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HABITAT AND SEASONAL DISTRIBUTION OF ODONATA (INSECTA) OF MULA AND MUTHA RIVER BASINS, MAHARASHTRA, INDIA

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Abstract: Catchment landscape degradation and habitat modifications of freshwater ecosystems are a primary cause of biodiversity loss in riverine ecosystems all over the world. Many elements of the flora and fauna of freshwater ecosystems are sensitive to the changes in catchment land use and habitat modification. These sensitive taxa are also reliable indicators of freshwater ecosystem health. In the current study we investigate the seasonal and habitat distribution of Odonata (Insecta) across riparian land use types in Mula and Mutha river basins, northern Western Ghats, Maharashtra. There was a difference in the species composition across land use types and across seasons with highest diversity and abundance during the post monsoon period. The highest Odonata diversity was observed in urban areas followed by forest and agriculture fields. There was a loss of 31% of the odonate fauna in the study area over 50 years which could be due to rapid industrialization and urbanization of the region and consequent degradation of freshwater ecosystems. The significance of catchment land use on Odonata diversity and its value in landscape monitoring is discussed.

Keywords: Habitat use, local extinctions, northern Western Ghats, Odonata, seasonal distribution.

Marathi Abstract:

नदीच्या खोऱ्यातील भूप्रदेशांचा -ह्रास आणि तेथील अधिवासांमध्ये होणारे बदल ही जगभरात नद्यांच्या परिसंस्थांमध्ये होणाऱ्या बदलांची मुख्य कारणे आहेत. या परिसंस्थेतील प्राणी आणि वनस्पती अधिवासांमधील आणि नदीच्या खोऱ्यांमधील भूप्रदेश वापरामधील बदलांना अत्यंत संवेदनशील असतात. अशा संवेदनशील जातींच्या अस्तित्वासुळे या अधिवासांची सद्यस्थिती ध्यानात येऊ शकते. प्रस्तुत अभ्यासात आम्ही कीटकवर्गातील ओडोनेटा गणातील (चतुर) प्रजातींचा जलसमीप असणाऱ्या अधिवासातील ऋतुनुसार होणाऱ्या वितरणाचा अभ्यास केला. उत्तर सह्याद्रीमधील मुळा-मुठा नद्यांच्या खोऱ्यात केलेल्या ह्या अभ्यासात भूप्रदेश वापराच्या वेगवेगळ्या श्रेणीनुसार आणि ऋतुनुसार वितरणात विविधता होती व ती पावसाळ्यानंतरच्या काळात सर्वाधिक होती असे लक्षात आले. ओडोनेटा गणातील प्रजातींची सर्वाधिक विविधता नागरी विभागात व त्यापाठोपाठ वनांमध्ये व शेतांमध्ये होती. सदर भूप्रदेशात बहुधा वाढते औद्योगिकरण तसेच शहरीकरण आणि त्या अनुषंगाने जलीय परिसंस्थांचा होणारा -ह्रास यामुळे गेल्या पन्नास वर्षांत ओडोनेटा गणातील जातींमध्ये सुमारे ३१ टक्क्यांनी घट झाली आहे. ओडोनेटा गणातील प्रजातींमधील विविधतेच्या दृष्टीने भूप्रदेश वापराचे महत्व काय असते याची चर्चा येथे केली आहे.

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Author Contribution: AK did the field work, identified the odonata and analyzed the data. KAS designed the study, identified odonata, analyzed the data and wrote the manuscript.

Author Details: Ms. ABOLI KULKARNI is a post graduate student of biodiversity and this work is a part of her MSc Thesis. Currently, she is working on documentation of flora and fauna of Sacred Groves from Pune District at Agharkar Research Institute, Pune. She is deeply interested in studying Habitat Ecology and habitat preferences of organisms.

DR. K.A. SUBRAMANIAN is scientist at Zoological Survey of India, Kolkata. Currently he is working on the diversity and distribution of Odonata, Ephemeroptera and Plecoptera of India.

INTRODUCTION

Around the world, freshwater habitats are being subjected to increased levels of human disturbance (Saunders et al. 2002). An assessment of the status of inland water ecosystems shows that globally, the most threatened river catchments are found in the Indian subcontinent (WCMC 2000; Subramanian 2010; Subramanian et al. 2011). Healthy riverine ecosystems are vital for ecological integrity of the landscape. However, anthropogenic modifications such as the construction of dams, draining of streams, agricultural expansion, urban and industrial pollution and riparian deforestation have resulted in degradation of aquatic ecosystems and loss of freshwater biodiversity all over the world, especially in tropical Asia and including the Western Ghats (Dudgeon 1994, 2000; Subramanian, 2010; Molur et al. 2011). Such activity influences natural resources, hydrology, nutrient cycle and natural habitat over time and space, changes which in turn reduce the biodiversity of a region. Some modifications result in loss of certain species which are sensitive to habitat changes while promoting colonization by generalized widespread species which can tolerate the changed conditions. A detailed review of biodiversity and threats to riverine ecosystems of the Western Ghats (Subramanian 2010; Molur et al. 2011) highlights the impact of anthropogenic modifications to the riparian zones in terms of depleting fresh water biodiversity of the region. These reviews emphasize the need for long term catchment scale conservation strategies for the freshwater biodiversity of the Western Ghats. These strategies are directly dependant upon detailed documentation of biodiversity at various spatio-temporal scales and development of suitable indicators for long term monitoring. The indicator approach was followed using aquatic macroinvertebrates such as dragonflies and damselflies (Odonata), Coleoptera and Mollusca to identify, monitor and conserve freshwater ecosystems in South Africa and United Kingdom. These studies have shown that Odonata are reliable indicators for freshwater ecosystem health (Samways 1992, 1993, 1995; Clark & Samways 1996; Painter 1999). Odonata forms an important tool for various types of assessments and monitoring such as measure of biodiversity, wetland health and integrity, biological impact of climate change etc (Ortelli 2008).

The odonate fauna of the Western Ghats is diverse with 176 species, 68 of which are endemic (Subramanian 2009; Subramanian et al. 2008, 2011). Many species are very specific to particular breeding habitat and adults are usually found close to these. This habitat specificity

of species makes them an ideal candidate to assess and monitor ecosystem health.

The rich diversity and habitat specificity of Odonata of India provide a unique opportunity to develop tools for assessing freshwater ecosystem health. An earlier study conducted in Uttara Kannada District, Karnataka has shown that there is a clear relationship between Odonata diversity and riparian land use (Subramanian 2008). The Odonata of Pune District was documented by various workers since the beginning of the 20th century (Fraser 1933–36; Prasad 1996). These studies were mostly species checklists and details of habitat and season distribution were not available. Pune is one of the most industrialized and urbanized landscapes of the subcontinent with rapid changes in land use. The freshwater ecosystems of the region are highly stressed due to pollution and habitat alteration. The river basins of the region are heavily deforested and also have the highest density of dams in the Western Ghats (Subramanian 2010). A study on diversity and distribution pattern of odonates in such highly impacted landscapes will help in understanding ongoing ecological processes in shaping species communities and identifying factors driving local species loss. The present study aims to document habitat and seasonal distribution of Odonata in the Mula-Mutha river basins, major tributaries of the Bhima River which eventually drains into the Krishna basin.

MATERIALS AND METHODS

Study Area

The study was carried out in the Mula-Mutha river basins between Tamhini Reserve Forest (18.460°N & 73.414°E) and Ujani Wetland (18.299°N & 74.763°E) in Pune District, Maharashtra State during May 2010 to April 2011. It covers an area of approximately 150km² (Image 1). There is a clear altitude and rainfall gradient from west to east in the study area (Table 1). The Tamhini Reserve Forest in the Western Ghats is at a higher elevation and receives more rainfall than the Ujani Wetland in the east.

The study area includes various habitats such as semi evergreen forest, agricultural land, urban-industrial area (Pune City), natural and manmade wetlands. Study sites were selected in three predominant land use types viz., forest, agriculture and urban (Images 2–7). In forested landscapes, we sampled streams with forest cover. The important stream habitats were cascades, riffles, small waterfalls and pools. Paddy and sugarcane dominate the

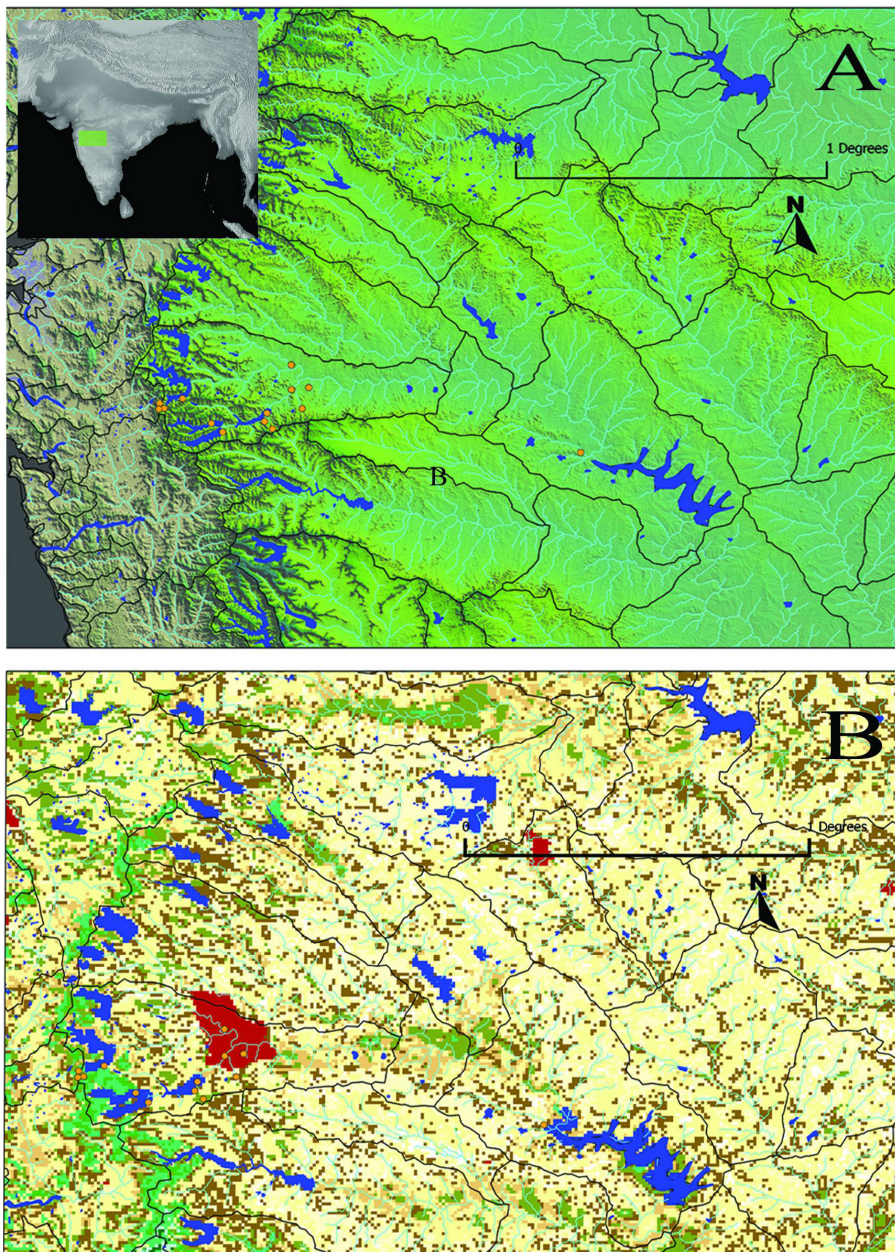


Image 1. Inset: Location of the study area (highlighted green) (A) Physiography of study area with streams and dams. Sampling localities are marked orange (B) Current landuse pattern of the study area. Light and dark green cells are forests/tree covered areas. Red cells are urban/industrial areas. Blue cells are water bodies. Brown, light brown and cream coloured cells are agricultural fields. Orange spots are study sites.

agricultural landscapes. This land use type is scattered throughout the study area from west to east. The urban zone is largely located between forest and agriculture landscape to the west and agriculture landscape to the east and we sampled dams, rivers, garden ponds and lakes in this region.

Sampling Methods

Adult odonates were sampled in 12 sampling localities (Table 1). The sampling was carried out using

a belt transect of 500x10 m for one and half hour in the study sites between 0900 to 1300 hrs when their activity was at its peak. Field sampling was done during the premonsoon (May–June) and postmonsoon (August–October) periods and winter (November–February) during May 2009 to February 2010. Each transect was traversed on foot and all the adult dragonflies observed within 5m of transect line were identified and counted. Common species were identified, photographed in the field (Appendix 1) and unidentified ones were collected

Table 1. Details of study localities

Locality	Land use type	Latitude	Longitude	Altitude (m)	Annual Mean Temp (°C)	Annual Mean Rainfall (mm)
Bhigwan	Agricultural	18.2995	74.7639	507	26	517
Empress Garden	Urban	18.5121	73.8923	567	25	702
College of Military Engineering (CME)	Urban	18.5864	73.8363	573	25	766
Mutha River	Urban	18.5057	73.837	560	25	768
Katraj Tekdi	Urban	18.4433	73.8712	693	24	920
Khadakwasla	Urban	18.4283	73.7584	605	25	1128
Sinhagad Valley	Agricultural	18.3766	73.7759	735	24	1308
Stream 1	Forest	18.4762	73.4877	723	24	3026
Paddy field 1	Agricultural	18.444	73.4289	780	23	3371
Stream 2	Forest	18.4442	73.4288	780	23	3371
Stream 3	Forest	18.4416	73.4116	408	25	3745
Stream 4	Forest	18.4606	73.414	379	25	3825



Images 2–7. Sampling sites in the study area showing different land use types.

2&3 - Paddy fields of Tamhini Village, Pune;
 4 - A view of the Mutha River, Pune;
 5 - A view of College of Military Engineering Lake;
 6&7 - A stream from Tamhini Ghat, Pune
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using a butterfly net and identified in the laboratory using taxonomic literature and field identification guides (Fraser 1933–1936; Subramanian 2009).

Habitat Assessment

Habitat quality was assessed during sampling. The following observations were made for each of the transect: availability of perching sites, presence of emergent aquatic vegetation, human disturbance such as domestic sewage, industrial effluent, solid waste, check dams, canalization, riparian deforestation, flow modification, agricultural runoff, and soil erosion. Based on these observations each site was ranked for a disturbance score ranging from 1–10, 1 being the lowest and 10 the highest.

Data Analysis

The input for the data analysis was a relative abundance matrix of family, genera and species across sites, land use types and seasons. Abundance data were log transformed to study relative abundance across seasons in different land use types. Diversity indices were calculated using the software PAST (Hammer et al. 2001).

RESULTS

Species Abundance

A total of 609 individuals belonging to 46 species in 26 genera and eight families was recorded during the study period (Table 2). The most dominant species was *Pantala flavescens* (Fabricius, 1798) which accounted for 23% of total number of individuals found during sampling. This dominance could be due to mass emergence of the species after monsoon and their yearly aggregation before migration. Individuals of this species congregate every year before migration to Eastern Africa (Anderson 2009). This was followed by *Brachythemis contaminata* (Fabricius, 1793) with 17% individuals found only in urban and agricultural landscapes except a single record from one of the streams in a forest area. *Brachythemis contaminata* is a dragonfly of polluted water, which was seen abundantly where sewage is discharged. Interestingly, this species was observed in one stream which is located near Mulshi Lake during one of the post-monsoon surveys. This stream near Mulshi Lake being a picnic spot attracts tourists during the monsoon and post-monsoon season resulting in pollution of streams with organic waste. The species was recorded only when the stream was polluted in post-monsoon.

The third most abundant species was *Trithemis festiva* (Rambur, 1842) with 11% of individuals that were recorded mostly from forested areas except a single record from one garden pond in an urban area. *Trithemis festiva* is known to breed in sluggish streams and usually perches on boulders and aquatic plants. This is a common species in the streams of northern Western Ghats.

Species such as *Diplacodes trivialis* (Rambur, 1842), *Orthetrum sabina* (Drury, 1770), *Trithemis aurora* (Burmeister, 1839), *Rhodischnura nursei* (Morton, 1907) were locally abundant in some of the study areas with less than 50 individuals in overall study area. Whereas species such as *Vestalis apicalis* (Rambur, 1842), *Ceragrion olivaceum* (Laidlaw, 1916), *Pseudagrion decorum* (Rambur, 1842) were recorded only once (Fig 2).

Species such as *Paragomphus lineatus* Selys, 1850, *Acisoma panorpoides* Rambur, 1842, *Gynacantha dravida* Lieftinck, 1960, *Gynacantha bayadera* Selys, 1854, *Tholymis tillagra* Fabricius, 1798, *Orthetrum chrysis* Selys, 1891, *Copera marginipes* Rambur, 1842 and *Neurothemis intermedia* Rambur, 1842 were recorded from the sampling area but they were not encountered during transect counts. This could be due to their relative rarity or crepuscular flight activity.

Species Diversity and Community Composition

Forest Landscapes: In forest streams a total of 21 species and 185 individuals were recorded. *Trithemis festiva* (Rambur, 1842) was the dominant species with 66 individuals followed by *Pantala flavescens* (Fabricius, 1798) and *Trithemis aurora* (Burmeister, 1839) with 33 and 16 individuals respectively. Species such as *Vestalis gracilis* (Rambur, 1842), *Disparoneura quadrimaculata* (Rambur, 1842) which usually occur in forested areas were also recorded. *Rhinocypha bisignata* (Selys 1853), *Vestalis apicalis* (Selys 1873), *Microgomphus torquatus* (Selys, 1854), *Neurothemis fulvia* (Drury, 1773) were recorded only once from a single stream. *Disparoneura quadrimaculata*, *Vestalis apicalis*, *Vestalis gracilis*, *Neurothemis fulvia* are known to breed in streams and their geographic restrictedness in the study area is due to the availability of suitable breeding habitat. *Vestalis gracilis*, *Vestalis apicalis* and *Rhinocypha bisignata* were observed from only two streams where canopy cover is greater than 50%. It was observed that the abundance of these species were very low when compared with other species found in forested streams and restricted to shaded areas of the stream. Another interesting observation was presence of *Microgomphus torquatus*

Table 2. Seasonal abundance of Odonata across land use types.

	Species	Season									Total
		Pre monsoon			Post monsoon			Winter			
		AG	FO	UR	AG	FO	UR	AG	FO	UR	
1	<i>Vestalis apicalis</i>	0	1	0	0	0	0	0	0	0	1
2	<i>Vestalis gracilis</i>	0	0	0	0	1	0	0	2	0	3
3	<i>Agriocnemis pygmaea</i>	0	0	0	0	0	0	5	0	4	9
4	<i>Ceriagrion coromandelianum</i>	0	0	0	1	0	3	0	0	2	6
5	<i>Ceriagrion olivaceum</i>	0	0	1	0	0	0	0	1	0	2
6	<i>Coenagrion dyeri</i>	0	0	0	0	0	0	2	0	0	2
7	<i>Ischnura aurora</i>	0	0	2	0	2	2	0	0	2	8
8	<i>Ischnura senegalensis</i>	0	0	0	0	0	6	0	0	8	14
9	<i>Pseudagrion decorum</i>	0	0	0	0	0	1	0	0	0	1
10	<i>Pseudagrion indicum</i>	0	0	0	0	1	0	0	0	0	1
11	<i>Pseudagrion microcephalum</i>	1	0	0	0	0	8	0	0	0	9
12	<i>Pseudagrion rubriceps</i>	0	0	0	0	0	5	0	0	16	21
13	<i>Rhodischnura nursei</i>	0	0	0	0	0	0	9	0	0	9
14	<i>Lestes elatus</i>	0	0	0	2	0	0	0	0	0	2
15	<i>Disparoneura quadrimaculata</i>	0	3	0	1	12	0	0	0	0	16
16	<i>Anax immaculifrons</i>	0	4	0	0	3	5	0	0	4	16
17	<i>Ictinogomphus rapax</i>	0	0	0	0	0	7	0	0	0	7
18	<i>Microgomphus torquatus</i>	0	1	0	0	0	1	0	0	0	2
19	<i>Brachydiplax sorbina</i>	1	0	0	0	0	1	0	0	0	2
20	<i>Brachythemis contaminata</i>	24	0	2	1	2	70	2	0	19	120
21	<i>Bradinopyga geminata</i>	0	0	3	0	0	0	0	2	0	5
22	<i>Crocothemis servilla</i>	0	0	1	2	0	3	0	2	0	8
23	<i>Diplacodes trivialis</i>	0	1	3	6	3	5	6	2	0	26
24	<i>Neurothemis fulvia</i>	0	0	0	0	2	0	0	0	0	2
25	<i>Orthetrum chrysostigma</i>	0	0	0	0	0	1	0	0	0	1
26	<i>Orthetrum glaucum</i>	0	0	0	0	0	1	0	2	0	3
27	<i>Orthetrum luzonicum</i>	0	0	0	0	0	0	3	0	0	3
28	<i>Orthetrum pruinosum</i>	0	0	0	0	2	4	1	7	2	16
29	<i>Orthetrum sabina</i>	0	0	1	2	0	20	0	0	10	33
30	<i>Orthetrum taeniolatum</i>	0	0	0	1	2	2	0	4	1	10
31	<i>Pantala flavescens</i>	0	1	0	49	31	55	4	2	0	142
32	<i>Potamarcha congener</i>	0	0	0	0	0	0	4	0	0	4
33	<i>Rhinocypha bisignata</i>	0	0	0	0	1	0	0	0	0	1
34	<i>Rhyothemis variegata</i>	0	0	1	0	0	14	0	0	0	15
35	<i>Sympetrum fonscolombi</i>	0	0	0	0	0	2	0	0	0	2
36	<i>Tramea basiliaris</i>	0	0	0	1	0	9	0	0	0	10
37	<i>Trithemis aurora</i>	0	1	4	0	5	13	0	10	3	36
38	<i>Trithemis festiva</i>	0	2	0	6	47	1	0	27	1	84
39	<i>Trithemis kirbyi</i>	0	0	0	0	1	0	0	2	0	3
40	<i>Trithemis pallidinervis</i>	2	0	0	0	0	4	0	0	0	6
	Grand Total	28	14	18	72	115	243	36	63	72	661

Legend: AG - Agriculture; FO - Forest; UR - Urban

(Selys, 1854). This species was originally described by Fraser from the Mula River in Pune in 1933. Currently this species was not encountered within the urban limits and now restricted to upper forested catchments of study area. This clearly indicates the change in habitat of the riverine ecosystem of the region.

Of the eight families which were recorded from the entire study area, species belonging to seven families were recorded from forest streams. The family richness was highest in forest streams; however they were represented by fewer species. This high family richness was observed only during post-monsoon season. Libellulidae was the most abundant family due to presence of common wide-spread species such as *Trithemis festiva*, *Orthetrum pruinatum* and *Orthetrum taeniolatum*. It was followed by Aeshnidae and Protoneuridae. The families Calopterygidae, Chlorocyphidae, Gomphidae were all represented by fewer than five individuals.

Agricultural Landscapes: In agricultural area, a total of 19 species and 137 individuals were recorded from four sites. Agricultural land was also dominated by *Pantala flavescens*, which accounted for 40% individuals followed by *Brachythemis contaminata* (20%) and *Diplacodes trivialis* (9%). The remainder of species found in agricultural landscapes were of low abundance with fewer than 10 individuals. The species *Potamarcha congener* (Rambur, 1842) and *Coenagrion dyeri* (Fraser, 1924) were recorded only from one paddy field. *Trithemis palidinervis* was recorded only during the pre-monsoon period. *Lestes elatus* was recorded during post-monsoon surveys from paddy fields of Sinhagad Valley and large congregation was seen during winter on the hill tops of Sinhagad Valley. *Rhodischnura nursei* was recorded during winter only from Bhigwan located in the eastern part of the study area. This species is confined to semi-arid zones of northwestern India (Fraser 1933) and usually seen during September to November. However, nine individuals of this species were recorded from Bhigwan in January. Another species which was recorded only from Bhigwan is *Coenagrion dyeri*. This species is widely distributed in peninsular India and known to breed in

stagnant and weedy ponds and is often seen perching flat on floating aquatic plants.

Urban Landscapes: A total of 287 individuals belonging to 32 species was recorded from urban areas. *Brachythemis contaminata* (Fabricius, 1793) was the dominant species with 25% of individuals followed by *Pantala flavescens* and *Orthetrum sabina* with 19% and 7% of individuals respectively. Species such as *Orthetrum glaucum* (Brauer, 1865) and *Pseudagrion decorum* (Rambur, 1842) were recorded only once. The species such as *Rhyothemis variegata* and *Pseudagrion rubriceps* were recorded only from the College of Military Engineering (CME) Lake and *Tramea basilaris* was observed from Katraj Hill and from one of the paddy fields from Tamhini Village. Across three land use types, there was a difference between the species composition and, in terms of species richness, urban habitats were the most diverse followed by forest and agricultural land. Simpson, Fisher's alpha and Margalef indices all show the same relationship (Table 3).

Seasonality

Species diversity and abundance varied across seasons with post-monsoon being highest in species diversity as well as abundance. Many species have their flight period during the post monsoon season and a high diversity of odonates during this season could be attributed to this. During the post-monsoon, 12 species from agricultural land, 16 species from forest streams and 28 species from urban habitats were recorded. The species *Pantala flavescens*, *Trithemis festiva* and *Brachythemis contaminata* dominated all land use types.

The pre-monsoon season had the lowest species diversity and abundance. During this season, a total of four, eight and nine species were recorded from agriculture, forest and urban areas, respectively. *Brachythemis contaminata*, *Anax immaculifrons* and *Trithemis aurora* dominated urban, forest and agriculture landscapes, respectively during this season.

During winter, nine, 12 and 13 species were recorded from agriculture, forest and urban areas, respectively. The species *Rhodischnura nursei*, *Trithemis festiva*,

Table 3. Diversity indices for different land use types

Landuse type	No of species	No of individuals	Simpson (1-D)	Fisher's alpha	Margalef
Agriculture	19	137	0.782	5.988	3.659
Forest	21	185	0.8179	6.095	3.831
Urban	32	287	0.8779	9.224	5.478

Brachythemis contaminata dominated agricultural, forest and urban landscapes, respectively during this season.

Species Turnover

Species turnover across land use types as measured by Jaccard's index shows that urban and agricultural areas have similar Odonata communities and they share about 38% of species. The odonate communities of forest streams were distinct and they shared only 25 and 32 percent of odonate species with agricultural and urban landscapes, respectively (Table 4). The distinctiveness of forest stream odonate communities was due to the presence of families such as Calopterygidae, Chlorocyphidae and Protoneuridae as represented by *Vestalis gracilis*, *V. apicalis*, *Rhinocypha bisignata* and *Disparoneura quadrimaculata*, respectively. There were 11 species which were observed from both urban and agricultural areas. Those species shared between agricultural and urban land use types are common widespread species breeding in a wide spectrum of wetland habitats. These landscapes are also undergoing similar human induced habitat modifications due to disturbance.

Disturbance scores of study localities and species diversity shows that there is no clear relationship between species diversity and disturbance (Table 5). Study sites with high disturbance scores such as the Mutha River also have high species diversity. Conversely, sites with low disturbance scores (e.g., Stream-4) reported low

Table 4. Jaccard's Index of similarity for land use types

	Agriculture	Forest	Urban
Agriculture	1	0.25	0.37838
Forest	0.25	1	0.325
Urban	0.37838	0.325	1

species diversity. High diversity in some of the degraded areas are due to presence of common widespread species with tolerance of disturbance and pollution. This shows that in this landscape over all, species diversity per se is not a good indicator for assessment of wetland ecosystem health. Presence/absence of habitat specialist species should be taken into consideration for monitoring wetland ecosystem health.

DISCUSSION

Fraser documented the fauna of Pune region while surveying the Odonata fauna of western India (Fraser 1924, 1932, 1933–36). Subsequently, Prasad (1996) also documented the odonate fauna of the region. These studies recorded 70 species of odonates from Pune (Appendix 2). Our current study and another in the region conducted over two years (Subramanian & Talmale 2010) recorded 46 species from transects and eight species outside transects. The remaining 22 species were not recorded even after repeated searching. Many

Table 5. Disturbance score matrix for study localities

Locality	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Average Disturbance Score
Mutha River	17	0	9	10	10	10	10	0	10	4	6	0	10	7	6.62
Bhigwan	8	0	8	8	10	10	10	0	0	5	4	10	10	6	6.23
Khadakwasla	13	0	9	7	6	4	6	10	7	6	10	4	5	7	6.23
Sinhagad valley	7	0	0	0	4	4	2	10	5	4	10	6	6	5	4.31
Empress Garden	12	3	5	0	4	0	1	7	10	2	9	0	2	1	3.38
CME	18	3	7	7	0	0	0	6	8	2	7	0	2	1	3.31
Stream 2	10	1	7	0	5	0	2	5	0	4	6	0	4	5	3.00
Katraj tekdi	9	0	2	0	7	0	1	7	0	4	0	0	2	4	2.08
Stream 1	7	1	5	4	3	0	3	0	0	4	0	0	2	1	1.77
Stream 3	14	6	9	0	0	0	0	0	0	6	0	0	0	1	1.69
Stream 4	6	9	9	0	0	0	0	0	0	0	0	0	0	1	1.46
Paddy field 1	9	0	1	0	0	0	0	0	0	0	0	5	1	1	0.62

Legend: (A) Species Richness (B) Shade Cover (C) Perching site availability (D) Emergent Aquatic Vegetation (E) Domestic Sewage (F) Industrial effluent (G) Solid waste (H) Check dams (I) Canalization (J) Riparian deforestation (K) Flow modification (L) Agricultural runoff (M) Water pollution (N) Soil Erosion

of these species such as *Anaciaeschna jaspidea*, *Anax guttatus*, *Epothemia vittata*, *Hemianax ephippiger* and *Macromia cingulata*, can still be found in nearby less disturbed areas such as Lonavala-Khandala, Karjat, Karad, etc. However, species such as *Burmagomphus pyramidalis*, *Cyclogomphus heterostylus*, *Cyclogomphus vesiculosus*, *Cyclogomphus ypsilon* and *Cyclogomphus wilkinsi*, have not been recorded from Pune for a long time. These species are also not represented in the National Zoological Collection, Western Regional Centre, Zoological Survey of India, Pune which has been collecting odonates from the region for the past 50 years. This indicates that these species have become locally extinct or have reached such low levels of population that they cannot be detected by our sampling protocols.

The loss of 31% of odonates from this region is alarming. Many species not recorded such as *Burmagomphus pyramidalis*, *Cyclogomphus heterostylus*, *Cyclogomphus ypsilon* and *Cyclogomphus wilkinsi*, breed in and are closely associated with unpolluted rivers and streams. In the last 50 years, the riverine ecosystems of the region have been drastically altered. Seventeen dams currently exist in this region supplying water for irrigation, housing, industry and power generation. This catastrophic landscape and riverine ecosystem alteration over the years almost certainly depauperated the odonate fauna. In agreement with our findings, remarkably similar results are also reported for the fish fauna of Mula and Mutha rivers, where 30% of fish fauna was reported to be lost in the past 60 years (Wagh & Ghate 2002). These results strongly indicate that landscape and riverine ecosystem level impacts could have affected other freshwater biodiversity elements, which need further investigation.

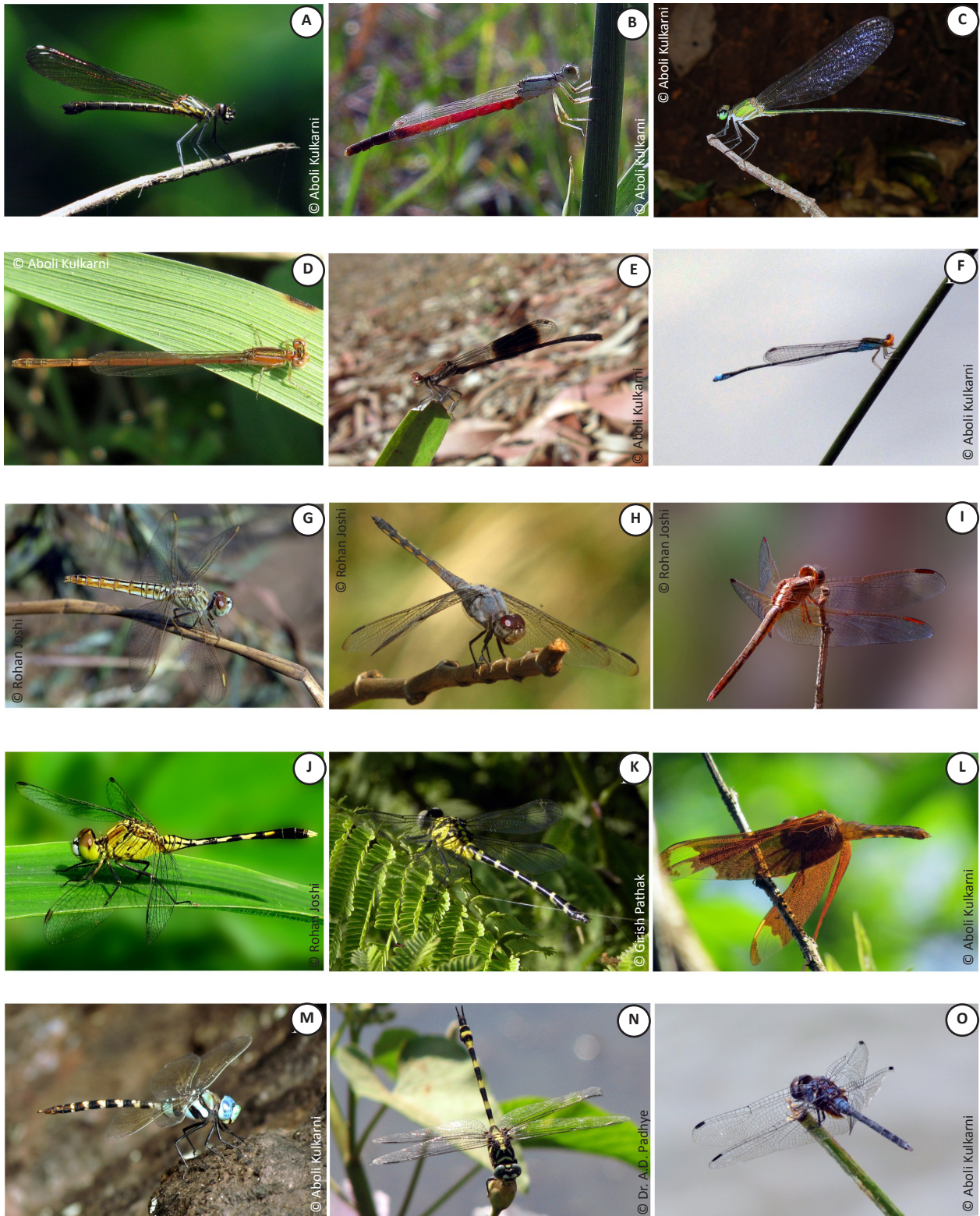
Our study shows that species turnover and abundance vary across seasons and land use types in the study region. It is evident from this study that there is strong habitat and land use association and seasonality in species richness which is responsible for shaping the odonate community of the region. Loss of regional odonate diversity could be attributed to major changes in freshwater ecosystems, habitat loss and degradation of quality of available habitats of the region. These changes could have also had an effect on other freshwater biodiversity elements and a cascading effect on terrestrial biodiversity. This link needs further study.

This result has important implications for developing long term biomonitoring tools using odonates as surrogates. Seasonal and landscape variations in species diversity needs to be taken into account while designing any landscape level biodiversity monitoring programmes.

Our study also emphasizes the importance of urban green spaces with wetlands in conserving regional Odonata fauna. High diversity and abundance in urban areas was mainly due to the CME campus where there is a network of man made lakes and natural or semi-natural vegetation with minimal disturbance. Such habitats are not only refugia for odonates but also for other flora and fauna. Hitherto about 25 species of trees, many species of herbs, aquatic plants, butterflies, and 112 species of birds including migrants have been recorded from CME campus. Moreover, the lakes of the CME are important wintering grounds for a large number of resident and migratory water birds. Such green patches in the highly industrialized and polluted landscape of the Pune region provide much needed refugia for the biodiversity. Similar refugia need to be identified in other urban centres in India and long term protection needs to be provided for conserving regional biodiversity.

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Appendix 1. Some of the damselflies and dragonflies photographed from the study sites.

A - *Rhinocypha bisignata*; B - *Rhodischnura nursei*; C - *Vestalis gracilis*; D - *Coenagrion dyeri*; E - *Disparoneura quadrimaculata*; F - *Pseudagrion rubriceps*; G - *Brachythemis contaminata*; H - *Potamarcha congener*; I - *Neurothemis intermedia*; J - *Diplacodes trivialis*; K - *Microgomphus torquatus*; L - *Neurothemis fulvia*; M - *Anax immaculifrons*; N - *Ictinogomphus rapax*; O - *Trithemis festiva*

Appendix 2. Checklist of Odonata of Pune

	Order	Family	Species	Remarks	Reference
1	Zygoptera	Calycopterigidae	<i>Vestalis apicalis</i> Selys, 1873	*	
2	Zygoptera	Calycopterigidae	<i>Vestalis gracilis</i> (Rambur, 1842)	*	
3	Zygoptera	Chlorocyphidae	<i>Libellago lineata</i> (Burmeister, 1839)	***	Prasad (1996)
4	Zygoptera	Chlorocyphidae	<i>Rhinocypha bisignata</i> Hagen in Selys, 1853	*	
5	Zygoptera	Coenagrionidae	<i>Aciagrion occidentale</i> Laidlaw, 1919	***	Prasad (1996)
6	Zygoptera	Coenagrionidae	<i>Aciagrion pallidum</i> Selys, 1891	***	Fraser (1933)
7	Zygoptera	Coenagrionidae	<i>Aciagrion hisopa</i> (Selys, 1876)	***	Fraser (1933)
8	Zygoptera	Coenagrionidae	<i>Agriocnemis femina</i> (Brauer, 1868)	***	Prasad (1996)
9	Zygoptera	Coenagrionidae	<i>Agriocnemis pygmaea</i> (Rambur, 1842)	*	
10	Zygoptera	Coenagrionidae	<i>Ceriagrion rubiae</i> Laidlaw, 1916	***	Fraser (1933)
11	Zygoptera	Coenagrionidae	<i>Ceriagrion coromandelianum</i> (Fabricius, 1798)	*	
12	Zygoptera	Coenagrionidae	<i>Ceriagrion olivaceum</i> Laidlaw, 1914	*	
13	Zygoptera	Coenagrionidae	<i>Coenagrion dyeri</i> (Fraser, 1924)	*	
14	Zygoptera	Coenagrionidae	<i>Ischnura aurora</i> (Brauer, 1865)	*	
15	Zygoptera	Coenagrionidae	<i>Ischnura senegalensis</i> (Rambur, 1842)	*	
16	Zygoptera	Coenagrionidae	<i>Pseudagrion decorum</i> (Rambur, 1842)	*	
17	Zygoptera	Coenagrionidae	<i>Pseudagrion indicum</i> Fraser, 1924	*	
18	Zygoptera	Coenagrionidae	<i>Pseudagrion microcephalum</i> (Rambur, 1842)	*	
19	Zygoptera	Coenagrionidae	<i>Pseudagrion rubriceps</i> Selys, 1876	*	
20	Zygoptera	Coenagrionidae	<i>Pseudagrion microcephalum</i> (Rambur, 1842)	*	
21	Zygoptera	Coenagrionidae	<i>Rhodischnura nursei</i> (Morton, 1907)	*	
22	Zygoptera	Lestidae	<i>Lestes elatus</i> Hagen in Selys, 1862	*	
23	Zygoptera	Platycnemididae	<i>Copera migrinipes</i> (Rambur, 1842)	**	
24	Zygoptera	Protoneuridae	<i>Disparoneura quadrimaculata</i> (Rambur, 1842)	*	
25	Anisoptera	Aeshnidae	<i>Anaciaeschna jaspidea</i> (Burmeister, 1839)	***	Fraser (1936)
26	Anisoptera	Aeshnidae	<i>Anax guttatus</i> (Burmeister, 1839)	***	Prasad (1996)
27	Anisoptera	Aeshnidae	<i>Anax immaculifrons</i> Rambur, 1842	*	
28	Anisoptera	Aeshnidae	<i>Gynacantha bayadera</i> Selys, 1854	**	
29	Anisoptera	Aeshnidae	<i>Gynacantha dravida</i> Lieftinck, 1960	**	
30	Anisoptera	Aeshnidae	<i>Hemianax ephippiger</i> (Burmeister, 1839)	***	Fraser (1936)
31	Anisoptera	Cordullidae	<i>Epopthalmia vittata</i> Burmeister, 1839	***	Fraser (1936)
32	Anisoptera	Gomphidae	<i>Burmagomphus pyramidalis</i> Laidlaw, 1922	***	Fraser (1934)
33	Anisoptera	Gomphidae	<i>Cyclogomphus heterostylus</i> Selys, 1854	***	Fraser (1934)
34	Anisoptera	Gomphidae	<i>Cyclogomphus vesiculosus</i> Selys, 1873	***	Fraser (1934)
35	Anisoptera	Gomphidae	<i>Cyclogomphus ypsilon</i> Selys, 1854	***	Fraser (1934)
36	Anisoptera	Gomphidae	<i>Cyclogomphus wilkinsi</i> Fraser, 1926	***	Prasad (1996)
37	Anisoptera	Gomphidae	<i>Gomphidia T-nigrum</i> Selys, 1854	***	Fraser (1934)
38	Anisoptera	Gomphidae	<i>Ictinogomphus rapax</i> (Rambur, 1842)	*	
39	Anisoptera	Gomphidae	<i>Macrogomphus annulatus</i> (Selys, 1854)	***	Fraser (1934); Prasad (1996)
40	Anisoptera	Gomphidae	<i>Microgomphus torquatus</i> (Selys, 1854)	*	
41	Anisoptera	Gomphidae	<i>Paragomphus lineatus</i> (Selys, 1850)	**	
42	Anisoptera	Libellulidae	<i>Acisoma panorpoides</i> Rambur, 1842	**	
43	Anisoptera	Libellulidae	<i>Brachydiplax sorbina</i> (Rambur, 1842)	*	
44	Anisoptera	Libellulidae	<i>Brachythemis contaminata</i> (Fabricius, 1793)	*	

	Order	Family	Species	Remarks	Reference
45	Anisoptera	Libellulidae	<i>Bradinopyga geminata</i> (Rambur, 1842)	*	
46	Anisoptera	Libellulidae	<i>Crocothemis servilia</i> (Drury, 1770)	*	
47	Anisoptera	Libellulidae	<i>Diplacodes trivialis</i> (Rambur, 1842)	*	
48	Anisoptera	Libellulidae	<i>Neurothemis fulvia</i> (Drury, 1773)	*	
49	Anisoptera	Libellulidae	<i>Neurothemis intermedia</i> (Rambur, 1842)	**	
50	Anisoptera	Libellulidae	<i>Orthetrum anceps</i> (Schneider, 1845)	***	Prasad (1996)
51	Anisoptera	Libellulidae	<i>Orthetrum chrysis</i> (Selys, 1891)	**	
52	Anisoptera	Libellulidae	<i>Orthetrum glaucum</i> (Brauer, 1865)	*	
53	Anisoptera	Libellulidae	<i>Orthetrum luzonicum</i> (Brauer, 1868)	*	
54	Anisoptera	Libellulidae	<i>Orthetrum pruinosum</i> (Burmeister, 1839)	*	
55	Anisoptera	Libellulidae	<i>Orthetrum sabina</i> (Drury, 1770)	*	
56	Anisoptera	Libellulidae	<i>Orthetrum taeniolatum</i> (Schneider, 1845)	*	
57	Anisoptera	Libellulidae	<i>Pantala flavescens</i> (Fabricius, 1798)	*	
58	Anisoptera	Libellulidae	<i>Potamarcha congener</i> (Rambur, 1842)	*	
59	Anisoptera	Libellulidae	<i>Rhyothemis variegata</i> (Linnaeus, 1763)	*	
60	Anisoptera	Libellulidae	<i>Sympetrum fonscolombi</i> (Selys, 1840)	*	
61	Anisoptera	Libellulidae	<i>Tholymis tillagra</i> (Fabricius, 1798)	**	
62	Anisoptera	Libellulidae	<i>Tramea basiliaris</i> (Palisot de Beauvois, 1805)	*	
63	Anisoptera	Libellulidae	<i>Trithemis aurora</i> (Burmeister, 1839)	*	
64	Anisoptera	Libellulidae	<i>Trithemis festiva</i> (Rambur, 1842)	*	
65	Anisoptera	Libellulidae	<i>Trithemis kirbyi</i> Selys, 1891	*	
66	Anisoptera	Libellulidae	<i>Trithemis pallidinervis</i> (Kirby, 1889)	*	
67	Anisoptera	Libellulidae	<i>Urothemis signata</i> (Rambur, 1842)	***	Fraser (1936)
68	Anisoptera	Libellulidae	<i>Zyxomma petiolatum</i> (Rambur, 1842)	***	Fraser (1936)
69	Anisoptera	Macromidae	<i>Macromia cingulata</i> Rambur, 1842	***	Fraser (1936)
70	Anisoptera	Macromidae	<i>Macromia flavicincta</i> Selys, 1874	***	Fraser (1936)

* - Observed in transects; ** - Observed outside transects; *** - Previous records

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