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Seasonal variation and species assemblage of Odonates (Class- Insecta) in different habitats of Pune district, Northern Western Ghats, Maharashtra, India

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Abstract
Sixty-eight localities from Pune district, Maharashtra, India were surveyed for diversity, assemblage and seasonal distribution of Odonata along three different habitats *viz*. agricultural land, forest and wetlands, and urban. The present investigation is based on extensive survey of all three habitats during three major seasons (pre-monsoon, post-monsoon and winter). A total of 4,268 individuals belonging to 68 species in 39 genera under 9 families were recorded during the study period (December 2011-December 2015). Family Libellulidae (44%) was the most dominant and widely distributed in different sampling sites in all the three habitats. The most dominant species was *Pantala flavescens*(18.35 %). Across the three land-use types, there was a difference between the species composition with forest being the most diverse followed by urban habitat and agricultural land, though, the abundance of species were much more in urban habitat. Clustering analysis showed that urban and agricultural lands are more similar forming the same clusters whereas forest forms a different one. Species richness and abundance varied with seasons, post-monsoon being highest in richness as well as abundance. Variation in rainfall patterns has been reported to be one of the important factors. During the present investigation, a total of 52 species were reported from Bhimashankar Wildlife Sanctuary (WLS), and out of which 40 species were new records from the area. A total of 37 species was documented from Ujani Wetland, out of which 21 species have been recorded first time. Thus the present work aims to document the Odonate diversity of the Pune district along with their habitat selection and seasonal variations which provides baseline data that can be used for their conservation strategies.

Keywords: diversity, abundance, assemblage, seasonality, odonates, habitat

Introduction
Odonata is sensitive to habitat structure and is an excellent indicator of changes in habitat structure (Clausnitzer, 2004). The group constitutes a valuable tool for various types of bio-assessment and bio-monitoring of aquatic habitats which include the measure of biodiversity, the assessment of water body health or integrity (including water quality and ecosystem function), the monitoring of management or restoration practices, and the detection and prediction of biological impacts of climate warming (Oertli, 2008).[34]
The Odonata fauna of India has been well documented from different parts of the country by (Fraser, 1933, 1934, 1936; Prasad and Varshney,1996; Emiliyamma *et al*,.2005; Subramanian, 2005, 2007, Subramanian and Babu, 2017)[13, 14, 15, 37, 11, 44, 45, 46, 49]. The Western Ghats, a global biodiversity hotspot (Myers *et al.*, 2000; Mittermeier *et al.*, 2011)[31,30], have a rich Odonata fauna which is relatively well worked out (Emiliyamma and Radhakrishnan, 2000, 2007; Babu *et al*. 2009; Ranganekar *et al*., 2010; Kulkarni *et al*.,2012; Kulkarni and Subramanian, 2013; Babu *et al*. 2013; Tiple *et al.*, 2013; Ragnekar and Naik, 2014; Koparde *et al*. 2014; Tiple and Koparde 2015).[10, 12, 1, 39, 23, 24, 2, 50, 51]
Riverine ecosystems, which are home to a rich array of biodiversity and play an important role in supporting people's livelihoods, are under great threat due to their great demand (Felipe-Lucia, 2015; Vörösmarty *et al*., 2010).[16, 54] The influence of different substrate type and categories of riparian vegetations and habitat disturbances on larval and adult odonate community structure has been studied in detail (Luke S.H. *et al.*, 2017; Pires M.M. *et al*., 2020) [26, 38] It has been suggest that in stream insects of Western Ghats, species richness is affected by altitude, micro-habitat richness, canopy cover, and annual rainfall in different aquatic habitats (Subramanian and Sivaramkrishnan, 2005) [44]. The Odonate species assemblage and habitat correlates from Sahyadri Tiger Reserve, Maharashtra has also been documented in detail (Koparde *et al*. 2015) [21].
The choice of Pune district as a study site under the present investigation is influenced by many considerations. The study area falls under two separate geographical regions *viz*, western high rainfall area (annual rainfall 700 to 7000 mm) and eastern drought-prone region of the Deccan trap of Maharashtra (annual average rainfall 400-500 mm). Moreover, this region has not been so far fully explored for faunal diversity, and the abundance and diversity study of such an useful insect group with their habitat and seasonal variation is fairly novel for this

region. Hence, an attempt was made to record the habitat diversity and seasonal variation of Odonata of Pune district, which may be useful for conservationists and biodiversity managers.

In the present state of rapid urbanization, most of the preferred sites of these elegant insects are vanishing. Moreover, indiscriminate assault on forest lands have reduced the number of perennial streams thus the breeding has become localized and restricted. However, all previous works deals with sporadic species list and do not give a detailed study of Odonata fauna in relation to seasonality or habitat selection of the Pune district. Being, one of the most industrialized and urbanized cities in India, the present study aims to document habitat and seasonal distribution of Odonata of Pune district.

Materials and Methods

The present study is based on the collection made from December 2011 to December 2015. The field surveys were conducted thrice a year during winter (December to February), Pre-monsoon (March-May) and Post-monsoon (September-November) periods. Collections were made during the daytime from 9.00 am to 1.00 pm, since during this time the Odonates are at the peak of their activity.

Collection site

Collection sites were mainly divided under three land-use categories of different Odonates habitats. These are as follows:

1. Agricultural land-use
2. Forests and wetlands
3. Urban habitat

1. **Agricultural lands:** Pune district has 3,100 hectares of cultivable land. It includes four among the seven agricultural climate zones in Maharashtra namely the Ghat Zone, Sub Mountain Zone, Plain Zone and Scarcity Zone. There is a variety of soil types and rainfall ranging from 60 to 300 cm in the district. There are two cropping seasons in the district, which includes Kharif (begins in June or July and ends in September or October) and Rabbi (season starts from September or October and ends in February or March). Jowar, bajara, rice, tur, moong, groundnut and soybeans are the major Kharif crops grown in study region while wheat, gram, maize, sunflower are rabbi crops. Sugarcane is grown on a large scale in both Kharif and Rabbi seasons in Pune District (http://krishi.maharashtra.gov.in/Site/Upload/Pdf/pune_cdap.pdf)

2. **Forests and Wetlands:** Pune district has a good stretch of forest cover mostly along its western boundary, on the hill ranges of the Western Ghats. The Bhimashankar wildlife sanctuary is located in the Ambegaon taluka of Pune District, spreading across an extensive area of 120 sq. km on the Sahyadri ranges and spread over Pune, Raigad and Thane districts of Maharashtra. Being a densely forested area, this sanctuary receives heavy monsoon rainfall. A vast wetland Ujani Reservoir is the terminal water body in the upper Bhima river basin. It has a huge catchment of 1, 4500 sq. km and a part of it comes under the Pune district. Intense urbanization, industrial and agricultural activities have altered its water over period of time. All the information regarding Pune district has been derived from Pune websites: www.maharashtratourism.gov.in; en.wikipedia.org/wiki/Pune.

Sampling and data collection

Sampling was made by the belt transect method. For streams, the transect passed through the streams and for reservoirs, the transect was placed on the banks. The data on latitude, longitude and altitude was collected in the field using a Garmin GPS. Information regarding the number of individuals, habitat type, aquatic vegetation in the collection site was noted down. Only individuals difficult to identify were caught, others were observed and photographed in the field using Olympus and Canon 50D digital cameras.

All the collected samples were identified using standard and authorised literatures that followed the present norms of International Code of Zoological Nomenclature. The identification and classification were facilitated with the help of a taxonomic key provided by Fraser, 1933-1936; Nair, 2011; Dijkstra *et al*.,2013; and Subramanian, 2017 [13. 14, 15, 32, 9, 49]. The specimens have been submitted to Zoological Survey of India,Western Regional Centre, Pune.

Statistical Analysis and Diversity indices

Alpha diversity and beta or differentiation diversity were used to measure the genus and family diversity within and between sampling localities and riparian land-use types. Alpha diversity was calculated by Simpson's index. Diversity indices were calculated using the software PAST.

Cluster analysis

Cluster analysis is based upon similarity measure of the different collection sites which help us to understand the uniqueness and overlap of different species in different habitats. Clustering was done using Bray-Curtis, on a non-matrix multivariate scaling and results were plotted as dendograms.

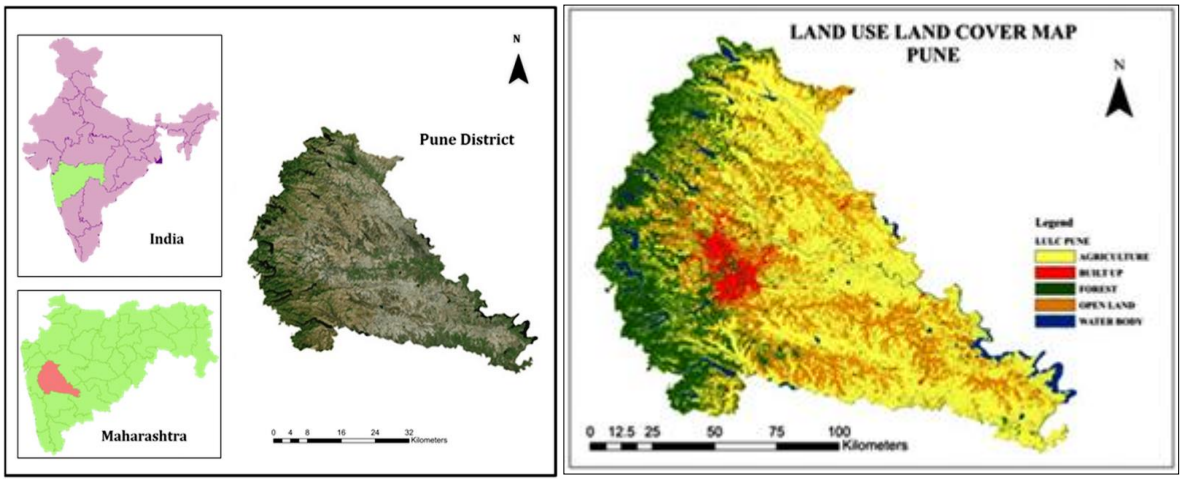

Fig 1: Map of the study area (Source:http://www.springerlink.com/openurl.asp?genre=journal&issn=1387-585X)

Result and Discussion

1. Species Diversity in the study area

A total of 4,268 individuals belonging to 68 species in 39 genera and 9 families were recorded during the study Period from 68 sampling localities. During the present investigation, the suborder Anisoptera with 40 species (59%) was found to be abundant in comparison to Zygoptera for the remaining 41% with a total of 28 species.

Species Diversity in Agricultural Land use type:

In agricultural lands, a total of 1,080 individuals pertaining to 42 species were recorded from 17 sampling sites from different talukas of Pune district. Family Libellulidae was the most dominating with 23 species (55%) followed by family Coenagrionidae with 12 species (29%). Family Lestidae and Platycnemidae with 3 species each (7%) and family Aeshnidae was the least dominant one with only a single species recorded (Figure 2).

Species Diversity in Forests and wetland habitat type

In forest streams and from wetlands a total of 661 individuals belonging to 59 species were recorded from 15 localities. These areas were comparatively less disturbed and polluted by anthropogenic activities. Family Libellulidae was the most dominating with 27 species (46%) followed by family Coenagrionidae with 13 species (22%). Family Gomphidae and Aeshnidae both formed 5% of the total with 4 species each. Family Lestidae (5%) and Platycnemidae (5%) both recorded with 3 species each. Families Calopterygidae (3%) and Chlorocyphidae (3%) comprised of 2 species each. Macromiidae was the least dominant family with only a single species (2%) recorded (Figure 3).

Species Diversity in Urban land use type

In urban land-use type, a total of 2,492 individuals belonging to 57 species were recorded from 36 sampling localities. Family Libellulidae was most dominating with 26 species (46%) followed by family Coenagrionidae with 16 species (28%). Families Gomphidae, Aeshnidae, Lestidae and Platycnemidae all formed 5% of the total consisting of 3 species each. Macromiidae (4%) was the next with 2 species and Family Chlorocyphidae was the least dominant family with only a single species (2%) (Figure 4).

Seasonality

Species diversity and abundance varied across seasons with post-monsoon being highest in species diversity as well as in abundance with a total number of 2,243 individuals pertaining to 55 species. During pre-monsoon a total number of 1,313 individuals belonging to 39 species was recorded. Winter abundance was comparatively lower with 702 individuals pertaining to 16 species (Figure 5)

1. Pre-monsoon family and species abundance

During pre-monsoon (March-June) 18 species and 316 individual pertaining to 3 families i.e. Libellulidae, Coenagrionidae and Platycnemididae were recorded from agricultural land. Family Libellulidae being dominant recorded 11 species (61%), followed by Coenagrionidae with 5 species (28%) and Platycnemididae with 2 species (11%). *Brachythemis contaminata* was the most dominant species (46 individuals) followed by *Pantala flavescens* (45 individuals).

From forest streams and wetlands, a total of 200 individuals pertaining to 24 species under 7 families were recorded. Libellulidae was the dominant family with 13 species (54%) which was followed by family Coenagrionidae with 6 species (25%) followed by Aeshnidae, Platycnemididae and Calopterygidae with 2 species (11%) each. *Brachythemis contaminata* was the dominant species with 29 individuals followed by *Orthetrum sabina* (24 individuals).

In urban habitat type, a total of 732 individuals pertaining to 34 species under 5 families were recorded during pre-monsoon surveys. Libellulidae was dominant with 18 species (55%) which was followed by Coenagrionidae with 9 species (27%), Platycnemididae with 3 species (9%), Aeshnidae with 2 species(6%) and Lestidae with a single species (3%) were documented during the study. *B. contaminata* being the most dominant with 111 individuals, followed by *P. flavescens* (85 individuals). (Figure 6).

2. Post-Monsoon Family and species abundance

During post-monsoon (September-November), a total number of 521 individual pertaining to 30 species belonging to 4 families was reported. Family Libellulidae (67%) with 20 species was most dominant. This was followed by family Coenagrionidae with 8 species (27%) and family Aeshnidae and Platycnemididae (3%) with a single species each. *P. flavescens* is the most common species followed by *Diplacodes trivialis.*

In forest and wetlands, a total of 283 individuals belonging to 37 species under 8 families were recorded during post-monsoon. Family Libelullidae was dominant with 15 species (40%) followed by Coenagrionidae with 8 species (22%), Gomphidae with 4 species (11%), Aeshnidae and Lestidae each with 3 species (8%), Calopterygidae with 2 species (5%), family Macromiidae and Chlorocyphidae with one species each. *P. flavescens* is the most dominant species.

In urban habitat, a colossal total of 1,366 individuals pertaining to 45 species under 8 families were reported during post-monsoon. Family Libellulidae was dominant with 20 species (44%) followed by Coenagrionidae with 13 species (29%). Family Aeshnidae and Gomphidae each with 3 species (7%), Macromiidae and Platycnemidae each with 2 species, Lestidae and Chlorocyphidae with one species each. *P. flavescens* is the most dominant species. (Figure 7)

3. Winter abundance of species and families

During winter (December-February) 214 individuals belonging to 14 species and 3 families Libellulidae, Coenagrionidae and Platycnemidae were recorded from agricultural land. *Brachythemis contaminata* was the most abundant. *Paracercion calamorum* was recorded only during this season from agricultural land.

From forested streams and wetlands during winter 102 individuals belonging to 11 species under 4 families were reported. *Trithemis festiva* was the dominant one. In Urban habitat, 347 individuals belonging to 15 species under 3 families were recorded. Libellulidae was dominant with 9 species, Coenagrionidae with 3 species, and Platycnemididae with 2 species. The most dominant one was *Diplacodes trivialis* (Figure 8)

There was notable variation in species abundance in the study area during the three different seasons, post monsson with maximum recorded species (55 species) followed by pre monsoon (39 species) and winter (16 species) (Figure 9)

4. Diversity Indices

The Shannon diversity and the Simpson's dominance indices were obtained for the sampling sites using the Software PAST. Bhigwan wetland was found to be the most diverse site with highest Shannon diversity index (3.024) which is followed by Manikdoh dam (2.997) (Table 2).

5. Species Assemblage:

Codes corresponding to the sampling localities have been assigned to ease understanding (Table 1). Clustering was done using Bray-Curtis, on a non-matrix multivariate scaling and results were plotted as dendrograms. The cluster analysis (Figure 10) shows a similarity between different habitat in their species composition. Sites F4 and F11 forms distinct cluster since both these regions are at very high altitudes and are with dense and similar type of forest cover. Sites U13 and U33 (both urban riverbanks), F7 and F14 (foothills), A6 and A11(agricultural lands) comprise of all the three habitats of urban, forest and agriculture. All these sites are situated just at the bank of a waterbody, *viz*. Nira, Kukadi and Mutha and have similar structures of riparian vegetations. Sites U5, A7, U24, U6, U21, U10, U1, U23, U17, U31, U11, F15, U8, U16, U34, U35 and A9 form one huge cluster comprising urban habitat in and around large dams and reservoirs like Dimbhe Dam, Katraj Lake, Manikdoh Dam, Holkar Talav with good species diversity. The abundance of wetland macrophytes like *Ipomoea carnea* Jacq., *Typha angustifolia* L., *Chrozophora rottleri* (Gies.) makes a suitable breeding grounds of odonates. The backwaters of these dams particularly in post monsoon harbours good species diversity as well as abundance. The sites A3, A17, A15 are paddy fields which show similar species assemblages as odonates are predators for pests of paddy. A1 and A14 are irrigated agricultural land with sugarcane as standing crop that shows many similarities in species assemblage. The sites U8, U16, U34 and U35 comprise of artificial reservoir in urban areas and shows similar species diversity. Altogether, the forests with high canopy cover and rapid streams forms a closed group with similar species assemblages. But there exist similarity in species composition in urban and some agricultural fields due to similar type of anthropogenic activities and the presence of human and animal excreta.

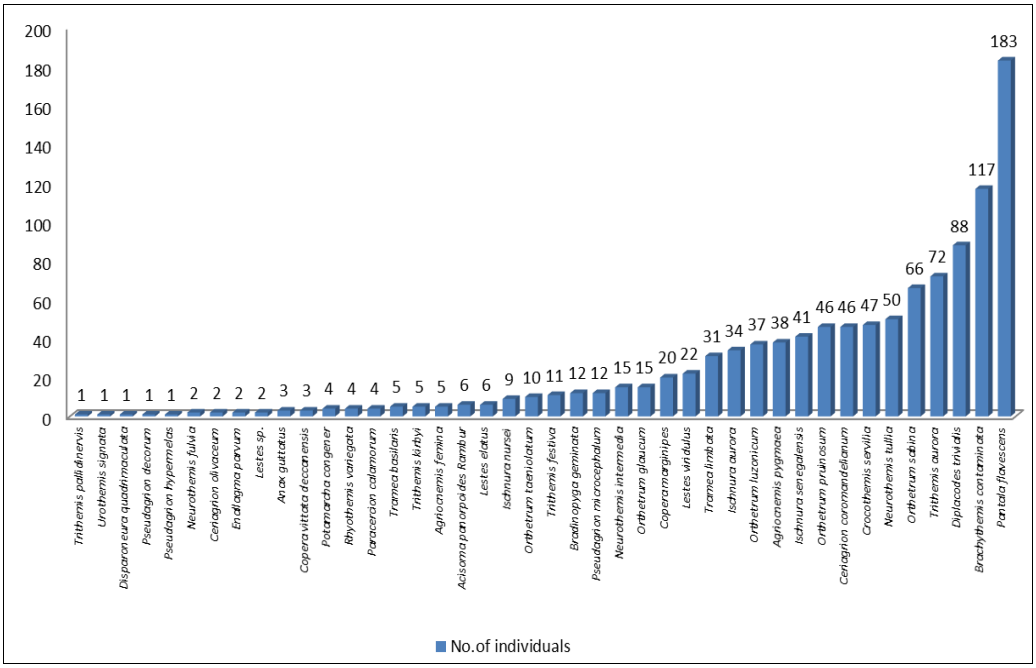

Fig 2: Species abundance in Agricultural land-use type

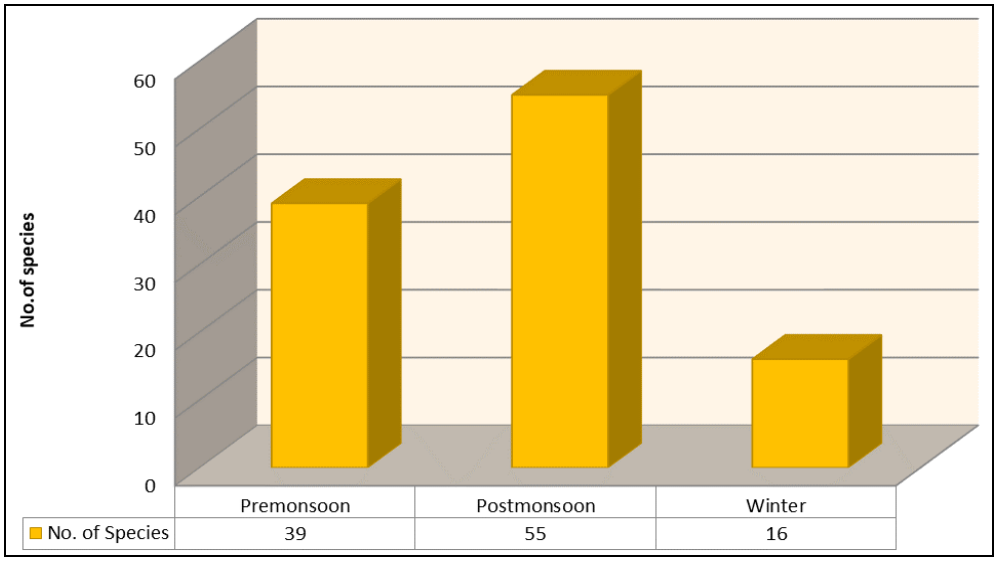

Fig 3: Seasonal Abundance of Species in study area

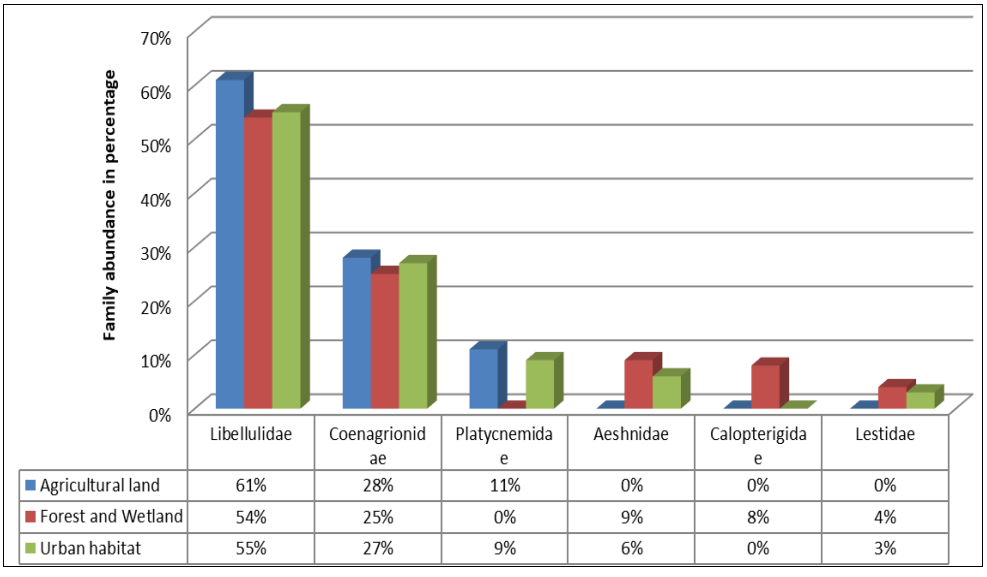

Fig 4: Family abundance during Pre-monsoon across three land-use types

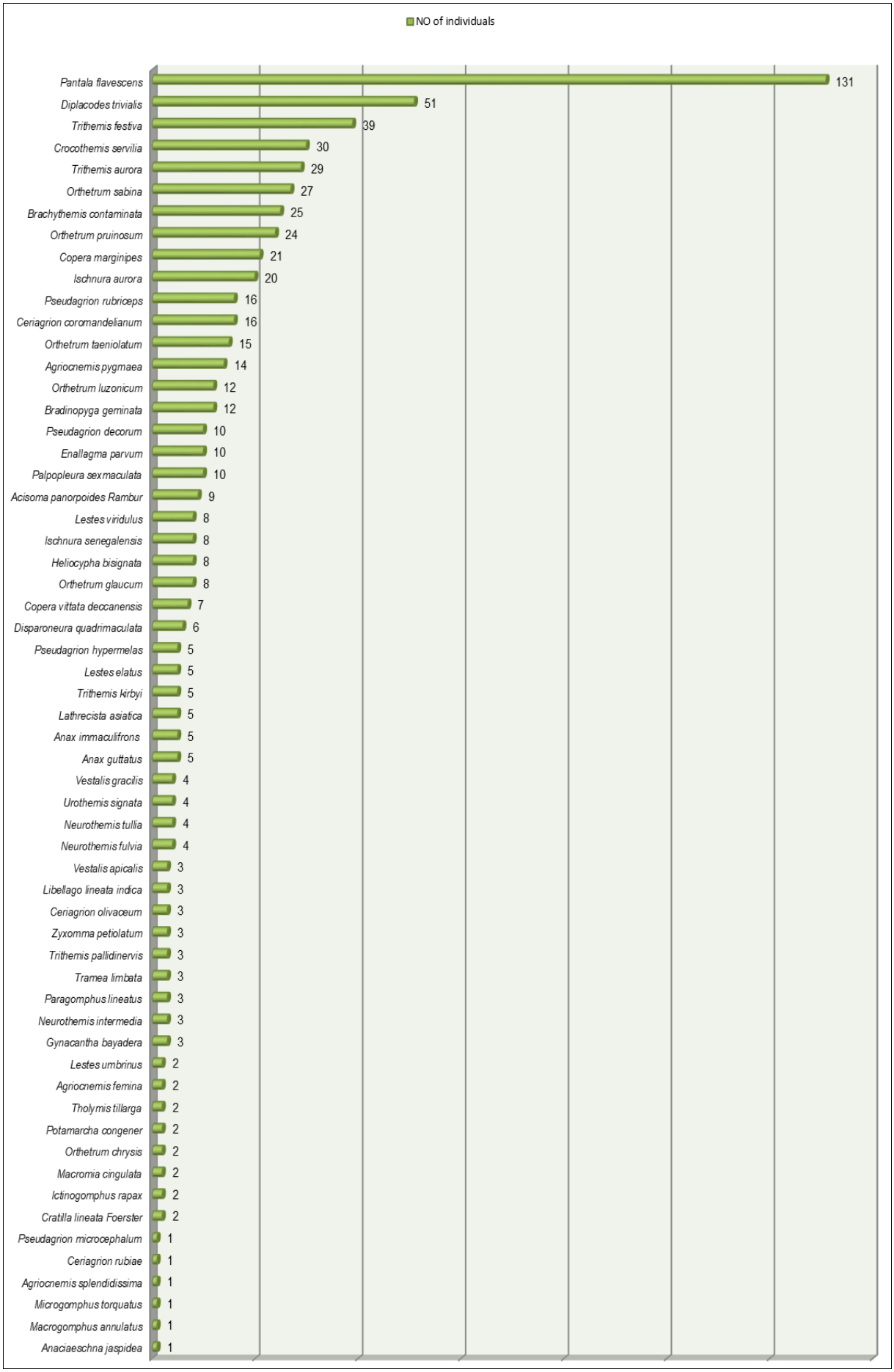

Fig 5: Species abundance in Forests and Wetland Habitat

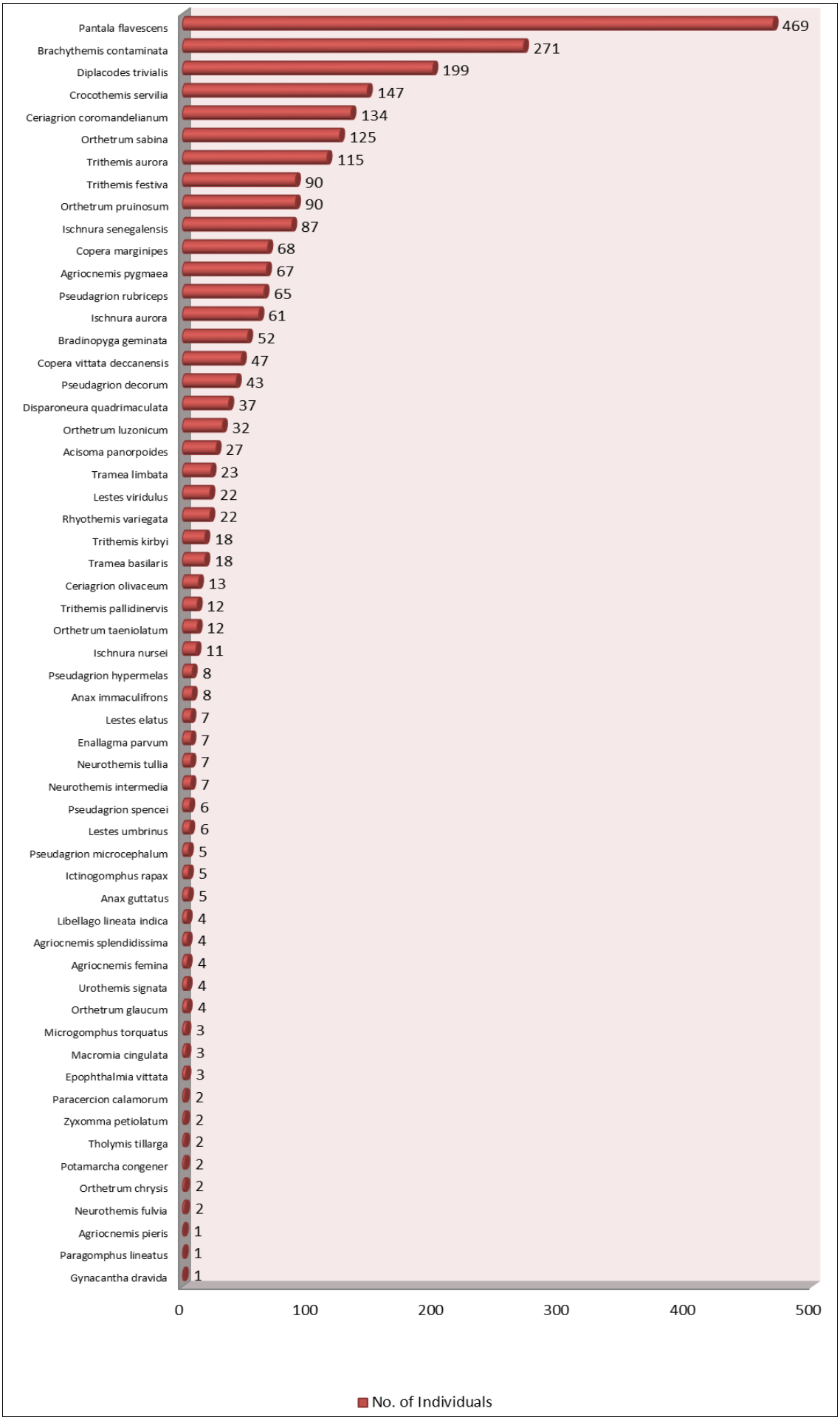

Fig 6: Species abundance in Urban Land-use

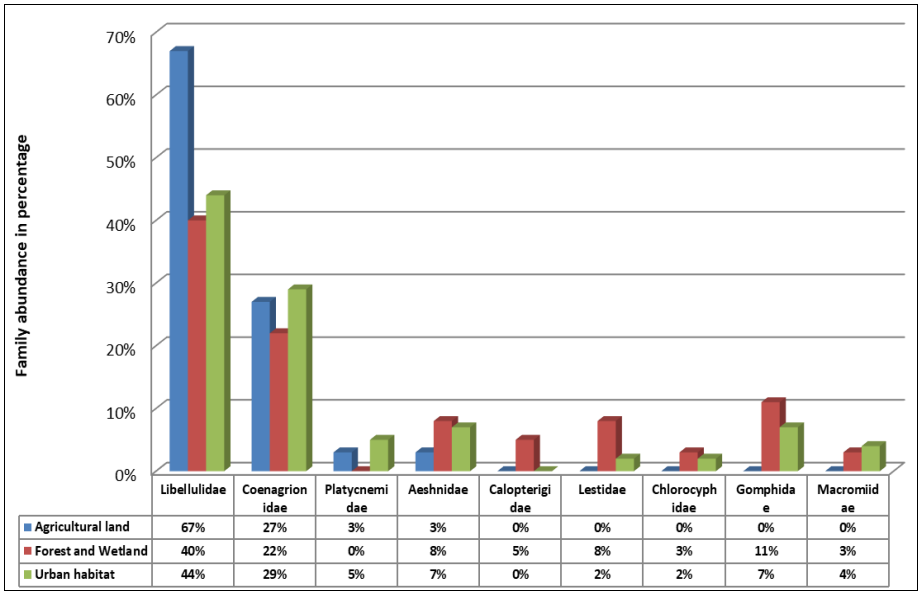

Fig 7: Family abundance during Post- monsoon across three land-use types

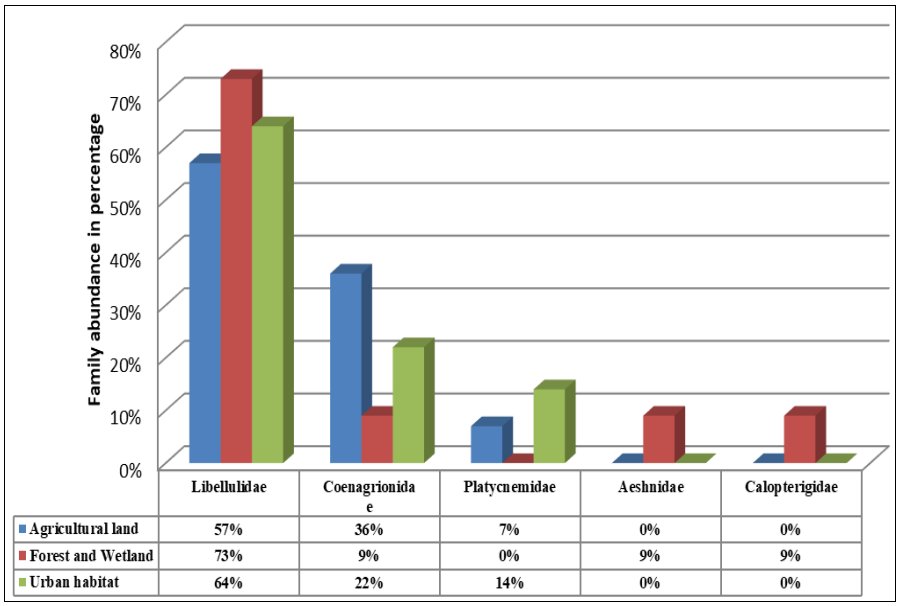

Fig 8: Family abundance during winter across three land-use types

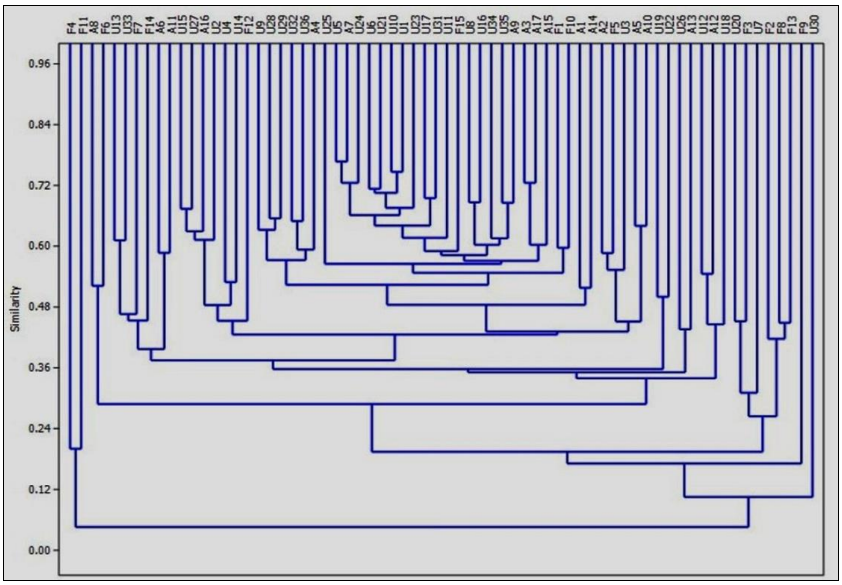

Fig 9: Cluster Analysis of study sites

Table 1: Details of survey localities in Pune District along with their species richness

Sl No	Locality Name	Codes	Taluka	Latitude	Longitude	Alt	Habitat	No of Species
1	Agricultural land beside Dimbhe Dam	A1	Ambegaon	19.089858	73.742233	661	Agricultural land	15
2	Ahupe Lake, Bhimashankar WLS	F1	Ambegaon	19.173131	73.569722	913	Forest lake	25
3	Bhimashankar WLS	F2	Ambegaon	19.076375	73.530589		Forest	11
4	Bhorgiri, Bhimashankar WLS	F3	Ambegaon	19.045469	73.567839	673	Forest	9
5	Dimbhe Dam	U1	Ambegaon	19.102978	73.755344	739	Urban	19
6	Nagfaani, Bhimashankar WLS	F4	Ambegaon	19.070872	73.528714	860	Forest with streams	7
7	Kondhaval Nalla (Forested stream)	F5	Ambegaon	19.104389	73.560875	825	Forest stream	17
8	Blue Mormon, Bhimashankar WLS	F6	Ambegaon	19.070147	73.603469		Urban	7
9	Nigdale, Bhimashankar WLS	F7	Ambegaon	19.073058	73.553633	979	Forest	8
10	Ricefield beside Bhima river, Bhorgiri	A2	Ambegaon	19.041772	73.566039	687	Agricultural land	17
12	Agricultural land, bank of Nira.	A3	Baramati	18.167431	74.568283	549	Agricultural land	16
13	Agricultural land (Shirsuphal village	A4	Baramati	18.324658	74.597175	558	Agricultural land	14
14	Anjangaon	U2	Baramati	18.214333	74.483758	565	Urban	7
15	Bhatgar Dam	U3	Bhor	18.180581	73.873556	602	Urban	19
16	Paddy field, Bhor	A5	Bhor	18.139722	73.849539	628	Agricultural land	14
17	Parit dhuna, agricultural field	A6	Bhor	18.151997	73.839986	606	Agricultural land	10
18	Agricultural field, Diksal	A7	Daund	18.328414	74.790367	508	Agricultural land	22
19	Agricultural land near Gar	A8	Daund	18.479067	74.592097	513	Agricultural land	5
20	Bhigwan near Ujani Wetland	F15	Daund	18.300178	74.762633	499	Wetland with forest cover	36
21	River near Sonwadi	U4	Daund	18.488333	74.559892	509	Urban	11
22	Bank of Mutha river, Pune city	U5	Haveli	18.520969	73.852386	546	Urban	18
23	Beside Pawna River, Akurdi	U6	Haveli	18.639694	73.748297	563	Urban	23
24	Dapodi, Pune	U7	Haveli	18.581922	73.826281	561	Urban	4
25	Donaje farmland, Sinhagad fort	A9	Haveli	18.4	73.77	649	Agricultural land	22
26	Empress Garden	U8	Haveli	18.512583	73.898506	579	Agricultural land	16
27	Kasarsai dam and around, Pune	U9	Haveli	18.63	73.66	714	Urban lake	18
28	Katraj Lake	U10	Haveli	18.453611	73.861667	648	Urban lake	18
29	Khadakwasla dam	U21	Haveli	18.432339	73.769669	593	Urban lake	21
30	Khadki	U11	Haveli	18.5563	73.831875	568	Urban	15
31	Pashan Lake	U12	Haveli	18.531286	73.780978	591	Urban lake	11
32	River in wakrewadi, Shivajinagar	U13	Haveli	18.540883	73.853364	546	Urban	8
33	Ropevatika, Aundh	U14	Haveli	18.563044	73.8264	562	Urban garden	17
34	Sarasbag	U15	Haveli	18.500339	73.853208	574	Urban garden	9
35	Savitribai Phule Pune University Campus	U16	Haveli	18.552653	73.826958	582	Urban	17
36	Sinhagad and around	U17	Haveli	18.363544	73.753853	1268	Urban land	21
37	Tathawade	U18	Haveli	18.63	73.75	565	Urban	9
38	Wakrebadi, Shivaji Nagar	U19	Haveli	18.540883	73.853364	546	Urban	8
39	Z.S.I., Office campus,	U20	Haveli	18.648286	73.760106	579	Urban	11
40	Agricultural land, Shaha Village	A10	Indapur	18.106067	75.100719	514	Agricultural land	11
41	Agricultural land, near Kandalgaon	A11	Indapur	18.105372	75.117114	508	Agricultural land	13
42	Agricultural land near Palasdev	A12	Indapur	18.234083	74.889114	505	Agricultural land	14

43	Agricultural field, Golegaon village.	A13	Junnar	19.210267	73.885397	659	Agricultural land	12
44	Kukri river, Manikdoh dam	U22	Junnar	19.228914	73.825497	670	Urban	12
45	Farm land near Manikdoh Dam	A14	Junnar	19.228569	73.822544	678	Forest	12
46	Forest around Shivneri fort	F8	Junnar	19.202089	73.861544	792	Forest	12
47	Manikdoh Dam	U23	Junnar	19.234303	73.815872	674	Urban	26
48	Bhusi dam, Lonavla	U24	Maval	18.722669	73.397908	643	Urban	13
49	Karla Caves and around	U26	Maval	18.783472	73.469817	764	Urban	9
50	Pavana dam	U25	Maval	18.661383	73.497856	618	Urban lake	24
51	Adarwadi, Tamhini Ghat	U27	Mulshi	18.441856	73.434139	553	Urban	12
52	Agricultural field,Paud	A15	Mulshi	18.525214	73.614542	585	Agricultural land	15
53	Beside Mula river, Paud	U28	Mulshi	18.526606	73.608604		Urban	12
54	Dongarwadi, Tamhini Ghat	U29	Mulshi	18.373	73.495	543	Forest with streams	12
55	Forest near plus valley in Tamhini	F9	Mulshi	18.47	73.41	598	Forest with streams	10
56	Hulawalewadi, Paud	U30	Mulshi	18.529028	73.614025	575	Urban	4
57	Lonavla and around	U31	Mulshi	18.713647	73.381803	698	Urban	23
58	Tamhini and around	F10	Mulshi	18.44692	73.44444	560	Forest	16
59	Tamhini forest(Plus valley)	F11	Mulshi	18.475608	73.416881	609	Forest	6
60	Forest around Purandar fort	F12	Purandar	18.274644	73.975464	1137	Forest	13
61	Rajewadi,	U32	Purandar	18.388436	74.166258	716	Urban	19
62	Agricultural land, Chaas village	A16	Rajgurunagar	18.921478	73.831206	794	Agricultural land	13
63	Shiroli, near Kukadi river	U33	Rajgurunagar	19.234753	73.735558	760	Urban	9
64	Holkar Talav, Jejuri	U34	Saswad	18.278269	74.156792	733	Urban lake	21
65	Pabal village	U35	Shirur	18.828817	74.053983	666	Urban	21
66	Agricultural land near Margasani village	A17	Velhe	18.280133	73.739844	663	Agricultural land	14
67	Khodad village	U36	velhe	18.295556	73.672683	672	Urban	18
68	Valley of Torna Fort	F14	Velhe	18.29	73.63	742	Forest	10

Table 2: Table showing the diversity indices of the samplings sites in the study area.

Localities	**Species Richness**	**Abundance**	**Shannon Diversity Index (H´)**	**Simpson's Dominance Index (C)**	**Shannon's Evenness Index (J´)**
Dimbhe Dam	19	112	2.635	0.091	0.734
Anjangaon	7	29	1.661	0.241	0.752
Bhatgar Dam	19	74	2.732	0.079	0.809
River near Sonwadi	11	37	2.261	0.122	0.872
Bank of Mutha river, Pune city	18	101	2.474	0.112	0.660
Beside Pawna River, Akurdi	23	119	2.753	0.088	0.682
Dapodi, Pune	4	13	1.352	0.266	0.966
Empress Garden	16	78	2.552	0.099	0.802
Kasarsai dam, Pune	18	70	2.667	0.087	0.800
Katraj Lake	18	105	2.730	0.077	0.851
Khadki	15	80	2.376	0.118	0.717
Pashan Lake	11	41	2.295	0.110	0.903
River in wakrewadi, Shivajinagar	8	39	1.850	0.195	0.795
Ropevatika, Aundh	17	65	2.672	0.079	0.851
Sarasbag	9	46	2.064	0.142	0.876
Savitribai Phule University Campus, Pune	17	91	2.533	0.108	0.741
Sinhagad and around	21	101	2.598	0.113	0.640
Tathawade	9	32	2.115	0.127	0.922
Wakrebadi, Shivaji Nagar	8	38	1.819	0.213	0.770
Z.S.I., WRC, Office campus, Akurdi	11	37	2.334	0.103	0.939
Khadakwasla dam	21	111	2.730	0.087	0.730
Along the bank of Kukri river	12	42	2.255	0.130	0.795

Manikdoh Dam	26	108	2.997	0.066	0.770
Bhusi dam, Lonavla	13	86	2.319	0.119	0.782
Pavana dam	24	116	2.853	0.078	0.723
Karla Caves and around	9	27	2.089	0.136	0.897
Adarwadi, Tamhini Ghat	12	49	2.305	0.117	0.835
Beside Mula river, Paud	12	54	2.285	0.115	0.819
Dongarwadi, Tamhini Ghat	12	62	2.284	0.123	0.818
Hulawalewadi, Paud	4	14	1.334	0.276	0.949
Lonavla and around	23	112	2.827	0.084	0.735
Rajewadi,	19	87	2.718	0.083	0.798
Shiroli, near Kukadi river	9	46	1.884	0.206	0.731
Holkar Talav, Jejuri	21	80	2.766	0.085	0.757
Pabal village	21	90	2.803	0.070	0.786
Khodad village	18	67	2.723	0.074	0.846
Agricultural land beside Dimbhe Dam	15	116	2.492	0.100	0.806
Ricefield beside Bhima river, Bhorgiri	17	79	2.592	0.086	0.785
Agricultural land, on bank of Nira's left canal.	16	95	2.601	0.087	0.842
Agricultural land near Shirsuphal village	14	70	2.518	0.091	0.886
Paddy field, Bhor	14	58	2.471	0.093	0.845
Parit dhuna, agricultural field	10	36	2.088	0.147	0.807
Agricultural field, Diksal	22	105	2.655	0.097	0.647
Agricultural land near Gar, Daund	5	24	1.452	0.257	0.855
Donaje, farmland(foot hills of Sinhagad fort)	22	88	2.767	0.087	0.723
Agricultural land (Paddy) in Shaha Village	11	42	2.294	0.110	0.901
Agricultural land beside Bhima river, near Kandalgaon	13	39	2.422	0.098	0.867
Agricultural land near Palasdev	14	47	2.483	0.094	0.855
Agricultural field, near Golegaon village.	12	51	2.252	0.124	0.792
Farm land (Manikdoh Dam)	12	56	2.292	0.117	0.825
Agricultural field (Paud)	15	72	2.334	0.135	0.688
Agricultural land,(Chaas village)	13	67	2.321	0.116	0.783
Agricultural land (Margasani village)	14	68	2.359	0.120	0.756
Ahupe Lake, Bhimashankar WLS	25	100	2.841	0.084	0.686
Bhimashankar WLS	11	33	2.249	0.117	0.862
Bhorgiri, Bhimashankar WLS	9	25	2.044	0.142	0.858
Nagfaani, Bhimashankar WLS	7	10	1.887	0.160	0.943
Kondhaval Nalla, Bhimashankar WLS	17	54	2.538	0.097	0.744
Near blue Mormon hotel, Bhimashankar WLS	7	22	1.731	0.211	0.807
Nigdale, Bhimashankar WLS	8	27	1.589	0.289	0.613
Forest (foot hills Shivneri fort)	12	25	2.301	0.117	0.832
Forest near plus valley in Tamhini	10	23	2.054	0.157	0.780
Tamhini and around	16	91	2.295	0.149	0.621
Tamhini forest (near Plus Valley)	6	10	1.748	0.180	0.957
Forest around Purandar Fort	13	40	2.337	0.116	0.796
Forest around Sinhagad Fort	14	24	2.535	0.087	0.901
Valley of Torna Fort	10	42	1.826	0.246	0.621
Bhigwan near Ujani Wetland	36	148	3.024	0.082	0.572

Discussions

During the present investigation, the suborder Anisoptera with a total number of 40 species (59%) found to be abundant in comparison to Zygoptera (28 species, 41%). This matches with the findings of almost all the workers from different parts of world which corroborate Anisoptera to be a much dominant and diversified one. This might be due to their adaptability to a wide range and high dispersal ability (Williams, 1997; Clark and Samways, 1996). [55, 3] Out of 68 species recorded, 30 species belonged to family Libellulide making it the most dominant family (44%) followed by Coenagrionidae which consist of 17 species (25%). The findings of this study thus agrees with Keize and Kalkman (2009) [19] who gave the same opinion that Coenagrionidae and Libellulidae are the two worldwide largest families which dominated the Odonata fauna of standing water in every continent.

Across the three land-use types, there was a difference between the species composition with forest being the most diverse followed by urban and agriculture, though the species abundance were much more in urban habitat. Clustering analysis showed that urban and agriculture habitats are quite similar sometimes even forming one closed group whereas forest forms a different one. These findings are in accordance with Lawler, 2001; Villanueva, 2010. [25, 53] This can be due to more number of shared species and similar type of disturbance

between urban and agricultural land-use. The wetlands altogether forms a relative different community with availability of some unique species. There was a difference in species richness as well as abundance across the season with post-monsoon being highest in species richness as well as abundance. Although the breeding times vary among odonate species, but then many species breeds mostly during August to December.

The maximum number of individuals has been recorded from agricultural land-use was from paddy fields. The agricultural land comprises of the area of cultivation along with adjacent small temporary artificial water bodies like wells, ponds, tanks etc. for irrigation. Single farmland is also comprised of not only a single crop but sometimes multiple crops like sugarcane plantations just beside paddy fields. Odonate assemblage to these adjoining areas have also been considered during sampling. Ruggiero *et al*., 2008 [43] got similar findings and mentioned in detail the importance of farm pond on the species richness and assemblage of Odonata. In this land-use, *P. flavescens* was the dominant one followed by *B. contaminata* and *D. trivialis*. *B. contaminata* is known to breed in marshes, ponds and tanks while *D. trivialis* is known to inhabit in fields, gardens etc. and breeds in muddy puddles and ditches. These type of breeding areas are abundant in paddy fields which are provided with ditches and water-logged patches. The maximum and minimum temperature of the fields in study area recorded was 28°C and 41°C, mostly. The damselflies like *Ceriagrion coromandelianum*, *Ischnura senegalensis*, *Ischnura aurora* and *Agriocnemis pygmaea* etc. are known predators and they predate upon leaf and plant hoppers. Dragonflies like *O. sabina*, *Crocothemis servilia*, *P. flavescens,* are important predators of rice field pests like lepidoptera. Being the most important predator (Fraser, 1936) [15], *O. sabina* was found almost in every field. The species *Agriocnemis femina* occurred only in paddy fields. Another prominent and interesting feature was that in the fields where *O. sabina* dominated, the abundance of other species reduced. This might be due to the reason that *O. sabina* is highly predaceous and even shows cannibalism. The difference in species composition was also observed within this land use type across seasons. *A. femina* and *Copera vittata* were only recorded in premonsoon. *Acisoma panorpoides*, *Anax guttatus*, *Orthetrum taeniolatum*, *Tramea limbata, Lestes elatus* and large swarms of *P. flavescens* were seen during post monsoon season. *P. calamorum* was only observed from agricultural land only during winter.

Though clubbed under the same type of landuse, both forests and wetland show some distinctness between them. The forested riparian ecosystem in Pune district includes evergreen and deciduous forest along the Western Ghats mountain slope, tracts of some natural bottomland forests, forests covering slopes of hills. Some parts of "Ujani Wetland" which comes under the study area have also been included. The vegetation of the Ujani Wetland that falls under the study area is mostly dominated by shrubs and grasses and there is a paucity of higher plants. A total number of 157 individuals have been recorded from three seasons belonging to 37 species under 7 families. Out of the documented species, 21 species have been recorded first time from the study area (after Kulkarni *et al.*, 2002) [22].

The most species rich site was Manikdoh dam and the surrounding area (Junnar taluka) with a total of 26 species belonging to 18 genera under 5 families. The reason for the high assemblage of species might be that, though being urban, the only pollutant present was faecal matters of humans and animals. Moreover, the area had a good riparian vegetation cover which the adult Odonates use as sites for emergence, wings hardening, oviposition, mate attraction and reproduction, as a shelter for protection from predators and wind and to locate prey (Corbet, 2004; Remsberg *et.al*,2008, De Marco Júnior & Resende, 2004) [5, 27, 7]. Thus, increasing reductions in riparian vegetation represent a significant thermoregulatory limitation for the occurrence of certain odonate species, and eventually affect the community composition (De Marco Júnioret *et al*., 2015) [8]. Changes in the structure of riparian vegetation also influence odonate species composition due to reduction in their available habitats. Similar evidence for the above-mentioned pattern also includes studies with larval stages (Peterson *et al*., 2004; Mendes *et al.*, 2019) [36, 33]. Our results have generally supported this pattern. Zygoptera taxa were more closely associated with the broader riparian vegetation widths, while Anisoptera comprised the narrower widths.

Seasonal variations are a common phenomenon in insect populations in all the land-use type. Odonates abundance and species richness increased as soon as heavy pours of monsoon stopped till early winter when the weather conditions are warm and moderate. The population decreases from late winter and declined up to the end of summer when the climate started becoming hostile. Variation in rainfall patterns has been reported to be one of the important factors. Most of the species have their breeding season during this period of September to November. Moreover, the mass emergence of some species and the mass migration of some takes place during this period of the year.

Numerous studies have shown that anthropogenic disturbances like agricultural pollution, urbanization, habitat destruction and changes in the amount of forest cover affect the composition and species assemblages of odonates and can have detrimental effects on sensitive Odonata species (Oertli B**,** 2008; Villanueva & Mohagan, 2010; Subramanian *et al*., 2011, Rodrigues *et al*. 2016, 2019, ValenteNeto *et al.* 2016). [34, 53, 48, 41, 42, 52]

Conclusion

Diversity is the central dogma of any ecosystem and any kind of damage to it will result in imbalance, disparity and deterioration of the natural environment making it incongruous for sustaining life. Many endemic and rare species are localized in small patches of suitable habitat. So protection of the microhabitat is urgently required for their conservation. This study detected significant variation of species diversity and abundance across different habitats during different seasons. To summarise, this study illustrates that Odonata diversity is generally low in urban cities than in surrounding areas. However, urban areas could increase diversity through

proper planning and management. We encourage further research in understanding urban ecosystems using odonates as they are important bioindicators of both aquatic and terrestrial habitats. Conservation is thus needed to protect the micro habitat of odonates as habitat fragmentation is again one of the main reasons for the loss of diversity of this exquisite insect.

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