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Population assemblage of the small fruit flies (Diptera, Drosophilidae) in the North Western Ghats of Karnataka (India) with special report on the dominant species

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ABSTRACT. The population assemblage of Drosophilidae in the four districts of North Western Ghats was analysed. A total of 13,604 individuals comprising 17 species collected from 8 localities during the period of 2021–22 across various seasons. The study highlights the dominance of three species (*Drosophila bipectinata* Duda, *D. malerkotliana* Parshad & Paika and *D. eugracilis* Bock & Wheeler) belonging to *ananassae* and *eugracilis* subgroups. Overall collection data revealed the highest species richness and diversity for Dharwad and UK interior forests, whereas the maximum abundance and the highest evenness were observed in UK coastal and Belagavi forests respectively. The species rank-abundance curve revealed Dharwad forest had higher species richness and comparatively stable species assemblage. *Drosophila eugracilis* was the dominant species in localities of Dharwad and Belagavi forests, whereas *D. bipectinata* was the dominant species in both coastal and interior localities of UK forests. Rare faction curves plotted across the different seasons for all the forest localities revealed population assemblage and species richness of all forests across different seasons. Morisita index of similarities showed similarities for populations across localities and seasons. Nonparametric independent sample Kruskal-Wallis test was done to test distribution of abundance of individual species across spatial and temporal groups. The study reveals variation of population assemblage across the forests of Dharwad, Belagavi, and Uttara Kannada (coastal and interior) and dominance of *D. bipectinata*, *D. malerkotliana* and *D. eugracilis*.

Key words: Abundance, diversity, *Drosophila*, dominant, species composition, western Ghats

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INTRODUCTION

The success of any population is dependent on its assemblage. Hence, the studies on the population assemblage become essential for the researchers to understand their dynamics, inter and intra-specific interactions, dominance etc. The species assemblage changes among different microhabitats, vegetation

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and altitude. Insects are the most dominant and diverse group of fauna in the world. Seasonal patterns also tend to influence population size and availability of food resources (Wolda, 1988) which implies that availability of natural food sources must be sufficient for the sustainability of species. Their population is influenced by the temperature, seasons and availability of food source. The family Drosophilidae is one of the major taxa in the order Diptera. Some drosophilids are cosmopolitan and many are endemic. It consists of around 4655 species distributed all over the world (Bachli, 2022). It has inhabited almost all the regions of the world because of its ability to adapt and evolve in diverse environmental conditions (DeSalle & Grimaldi, 1991). The Drosophilidae also act as indicators of biodiversity; the more rare and endemic species collected in a locality implies that the locality is rich in biodiversity while the more common and exotic species collected means that the locality has been affected by anthropogenic activities and is not rich in biodiversity. As an insect model, drosophilids can be studied as indicators of biodiversity (van der linde & Sevenster, 2002), as they are primary consumers of yeasts and other microorganisms which are found during initial decay of fruits or vegetables (Schmitz et al., 2007). Some species are considered as serious pests of fruit crops for instance *Drosophila suzukii* and *Zaprionus indianus* which originated from Asia and Africa, have invaded different continents such as Europe, North and South America, and are considered to be primary infesters of fruits such as blueberries, blackberries, raspberries, cherries, or strawberries, and hard fruits such as apples and pears (Vilela, 1999; Santos et al., 2003; Vander linde et al., 2006; Mortelmans et al., 2012; Calabria et al., 2010). Taxonomic survey of Drosophilidae was given by Sturtevant (1921) for the North American species and for Mexican species by Patterson and Mainland (1944). Geographical survey of drosophilids has been made all over the six zoogeographic regions of the world (Markow & O'Grady, 2006). India accounts for 319 species (Kandpal & Singh, 2010). Out of these species, South India accounts for 54 species (Hegde et al., 2001; Srinath & Shivanna, 2012, 2014a, 2017, 2019).

Studies on population assemblage of Drosophilidae are known from North America (Bombin & Reed, 2016) and Australia (van Klinken & Walter, 2001). Significant information on population assemblage is known from tropical forests of South America. In this region, researchers have extensively studied the effect of several factors such as precipitation, temperature, humidity, habitat, habitat loss, and global warming, with pioneering survey by Dobzhansky and Pavan (1950) from Brazil and subsequent studies by other researchers such as Benado & Brncic (1994) in forests of Chile, other localities of Brazilian forests (De Toni & Hofmann, 1995; Martins, 2001; Tidon, 2006; Torres & Madi- Ravazzi, 2006; Mata et al., 2008; Gottschalk et al., 2008; Schmitz et al., 2007, 2010; De Toni et al., 2007; Bizzo et al., 2010; Poppe et al., 2012, 2014; Penariol & Madi- Ravazzi, 2013; Garcia et al., 2014; Cavasini et al., 2014; Monteiro et al., 2016; Oliveira et al., 2016; Coutinho–Silva et al., 2017; Duarte et al., 2018). Population assemblage of Drosophilidae from India are poorly understood (Hegde et al., 2001), except few studies (Guruprasad et al., 2010; Achumi et al., 2013; Srinath & Shivanna, 2014b). All these studies have analysed drosophilid population with respect to variations in temperature, rainfall, seasons, and altitude.

The Western Ghats of India is considered as one of the biodiversity hotspots in the world (Chitale et al., 2015). It runs parallel along with the Western coast of India and has spread across the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. The forests of Western Ghats are characterized by evergreen, semi-evergreen, shola, mangroves, moist and dry deciduous forests with annual rainfall ranging between 1000 to 6000 mm per year. The fauna is equally rich and diverse with maximum number of endemic species found (Subhas Chandran, 1997). In the state of Karnataka the Western Ghats traverses the districts of Belagavi, Uttara Kannada, Dharwad, in the North whereas Shivamogga, Chikmagalur and Hassan in the central and Dakshina Kannada, Mysuru, Chamarajanagara and Kodagu districts in the South (Ramachandra et al., 2012). Drosophilidae of Western Ghats is not comprehensively understood, although there are reports of collections and novel species from few localities in the Southern and Central Western Ghats of Karnataka and parts of Uttara Kannada (Hegde et al., 2001). None of the studies have analysed the population assemblage of Drosophilidae of North Western Ghats. In view of this, a study was designed to collect and analyze the population assemblage in

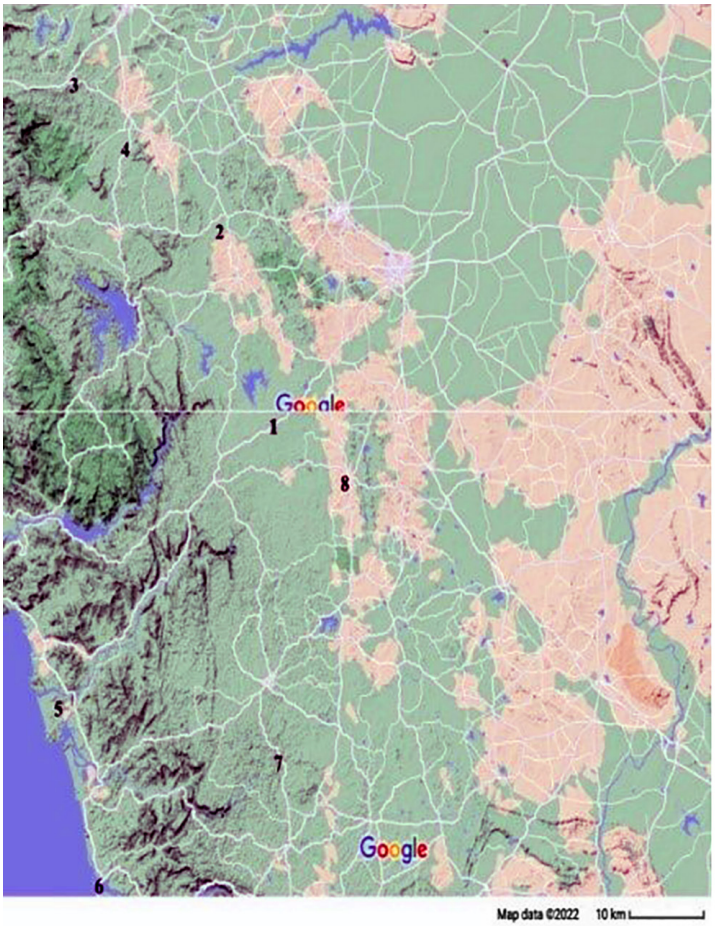
different localities of North Western Ghats forests of Dharwad, Belagavi and Uttara Kannada districts with respect to different seasons.

MATERIAL AND METHODS

Area of collection. Collection of Drosophilidae was done at different localities of Western Ghats forests of Dharwad, Belagavi and Uttara Kannada Districts (Table 1; Figs 1–2). The collection of the flies was usually done in the morning hours from 6 am to 10 am because of the lower and more favourable temperatures for collecting the samples, especially during winter and summer. Further the district of Uttara Kannada was divided as Uttara Kannada Coastal (UK coastal) and Uttara Kannada Interior (UK interior) to differentiate between the populations of coastal and interior forests.

Collection of Drosophilidae. The specimens were collected by two methods including Bottle Trapping and Net Sweeping. These methods were followed as procedure described by Hegde et al. (2001) (Fig. 3). Banana was used as the main bait; other fruits such as papaya, guava, sapota, mango, apple and orange were also used during collection (Srinath, 2017).

Categorization and Identification of species. After the collection, flies were brought to the laboratory and were etherized using Diethyl ether and separated into their respective sexes based on their characters such as shape, pattern and number of the abdominal segments and the genital plate under the stereomicroscope. The number of individual males and females were recorded and the females were placed individually into vials containing wheat cream agar medium (Shivanna et al., 1996).



1 Kalghatgi
2 Alnavar
3 Jamboti
4 Khanapur
5 Gokarna
6 Honnavar
7 Sirsi-Siddapur
8 Mundagod

Figure 1. Map showing the collection localities of Drosophilids from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada Districts.

Table 1. List of localities of Drosophilid collections from Western Ghats Forests of Dharwad, Belagavi and Uttara Kannada Districts.

Name of Forest	Location	Coordinate data
Dharwad Forest	Kalghatgi Alnavar	15°04'12"N, 74°52'48"E 15°25'48"N, 74°42'36"E
Belagavi Forest	Jamboti Khanapur	15°40'48"N, 74°21'00"E 15°37'48"N, 74°31'12"E
Uttara Kannada (UK) Coastal Forest	Gokarna Honnavar	14°32'24"N, 74°18'36"E 14°13'48"N, 74°26'24"E
Uttara Kannada (UK) Interior Forest	Sirsi-Siddapur Mundagod	14°25'12"N, 74°52'12"E 15°00'36"N, 75°03'00"E

Identification of flies. The males were identified based on the keys provided by Bock and Wheeler (1972) and Markow and O'Grady (2006). Later, flies were preserved in 70% ethanol and were deposited in the *Drosophila* research laboratory, Department of Zoology, Karnatak University Dharwad.

Mounting of the genital plate. The genital plate was mounted following the procedure mentioned by Parshad and Paika (1964) with minor modifications such as the duration of boiling of genital organs in 10% KOH was increased from 20 to 30 minutes and the mounting medium used was DPX instead of Euparal medium. Later the slides were observed under the microscope.

Seasonal study. The present study was categorized seasonally during 2021–22 as monsoon (June to September), post-monsoon (October to December), winter (January to February) and summer (March to May) as per the classification by Indian Meteorological Department (IMD report, 2022). The abundance of the population was observed accordingly. The data also included temperature and rainfall records of the localities during their respective seasons.

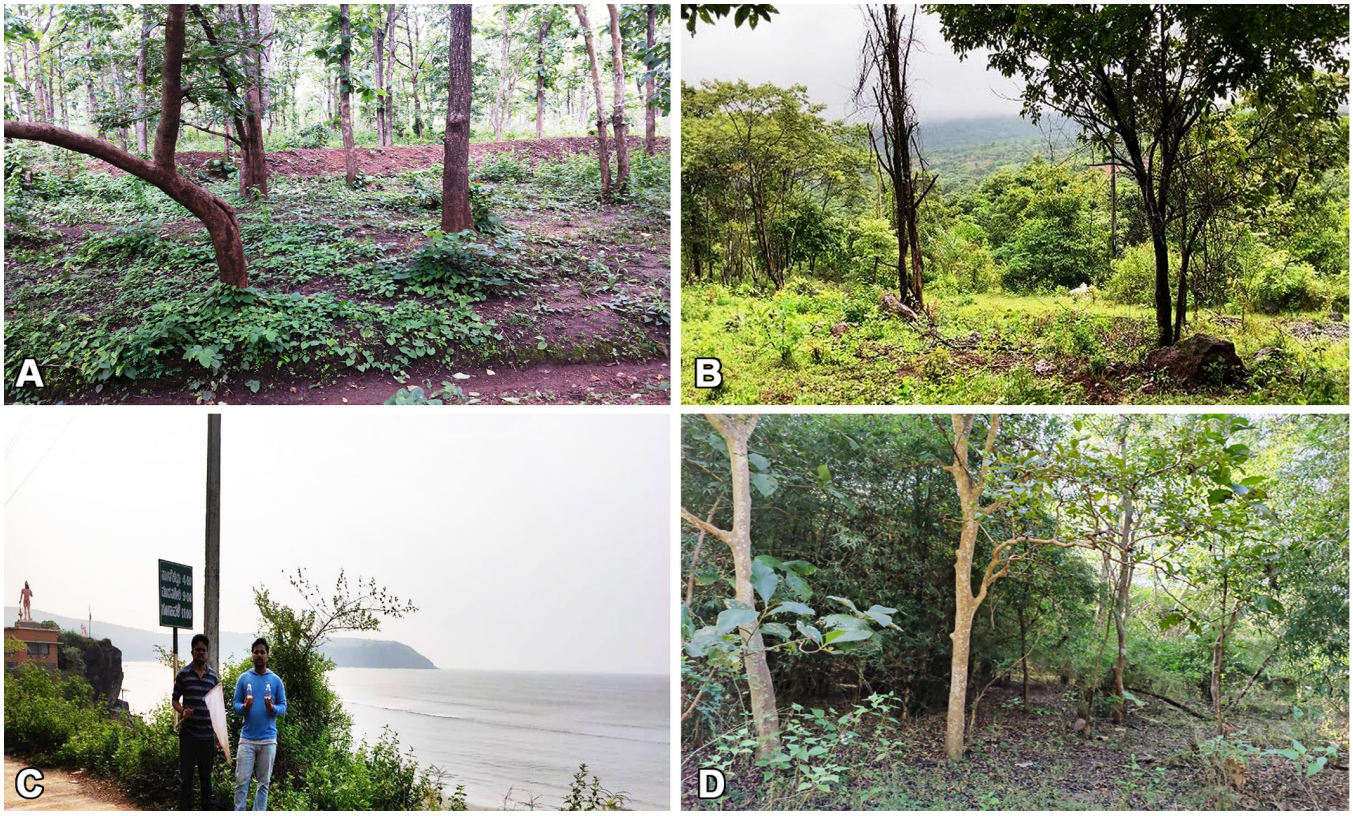


Figure 2. Collection of drosophilids from different habitats of the North Western Ghats, Karnataka. **A.** Dharwad forest; **B.** Belagavi forest; **C.** UK coastal forest; **D.** UK Inerior forest.

Figure 3. Methods for collecting the drosophilids. **A.** Bait trapping; **B.** Net sweeping; **C.** Bottle trapping.

Statistical and Diversity analysis of Data. Diversity of individual localities was analysed by Shannon (*H'*), Simpson (*1-D*), Berger-Parker (*d*) indices, Individual Rare faction curves were also plotted for temporal data of all forests. Morisita index was applied on abundance to check the relation between population assemblages of all forests during different seasons using PAST 4.03 diversity software whereas Evenness was calculated by Smith and Wilson (E_{var}) using microbiome R package. Species rank/abundance plot (Whittaker plots) was constructed for all localities. The influence of rainfall and temperature on abundance was compared by using Linear regression analysis test, in which abundance of drosophilids as dependent variable, whereas temperature and rainfall as independent variables. Finally, the population abundance between forests of all localities was compared spatially and temporally using non-parametric kruskal-wallis test using SPSS statistical package 21.0 version.

RESULTS

Table 2 shows list of drosophilids collected from different localities of Dharwad, Belagavi and Uttara Kannada forests. It revealed a total of 13604 flies comprising of 17 species of which 15 belonging to genus *Drosophila* Fallen whereas 2 belonging to genus *Zaprionus* Coquillet. Figure 4A depicts the species-rank abundance curves (Whittaker plots) revealing that Dharwad forest has more stable curve with respect to abundance and species richness and Belagavi forest (Fig. 4B) has shorter and low species richness rank abundance curve. The forests of UK interior were more stable (Fig. 4D) than the UK coastal (Fig. 4C).

Table 2. Different species of Drosophilidae collected from Dharwad, Belagavi and UK forests.

Genus *Drosophila* Fallen, 1823
Subgenus *Sophophora* Sturtevant, 1939
Species group *melanogaster*
Subgroup *ananassae*
1. *D. bipectinata* Duda, 1923
2. *D. malerkotliana* Parshad & Paika, 1964
Subgroup *eugracilis*
3. *D. eugracilis* Bock & Wheeler, 1972
Subgroup *suzukii*
4. *D. rajasekari* Reddy & Krishnamurthy, 1968
Subgroup *takahashii*
5. *D. takahashii* Sturtevant, 1927
Subgroup *montium*
6. *D. jambulina* Parshad & Paika, 1964
7. *D. punjabiensis* Parshad & Paika, 1964
8. *D. kikkawai* Burla, 1954
9. *D. anomelani* Reddy & Krishnamurthy, 1973
Subgenus *Drosophila* Sturtevant, 1939
Species group *immigrans*
Subgroup *nasuta*
10. *D. nasuta nasuta* Lamb, 1914
11. *D. sulfurigaster neonasuta* Sajjan & Krishnamurthy, 1973
Subgroup *immigrans*
12. *D. immigrans* Sturtevant, 1921
Subgroup *hypocausta*
13. *D. hypocausta* Osten-Sacken, 1882
Species group *polychaeta*
14. *D. daruma* Okada, 1956
Species group *repleta*
15. *D. repleta* Wollaston, 1858
Genus *Zaprionus* Coquillet, 1902
Subgenus *Anaprionus* Okada, 1990
16. *Z. bogoriensis* Mainx, 1958
Subgenus *Zaprionus* Coquillet, 1902
17. *Z. indianus* Gupta, 1970

Bar graphs of individual species based on their absolute abundance were plotted for all forests corresponding to different seasons; they revealed dominance of *D. eugracilis* in both the forests of Dharwad and Belagavi followed by *D. bipectinata* and *D. malerkotliana* as second and third dominant species respectively (Figs 5A–5B) whereas dominance of *D. bipectinata* was more evident in coastal and interior forests of UK (Figs 5C–5D). The study also revealed that *D. sulfurigaster neonasuta*, a subspecies of *D. sulfurigaster*, belonging to subgenus *Drosophila* was the fourth highest abundant species and was found in all the localities surveyed.

The overall regression analysis was statistically insignificant ($R^2 = 0.088$, F (1, 416) = 1.395, $P = 0.264$). It was found that rainfall and temperature did not significantly influence abundance ($\beta = 0.050$, $P = 0.781$; $\beta = 0.300$, $P = 0.106$). The diversity of drosophilids during monsoon and post-monsoon revealed maximum species richness and diversity (except E_{var}) for Alnavar and Kalghatgi forests, whereas minimum diversity for Honnavar forests of UK coastal. Honnavar locality also had the maximum values for Berger-parker index which is an index of dominance (Tables 3–4). Table 5 revealed that Sirsi-Siddapur forests had the maximum species richness and diversity (Shannon) during winter whereas, Alnavar forests had the maximum diversity for Simpson and evenness, and Honnavar forests had the minimum diversity values. During summer Sirsi- Siddapur forests had maximum diversity (except E_{var}); the maximum species richness was found in Kalghatgi forests whereas the minimum diversity was again found in Honnavar forests (Table 6).

Table 3. Diversity of Drosophilids during 2021–22 from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada districts during Monsoon.

	Dharwad		Belagavi		Uttara Kannada Coastal		Uttara Kannada Interior	
	Kalghatgi	Alnavar	Jamboti	Khanapur	Gokarna	Honnavar	Sirsi-Siddapur	Mundagod
Abundance (N)	469	210	140	232	142	189	1730	302
Species Richness (*S*)	8	9	3	7	8	6	9	6
Shannon (*H'*)	1.432	1.528	1.053	1.391	1.45	1.203	1.477	1.434
Simpson (*1-D*)	0.7036	0.731	0.6384	0.7153	0.6998	0.5734	0.7098	0.7157
Berger Parker (*d*)	0.4478	0.3905	0.4286	0.3836	0.4648	0.6243	0.4543	0.4139
Smith & Wilson (E_{var})	0.231941	0.262996	0.930634	0.215847	0.283537	0.455914	0.188603	0.5074374
Temp (°C)	21.1	22.5	21.6	21.3	24.5	23.3	21	19.6
Rainfall (mm)	696	720	1882	1056	2791	3326	2038	870

Table 4. Diversity of Drosophilids during 2021–22 from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada districts during Post-Monsoon.

	Dharwad		Belagavi		Uttara Kannada Coastal		Uttara Kannada Interior	
	Kalghatgi	Alnavar	Jamboti	Khanapur	Gokarna	Honnavar	Sirsi-Siddapur	Mundagod
Abundance (*N*)	259	235	296	263	681	609	604	119
Species Richness (*S*)	14	7	7	6	11	7	11	9
Shannon (*H'*)	1.891	1.509	1.328	1.515	1.644	0.9807	1.786	1.533
Simpson (*1-D*)	0.7682	0.7298	0.6818	0.7597	0.7572	0.4625	0.7507	0.6766
Berger Parker (*d*)	0.4131	0.434	0.3986	0.3422	0.3412	0.7159	0.4255	0.5233
Smith & Wilson (E_{var})	0.417774	0.291549	0.241658	0.260829	0.27294	0.229571	0.476311	0.448992
Temp (°C)	22	21	20.1	21.5	27	26	21.1	20.5
Rainfall (mm)	352	364	270	310	368	435	409	336

Table 5. Diversity of Drosophilids during 2021–22 from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada districts during winter.

	Dharwad		Belagavi		Uttara Kannada Coastal		Uttara Kannada Interior	
	Kalghatgi	Alnavar	Jamboti	Khanapur	Gokarna	Honnavar	Sirsi-Siddapur	Mundagod
Abundance (*N*)	15	60	80	34	806	1873	423	24
Species Richness (*S*)	3	5	5	5	5	7	10	3
Shannon (*H'*)	0.8069	1.51	1.426	1.262	0.6153	0.3145	1.58	0.857
Simpson (*1-D*)	0.4798	0.7617	0.7197	0.6471	0.283	0.1367	0.7231	0.4965
Berger Parker (*d*)	0.6667	0.3333	0.4375	0.5294	0.8412	0.9274	0.4492	0.6667
Smith & Wilson (E_{var})	0.721788	0.852246	0.763439	0.529651	0.24808	0.104668	0.237114	0.709601
Temp (°C)	20.4	20	20.1	20.5	24	24.4	20	20.1
Rainfall (mm)	0	0	2	1	0	1	1	1

Table 6. Diversity of Drosophilids during 2021–22 from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada districts during summer.

	Dharwad		Belagavi		Uttara Kannada Coastal		Uttara Kannada Interior	
	Kalghatgi	Alnavar	Jamboti	Khanapur	Gokarna	Honnavar	Sirsi-Siddapur	Mundagod
Abundance (*N*)	779	262	373	237	761	1134	163	100
Species Richness (*S*)	13	8	7	8	8	8	12	7
Shannon (*H'*)	1.637	1.396	1.397	1.654	1.116	0.9508	2.038	1.624
Simpson (*1-D*)	0.7381	0.6857	0.7093	0.7732	0.5625	0.4729	0.8381	0.7718
Berger Parker (*d*)	0.4108	0.4695	0.3861	0.3207	0.615	0.6958	0.2454	0.32
Smith & Wilson (E_{var})	0.228893	0.255120	0.2448967	0.3056625	0.1987261	0.1653201	0.4250416	0.4882888
Temp (°C)	27.6	28	28.2	28	32.3	32.3	27.8	27.9
Rainfall (mm)	134.9	130.6	100.1	111.3	42.5	29.6	50.5	130.6

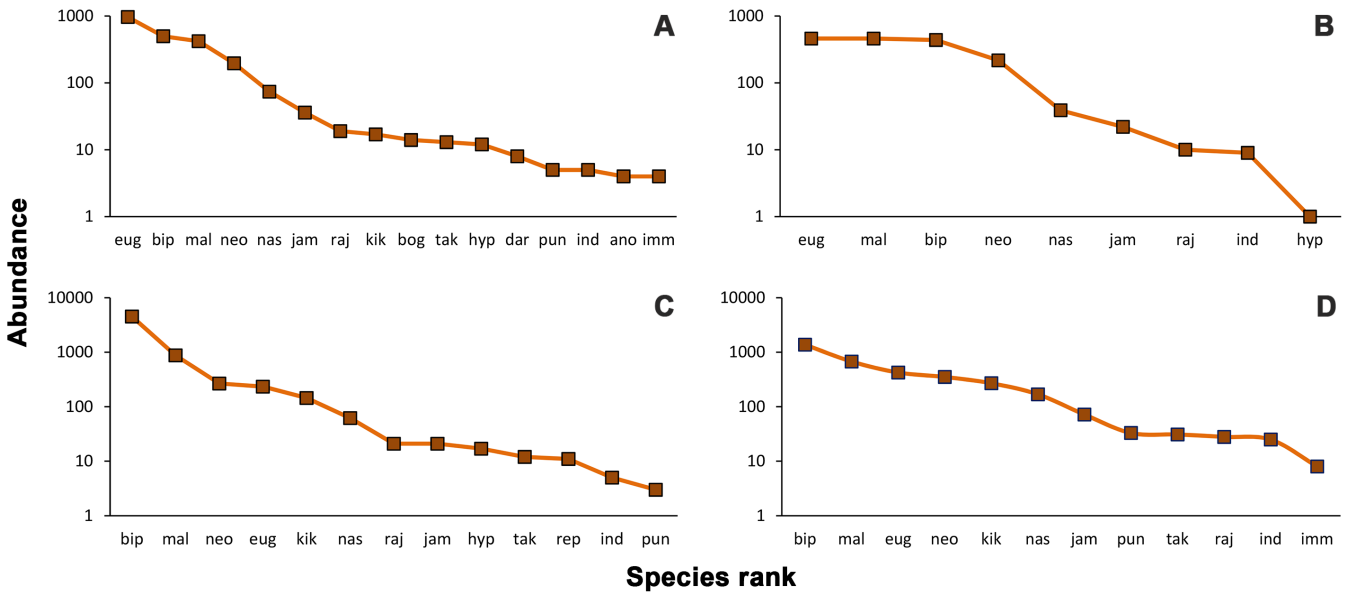


Figure 4. Species rank/abundance plot of Drosophilids collected from North Western Ghats forests of Karnataka. **A.** Dharwad; **B.** Belagavi; **C.** Uttara Kannada Coastal; **D.** Uttara Kannada Interior forests. eug: *D. eugracilis*; bip: *D. bipectinata*; mal: *D. malerkotliana*; neo: *D.s.neonasuta*; nas: *D.n.nasuta*; jam: *D. jambulina*; raj: *D. rajasekari*; tak: *D. takahashii*; pun: *D. punjabiensis*; kik: *D. kikkawai*; dar: *D. daruma*; ano: *D. anomelani*; imm: *D. immigrans*; hyp: *D. hypocausta*; rep: *D. repleta*; bog: *Z. bogoriensis*; ind: *Z. indianus*.

Table 7 shows the overall data of collection of drosophilids from different localities of Dharwad, Belagavi and Uttara Kannada forests. Among the localities, Honnavar forests of UK coastal had the maximum abundance for the flies, whereas; Mundagod of UK interior forests had the minimum abundance. Species richness was more for Kalghatgi forests of Dharwad and less for Jamboti forests of Belagavi district. Diversity analysis- showed that Sirsi-Siddapur forests of UK interior had the maximum Shannon index of diversity (1.769) whereas Khanapur forests of Belagavi had maximum Simpson (0.7695) and Berger–Parker (0.2885) diversity indices. Mundagod of UK interior showed maximum values for evenness index (0.3321). Gokarna and Honnavar of UK coastal forests had the minimum of Shannon, Simpson, Berger-Parker indices of diversity and also the minimum evenness index. The non-parametric test of kruskal-wallis on the distribution of absolute abundance across spatial and temporal components revealed significant difference ($p < 0.05$) for few species of drosophilids; *D. bipectinata* and *D. kikkawai* showed significant difference spatially whereas distribution of *D. eugracilis*, *D. rajasekari*, *D. jambulina* and *D. punjabiensis* were significant temporally. Among pair-wise comparisons, *D. bipectinata*'s distribution was significant between forests of UK coastal and forests of Dharwad and Belagavi.

Table 7. Overall collection of Drosophilids during 2021–22 from Western Ghats forests of Dharwad, Belagavi and Uttara Kannada Districts.

	Dharwad		Belagavi		Uttara Kannada Coastal		Uttara Kannada Interior	
	Kalghatgi	Alnavar	Jamboti	Khanapur	Gokarna	Honnavar	Sirsi-Siddapur	Mundagod
Abundance (*N*)	1522	767	889	766	2390	3805	2920	545
Species Richness (*S*)	15	11	8	9	13	9	12	11
Shannon (*H'*)	1.656	1.521	1.472	1.586	1.307	0.7356	1.769	1.71
Simpson (*1-D*)	0.7365	0.7243	0.7436	0.7695	0.5902	0.3311	0.7674	0.7605
Berger Parker (*d*)	0.4185	0.4263	0.315	0.2885	0.6038	0.8092	0.4014	0.3743
Smith & Wilson (E_{var})	0.226593	0.174009	0.203046	0.142766	0.186025	0.132202	0.260804	0.332135

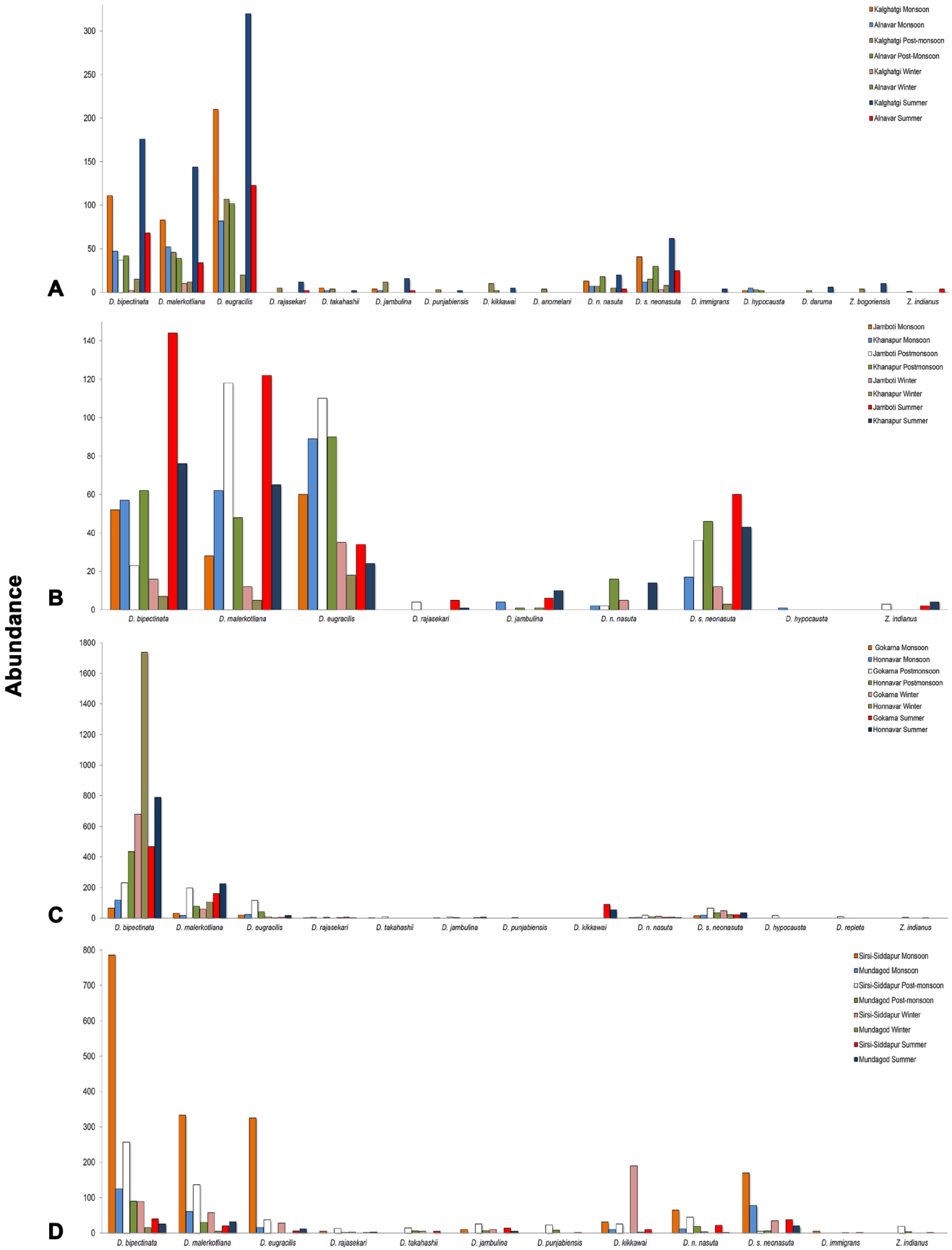


Figure 5. Abundance of individual Drosophilidae during different seasons from forest localities. **A.** Dharwad; **B.** Belagavi; **C.** Uttara Kannada Coastal; **D.** Uttara Kannada Interior.

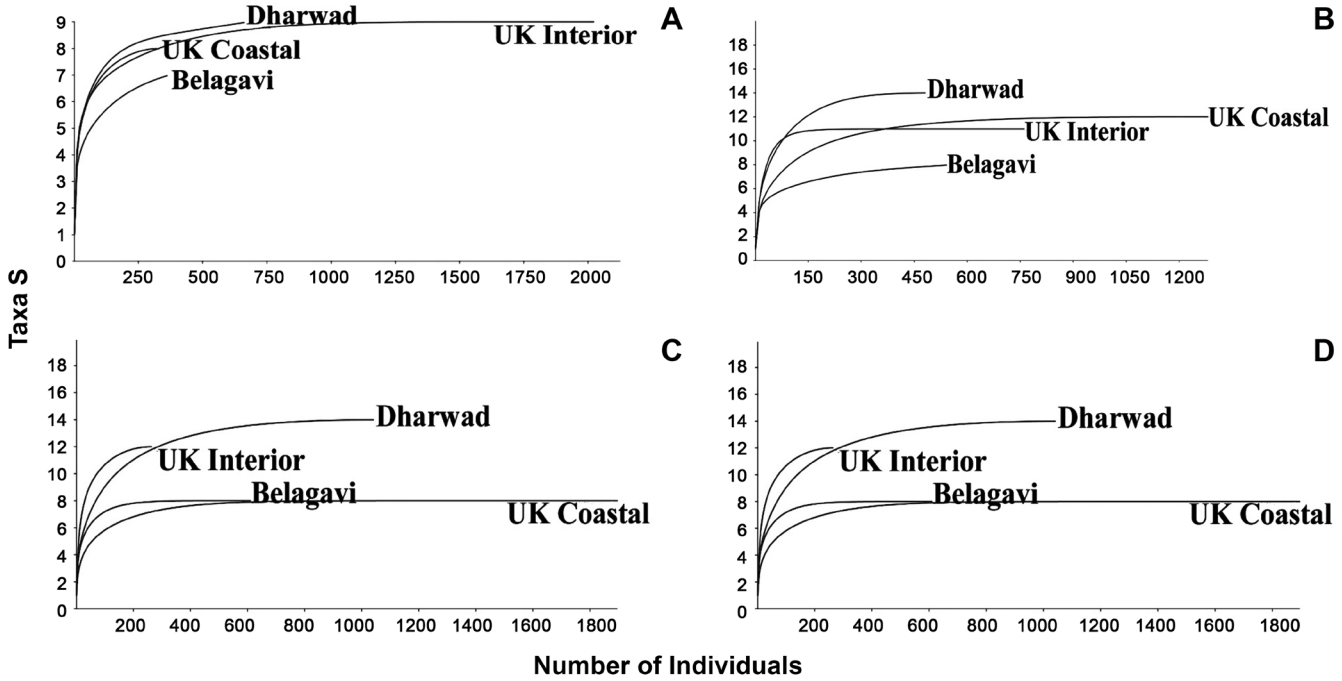


Figure 6. Individual Rarefaction curves of Drosophilid abundance in forests of Dharwad, Belagavi and Uttara Kannada during various periods. **A.** Monsoon; **B.** Post-Monsoon; **C.** Winter; **D.** Summer.

Significant difference was found between Belagavi and UK interior forests with respect to distribution of *D. kikkawai*. For temporal variation among species, population of *D. eugracilis* was significant between (monsoon vs winter) and (winter vs summer), *D. rajasekari* between (monsoon vs summer) and (winter vs summer), *D. jambulina* between (winter vs summer) and *D. punjabiensis* between (monsoon vs post-monsoon) and (monsoon vs winter) (Table 8). Individual rarefaction curves plotted temporally for all forests revealed more stability for Dharwad having more stable population assemblage compared to others during monsoon, post-monsoon and summer (Species richness and abundance) whereas UK interior had stable population assemblage during winter (Figs 6A–6D). Similarly Morisita index has revealed population assemblage of all forests during monsoon and post-monsoon and winter of Dharwad and Belagavi under one major group whereas winters of UK coastal and interior forests appeared to be separated individual groups and finally the summer population assemblages belonged to a separate group (Fig. 7).

Table 8. Comparisons of species abundance based on spatial and temporal components using a Kruskal–Wallis test.

Species	Sampled forests					Sampled seasons				
	Dharwad	Belagavi	UK coastal	UK interior	*p*-value (spatial)	Monsoon	Post-Monsoon	Winter	Summer	*p*-value (temporal)
D. bipectinata	249±77^{A}	218±16.5^{A}	2261±818^{B}	688±484	<0.05	-	-	-	-	-
D. kikkawai	8.5±6.5	0^{A}	72.5±17.5	135±122^{B}	<0.05	-	-	-	-	-
D. eugracilis	-	-	-	-	-	103.25±38.71^{A}	75.62±15.2^{A}	13.87±4.7^{B}	67.62±38.5^{A}	<0.05
D. rajasekari	-	-	-	-	-	1.37±0.8^{A}	3.5±1.535	0.75±0.49^{A}	4.12±1.27^{B}	<0.05
D. jambulina	-	-	-	-	-	2.75±1.19	6.87±3.09	1.375±1.2^{A}	7.87±1.78^{B}	<0.05
D. punjabiensis	-	-	-	-	-	0^{A}	4.62±2.80^{B}	0^{A}	0.5±0.32	<0.05

Only species with absolute abundance significant across spatial and temporal are shown. Data are presented as the means (± standard error) of the absolute abundance. Different letters indicate significant difference in the non parametric pair-wise multiple comparisons between sampled forests or between sampled seasons.

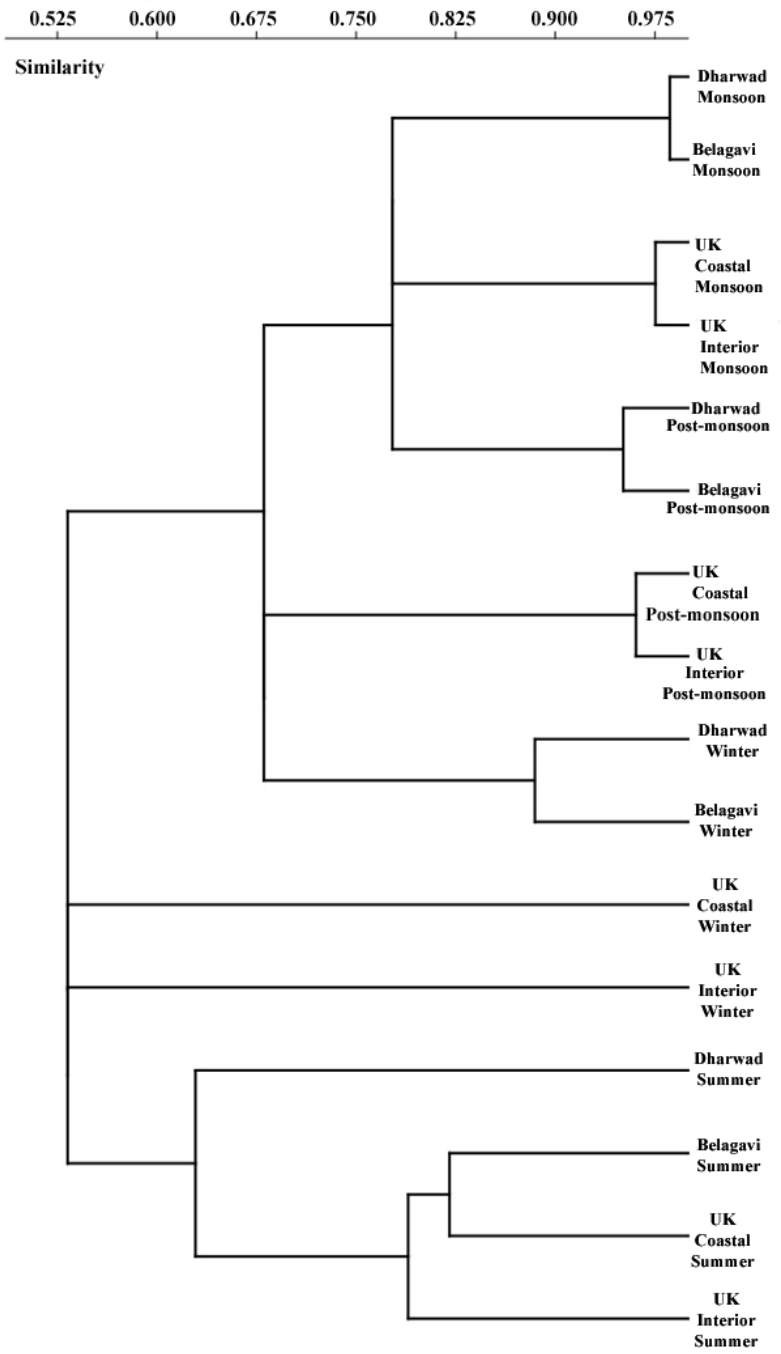


Figure 7. Morisita index showing temporal relation of abundance among Dharwad, Belagavi and Uttara Kannada coastal and interior forests.

DISCUSSION

The present study reveals the predominance of the genus *Drosophila* over other genera, which is very much evident from earlier surveys of the Indian subcontinent (Hegde et al., 2001). In particular, the dominancy of the subgenus *Sophophora* is well established among the commonly found flies belonging to *melanogaster* species group (Bock & Wheeler, 1972; Hegde et al., 2001). Population assemblage of Drosophilidae in the North Western Ghats of Karnataka is predominantly inhabited by three species, *D. bipectinata, D. malerkotliana* and *D. eugracilis* in all the localities and seasons surveyed (Figs 5A–5D).

The distance between these localities ranges from 30 to 250 km and knowing the broad distribution of *Drosophila* species (Bock & Wheeler, 1972; Markow & O'Grady, 2006); the possible representation of these species in such a dominant form is justified in this part of the subcontinent. Another important observation that was made from this study was that the cosmopolitan species such as *D. melanogaster* and *D. ananassae* were absent. Other species of the subgenus *Sophophora*, *Drosophila* and other drosophilids were more sensitive to seasonal changes.

Dharwad and Belagavi Forests. The Western Ghats forests of Dharwad and Belagavi are geographically present adjacent to each other and vary in vegetation and forest type. The forests of Dharwad are dominated by dry deciduous forests with annual precipitation of 594 to 998 mm whereas the forests of Belagavi are characterized by semi-evergreen, moist and lesser dry deciduous forests with annual precipitation more than 1000 mm (Khaple et al., 2015; Pramod Kumar et al., 2014). Both forests are dominated by the sympatric species *D. bipectinata*, *D. malerkotliana* and *D. eugracilis*. Between the two forests, Dharwad forest has provided a stable assemblage for populations of Drosophilidae (Figs 4A–4B) with the highest species richness, presence of rare species such as *D. daruma* and *D. latifshahi* (Srinath & Shivanna, 2012, 2014a, 2014b) and more diversity (Shannon and Simpson) during monsoon and post-monsoon than the forests of Belagavi (Tables 3–4). This is also evident from the rarefaction analysis curves (Figs 6A–6B). The only similarity between these two populations can be found temporally through Morisita similarity index which reveals similar community structure for Dharwad and Belagavi forests when compared with the populations of UK forests (Fig. 7).

The present study is the virgin survey of *Drosophila* in Belagavi forests. The abundance and richness is low (Fig. 4B; Tables 3–7). The reason for the low abundance and richness during monsoon and post-monsoon is more precipitation. Even though many literatures generally cited that *Drosophila* abundance increases with increased rainfall (Dobzhansky & Pavan, 1950; Torres & Madi Ravazi, 2006); this may not be true for all the localities. Abundance of a population is also dependent on the availability of food source and other factors (Bizzo et al., 2010). Consistent rainfall can make the collection of flies difficult in their natural populations, as rainfall tends to wash away the bait or dilute the effect of bait, fails to attract the flies. Hence, moderate rainfall accompanied by cooler temperature and food source provides optimal condition for *Drosophila* population during monsoon and post-monsoon. In both the forests fall of abundance, richness and diversity during winter is because of dry deciduous forests shedding their leaves; dry conditions, nearly no rainfall, low temperatures and lack of naturally available food source reduces *Drosophila* population. Rarefaction analysis provides the evidence that Dharwad and Belagavi forests during winter has lowest species richness and abundance, hence forms small community. But, during summer there is variation in the population structure of these two forests (Figs 6D & 7). Both the forests have precipitation with thunder showers which cools the temperature and also creates some source of food. The main reason in increase of species richness and abundance between the two forests is the commercial harvesting of mango which is grown extensively in these regions and found around the Western Ghats forests of Dharwad and Belagavi along with other fruits attracts *Drosophila*. Harvesting season generally influences drosophilid population (Srinath & Shivanna, 2013). Hence overall study reveals monsoon, post-monsoon and summer experiences more *Drosophila* abundance and species richness, diversity than winter in Dharwad and Belagavi forests.

UK forests. The Western Ghats forests of UK are denser and more diverse than the forests of Dharwad and Belagavi. These forests differ from mangroves to semi-evergreen and moist deciduous forests near Honnavar and Gokarna and from evergreen, and semi-evergreen to dry deciduous near Sirsi-Siddapur and Mundagod (Ramachandra, 2007; Ramachandra & Ganapathy, 2007). In the present study, drosophilids were found throughout the seasons. The interior forests were found more diverse and richer in species during monsoon and post-monsoon. This could be because coastal forests are usually affected by higher insolation, winds, drought, and daily temperature fluctuations. This plays an important role in determining resource availability (Bizzo et al., 2010). During winter the abundance of

D. bipectinata and *D. malerkotliana* in coastal forests increased and dominated the population assemblage outclassing other species of *Drosophila* (Figs 5C–5D). Hence coastal forests have more values for dominance index and less evenness (Tables 5–6). Yet temporally, the population structure is similar between the coastal and interior forests (Fig. 7).

In the evergreen and semi-evergreen forests of UK, the availability of natural fruits throughout the year especially during winter (Hebbar et al., 2010) with favourable climatic conditions provide a good chance for survival of *Drosophila*. Also commercially, areca is harvested in the plantations surrounding the UK forests throughout the winter and continues till the beginning of summer season, which also has the potential to attract drosophilids in mass. *D. kikkawai* is the only species found to be the dominant species in interior forests during winter, which is associated with fruiting of areca (Srinath & Shivanna, 2015). Hence abundance of *Drosophila* during winter and summer in UK forests is justified. The last survey of *Drosophila* from UK was done 40 years ago by Nagaraj & Krishnamurthy (1980). The study also showed similar pattern of species abundance and richness and dominancy of *D. bipectinata* and *D. malerkotliana* with other common species of *melanogaster* species group.

Dominancy of sympatric species. All the forests surveyed have shown the dominancy of *D. bipectinata* and *D. malerkotliana*. These species belong to *ananassae* subgroup of *melanogaster* species group. Both species are considered as sympatric and are distributed throughout the subcontinent and South East tropical regions of Asia (Bock & Wheeler, 1972; Markow & O'Grady, 2006). They were found to be dominant during rainy and autumn season in some parts of North India (Parkash et al., 2014). Present study also highlights that the diversity of drosophilids is severely influenced by the dominance of these two species. Index such as Berger Parker is sensitive to dominance of individual species and species richness and has higher values (Magurran, 2004). As a result, the other measures of diversity are also affected and hence localities such as Honnavar and Gokarna have low diversity of *Drosophila* species during winter and summer. Further evidence is provided by Kruskal-Wallis analysis which revealed significant difference between abundance of *D. bipectinata* between Dharwad, Belagavi forests and UK coastal forests (Table 4). Coutinho-Silva et al. (2017) studied diversity of drosophilids from Atlantic forests of South America. Their study revealed that species such as *D. malerkotliana*, which is an exotic species in Brazil, was found abundantly against native species. A similar report of dominancy was also reported from Florida, USA (Birdsley, 2003).

Generally arthropods are known for their high tolerance to stress such as desiccation and temperatures (Hadley, 1989; Hadley & Quinlan, 1989). In *Drosophila* this adaptation is well understood in some species (Hoffmann, 2010; Marron et al., 2003; Parkash et al., 2013). Studies on *D. bipectinata* and *D. malerkotliana* species have shown rapid colonization and resistance to desiccation and cold stress. Laboratory experiments have tested developmental acclimation at two growth temperatures (17 and 25°C). There was a significant variation in cuticular traits, i.e. increase of body melanisation, cuticular lipid mass. Both species showed significantly higher effects of developmental acclimation on body water content, rate of water loss and dehydration tolerance resulting in higher desiccation resistance. Similar observations were made in seasonally varying populations (Parkash et al., 2014). This may be the determining factor responsible for their dominance and ecological success spatially and temporally. *Drosophila eugracilis* is less commonly studied species when compared to the sympatric species. This species is also a native of tropical and subtropical regions (Bock & Wheeler, 1972). This species was also reported in earlier studies from Dharwad and other localities from South Western Ghats (Srinath & Shivanna, 2014a, 2014b; Hegde et al., 2001). In the present study it was found more common during monsoon and post-monsoon, during winter and summer (especially in UK forests) its abundance was low. This is evident from Kruskal Wallis test which showed significant difference between winter and other seasons (Table 7). This could be due to its inability to adaptation to cold and dry habitats. Yet, the adaptability of this species to the tropical and sub tropical environment is presently unknown. Studies on tolerance to desiccation and temperatures may provide some evidence on its population structure. This species is difficult to culture in the regular laboratory media (personal observation). *Drosophila s.*

neonasuta belonging to subgenus *Drosophila* was also found across all forests and seasons. This subspecies along with its sympatric subspecies *Drosophila nasuta nasuta* is also common species found in surrounding areas of Dharwad (Srinath & Shivanna, 2014a); *D. n. nasuta* is an invasive subspecies in other parts of the world such as South America which has influenced the population assemblage of local species such as *D. cardini*, *D. polymorpha*, *D. mercatorum, D. sturtevanti*, and *D. willistoni* (Montes et al., 2021; Garcia et al., 2022). In the Western Ghats, from the present study, *D. s. neonasuta* is more commonly found than *D. n. nasuta* and currently this subspecies is not dominant in the Western Ghats. This is probably because of the presence of the other invasive species such as *D. bipectinata* and *D. malerkotliana* also occupying the same ecological niche.

The present study revealed that the North Western Ghats of Karnataka which includes the forests of Dharwad, Belagavi and Uttara Kannada are dominated by the subgenus *Drosophila* with 17 species of the Drosophilidae family, specially three species *D. bipectinata* and *D. malerkotliana* and *D. eugracilis*, which have highly dominated across all the localities and seasons.

AUTHOR'S CONTRIBUTION

The authors confirm contribution to the paper as follows: S.B.S. designed the experiment, supervised the project and took the lead in manuscript writing and accompanied during collection of flies. A.B.S. took lead in the collection, identification and helped in data generation. N.S. co-wrote the manuscript and provided valuable suggestions throughout the work. All authors approved the final version of the manuscript.

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Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The author declare that there is no conflict of interest regarding the publication of this paper.

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ترکیب جمعیتی مگس‌های سرکه (Diptera, Drosophilidae) در شمال غرب گهات، کارناتاکا (هند) به همراه گزارش ویژه در مورد گونه غالب

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چکیـــده: جمعیت مگس‌های سرکه خانواده Drosophilidae در چهار ناحیه از شمال گهات غربی مورد تجزیه و تحلیل قرار گرفت. در مجموع ۱۳۶۰۴ فرد متعلق به ۱۷ گونه از هشت منطقه در فصول مختلف سال‌های ۲۰۲۱-۲۰۲۲ جمع‌آوری شد. این مطالعه غالبیت سه گونه (*Drosophila bipectinata* Duda، *D. malerkotliana* Parshad & Paika و *D. eugracilis* Bock & Wheeler) متعلق به زیرگروه‌های ananassae و eugracilis را نشان داد. داده‌های جمع‌آوری شده بیشترین غنا و تنوع گونه‌ای را برای جنگل‌های Dharwad و UK interior نشان داد، در حالی‌که بیشترین فراوانی و بیشترین یکنواختی به ترتیب در جنگل‌های UK coastal و Belagavi مشاهده شد. منحنی رتبه-فراوانی گونه‌ها نشان داد که جنگل Dharwad دارای غنای گونه‌ای بالاتر و مجموعه گونه‌ای نسبتاً پایداری است. گونه *Drosophila eugracilis*، گونه غالب در جنگل‌های Dharwad و Belagavi، در حالی‌که گونه *D. bipectinata* گونه غالب جنگل‌های coastal UK و interior UK بود. منحنی‌های Rare faction که در فصول مختلف برای همه مناطق جنگلی ترسیم شده است، مجموعه جمعیت و غنای گونه‌ای همه جنگل‌ها را در فصول مختلف نشان می‌دهد. شاخص شباهت گونه‌ای موریسیتا برای جمعیت‌ها بین مناطق و فصول شباهت‌هایی را نشان داد. آزمون کروسکال-والیس برای آزمایش توزیع فراوانی گونه‌ها در گروه‌های زمانی و مکانی انجام شد. این مطالعه تنوع تجمع جمعیت در جنگل‌های Dharwad، Belagavi و Uttara Kannada (coastal and interior) و غالبیت گونه‌های *D. bipectinata*، *D. malerkotliana* و *D. eugracilis* را نشان می‌دهد.

واژگـان کلیدی: فراوانی، تنوع، مگس سرکه، غالب، ترکیب گونه‌ای، گهات غربی