An empirical mathematical models of biodiversity indices in assessing the diversity of *Drosophila* (Fruit fly)

Guruprasad B.R[1*]
Department of Zoology, Yuvaraja's College, University of Mysore, Karnataka, INDIA
Anand Krishna Tiwar[2]
Genetics & Developmental Biology Laboratory, Department of Biological Sciences & Biotechnology, Institute of Advanced Research, Gandhinagar-Gujarat, INDIA
Manjunatha Prabhu B.H [ab1*]
[a]Senior Scientist, Dept. of Food Protection And Infestation Control (FPIC), CSIR- Central Food Technological Research Institute (CFTRI),Mysore, Karnataka, INDIA
[b]Assistant Professor (AcSIR), Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, UP, INDIA

*** Corresponding Author**

Abstract-*Drosophila* (Diptera: Drosophilidae), a fruit fly is an excellent model for studying the eco-distributional patterns of various species. In this study *Drosophila* communities of 5 different fruit yards in and around Mysuru, India region were assessed by various biodiversity indices. A total of 573 *Drosophila* flies belonging to 17 species of 4 subgenera were collected at different yards (Coconut yard (CY), Banana yard (BY), Guava yard (GY), Custard apple (CastY), Mango yard (MY) and Sapota Yard (SY)). The sub-genus *Sophophora* is predominant with 10 species, followed by Drosophila, with 4 species, Subgenus *Scaptodrosophila* (2 species) and subgenus *Dorsilopha* represented by single species each. At Banana yard (BY), the number of flies collected was the highest (179) compared to all other yards and the least number was collected at Custard apple yard. Surprisingly, *D.malerkotliana, D.rajasekari, D.nasuta, D.neonasuta* and *D.brindavani* were the most common species found in all localities. Alpha, beta diversity and individual rarefaction indices were employed to study the species richness and species turn over in the given region. According to the many biodiversity indices Banana yard exhibit rich biodiversity with many numbers of species. Along with this cluster and dendrogram methods were used to analyze the species occurrence qualitatively and their relationship. Our results suggest the eco-distributional pattern of species group or related group was uneven in space and time.

Keywords- ***Drosophila*, biodiversity, Alpha, beta diversity, individual rarefaction, cluster, dendrogram**

I. INTRODUCTION

Biological diversity is a common phenomenon among living organisms; which can broadly referred as "biodiversity". The most important attribute of the biodiversity is that it is unevenly distributed on our planet, thus, different ecosystem harbors different flora and fauna communities. This can be measured at different levels ranging from the ecosystem to the genetic level. It is figured as copiousness in the diversification of all life forms in a zone. Assessing the similarity and dissimilarity among biological groups is a vital pace to known how variety of life is distributed in this way. The Indian subcontinent comprises rich diversity in forest, wetlands, marine and desert ecosystem for this purpose it is well known as one of 12th mega diverse countries in the world. This encompassing a wide variety of flora and fauna in nature (Ref).The fruit fly *Drosophila* (L.) (Diptera: Drosophilidae) is also one among them. Today, *Drosophila* is used as a best popular organism for answering many questions in research studies especially in natural sciences.

Drosophila belongs to the family *Drosophilidae* subsumes 3,952 species distributed in two subfamilies (*Stegnainae* and *Drosophilinae*) and 73 genera (Ref). Among this *Drosophilinae* represents more than 3,241 species incorporated in 44 genera of which *Drosophila* is well divergent with 1,160 species (Bachli, 1998, 2009). Many studies had been made in nomenclature the family *Drosophilidae* in India. More or less 200 species belonging to 20 genera have been recording from different parts of India (Reddy and Krishnamurthy 1977; Singh and Gupta 1977, Diwivedi and Gupta 1979, Guruprasad et al., 2010). These species are endemic, cosmopolitan, associated with anthropological activities and often noticed from the sea level to different altitudes as well as in temperate to equatorial zones (Throckmorton, 1975, Hedge 1979; Hedge et al., 2000, Guruprasad et al., 2016). *Drosophila* in different geographical regions represents the fundamental basis of adaptive radiation and speciation (Muniyappa 1981).

The *Drosophila*, fruit flies are highly sensitive to slight a environmental change, which reflects structure and ecology of the natural population (Markow). It is the variation in abiotic factors such as temperature, light intensity and rainfall that affects developmental time, fertility, viability and other factors that influence life cycle and span of *Drosophil*a flies (Torres and Madi-Ravazzi 2006). These above abiotic factors also have an impact on the supply of resources principally in relation to the time of flowering and fruiting of many vegetable plant resources that provide most of the sites for oviposition and feeding of flies (Brncic et al., 1985). In addition to this above abiotic factors and biotic factors also influence the heterogeneity and ample of natural populations of fruit flies including intra–interspecific relationships, such as compactness, population age, dispersal, conflict and relationship between *Drosophilads* and their host and predators (Markow). The numerical of the individual of a species in a locality is significantly influenced by the presence or the absence of another species, especially those that are closely ecologically related (Putman 1995; Begon 1996). The ability to colonize multiple richness is an indication of the biological success of many species (Torres and Madi-Ravazzi 2006). Thus, the presence or absence of a species in an ecological edge and its richness or abundance in that area is an indicator of both the biological and ecological diversity of that ecosystem. Therefore, the composition and structure of a *Drosophilads* assemblage depend on the domain in which it was set up. In the current manuscript we aim to study the presence of taxonomically or phylogenetically related species in an ecological niche indicates coexistence and the absence of such related species suggests the competitive exclusion and the second goal is to understand whether particular vegetation is related to species existence along with this diversification of the flies using some mathematical models.

II.MATERIALS AND METHODS

The diversity of *Drosophila* fauna was studied in five different localities of fruit yard such as Coconut yard (CY), Banana yard (BY), Guava yard (GY), Custard apple (CastY) Mango yard (MY) and Sapota Yard (SY) located in and around Mysore and southern part of the Karnataka in India. Collections of flies were made in the above spots during fruiting seasons in2018. Usingboth bottle trapping and net sweeping methods. For bottle trapping, milk bottles of 250mLcapacity containing smashed ripe Banana sprayed with yeast were tied to twigs underneath small bushes at a height of three to five feet above the ground. Four traps were kept at each altitude. The following day the mouth of the each bottle was plugged with cotton and removed from the bushes. The flies that were collected in bottles were transferred to fresh bottles containing wheat cream agar medium (Consisting 100gms, wheat powder, 120gms raw sugar, 10gm agar-agar, 7mL Propionic acid boiled in 1000mL water and cooled according to Hegde et al.,2001, Guruprasad et al., 2010 as food. Net Sweeping was done on naturally rooting fruits if available or on fruits placed beneath shaded areas of the bushes one day before the collection. After each sweep, flies were transferred to the bottles containing fresh food. Five sweeps were made at each place to maintain the uniformity in the collection in each locality. The collected flies were brought to the laboratory, isolated, identified and sexed. Categorization of the collected *Drosophila* flies was made respective to taxonomic groups by employing several keys (Sturtevant 1927; Patterson and stone 1952; Thorckmorton 1962; Bock 1971).

Statistics

The relationship between the abundance, richness, evenness, β-diversity of all groups of *Drosophila* flies collected in different localities was deliberated by following indices.

a. Number of species ***(S)*:**
b. Total number of individuals **(n):**
c. Dominance is measured by Simpson index ***(D)***

$$D = \frac{\sum_i n_i (n_i - 1)}{n(n-1)}$$

Where n= the total number of organisms of a particular species and N=the total number of organisms. The Simpson index 1-*D*, measures evenness of the community from 0 to 1.

d. Shannon index *(H):* This diversity taking into account the number of individuals as well as number of species. Varies from 0 for communities with only a single species to high values for communities with many species, each with few individuals

$$H=-\sum n_i/n \ln n_i/n$$

e. Buzas and Gibson's evenness: e^H/S

f. Brillouin's index: $HB=\frac{\ln(n!)-\sum_i \ln(n_i!)}{n}$

g. Menhinick's richness index**:** $s/\sqrt{n}$

h. Margalef's richness index: (S-1)/ln(n)

i. Equitability (Pielou's evenness): Shannon diversity divided by the logarithm of the number of taxa. This measures the evenness with which individuals are divided among the species present.

j. Fisher's alpha: A diversity index, defined implicitly by the formula S=a*ln (1+n/a) where Sis the number of taxa, n is number of individuals and a is the Fisher's alpha

k. Berger-Parker dominance: Simply the number of individuals in the dominant taxon relative to n

l. Chao1: An estimate of total species richness. $Chao1= S+F_1(F_1-1)/(2(F_2+1))$, where F2 is the number of singleton species and F2 the m=number of doubleton species

All these above indices are explained in Harper (1999)
Eight measures for beta diversity of *Drosophila* samples were described below
m. Whittaker (1960)$b_w= \frac{S}{\alpha} - 1$

where S = the total number of species and α the average species richness of the samples. All samples must have the same size.

n. Harrison et al (1992) $b_{-1}=\frac{\frac{S}{\alpha}-1}{N-1}\times 100$
where α the average species richness of the samples. This measure ranges from 0 (no species turn over) to 100 (every sample holds a unique set of species). This measure allows transects of different size to be compared.

o. Cody (1975) $b_c= \frac{g(H)+l(H)}{2}$
where g(H) is the number of species gained and l(H) the number lost moving along the transect.

p. Routledge (1977) $b_i=\log_{10}(T) - \left[\frac{1}{T}\sum_i e_i \log_{10}(e_i)\right] - \left[\frac{1}{T}\sum_i \alpha \log_{10}(\alpha_i)\right]$

where e_i is the number of samples along the transect in which species i is present and α_i the species richness of sample i and T is Σe_i.

q. Wilson-Shmide (1984) $b_t= \frac{g(H)+l(H)}{2\overline{\alpha}}$
where g(H) is the number of species gained and l(H) the number lost moving along the transect.

r. Mourelle (1992) $b_{me} = \frac{g\,(H)+l(H)}{2\bar{\alpha}(N-1)}$

where g*(H)* is the number of species gained and l(H) the number lost moving along the transect, N number of the species.

s. Harrison 2: $b_{-2} = \frac{\frac{S}{\alpha_{max}}-1}{N-1} \times 100$

where α the maximum species richness in any one sample.

t. Williams (1996) $b_{-3} = 1 - \frac{\alpha_{max}}{S}$

Further *Drosophila* communities were analyzed using *SHE* analysis (Hayek &Buzas 1997, Buzas & Hayek 1998). This calculates log species abundance (*lnS*), Shannon index (*H*) and log evenness (*ln E=H-lnS*) for the first sample. Then the second sample is added to the first, and the process continues.

The module individual rarefaction evaluate amount of species you would expect to find in a sample with a smaller total number of individuals. With this method, one can compare the number species in a sample of different size. Using rarefaction analysis on a large sample, one can read out the number of expected taxa for any smaller sample size (including that of the smallest samples) (Adrain et al., 2000).

Let N be the total number of individuals in the sample, s the total number of species, and N_I the number of species number i. The expected number of species $E(S_n)$ in a sample of size n and variance $V(S_n)$ are then given by

$$E(S_n) = \sum_{i=1}^{s}\left[1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}}\right]$$

$$E(S_n) = \sum_{i=1}^{s}\left[\frac{\binom{N-N_i}{n}}{\binom{N}{n}}\left(1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}}\right)\right]$$

$$+2\sum_{j=2}^{s}\sum_{i=1}^{j=1}\left[\frac{\binom{N-N_i-N_j}{n}}{\binom{N}{n}} - \frac{\binom{N-N_i}{n}\binom{N-N_j}{n}}{\binom{N}{n}\binom{N}{n}}\right]$$

Alpha diversity: The main purpose of this module is to compare diversities in several samples. The validity of contrasting diversities samples can be criticized because of the arbitrary choice of diversity index. One sample may for example contain a larger number of taxas, while the other has a larger Shannon index. A number of diversity indices may be compared to make sure that the diversity ordering is robust. A formal way of doing this is to define a family of diversity indices, Dependent upon a single continuous parameter (Tothmeresz 1995).

$$\exp(H_\alpha) = \exp\ln\left(\frac{1}{1-\alpha}\ln\sum_{i=1}^{S}P_i^{\alpha}\right)$$

From cluster analysis, Euclidean distance was chosen to measure the similarity between different localities of *Drosophila* and Ward's Strategy (Giri et al., 2007) was used to unit two clusters. A feature of Euclidean distance was that it is a weighted computation; the higher the absolute value of the measurement the higher will be its weight. PAST version 3.5 and SPSS software was employed in this present study.

III. RESULTS

The distribution pattern of *Drosophila* species collected in six different localities during August 2018 and their nomenclature was depicted in Table 1. A total of 17 species were encountered which belongs to subgenera (*Dorsilopha, Scaptodrosophila, Drosophila* and *Sophophora).* Most of the species group belonged to the *Drosophila melanogaster* species group. The only one species belonging to subgenus *Drosilopha* is *Drosophila buskii*. The total number of *Drosophila* flies captured was 573 with 17 species. At Banana yard (BY), the number of flies collected was the highest (179) compared to all other yards and the least number was collected at Custard yard (CY). Surprisingly, *D.malerkotliana, D.rajasekari, D.nasuta, D.neonasuta* and *D.brindavani* were the most common species found in all localities compared to other species such as *D.anomelani, D.bipectinata, D.gangotri, D.jambulina, D.suzukii, D.mysorensis, D.repleta, D.nigra, D.buskii, D.takahasii* were not found in all localities(Table 1).

The values of alpha diversity index was given in Table 2 using eight different indices of biodiversity. All the indices indicate the presence of abundance, richness and diversity of *Drosophila* flies of different localities. The data (Table 2) has revealed the Banana yard (By) locality was very shows high diversity having 14 species with 179 individuals with 0.10 as dominance value compares to other localities. Along with this Banana yard (BY) exhibits values of Simpson, Shannon, Evenness, Brillouin, Menhinick, Margalef, Equitability(J) Fisher-alpha, Berger-Parker and Chao-1 indices was (0.89; 2.43; 0.81;2.29;1.04;2.50;0.92; 3.55; 0.15). The less diversity of *Drosophila* flies was observed in the Coconut yard and Custard yard according to the values are shown in Table 2. To compare the degree of species turnover in species composition along the gradient of yards. We have calculated the values of different biodiversity indices between different yards. The table 3 represents the summary of beta diversity according Whittaker (0.7); Harrison (0.14); Cody (12); Routledge (0.14656); Wilson-Shmida(1.2); Mourelle (0.24); Harrison (20.0); and Williams (0.23529) to the (Presence(1) – Absence (0)) of *Drosophila* species between the localities.

The results of SHE analysis for all the samples collected in the different locality is showed in figure 1 where it indicates log species abundance lnS= 1.9; (H)= 1.4 and (lnE) = H-lnS (-0.5). The Euclidean cluster analysis perform done the basis of localities where *Drosophila* is collected to assess the species richness of the particular locality (Figure 4). According to the results Bannana Yard (BY) forms entirely different cluster compared to other yards. Guava yard (GY) and Custard Yard (CY); Mango (MY) and Sapota (SY) Yard forms separate clusters along with Coconut yard separately. The results of dendrogram according Ward linkage was showed in figure 5 according to this two major clusters were formed, The first cluster belongs to *montium* sub group and included *D.kikkawai, D.gangotri*, *D.takahashii, D.anomelani, D.mysorensis* but *D.suzukii*, belongs to *suzukii* subgroup. Both these subgroups belong to the *melanogaster* species group of the subgenus *sophophora. D.repleta, D.buskii* and *D.immigrans* of the same cluster belong to subgenus *Drosophila,* while *D.nigra* belongs to subgenus *Scaptodrosophila. D. jambulina* belongs to *montium* subgroup and the *bipectinata* belongs to the *ananassae* subgroup which is linked with the first cluster. In the second cluster, *D.rajasekari* belongs to *suzukii* subgroup of the *melanogaster* species group of subgenus *sophophora* while *D.neonasuta* belongs to the subgenus *Drosophila* and *D.malerkotliana* which joins with *D.brindavani* and *D.nasuta* belong to two different taxonomic categories. Among these *D.malerkotliana* belongs to subgenus *Sophophora* and *D. brindavani* belongs to subgenus *Scaptodrosphila*. *D.nasuta* the alone is in fourth tier 1 species of this cluster. Thus most of the species of first cluster have closer taxonomic relationships than the second one.

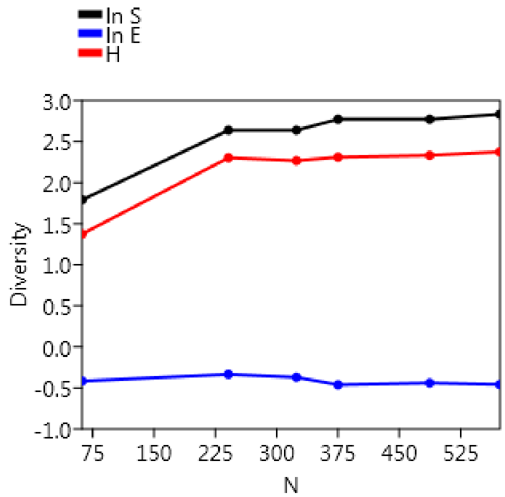

Figure 1 SHE Analysis of *Drosophila* community in all localities (BY, MY, SY,GY, CY & Cast Y); (N= number of flies).

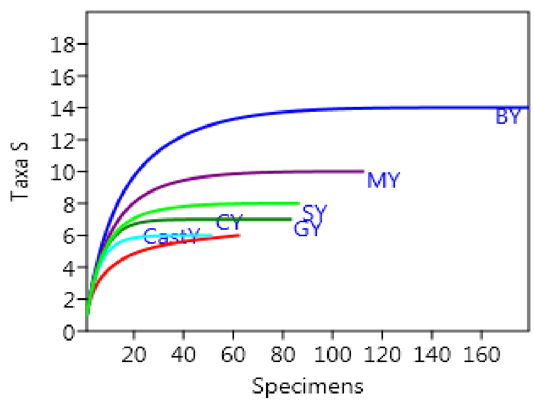

Figure 2. Analysis of Individual rarefaction for comparing *Drosophila* diversity in different localities (BY, MY, SY,GY, CY & Cast Y)

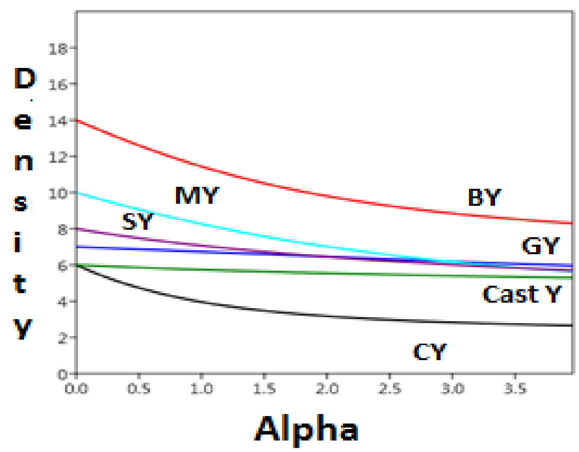

Figure 3. Alpha diversity profile of *Drosophila* density in different localities (BY, MY, SY,GY, CY & Cast Y)

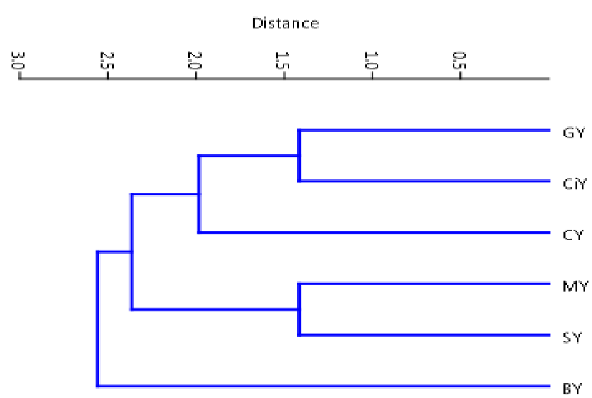

Figure 4. Euclidean clustering analysis of different localities of *Drosophila* community

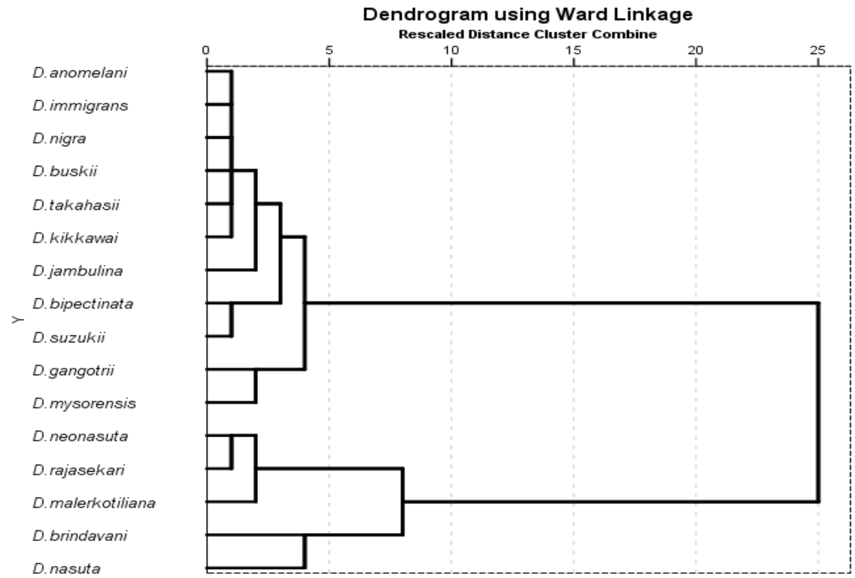

Figure 5. The Dendrogram of *Drosophila* species present on different localities (constructed by cluster analysis using Ward Linkage)

Table 1: The *Drosophila* fruit flies and their numericals collected in different sites during 2018 (Cocunut yard (CY), Bannana yard (BY), Gauva yard (GY), Castard apple (CastY) Mango yard (MY) and Sapota Yard (SY))

Genus	Subgenus	Species	Collection site of *Drosophila* species						Total
			CY	BY	GY	CastY	MY	SY	
Drosophila	***Sophophora***	***D.anomelani***	00	05	00	00	04	00	09
		D.bipectinata	03	15	09	00	08	00	35
		D.gangotrii	00	00	00	00	00	15	15
		D.Jambulina	00	00	00	08	10	00	18
		D.kikkawai	00	00	00	04	00	00	04
		D.malerkotliana	01	25	11	09	18	05	69
		D.mysorensis	00	10	12	00	00	11	33
		D.rajasekari	06	07	08	00	14	12	47
		D.suzukii	00	15	00	00	00	00	15
		D.takahasii	00	09	00	00	00	00	09
		Total	10	86	40	21	54	43	254
	Drosophila	***D.nasuta***	17	28	19	10	29	21	124
		D.neonasuta	06	16	10	08	09	10	59
		D.repleta	00	07	00	00	00	00	07
		D.immigrans	00	04	00	00	06	00	10
		Total	23	55	29	18	44	31	200
	Dorsilopha	***D.buskii***	00	05	00	00	00	00	05
		Total	00	05	00	00	00	00	05

	Scaptodroso-phila	*D.brindavani*	29	28	14	12	11	09	103
		D.nigra	00	05	00	00	03	03	11
		Total	29	33	14	12	14	12	114
		Grand total	62	179	83	51	112	86	573
		Temperature in ^{0}C	28.0	27.0	26.0	28.0	29.0	26.0	27.0

Table 2: Alpha diversity of *Drosophila species* using different biodiversity indices according to collection sites

Sl no	Indices	Collection site of *Drosophila* species and its biodiversity valves						
		Cy	By	Gy	Casty	My	Sy	
1	Taxa Species	06	14	07	06	10	08	
2	Individuals	62	179	83	51	112	86	
3	Dominance (D)	0.31	0.10	0.15	0.18	0.14	0.15	
4	Simpson (1-D)	0.68	0.89	0.84	0.81	0.85	0.84	
5	Shannon (H)	1.37	2.43	1.90	1.74	2.11	1.97	
6	Evenness	0.65	0.81	0.96	0.95	0.82	0.88	
7	Brillouin	1.24	2.29	1.76	1.57	1.95	1.80	
8	Menhinick	0.76	1.04	0.76	0.84	0.94	0.86	
9	Margalef	1.21	2.50	1.35	1.27	1.90	1.57	
10	Equitability (J)	0.76	0.92	0.97	0.97	0.91	0.94	
11	Fisher-alpha	1.64	3.55	1.82	1.76	2.65	2.15	
12	Berger-Parker	0.46	0.15	0.22	0.23	0.25	0.24	
13	Chao-1	06	14	07	06	10	08	

Table 3: Beta Global diversity of *Drosophila* in between collection sites of localities

Sl no	**Beta Diversity of locations**	
	Indices	**Values**
01	**Whittaker:**	0.7
02	**Harrison:**	0.14
03	**Cody:**	12
04	**Routledge:**	0.14656
05	**Wilson-Shmida**	1.2
06	**Mourelle:**	0.24
07	**Harrison 2:**	0.06153
08	**Williams:**	0.23529

IV. DISCUSSION

In the current study the density of *Drosophila* fauna in five distinct localities of fruit yard vary in different localities of fruit yards (Table 1). The grand total fruit flies collected in the different fruit yard was about 573 flies which belong to the 4 subgenus. Among them Sophophora stands first in dominating other subgenus with 254 flies with different species and *Dorsilopha* stands last with only one species that is *Drosophila buskii.* Moreover, by analysis of localities of *Drosophila* community Bannana yard (BY) harbors more number of fruit flies compare to other yards (Table 1). This agrees the studies of (Hegde et.al 2000a, Guruprasad et al 2010, 2011, 2006, 2015), The magnification of the population depend on several environmental factors in addition to genetic structure. In the existing study, consideration of the common and abundant species shows that numerical difference in regard to these species in all localities of fruit yards studied. The event of the supremacy of one species over the others in any given area can be corresponds with the supremacy species ecological flexibility to exploit the conditions available in those domain. Along with there are many unknown micro factors that could also affect the population of *Drosophila*. This results of our study will more or less endorse with the work of Muniyappa and Reddy (1981), Vasudeva et al.(2001) where the occurrence of the thick vegetation, which provided good sources of food and a more congenial environmental at different of the fruit yards.

By applying alpha diversity to *Drosophila* community encountered in different localities species richness of the flies is varied between localities. Alpha diversity indices were higher in Banana yard (BY) than for other locality (Table 2 and figure 3) and least was found in Coconut yard (CY), This might be due to present of more fruit and flowery plants in banana compare to other yards This understands the measurement of biodiversity of flies at regions. This will give clear picture that Banana yard (BY) is most diverse among yard wise. Here author has used different kind of indices to measure diversity of flies in different way to assess the richness of the flies. Table 3 also suggests the global beta diversity of *Drosophila* community in different localities. Beta diversity measures presence and absence of species from one environment to another. This diversity quantifies the number of different communities in given zone. So its clear that beta diversity shows relationship between local and regional diversity, but also reflects the degree of differentiation among biological communities. This is because alpha diversity is different if the biological communities within the region are different. In simpler terms, it calculates the number of species that are not the same in two different localities. These indices which measure beta diversity on a normalized scale, usually from 0 to 1. A high beta diversity index (values more than 1) indicates a low level of similarity, while a low beta diversity index (values less than 1) shows a high level of similarity. In the present study author have noted most of the results procured by the beta global diversity formula depicted in the Table 3. This reflects there is high level of similarity between the flies collected in different localities of the fruit yards.

The careful scrutiny of figure 1of SHE analysis (of *Drosophila* community of all localities indicate the distribution of *Drosophila* species is uneven in time and space. Even though the species are uneven in different localities but the localities selected for the studies are best places for harboring different kind of *Drosophila* species. This was justified bylooking the *D.suzukii* and *D.takahasii* which is found only in Banana yard (BY) and not in any other localities and repeated in case of *D.buskii* only one species belongs to subgenus *Dorsilopha* found in Banana yard. Apart from this figure 2 depicts the analysis of individual rarefaction for comparing *Drosophila* diversity in different localities (BY, MY, SY,GY, CY & CastY) finds the again Banana yard (BY) is very much suitable for providing the good shelter for the number of species that is about 14 species which is encounter in the present study. Moreover, Banana yard (BY) is the most suitable place and it has entirely different compare to other localities this was proved by the Euclidean clustering analysis of different localities of *Drosophila* community (figure 4).

According to the present investigation of the *Drosophil*a community in the different fruit yards some *Drosophila* species are considered as champion species such as *D.brindavani* and *D. nasuta* which are most common flies with highest number found in all localities. These above flies are considered as constant species commonly found in all localities this is shown in the last tier of the dendrogram using ward linkage. Further, in the first cluster, all species except *D.nigra, D.buskii,* and *D.immigrans* are phylogenetically related and hence they are grouped in one subgenus *Sophophora*. Our study indicates the co-existence of species having similar ecological preferences and also supports the work of Ayala (1969) and Guruprasad et al., (2010, 2006, 2015, 2009, 2011) and also many workers. Apart from this from the cluster analysis in the second tier species belonging to different species occupying different sub-clusters but joining with the main cluster at different tiers. From our studies, there are many biodiversity indices which one can apply for the explanation of biodiversity of *Drosophila* in a different way. Finally, some flexibility is needed in deciding among the recommended indices used to estimate biodiversity. Thus from the existing eco-distributional pattern of *Drosophila* in different fruit yards clarifies that the distributional motif of species or related group of species is unequal, uneven and irregular in space and time. *D.nasuta* and *D.brindavani* could be considered as supremacy species, as they are recorded in all fruit yards with leading numbers.

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