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***Full Length Article***

# Bionomics of Phlebotomine Sandflies (Diptera: Psychodidae) in and around Dhamar City, Yemen

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## Abstract

The association between phlebotomine sandflies and their ecology was investigated in and around Dhamar City, Yemen. Species diversity, temporal and geographic distribution of the sandflies were studied. CDC and Sticky traps biweekly collected Sandflies from six districts/ sites representing different altitudes of Dhamar city and round districts. Sandflies were identified morphologically based on male and female genitalia and Pharynx(cibarium). Out of 1007 sandflies captured during the study period, 631 (62.7%) were males and 376 (37.3%) females. The sex ratio was 1.7:1. The species identified and their relative abundance were *Phlebotomus arabicus* (44.09%), *P. alexandri* (35.15%) and *P. sergenti* (20.75%). Significant differences ($P < 0.05$) existed between species and their relative abundance. Maximum diversity of sandflies was observed at high altitudes (Simpson index 1-D = 2.9; Shannon index, H = 1.06); whereas the minimum at low altitudes (1-D = 2.7; H = 1.04). Based on the single trap collection of flies, CDC traps were more efficient ($P = 0.000$) in capturing sandflies compared to sticky traps. The seasonal activity of sandfly species researched the peak in July (r = 0.869; $P < 0.01$) and declined to lower level in December. A positive correlation was observed between number of sandflies captured and temperature (r = 0.105; $P < 0.05$). In conclusion, sandflies are prevalent in study areas. The study provides useful data on the spatiotemporal distribution, abundance and diversity of sandfly species in Dhamar city and around districts. A combination of ecological and topographical factors influences the distribution and abundance of sandflies in different areas of Dhamar. The findings of this study could be useful as a predictor for occurring of leishmaniasis among people in study areas and for designing a control program for sandflies. Further entomological studies on epidemiology of sandfly and its disease transmission should be carried out regularly in different regions the country. 

**Keywords:** Bionomics; Phlebotomine sandflies; Dhamar; Yemen

## Introduction

Bionomics deal with the relationship between an organism and its environment. understanding of sandfly bionomics is a key of sand-fly-borne diseases epidemiology (WHO 2015). It helps to establish effective and appropriate vector control measures by providing information on abundance and seasonal trend of sandfly species in focus (Al-Koleeby *et al.* 2021). Sandflies belong to the subfamily Phlebotominae of the dipteran family Psychodidae. They possess small bodies, 3mm long, densely hairy wings, large black eyes; at rest, they hold their wings erected above the body (Maroli *et al*. 2013; Elhadi *et al*. 2022).

Phlebotomies sandflies are known as sole vectors for the parasitic protozoa of the Leishmania genus, which causes leishmaniasis in humans and animals (Depaquit *et al*. 2010; Michelutti *et al*. 2021). Several species of Phlebotomies sandflies have been identified worldwide. But few species (98 species) are known as vectors of human and animal leishmaniases (Maroli *et al*. 2013; Sofizadeh *et al.* 2021). Leishmaniasis is a parasitic disease that remains serious public health problem worldwide (Sawalha *et al.* 2003; Al-Ajmi *et al*. 2015; Sofizadeh *et al*. 2021). The incidence of leishmaniasis is nearly two million cases per year, with an annual mortality of approximately 50,000 persons, and more than 350 million individuals are at risk of the diseases (WHO 2010). Sandfly control depends on the epidemiological and entomological characteristics of sandfly in each location, the common methods used are chemical control, physical control and interrupting the life cycle of fly and elimination of the canine reservoir (Alexander 2000; Fonseca *et al.* 2020).

In general, sandflies are distributed in different geographic regions, particularly in tropic and subtropics regions. However, their distribution and population dynamics depend on environmental, topological factors

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and host availability (Doha and Samy 2010; Al-Ajmi *et al*. 2015; Prudhomme *et al*. 2015). Several studies are available on the distribution, composition, dynamic, and diversity of sandflies in different geographical zones of the world (Jacobson *et al*. 2003; Al-Barrak 2005; Ibrahim and Abdoon 2005; Doha and Samy 2010; Kenawy *et al*. 2015; Boussaa *et al*. 2016; Sawalha *et al*. 2017; Nawaz *et al.* 2020; Sofizadeh *et al.* 2021).

In Dhamar, to our knowledge, information on sandflies is unavailable. Therefore, the present study aimed to identify species, relative abundance, diversity and seasonal dynamic of sandflies in and around Dhamar city, Yemen.

## Materials and Methods

### Study area

An entomologic study was performed between January and December 2018 in Dhamar city and around Dhamar governorate districts. Yemen. Dhamar is located south of Sana`a, the capital of Yemen. The governorate is divided into 12 administrative districts, with Dhamar City as the capital of the governorate (Abbas *et al*. 2018; NIC 2021). The annual mean of temperature, relative humidity and rainfall is 26.41°C, 59.29% and 71.29.2 mm, respectively. According to the last Census in 2004, the total population of the governorate is about 1,330,108, which is expected to be 3,311,033 in 2034 (Abbas *et al*. 2018). Agriculture is the main activity in the area. The majority of the population works in agriculture. Dhamar is irrigated by underground water for the cultivation of fruits, legumes, root vegetables (e.g., Potatoes) and cereals. Dhamar plays a vital role in the agriculture economy of the country.

### Collection of sandflies

The current study covered sandflies sampling from six sites/districts including: U'tmah, Anss, Wasab, Anes, Jahran and Dhamar city with altitude ranges between 1860 to 2430 meters above sea level (ALS). Sandflies were collected biweekly between January to December 2018 from peri-domestic and domestic resting sites. In each collection trip, Three CDC traps and six sticky traps were deployed overnight. In the sticky trapping technique, Sticky traps were made by brushing each side of standard sheets of A4 polypropylene paper with castor oil. Each impregnated paper was skewered vertically on a wooden support so that the longer edge of the paper ran parallel with the ground (Cameron *et al*. 1994). At each collection site, 6 sticky traps (6 traps/site/night) were set indoors and outdoors in human and animal dwellings. Traps were placed at the collection site before sunset (18:00 h) and collected the following morning before sunrise (06:00 h). Flies were removed from the sticky sheet, placed in 70% ethanol for preservation until identification process according to the guidance of Ibrahim and Abdoon (2005) and then transferred to the laboratory for further processing.

The sandflies also were captured by using CDC light traps technique. The CDC miniature light trap is a trap used to capture sandflies and other potential disease-borne vectors (Coleman *et al.* (2007). All light traps were equipped with the necessary parts for collecting sandflies. The traps (3 traps/site/night) were set and operated in placed at a height of 1.5 m in the peri- and intra-domiciliary collection sites/districts before sunset (6:00 pm) and collected before sunrise (6:00 am) next morning which coincide with peak sandfly activity. The traps were hung from trees at a uniform height of 1.5 meters. The captured phlebotomine sandflies were segregated by each trap, then placed in vials with 70% ethanol for preservation according to the technique described by Feliciangeli (1987); Coleman *et al.* (2007).

### Mounting and identification of sandflies

The collected flies' specimens were brought to the laboratory for subsequent processing and identification at the species level. In brief, mounting and identification of sandflies were carried out as following: Sandflies were transferred to micro-Eppendorf tubes containing puri`s medium and kept for 1 to 3 days, for complete removal of bristle, hairs, dust particles and cleaning the internal organs. The sandfly`s head was separated and placed ventrally on glass slides to expose the mouth parts (cibarium and pharynx), whereas the abdominal part was laterally placed on the slide to identify spermathecae of females and external genitalia of males as suggested by Aslamkhan and AslamKhan (2000); Rigg *et al.* (2021). Identification of Phlebotomine sandflies was performed under a dissection microscope using the taxonomic keys given by Lewis (1974); Lewis and Buttiker (1982); Ozbel *et al.* (2011); Yared *et al.* (2017).

### Meteorological data

Meteorological data such as the mean of temperatures (℃), relative humidity (%) and total precipitation (mm) in Dhamar governorate were obtained from the Agriculture Research and Extension Authority (AREA) Station, Dhamar, Yemen.

### Data analysis

Data obtained were loaded into a Microsoft Excel spreadsheet (Office, Window Version 10 Pro) and summarized using Tables and line graphs. Descriptive and other statistical analyses were executed using SPSS version 21 for Windows (SPSS Inc., Chicago, IL, USA). In all tests $P \leq 0.05$ was considered significant. Pearson`s correlation analyses were performed to estimate the association between the abundance of phlebotomine sandfly species and climatic data. Regression's analysis was considered to explore associations of the categorical factors with the presence of the species. Shannon-Weiner species diversity index was used to estimate species diversity between altitudes using the Biodiversity Professional version 2. software for calculating ecological indices.

## Results

### Species composition and relative abundance

A total of 1007 sandflies were captured; 631(62.7%) were males and 376(37.3%) females. The sex ratio was 1.7:1. All identified species belonged to the *Phlebotomus* genus. The species and their relative abundance in order were *P. arabicus* (44.09%) *P. alexandri* (35.15%) and *P. sergenti* (20.75%). Significant differences (*P < 0.05*) were observed in relative abundance and species identified as well as their sex as presented in Table 1 and 2.

### Distribution of phlebotomine sandflies in relation to study areas

During the study period, 1007 phlebotomine sandflies were collected in 216 traps/ nights (9 traps for 24 nights). The number of sandflies collected by sticky traps (563; 55.91%) was more compared to CDC traps (444; 44.09%) as presented in Table 3. Significant differences (*P = 0.126*) were not observed between the number of sandflies captured by CDC and sticky traps. However, on the basis of single trap collection, a higher number of sandflies was collected in a single CDC trap 109 (mean:18.07 trap/nights) compared to 96 (mean: 16.00 trap/nights); on single sticky trap.

Regarding collection sites/areas, the lower numbers of sandflies were collected from Dhamar city/site (7; mean = 3.5 Trap/ night) and the higher number from Utuma/site (343; mean = 171.5 trap/night). Significant differences (*P = 0.308*) were not observed between the number of sandflies captured and the sites/ areas of collection.

The distribution of sandflies indoors and outdoors (peri domestic and domestic biotopes) is presented in Table 4. As shown, *P. arabicus* were the most abundant in both Peridomestic (27.8%) and domestic (16.3%) biotopes followed *P. alexandri* (21.8%; 13.3%) and *P. sergenti* (13.9%; 6.9%). Significant differences (*P = 0.494*) were not observed among the density of sandfly species in Peridomestic and domestic biotopes.

### Diversity of sandfly population at different altitudes of study areas

A higher number of sandflies 343 (mean = 171.5 trap/night) were collected at an altitude of 1860 above the level sea (ALS), whereas the lower number 7 (mean= 3.5 trap/night) at an altitude of 2430 ALS as presented in Table 5. The regression analysis demonstrated no correlation between the number of sandflies collected and the altitudes (*P = 0.144*). The maximum diversity of sandflies was observed at high altitudes (Simpson index 1-D = 2.9; Shannon index, H = 1.06), whereas minimum diversity in low altitude (1-D = 2.7; H = 1.04). The rest localities exhibited medium biodiversity indices as presented in Table 5.

### Temporal distribution of sandflies

The temporal abundance of sandflies is presented in Table 6. As shown, in the winter season, the number of sandflies collected from different study sites/areas was very low and the minimum number of flies recorded in December (4; mean = 2 trap/night), which coincided with low values of weather conditions (Temperature = 23.8°C and Relative humidity = 47% and Precipitation = zero mm) and began increasing in early of spring and maximum numbers of flies was recorded in May (141; mean = 70.5 trap/ night). In summer, the number of sandflies captured was researched the highest number and maximum recorded in July (259; mean =129.5 trap/night) which coincides with high values of climatic conditions (mean temperature = 28.1°C, RH = 61.9% and rainfall = 84.3 mm). In the autumn, the number of sandflies decreased rapidly and reached a lowest level in November (8; mean = 4 trap/night). Significant differences (*P = 0.000*) were observed among the relative abundance of sandfly species in different year seasons. Furthermore, the results of correlation analysis demonstrated that the number and abundance of sandflies were correlated with temperature (r = 0.105; *P = 0.001*, whereas; none with RH (r = 053; *P= 0.096*) and rainfall (r = 0.032; *P = 0.316*).

### Seasonal activity and dynamics of sandfly species

In this study, sandfly species showed different seasonal activity patterns in study areas (Fig. 1). All *Phlebotomus* species were found during all months of the year. The seasonal activity of *P. arabicus* peaked in June and declined rapidly to a lower level in January. The activity of *P. alexandri* was more during July and dropped to zero in February. Similarly, the activity of *P. sergenti* began at the end of May and researched to peak in July. The correlation analysis demonstrated a strong positive (r = 0.869; *P < 0.01*) correlation between seasonal activities, the dynamic of sandflies and seasons (month variation).

## Discussion

Understanding the distribution of sandfly vectors is very important to determine transmission of leishmaniasis to human and animals. In this regard, this study documented the species composition, seasonal dynamics and diversity of phlebotomine of sand flies in Dhamar city and around districts. The results of this study revealed CDC and Sticky traps captured 1007 sandflies from different collection sites of study areas. These results are partly in line with findings of previous studies (Branco *et al.* 2013).

**Table 1:** Phlebotomine sandfly species identified and their relative abundance in Dhamar city and around districts

| Species | CDC traps | Sticky traps | Total | mean | R. abundance (%) | *P* value |
|---|---|---|---|---|---|---|
| | No. flies captured | No. flies captured | | | | |
| *P. arabicus* | 185 | 259 | 444 | 222 | 44.09 | 0.000 |
| *P. alexandri* | 159 | 195 | 354 | 177 | 35.15 | |
| *P. sergenti* | 100 | 109 | 209 | 104.5 | 20.75 | |
| Total | 444 | 563 | 1007 | 503.5 | 100 | |

CDC = Center for Disease Control Trap, R = Relative

**Table 2:** Numbers of Males and Females of Phlebotomine sandflies captured and their relative abundance in study area

| Species | Males | | Females | | Total | R. abundance (%) | *P* value |
|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | | | |
| *P. arabicus* | 314 | 31.2 | 130 | 12.9 | 444 | 44.1 | 0.000 |
| *P. alexandri* | 204 | 20.3 | 150 | 14.9 | 354 | 35.2 | |
| *P. sergenti* | 113 | 11.2 | 96 | 9.5 | 209 | 20.8 | |
| Total | 631 | 62.7 | 376 | 37.3 | 1007 | 100.0 | |

**Table 3:** Geographical distribution of Phlebotomine sandflies according to sites/ areas of study

| Site/Area | CDC traps | | Sticky traps | | Total | R. Abundance (%) | Mean | *P* value |
|---|---|---|---|---|---|---|---|---|
| | No. flies captured | % | No. flies captured | % | | | | |
| U'tmah | 174 | 17.28 | 169 | 16.78 | 343 | 34.06 | 171.5 | 0.302 |
| Anss | 97 | 9.63 | 165 | 16.39 | 262 | 26.02 | 131 | |
| Wasab | 126 | 12.51 | 153 | 15.19 | 279 | 27.71 | 139.5 | |
| Anes | 27 | 2.68 | 38 | 3.77 | 65 | 6.45 | 32.5 | |
| Jahran | 18 | 1.79 | 33 | 3.28 | 51 | 5.06 | 25.5 | |
| Dhamar city | 2.0 | 0.20 | 5.0 | 0.50 | 7.0 | 0.70 | 3.5 | |
| Total | 444 | 44.09 | 563 | 55.91 | 1007 | 100.00 | 503.5 | |

**Table 4:** Distribution of Phlebotomine sandfly species according to biotopes

| Species | Peri domestic | | Domestic | | Total | Mean | R. Abundance (%) | *P* value |
|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | | | | |
| *P. arabicus* | 280 | 27.8 | 164 | 16.3 | 444 | 222.00 | 44.09 | 0.494 |
| *P. alexandri* | 220 | 21.8 | 134 | 13.3 | 354 | 177.00 | 35.15 | |
| *P. sergenti* | 140 | 13.9 | 69 | 6.9 | 209 | 104.50 | 20.75 | |
| Total | 640 | 63.5 | 367 | 36.5 | 1007 | 503.50 | 100.00 | |

**Table 5:** Distribution and diversity of Phlebotomine sandflies at different altitudes of study area

| Altitude | CDC traps | Stick traps | Total | Mean | SD | H | 1-D |
|---|---|---|---|---|---|---|---|
| | No. Flies captured | No. Flies captured | | | | | |
| 1860 | 174 | 169 | 343 | 171.5 | 3.5 | 1.04 | 2.7 |
| 2000 | 126 | 153 | 279 | 139.5 | 19.1 | 1.02 | 2.5 |
| 2050 | 27 | 38 | 65 | 32.5 | 9.2 | 1.01 | 1.9 |
| 2250 | 97 | 165 | 262 | 131 | 48.1 | 1.05 | 2.9 |
| 2400 | 18 | 33 | 51 | 25.5 | 9.9 | 1.06 | 2.1 |
| 2430 | 2 | 5 | 7 | 3.5 | 1.4 | 1.05 | 1.40 |

SD = standard deviation, H = Shannon index, 1-D = Simpson index

**Table 6:** Effect of Season and climatic data on distribution of Phlebotomine sandflies species in study area

| Season | Months | CDC trap | sticky trap | Total | Mean | Temp** (°C) | Rainfall (mm) | RH ( %) | **P value* |
|---|---|---|---|---|---|---|---|---|---|
| | | No. Flies | No. Flies | | | | | | |
| Winter | Dec | 2.0 | 2.0 | 4.0 | 2.0 | 23.8 | 0.0 | 47.0 | 0.000 |
| | Jan | 2.0 | 5.0 | 7.0 | 3.5 | 22.9 | 1.0 | 57.6 | |
| | Feb | 5.0 | 13 | 18 | 9.0 | 25.8 | 1.1 | 54.4 | |
| Spring | Mar | 26 | 36 | 62 | 31 | 25.2 | 21.9 | 51.3 | |
| | Apr | 24 | 57 | 81 | 40.5 | 22.6 | 92.9 | 73.9 | |
| | May | 71 | 70 | 141 | 70.5 | 25.3 | 149.9 | 49.6 | |
| Summer | Jun | 97 | 130 | 227 | 113.5 | 29.2 | 41.6 | 58.7 | |
| | Jul | 122 | 137 | 259 | 129.5 | 28.1 | 84.3 | 61.9 | |
| | Aug | 46 | 47 | 93 | 46.5 | 24.1 | 103.0 | 68.8 | |
| Autumn | Sep | 26 | 35 | 61 | 30.5 | 24.1 | 13.4 | 59.1 | |
| | Oct | 19 | 27 | 46 | 23 | 23.7 | 0.6 | 45.3 | |
| | Nov | 4.0 | 4.0 | 8.0 | 4.0 | 25.0 | 5.0 | 66.0 | |

Mm = millimeter, RH = Relative humidity, Temp = Temperature, °C = Celsius, r = correlation coefficient, *$P < 0.05$, **$P < 0.01$

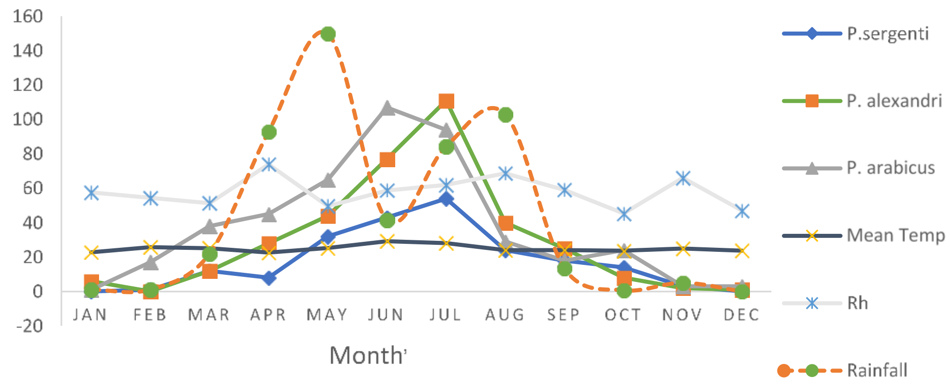


**Fig. 1:** Seasonal activity of Phlebotomine Sandfly species

However, the sandflies number was higher than that reported by Kenawy *et al.* (2015) in Saudi Arabia and was lower than sandflies number reported by Sawalha *et al*. (2003); Abdoli *et al.* (2007); Sawalha *et al.* (2017). The differences in sandfly numbers collected in current study and above studies may be due to efficacy, types and numbers of traps used, and ecological factors. Furthermore, Ozbel *et al.* (2011) cited distribution and abundance of the phlebotomine sandflies are depending on local environmental factors such as precipitation and temperature, physical factors such as geographical barriers, and hosts availability.

Results revealed that, out of the total sandflies captured, 631 (62.7%) were males and 376 (37.3%) females and the sex ratio was 1.7:1. These results are consistent with the findings of Doha and Samy (2010) and contrast with the findings of Coleman *et al*. (2007) and Pérez *et al*. (2014), who reported in their study a higher number of female flies captured. In nature, the sex ration of these species is approximately 1:1 (Killick-Kendrick 1999), the higher ratio of male captured in this study may be due to the trapping methods, behavior and attractants preferred by males (Alexander 2000). However, the higher number of sandfly females captured by Coleman *et al.* (2007) study, showed that females may seek meal blood before laying their eggs and aggregating around houses, and animal shelters, thus leading to captured by traps.

During this study, three sandfly species were identified and all belong to the genus *Phlebotomus*, namely, *P. arabicus*, *P. alexandri* and *P. sergenti*. Similar species or more were previously reported from Yemen (Mogalli 2015; Sawaf *et al*. 2016) and different part of the world *i.e.*, Ibrahim and Abdoon (2005) in Asir Region, Doha and Samy (2010) in Al-Baha, Kenawy *et al.* (2015) in Saudi Arabia, Darvishi *et al.* (2015) in Iran, Boussaa *et al.* (2016) in Morocco, Sawalha *et al.* (2017) in Palestinian Territories and June (2018) in Ethiopia. The consistent and contrary species of sandflies reported by the above workers and this study may be due to climatic conditions, vegetation and geographical factors in studied areas. In addition, Alexander and Maroli (2003) suggested that the diversity of species captured in different regions and localities may be influenced by the sampling technique.

Relatively little information exists on the biology of *P. arabicus*, despite its widespread in Yemen, Saudi Arabia and elsewhere in the world (Lewis and Buttiker 1982), this species was not known to be a vector of *Leishmania tropica* which causes cutaneous leishmaniasis in human anywhere until Jacobson *et al.* (2003) proved it to be vector of *L. tropica* in the Galilee focus, *P. arabicus* species was the dominant and most abundant species identified in the current study. This agrees with the previous observation of Ibrahim and Abdoon (2005) and Doha and Samy (2010) in Saudi Arabia. However, the relative abundance of this species reported by these researchers was very low compared to current study`s findings. This could be attributed to biotic potential of species and ecological factors.

*P. alexandri* species was the second in abundance order. This species has medical importance because of its proven roles as vectors of *L. donovani* and is a suspected vector of *L. infantum* protozoal parasites, both cause visceral leishmaniasis in human in the old world (Guan *et al.* 1986; Colacicco-Mayhugh *et al*. 2010; Maroli *et al*. 2013). *P. alexandri* extends from North Africa, the Arabian Peninsula and the southern states of the former Soviet Union, reaching as far as Pakistan eastwards (Kakarsulemankhel 2010). Moreover, *P. alexandri* reported previously by many workers (Coleman *et al*. 2007; El-Badry *et al*. 2009; Doha and Samy 2010; Belen and Alten 2011; Durrani *et al.* 2012; Branco *et al*. 2013; Darvishi *et al.* 2015; Kenawy *et al.* 2015; Al-Koleeby *et al.* 2021). The relative abundance reported by above workers ranged between 3–76.07%. The higher abundance rates of sandflies recorded by the above workers may be due to size of samples collected, behavior and richness of sandflies in those geographic areas.

*P. sergenti* is the vector of the *L. tropica* parasite which causes cutaneous leishmaniasis in human in North Africa and the Middle East, and its abundance, combined with the association to peri domestic environments (Branco *et al*. 2013). In the current study, *P. sergenti* was the third species in abundance order. This species is reported by many researchers in different countries of the globe (Aransay *et al.* 2004; Ibrahim and Abdoon 2005; Ramaoui *et al.* 2008; Doha 2009; Belen and Alten 2011; Branco *et al.* 2013; Talbi *et al.* 2015; Boussaa *et al.* 2016; Mirhoseini *et al.* 2017; Sawalha *et al.* 2017; Nawaz *et al.* 2020). The relative abundance rates reported by the above workers ranged between 1.4–22%. The consistency and contradiction between our results and findings of above workers might be due to species` habitat preference adjacent to humans and animals' dwellings (Kravchenko *et al*. 2004).

Vector survey aims to detect a vector in a given population and its abundance for estimating the risk of disease transmission and control, hence the sampling methods are depended upon the problem to be addressed. Sampling methods are available for both the adult and the immature stages of sand flies (Alten *et al.* 2015). In this study, two different trap types were used, namely, light traps (LT) and sticky traps (ST) because they provide complementary information on the sandfly host-seeking and resting populations. light traps usually target highly phototropic species (Prudhomme *et al.* 2015) and allow capturing large numbers of sandflies and measuring the relative fluctuations in abundance in different period and areas (Alten *et al.* 2015). Furthermore, light traps are useful to determine the seasonal activity because they capture active sandflies. However, sticky traps are easily to produce in large numbers, and they are capture the sandflies by interception mechanism rather than attraction. Therefore, they provide data on resting flies (Prudhomme *et al.* 2015). Surprisingly, the number of sandflies collected by sticky traps was more compared to CDC traps in present study. The lower sandfly numbers captured by CDC traps could be explained with view of Coleman *et al*. (2007) who cited that CDC miniature light trap is most effective when $CO_2$ is used as a bait however, neither dry ice nor compressed $CO_2$ was used in this study. Moreover, the number of CDC traps was less than sticky traps during trapping of the flies. The regression analysis results displayed no significant differences ($P = 0.308$) between the number of sandflies captured and the sampling methods. However, Based on a single trap collection, more sandflies were collected in single CDC trap than a sticky trap. This could be explained that, more sandflies are attracted to the CDC light trap due to the phototaxis phenomenon (Santos *et al.* 2002). Moreover, CDC traps were made and subjected for many modifications for sandflies capturing (Rodríguez-Rojas and Rebollar-Tellez 2017).

In the current study, the higher numbers of sandflies were captured from peri-domestic biotopes, whereas, the lower numbers were from domestic biotopes. These results are in line with the findings of Coleman *et al.* (2007) and contrast with findings of Quintana *et al.* (2010); Sawalha *et al*. (2017). The consistency or disagreement between the results of the current study and the above studies could be attributed to biotopes preferred by sandflies in which shelter and food are available (Branco *et al*. 2013). Moreover, chemical substance such as pheromones and kairomones released by insects and hosts also play a vital role in the aggregation, feeding and reproduction of sandflies in the peri-domiciliary environment or near human and animal dwellings (Kelly and Dye 1997; Ximenes *et al*. 1999). On other hand, in Yemen, commonly domestic animals are housed in peridomicile settings which may attack by sandfly. Sanitary and hygienic conditions were often poor in these settings, with discarded garbage, boxes, and organic debris that could provide a good microenvironment for the breeding of sandfly (Fátima *et al.* 2000).

Sand fly distribution is varied with different altitude ranges in the study area, and their distributions are highly dependent on local environment, geographical barriers and availability of hosts (Cross *et al*. 1996; Ghosh *et al.* 1999; Yousefi *et al*. 2020). The results of this study revealed that higher diversity was observed among sandflies captured at high altitudes, whereas, lower at low altitudes. In the rest of the localities, they exhibited medium biodiversity indices. These results agree with findings of Doha and Samy (2010); Belen and Alten (2011); Rigg *et al.* (2021) and contrast with findings of Kenawy *et al*. (2015). The consistently and dissimilarity between findings of current study and above workers my due be microclimate environments and biotopes. Furthermore, Karan *et al.* (2000) suggested that there is a remarkable difference in the diversity of the sand fly fauna across the different altitudes, although altitude is not a selective factor for fly distribution. The higher diversity among sandflies recorded in higher altitudes our study may be that areas favor sandflies and their host availability.

The temporal abundance of sandflies was also investigated in the present study, and the results displayed significant differences ($P < 0.05$) among the numbers of sandflies collected in different seasons of the year. These results are in accordance with findings of Coleman *et al.* (2007); Doha and Samy (2010) and Srinivasan *et al*. (2015) who reported that the climatic condition influenced significantly on density of sandflies during the seasons of the year. The fluctuation density of sandflies during different seasons of the year may be due to the fact that; months of the winter season exhibited the coolest night time temperatures, often dipping as low as zero. The cool temperature may serve to inhibit reproduction or delay development. In summer, the combination of warmer weather and the short rains, which occurs during summer, may be provided favorable conditions for the rise in population levels.

Knowledge of the seasonal activity of sandfly species is vital in forecasting the transmission and spread of leishmaniasis among people and carrying out an effective control program (Kenawy *et al*. 2015). The interaction between the biotic potential of species and environmental conditions controls sandflies population dynamics. In this study, sandflies showed different seasonal activity patterns in study areas (Fig. 1). The seasonal activity of *P. arabicus* peaked in June and declined rapidly to lower level in January. The activity of *P. alexandri* was more during July and dropped to zero in February. Similarly, the activity, *P. sergenti* begins at the end of May and is researched to peak in July. Numbers of all sandfly species dropped markedly in November, except for *P. alexandri*. These results are partially consistent with findings of Ibrahim and Abdoon (2005) who reported higher abundance rate of sandflies during the spring and summer (March to September) and the lower abundance rate from November to February. The variation in relative abundance and dynamics among sandfly species of the current study in different months of the year could be attributed to fluctuation in climatic conditions. In addition, Durrani *et al.* (2012) suggested that sandflies species require 28°C temperature and 40% humidity for growth and development. The current study, recorded the highest number of sandflies in the temperature range between 28.1–29.2°C.

A repaid decrease in abundance, activities and dynamics of sandflies which began in August and researched lower levels in December, January and February, could be explained in view of Gebresilassie *et al.* (2015) who suggested that; the decrease in temperature and rainfall influenced the larval stages of insect which underwent to the diapause and possibly broken by the end of rainy season as temperature increases reopening of soil cracks and other factors favor for survival and reproductions of sandflies. In the terms of predicting leishmaniasis transmission to host, Salomón (2002); Salomón *et al.* (2004); Quintana *et al.* (2010) in Argentina and Sofizadeh *et al.* (2021) in Iran studied the relationship between the abundance of sandflies and meteorological variables, and suggested there is association between the occurrence of leishmaniasis, a higher proportion of gravid females and favorable meteorological conditions such as rain, temperature and relative humidity. Recently, ecological niche models (ENMs) were developed for predicting the distribution sandflies and their role for transmitting leishmaniasis in targeted geographical zones (Fonseca *et al.* 2020).

## Conclusion

This study provides useful data on the spatiotemporal distribution, abundance and diversity of sandfly species in Dhamar city and around districts. A combination of ecological and topographical factors influences the distribution and abundance of sandflies in different areas of Dhamar. It could be suggested that the findings of this could be useful for designing a control program for sandflies in study areas. The ecological and topographical findings may be used to establish a vector monitoring system to predict occurrence of leishmaniasis among people in the study area. Further, entomological studies on epidemiology of sandfly and its disease transmission should be carried out regularly in different regions the country.


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## Authors Contributions

IRMSA proposed, wrote protocol of study, analyzed, interpretation of data, wrote the preliminary and final versions of the manuscript. Authors MAMT executed the entomological captures and processing of specimen. NMM identified the sandflies.

## Conflicts of Interest

We are the authors of this article declare that no conflict of interest regarding to this article and research.

## Data Availability

The data are available within text of the article.

## Ethics Approval

Not applicable.


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