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Implying quantitative ecology of Drosophilid fauna as a tool for biodiversity assessment - A case study along an altitudinal transect in the Garhwal region of Central Himalaya

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Abstract: Very few studies to date have exploited Drosophilids as potential bio-indicators of biodiversity or ecological integrity. Here we investigate the *Drosophila* assemblage as a bio-indication system especially for the management of tropical areas with high rates of habitat destruction and biodiversity loss. Several sampling surveys were carried out for more than a year along an altitudinal gradient at six stations in the Garhwal region to provide information about the composition of the drosophilid community. Various diversity indices, constancy method and cluster analysis were used to analyse species occurrence. The ecological indices showed a possible positive association between species abundance and environmental heterogeneity of the studied areas. Mandal (1600 m asl) being a transition area between sub-tropical and temperate zones, with a high degree of heterogeneity in climate and vegetation, proved to be most diverse of all stations studied. Consistent with the fact that the corridor from Mandal via Kanchula-Kharak upto Chopta is already advocated as a protected zone, our study proposes usage of drosophilid assemblage composition as a very efficient and accurate tool for future selection and design of protected areas in the region.

Key words: Altitudinal distribution, biodiversity, climate change, cluster analysis, diversity indices, Mandal, Uttarakhand.

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Introduction

Uttarakhand state in the central Himalayan region of India was carved out in the year 2000, recognising the socio-economic demands of the locales and a need for better management of a plethora of ecological resources. Fundamental to any good governance policy in a newly created state is the harmonious relationship between biodiversity and subsequent ecosystem services. This harmonious link between biodiversity and ecosystem services is often severed due to the lack of proper methods to assess and monitor biodiversity, especially at regional scales. Regardless of imperative efforts to prevent the loss of biodiversity in the state, the decline has continued largely due to lack of simple yet efficient methods of biodiversity assessment. Conversely, it is never sensible to measure every aspect of biodiversity at all spatial and temporal levels. Thus, the need has arisen for a well optimized assessment method that could be well correlated with all levels of biodiversity and ecosystem integrity.

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The development of an efficient indicator system for assessing and monitoring ecosystem health and functioning has been long advocated (UN 2002). Assessing species diversity is among the most sensitive and extensively adopted measures of biodiversity (Colwell & Coddington 1994) which could be robustly related with different levels of ecosystem organization. However, an indicator species should also be representative of the diversity of other groups and depict a clear correlation with any disturbance gradient. Invertebrates have universally been employed as model organisms in research delineating data for conservation planning and management, and subsequent implications in selection of protected areas. They respond quickly to even subtle differences in habitat and ecosystem disturbances, serving as indicators of discrete biogeographical zones, regions of endemism or potential biodiversity hotspots. Thus, studying community structures or assemblages of insects can provide substantial data valuable towards policies of conservation planning and management (Kremen *et al.* 1993).

Studies on *Drosophila* have long contributed to our understanding of principles of genetics, molecular biology, population genetics and even evolution, as they are highly sensitive to slight environmental modifications that are reflected by significant variation in their natural population size and structure, morphology and even in their ecology. As compared to other conventional ecotypes which are well integrated units and undergo no substantial change in shorter time span, the altitudinal or latitudinal ecotypes in drosophilids are in a constant flux due to short generation times, and they respond to environmental differences by adaptive modification of genetic composition leading to niche specialization. Local adaptation is most probable when populations inhabit highly divergent adjoining ecological environments, such as found in the Central Himalayan region of India, which encompasses tropical to temperate taxa in the span of just few a hundred kilometres. Here, altitudinal isolation arises as a response of the species to environmental differences in the habitats at different elevations. However, despite such highly varied and sensitive environmental conditions, no such studies involving drosophilids as proposed bio-indicator in this geographic region have been conducted. Though *Drosophila* is documented by several workers as potentially good bio-indicators, in comparison to any other insect group (Ferreira & Tidon 2005; Parsons 1991, 1995; Powell 1997; Saavedra *et al.* 1995) the prospect of these flies as bio-indicators remains to be tested in this region.

Several drosophilid species have been recorded and described so far from varied eco-geographical zones in India (Gupta 2005). The results of the taxonomic studies in this state have revealed the presence of many interesting species in these areas besides some of the common species. To name few, *Drosophila nainitalensis*, *D. paunii*, *D. bishtii, D. neobaimai, D. neokhaoyana, D. sarswati, Scaptodrosophila hirsute, Hirtodrosophila hexaspina, Leucophenga neolacteusa, L. angulata, L. clubiata, L. trispina, Scaptomyza quadruangulata*, *Stegana nainitalensis and Micodrosophila bamanpuriensis* were described as new species. *Gitona distigma, D. sulfurigaster, Amiota biprotrusa, Hirtodrosophila quadrivittata, H. actinia, Leucophenga albiceps, Mulgravea parasiatica*, *Dittopsomyia nigrovittata* and *Dichaetophora acutissima* and *Leucophenga argentata de Meijere* were recorded for the first time from India (Fartyal & Singh 2002, 2004; Singh & Bhatt 1988; Singh & Fartyal 2002; Singh & Negi 1989, 1992, 1995; Singh *et al.* 2004; Upadhyay & Singh 2007, 2012). This list is not exhaustive, yet it shows Central Himalaya as a drosophilid biodiversity hotspot, and suggests the potential of this group for evolutionary and conservation biology research.

Therefore, through this work we propose drosophilid assemblages as a potential bio-indicator system based on extensive exploration of the drosophilid fauna inhabiting Garhwal region of Central Himalaya. Garhwal region is among the key components of the Himalayan hotspot with high conservation value and several disturbance threats. It is undergoing extensive transformation due to rapid, unplanned urbanization, which poses a threat to the rich bio-diverse legacy of the region. Thus, we aimed to develop a diagnostic tool which would aid in monitoring and management of biodiversity and future conservation planning for this region. We explored the drosophilid assemblages along an altitudinal gradient from a few selected sites with habitats as varied as Tropical-Subtropical Forest zone, Subtropical-Temperate zone and Temperate-Subalpine zone in an attempt to find any correlation with already established conservation areas in the region (Mandal-Kanchula-Kharak corridor) and also compared these with other much disturbed and human intervened habitats. In particular, we analysed the similarity in assemblage composition between different regions so as to determine the relative impor-

Fig. 1. Sampling Sites (SG - Srinagar-Garhwal, AG - Augustyamuni, UC - Upper Chamoli, MD - Mandal, KK - Kanchula-Kharak and CP - Chopta).

tance of regional drosophilid diversity as a potential bio-indicator.

Materials and methods

For the present study several sampling surveys were carried out for more than a year, from February 2013 to March 2014, so as to assess Drosophilid diversity of Garhwal region (Fig. 1) especially from Srinagar-Garhwal (550 m asl, 30° 22´ N and 78° 78´ E, District-Pauri), Augustyamuni (800 m asl, 30° 39´ N and 79° 02´ E, District-Rudraprayag), Upper Chamoli (1150 m asl, 30° 24´ N and 79° 21´ E, District-Chamoli), Mandal (1600 m asl, 30° 46´ N and 79° 26´ E, District-Chamoli), Kanchula-Kharak (2100 m asl, 28° 43´ N and 77º 34´ E, District-Chamoli) and Chopta (2700 m asl, 30° 29´ N and 79° 10´ E, District- Rudraprayag).

Sample collection

The cosmopolitan or wide ranging species of fruit fly were easily collected from the rotten fruits, fungi, flowers and other vegetable materials rich in carbohydrates, but the collection of Drosophilid flies from natural habitats required the application of a large range of techniques. The following methods were used during the present survey. The specimens studied were preserved in 70 % ethanol.

i) Trap bait method: Collections were made largely through the use of small containers baited with yeasted banana or some other fermenting fruits such as oranges, tomato, guava, apples etc, suspended by strings from the branches of bushes and the trees. The containers were placed in a triangular quadrat, no closer than 100 m from each other around mid of every month and removed on the following day. The flies were transferred to fresh bottles containing agar-based culture medium and containers were again suspended. This method was found very effective for collecting species particularly belonging to the two sub-genera, *Sophophora* and *Drosophila* of the genus *Drosophila*.

ii) Net sweeping method: In view of the fact that unlike *Drosophila* members of the others genera of the family Drosophilidae are rarely, or only occasionally attracted towards fermenting fruits, collection by net over natural feeding sites, such as decaying fruits and leaves, wild grasses and cultivated vegetation was therefore done in close vicinity of trap baits to capture these flies. In order to maintain uniformity in collection from each locality net sweeping was also done in a triangular quadrat with five sweeps at each node of the quadrat using commercially available small modified insect net (75 cm long net bag fitted in ring through 5cm wide cloth rim. Diameter of bag at free end 25 cm, Ring diameter 30 cm with 75 cm long handle).

iii) Direct collection with aspirator: Net sweeping was not possible for rare flies as these show occasional appearance, mostly upon their preferred host plant. Thus, this method was frequently employed to trap such flies directly with the help of an aspirator while they were either courting or resting over the leaves, petals, fungi etc.

Identification and morphological study

Collected flies were etherized, categorized and subsequently identified using published monographs and guide to species identification (Gupta 2005; Markow & O'Grady 2006) and online identification tools like BioCIS (2004), JDD (2014) and FlyBase (2014). External morphology viz., head, thorax, wing and body length of adult flies was examined under a stereo zoom microscope (Magnus MS24 model, at 3X objective zoom) and metric characters were measured with an ocular micrometer. For further confirmation the detailed structures of male and female terminalia were observed under trinocular microscope (Magnus MLX-DX model, at 10X magnification). The respective genital organs were detached from the adult body and cleared by warming in 10 % KOH solution around 100 °C for 20 - 30 minutes, and observed in a droplet of glycerol. The morphological terminology and the definitions of measurements and indices mostly followed were of McAlpine (1981); Zhang & Toda (1992); Hu & Toda (2001). The examined specimens of all species are deposited in the Cytogenetics & Molecular Systematics Laboratory, Department of Zoology, H.N.B Garhwal University, Chauras Campus, Srinagar-Garhwal, Uttarakhand, India.

Establishment of stock culture

The individual females, which could not be identified, were isolated and allowed to breed in separate vials containing standard laboratory food medium. For the species which do not breed on culture medium, many individuals were separately placed with single female per vial assuming some of them may be naturally impregnated. The progeny thus obtained from such single gravid females in both case, was used for species identification study.

Data analysis

Qualitative occurrence of species was verified using Occurrence Constancy Method (Dajoz 1983). The constancy value (c) was calculated as ratio of the number of collections in which particular species occurred to the total number of collections done, and multiplying the result by 100. Species with index $c \geq 50$ were considered constant species. Accessory species were those with $25 \leq c < 50$. Accidental species had $c < 25$. Species that occurred in only one area were considered exclusive. Drosophilid fauna along altitudinal transects were analysed using different ecological indices: Berger-Parker (1/d), Shannon-Wienner (H´), Simpson (D), Margalef (D_{Mg}) and Jaccard (J). The relationships among communities at different altitudes were assessed through two cluster analyses performed by: 1) presence and absence of species; and 2) number of specimens collected for each species along different altitude. To analyse community similarities, the Jaccard index between a pair of communities was also calculated. All statistical analyses were performed in SPSS 16.0.

Observations

The following observations were made regarding climate, rainfall, vegetation and corresponding species density at different sampling sites:

Average Temperature: Wide variation was observed in both annual and diurnal temperatures at the valley regions like Srinagar-Garhwal and even at Augustyamuni than at the higher altitudes. The valley beds receive more frost than the mountain tops. Thus, the climate ranged from subtropical-like in the valleys to temperate-like on the higher slopes. Average temperature varied between 15 to 38 °C in the lower valley regions, between 12 to 26 °C in forests of Mandal and Kanchula-Kharak and between 2 to 14 °C (dropping even below 0 °C during the winters) in many parts of the higher mountain reaches like Chopta. A typical Sub-tropical climate is experienced near Srinagar valley and up to an elevation of about 800 m in the lower Himalaya. Sub-tropical followed by temperate climate prevailed up from 800 m to 2400 m, with Mandal being transition zone at around 1600 m. Alpine-like conditions occurred above 2400 m. Therefore, walking along the altitudinal transect, temperatures may vary from tropical to temperate on the same day, providing a well established arena for future research on climate change.

Average Rainfall: Almost all sites receive very heavy rainfall from the south-west monsoons from late June to the mid of September. While Srinagar (District Pauri-Garhwal) receives less average annual rainfall (< 800 mm), District Rudraprayag and Chamoli (> 900 mm) have moister climate due to much higher average annual rainfall.

Dominant Vegetation: Variety of forest cover is observed due to variation in climatic conditions at different altitudes, thus divided into different zones (Kumar & Ram 2005). Deciduous and sub-deciduous species dominated Tropical-Subtropical region like Srinagar-Garhwal and Augustyamuni, with Sal being the most dominant found up to 1200 m. Sub-tropical to Temperate region was occupied by Pine forest with chir pine dominating along with shrubs between 1000 and 2000 m. Temperate-Subalpine region was dominated by mixed coni-ferous forests of fir, spruce and birch extending above 1500 m. Mandal being the transition zone between Sub-tropical and Temperate region showed wide heterogeneity in vegetation.

Species Diversity: The collection of Drosophilid flies was done between 14th to 16th day of every month from February 2013 to March 2014 in the wild, employing wide range of techniques (mentioned above). Data could not be obtained for the months, December-January 2014 due to extreme weather conditions. During the present survey a total of 6521 Drosophilid flies were collected belonging to different genera.

Results

Through extensive surveys and wide range of sampling strategies, altogether 6521 flies were collected from six stations along an altitudinal transect (Table 1). A total of twenty one species were encountered belonging to seven different genera. Most of the species belonged to Genus *Drosophila*. Genus *Leucophenga* and *Paraleucophenga* were represented by two species each while Genus *Dettopsomyia*, *Mycodrosophila*, *Scaptomyza* and *Zaprionus* were represented by one species each. Approximately 86 % of the total collected species (18 of 21) were constant ($c \geq 50$). One accessory (~ 4 %) and two accidental species (~ 10 %) were found (Table 2). All genera showed constant species, except for *Paraleucophenga* genus that showed two accidental species (*Paraleucophenga todai*, *Paraleucophenga neojavanai*).

The number of Drosophilid flies collected decreased on moving up along the altitudinal transects. At Srinagar-Garhwal (550 m), 1578 flies represented by twenty species were collected and least number of flies (496) of fourteen species was recorded from Chopta, located 2700 m above sea level. This variation in the number of species at different altitudes could be well related to their habitat preferences. Twelve species of Genus *Drosophila* (*Drosophila melanogaster, D. nepalensis, D. kikkawai, D. bifasciata, D. jambulina, D. suzukii indicus, D. takahashii, D. punjabiensis, D. busckii, D. immigrans, D. lacertosa* and *D. repleta*) alongwith *Zaprionus indianus* were recorded at all six altitudes, thus can be considered abundant. Theses species depict generalist nature occupying broad niche i.e. no specificity towards one habitat type and occurred across a range of habitats. Other species like of Genus *Leucophenga*, *Paraleucophenga* etc. were highly specific and restricted to a particular habitat type and thus also are more vulnerable to change in their preferred habitat. These findings are in congruence with earlier reports (Guruprasad *et al.* 2010; Reddy & Krishnamurthy 1977; Wakahama 1962). Further, though most of the recorded species exploit a very broad range of habitats spreading around almost all the stations sampled, harsh climatic conditions at higher altitudes may account for the decrease in population density of all species. However, maxi-

Table 1. The Drosophilid species and their numbers collected along altitudinal transect during 2013-2014.

Species	Srinagar (550 m)	Augustyamuni (800 m)	Upper Chamoli (1150 m)	Mandal (1600 m)	Kanchula-Kharak (2100 m)	Chopta (2700 m)	Total
Genus *Drosophila*							
Drosophila melanogaster	78	65	67	51	40	39	340
Drosophila nepalensis	181	114	95	130	62	42	624
Drosophila kikkawai	41	54	34	67	19	21	236
Drosophila bifasciata	27	31	8	53	23	20	162
Drosophila jambulina	47	65	50	95	42	31	330
Drosophila suzukii indicus	147	138	59	74	48	29	495
Drosophila takahashii	44	26	18	65	11	17	181
Drosophila punjabiensis	88	63	46	95	35	31	358
Drosophila busckii	221	171	89	211	67	36	795
Drosophila paunai	13	18	0	0	0	0	31
Drosophila immigrans	115	148	120	201	119	75	778
Drosophila lacertosa	38	46	4	62	14	34	198
Drosophila repleta	165	189	56	94	45	29	578
Total	1205	1128	646	1198	525	404	5106
Genus *Leucophenga*							
Leucophenga bellula	23	0	0	38	8	0	69
Leucophenga albiceps	27	0	4	89	65	44	229
Total	50	0	4	127	73	44	298
Genus *Dettopsomyia*							
Dettopsomyia nigrovittata	0	17	0	32	3	0	52
Total	0	17	0	32	3	0	52
Genus *Mycodrosophila*							
Mycodrosophila gratiosa	49	15	0	26	14	0	104
Total	49	15	0	26	14	0	104
Genus *Paraleucophenga*							
Paraleucophenga todai	16	0	0	0	0	0	16
Paraleucophenga neojavanai	14	0	0	0	0	0	14
Total	30	0	0	0	0	0	30
Genus *Scaptomyza*							
Scaptomyza himalayana	65	36	21	54	9	0	185
Total	65	36	21	54	9	0	185
Genus *Zaprionus*							
Zaprionus indianus	179	150	93	164	112	48	746
Total	179	150	93	164	112	48	746
Grand Total	1578	1346	764	1601	736	496	6521

Table 2. The absolute (A), relative abundance (R) and constancy value (*c*) of drosophilid flies collected along altitudinal transect during 2013-2014.

Species	Srinagar (550 m)		Augustya-muni (800 m)		Upper Chamoli (1150 m)		Mandal (1600 m)		Kanchula-Kharak (2100 m)		Chopta (2700 m)		*c*
	A	R	A	R	A	R	A	R	A	R	A	R	
Genus *Drosophila*													
Drosophila melanogaster	78	0.05	65	0.05	67	0.09	51	0.03	40	0.05	39	0.08	100
Drosophila nepalensis	181	0.11	114	0.08	95	0.12	130	0.08	62	0.08	42	0.08	100
Drosophila kikkawai	41	0.03	54	0.04	34	0.04	67	0.04	19	0.03	21	0.04	100
Drosophila bifasciata	27	0.02	31	0.02	8	0.01	53	0.03	23	0.03	20	0.04	100
Drosophila jambulina	47	0.03	65	0.05	50	0.07	95	0.06	42	0.06	31	0.06	100
Drosophila suzukii indicus	147	0.09	138	0.10	59	0.08	74	0.05	48	0.07	29	0.06	100
Drosophila takahashii	44	0.03	26	0.02	18	0.02	65	0.04	11	0.01	17	0.03	100
Drosophila punjabiensis	88	0.06	63	0.05	46	0.06	95	0.06	35	0.05	31	0.06	100
Drosophila busckii	221	0.14	171	0.13	89	0.12	211	0.13	67	0.09	36	0.07	100
Drosophila paunai	13	0.01	18	0.01	0	0.00	0	0.00	0	0.00	0	0.00	33.3
Drosophila immigrans	115	0.07	148	0.11	120	0.16	201	0.13	119	0.16	75	0.15	100
Drosophila lacertosa	38	0.02	46	0.03	4	0.01	62	0.04	14	0.02	34	0.07	100
Drosophila repleta	165	0.10	189	0.14	56	0.07	94	0.06	45	0.06	29	0.06	100
Total	1205	0.76	1128	0.83	646	0.85	1198	0.75	525	0.71	404	0.80	-
Genus *Leucophenga*													
Leucophenga bellula	23	0.01	0	0	0	0	38	0.02	8	0.01	0	0	50
Leucophenga albiceps	27	0.02	0	0	4	0.01	89	0.06	65	0.09	44	0.09	83.3
Total	50	0.03	0	0	4	0.01	127	0.08	73	0.10	44	0.09	-
Genus *Dettopsomyia*													
Dettopsomyia nigrovittata	0	0	17	0.01	0	0	32	0.02	3	0.004	0	0	50
Total	0	0	17	0.01	0	0	32	0.02	3	0.004	0	0	-
Genus *Mycodrosophila*													
Mycodrosophila gratiosa	49	0.03	15	0.01	0	0	26	0.02	14	0.02	0	0	66.7
Total	49	0.03	15	0.01	0	0	26	0.02	14	0.02	0	0	-
Genus *Paraleucophenga*													
Paraleucophenga todai	16	0.01	0	0	0	0	0	0	0	0	0	0	16.7
Paraleucophenga neojavanai	14	0.01	0	0	0	0	0	0	0	0	0	0	16.7
Total	30	0.02	0	0	0	0	0	0	0	0	0	0	-

Contd...

Table 2. Continued.

Species	Srinagar (550 m)		Augustya-muni (800 m)		Upper Chamoli (1150 m)		Mandal (1600 m)		Kanchula-Kharak (2100 m)		Chopta (2700 m)		*c*
	A	R	A	R	A	R	A	R	A	R	A	R	
Genus *Scaptomyza*													
Scaptomyza himalayana	65	0.04	36	0.03	21	0.03	54	0.03	9	0.01	0	0	83.3
Total	65	0.04	36	0.03	21	0.03	54	0.03	9	0.01	0	0	-
Genus *Zaprionus*													
Zaprionus indianus	179	0.11	150	0.11	93	0.12	164	0.10	112	0.15	48	0.10	100
Total	179	0.11	150	0.11	93	0.12	164	0.10	112	0.15	48	0.10	-
Grand Total	1578	-	1346	-	764	-	1601	-	736	-	496	-	-

Table 3. Richness (S), Absolute Abundance (A), Berger-Parker index (1/d), Shannon index (H′), Simpson index (D) and Margalef index (D_{Mg}). Highlighted boxes and bold numbers indicate highest and lowest values, respectively.

Collection locality	S	A	1/d	H′	D	D_{Mg}
SG (550 m)	20	1578	7.14	2.69	0.083	2.58
AG (800 m)	17	1346	7.12	2.57	0.090	2.22
UC (1150 m)	15	764	6.37	**2.44**	0.099	2.11
MD (1600 m)	18	1601	7.59	2.73	**0.075**	2.30
KK (2100 m)	18	736	**6.18**	2.58	0.092	2.58
CP (2700 m)	14	496	6.61	2.57	0.083	**2.10**

mum number of flies was collected from Mandal (1600 m) where 18 species were recorded with total 1601 individuals, reflecting high abundance in the transition zone.

Also according to ecological indices (Table 3), Mandal proved to be most diverse with highest value generated in Berger-Parker & Shannon index (1/d = 7.5872; H´ = 2.729), least value in Simpson (D = 0.07531) and intermediated value for Margalef index. Since, the Simpson index (D = 0) reflects infinite diversity and (D = 1) no diversity, the higher the value of D the lower is the diversity but reverse is true for Berger-Parker and Shannon-Wiener indices (Ludwig & Reynold 1988; Mateus *et al.* 2006). Further, Margalef index showed Srinagar-Garhwal to be the most diverse area (D_{Mg} = 2.580) and Chopta, the least diverse (D_{Mg} = 2.095). This contradiction could be explained as more species were collected at lower altitude than at highest. Since, most indices take into account both number of species and uniformity, i.e. the number of individuals recorded for each species (Ludwig & Reynold 1988; Torres & Madi-Ravazzi 2006), which inturn can be correlated to the heterogeneity in climate and vegetation; Mandal being the transition zone proves to be most diverse.

Upper Chamoli was the least diverse of our study localities as per Shannon (H´) and Simpson index (D), while Augustyamuni obtained intermediate value for all of the indices calculated. These observations are in congruence with the superficial evaluation of human interference in these areas. As among all the studied areas there is least vegetation in upper Chamoli area, the natural cover in Augustyamuni is largely degraded due to massive human construction and hydro power project.

Table 4. Jaccard (J) index between pair-wise of populations. SG-Srinagar, Ag-Augustyamuni, UC-Upper Chamoli, MD-Mandal, KK-Kanchula-Kharak, CP-Chopta. Highlighted box indicates the highest Jacard value.

	SG	AG	UC	MD	KK	CP
SG	-	-	-	-	-	-
AG	0.762	-	-	-	-	-
UC	0.750	0.778	-	-	-	-
MD	0.810	0.842	0.833	-	-	-
KK	0.810	0.842	0.833	1.000	-	-
CP	0.700	0.722	0.933	0.778	0.778	-

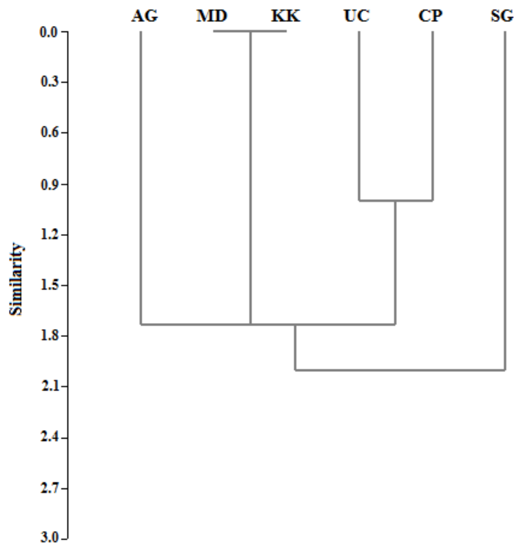

Fig. 2. Cluster analysis using presence and absence of species at different altitudes obtained selecting Euclidean distance and the Single Linkage method.

The pair-wise comparison of all six sampling stations using the Jaccard index (Table 4) showed that Mandal and Kanchula-Kharak communities had the highest similarity among all comparisons (J = 1.0) while Srinagar-Garhwal and Chopta were least similar (J = 0.7). The cluster analyses using presence and absence of species data (Fig. 2) also grouped Mandal and Kanchula-Kharak together and the cluster grouping of all stations using absolute abundance, again displayed Mandal as the most divergent community (Fig. 3). The pattern obtained in these comparisons is justified as both stations are not so far away and share more or less similar vegetation. *Quercus leucotrichophora* (oak) forest dominates at lower elevation near Mandal and *Quercus semicarpifolia* & *Q. floribunda* along with *Abies pindrow* is dominant at higher elevations.

Discussion

The present study provides the most comprehensive diversity and assemblage data for drosophilids of Garhwal region of Central Himalaya, which could provide a baseline for the development of future conservation strategies & policies for the region. Mandal (1600 m) being a transition area between sub-tropical and temperate zones, with a high degree of heterogeneity in climate and vegetation, proved to be most diverse of all stations studied while pair-wise comparison of all six sampling stations showed highest similarity among Mandal and Kanchula-Kharak for all comparisons. It is noteworthy that drosophilid assemblages in the corridor from Mandal via Kanchula-Kharak upto Chopta are unique and an important indicator to preserve the regional biodiversity. Further, since such assemblages of indicator species significantly change among local habitats, the extensive biogeographic studies across habitats would prove vital for diversity assessment and subsequent conservation strategies.

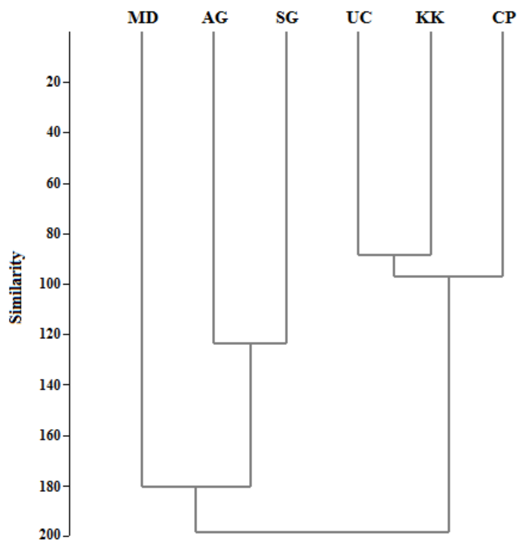

Fig. 3. Cluster analysis using number of specimens collected for each species at different altitudes obtained selecting Euclidean distance and the Single Linkage method.

This data obtained for the *Drosophila* assemblage clearly indicates that well forested Mandal-Kanchula-Kharak corridor contributes more to diversity not just because of the presence of more species, but because almost all species are well represented and much abundant as compared to Srinagar where some species showed much abundance while others were found in lesser numbers. Also the two new records, *Hirtodrosophila M1 sp. nov.* and *Hirtodrosophila M2 sp. nov.* (unpublished) from Mandal firmly ascertains its potential species richness. These findings affirm high conservation value of the region which could well relate to species richness of several other taxa. Using drosophilids as tool for conservation biology could well answer the call for development of conservation strategies towards perpetuating biodiversity threats of rapid, unplanned urbanization substituting the natural habitats. They are intimately associated to environmental variations with extreme sensitivity, demonstrating their potential as early warning signals for range of environmental disturbances. This model could be imitated at regional level in the identification of diverse, endemic, local hotspots with high conservation values and subsequent planning and designing of future protected areas.

Conclusion

Nevertheless, there are possibly several other areas in this regions with enormous biodiversity riches yet to be identified and explored. This drosophilid assemblage model could support deciphering of several other rich biodiversity centres. Further, these flies are versatile tools to understand the patterns and processes related to biodiversity, and the affect of human intervention at various temporal and spatial scales. Such model would permit the development of more accurate and proficient biodiversity management strategies, as well as an advance projection system to predict future biodiversity losses.

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