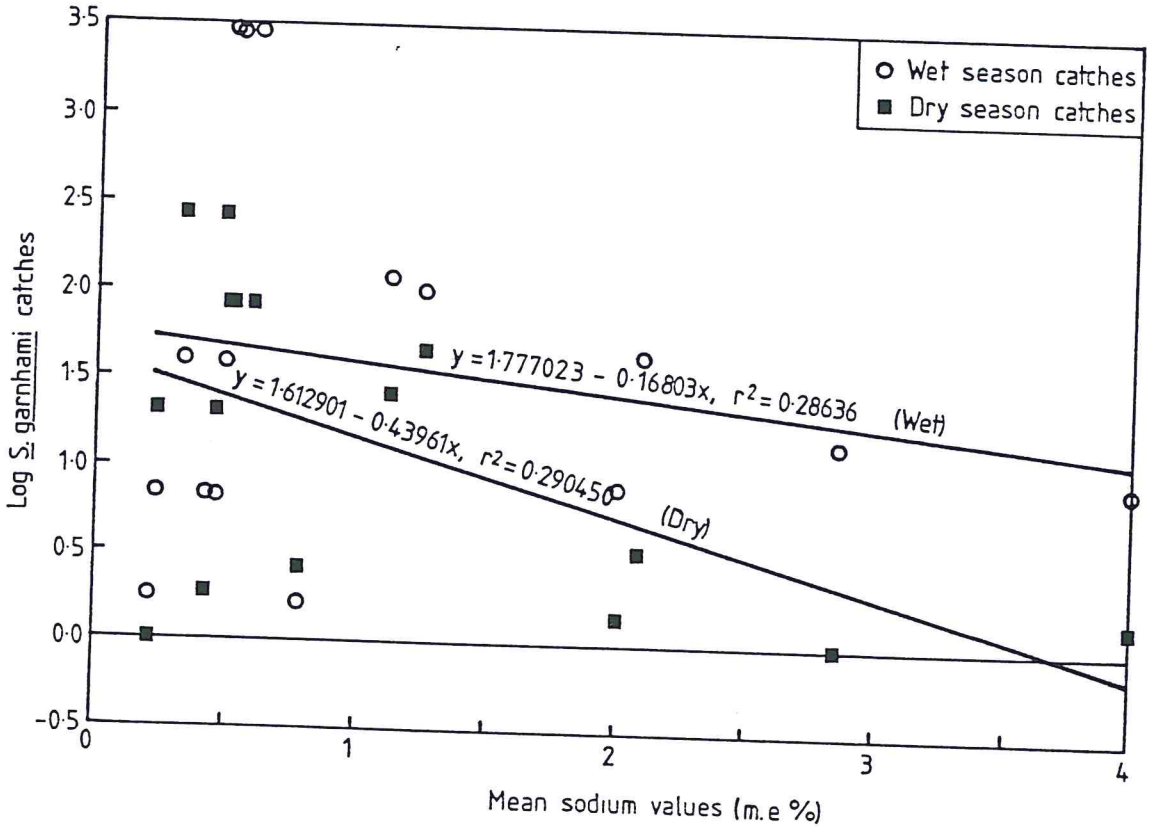


Fig 9.2 Relationship between soil sodium and *S. garnhami* populations

season. The highest values were obtained from animal enclosures in both seasons whereas the lowest values were from soils collected near animal burrows. Statistical correlation of *S. garnhami* and the overall sandfly catches of both seasons gave negative correlations with soil sodium. Only dry season catches of *S. garnhami* were significant (table 9.12). Wet and dry seasons values of sodium showed positive significant correlation with each another ($r = 0.94940^*$, $P = 0.0001$). Scatter plots of *S. garnhami* catches in both seasons against mean sodium values gave inverse linear relationship for both seasons catches (fig 9.2). Most of the *S. garnhami* were collected within the sodium range of 0.5-1.0 m.e.%. This shows that relatively small amount of sodium is needed by the immature stages of *S. garnhami*.

9.3.3 Potassium (K)

Table 9.3 shows the data on soil potassium values of various sites. The mean values of potassium in the various sites ranged from 0.16-7.76 m.e. % with a mean of 1.65 ± 1.91 in the wet season and from 0.11-7.62 with a mean of 1.88 ± 2.08 in the dry season (table 9.3). The highest values were obtained from animal enclosures and the least were from river bed in both seasons. Statistical correlation of both seasons *S. garnhami* and

Table 9.3: Potassium contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	K			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	0.53	0.52	0.525	6	20.22	39.6	81.56
ABS	0.64	0.47	0.555	39.6	269.3	312.4	933.7
AE	7.76	7.62	7.69	8	0.44	36.8	32.44
FG	0.68	1.01	0.845	3004.4	84.67	5294	628.4
VS	0.55	0.38	0.465	3004.4	84.67	5294	628.4
GR	0.64	0.75	0.695	6	0.89	34.8	28.22
RIV	0.16	0.11	0.135	0.8	0	14.4	12.89
HIN	2.29	1.93	2.11	14	0	331.2	198.2
HOUT	2.07	1.82	1.945	6.8	0.44	296.4	220.4
RB	1.65	1.73	1.69	119.6	26	255.6	120
HT	2.84	4.75	3.795	44	2.44	161.6	64.22
NABL	0.34	0.68	0.51	6	20.22	39.6	81.56
NABS	0.51	0.77	0.64	39.6	269.3	312.4	933
NTH	0.65	1.98	1.315	3004.4	84.67	5294	628.4
RC	0.99	1.07	1.03	104	46.88	668.4	861.1
THIC	0.146	0.92	0.533	0.67	1.67	20.67	58.33
CC	4.26	5.46	4.86	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

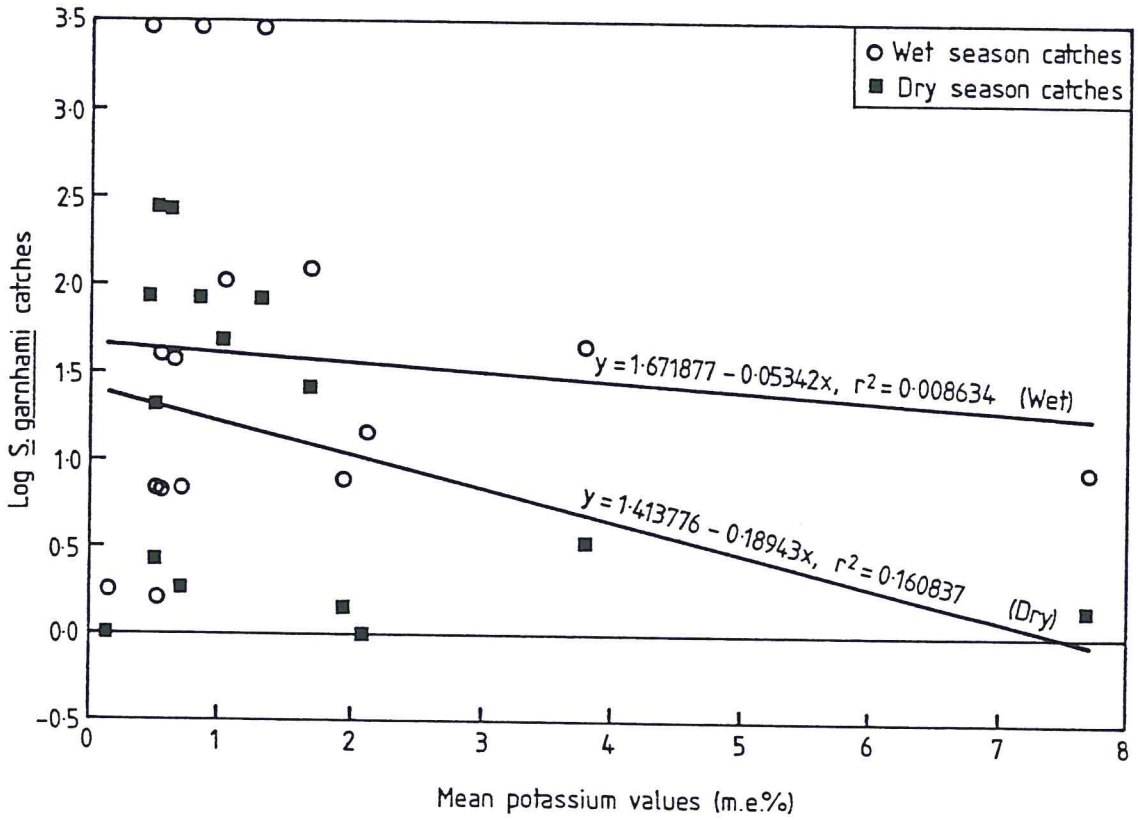


Fig 9.3 Relationship between soil potassium and *S. garnhami* populations

other phlebotomine sandfly catches with potassium values in both wet and dry seasons showed non-significant negative correlations (table 9.12). Wet and dry seasons values of potassium showed positive significant correlation with each other ($r = 0.94913^*$, $P = 0.0001$). Scatter plots of *S. garnhami* catches in both seasons against mean potassium values showed that both seasons catches had negative linear relationship in which *S. garnhami* populations decreased with increased potassium values. However, wet season catches showed very slight negative correlation (fig 9.3). Most *S. garnhami* were collected within the potassium value range of 0.5 - 2.0 m.e.% indicating the probable optimal potassium requirement range for the immature stages of *S. garnhami*.

9.3.4 Calcium (Ca)

Table 9.4 is data on the soil calcium values of various sites. The mean calcium values in various sites varied from 7.47-33 m.e. % with a mean of 22.05 $\pm$ 7.25 m.e. % in wet season and from 10-39.48 m.e. % mean of 21.28 $\pm$ 8.89 m.e. % in the dry season. High values were obtained from termite hill fungus garden and ventilation shafts, small animal burrows, animal enclosures, inside houses, treeholes and thickets. Low values were obtained from grass vegetation and outside houses.

Table 9.4: Calcium contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Ca			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	14.48	23.9	19.19	6	20.22	39.6	81.56
ABS	24.65	25.8	25.225	39.6	269.3	312.4	933.7
AE	23.85	20.88	22.365	8	0.44	36.8	32.44
FG	27.45	38.08	32.765	3004.4	84.67	5294	628.4
VS	31.55	39.48	35.515	3004.4	84.67	5294	628.4
GR	7.47	11.7	9.585	6	0.89	34.8	28.22
RIV	8.48	4.5	6.49	0.8	0	14.4	12.89
HIN	24.3	26.4	25.35	14	0	331.2	198.2
HOUT	20.8	10	15.4	6.8	0.44	296.4	220.4
RB	20.27	17.8	19.035	119.6	26	255.6	120
HT	25.44	20.23	22.835	44	2.44	161.6	64.22
NABL	19.8	24	21.9	6	20.22	39.6	81.56
NABS	17.5	19.7	18.6	39.6	269.3	312.4	933
NTH	26.84	22.25	24.545	3004.4	84.67	5294	628.4
RC	29.71	24.76	27.235	104	46.88	668.4	861.1
THIC	33	14.1	23.55	0.67	1.67	20.67	58.33
CC	19.37	18.26	18.82	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

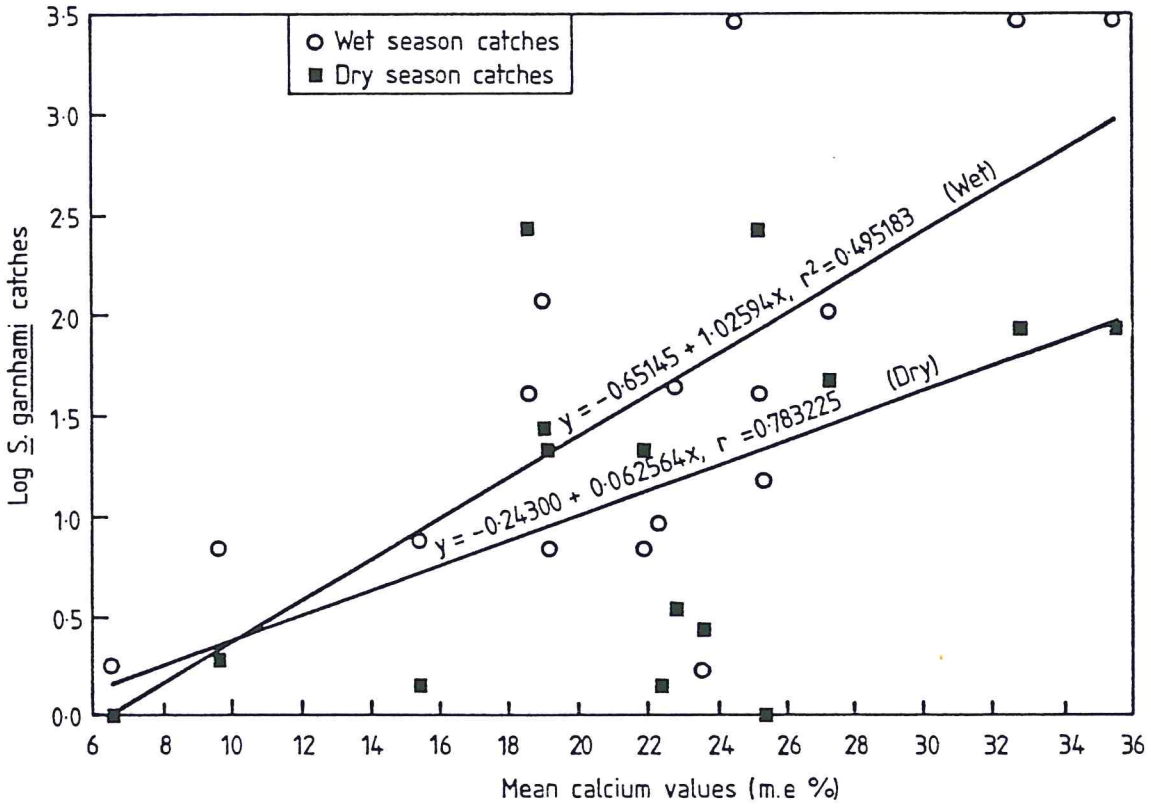


Fig 9.4 Relationship between soil calcium and *S. garnhami* populations

Statistical correlation of both seasons catches of *S. garnhami* and the overall phlebotomine sandfly catches with both seasons values of calcium gave significant positive correlations (table 9.12). Wet and dry seasons values of calcium showed positive significant correlation with one another ($r = 0.59097^*$, $P = 0.0159$). Scatter plots of *S. garnhami* catches of both seasons against mean values of calcium showed strong positive correlations for both seasons catches (fig 9.4). Most *S. garnhami* were collected within the calcium range of 16 - 28 which is probably the optimal requirement range of the immature stages of *S. garnhami*.

9.3.5 Magnesium (Mg)

Table 9.5 is the data on the soil magnessium values of the different sites. The mean magnesium values from various sites varied from 1.58-6.8 m.e. % with a mean of 3.96 ± 1.72 m.e. % in the wet season and from 0.6-7.32 m.e. % with a mean of 4.74 ± 1.77 m.e. % in the dry season. The highest values were obtained from the rock crevices soil, animal enclosures and treeholes. The lowest values were from river bed soils in both seasons. Statistical correlation of *S. garnhami* and other phlebotomine sandflies catches for both seasons showed non significant positive correlations (table 9.12). Wet and dry seasons magnesium values showed significant

Table 9.5: Magnesium contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Mg			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	2.63	4.42	3.525	6	20.22	39.6	81.56
ABS	5.9	4.15	5.025	39.6	269.3	312.4	933.7
AE	6.8	6.97	6.885	8	0.44	36.8	32.44
FG	3.8	3.96	3.88	3004.4	84.67	5294	628.4
VS	3.96	3.72	3.84	3004.4	84.67	5294	628.4
GR	1.67	3.88	2.775	6	0.89	34.8	28.22
RIV	1.58	0.6	1.09	0.8	0	14.4	12.89
HIN	3.25	4	3.625	14	0	331.2	198.2
HOUT	2.7	4.7	3.7	6.8	0.44	296.4	220.4
RB	3.53	6.5	5.015	119.6	26	255.6	120
HT	6.8	7.1	6.95	44	2.44	161.6	64.22
NABL	4.7	4.8	4.75	6	20.22	39.6	81.56
NABS	4.6	4.16	4.38	39.6	269.3	312.4	933
NTH	3.36	4.16	3.76	3004.4	84.67	5294	628.4
RC	6.47	7.32	6.895	104	46.88	668.4	861.1
THIC	1.8	2.98	2.39	0.67	1.67	20.67	58.33
CC	3.7	7.09	5.40	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = river bed, HIN Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows,NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

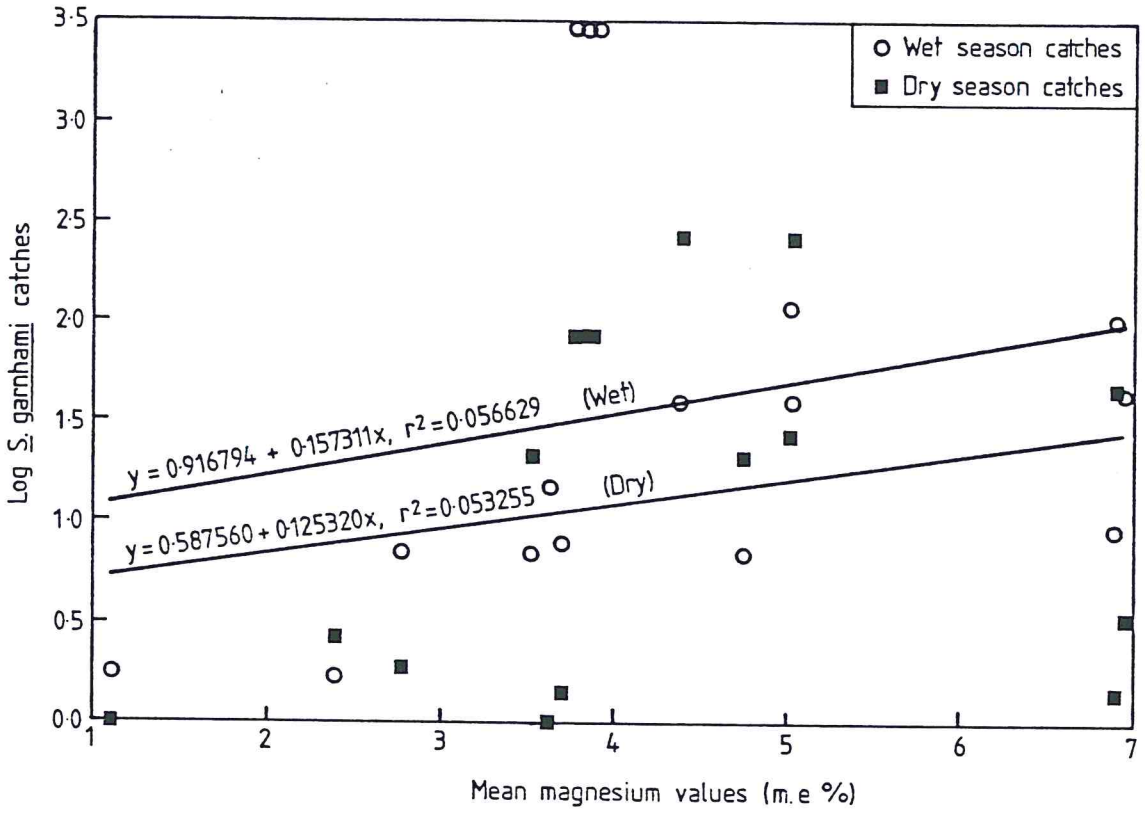


Fig 9.5 Relationship between soil magnesium and *S. garnhami* populations

positive correlations with each other (r = 0.75345*, P = 0.0008). Scatter plots of *S. garnhami* catches of both seasons against mean values of magnesium also showed positive linear relationship for both seasons catches to each other (fig 9.5). Most of *S. garnhami* were collected within the magnesium range of 2.5-5.0 m.e.%.

9.3.6 Manganese (Mn)

Table 9.6 shows data on the soil manganese values of the different sites. The mean values of manganese from the various sites varied from 0.10-0.42 m.e. % with a mean of 0.22 $\pm$ 0.11 m.e.% in the wet season and from 0.06-0.40 m.e. % with a mean of 0.28 $\pm$ 0.08 m.e.% in the dry season. The highest values were obtained from the inside and outside soils samples, treeholes, animal burrows and from soils near animal burrows. The lowest values were obtained in river beds and chicken coops. Statistical correlation of *S. garnhami* and the overall phlebotomine sandflies catches of both seasons with dry and wet seasons values of manganese gave non-significant positive correlations with the dry seasons values of manganese and non-significant negative correlations with wet season values of manganese (table 9.12). Wet and dry seasons values showed significant positive correlation with each other (r = 0.48349, P = 0.0578). Scatter plots of *S. garnhami* catches of both seasons

Table 9.6: Manganese contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Mn			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	0.29	0.3	0.295	6 20.	22	39.6	81.56
ABS	0.32	0.3	0.31	39.6	269.3	312.4	933.7
AE	0.1	0.26	0.18	8	0.44	36.8	32.44
FG	0.1	0.28	0.19	3004.4	84.67	5294	628.4
VS	0.1	0.29	0.195	3004.4	84.67	5294	628.4
GR	0.21	0.29	0.25	6	0.89	34.8	28.22
RIV	0.1	0.06	0.08	0.8	0	14.4	12.89
HIN	0.37	0.34	0.355	14	0	331.2	198.2
HOUT	0.29	0.28	0.285	6.8	0.44	296.4	220.4
RB	0.35	0.31	0.33	119.6	26	255.6	120
HT	0.42	0.34	0.38	44	2.44	161.6	64.22
NABL	0.26	0.33	0.295	6	20.22	39.6	81.56
NABS	0.3	0.36	0.33	39.6	269.3	312.4	933
NTH	0.13	0.4	0.265	3004.4	84.67	5294	628.4
RC	0.14	0.12	0.13	104	46.88	668.4	861.1
THIC	0.19	0.23	0.21	0.67	1.67	20.67	58.33
CC	0.11	0.20	0.17	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

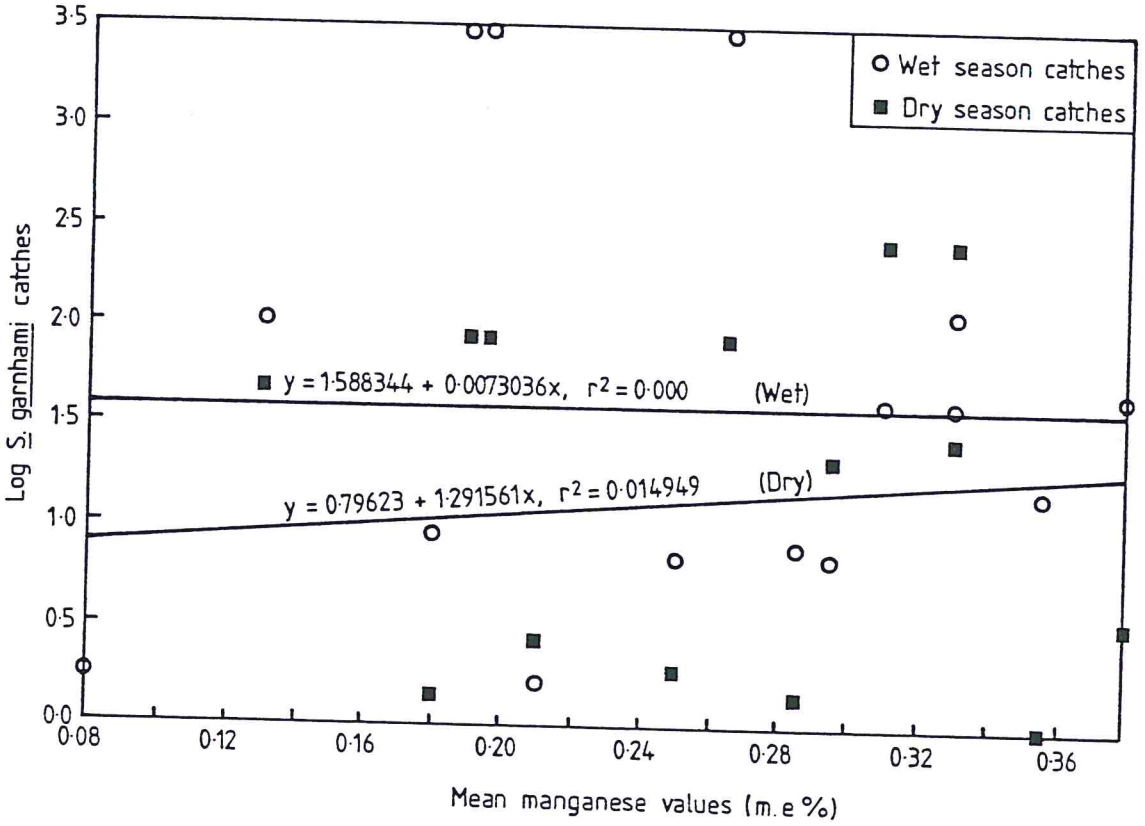


Fig 9.6 Relationship between soil manganese and *S. garnhami* populations

against mean values of manganese showed that dry season catches had slight positive linear relationship with manganese values whereas wet season values showed no relationship (fig 9.6). Most *S. garnhami* were collected within the manganese range of 0.18 - 0.32 m.e.%. These results indicated that manganese is required in very small quantity below or beyond which negative or no correlation occurs.

9.3.7 Phosphorus (P-olsen)

Table 9.7 contains the data on the soil phosphorus values of the different sites investigated. The mean value of available phosphorus from various sites varied from 8.4-68 m.e.% with a mean of 28.83 $\pm$ 18.02 m.e.% in the wet season and from 4.0-231 m.e.% with a mean of 114.77 $\pm$ 88.89 m.e.% in the dry season. The dry season values of phosphorus were higher than those of the wet season except in the river beds and soils collected near termite hills. The highest values were got from large and small animal burrows, grass vegetation, inside and outside houses, treeholes, rock crevices and thicket in both seasons. In wet season high values were obtained from chicken coops, inside and outside homes, plant bases and treeholes but their dry season values were relatively smaller than others. Statistical correlation of *S. garnhami* and the overall phlebotomine sandflies

Table 9.7: Phosphorus contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	P			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	15.33	149.3	82.315	6	20.22	39.6	81.56
ABS	8.4	117.2	62.8	39.6	269.3	312.4	933.7
AE	68	63	65.5	8	0.44	36.8	32.44
FG	26.37	35	30.685	3004.4	84.67	5294	628.4
VS	21.11	28.33	24.72	3004.4	84.67	5294	628.4
GR	18.83	231.7	125.265	6	0.89	34.8	28.22
RIV	8.8	4	6.4	0.8	0	14.4	12.89
HIN	48	192.8	120.4	14	0	331.2	198.2
HOUT	46	231	138.5	6.8	0.44	296.4	220.4
RB	30.75	201	115.875	119.6	26	255.6	120
HT	35.28	224	129.64	44	2.44	161.6	64.22
NABL	18	20	19	6	20.22	39.6	81.56
NABS	10.5	18.4	14.45	39.6	269.3	312.4	933
NTH	20.88	14.5	17.69	3004.4	84.67	5294	628.4
RC	30.16	128	79.08	104	46.88	668.4	861.1
THIC	20	228	124	0.67	1.67	20.67	58.33
CC	63	64.86	63.98	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

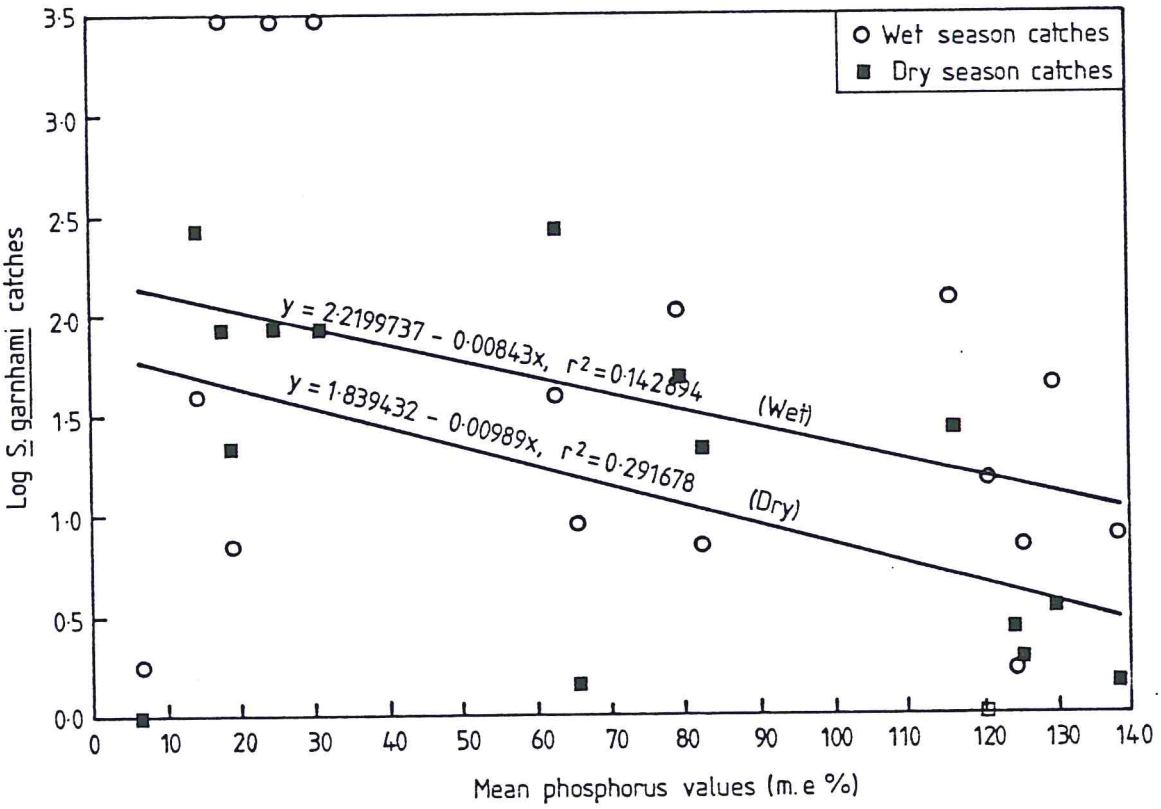


Fig 9.7 Relationship between soil phosphorus and *S. garnhami* populations

catches of both seasons wit wet and dry seasons values of phosphorus showed that d season catches of *S. garnhami* had significant ne tive correlation with phosphorus values of both s sons. Others showed non-significant negative correl ons (table 9.12). Wet and dry seasons phosphorus valu showed non-significant positive correlation to eac other (r = 0.29237, P = 0.2718). Scatter plots of *garnhami* catches of both seasons were shown in figur 9.7. Inverse linear relationships in which *S. g nhami* populations decreased with increasing phosphorus ues were observed. No specific range of phosphoru values could be said to be most favoured by *S. garnham* populations.

9.3.8 Carbon (C)

Table 9.8 shows the dat on the soil carbon content of the different sites. The ean percentage carbon values were generally small nd varied from 0.16-5.49% with a mean of 1.38 ± 1.32% wet season and from 0.1-4.46% with a mean of 1.33 ± .15% in the dry season. The highest values of carbo were obtained from animal enclosures and treeholes whe eas the lowest values were from river beds in both seas ns. Statistical correlation of *S. garnhami* a the overall phlebotomine sandflies catches of both se sons with the carbon values of both seasons showed non-s gnificant negative

Table 9.8: Carbon contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	C			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	0.4	0.33	0.365	6	20.22	39.6	81.56
ABS	0.67	0.39	0.53	39.6	269.3	312.4	933.7
AE	5.49	4.46	4.975	8	0.44	36.8	32.44
FG	0.78	0.55	0.665	3004.4	84.67	5294	628.4
VS	0.76	0.46	0.61	3004.4	84.67	5294	628.4
GR	0.64	0.91	0.775	6	0.89	34.8	28.22
RIV	0.18	0.1	0.14	0.8	0	14.4	12.89
HIN	1.68	1.57	1.625	14	0	331.2	198.2
HOUT	1.07	0.53	0.8	6.8	0.44	296.4	220.4
RB	1.43	1.4	1.415	119.6	26	255.6	120
HT	3.36	3.28	3.32	44	2.44	161.6	64.22
NABL	1.52	0.87	1.195	6	20.22	39.6	81.56
NABS	1.04	1.12	1.08	39.6	269.3	312.4	933
NTH	0.78	1.26	1.02	3004.4	84.67	5294	628.4
RC	1.32	0.99	1.155	104	46.88	668.4	861.1
THIC	0.21	2.08	1.145	0.67	1.67	20.67	58.33
CC	2.16	2.32	2.24	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

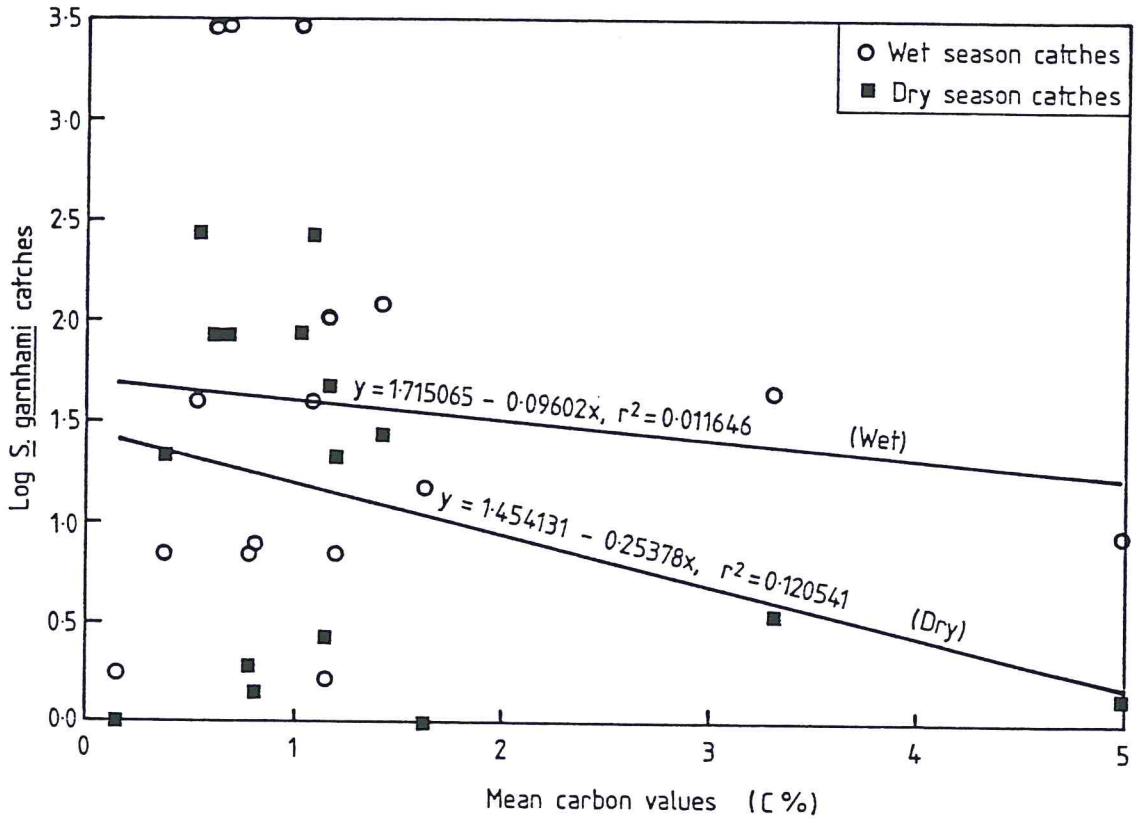


Fig 9.8 Relationship between soil carbon and *S. garnhami* populations

correlations with carbon values of both seasons (table 9.12). Wet and dry seasons carbon contents showed significant positive correlations (r = 0.88493**, P = 0.0001). Scatter plots of *S. garnhami* catches of both seasons against mean carbon values revealed inverse linear relationships in which *S. garnhami* populations decreased with increased carbon values (fig 9.8). The wet season catches showed very slight negative correlation. Most *S. garnhami* were collected between 0 - 1.5 %.carbon content.

9.3.9 Exchangeable salts

Table 9.9 is data on the soil exchangeable salts values of the diffrent sites. The mean values of exchangeable salts varied from 0.16-15.17 m.e.% with a mean of 2.74 $\pm$ 3.67 m.e.% in the wet season and from 0.16-6.08 me % with a mean of 2.67 $\pm$ 3.28 m.e.% in the dry season. The highest values were obtained from the chicken coops, animal enclosures and treeholes. The lowest values were obtained from the animal burrows and soil samples near the animal burrows. Statistical correlation of *S. garnhami* and other phlebotomine sandflies catches in both seasons with exchangeable salts values of both seasons showed that *S. garnhami* collections in the dry season had negative but significant correlation with dry season values. Wet

Table 9.9: Exchangeable salts contents of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	EC			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	0.73	1.6	1.165	6	20.22	39.6	81.56
ABS	0.5	0.16	0.33	39.6	269.3	312.4	933.7
AE	7.67	6.08	6.875	8	0.44	36.8	32.44
FG	3.04	1.38	2.21	3004.4	84.67	5294	628.4
VS	2.59	1.73	2.16	3004.4	84.67	5294	628.4
GR	0.35	0.65	0.5	6	0.89	34.8	28.22
RIV	0.16	0.2	0.18	0.8	0	14.4	12.89
HIN	3	5.36	4.18	14	0	331.2	198.2
HOUT	1.8	4	2.9	6.8	0.44	296.4	220.4
RB	0.7	0.88	0.79	119.6	26	255.6	120
HT	2.76	6.35	4.555	44	2.44	161.6	64.22
NABL	0.55	0.4	0.475	6	20.22	39.6	81.56
NABS	0.4	0.46	0.43	39.6	269.3	312.4	933
NTH	1.34	1.42	1.38	3004.4	84.67	5294	628.4
RC	4.02	1.93	2.975	104	46.88	668.4	861.1
THIC	2	0.3	1.15	0.67	1.67	20.67	58.33
CC	15	12.5	13.75	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

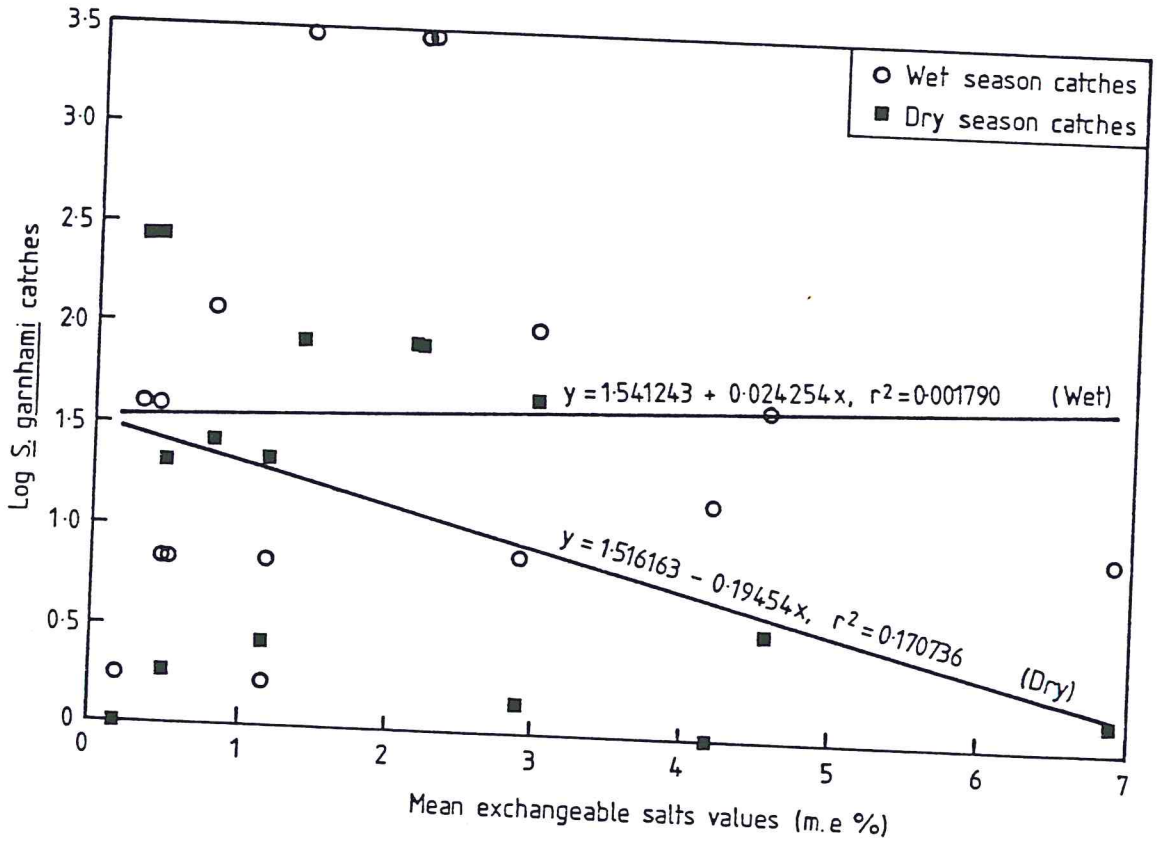


Fig 9.9 Relationship between soil exchangeable salts and *S. garnhami* populations

season collections of *S. garnhami* and other species were positively correlated but not significant with wet and dry seasons values of the exchangeable salts (table 9.12). Others were negatively correlated but not significant. Wet and dry seasons exchangeable salts value showed significant positive correlations (r = 0.70468**, P = 0.0023). Scatter plots of *S. garnhami* collections in both seasons against mean values of the exchangeable salts showed a negative linear relationship with dry season collections of *S. garnhami* whereas the wet seasons collections showed no correlations (fig 9.9). Most *S. garnhami* were collected within 0-4.5 m.e.% value range for exchangeable salts. These results vividly illustrated that the crystallization of salts as a result of dry season may have a limiting effect on the development of *S. garnhami* immature stages.

9.3.10 Capillarity

Table 9.10 shows the data on the soil capillarity rates of the different sites. The mean capillarity rates of soil samples of the various sites varied from 3.5-201.9 cm/hr with a mean of 25.20 $\pm$ 46.67 cm/hr in the wet season and from 0.97-144.8 cm/hr with a mean of 14.76 $\pm$ 34.05 cm/hr in the dry season. Very high capillarity rates were obtained from river beds which were mainly sandy soil. The lowest rates were from

Table 9.10: Capillarity rates of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Capillarity			*S. garnhami*		All Species	
	Wet	Dry	Avg	Wet	Dry	Wet	Dry
ABL	12.4	6.77	9.585	6	20.22	39.6	81.56
ABS	8.67	9.28	8.975	39.6	269.3	312.4	933.7
AE	11.35	12.05	11.7	8	0.44	36.8	32.44
FG	3.5	1.41	2.455	3004.4	84.67	5294	628.4
VS	4.87	1.2	3.035	3004.4	84.67	5294	628.4
GR	36	9.88	22.94	6	0.89	34.8	28.22
RIV	201.9	144.8	173.35	0.8	0	14.4	12.89
HIN	3.78	0.97	2.375	14	0	331.2	198.2
HOUT	15.46	2.6	9.03	6.8	0.44	296.4	220.4
RB	0.7	6.35	3.525	119.6	26	255.6	120
HT	18.37	4.52	11.445	44	2.44	161.6	64.22
NABL	11.2	5.2	8.2	6	20.22	39.6	81.56
NABS	24.2	3.88	14.04	39.6	269.3	312.4	933
NTH	7.45	2.82	5.135	3004.4	84.67	5294	628.4
RC	16.68	8.1	12.39	104	46.88	668.4	861.1
THIC	38.1	26.52	32.31	0.67	1.67	20.67	58.33
CC	7.55	4.54	6.05	-	- -	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

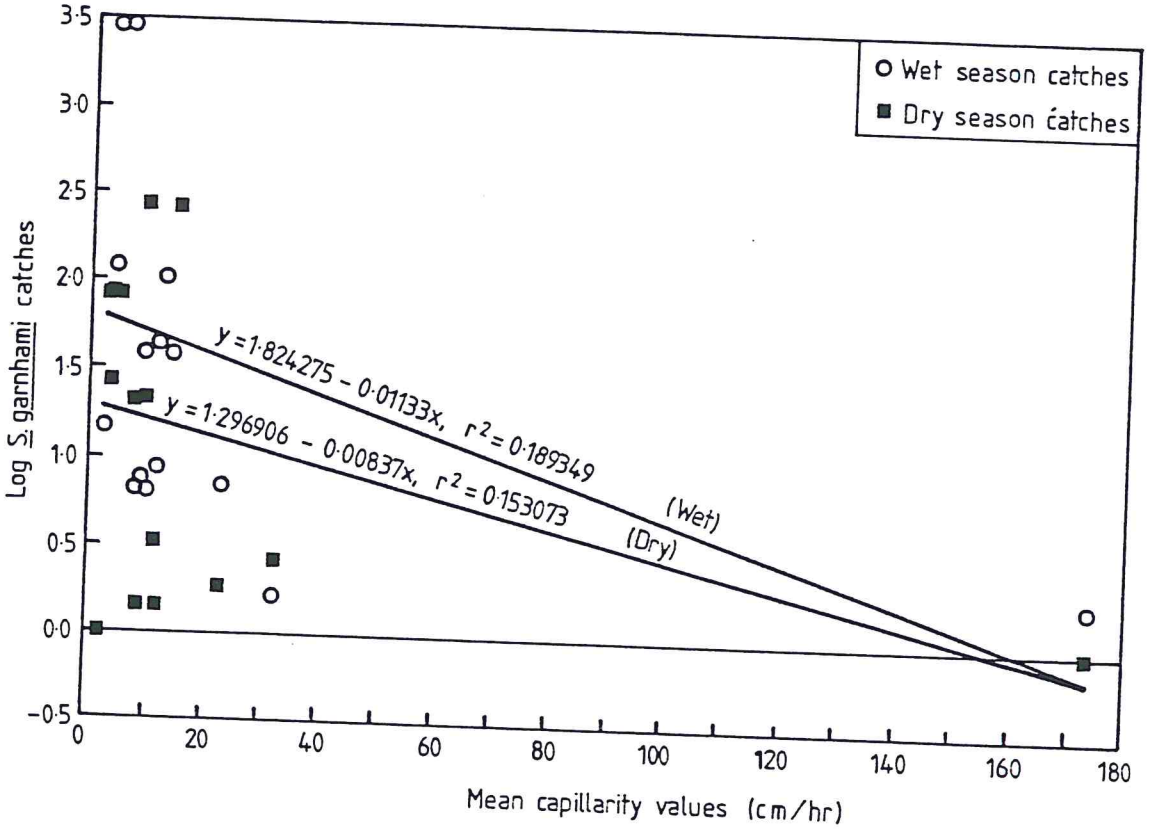


Fig 9.10 Relationship between soil capillarity rate and *S. garnhami* populations

termite hill fungus garden and ventilation shafts and from inside and outside houses. Statistical correlation of *S. garnhami* and the overall phlebotomine sandfly catches of both seasons with dry and wet seasons capillarity rates showed the dry season catches of all the species put together had significant negative correlation with both wet and dry seasons capillarity rates. Both seasons catches of *S. garnhami* and the wet seasons collections of all the species put together showed negative but not significant correlations with capillarity rates of both seasons (table 9.12). Wet and dry seasons values of capillarity rates showed significant positive correlation to each other ($r = 0.98572^{**}$, $P = 0.0001$). Scatter plots of *S. garnhami* catches of both seasons against mean capillarity rates gave an inverse linear relationship in which *S. garnhami* populations decreased with increased capillarity rates (figure 9.10). Most of the *S. garnhami* were collected within the capillarity rate of 0-20. Capillarity rates were graded as follows:

High	3.0-8.0
Medium high	1.5-3.0
Medium low	0.5-1.5
Low	0.2-0.5

Based on the above classification of capillarity rates ,the capillarity rates of Tseikuru soil could be regarded as being extremely high. However these rates

were obtained from disturbed soil samples which can provide a comparative data to the actual field condition. It is therefore evident from the results that capillarity rates of the various habitats limit the period optimal for the development of sandfly immature stages (eggs, larvae and pupae). Thus, it limits the number of generations per season thereby affecting the population numbers of the adult .

9.3.11 Soil texture

Table 9.11 shows data on the soil texture of the various sites. The soil texture were graded into

(a) Sand (S)

(b) Sandy loam (SL)

(c) Loamy sand (LS)

(d) Sandy clay loam (SCL) and

(e) Clay (C).

The gradations were based on the percentage content of sand, silt and clay in the soil samples. There were no variations in the wet and dry seasons soil texture. Because soil samples of each ecological habitat were collected from 5 different sites in each season, combinations of soil grades per habitat were observed. For example scl/sl/sc/c were obtained for termite hills alone. The most common soil grade of each habitat was selected and coded for analysis. A general observation

Table 9.11: Texture of wet and dry seasons soil samples from various breeding sites of *S. garnhami*

Site	Texture Type	Texture code	*S. garnhami* Wet	*S. garnhami* Dry	All Species Wet	All Species Dry
ABL	ls	1	6	20.22	39.6	81.56
ABS	sl	2	39.6	269.3	312.4	933.7
AE	sl	2	8	0.44	36.8	32.44
FG	scl	3	3004.4	84.67	5294	628.4
VS	scl	3	3004.4	84.67	5294	628.4
GR	sl	2	6	0.89	34.8	28.22
RIV	s	4	0.8	0	14.4	12.89
HIN	scl	3	14	0	331.2	198.2
HOUT	sl	2	6.8	0.44	296.4	220.4
RB	ls	1	119.6	26	255.6	120
HT	ls	1	44	2.44	161.6	64.22
NABL	sl	2	6	20.22	39.6	81.56
NABS	sl	2	39.6	269.3	312.4	933
NTH	scl	3	3004.4	84.67	5294	628.4
RC	sl	2	104	46.88	668.4	861.1
THIC	ls	1	0.67	1.67	20.67	58.33
CC	scl	3	-	-	-	-

ABL=Large animal burrows, ABS = Small animal burrows, AE = Animal enclosures, FG = Fungus garden, VS = Ventilation shaft, GR = Grass vegetation, RIV = River bed, HIN = Inside house, HOUT = Outside house, RB = Tree base, HT= treeholes, NABL = Near large animal burrows, NABS = Near small animal burrows, NTH = Near termite hills, RC = Rock crevices, THIC = thicket and CC = Chicken coop.

Table 9.12: Correlation analysis
Pearson correlation coefficients/prob > R under Ho:Rho=0 / N=16

Factor	Species	Wet season	Dry season
pH	*S. garnhami*	-0.35576 (0.1763)+	0.22902 (0.3935)
	All species	-0.35644 (0.1754)	-0.19760 (0.4632)
Na	*S. garnhami*	-0.23922 (0.3722)	-0.49938 (0.0489)*
	All species	-0.14085 (0.6029)	-0.20534 (0.4455)
K	*S. garnhami*	-0.12769 (0.6374	-0.37965 (0.1470)
	All species	-0.15726 (0.5608)	-0.11896 (0.6608)
Ca	*S. garnhami*	0.49645 (0.0505)*	0.59976 (0.0141)**
	All species	0.55378 (0.0260)*	0.63605 (0.0081)**
Mg	*S. garnhami*	0.25433 (0.3418)	0.10537 (0.6977)
	All species	0.21607 (0.4216)	0.17752 (0.5107)
Mn	*S. garnhami*	-0.2744 (0.3036)	0.31744 (0.2309)
	All species	-0.18835 (0.4848)	0.33256 (0.2082)
P	*S. garnhami*	-0.05132 (0.8503)	-0.48335 (0.0579)*
	All species	0.01168 (0.9658)	-0.26303 (0.3250)
C	*S. garnhami*	-0.06776 (0.8031)	-0.37682 (0.1502)
	All species	-0.13687 (0.6132)	-0.32575 (0.2182)
EC	*S. garnhami*	0.12410 (0.6470)	-0.49805 (0.0496)*
	All species	0.11803 (0.6633)	-0.15695 (0.5616)
Cap	*S. garnhami*	-0.44391 (0.0850)	-0.37932 (0.1473)
	All species	-0.47600 (0.0624)	-0.54061 (0.0306)*
Text	*S. garnhami*	0.34284 (0.1936)	-0.03469 (0.8985)
	All species	0.39313 (0.1320)	0.13689 (0.6132)
Sp. *S.garnhami*/species		0.94828 (0.0001)**	1.00000 (0.0)**

\+ = Probability bracketed
* = Significant at 5% level
** = Significant at 1% level

Statistical correlation of *S. garnhami* and other sandflies catches in both seasons with wet and dry seasons soil samples showed non-significant positive correlations except for the dry season catches of *S. garnhami* which were negative but not significant (table 9.12).

9.4 Discussion

The results of the soil chemistry revealed that the soil pH ranged from near neutral to very strongly alkaline. The major plant nutrients were in adequate quantities. Available bases were quite high particularly sodium and calcium. Problem due to sodicity and/or salinity were therefore suspected. This could be harmful to salt sensitive plants and other organisms. Available phosphorus were quite high in most samples. Trace elements such as manganese were also quite low. Organic carbon content (hence total nitrogen) was variable but very low generally. Exchangeable salts were in excess quantities. This could pose salinity problems. The implications of the observations on individual factors are discussed below.

9.4.1 Soil reaction (pH)

Non-significant negative correlations and linear relationship between soil reactions, *S. garnhami* population of wet season and other sandflies populations of both seasons were observed. There was a non-significant positive correlation between pH values and dry season populations of *S. garnhami*. These results indicated that in the dry season soil pH was probably below the required pH (acidic) for *S. garnhami* immature stages hence the positive correlation. It also showed that soil pH could be affected by season. The existence of some relationship between soil pH and sandfly populations probably suggests that soil pH is necessary for the development of immature stages of *S. garnhami* and other sandfly species. The collection of most *S. garnhami* and probably other sandfly species within pH range of 7.0-8.1 indicates that *S. garnhami* larvae thrives well under neutral to slightly alkaline condition. Rutledge and Mosser (1972) reported pH values of 6.8-7.9 for soil samples taken from sandfly breeding habitats in Panama. Schlein et al (1982) showed that areas with low or high salinity values presented low populations of sandflies. Hoberg (1986) reported that soils of arid areas have alkaline topsoils due to their accumulation of basis and that the liberation of base cations during fires in the savannas

will cause increases in pH. The highest pH values were obtained from river bed soil whereas the lowest were from treeholes and animal burrows. This could be possibly due to the availability of replenishing source close to the various sites. Soil pH is dependent on the availability of base metals and exchangeable salts and water. These were very abundant in bedrocks along the banks of the rivers and were constantly being dissolved by water from the rivers and washed down along the water path. The base metals and salts in treeholes may be as a result of decomposing dead parts of the plant as well as from traces from excrements of animals taking refuge in treeholes. The same is probably the case in animal burrows which may be as a result of decomposing plant remains used as food by the animals, as well as little traces in animal excretion with urine serving as source water.

9.4.2 Sodium

Non-significant negative correlation between sodium, *S. garnhami* and other phlebotomine sandflies were recorded. This showed that increased sodium concentrations may have suppressive effect on *S. garnhami* and other sandfly populations irrespective of season. Basimike (1988) noted that sodium has suppressive effect on the population numbers of

sandflies. Most of the flies were collected between 0.5 - 1.0 m.e.% sodium range indicating the optimal sodium range at which the immature stages of *S. garnhami* and other sandflies could thrive. Sodium, calcium, or chloride are required in small quantities by insects and were often provided sufficiently as dietary impurities (Dadd 1973). This is important considering that sodium is high in the area. It probably indicates that sandfly larvae may tolerate high levels of sodium salt. Schlein et al (1982) measured high salinity values (40-433 m.e/l) in localities with low and high population densities of P.papatasi and concluded that sodium could not account for the low *P .papatasi* densities in some areas.

The highest sodium values were obtained in soil samples from animal enclosures while the least was collected from soil near animal burrows. It is likely that high sodium from animal enclosures may be as a result of salts excreted by the animals in their urine.

9.4.3 Potassium

Non-significant negative correlation between potassium values, *S. garnhami* and all sandfly populations were observed in both seasons. This again showed that increased potassium values may also effect a downward trend of sandfly populations in both seasons.

Most *S. garnhami* were collected in the range of 0.5-2.0 m.e.% indicating the optimal requirement range of potassium but may tolerate further increase hence *S. garnhami* were collected below and above this value range. This range could be regarded as small since substantial amounts of potassium, phosphate and magnesium are known to be required by all insects (Dadd 1973). *Drosophila* has been reared in diet containing K_2SO_4 and $MgSO_4$ as the sole salts with NaCl and $CaCl_2$ being trace elements present as impurities. The potassium and phosphate were essential that no flies were raised when sodium were substituted for potassium. Potassium was also an essential constituent of the diet of *Tenebrio* (Wigglesworth 1972). The highest value were from animal enclosures but the least were from the river bed. The small value of river bed potassium may be associated with erosion whereas the high value in the animal enclosures may be associated with the excretion in animals.

9.4.4 Calcium

Significant positive correlations and strong positive linear relationships were obtained between calcium values, *S. garnhami* and other sandfly species in both seasons. This shows that calcium is not only necessary but may be an indispensable factor, as such

could be limiting in areas with minute deposits. In Tseikuru deposits seemed to exceed requirement and therefore not limiting. Most flies were collected between 16 - 28 m.e.% range though flies where collected below or above this range suggesting some tolerance to lower or higher values. High values of calcium were obtained from termite hills, animal burrows, treeholes e.t.c., while the lowest value were from grass vegetation. This is probably associated with animal activities in the various sites.

9.4.5 Magnesium

Positive but not significant correlations were obtained between magnesium values, *S. garnhami* and other phlebotomine sandflies in both seasons. Scatter plots also gave positive relationships between *S. garnhami* and magnesium values of both seasons. These results also indicated that magnesium is important in the development of sandfly immature stages. High values of magnesium were obtained from rock crevices, animal enclosures and treeholes whereas the lowest values were from river beds. The high level of magnesium in the rock crevices could be probably due to the existence of its deposits in the rocks whereas those of animal enclosures and treeholes could be attributed to excretion of animals on one hand and the decomposition of plant and animal

materials on the other. Magnesium is an essential component of plant chlorophyll and without it no ecosystem could operate (Odum 1971). It is also required in large quantities by all insects (Dadd 1973).

9.4.6 Manganese

Wet seasons collections showed negative but not significant correlations with manganese values while dry seasons collections showed non-significant positive relationships with manganese levels. This result also illustrated the importance of manganese in the development of immature stages of *S. garnhami* and other sandflies although this is not statistically significant. Eyster (1964) listed 10 micronutrients of plants and animals and grouped Mn amongst those necessary for metabolic functions including photosynthesis in plants. The results also showed that the relationship/requirement varied with season as weather seemed to have effect on the available manganese. Most *S. garnhami* and probably other sandfly species were collected within the manganese range of 0.18 and 0.32 m.e.%. This range values could be regarded as small and the manganese values were also small. These are major properties of a limiting micronutrient factor (requirements and deposits small,

Odum 1971) and this could be suspected. Further rearing of the larvae in substitution diet will help to isolate whether Mn is a limiting factor.

9.4.7 Phosphorus

Significant negative relationship were observed between available phosphorus values and *S. garnhami* populations in dry season. Negative but not significant relationship between available phosphorus, wet season populations of *S. garnhami* and the dry season populations of all the sandfly species put together were also observed. The wet seasons populations of all species showed non-significant positive correlation. No specific value range could be regarded favourable for *S. garnhami* and probably other sandflies. Phosphates were among the minerals required in large quantities by insects (Dadd 1973). Hutchinson (1957) classified phosphorus as an A-1 limiting factor. He noted that among the elements present in living organisms that phosphorus is likely to be the most important ecologically because the ratio of phosphorus to other elements in organisms tend to be greater than the ratio in the primary sources of biological elements. Phosphorus composes about 0.19% of the wet weight of *Tribolium* larvae at all stages and growth was delayed when phosphorus was depressed below 0.10% (Nelson and

Palmer 1935). Hobson (1932) showed that phosphorus may also be a limiting factor in the growth of *Lucilia* larvae reared on mammalian blood. Phosphate and Potassium were essential minerals in the rearing of *Drosophila* (Wigglesworth 1972). For all the species put together the result showed variable requirement with season probably due to the cumulative effect of different species larval requirements or due to erosion or dilution effect during rains making available phosphorus inadequate to larvae. This may account for the positive but non-significant correlation observed. Hoberg (1986) reported that the available phosphorus in an area is dependent on soil reaction. In alkaline soils of arid areas, phosphorus is bound into less soluble calcium phosphate and are readily available than in acid soils of rain forest regions where it is strongly fixed into insoluble iron and aluminium phosphates. For *S. garnhami* these results probably showed that increased level of phosphorus could have suppressing effect on their population numbers although they were collected over a wide range of phosphorus values. High values were obtained in animal burrows, grass vegetation, treeholes and rock crevices. Again this could be associated to the available deposits in rocks, animal wastes and decomposition of plant materials in animal burrows and treeholes.

9.4.8 Carbon

Negative but not significant correlations between carbon values, *S. garnhami* and other sandflies were observed for both seasons. Most *S. garnhami* and probably other sandfly species were collected in the range of 0-1.5%. These results showed that immature stages of sandfly could thrive well in areas with low to moderate organic nutrient. In Saudi Arabia, Buttiker and Lewis (1979) reported that sandy loam soil has extremely low organic content. Short et al (1930) noted that the presence of organic debris was necessary for the continuance of sandfly breeding although he did not quantify this. It seems that high carbon content (organic nutrient) could have suppressing effect on the population numbers of *S. garnhami* and other sandfly species. In contrast many authors (Hanson 1961, Thatcher 1968, Mutinga 1972) have collected large numbers of sandflies in areas rich in decaying organic matter. This suggests that the ecological demands of sandflies may differ not only amongst species but also with locality. The highest values were obtained from animal enclosures where there were decomposing plant and animal wastes whereas the lowest were obtained from river beds apparently devoid of vegetation and subject to constant erosion. Bettini and Melis (1988) and Basimike (1988) reported that the differences in the organic content of

different soil samples may be due to differences in the distribution of sheep urine and faeces. Carbon and nitrogen contents of soils are positively correlated with plant biomass and with each other (Hoberg 1986, Lugo and Murphy 1986). Nitrogen is high in evergreen forest regions but low in the drier arid and semi-arid regions (Hoberg 1986). Jones (1990) observed that in a place with a high number of termite mounds, termite activity exhaustively partitions litterfalls amongst adjacent competing colonies where it is so thoroughly decomposed that little or no organic carbon is incorporated into the soils. Jones also noted that the associated N, P, and cations build up in the mounds but carbon is apparently emitted as CO_2 and CH_4 from mounds (Jones 1990).

9.4.9 Exchangeable salts

Positive but not significant relationship between exchangeable salts, *S. garnhami* and all sandfly species were obtained in wet season, while non-significant negative correlations were obtained in dry season. These results showed that salts are important to sandflies and that seasons may influence the availability of exchangeable salts to them. Salts are necessary for insect growth (Wigglesworth 1972) and

their distribution (Odum 1971). Odum (1971) also noted that nitrogen and phosphorus salts are major limiting factors and the biologist may do well to consider them first as a matter of routine. Dadd (1973) showed that *M. persicae* was successfully reared in a diet containing trace metal chlorides and two chelating agents (ascorbic and citric acids). The anal papillae of culicids and other nematocerous insects are permeable to salts and water and are used to take up salts from water but the most important function is for the uptake of chloride ions. *Aedes eagypti* larvae grow better than those of *Culex pipiens* in water with a smaller chloride content (Wigglesworth 1972). To obtain salts adult lepidotera frequently drink water where it is contaminated with excrement.

The seasonal variation may be that in the dry season high temperatures caused rapid evaporation of water and the concentration of salts thereby creating an inverse relationship between salt concentrations and sandfly populations. In the wet season the reverse seemed to be the case. Salt concentrates were diluted by rainfall water but the extent of dilution was probably compensated by the dissolution of more salts from the deposits hence non- significant positive correlation observed. In arid areas, bases accumulate in the top soils after capillary upward movement following occasional rains and that the availability of base

cations also increases temporarily after fires (Hoberg 1986). Most *S. garnhami* were collected within the exchangeable salt range of 0-4.0 m.e.%. This shows that this value range could probably be the optimal for the development of the immature stages of *S. garnhami* and other sandfly species.

9.4.10 Capillarity.

Non-significant negative correlations were obtained between capillarity rates, *S. garnhami* populations of both seasons and all species populations of wet season only. Dry season populations of all species showed significant negative correlations. The results showed that increased capillarity rates have suppressing effects on *S. garnhami* and other sandfly populations in both wet and dry seasons and could have pronounced effect during dry season on the overall sandfly population. Schlein et al (1982) observed in Jordan that the high density of *Phlebotomus papatasi* populations correlated with soil conditions favouring high humidity. These authors collected more flies in localities with water conductivity between 6.41-8.64mm/hr in contrast to a locality with water conductivity of 21.62mm/hr. It is most likely that capillarity rate of soil might be a major contributory factor to the overall factors responsible for the low

sandfly populations during the dry season. Most *S. garnhami* were collected within the capillarity rate range of 0-20 cm/hr. This range probably indicates the tolerance limits of *S. garnhami* immature stages. High capillarity (evaporation) rates are results of soil texture and weather. Sandy soils are by the size of their soil particles more porous and are bound to lose more water on hot dry day than on a cold wet day. Rapid evaporation may be a factor limiting the development of eggs to adults during the dry season thereby causing a rapid drop in adult sandfly populations. It is probably the factor limiting the development of many generations of *S. garnhami* in a year. Most *S. garnhami* and other sandfly species were collected in termite hills and animal burrows with moderate evaporation rates.

9.4.11 Soil texture

Non-significant positive correlations were obtained between soil texture grades, all sandfly species populations of both seasons and wet season populations of *S. garnhami*. There was non-significant negative correlation between soil texture grades and dry season *S. garnhami* populations. This shows that soil quality of both seasons are important for the development of immature stages. It also showed that although the differences in soil texture were not statistically

significant in both seasons, adverse alterations in soil quality probably due to high temperatures, high evaporation rates leading to low soil moisture and the concentration or erosion of available nutrients may have suppressing effects on *S. garnhami* and other sandfly populations. Most sandflies were collected from termite hills, animal burrows, rock crevices, treeholes and plant bases where the soil quality undergo moderate changes as a result of weather and probably animal activities as is obvious in the termite hills and animal burrows.

In conclusion all the soil factors considered seem to have either positive or negative relationship with the sandfly populations. In particular calcium, manganese and soil texture showed positive relationship for both seasons with only calcium being significant whereas sodium, potassium, carbon, and phosphorus gave negative relationship with sandfly populations for both seasons. Dry season values of sodium, phosphorus and exchangeable salts which showed negative linear relationship with dry season *S. garnhami* populations were significant. Other factors such as soil pH manganese and exchangeable salts showed either positive or negative relationship with season. It is most likely that the factors (calcium and magnesium) that showed positive relationship with sandfly populations in both seasons may be very much necessary for the normal

development of their immature stages and may be limiting when they are in short supply. Those factors (sodium, potassium, and phosphorus) that showed negative relationship are likely to be required in very low quantity or not at all such that increases in their quantities may have suppressive effects on the sandfly species population. The fact that these factors occurred in large quantities where these sandflies were collected even in large numbers shows that although they might have suppressive effects on the sandfly population size, they might not be totally limiting in their distribution. The physical factors (soil texture and capillarity) appear to be of immense relevance as soil texture is a composite of other factors and the particle size of the components determine the evaporation or water retention rate of the soil. This in turn affects the sandfly fauna depending on the species tolerance to individual factors. Excessive water loss through high capillarity rate is likely to be detrimental to the immature stages of sandfly species and therefore suppressive to the adult populations.

CHAPTER TEN

HOURLY FEEDING PATTERN OF *S. GARNHAMI* THROUGH STUDIES WITH MAN AND ANIMAL BAITS

10.1 Introduction

The degree of host-vector contact is very important in incriminating a suspected insect species as a vector of common insect-borne ailment prevalent in the area. Service (1977) noted that the best method of sampling anthropophilic species is through human baited catches whereas animals and birds are used for zoophilic and ornithophilic species. WHO (1984) also recommended this method with caution that flies will not be allowed to engorge to avoid possible risk of infection. This work was aimed at investigating the hourly feeding patterns of *S. garnhami* on man and animal baits within human dwellings and near termite hills .

10.2 Materials and methods

10.2.1 Man-baited catches

Six volunteer workers acted as both baits and catchers. Sandflies were collected at an hourly intervals from dusk to dawn (6.00pm-6.00am) for three nights inside and outside human homes and while sitting

on or near a termiterium (Plates 10.1 & 2). Hourly catches were emptied into appropriately labelled cages. The cages were improvised from white plastic cups of commercial vegetable oils commonly available. The cups were properly washed off the oils, sandfly nets cut to appropriate sizes were held over the open end of the cups and kept in position with rubber bands. A hole about 1cm in size were made at the middle of each net and plugged with cotton wool to prevent escape of the sandflies. Sandflies were collected with the aid of torch lights and aspirators from the exposed extremities (hands and feet) of the volunteer workers. The work was carried out during the peak period of *S. garnhami* in December 1989

10.2.2 Animal baited catches

An adult goat and two puppies of about 3 months old were used for this study. The study was carried out near a termiterium for a period of 3 nights during the December 1989 *S. garnhami* peak.

The goat was placed in a temporary cage constructed with thorny twigs (Plate 10.3) near the termite hill. The puppies were placed in a rectangular cage of 4 x 1.5 x 1.5 ft and the cage was placed on opposite side to the goat. The positions of the goat and the puppies were equidistant to the termiterium (Plate 10.3).

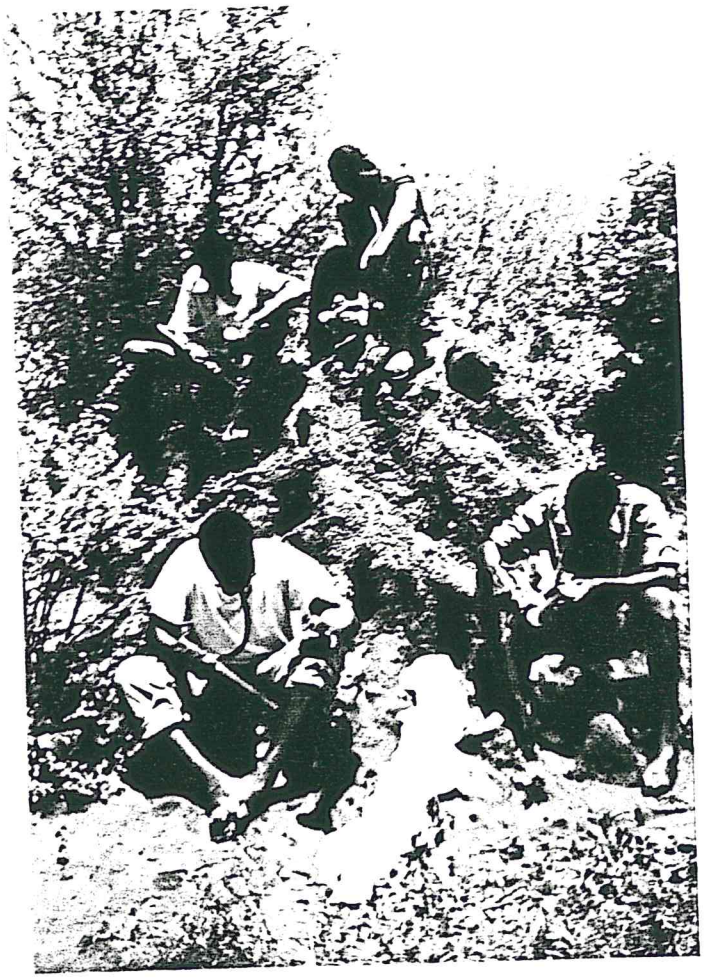


Plate 10.1 Human baited catches on and around a termite hill

Plate 10.2 Human baited catches within and outside human dwellings

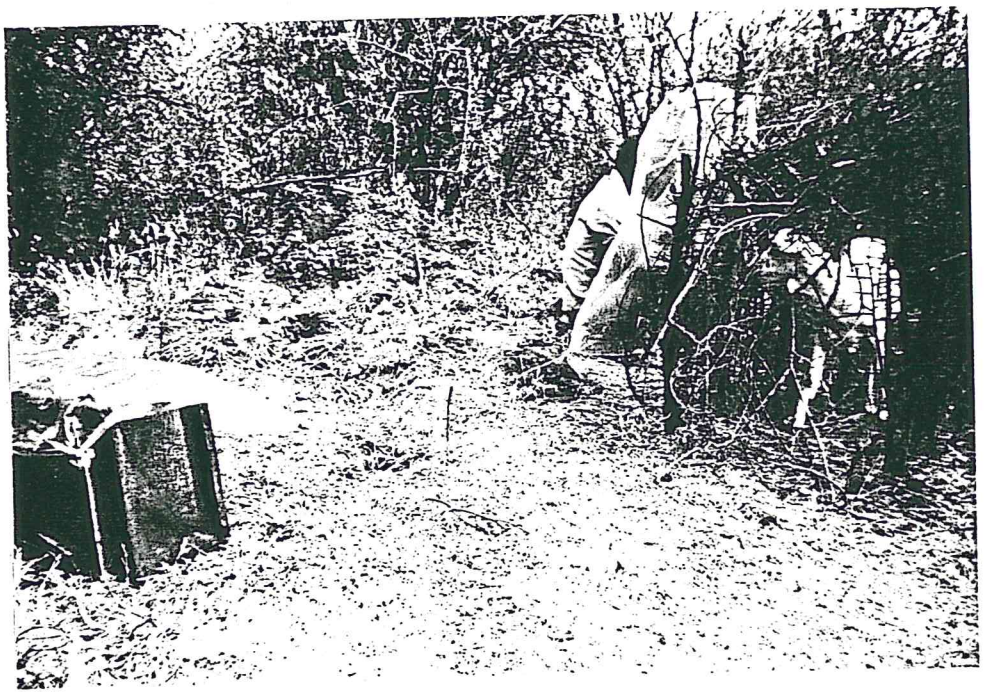


Plate 10.3 Animal baited catches near a termiterium.

Sandflies were collected at hourly intervals using sticky traps of size $1m^2$. 24 sticky traps were used per night ,ie 2 per hour, one for the goat and the other for the puppies. Each night of studies lasted from 6.00pm-6.00am.

10.2.3 Feeding of *S. garnhami* with wild animals

In the course of this study we also fed some *S. garnhami* with wild animals caught with our rectangular cage. Three animals (white-tailed mongoose, a ground squirrel and a chicken) were used.

The mongoose was sedated, the hairs on one side of the abdomen were sheared and it was kept into a cage with the shaved part upwards to allow easy feeding by the sandflies. The cage was improvised with a rectangular cooler box (Plate 10.4). The open top of the box was covered with white nylon net of fine mesh (sandfly net). A hole of 1cm in diameter was cut at the centre of the net and plugged with cotton wool. Wild caught sandflies from ventilation shafts of termite hills were introduced into the cages through the hole after ensuring that they were not engorged with blood. The hole was again plugged with cotton wool. The cage was then covered with a black polythene sheet to provide a dark condition to induce feeding by sandflies. The set up was left for 3 hours, at the end of which the

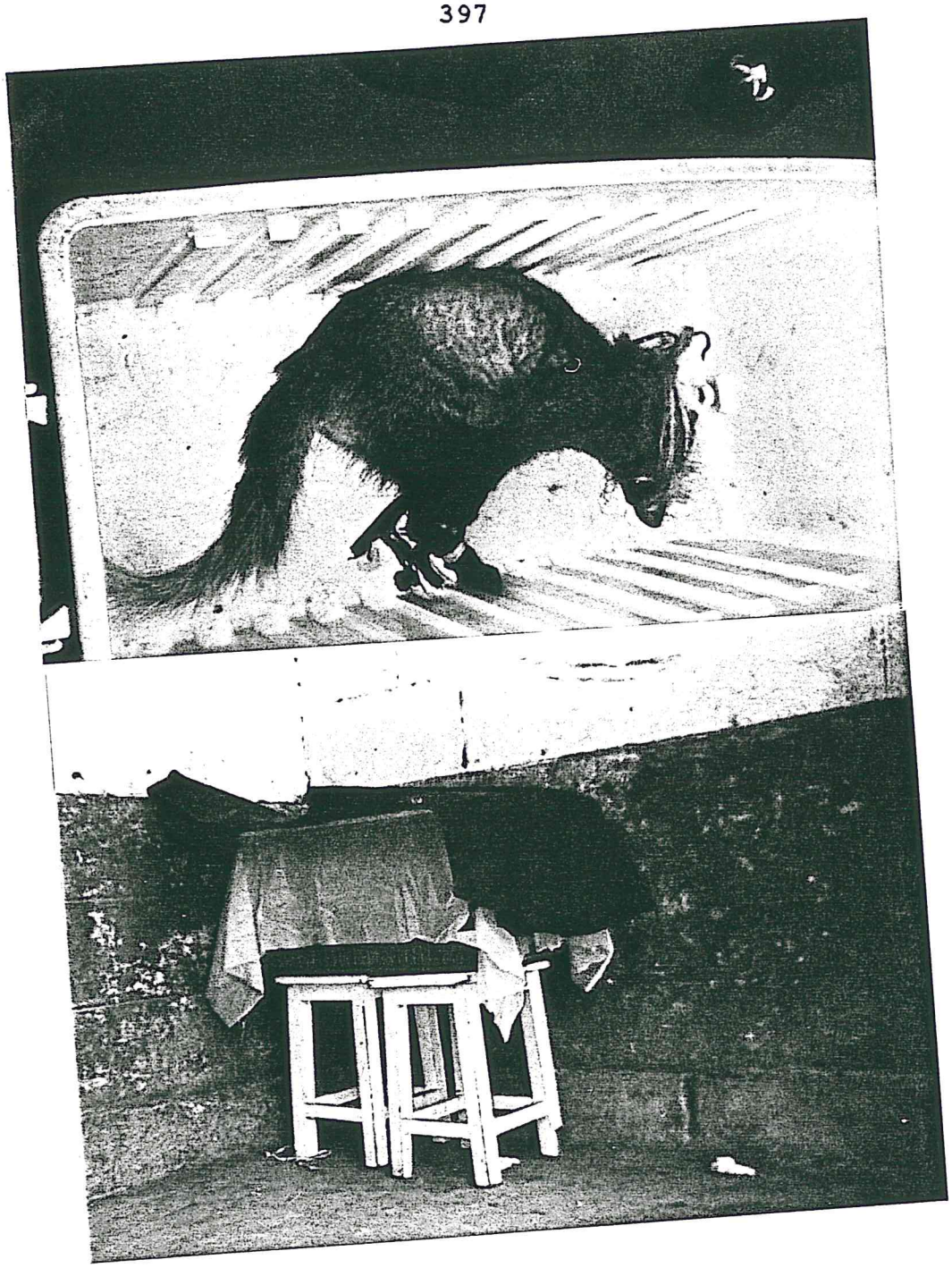


Plate 10.4 Apparatus for feeding *S.garnhami* on a white-tailed mongoose.

sandflies were recovered using aspirator. The flies were then processed, identified and the number of the fed and unfed sandflies counted.

The experiment was repeated for the chicken and the squirrel but the cages were the normal perspex cages in our laboratory. The squirrel was sedated but the chicken was not. The wings and the legs of the chicken were tied together to prevent beating and similar movements that could affect sandfly feeding. The beaks were held together with cellotape making sure the breathing channels were not blocked. The feathers were removed on one side and the chicken placed into the cage with the feather-free part upwards. All the experiments were left for three hours to allow sufficient time for the sandflies to feed.

10.3 Results

10.3.1 Human baited catches near termites hills.

Table 10.1 shows the data on three nights human-baited catches near termite hills. *S. garnhami* was human-baited throughout the night during the 3 nights of study. A large number was caught biting man between 6.00-7.00pm, but a peak was reached between 7.00-8.00pm. This was followed by a decline of biting sandflies until between 11.00pm-12.00 mid night when another peak was

Table 10.1: ee nights hourly man-baited catches of *S. hami* near termite hills

Time	y 1	Day 2	Day 3	Total	B/rate
6.00-7.00pm	8	129	29	416	23.1
7.00-800pm		239	121	455	25.3
8.00-9.00pm	6	203	41	380	21.1
9.00-10.00pm	1	142	15	278	15.4
10.00-11.00pm		139	9	178	9.9
11.00-12.00pm	3	181	18	307	17.1
12.00-1.00am		103	16	190	10.6
1.00-2.00am		97	4	107	5.9
2.00-3.00am		61	8	105	5.8
3.00-4.00am		12	8	55	3.1
4.00-5.00am		42	148	220	12.2
5.00-6.00am		48	3	90	5.0

Note:- Only fe s recorded

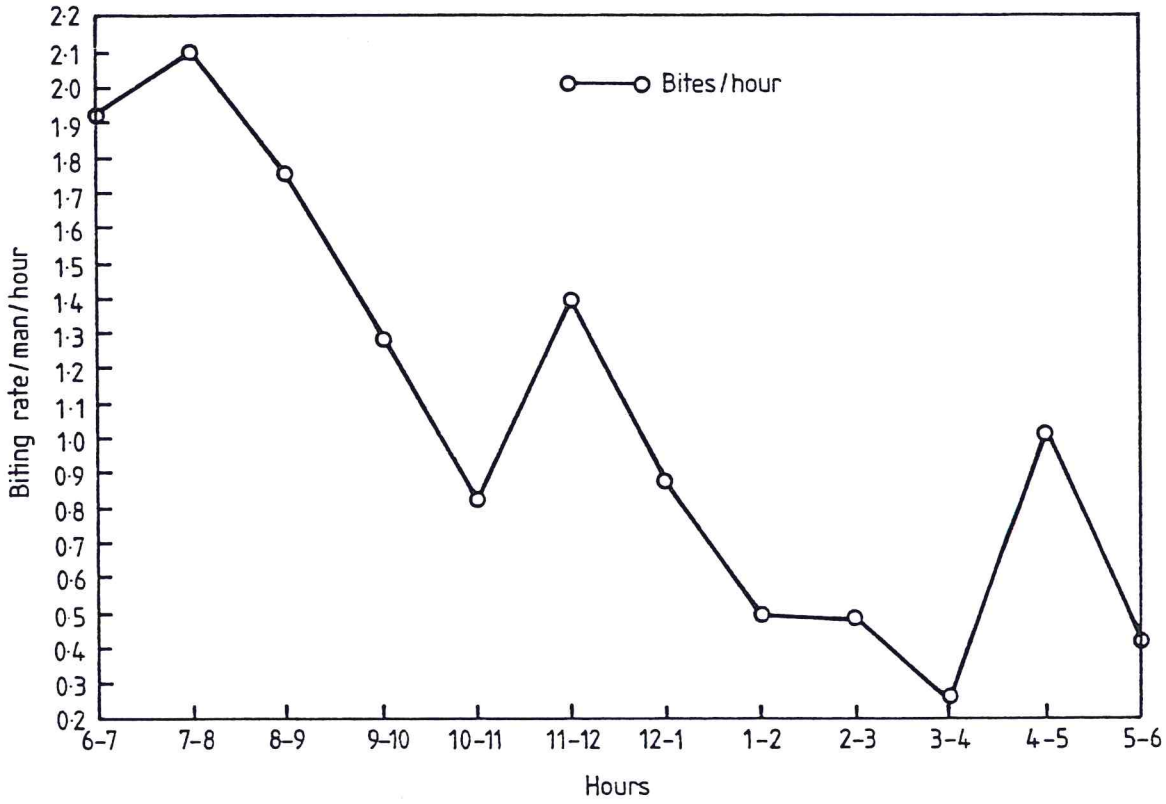


Fig 10.1 Hourly biting rate of *S. garnhami* around termite hills

observed. There was again a rapid decline in the biting activity until between 4.00-5.00am when another peak occurred and then a decline culminating in day break at 6.00am. The landing or biting rate/man/hour of *S. garnhami* was plotted against time (fig 10.1). The highest landing rate of 23-25 flies/man/hour was observed between 6.00-8.00pm.

10.3.2 Human baited catches within and outside human homes

The results of these sites were not similar to those of the termite hills. A total of four female *S. garnhami* was collected inside the houses for the 3 nights of study. In the first day 2 were collected, one was caught between the 6.00-7.00pm and the other between 7.00.8.00pm. In the second day the catches were also 2, one was caught between 6.00-7.00pm and the other between 7.00-8.00pm. None was collected on the third day. One female *S. kirki* was collected on the second day between 9.00-10.00pm. However volunteers complained of vicious bites from mosquitoes especially *Anopheles* species. This was also the case around termite hills.

From the outside the houses only one female of *S. garnhami* was collected between the 6.00-7.00pm on the second day. No *S. garnhami* was caught on both the first and third days respectively. One female *S. kirki* was

collected between 8.00-9.00pm on the first day. No sandfly was collected on the third day.

10.3.3. Animal baited catches

10 3.3.1 Goat

Table 10.2 shows data on animal baited catches near termite hills. A total of 5 *S. garnhami* (3 females and 2 males) was collected in the goat baited cage for the 3 nights of study. All of them were caught on the first day. One male was collected between 10.00-11.00pm and the other between 4.00-5.00am. The females were collected as follows, one between 9.00-10.00pm, one between 10.00-11.00pm and the other between 4.00-5.00am. Other species collected were 3 females of *S. bedfordi* and 3 *S. kirki* (2 females and one male).

10.3.3.2 Puppies

Table 10.2 also contains data on puupy baited cage. Eight *S. garnhami* (7 females and 1 male) were collected from the puppy-baited cage for the 3 nights of study. All were collected on the first and second days of study. Nothing was collected on the third day. On the first day 4 females were collected, one between 7.00-8.00pm one between 8.00-9.00pm, one between 9.00

Table 10.2: Three nights hourly animal-baited catches of *S. garnhami* near termite hills.

	Goat			Dog		
Time	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
6.00-7.00pm	0	0	0	0	1	0
7.00-8.00pm	0	0	0	1	1	0
8.00-9.00pm	0	0	0	1	1	0
9.00-10.00pm	1	0	0	1	0	0
10.00-11.00pm	2(1)	0	0	0	0	0
11.00-12.00pm	0	0	0	0	(1)	0
12.00-1.00am	0	0	0	0	0	0
1.00-2.00am	0	0	0	0	0	0
2.00-3.00am	(1)	0	0	1	0	0
3.00-4.00am	0	0	0	0	0	0
4.00-5.00am	1	0	0	0	0	0
5.00-6.00am	0	0	0	0	0	0
Total	5	0	0	4	4	0

( ) = males

10.00pm and the other between 2.00-3.00am. On the second day, 3 females and one male were collected. The male was collected between 11.00pm-12.00 mid night whereas the females were collected thus, one between 7.00-8.00pm, one between 8.00-9.00pm and the other between 11.00pm-12.00 mid night. Other species collected were *S. antennatus* (1 female), *S. bedfordi* (1 male and 1 female), *Synphlebotomus* complex (1 female) and *S. kirki* (11 females).

10.3.4 Feeding of *S. garnhami* with wild animals

10.3.4.1 Mongoose

A total of 45 sandflies were introduced into the cage, 30 of which were *S. garnhami* (23 females and 7 males). Only 1 female of *S. garnhami* fed. The rest of the sandflies were mainly *S. bedfordi* (13) and *S. affinis* (2). None was found bloodfed.

10.3.4.2 Squirrel

A total of 36 sandflies were introduced into the cage. 28 were *S. garnhami* (18 females and 10 males). Only 2 fed at the end of the 3 hours. Other flies introduced into the cage were *S. bedfordi* (5), *S. antennatus* (2) and *S. affinis* (1). None was found bloodfed.

10.3.3.3 Chicken

A total of 43 sandflies were introduced into the cage, 32 were *S. garnhami* (24 females and 8 males) but 9 females were bloodfed at the end of 3 hours. Other sandflies introduced into the cage were *S .bedfordi* (6) *S. antennatus* (4) and *S. schwetzi* (1). None was found bloodfed.

10.4 Discussion

The collection of *S. garnhami* through human baited catches further reveals the anthropophilic nature of this sandfly (Heisch 1954, Mutinga and Odhiambo 1982 and Mutinga et al 1986b). Catches from the termite hills showed that *S. garnhami* could bite throughout the hours of the night especially around the breeding and the resting sites. Heisch (1954) however, observed that it bites during dusk and dawn hours with little or nothing happening in between. The limited catches within and just outside human dwellings suggested that *S. garnhami* is not strongly endophagic.

The small numbers of *S. garnhami* caught with the animal-baited cages probably indicated lower attractions of *S. garnhami* to mammals other than man. In spite of the small catches, collections from puppy-baited cage

were about twice that of the goat. This probably shows that *S. garnhami* prefers canids to ruminants. Southgate and Oriedo (1962) observed that the incidence of visceral leishmaniasis was higher amongst Kenyans who slept in the company of their dogs. Mutinga and Ngoka (1977, 1978 and 1980) have isolated leishmanial parasites from dogs. However the attraction of sandflies to domestic animals is by itself very important in the epidemiology of leishmaniasis. Mutinga et al (1988 and 1989) have successfully isolated leishmanial parasites from sick goats. They also successfully cross infected other goats and sheep with the isolated leishmanial parasites. This shows the important need for detailed parasitological investigations of our livestock especially those with weeping sores around the mouth, nostrils and tail junctions.

It is likely that such examinations may lead to further incrimination of new reservoir hosts of leishmanial parasites associated with man.

The feeding experiments showed that hungry *S. garnhami* could feed on a variety of animal hosts available to it though *Sergentomyia* species prefer to feed on lizards and other reptiles (Kirki and Lewis 1951, Perfile'v 1966). In a laboratory studies on host preference of sandflies using various animal models, *P. martini* and *S garnhami* preferred mammals (Mutinga et al

1981). In a similar studies under field conditions the *Sergentomyia* species showed preference to lizards although a few where opportunistic feeders on animals which were not favoured hosts (Mutinga et al 1986a). This type of feeding predisposes *S. garnhami* to picking up various species of haemoparasites from their different animal hosts. However the survival and the development of these parasites to their infective stages depend solely on their survival of the insect immune system. The implications of this type of feeding is that the isolation of freshly imbibed parasite during dissections may lead to wrong conclusions.

CHAPTER ELEVEN

HOST PREFERENCE OF *S. GARNHAMI* THROUGH BLOODMEAL IDENTIFICATION

11.1 Introduction

The use of immune reactions to determine the source of a vertebrate bloodmeal in a haematophagous insect vector species helps in the correct identification of the vertebrate host species. This also leads to the knowledge of the natural sources of infection of the insect with pathogen and also the possible interpretation of the vector borne ailment. This work was intended to investigate the naturally preferred hosts of *S. garnhami* (i.e man, other mammals, lizards or other reptiles and even birds) through the identification of bloodmeals of wild caught bloodfed sandflies.

11.2 Materials and methods

Three methods were used in the collection of engorged female flies for bloodmeal analysis. These were aspirator method, sticky trap and human lure.

11.2.1 Aspirator method.

Based on the knowledge that most sandflies derive their food from the animals inhabiting their breeding and resting sites, termite hills were visited from 0600-0800 hours and from 1700-1800 hours, and engorged female flies crawling on the walls of the ventilation shafts of the termite hills were collected with an aspirator. After, a twig was used to disturb the inner walls of the shaft, the sandflies resting deep inside the shaft hoppped or crawled out and were collected also. Animal burrows, treeholes and plant bases were also visited and similar methods were used to collect any fly seen.

11.2.2 Sticky trap method

Engorged female sandflies found in the regular oil traps set in the field were also collected and prepared for bloodmeal studies.

11.2.3 Human lure method:

To be certain that *S. garnhami* actually feeds on man, a preliminary survey of man-biting activity of this sandfly was undertaken. Two volunteer workers carried out two hourly catches between 1800-2000hr near termite hills for two nights in May 1989. The engorged females

of sandflies from the catches were incorporated into the studies to understand if these flies actually fed on man.

The sources of sandflies for bloodmeal studies included termite hills, houses, treeholes, animal burrows, plant bases and rock crevices.

11.2.4 Preparation of sandflies for bloodmeal analysis

All the engorged female flies from any of the methods were washed in 1.0% detergent saline to wet them and remove the hairs, rinsed in physiological saline. The sandflies were then transferred individually onto a clean microscopic glass slide, the head was severed, mounted with gum chloral mountant and kept for identification. The body of each sandfly was transferred from the slide onto an 11cm diameter Whatman filter paper. The bloodmeal in the abdomen of each sandfly was squeezed out by first cutting the tip of the abdomen with one end of a clean microscopic glass slide and pressing on the abdominal segments with a dissecting pin. Two bloodmeals were prepared per filter paper. Each tip of the slide was used once to avoid contamination. Also in order to prevent contamination, each filter paper was folded twice to divide it into four equal parts and stretched again. Bloodmeals were prepared on the two opposite divisions of the paper such

that on folding, no contamination would occur. The bloodmeals were labelled properly, allowed to air dry under room temperature, then folded and carefully packed into polythene bags, and stored in a refrigerator They were later sent to Professor Staak of Robert Ostertag Institute Service Laboratory in Germany who kindly agreed to carry out the service gratis in a WHO collaboratory laboratory.

11.2.5 Bloodmeal analysis

The bloodmeals were analysed by using antisera directed against ruminant (total), cow, small ruminant (sheep/goat), pig, monitor lizard, rat, hippo, man, dog and chicken.

11.3 Results

Table 11.1 shows the bloodfed sandfly species from various sites investigated. A total of 1068 bloodmeal preparations from wild caught phlebotomine sandflies comprising 16 bloodfed females of the *Synphlebotomus* complex (*P.martini*, *P.celiae*, and *P.vansomerenae*), and 1052 bloodfed females of the *Sergentomyia* genus were sent for analysis. The *Sergentomyia* species included *S. affinis* (14), *S. antennatus* (27), *S. bedfordi* (144), *S. clydei* (3), *S. garnhami* (823), *S. graingeri* (1), *S.*

Table 11.1:- The prevalence of bloodfed *S. garnhami* and other phlebotomine sandflies in various ecological sites.

Species	Animal burrow	Animal enclosure	Inside house	Outside house	Open space	Tree hole	Tree stem	Tree base	Rock crevice	Tree foliage	Termite hill	Total
S.affinis	6	0	0	0	0	0	0	1	2	0	6	14
S.antennatus	2	0	11	6	0	1	0	1	0	0	6	27
S.bedfordi	28	2	29	4	0	4	48	9	14	0	4	144
S.clydei	1	1	0	0	0	0	0	0	0	2	1	3
S.garnhami	293	0	2	0	1	0	0	0	1	0	526	823
S.graingeri	0	0	0	0	0	0	0	0	0	0	1	1
S.harveyi	0	0	0	0	0	1	2	3	0	0	0	6
S.ingrami	0	0	0	0	0	2	7	1	0	0	1	11
S.kirki	9	0	0	0	0	1	0	0	1	0	11	22
S.schwetzi	0	0	0	0	0	0	1	0	0	0	0	1
Phlebotomus	1	1	0	1	0	0	0	1	2	0	10	16
Total	340	4	42	11	1	9	58	16	20	2	565	1068
Percent	31.8	0.40	1.39	1.03	0.10	0.80	5.43	1.50	1.80	0.20	52.90	100

harveyi (6), *S. ingrami* (11) *S. kirki* (22), and *S. schwetzi* (1). Table 11.1 also shows the prevalence of the bloodfed female phlebotmine sandflies in the different ecological sites investigated. Most of these sandflies were found resting in animal burrows (340 or 31.84%) and in the termite hills 565 (or 52.90%).

Table 11.2 shows the number of identified bloodmeals from different sandfly species. Only 330 (or 30.9%) of the bloodmeal preparations could be identified. 249 out of 330 (or 75.5%) were *S. garnhami*. Others identified included *S. affinis* 9 (or 2.7%), *S. antennatus* 6 (or 1.8%), *S. bedfordi* 46 (or 13.9%), *S. harveyi* 1 (or 0.3%), *S. ingrami* 2 (or 0.60%), *S. kirki* 9 (or 2.7%), and the *Synphlebotomus* complex 8 (or 2.4%).

Table 11.3 shows the natural hosts of *S.garnhami*. The bloodmeals of *S. garnhami* were typed to 13 different animal hosts ranging from reptiles to mammals. 155 (or 62.3%) fed on lizards, 58 (or 23.3) fed on man, 13 (or 5.22%) fed on porcupines whereas 7 (or 2.8%) fed on carnivores. The numbers of *S. garnhami* that fed on the other hosts (bovine, chicken, gerbil, donkey, rodent, ruminant and a wild ruminant described as neither cow, goat or sheep), ranged from 1-3 (or 0.40-1.20%). One mixed feeding of man and a small ruminant was also identified (fig 11.1). These results show that lizards are the preferred natural hosts of *S. garnhami*.

Table 11.2 The number of identified bloodmeals from different sandfly species.

Species	Number identified	Percent
S.garnhami	249	75.5
S.affinis	9	2.7
S.antennatus	6	1.8
S.bedfordi	46	13.9
S.harveyi	1	0.3
S.ingrami	2	0.6
S.kirki	9	2.7
Synphlebotomus	8	2.4
Total	330	100

Table 11.3:- Natural hosts of *S. garnhami* collected from various ecological sites as identified by bloodmeal analysis of engorged females

Nº collected	Nº identified	Host	Fly/ host	Percent/ host
823	249	bovine	2	0.80
		canidae	7	2.81
		chicken	1	0.40
		gerbil	1	0.40
		horse(donkey)	3	1.20
		lizard	155	62.25
		man	58	23.29
		monkey	2	0.80
		porcupine	13	5.22
		rodent	2	0.80
		small ruminant	3	1.20
		small ruminant/man	1	0.40
		wild animal	1	0.40

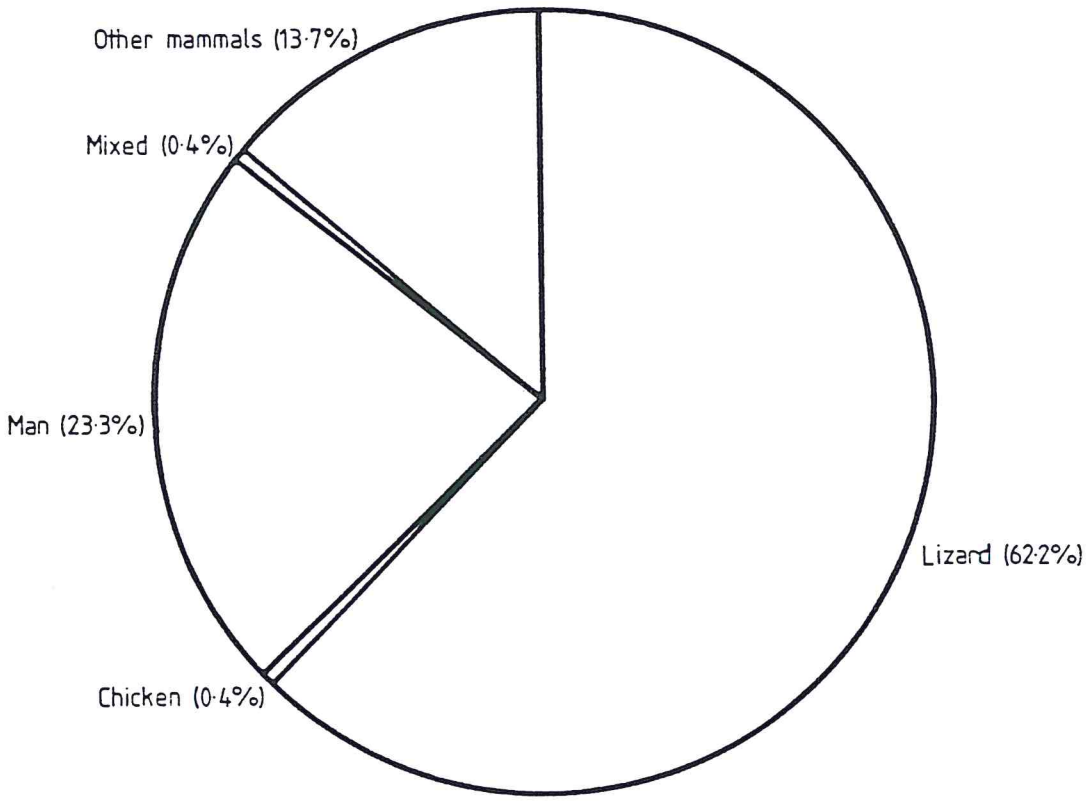


Fig 11.1 Percentage feeding of *S. garnhami* on various hosts

Table 11.4 shows the sites and animal hosts associated with the sites from which the identified S.garnhami bloodmeals were collected. Most of the *S. garnhami* bloodmeals identified were from animal burrows (26 or 10.40%), termite hills (223 or 89.20%) and inside human homes (1 or 0.40%). This is opposed to the 11 ecological sites from which the sandflies were collected (table 11.1).

Seven of the 13 animal hosts of *S.garnhami* were associated with the animal burrows, all the 13 were identified with the termite hills whereas 1 (man) was associated with human homes. In particular man was associated to termite hills and human homes. Of the 58 bloodmeals typed to man only one was collected with sticky trap inside human homes while others were collected through human bait catches on or around the termite hills. This shows that in most cases man is accidentally bitten while pursuing most of his socio-economic activities inside the woods late in the evening while occasional bites may take place at homes.

Three bloodmeals were typed to horse. Horse is a rare game in the area but donkeys are the common beasts of burden. It is likely that the identification is a case of cross reaction between donkeys and horse sera. Two bloodmeals were typed to monkey and were associated to both the animal burrows and termite hills. In the two years of my stay in the area I saw one monkey in the

Table 11.4:- Various animal hosts resting in different ecological sites as identified by bloodmeal analysis of engorged females of *S. garnhami*.

Animal host	Animal burrow	Inside house	Termite hill
Bovine	0	0	2
Canide	6	0	1
Chicken	0	0	1
Gerbil	0	0	1
Horse	1	0	1
Lizard	9	0	146
Man	0	1	57
Monkey	1	0	1
Porcupine	7	0	6
Rodent	1	0	1
Small ruminant	1	0	0
Small ruminant/man	0	0	1
Wild animal	0	0	1
Total	26	1	222
Percent	10.44	0.40	89.16

Kyandani section of the area which is the location of our animal burrows but about 6 km from the location of our termite hills.

Natural hosts of other phlebotomine sandflies encountered in the study were shown in table 11.5 and are summarized as follows:

S. affinis:- Nine bloodmeals were identified, 7 fed on lizards, and 2 fed on chicken.

S. antennatus:- Six bloodmeals were identified, 3 fed on lizards, 2 fed on dogs/canids whereas one fed on porcupine.

S. bedfordi:- 46 bloodmeals were identified, 31 fed on lizards, 2 fed on chicken, 4 fed on dogs/canids, 2 fed on bovids/ruminants, and 7 fed on porcupines.

S. harveyi:- Only one bloodmeal was identified and that fed on lizard.

S. ingrami:- Two bloodmeals were identified, one fed on lizard and the other fed on porcupine.

S. kirki:-Nine bloodmeals were identified and all fed on lizards.

Table 11.5 Natural hosts of other phlebotomine sandflies as identified by bloodmeal analysis

Species	Lizard	Chicken	Dog/ Canide	Bovine/ ruminant	Small ruminant	Porcupine	Total
S.affinis	7	2	0	0	0	0	9
S.antennatus	3	0	2	0	0	1	6
S.bedfordi	31	2	4	2	0	7	46
S.harveyi	1	0	0	0	0	0	1
S.ingrami	1	0	0	0	0	1	2
S.kirki	9	0	0	0	0	0	9
Synphlebotomus	1	1	0	3	3	0	8
Total	53	5	6	5	3	9	81
Percent	65.2	6.2	7.4	6.3	3.7	11.1	

Synphlebotomus species:- Eight bloodmeals were identified, one fed on lizard, one fed on chicken, three fed on bovids and three fed on small ruminants.

It is evident from the results that the *Sergentomyia* species naturally feed mostly on lizards but may also feed on other animals ranging from other reptiles to mammals whereas the *Synphlebotomus* species have preference to mammals (bovids and small ruminants) but may also, in a small scale, feed on lizards and birds.

11.4 Discussions

Bloodmeal identifications have several advantages in the epidemiological investigations of a vector-borne disease. Amongst others, it does not only help in the identification of the natural sources of the insect vector bloodmeals, probable sources of vector infestations with the parasite organisms, but also, through further research, the incrimination of the animal reservoir hosts of the disease organism(s) and finally the elucidation of the transmission links of the disease organism (Washino and Tempelis 1983 Mutinga et al 1990). It also reveals some aspects of the host feeding habits of the blood-sucking insect. The findings of this study showed that *S. garnhami* feed

mostly on reptiles but also feed on other animals including man and other mammals. This is a pointer that epidemiological investigations to incriminate animal reservoir hosts of leishmania parasites found in the guts of this species could be extended to animals yet unthought of. This is important since some blood-sucking insects are known to alter their preferred hosts with season (Gillies 1974, Edman and Taylor 1968, DeFoliart and Ramachandra 1965) and with locality (Garret-Jones 1980, Washino and Tempelis 1983). This behavioural adjustment may no doubt result in shift of roles of the animals as reservoir hosts with seasons or even with localities. However feeding on a wide range of organisms depending on the availability of the host organism or the prevailing local circumstances is opportunistic feeding (Edman et al 1972, McCrae et al 1976). This fact bears heavily on the credibility of the vectorial competence of *S. garnhami* (Chandler et al 1976,). These workers noted that the mosquito species with a narrow range of hosts are most likely to be of importance as vectors of parasitic diseases such as malaria while those species that switch from one group of hosts to another according to local conditions are more likely to be involved in arbovirus transmission (a more or less mechanical transmission). This raises the question of mechanical transmission of leishmanial parasites and the mechanisms involved.

A case of mixed feeding of both man and small ruminants was also observed. This may be a case of interrupted feeding due to several reasons including host reactions (Washino and Tempelis 1983, Davis 1983 and 1990). This also points to the probable efficiency of *S. garnhami* as a mechanical transmitter. Davis (1990) highlighted the merits and demerits of interrupted and mixed feeding including efficiency in mechanical transmission and evolvement of new strains of a pathogen due to genetic recombinations of various strains of the same pathogen.

CHAPTER TWELVE

NATURAL INFECTION RATES OF *S. GARNHAMI* WITH *LEISHMANIA* PROMASTIGOTES

12.1 Introduction

Isolation from a wild-caught sandfly vector of *Leishmania* strains indistinguishable from those locally causing human disease in a given area is an important factor in the interpretation of the vector-borne disease epidemiology (Killick-Kendrick & Ward 1981). Literature is replete with isolation results from established wild caught phlebotomine sandfly vectors. A list of proven and suspected sandfly vectors of leishmanial parasites causing disease in man in different parts of the world has been catalogued by WHO (1984). In Kenya promastigotes have been isolated from the *Synphlebotomus* species (Heisch 1954, 1955, Heisch et al 1962, Minter and Wijers 1963, Minter et al 1962 and Wijers and Minter 1962). Also leishmanial parasites have been isolated from *Phlebotomus pedifer* and from other species of the phlebotomine sandflies (Mutinga 1971, Mutinga and Ngoka 1978 and Peters et al 1977). Isolations of *Leishmania* from *S. garnhami* caused leishmanial type of sores at the nose and tail junctions of Balb/c mice (Mutinga 1986). However, scanty information still exist on the natural infections of *S. garnhami* with leishmania promastigotes.

This work is aimed at reporting further investigations on the rate of natural infections in wild caught *S. garnhami*.

12.2 Materials and methods

Sandflies used for this study were captured from animal burrows, animal enclosures, inside and outside walls of human dwellings, treeholes, tree bases, rock crevices, termite hills and open spaces. They were collected using human baits, sticky traps, aspirator and light trap. Wild-caught sandflies were washed in 1.0% detergent saline to wet and remove the hairs, then rinsed in normal saline. Each sandfly was placed into a drop of normal saline on a new and clean microscopic glass slide. With a pair of dissecting pins mounted on wooden handles, it was dissected under a stereo microscope. One pin was placed on the thorax to hold it in position onto the slide, the other was used to sever the head. The head was separated from the rest of the body and placed in a drop of gum chloral mountant at one end of the slide, covered with a coverslip and left for identification. The gut was dissected out of the body by placing one pin on the thorax to hold it in position whereas the other was used to nip off the last two abdominal segments at the edges and gently pulled to expose the guts. The gut was covered with a clean

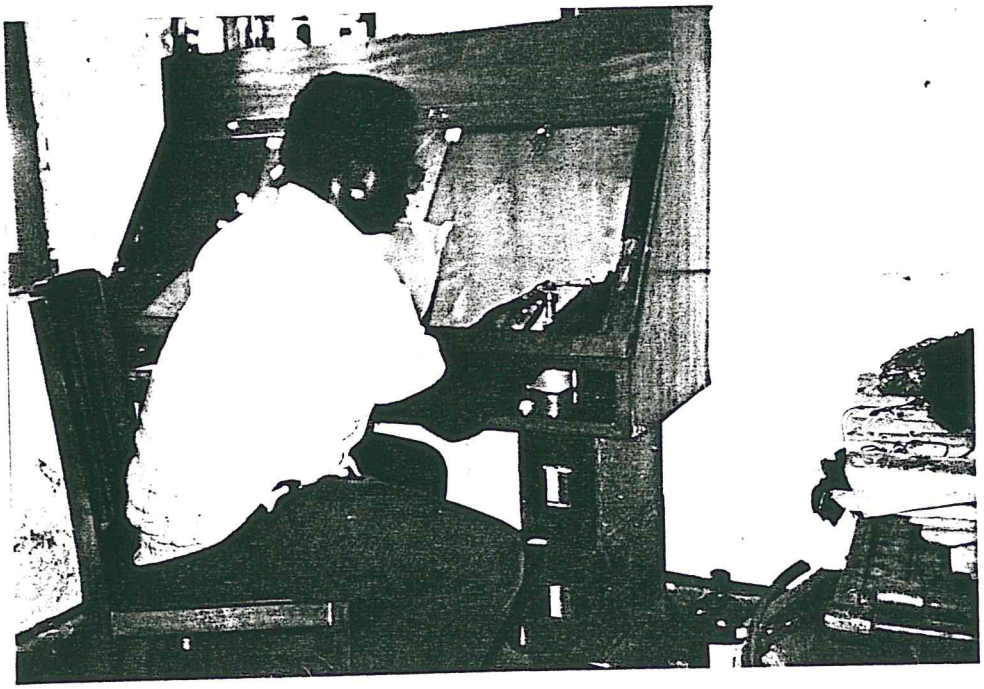


Plate 12.1 Culturing *Leishmania* isolates from wild- caught sandflies under flame in a wooden hood in the field laboratory

coverslip and examined under x40 objective of a compound microscope, starting from the crop to the rectum. Infected guts were triturated and cultured in NNN-diphasic medium using disposable 2 or 5ml sterile syringe and a 21 gauge needle (Plate 12.1).

12.3 Results.

Table 12.1 shows the prevalence of *Leishmania* promastigotes infection in different species of phlebotomine sandflies dissected. 1779 wild-caught female phlebotomine sandflies were dissected 12. This consisted of the *Synphlebotomus* complex females (114) and *Sergentomyia* species (1,665) of which 715 were *S. garnhami*. Other species were *S. affinis* 128, *S. antennatus* 138, *S. bedfordi* 590, *S. clydei* 5, *S. graingeri* 23, *S. harveyi* 11, *S. ingrami* 17, *S. kirki* 31, *S. multidens* 1, *S. schwetzi* 4, *and S. squamipleuris* 3. 82 out of 715 *S. garnhami* or (11.47%) were infected with *Leishmania* promastigotes. Eight of them grew in NNN-diphasic medium and RPMI 1640. They were cryopreserved awaiting identification in the Biomolecular laboratory of I.C.I.P.E. Infections from the other species of the *Sergentomyia* did not grow in the NNN-medium.

Six of the 114 *Synphlebotomus* females dissected were infected with leishmania promastigotes. This is 5.26% natural infection. Three grew up in the NNN

Table 12.1: Prevalence of *Leishmania* promastigotes infection in *S garnhami* and other phlebotomine sandflies.

Species	Nº dissected	Nº infected	Nº negative	Percent infection	Growths in Medium
S.affinis	128	1	127	0.78	0
S.antennatus	138	1	137	0.72	0
S.bedfordi	590	5	585	0.85	0
S.clydei	5	0	5	0	0
S.garnhami	715	82	633	11.47	8
S.graingeri	23	0	23	0	0
S.harveyi	11	0	11	0	0
S.ingrami	17	0	17	0	0
S.kirki	31	5	26	16.13	0
S.multidens	1	1	0	100	0
S.schwetzi	4	1	3	25	0
S.squamipleuris	3	0	3	0	0
Synphlebotomus	114	6	108	5.26	3
Total	1779	102	1678		11

diphasic medium and RPMI 1640. They were also cryopreserved awaiting identification. Altogether 102 sandflies were found infected with leishmanial parasites with infections in *S.garnhami* (82) forming the bulk.

During dissection, the distribution of the parasites within the gut of the sandflies (fig 12.1) were observed. In the *Synphlebotomus* females they were found swarming at the anterior portion of the mid gut whereas in the *S. garnhami* and the other *Sergentomyia* species the promastigotes were swarming in large numbers mainly in the pylorus, hindgut and the rectum. Also *S. garnhami* with parasites distributed throughout the midgut and even the malpighian tubules were encountered. It was also observed that the guts of uninfected flies were streaming with bacteria.

It was observed in the field that at the population peak of *S. garnhami* relatively very few flies were infected and these infections were localised within specific animal burrows and termite hills which were very difficult to locate. As the population declined, the numbers of infected flies increased giving rise to a highly infected residual population. This could be witnessed in the field from the 4th week of May through 3rd week of June and from 4th week of December through 3rd week of January. After this period, *S. garnhami* could hardly be found in the field.

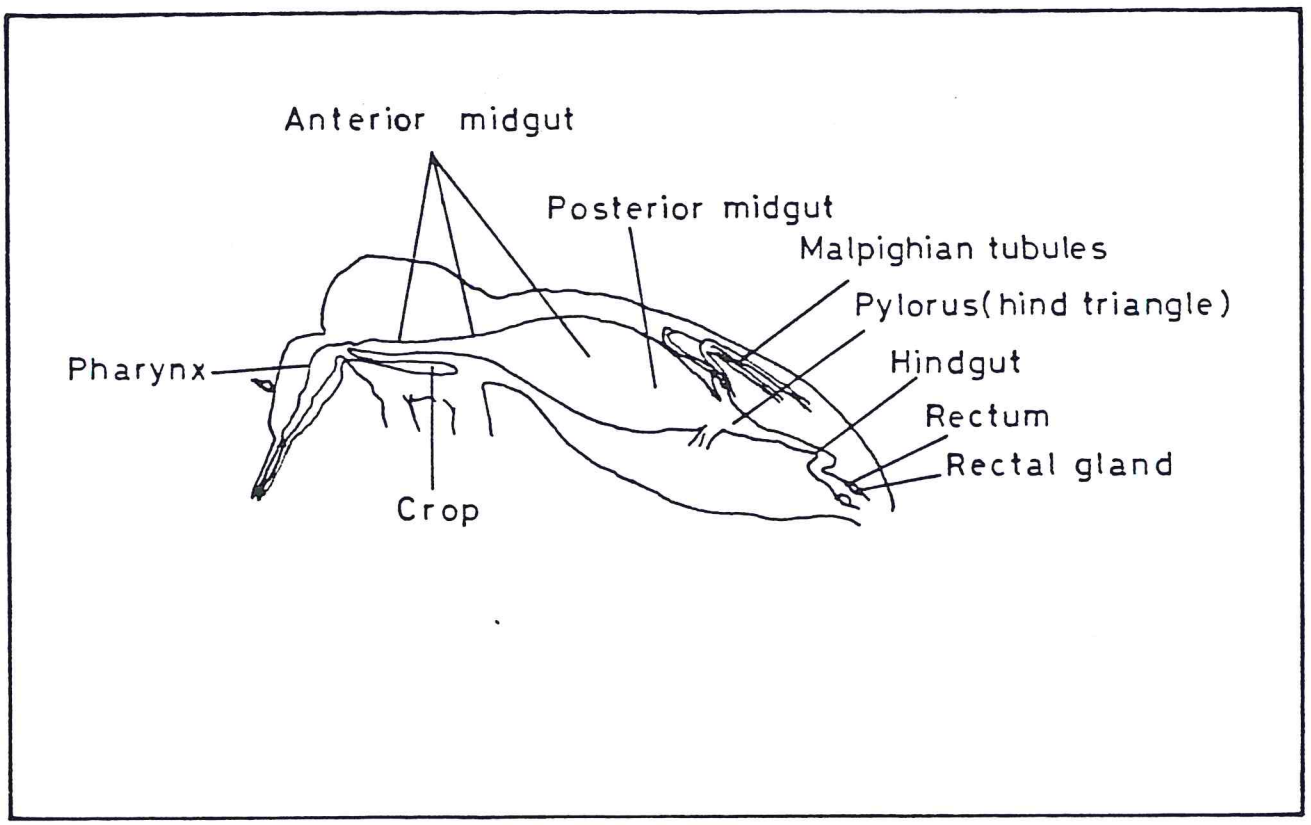


Fig. 12.1 Alimentary canal of a sandfly

Table 12.2: Prevalence of *Leishmania*-infected *S. garnhami* and other phlebotomine sandflies in different sites

Species	Number dissected per site								
	AB	AE	HIN	HOUT	HT	RB	RC	TH	OS
S.affinis	4	0	1	1	1	2	5	114(1)	0
S.antennatus	6	1	20	23	4	1	6	76(1)	1
S.bedfordi	72(1)	1	70	81	5	35	76	250(4)	0
S.clydei	0	1	2	0	0	0	0	2	0
S.garnhami	101(6)	0	3	1	6	14	7	583(76)	0
S.graingeri	1	0	0	0	0	0	0	22	0
S.harveyi	3	0	0	0	0	1	0	7	0
S.ingrami	4	0	0	0	0	5	0	8	0
S.kirki	7(1)	0	0	1	2	2	4(1)	15(3)	0
S.multidens	0	0	0	0	0	0	0	1(1)	0
S.schwetzi	0	0	0	0	0	0	1(1)	3	0
S.squamipleuris	0	1	0	0	0	0	1	1	0
Synphlebotomus	2	0	0	0	0	0	1	111(6)	0
Total	105 (8)	4	96	107	18	60	101 (2)	1193 (92)	1

AB = animal burrow, AE = animal enclosures, HIN = inside house, HOUT = outside house, HT = tree hole, RB = tree base, RC = rock crevices, TH = termite hill, OS = open spaces.

( ) = number infected.

Table 12.2 shows the prevalence of *Leishmania*-infected *S. garnhami* and other phlebotomine sandflies in different sites. 92 out of 102 total infections were found in the termite hills and 76 of this were *S. garnhami*. Eight infections were observed in animal burrows and 6 of them were *S. garnhami*. Only two infections were from the rock crevices. These were one *S. schwetzi* and one *S. kirki*.

12.4 Discussion.

A natural infection of 11.47% in *S.garnhami* was observed in this study. This is in line with the findings of Mutinga and Odhiambo (1982) who had an infection rate of 16.40% while dissecting sandflies attracted to man in Machakos district (a neighbouring district to Kitui District). Kaddu and Mutinga (1982) also found 12 out of 112 *S.garnhami* collected from Tseikuru infected with *Leishmania* promastigotes. Heisch observed 5% infection from *S. garnhami* he collected from Tseikuru. A natural infection rate of 11.47% in *S. garnhami* could be regarded quite high bearing in mind that it is the most predominant species in the area despite its seasonal occurrence (see section on spatial distribution, Heisch 1954, Heisch et al 1956, Minter 1964). This fly prefers resting in termite hills amongst other resting sites and was collected in large

numbers from a single ventilation shaft of a termite hill with an average of 20 shafts. Although 11.47% appears to be a small number, the termite hills are very numerous and scattered all over the place such that if all the shafts were equally productive, the number of *S. garnhami* involved would be quite high. This could possibly initiate infections to epidemic proportion and maintain the disease for the short period this fly flourishes in the field. However, since kala azar is endemic in the area one wonders how the disease transmission at the periods when *S. garnhami* subsides is maintained. The records of the first kala azar epidemics in the area showed this to have started in October 1952 (Heisch 1954), a period preceding the appearance of this fly in the field. A puzzling question is whether *S. garnhami* could have played a role as a mechanical vector enhancing easy spread during the epidemics. Although information on the mechanical transmission of leishmanial parasites of man is scanty, Lainson and Southgate (1965) and Barberrian (1938) successfully used *Stomxys calcitrans* to mechanically transmit *Leishmania mexicanum* amongst hamsters.

The distribution of parasites within the guts of *S. garnhami* did not seem to tally with the WHO guideline on the parasite distribution within the gut of a suspected vector species (WHO 1984). WHO suggested that the parasite distribution would be limited to the

foregut and midgut regions. Kaddu and Mutinga (1982) showed that 5 out of 12 infected *S.garnhami* they collected from Tseikuru had parasites in the malpighian tubules. The parasite distribution in the gut of *S. garnhami* probably corresponded to the peripylaria distribution of Lainson and Shaw (1979).

The observation of increased and localised infections in residual populations could be probably due to increased contact between the few flies and infected reservoir hosts such as lizards and mongooses usually found thriving in the resting sites. The few infections observed during population peaks of *S. garnhami* and other phlebotomine sandflies might be that sudden increase in the population of the flies caused biting nuisance to the animals which in turn adopted protective strategies that led to interrupted or none feeding at all by the sandflies until a build up of tolerance in the animals. Davies (1990) showed how animals could react to the biting insects.

This observation could be of practical value for further studies on *S. garnhami*. It provides the field information on the dynamics of infection in the field. Dissections carried out only during the population peaks or vice versa of *S. garnhami* could give erroneous impressions of the infection rates. It is therefore advisable that dissections to monitor the infection rates should be carried out during the entire season of

its prevalence in the area. However specific studies requiring naturally infected flies could be limited to residual populations. The localisation of infections should encourage the worker not to lose hope after sampling few sites or even to use different methods of trapping to increase his chances.

CHAPTER THIRTEEN

EPIDEMIOLOGICAL INVESTIGATIONS ON THE ROLE OF *S. GARNHAMI* IN THE TRANSMISSION OF LEISHMANIASES

13.1 Introduction

Previous investigations into the role of *Sergentomyia* species of *Phlebotominae* in the transmission of leishmaniasis in Kenya has shown that *S. garnhami* and *S. ingrami* are possibly involved in the disease transmission (Mutinga and Odhiambo 1982 and Mutinga 1986). However, a few factors must be put into consideration before a suspected sandfly species is declared a vector with certainty (Killick-Kendrick and Ward 1981 and WHO 1984). Some of the factors include:

(a) The sandfly must be anthropophilic and present in a place where man becomes infected.

(b) The distribution of a suspected vector should be in accord with the distribution of the disease in man and the sandfly should be sufficiently abundant to assume that it could maintain the transmission of the parasite in nature.

(c) *Leishmania* isolates from the wild-caught suspected sandfly vector should be identical to the

parasite causing disease in man in the same place.

(d) The suspected vector should be able to support full development of the parasite which culminates in the invasion of the pharynx and mouth-parts of the female fly by the parasite.

(e) The suspected sandfly vector should be able to transmit the parasite by bite.

This section is intended to provide basic information on some of these considerations in Tseikuru area of Kitui District through evidence available from this focus and to complement those obtained elsewhere.

13.2 Anthropophily

Human bait catches were carried out by volunteers while sitting on or near the termite hills, inside and outside human habitations. The results revealed further the strong anthropophily of this species. Comparatively more bites were experienced near termite hills than inside and outside human homes. Because investigations during this study showed that termites hills constituted major breeding and resting sites, it appeared that these same habitats formed potentially important foci of feeding for *S. garnhami*. Earlier workers also showed

that *S. garnhami* bites man (Heisch 1954 & 1955a, Heisch et al 1956, Wijers and Minter 1962, Mutinga and Ngoka 1978 and Mutinga and Odhiambo 1982). Although Wijers (1963) reported that this fly bites man reluctantly, Mutinga and Odhiambo (1982) noted that it bit man readily in Machakos district of Kenya. These findings were confirmed by these investigations at or near termite hills in Tseikuru. Host preference studies conducted through bloodmeal analysis of wild-caught bloodfed sandflies showed that amongst other hosts *S. garnhami* also fed on man (about 23%) but preferred lizards in nature.

13.3 Concordance of fly distribution with the disease in man

Tseikuru is the oldest focus of visceral leishmaniasis in Kenya. It has experienced two major epidemics between 1952 and 1954 and in the mid 60's. Since then the disease has assumed endemic state in the area. Spatial distribution studies of *S. garnhami* showed that it is the most abundant sandfly species in Kitui district of Kenya constituting about 48.16% of the total sandfly species population in the area. Earlier workers (Heisch 1954, Wijers and Minter 1962, Minter 1964) recorded high population densities of *S. garnhami* in Kitui district. This raises questions as to the

extent of this phenomenon in similar habitats where the disease occurs. Both epidemic and endemic cases have been reported in Machakos District were *S. garnhami* also occur in large numbers (Mutinga and Ngoka 1978 and Wijers and Kiilu 1982). *S. garnhami* has also been reported in restricted distribution in the Rift valley province (Mutinga 1985) where the disease is also endemic, but has not yet been reported in West Pokot and Baringo districts (Minter 1964) that have recorded both epidemic and endemic cases. Seasonal distribution studies revealed that *S. garnhami* is a seasonal fly being very abundant between April-June and November-January (about 6 months in the year). The adults are rarely present in the field within February-March and from July-October (6 months). Similar records were also observed by Heisch (1954) and Minter (1964). Data on positive cases of *Leishmania* patients reported at Tseikuru health centre from January 1980 to December 1990 (table 13.1) revealed two annual peaks, one in May and the other in September. This was plotted with already known vectors of the *Synphlebotomus* group and *S. garnhami* to synchronise the trend (figs 13.1, 13.2 and 13.3). The two groups showed the same basic trend with the patient population. The people suffering from the disease in the population increased with decreased sandfly populations. *S. garnhami* graph showed a remarkable break during July-October dry season period

Table 13.1 Monthly incidence of leishmaniasis cases in relation to *S.garnhami* and the *Synphlebotomus* complex species populations.

Month	Patient	*Garnhami*	*Synphlebotomus*	*Martini*	*Celiae*
Jan	6	1691	17	9	8
Feb	5	136	75	19	54
Mar	16	8	38	8	29
Apr	20	371	108	42	64
May	24	2674	145	49	86
Jun	10	154	96	23	70
Jul	16	0	67	15	45
Aug	21	0	30	10	13
Sep	25	0	38	14	20
Oct	21	0	48	11	35
Nov	12	407	474	70	372
Dec	17	944	45	18	22

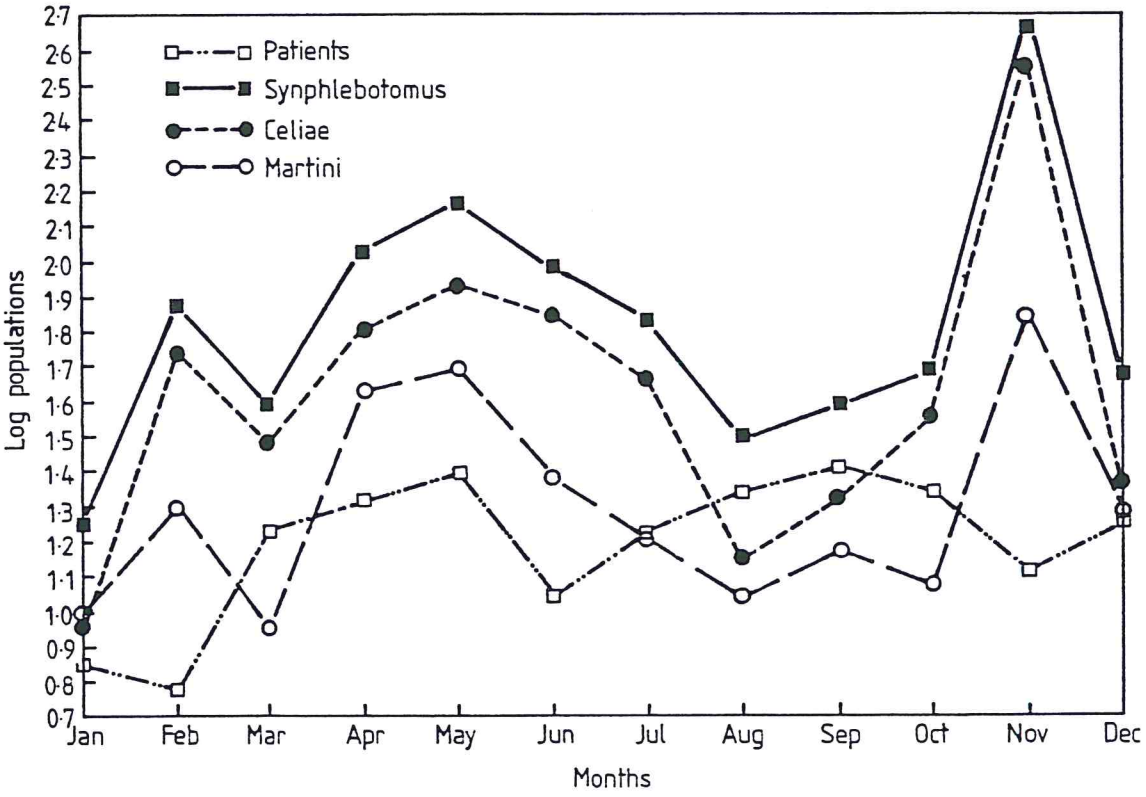


Fig 13.1 Monthly incidence of kala azar patients in relation to Synphlebotomus complex species population

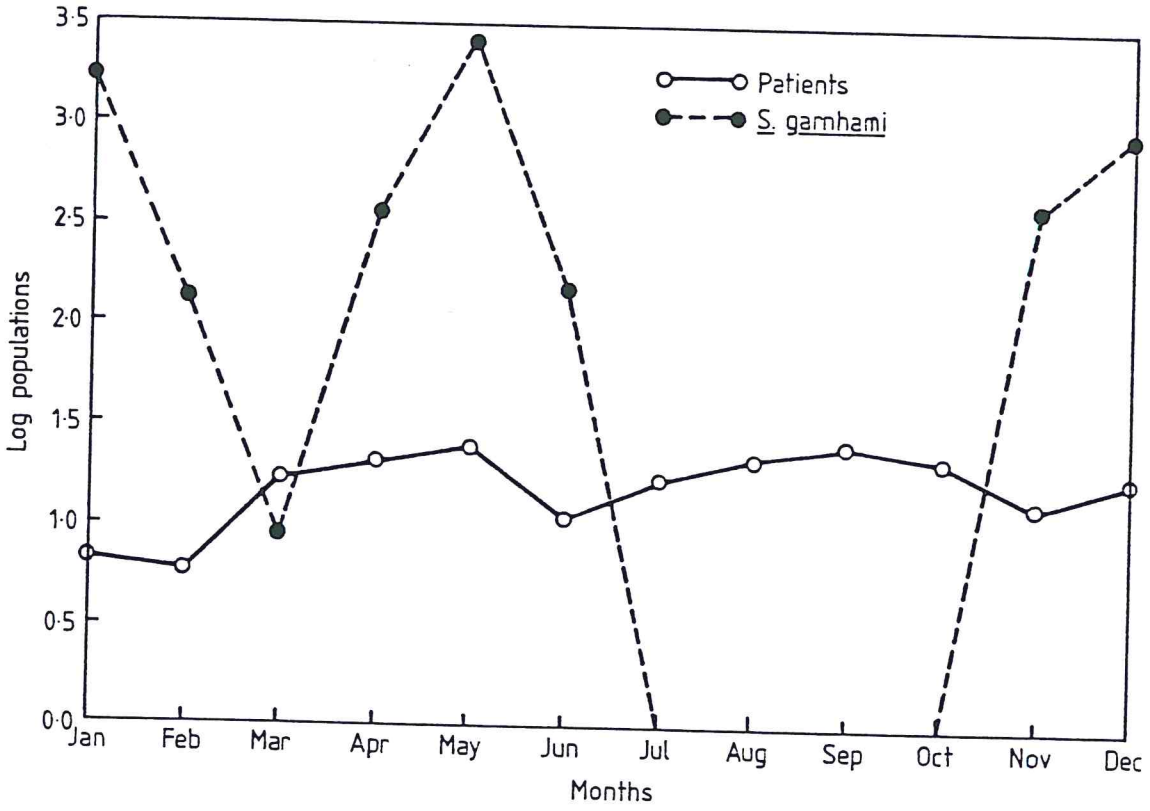


Fig 13.2 Monthly incidence of kala azar patients in relation to *S. garnhami* populations

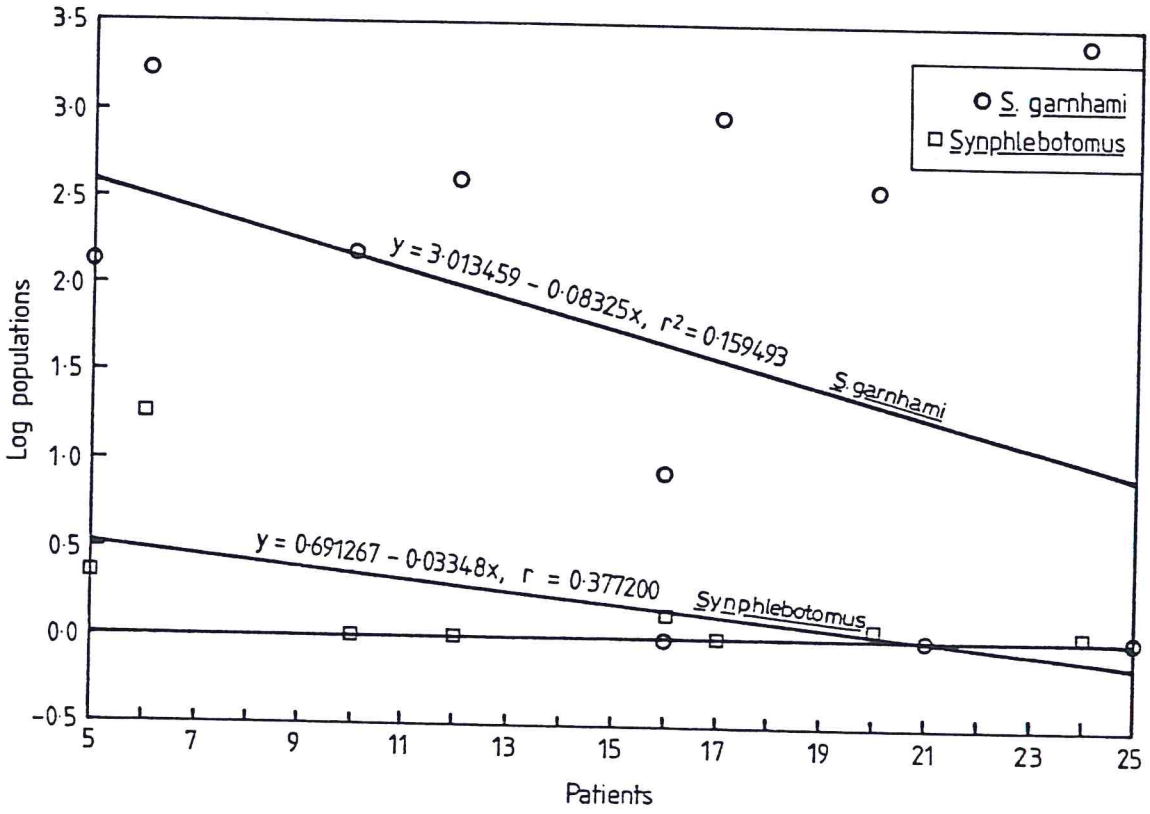


Fig.13.3 Scatter plots of monthly incidence of Kala azar patients against *S. garnhami* and Synphlebotomus complex populations

whereas the *Synphlebotomus* group were continuous with the upward trend. Scatter plots of sandfly populations against those of patients also showed decreased sandfly population with increased patient population ($Y = 3.013459 - 0.08325X$, $r^2 = 0.159493$ for *S. garnhami*, and $Y = 0.0691267 - 0.03348X$, $r^2 = 0.377200$ for the *Synphlebotomus* complex). Correlation analysis using Statistical Analysis Systems Programmme (SAS) showed that patients populations had non-significant negative correlation with both *S.garnhami and P. celiae* populations ($r = 0.40501$, $P = 0.1915$ for *S.garnhami* and $r = 0.00459$, $P = 0.9887$ for *P.celiae*), but non-significant positive correlation with *P. martini* and all the *Synphlebotomus* complex species populations put together ($r = 0.04661$, $P = 0.8856$ for the *Synphlebotomus* and $r = 0.04661$, $P = 0.7959$ for *P.martini*).

13.4 *Leishmania* isolates to be identical to those causing disease in man.

About 11.5% of 783 wild-caught female *S. garnhami* dissected had leishmanial promastigotes in their gut. Eight successfully grew up in NNN-medium and are still waiting for identification. Mutinga and Odhiambo (1982) observed 16.4% natural infection in wild caught *S. garnhami*. Kaddu and Mutinga (1982) noted that 12 out 112 wild-caught *S. garnhami* were infected with

leishmanial promastigotes. Heisch (1954) obtained a lower infection rate with wild caught *S. garnhami*. Earlier studies showed that *Leishmania* isolates from *S. garnhami* caused leishmania major type of sores in the nose and tail junctions of balb/c mice (Mutinga 1986). Host preference studies showed that *S. garnhami* prefers lizards in nature. Mutinga (1986) also had similar results. *Leishmania* isolates from lizards from Tseikuru and other parts of Kenya were recently identified to be *L. major* (Okot-Kotober et al 1989). So far none of the isolates reported by various workers have been identified to enable a definite conclusion.

13.5 Vector to be capable of supporting the full life cycle of the *Leishmania* parasite

Presently none of the experimental studies were aimed at further understanding of the parasite cycle in the fly. Heisch (1954) obtained 5% infection with *S. garnhami* collected from Tseikuru by allowing them to feed on visceral leishmaniasis (causative organism = *L. donovani*) patients. However an attempt to infect six species of laboratory reared sandflies including *S. garnhami* by feeding them on mammalian blood containing cultured promastigotes of *Leishmania donovani* showed that promastigotes were not found in *S. garnhami* when dissected five days latter (Kaddu et al 1986). However

only one out 10 *S. garnhami* used in the artificial feeding experiment fed through the cockerel membrane and it was the only one dissected. It was noteworthy from the results of the experiment that *Leishmaniae* promastigotes were found in the rates of 9.3% of *S. schwetzi*, 25% of *S. adleri* and 37.5% of *S. ingrami* used in the experiment. This is a pointer that *Sergentomyia* species could possibly maintain *L. donovani* in their guts. Field observations showed that large numbers of promastigotes were found swarming in the gut of *S. garnhami*. Studies on the distribution of the parasites within the gut indicated that most of the parasites were found in the hind gut and rectum although some were found in the midgut and anterior station. Mutinga (1986) observed parasites in the anterior station of *S. garnhami*. Kaddu and Mutinga (1982) observed that 5 out of 12 infected *S. garnhami* caught from Tseikuru had their parasites in the malpighian tubule.

13.6 Sandfly vector to be capable of transmitting the parasite by bite.

Meanwhile no experimental work has been done on this regard.

13.7 Discussion

S. garnhami satisfies the conditions of anthropophily, distribution in accord with the distribution of disease in man in both Kitui and Machakos districts, and high percentage of natural infections with leishmanial promastigotes. It is however unfortunate that none of the parasites isolated from it has been identified to date. From the available information therefore, *S. garnhami* is apparently a promising vector but few hurdles need to be scaled through before it could be called a vector with certainty. More work is required in the areas of identification of the parasites, studying of the life cycle of the parasite in *S. garnhami* and experimental infectivity studies. Host preference studies indicated that this fly feeds on a number of hosts indicating that it may be more fitted as a mechanical vector. Evidence on mechanical transmission of leishmaniasis by insects is scanty. Lainson and Southgate (1965) showed that *Stomxys* could transmit *Leishmaniae* mechanically by demonstrating *Leishmaniae* in the nasal secretions of dogs. Other established lines of transmission include

(a) Bites by infected proven sandfly vector (Swaminath et al 1942)

(b) Congenital infection via faeces or nasal mucus (Lowe & Cooke 1926 cited by Wilcocks and

Manson-Bahr 1980)

(c) Intradermal inoculation with needles (Manson-Bahr 1959, cited by Wilcocks and Manson-Bahr 1980)

The last two methods are equally suggestive of possible mechanical transmission of *Leishmaniae* by sandflies and probably other blood sucking flies. It would be worthwhile if this possibility is explored with regards to the true position of *S. garnhami* in leishmaniasis transmission.

SUMMARY

1 Ecological studies on *S. garnhami*, a suspected phlebotomine sandfly vector, have been undertaken from January 1989 to December 1990, in a kala azar endemic focus of Tseikuru in Kitui District. The studies carried out were the determination of the breeding and day-resting sites, distribution in various ecological habitats, vertical distributions in wooded and open field environments, seasonal distribution in relation to climatic factors, microclimatic and edaphic factors influencing *S. garnhami* in their breeding habitats, hourly feeding patterns, natural host preferences of *S. garnhami* and natural infection rate of *S. garnhami* with *Leishmania* promastigotes. The epidemiological role of *S. garnhami* was explored in line with WHO (1984) guideline. Before the full scale studies, a preliminary survey of the distribution of sandfly breeding and day resting sites was undertaken.

2 Experiments to determine the breeding sites of *S garnhami* showed that phlebotomine sandflies were recovered from 15 out of the 17 ecological habitats studied whereas *S. garnhami* was recovered from fourteen showing that *S. garnhami* and other phlebotomine sandflies have a very wide distribution of breeding sites. The termite hills were the most preferred breeding sites for most phlebotomine sandflies but it

was not possible to identify the preferred breeding sites of *S. garnhami* as all the sites yielded between one and three flies. *S. garnhami* were recovered from soil samples from both inside and outside human homes as well as from sylvatic sites with the possible implication of increasing the man-fly contact. Daily pattern of emergence showed that 60 days were sufficient for most sandflies to emerge while at least 100 days were required for *S. garnhami*. *S garnhami* was recovered in experiments conducted in February, September and March but not from that of June indicating that this species probably goes into quiescence between February and April but undergoes full diapause between June and October as a result of prolonged dry season.

3 Investigations on the day resting sites of *S. garnhami* showed that *S. garnhami* constituted 23.35% of the total collections with termite hills being the preferred day resting site. *S. garnhami* was collected in 9 out of 10 sites investigated suggesting a wide distribution of the resting sites. A weekly record of *S. garnhami* collections starting from the first week of November showed that *S. garnhami* was collected from the field three weeks after the first rains of the season. This duration was different from the laboratory observation of 60-98 days and raised the question of what stage of the fly goes into diapause or whether it

was a case of rapid development with the return of good weather conditions.

4 The distribution studies of *S. garnhami* and other phlebotomine sandflies revealed that *S. garnhami* was collected in large numbers from all the sites investigated but termite hills, animal burrows, rock crevices, treeholes and treebases were the preferred sites. Amongst the subsites exposed termite hills were preferred to those under shade. Small animal burrows were preferred to the large ones. There were no significant differences between open field with vegetation and those without vegetation and between treeholes and treebases. Tree stems were preferred to tree foliage. There was no significant difference between thicket floors and thicket foliage. *S. garnhami* constituted 48.16% of the total collection and is the most prevalent species in the area. The determination of pattern of distribution of *S.garnhami* and other phlebotomine sandflies in the various sites by calculation of variance, index of aggregation (K) and coefficient of variation (CV) showed that sandflies have strongly clumped populations.

5 Vertical zonation studies showed that *S. garnhami* and other sandfly populations decreased with the increased height with the highest number caught between

0-2m height. *S. garnhami* was not collected beyond 6 8m height. A total of 3272 sandflies were collected of which 67.18 % were from the woodland. 16 species of sandflies were collected comprising 2 Phlebotomus species and 14 *Sergentomyia* species.

6 Investigations on the seasonal population dynamics of *S. garnhami* showed that two annual peaks of *S. garnhami* and other sandfly species (one in May and the other in December) were observed. Peak populations of *S. garnhami* and other phlebotomine sandflies were observed within temperature range of 28.5-31.5°C, relative humidity range of 60-80% and rainfall range of 0-40mm. The influence of 3 climatic factors (temperature, humidity and rainfall) were considered and significant interplay between them observed. Temperature conditions were stable but the relative humidity fluctuated heavily with rainfall pattern. Rainfall supplies moisture to both the habitats for the development of immature stages and also to the atmosphere enhancing adult survival.

7 Studies on the influence of microclimatic factors on the distribution of *S. garnhami* showed that the immature stages of *S. garnhami* and other phlebotomine sandflies thrived well within the temperature range of 19-23 °C and moisture content of 80 to 100% in all the

sights investigated. Temperature values were stable throughout the year and moisture was considered important in sustained population of *S. garnhami* and other phlebotomine sandflies.

8 Investigations on the influence of edaphic factors on the populations of *S. garnhami* revealed that calcium, magnesium and soil texture were positively correlated with *S. garnhami* and other sandfly species in both seasons with only calcium significant whereas sodium, potassium, carbon, phosphorus and capillarity were negatively correlated with *S. garnhami* and other sandfly species populations in both seasons. Exchangeable salts and Manganese were either positively or negatively correlated with *S. garnhami* and other sandfly species depending on the season. Because *S. garnhami* were collected within and outside the requirement limits of these factors it was suggested that rearing in substitution diets will clarify the limiting value of each factor. High capillarity rate was a factor in increased water loss from the habitats and therefore an important factor suppressing *S. garnhami* and other sandfly populations.

9 Studies on the hourly feeding pattern of *S. garnhami* showed that it was caught biting man throughout the night while sitting on or around termite hills with

peaks between 1800-2000hr, 2300-2400hr and 0400-0500hr. The highest landing rate was observed between 1800-2000hr. Occasional bites of one fly/hour between 1800-2000hr were observed within or outside human homes. Few *S. garnhami* were caught from the animal baited cages placed near termite hills in different hours of the night.

10 Bloodmeal identifications to determine the natural host preference of *S. garnhami* showed that *S. garnhami* bloodmeals were typed to 13 different hosts ranging from reptiles to mammals including man but naturally prefers to feed on lizards. All the 13 hosts were identified to be associated with termite hills whereas seven were identified to animal burrows.

11 Natural infection studies showed that 82 (or 11.47%) of 715 wild-caught female *S. garnhami* dissected were found infected with *Leishmania* promastigotes and 8 of then grew in NNN-diphasic culture medium.

12 Investigations on the epidemiological role of *S. garnhami* showed that *S. garnhami* satisfies the conditions of anthropophily, concordance of its distribution with the disease distribution in man and high percentage of natural infections but more work is required in the areas of parasite identification,

studying the parasite life cycle in the fly and experimental infectivity studies.

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APPENDICES

APPENDIX 1: COMMON CHEMICALS AND CULTURE MEDIA USED IN SANDFLY ECOLOGY STUDIES

GUM CHLORAL MOUNTANT

Distilled water	10ml
Gum acaccia powder	8g
Chloral hydrate	70g
Glyceril	5ml
Acetic acid (Glacial)	3ml

BERLESE FLUID (MOUNTANT)

Distilled water	10ml
Gum acaccia	20g
Chloral hydrate	50g
Glyceril	20ml
Acetic acid (Glacial)	3ml

NESBIT SOLUTION (CLEARING FLUID)

Distilled water	25ml
Chloral hydrate	40
Acetic acid (Glacial)	25ml

Preparation

The same method is used in the the preparation of gum chloral, Berlese and Nesbit solutions. The ingredients are dissolved in a water bath at about 80°C in the order named above and the fluid filtered through 3 or 4 thickness of clean damp absorbent gauze. If there are no water bath proceed without it. Precaution is to add the acid bit by bit to avoid explosion.

LACTOPHENOL (CLEARING FLUID)

Phenol crystal	650 cc	(1 part)
Glycerine	1,300cc	(2 parts)
Distilled water	650cc	(1 part)
Lactic acid	650cc	(1 part)

Preparation

Put the bottle containing the 650cc of phenol crystal in a dish of cold water and slowly heat until all the phenol has dissolved. Add 1,300cc of glycerine, stir, and add 650cc water. Lastly add lactic acid bit by bit.

NORMAL SALINE

Dissolve 0.85g of NaCl in 100ml distilled water or 8.5g of NaCl in 1000ml of distilled water.

LOCK'S SOLUTION

Distilled water	1000ml (dionized)
Nacl	8g
KCl	0.2g
$CaCl_2$	0.2g
KH_2PO4	0.3g (Potassium dihydrogen orthophosphate)
Glucose	2.5g

Preparation

Dissolve the ingredients in order in dionized distilled water, stir until completely dissolved, dispense in small bottles and sterilize in autoclave 15-30 above 250°F

BUFFERED DISTILLED WATER pH 7.2

Distilled water	100ml
KH_2PO_4	0.18g
NaH_2PO_4	0.81g

NNN MEDIUM (NOVY, NICOLE McNEAL CULTURE MEDIUM)

Distilled water	2000ml
Peptone agar	40g
Beef extract	50g
Nutrient agar	40g
NaCl	10g

Preparation

Add 20% rabbit heart blood to the solution. Sterilize at 250-259°F for 30min . Then add antibiotics (streptomycin 1ml and 1ml of procaine penicillin). The antibiotics are prepared by adding 5ml of distilled water to 5g of Streptomycin powder and 10ml of distilled water to 10g of procaine penicillin powder. Dispense in bottles and store at -4°C.

RPMI 1640 (CULTURE MEDIA)

Sterile dionized redistilled water	1000ml
RPMI powder	10.43g
Hepes powder	5.206g
NaCl	1.8g
$NaHCO_3$	2.0g

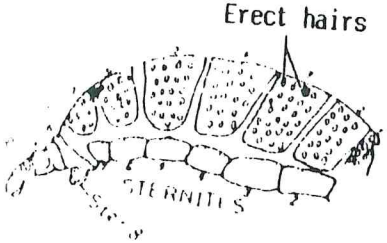
Preparation

Dissolve the ingredients in order and filter with filter membrane. This sterilizes the fluid. Add 20% foetal calf serum which is mycoplasma screened and virus cleaned. Then add antibiotics (1ml Streptomycin and 1ml Procaine penicillin, prepared as in NNN-medium).

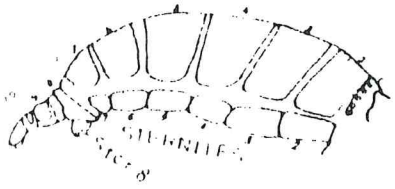
APPENDIX 2: STEPS IN SANDFLY IDENTIFICATION

Distribution of erect hairs

1



Phlebotomus sp.

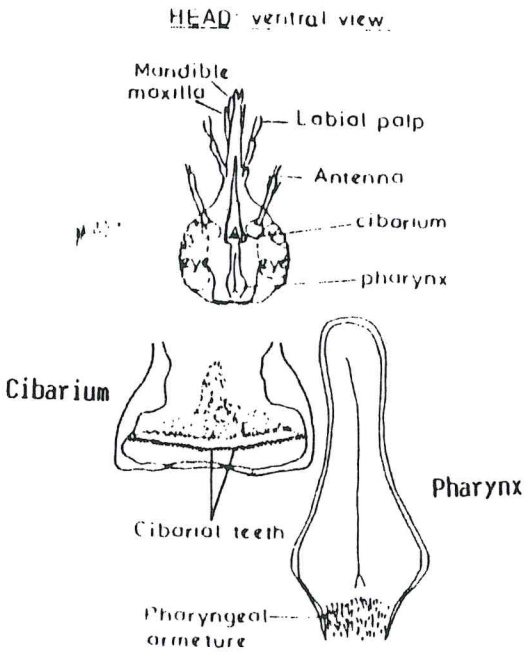


Sergentomyia Sergentomyia sp.

Sergentomyia Sintonius sp

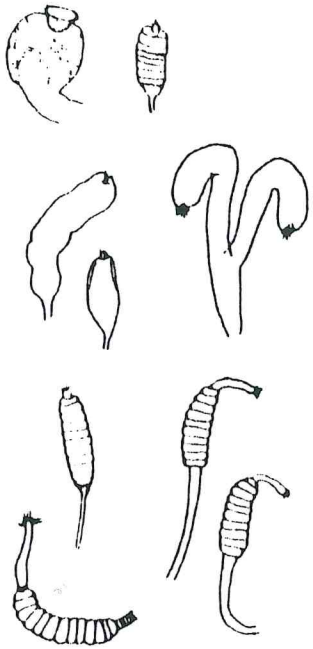
Head showing cibarium & pharynx

2



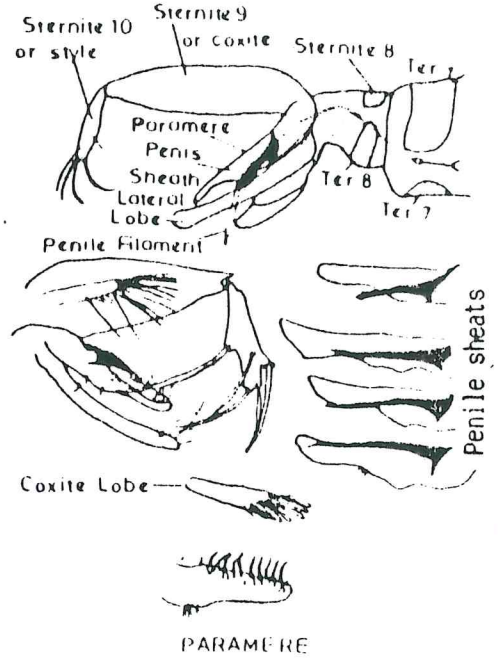
Types of Spermatheca

3



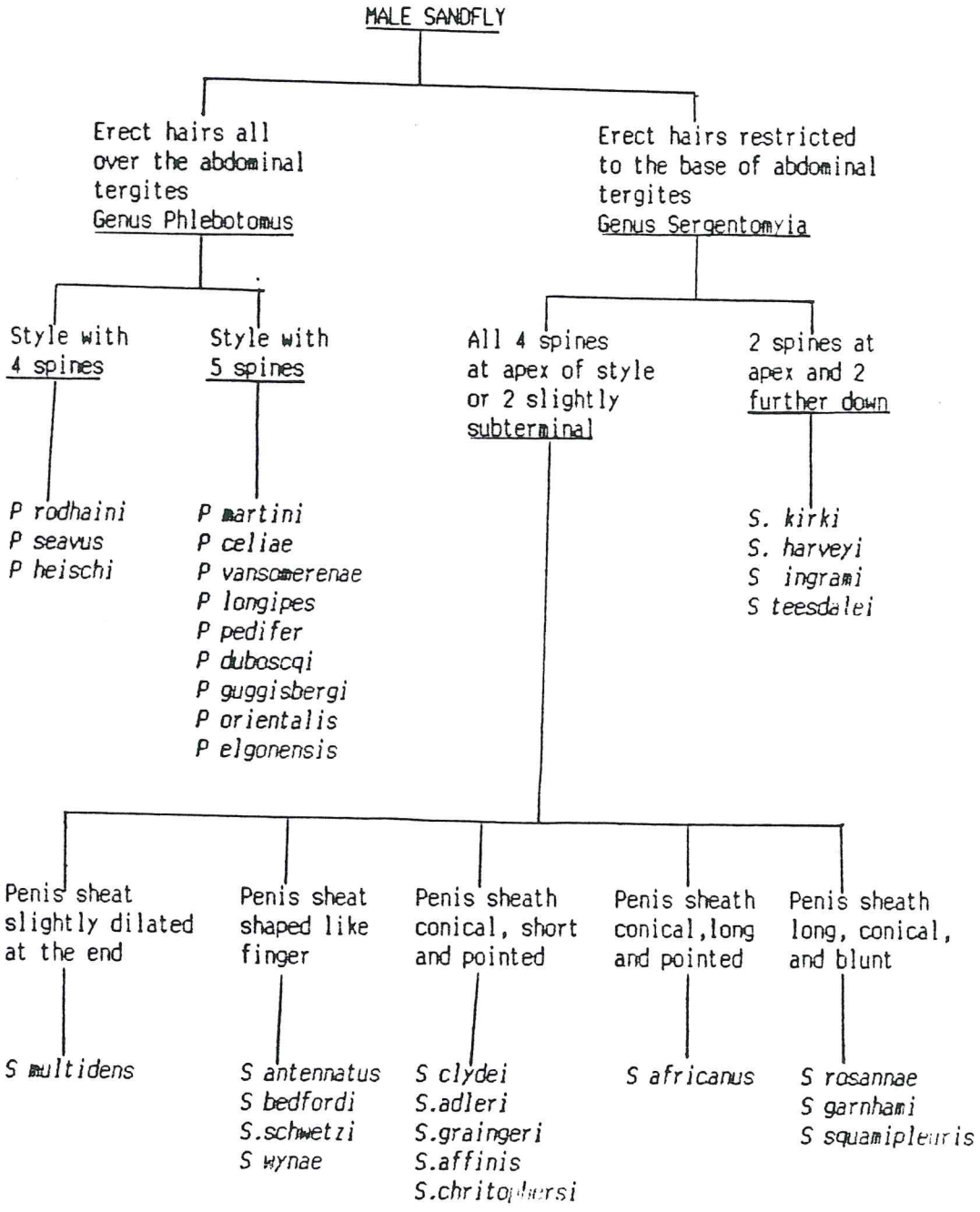
Male Terminalia

4



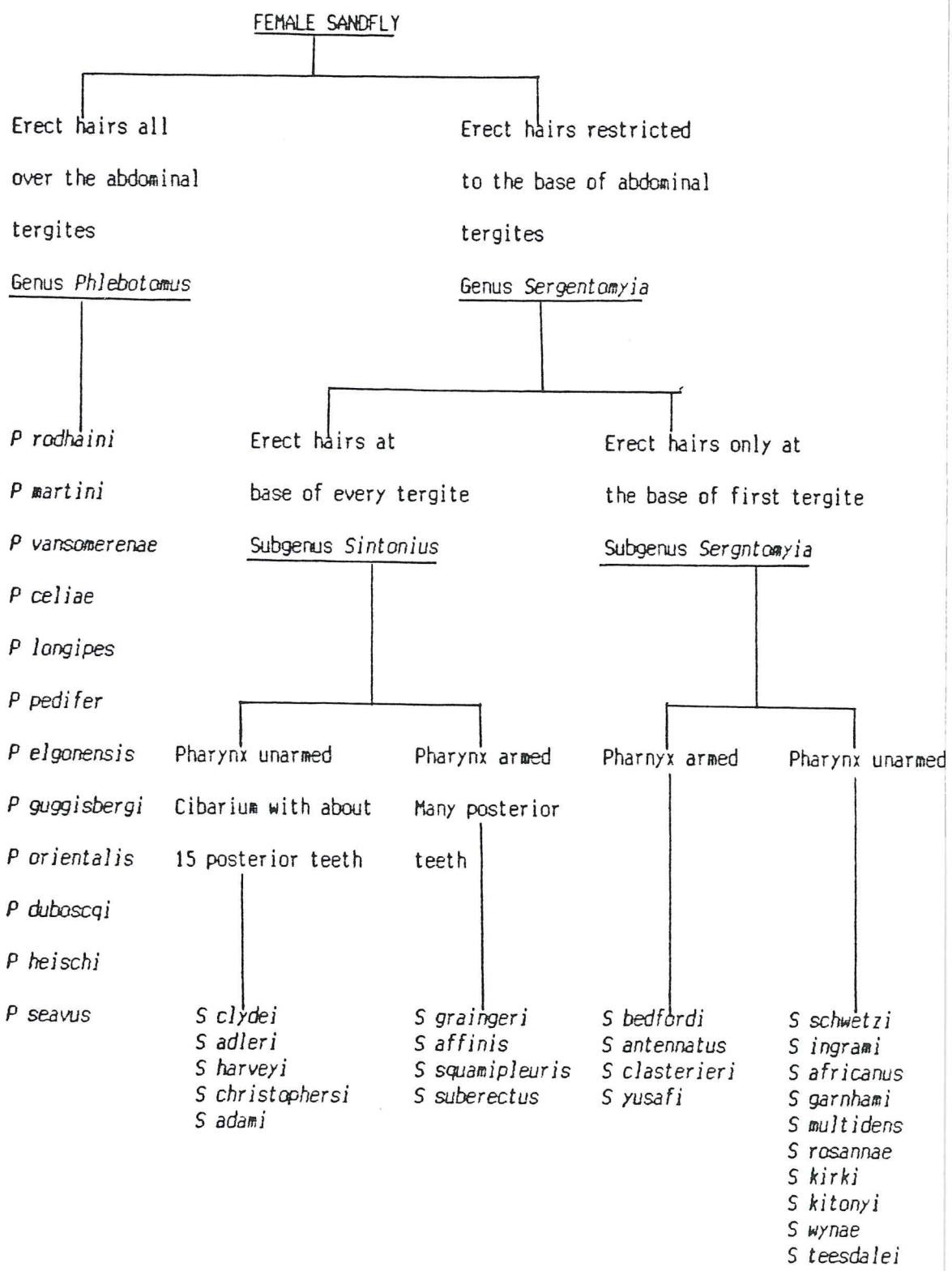
APPENDIX 3

CHART FOR THE IDENTIFICATION OF MALE PHLEBOTOMINE SANDFLIES



APPENDIX 4

CHART FOR THE IDENTIFICATION OF FEMALE PHLEBOTOMINE SANDFLIES



APPENDIX 5 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM TERMITE HILLS (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	1	7	23	31	26	3	33	31	54	32	24	46	23	22	8	5	7	13	17	18	129	243	17	5	818
P.martini	4	5	12	7	6	2	23	19	40	9	17	6	11	4	4	6	7	7	1	10	22	48	14	4	288
S.vansomerenae	0	0	2	0	0	1	4	1	3	7	1	2	2	5	7	0	2	2	1	1	27	5	2	3	78
S.adleri	0	4	0	0	0	0	0	3	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	10
S.affinis	25	62	41	9	13	7	30	127	396	226	52	7	1	5	3	7	3	3	4	2	59	280	352	133	1847
S.antennatus	22	30	36	24	29	6	4	5	19	6	41	52	14	16	8	4	10	13	16	19	34	11	75	13	507
S.bedfordi	22	7	49	99	71	40	43	115	306	65	279	262	139	72	36	27	14	21	10	10	39	85	535	208	2554
S.christophersi	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	4
S.clydei	22	28	1	1	1	0	0	1	0	31	0	2	0	0	0	0	1	3	0	0	1	0	6	0	98
S.garnhami	284	601	132	0	0	0	0	467	1282	1861	281	12	0	0	0	0	0	0	0	0	0	298	3380	1375	9973
S.graingeri	1	0	1	1	0	0	1	1	19	1	8	6	0	0	2	1	1	0	3	3	15	42	87	6	199
S.harveyi	1	2	5	0	0	0	0	0	0	3	5	1	0	0	0	0	0	0	0	0	0	0	2	1	20
S.ingrami	1	1	3	0	0	1	1	13	89	39	13	1	0	0	0	0	0	1	0	0	0	5	128	80	376
S.kirki	33	23	26	1	0	0	0	10	57	60	5	0	0	0	0	0	0	0	0	0	0	0	987	203	1405
S.multidens	3	15	3	0	0	0	0	55	31	8	9	0	0	0	0	0	0	0	0	0	0	11	109	28	272
S.rosannae	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
S.schwetzi	18	5	7	3	7	1	2	5	6	0	17	4	2	0	1	1	0	3	1	3	0	8	6	3	103
S.squamipleuris	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
S.suberectus	12	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Biweekly total	449	792	341	176	153	61	142	853	2302	2348	753	402	193	124	72	51	45	66	53	66	326	1036	5702	2062	18568

APPENDIX 6 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM TERMITE HILLS (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	1	10	56	44	44	59	13	83	44	53	77	27	46	36	27	28	37	15	34	47	156	259	44	17	1257
P.martini	9	10	13	14	16	33	22	42	17	25	15	16	17	15	13	14	14	10	25	23	13	53	28	12	469
P.vansomerenae	7	10	19	17	12	8	13	73	23	23	25	3	27	3	5	9	2	2	2	0	28	19	7	2	339
S.adleri	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3
S.affinis	63	38	56	18	25	61	20	263	127	82	32	15	3	3	1	0	0	0	0	2	0	9	140	40	998
S.antennatus	9	34	30	45	67	63	33	18	12	22	56	33	26	22	23	30	10	14	11	10	14	22	19	13	636
S.bedfordi	111	91	72	60	113	344	85	336	383	416	538	198	177	136	99	115	57	34	44	23	71	126	226	133	3988
S.clydei	3	1	9	0	3	3	9	12	4	0	0	3	1	0	0	0	0	0	3	0	1	4	6	5	67
S.garnhami	594	1097	112	24	0	8	6	365	1169	1505	143	11	0	0	0	0	0	0	0	0	0	407	659	285	6385
S.graingeri	0	2	1	0	1	20	1	24	13	6	2	2	0	0	0	0	0	1	0	0	11	3	48	14	149
S.harveyi	3	5	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	15
S.ingrami	7	1	0	0	0	0	2	1	3	2	20	3	0	0	0	0	0	0	0	0	0	13	3	10	65
S.kirki	107	206	67	13	4	6	9	176	210	267	3	0	0	0	0	0	0	0	0	0	0	0	394	256	1718
S.multidens	21	7	0	7	1	11	1	14	7	3	0	0	0	0	0	0	0	0	0	0	0	67	6	4	149
S.schwetzi	56	32	5	5	9	9	5	25	36	6	3	1	2	0	0	1	0	4	0	0	3	7	24	19	252
S.squamipleuris	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Biweekly total	991	1544	440	249	295	625	219	1434	2048	2413	914	312	299	215	168	198	120	80	119	105	297	989	1605	812	16491

APPENDIX 7 BIWEEKLY AND MONTHLY COLLECTIONS OF SANDFLY SPECIES FROM ANIMAL BURROWS (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	1	0	0	7	1	0	0	0	3	1	4	2	2	2	1	0	0	0	0	0	0	1	25
P.martini	0	0	1	0	2	1	4	0	0	2	13	3	1	7	11	6	4	10	13	26	6	0	1	0	111
P.vansomerenae	0	0	0	0	0	3	0	0	0	0	1	0	1	1	3	0	0	0	0	1	0	0	0	0	10
S.adleri	2	0	0	0	0	0	0	0	0	2	0	3	0	0	1	0	0	0	0	0	0	0	0	0	8
S.affinis	0	2	4	21	14	52	37	0	4	3	14	57	35	11	6	0	11	6	3	11	2	0	3	3	299
S.antennatus	1	4	5	12	11	4	0	0	2	1	3	4	13	9	16	25	22	30	50	22	1	0	0	1	236
S.bedfordi	18	26	48	209	169	138	158	8	40	23	171	229	352	381	434	362	212	270	410	377	134	0	12	39	4220
S.christophersi	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
S.clydei	3	3	0	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	14
S.garnhami	103	581	250	82	12	0	0	2	173	475	1186	84	27	6	0	0	0	0	0	0	0	0	64	47	3092
S.graingeri	0	0	0	0	0	0	0	0	1	0	1	2	3	0	0	6	3	0	0	0	0	0	0	0	16
S.harveyi	4	3	3	1	0	0	3	0	0	4	0	3	5	3	0	0	0	0	0	0	0	0	0	9	38
S.ingrami	0	0	0	0	1	1	0	0	1	0	14	3	0	1	0	0	0	0	0	0	0	0	0	1	22
S.kirki	10	15	2	6	0	0	0	0	9	4	4	0	0	0	0	0	0	0	0	0	0	0	73	14	137
S.multidens	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4
S.schwetzi	0	6	4	3	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
S.squamipleuris	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
Biweekly total	143	640	318	340	212	213	204	10	230	515	1411	389	441	421	473	401	253	316	477	437	145	0	153	115	8257

APPENDIX 8 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM ANIMAL BURROWS (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
P.martini	1	1	1	0	0	0	0	0	0	0	0	0	0	5	0	1	4	16	10	2	6	0	0	0	47
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
S.adleri	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
S.affinis	0	0	4	0	1	2	0	0	0	0	20	8	2	1	2	2	4	2	10	10	0	0	0	0	68
S.antennatus	0	1	1	7	0	0	0	0	0	0	5	3	8	5	11	16	94	70	76	42	0	0	0	0	339
S.bedfordi	38	48	48	229	172	124	1	1	34	60	192	263	267	283	260	537	550	634	595	339	15	11	8	20	4729
S.clydei	0	0	0	2	0	0	0	0	2	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	8
S.garnhami	548	450	191	40	2	1	0	2	94	1147	264	46	41	0	0	0	0	0	0	0	0	0	44	54	2924
S.graingeri	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	4
S.harveyi	8	6	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	31
S.ingrami	0	0	2	0	0	0	0	0	1	1	16	2	1	0	0	0	0	0	0	0	0	0	0	0	23
S.kirki	15	12	9	9	3	0	0	0	32	37	1	0	1	0	0	0	0	0	0	0	1	0	52	12	184
S.multidens	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
S.schwetzi	9	9	1	0	0	0	0	0	0	1	4	1	1	0	0	0	0	0	0	0	0	0	0	0	26
S.squamipleuris	0	0	1	0	3	1	0	0	4	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	11
Biweekly total	619	528	259	289	181	130	1	3	167	1246	504	324	321	297	274	558	655	723	691	393	22	11	104	98	8398

APPENDIX 9 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM ROCK CREVICES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	1	0	0	0	0	0	0	0	2	2	0	0	0	0	1	0	1	3	0	0	0	0	10
P.martini	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	1	0	1	7	0	0	5	18
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
S.adleri	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	5
S.affinis	6	2	2	11	7	3	3	6	13	6	11	30	7	8	8	7	3	5	0	2	0	0	6	4	150
S.antennatus	6	15	39	40	61	24	9	3	8	4	37	42	15	32	24	50	31	33	33	50	7	0	0	5	568
S.bedfordi	351	417	280	490	406	195	135	333	425	742	699	667	259	342	352	257	218	265	167	258	133	8	213	310	7922
S.christophersi	0	2	2	3	2	1	1	0	0	0	1	5	0	1	0	0	1	0	3	1	1	1	0	0	25
S.clydei	2	3	1	2	10	0	1	2	0	0	19	2	0	1	0	0	0	1	1	1	1	0	0	0	47
S.garnhami	151	125	15	14	0	0	0	12	228	422	206	8	3	0	0	0	0	0	0	0	0	0	137	124	1445
S.graingeri	0	0	4	0	0	0	0	0	0	2	4	1	1	0	1	1	1	0	0	0	0	0	0	0	15
S.harveyi	1	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	12	17
S.ingrami	0	0	2	0	0	0	1	0	1	2	10	3	0	0	0	0	0	0	0	0	0	0	0	3	22
S.kirki	47	25	3	0	0	0	0	34	63	104	5	0	0	0	0	0	0	0	0	0	0	0	288	89	658
S.multidens	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
S.schwetzi	8	12	1	3	0	2	0	0	1	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	35
S.squamipleuris	0	1	1	16	8	38	13	18	5	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	102
Biweekly total	572	602	351	579	495	264	163	413	744	1288	997	761	290	385	386	316	255	306	205	316	149	9	645	552	11043

APPENDIX 10 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM ROCK CREVICES (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
P.martini	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	2	0	2	0	0	0	0	9
S.affinis	4	9	2	3	4	2	2	5	7	16	13	13	12	19	5	4	3	0	1	2	1	3	3	2	135
S.antennatus	8	11	13	8	11	4	0	1	10	15	45	48	41	28	38	37	23	20	17	28	12	3	2	2	425
S.bedfordi	337	173	164	296	298	490	70	94	992	755	677	759	1069	445	464	417	261	271	306	284	355	426	800	580	10783
S.christophersi	0	0	1	0	1	2	0	0	0	2	2	3	1	3	0	0	1	0	0	0	0	0	0	1	17
S.clydei	1	0	0	2	1	0	0	0	0	0	2	1	2	0	1	0	0	0	2	2	2	1	0	0	17
S.garnhami	253	217	21	8	0	0	0	0	287	236	12	0	1	0	0	0	0	0	0	0	0	1	128	253	1417
S.harveyi	2	6	1	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	16
S.ingrami	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	6
S.kirki	101	37	10	16	0	0	0	20	89	161	1	0	0	0	0	0	0	0	0	0	0	0	208	110	753
S.schwetzi	22	13	2	0	0	0	0	0	1	1	4	0	1	0	0	0	0	0	0	0	0	0	1	1	46
S.squamipleuris	0	0	2	2	35	14	6	8	18	18	7	5	6	3	1	0	0	0	0	1	0	0	1	0	127

APPENDIX 11 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM PLANT BASES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	1	0	0	0	3	0	0	0	1	10
P.martini	1	0	0	0	1	0	1	1	0	1	2	0	0	0	0	0	0	1	0	4	1	0	0	0	13
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
S.adleri	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.affinis	3	4	0	9	5	5	1	0	1	6	4	1	0	1	0	0	0	0	0	0	0	3	3	4	50
S.antennatus	29	10	28	9	18	8	0	3	0	4	16	12	2	3	1	0	0	4	1	5	0	0	15	10	178
S.bedfordi	13	13	81	52	36	35	16	84	59	57	93	93	9	32	15	29	9	11	5	9	5	11	38	123	928
S.christophersi	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
S.clydei	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.garnhami	117	87	21	0	0	0	0	1	11	126	117	0	0	0	0	0	0	0	0	0	0	4	16	279	779
S.graingeri	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.harveyi	0	0	0	0	0	0	0	7	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3	10	23
S.ingrami	1	5	7	3	0	0	0	0	15	19	57	11	0	0	0	1	0	0	0	0	0	0	18	22	159
S.kirki	7	2	0	0	0	0	0	2	2	9	3	0	0	0	0	0	0	0	0	0	0	0	6	38	69
S.multidens	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.schwetzi	39	43	24	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	128
S.squamipleuris	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
S.suberectus	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Biweekly total	217	166	163	87	62	48	20	98	89	224	297	118	11	36	16	31	9	16	6	22	6	18	100	494	2354

APPENDIX 12 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM TREE BASES (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	1	0	0	0	3	1	0	0	0	0	0	0	0	1	6	0	0	0	12
P.martini	0	0	0	0	0	0	1	1	0	1	1	2	0	0	0	0	0	0	0	1	16	0	0	1	24
P.vansomerenae	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.affinis	2	0	0	0	1	0	1	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9
S.antennatus	0	1	1	2	4	4	1	1	6	3	15	10	5	5	6	4	4	1	7	2	0	0	0	5	87
S.bedfordi	92	179	73	34	45	308	136	70	191	105	146	162	103	70	54	57	64	17	19	26	64	5	86	83	2189
S.garnhami	117	227	11	1	0	0	0	0	18	56	0	0	0	0	0	0	0	0	0	0	0	4	8	24	466
S.harveyi	1	4	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3	12
S.ingrami	2	0	0	0	0	0	0	1	21	5	16	0	0	0	0	0	0	0	0	0	0	0	1	0	46
S.kirki	7	6	2	2	0	0	9	1	15	7	0	0	0	0	0	0	0	0	0	0	0	0	5	14	68
S.multidens	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3
S.schwetzi	67	89	7	1	0	0	0	1	0	19	0	0	0	0	0	0	0	0	0	0	0	0	4	17	205
S.squamipleuris	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Biweekly total	288	506	95	40	50	315	149	76	255	197	183	175	108	75	60	61	68	18	26	30	86	10	106	147	3124

APPENDIX 13 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM TREE HOLES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	1	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	4
P.martini	0	0	0	0	3	0	0	1	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	8
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
S.adleri	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	0	5
S.affinis	7	1	0	1	4	0	0	0	3	0	1	0	0	0	0	0	0	0	1	1	0	3	1	3	26
S.antennatus	4	36	24	2	26	5	1	2	1	1	10	3	2	5	3	3	2	0	5	7	9	0	13	7	171
S.bedfordi	12	10	12	18	14	10	10	19	23	51	64	29	8	9	7	7	4	4	2	1	2	4	31	14	365
S.christophersi	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.clydei	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	7	0	3	14
S.garnhami	8	4	0	0	0	0	0	8	91	127	7	2	0	0	0	0	0	0	0	0	0	14	90	6	357
S.graingeri	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.harveyi	1	1	0	0	0	0	0	12	2	4	1	3	0	0	0	0	0	0	0	0	0	0	11	7	42
S.ingrami	12	0	2	5	0	0	0	0	5	27	35	3	0	0	0	0	0	0	0	0	0	0	3	33	125
S.kirki	10	3	0	0	0	0	0	1	33	27	0	0	0	0	0	0	0	0	0	0	0	0	79	51	204
S.multidens	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
S.schwetzi	5	16	3	0	0	0	0	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	37
S.squamipleuris	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.suberectus	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
Biweekly total	31	51	37	21	48	15	11	30	119	180	87	36	10	19	10	10	6	5	8	9	12	29	136	33	953

APPENDIX 14 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM TREE HOLES (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	12	5	0	0	21
P.martini	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2	0	0	0	3	0	0	0	7
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	7	0	0	0	9
S.adleri	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	5
S.affinis	3	2	0	0	0	1	0	2	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1	14
S.antennatus	4	2	0	0	3	1	0	0	2	0	3	4	2	3	6	2	6	5	4	2	3	1	1	3	57
S.bedfordi	78	16	25	2	9	35	25	37	27	55	58	50	29	22	19	14	9	9	1	3	10	10	14	71	628
S.clydei	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
S.garnhami	267	49	4	8	0	0	1	45	65	123	3	1	0	1	0	0	0	0	0	0	0	13	23	32	635
S.harveyi	6	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	11	22
S.ingrami	22	0	1	0	0	0	0	0	1	6	4	4	0	0	0	0	0	0	0	0	0	0	0	1	39
S.kirki	17	16	1	0	0	0	0	8	21	30	0	0	0	1	0	0	0	0	0	0	0	0	25	44	163
S.multidens	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.schwetzi	19	12	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	19	58
Biweekly total	416	97	37	10	12	39	26	98	119	218	75	61	31	27	28	16	17	14	6	5	35	30	65	182	1664

APPENDIX 15 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM INSIDE WALLS OF HOUSES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3
P.martini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2
P.vansomerenae	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
S.adleri	0	1	1	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6
S.affinis	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	5	0	1	11
S.antennatus	28	18	52	7	30	25	3	5	15	9	20	14	21	6	43	7	10	11	16	16	10	1	16	17	400
S.bedfordi	125	73	248	65	113	116	45	53	200	198	138	173	79	29	88	70	42	54	57	47	24	29	369	219	2654
S.christophersi	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
S.clydei	0	2	0	1	1	2	4	1	3	1	1	1	0	0	0	0	0	0	2	1	0	0	2	1	23
S.garnhami	1	1	1	0	0	0	0	18	6	32	0	0	0	0	0	0	0	0	0	0	0	1	32	2	94
S.graingeri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
S.harveyi	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.ingrami	1	0	0	0	0	0	0	0	6	4	2	1	0	0	0	0	0	0	0	0	0	0	3	6	23
S.kirki	3	1	0	0	0	0	0	12	7	3	0	0	0	0	0	0	0	0	0	0	0	0	11	11	48
S.multidens	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.schwetzi	19	4	7	1	0	4	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	40
S.squamipleuris	0	0	0	0	0	2	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6
Biweekly total	177	101	309	75	144	152	56	89	238	250	162	190	100	36	132	77	52	67	76	64	34	39	436	257	3313

APPENDIX 16 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM INSIDE WALLS OF HUMAN HOMES (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	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
P.martini	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	4
P.vansomerenae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.affinis	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
S.antennatus	33	14	8	6	20	3	4	7	7	10	16	9	15	9	10	12	5	8	3	4	10	1	9	4	227
S.bedfordi	269	165	155	186	233	175	136	164	230	167	183	167	135	157	82	82	31	50	41	32	28	26	305	96	3295
S.clydei	2	0	0	5	2	0	1	1	0	0	0	1	0	0	1	2	1	0	0	2	0	2	3	3	26
S.garnhami	0	0	0	1	0	0	0	1	1	2	0	3	2	0	0	0	0	0	0	0	0	7	1	0	18
S.harveyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
S.ingrami	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	7
S.kirki	8	0	0	0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	15
S.schwetzi	4	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	4	6	17
S.squamipleuris	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4
Biweekly total	320	180	163	199	256	179	143	176	242	180	199	180	153	166	93	96	37	59	47	38	39	38	324	111	3618

APPENDIX 17 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM OUTSIDE WALLS OF HOUSES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	4
P.martini	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	5
P.vansomerenae	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
S.adleri	0	0	2	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
S.affinis	0	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0	0	2	0	1	0	2	3	0	17
S.antennatus	45	33	55	35	62	48	9	8	12	13	20	36	3	6	23	14	30	34	19	19	19	3	36	17	599
S.bedfordi	158	114	211	178	152	213	41	37	170	188	169	139	43	55	90	48	61	75	110	72	63	21	244	152	2804
S.christophersi	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.clydei	1	2	6	5	4	1	2	0	0	0	0	3	0	0	0	0	1	2	1	2	1	0	0	0	31
S.garnhami	6	2	24	1	0	0	0	5	3	12	2	0	0	0	0	0	0	0	0	0	0	2	12	3	72
S.graingeri	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.harveyi	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	4
S.ingrami	1	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	12
S.kirki	24	6	0	0	0	0	0	13	12	4	0	0	0	0	0	0	0	0	0	0	0	0	31	26	116
S.multidens	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.schwetzi	9	3	3	2	1	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	1	25
S.squamipleuris	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Biweekly total	246	161	303	222	222	265	54	63	205	225	194	178	46	63	113	62	92	113	131	95	83	31	332	201	3700

APPENDIX 18 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM OUTSIDE WALLS OF HUMAN HOMES (JAN-DEC 1990)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	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
P.martini	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
P.vansomerenae	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
S.affinis	1	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	5
S.antennatus	41	3	10	12	50	29	0	23	18	14	19	26	20	25	15	13	6	5	11	18	9	4	7	9	387
S.bedfordi	225	115	103	140	297	244	88	229	326	156	279	198	196	168	101	83	51	78	74	50	72	24	209	104	3610
S.clydei	1	0	3	2	3	3	1	4	2	0	1	3	0	0	1	2	1	0	15	14	1	3	0	2	62
S.garnhami	5	0	1	0	1	0	0	1	1	0	1	2	1	0	0	0	0	0	0	0	0	7	1	0	21
S.harveyi	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.ingrami	6	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	4	0	12
S.kirki	104	0	0	0	0	1	4	16	9	0	0	0	0	0	0	0	0	0	0	0	0	0	17	21	172
S.schwetzi	7	1	1	0	1	0	1	2	0	0	0	0	0	0	1	2	0	2	0	0	0	0	0	2	20
S.squamipleuris	0	0	0	0	1	0	0	2	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	16
Biweekly total	391	119	118	154	355	277	96	277	368	172	301	229	220	193	118	100	58	85	100	82	83	38	238	139	4311

APPENDIX 19 BIWEEKLY COLLECTIONS OF SANDFLY SPECIES FROM ANIMAL ENCLOSURES (JAN-DEC 1989)

SPECIES	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		TOTAL
P.celiae	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
P.martini	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
P.vansomerenae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
S.adleri	0	0	0	0	2	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	8
S.affinis	0	0	0	0	0	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	6
S.antennatus	5	22	9	3	14	3	4	1	6	1	10	5	11	3	14	3	5	1	2	0	2	0	1	0	125
S.bedfordi	5	16	24	12	7	3	5	9	35	17	26	11	12	8	5	4	7	3	5	4	5	4	18	6	251
S.christophersi	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S.clydei	4	3	5	3	0	1	1	1	7	2	2	0	1	1	0	0	0	0	0	2	0	1	0	0	34
S.garnhami	0	1	0	0	0	0	0	1	4	8	2	0	0	0	0	0	0	0	0	0	0	2	17	1	36
S.graingeri	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4
S.harveyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	0	8
S.ingrami	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4
S.kirki	1	0	0	0	0	0	0	2	5	1	0	0	0	0	0	0	0	0	0	0	0	0	14	2	25
S.multidens	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
S.schwetzi	0	1	1	0	2	0	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	9
S.squamipleuris	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Biweekly total	15	44	39	18	27	9	17	17	63	30	45	16	24	12	19	7	12	4	7	7	7	10	60	9	518

[redacted]	[redacted]	58	52	20	8	9	12	37	71	81	52	18	12	8	9	4	10	6	10	3	8	21	21	10	525
S.christophersi	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
S.clydei	6	7	3	6	2	3	2	4	0	1	3	2	0	0	0	0	0	0	0	0	0	0	0	1	40
S.garnhami	3	1	2	0	0	0	0	2	32	45	4	0	0	0	0	0	0	0	0	0	0	9	6	2	106
S.graingeri	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4
S.harveyi	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4
S.ingrami	1	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0	0	0	0	1	0	8
S.kirki	2	0	0	0	0	0	0	1	4	1	0	0	0	0	0	0	0	0	0	0	0	1	6	2	17
S.multidens	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S.schwetzi	9	4	0	0	1	0	0	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	18
S.squamipleuris	0	0	5	6	5	36	8	6	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	68
Biweekly total	37	57	85	38	27	56	34	62	125	153	73	28	15	14	9	5	18	7	16	11	12	38	37	20	977

APPENDIX 21: BREEDING HABITATS
(Expt 1)
General Linear Models Procedure

Source	DF	Type 1 SS	Mean Square	F value	Pr>F
Site	14	0.10668	0.00762	1.93	0.0208*
Period	1	0.00799	0.00799	2.02	0.1557
Species	14	0.06667	0.00476	1.20	0.2667
Sex	1	0.57661	0.57661	145.72	0.0001**

BREEDING HABITATS
(Expt 2)
General Linear Models Procedure

Source	DF	Type 1 SS	Mean Square	F value	Pr>F
Site	13	0.00526	0.000405	0.11	1.0000
Period	1	0.001469	0.001469	0.39	0.5306
Species	5	0.00110	0.000222	0.06	0.9976
Sex	1	0.09605	0.096052	25.81	0.0001***

BREEDING HABITATS
(Expt 3)
General Linear Models Procedure

Source	DF	Type 1 SS	Mean Square	F value	Pr>F
Site	13	0.00415	0.000319	0.09	1.0000
Period	1	0.00000	0.000000	0.00	0.9966
Species	8	0.00063	0.000079	0.02	1.0000
Sex	1	0.05217	0.052179	13.89	0.0002***

BREEDING HABITATS
(Expt 4)
General Linear Models Procedure

Source	DF	Type 1 SS	Mean Square	F value	Pr>F
Site	9	0.01121	0.001246	0.33	0.9653
Period	1	0.00258	0.002577	0.68	0.4097
Species	7	0.00133	0.000190	0.05	0.9998
Sex	1	0.17143	0.171427	45.29	0.0001***

APPENDIX 21 CONTD

BREEDING HABITATS
(Pooled data)

General Linear Models Procedure

Source	DF	Type 1 SS	Mean Square	F value	Pr>F
Expt	3	0.48784	0.016261	4.29	0.0050**
Site	15	0.07308	0.004872	1.28	0.2031
Period	1	0.0.0101	0.010112	2.67	0.1027
Species	14	0.049841	0.003560	0.94	0.5158
Sex	1	0.87189	0.871885	229.89	0.0001***

APPENDIX 22A :ECOLOGICAL DISTRIBUTION
Analysis of Variance Procedure

Source	DF	Anova SS	Mean Square	F value	Pr>F
Site	9	2765719	276571	78.12	0.0001
Subsite	15	2641151	203165	57.38	0.0001
Species	19	15639179	823114	232.48	0.0
Site*species	144	24488123	170056	48.03	0.0
Subsite*species	202	23078098	114248	32.27	0.0

APPENDIX 22B :DAY RESTING SITES
Analysis of Variance Procedure

Source	DF	Anova SS	Mean Square	F value	Pr>F
Sites	9	0.612741	0.068082	2.88	0.0027
Species	16	16.75954	0.047471	44.38	0.0001
Sex	1	0.008122	0.008122	0.34	0.5579