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Assessment of Odonate Diversity in Pandharkawada Forest Division of Maharashtra, India: Habitat Dynamics and Conservation Implications

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Odonate diversity, bioindicators, Pandharkawada Forest Division, wetlands, forest habitats, agricultural landscapes, urbanization, habitat degradation, conservation, biodiversity monitoring, ecological balance.

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ABSTRACT

This study investigates the diversity and distribution of Odonates across varied habitats in the Pandharkawada Forest Division, Maharashtra, India, focusing on wetlands, forest land, agricultural land, and urban areas. Odonates serve as bioindicators, making their diversity crucial for assessing ecosystem health. Wetlands in the division, though ecologically significant, are under threat from biotic pressures such as commercial fishing and domestic use, leading to habitat degradation. Saikheda Dam exhibited the highest Odonate diversity (H' = 1.37), followed closely by Muchi Dam (H' = 1.368) and Wai Dam (H' = 1.361). Forest habitats also supported a rich Odonate population, with Transect V (riverine area) showing the highest diversity (H' = 1.378). Agricultural lands adjacent to forest areas supported diverse populations, with wetland transects being the most diverse (H' = 1.384). However, urbanization and agricultural expansion threaten Odonate diversity through habitat loss, pollution, and pesticide use. The study highlights the critical role of wetlands and forested areas in sustaining Odonate diversity and emphasizes the need for conservation measures to mitigate the impacts of human activities. Continued monitoring and habitat restoration efforts are essential for preserving Odonate populations and maintaining the ecological balance in the region.

INTRODUCTION

Dragonflies and Damselflies, collectively known as Odonates, are prominent and visually captivating insects that inhabit diverse ecosystems, including wetlands, forests, agricultural landscapes, and urban environments (Nayak 2020). Their life cycle is closely tied to water bodies, with larvae dependent on aquatic habitats for development, making Odonates significant inhabitants of both standing and flowing water (Tiple et al. 2020). Due to their ecological specificity, Odonates are important bioindicators, reflecting changes in habitat quality, water conditions, and broader environmental factors (Supanekar et al. 2021; Bose 2019). Odonates contribute to ecosystem functions as both predators and prey. Their aquatic larvae play an essential role in controlling mosquito populations, thus helping to mitigate vector-borne diseases like malaria and dengue (Mitra 2009; Tiple et al. 2013). In turn, they serve as prey for fish and amphibians during their nymph stage, and adult Odonates are consumed by higher predators such as birds and bats (Sonawane 2014). The presence of high-quality wetlands supports diverse Odonate populations, underscoring the importance of conserving these habitats (Letsch et al. 2016).

The sensitivity of Odonates to habitat disturbances makes them excellent indicators of environmental health. Some species are well-adapted to human-modified landscapes, while others remain vulnerable to habitat degradation, particularly in forest ecosystems (Remsburg 2009; Subramanian et al. 2014). Agro-ecosystems, for instance, provide a habitat for Odonates that aid in pest control (Rathod et al. 2012), while deforestation has contributed to the global decline in Odonate diversity, with several species facing extinction (Choudhary et al. 2020). Despite these challenges, their relatively short life cycles make Odonates valuable for studying ecological dynamics and evolutionary biology.

Globally, over 6,300 species of Odonates have been identified, with 499 species documented in India (Schorr and Paulson 2020; Bedjanič et al. 2020). Though Fraser's pioneering work on Indian Odonata fauna in the 1930s provided an extensive foundation (Fraser 1933, 1934, 1936), subsequent research slowed until the Zoological Survey of India (ZSI) began documenting regional Odonata diversity. Maharashtra's Odonate fauna has been well-documented, with 134 species reported, but knowledge gaps remain in specific regions like Vidarbha, which harbors 85 species (Tiple et al. 2013, 2014; Talmale and Tiple 2013).

Pandharkawada Forest Division in Vidarbha is one such region lacking comprehensive studies on Odonate diversity. The present research undertaken from June 2021 to May 2022 aimed to assess Odonate diversity in this division, examining species composition and their correlation with different landscape features, including wetlands, forested areas, and agricultural landscapes. Our findings reveal that Odonate diversity is highest in wetland habitats, underscoring the importance of these ecosystems for conservation. The results highlight the potential impact of habitat alteration and emphasize the need for further biodiversity monitoring and habitat preservation in the region.

Material and Methods

Study area

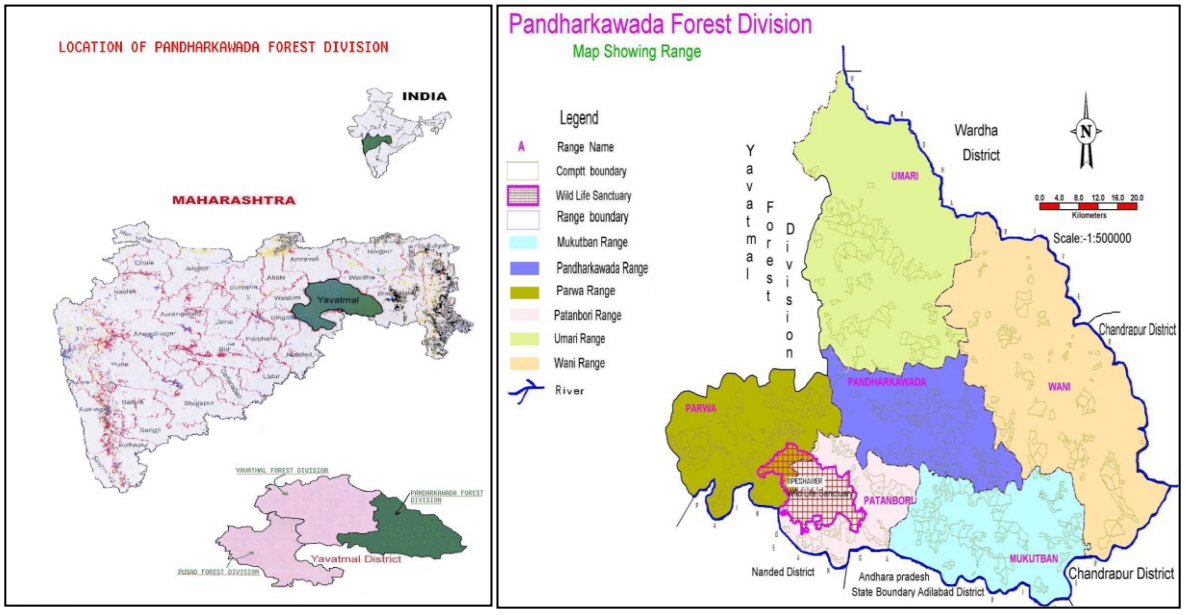
Pandharkawada forest division is located between 77˚31' to 78˚34' East longitude and 19˚52' to 20˚42'North latitude. Geographical area of Pandharkawada Forest Division is 422506 ha (422.506sq.km). The forest of the division belongs to Tropical dry deciduous Forest. *Teak* (*Tectona-grandis*) is the principal species. These forests are mostly situated in open areas and patches adjoining human habitations. The area of these forests division is mostly undulating and hilly. Pandharkawada forest division consists of a variety of floral and faunal diversity. It shows a wide variety of wild animals. The wild animals found in the area are *Blue bull, Samber, Spotted deer, Barking deer* etc. The average annual rainfall is 1011mm mostly from 2nd week of June and continues up to September. Temperature ranges from 8.2˚ c to 46 ˚c. The status of natural regeneration is very poor. These forests are affected with excessive biotic pressure of nearby villages. Study sites mainly divided under four land-use categories which form different habitats for Odonates, these includes forest, agricultural land, urban landscapes and natural as well as man-made wetland in Pandharkawada Forest Division.

Sampling Methods

Surveys were conducted in four different selected sites of the study area from June 2021 to May 2022 by using visual encounter method. The survey procedure involved spotting and taking a photograph of any Odonata species in its natural habitat, without collecting specimens. Each of these sites surveyed once in a week. During the survey photographic records of adult individuals of different Odonate species were maintained using a digital SLR camera Nikkon D850 with Nikkor 105 mm microlens. Adult Odonates specimens were identified with the help of identification keys provided by Fraser (1933, 1934, 1936), Mitra (2006), Subramanian (2005) and Andrew (2009).

Data Analysis

In order to compare the Diversity indices like Shannon Diversity , Simpsons Diversity (Pielou 1975) and Richness of Odonata across the different sites as well as different seasons were calculated by using the software PAST ((Palaeontological Statistics; Hammer 2012). Percentile Family level distribution was made by using Pie Chart.



Source: Pandharkawada Forest Division

Results

Species richness

A total of 55 species belonging to two suborders, 27 genera and six families were recorded from the study area. In which suborder Anisoptera (dragonflies) represented by 31 species with 17 genera and 3 families while suborder Zygoptera (damselflies) represented by 24 species with 10 genera and 3 families were recorded. Based on the frequency of occurrence 38.18 % of the species were common, 18.18 % were very common, 21.82 % were rare and 21.82 % were very rare. Libellulidae was the most dominant family with 49.09 % (27 species) of the total species count. Coenagrionidae showed next highest dominance with 30.90 % (17 species) of the species count followed by Platycnemididae with 7.28 % (4 species), Lestidae with 5.45 % (3 species), Gomphidae with 3.64 % (2 species), and Aeshnidae with 3.64 % (2 species).

Libellulidae was the best represented Anisopteran family with 27 species whereas Coenagrionidae was the most abundant Zygopteran family with 17 species. *Orthetrum* was recorded as most dominated genera with 6 species followed by *Pseudagrion*and *Ischnura* with 5 species each, *Diplacodes*with 4 species followed by *Agriocnemis,Trithemis,Lestes*with 3 species individually whereas *Anax*, *Ictinogomphus*, *Neurothemis, Ceriagrion, Copera and Tramea* contributed 2 species each individually and rest of the genera contributed only a single species. Maximum 36 species were recorded from Wetland habitat followed by Urban land (26), Agricultural land (24) and22 species were recorded from the Forest land. The occurrence of each species with respect to all sampling localities of Pandharkawada forest division has been summarized in (Table 1).

Population dynamics of Odonates

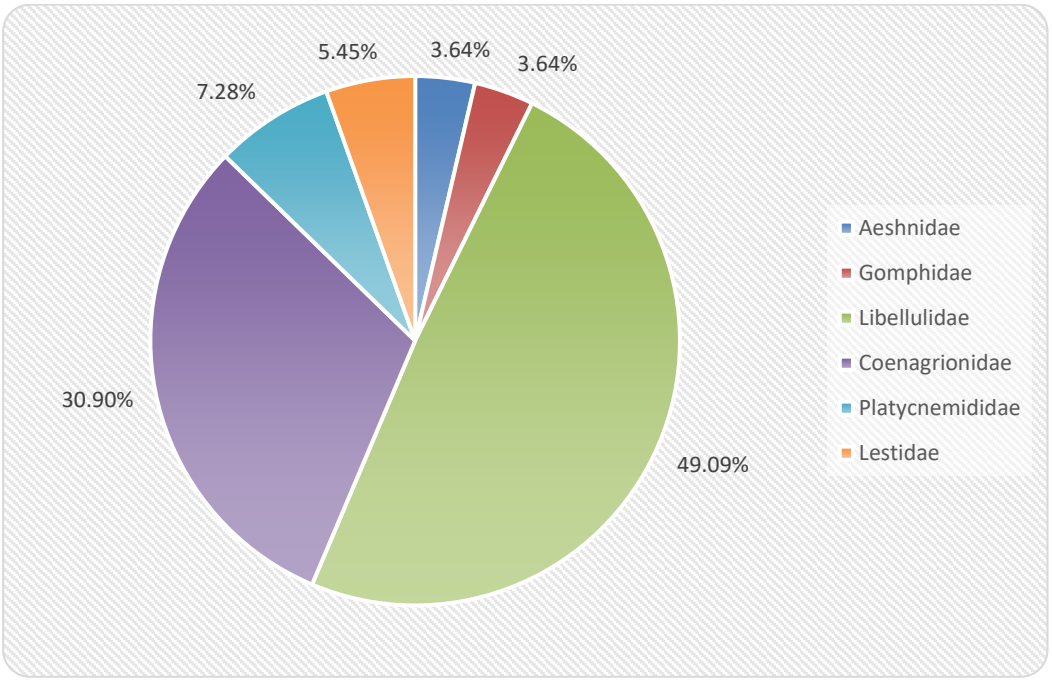
Population dynamics is a study of changes in species number and abundance of each species with reference to the time period. Visual encounter method was adopted for sampling the area. Population dynamics and diversity of Odonate was studied on four different habitats at Pandharkawada forest division. In the present investigation, all the Odonates belonging to the six families studied were at the maximum numbers during the post rainy season. Fluctuations in their number in most of the families largely observed in late winter and summer seasons only. The low population density was exhibited by most of the families during March to May which the environmental conditions prevailed was not favourable for them.

Table 1. Checklist of Odonates (damselflies and dragonflies) recorded from Pandharkawada Forest Division from June 2021 to May 2022.

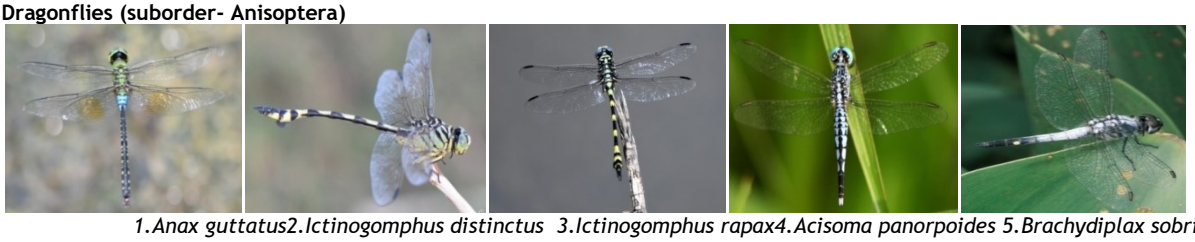
Sr. no.	Scientific Name	Common Name	Habitat	Occurrence	IUCN Status
(Suborder-Anisoptera)					
Family : Aeshnidae					
1	*Anax guttatus*	Blue-tailed Green Darner	WL,UL	R	LC
2	*Anax immaculifrons*	Blue Darner	WL,FL,AL	C	LC
Family : Gomphidae					
3	*Ictinogomphus distinctus*	_	UL	R	DD
4	*Ictinogomphus rapax*	Common Club Tail	WL,UL	VC	LC
Family: Libellulidae					
5	*Acisoma panorpoides*	Trumpet Tail	UL,FL	C	LC
6	*Brachydiplax sobrina*	Little Blue Marsh Hawk	WL,AL,	R	LC
7	*Brachythemis contaminate*	Ditch Jewel	WL,FL,AL,UL	VC	LC
8	*Bradinopyga geminate*	Granite Ghost	WL,FL,UL	VC	LC
9	*Crocothemis servilia*	Ruddy Marsh Skimmer	FL,AL	C	LC
10	*Diplacodes bipunctata*	Red Percher Dragonfly	WL,	C	LC
11	*Diplacodes haematodes*	Scarlet Percher	WL,AL	R	LC
12	*Diplacodes nebulosa*	Black-tipped Ground Skimmer	FL	R	LC
13	*Diplacodes trivialis*	Ground skimmer	WL,AL	VC	LC
14	*Lathrecista asiatica*	Asiatic Blood Tail	WL	VR	LC
15	*Neurothemis fulvia*	Fulvous Forest Skimmer	WL,	VR	LC
16	*Neurothemis tullia*	Pied Paddy Skimmer	WL,AL	VR	LC
17	*Orthetrum Chrysis*	Brown-backed Red Marsh Hawk	WL,UL	R	LC
18	*Orthetrum glaucum*	Blue Marsh Hawk	FL,UL	C	LC
19	*Orthetrum luzonicum*	Tricoloured Marsh Hawk	UL	VR	LC
20	*Orthetrum pruinosum*	Crimson- tailed Marsh Hawk	WL,UL	C	LC
21	*Orthetrum Sabina*	Green Marsh Hawk	WL,FL,AL	C	LC
22	*Orthetrum taeniolatum*	Small Skimmer	FL	R	LC
23	*Pantala flavescens*	Wandering Glider	WL,FL,AL,UL	VC	LC
24	*Potamarcha congener*	Yellow -tailed Ashy Skimmer	WL,	C	LC
25	*Rhyothemis variegate*	Common Picture Wing	WL,AL,UL	R	LC
26	*Tholymis tillarga*	Coral-tailed Cloud Wing	WL,AL	R	LC
27	*Tramea basilaris*	Red Marsh Trotter	FL	VR	LC
28	*Tramea limbata*	Black Marsh Trotter	AL	R	LC
29	*Trithemis aurora*	Crimson Marsh Skimmer	WL,UL	C	LC
30	*Trithemis festiva*	Black Stream Glider	WL,FL,	VC	LC
31	*Trithemis pallidinervis*	Long- legged Marsh Glider	WL,AL,UL	VC	LC
Suborder-Zygoptera					
Family: Coenagrionidae					
32	*Aciagrion pallidum*	Pale Slender Dartlet	WL,FL,UL	C	LC
33	*Agriocnemis lacteola*	Milky Dartlet	UL,AL	C	LC
34	*Agriocnemis femina*	White Blacked Wisp	WL,	C	LC
35	*Agriocnemis pygmaea*	Pigmy Dartlet	WL,FL,AL	VC	LC
36	*Ceriagrion coromandelianum*	Coromandel Marsh Dart	WL,AL,	C	LC
37	*Ceriagrion olivaceum*	Rusty Marsh Dart	FL,AL,UL	C	LC
38	*Enallagma parvum*	Azure Dartlet	WL,AL	VR	LC
39	*Ischnura aurora*	Golden Darlet	AL	C	LC
40	*Ischnura nursei*	Pixie Dartlet	FL,AL,UL	R	LC
41	*Ischnura rubilio*	Western Golden Dartlet	AL	C	LC
42	*Ischnura senegalensis*	Senegal Golden Dartlet	WL,UL	VC	LC
43	*Ischnura verticalis*	Eastern Fork Tail	FL,UL	VR	LC
44	*Pseudagrion hypermelas*	Violet- striped Blue Dart	WL,FL,AL	C	LC
45	*Pseudagrion decorum*	Three-striped Blue Dart	UL	C	LC
46	*Pseudagrion microcephalum*	Blue grass Dartlet	WL,	C	LC
47	*Pseudagrion rubriceps*	Saffron-faced Blue Dart	FL,AL	VC	LC
48	*Pseudagrion spencei*	Brook Sprite	WL,FL,AL,UL	VR	LC
Family: Platycnemididae					
49	*Copera marginipes*	Yellow Bush Dart	WL,AL	C	LC
50	*Copera vittata*	Blue Bush Dart	WL,FL	VR	LC
51	*Disparoneura qudrimacalata*	Black Winged Bamboo Tail	WL,UL	VR	LC
52	*Elattoneura nigerrima*	Thread Tail	UL	VR	DD
Family : Lestidae					
53	*Lestes concinnus*	Dusky Spread Wing	WL,	R	LC
54	*Lestes elatus*	Emerald Spread Wing	FL,AL	VR	LC
55	*Lestes umbrinus*	Brown Spread Wing	WL,	C	DD

Habitat:WL- Wetland, FL- Forest-land, AL- Agriculture -land, UL- Urban- land. **Occurrence:**C-Common, VC-Very Common, R-Rare, VR-Very Rare. **IUCN Status:**LC-Least concern, DD- Data deficient

Figure 2: Family wise distribution of odonates in the study area



Dragonflies (suborder- Anisoptera)



1.Anax guttatus2.Ictinogomphus distinctus 3.Ictinogomphus rapax4.Acisoma panorpoides 5.Brachydiplax sobrina

6.Brachythemis contaminata7.Bradinopyga geminata 8.Crocothemis servilia 9.Diplacodes trivialis 10.Neurothemis fulvia

11.Neurothemis tullia 12.Orthetrum chrysis13.Orthetrum pruinosum 14.Orthetrum Sabina 15.Orthetrum taeniolatum

16.Pantala flavescens 17.Potamarcha congener 18.Rhyothemis variegata19.Tholymis tillarga20.Tramea basilaris

21.Tramea limbata22.Trithemis aurora23.Trithemis festiva 24.Trithemis pallidinervis

Damselflies (suborder- Zygoptera)

1.Agriocnemis pygmaea 2. Ceriagrion coromandelianum3.Ceriagrion olivaceum

4. Enallagma parvum5.Ischnura nursei 6.Ischnura rubilio

7.Ischnura senegalensis 8.Pseudagrion hypermelas9.Pseudagrion decorum

10. Pseudagrion spencei11.Pseudagrion rubriceps 12.Pseudagrion microcephalum

13.Copera marginipes14.Copera vittata15.Disparoneura qudrimacalata

16. Elattoneura nigerrima17.Lestes concinnus 18. Lestes umbrinus

All the photographs are clicked in natural habitat from comfortable distance by author 1

Seasonal Variation of Odonates

Seasonal variation in climate depends on the resource of food and availability of water and changes in temperature. The average population density was high during the post-monsoon period. It was moderately high during the pre-monsoon and monsoon season. In general, the population densities were slightly lower during the summer season. Changes in the density of population at a place or time can usually be attributed to the direct or indirect influence of some of the environmental factors such as temperature, rainfall and humidity.

Landscape wise diversity of Odonates

Across the four land-use types, there was difference between the species composition. Wetlands being the most diverse followed by urban and agriculture. Population densities were lower in forest land. Urban and agriculture habitats are more similar types of Odonata communities. This can be due to a greater number of shared species and similar type of disturbance between urban and agricultural land-use. But as compared to urban habitats, agricultural land records a rather low Odonate diversity. This less diversity might be due to intensive use of pesticides, insecticides and fertilizers. The forest land again altogether forms a relative different community. It is due to the fact that these are the pristine areas with least anthropogenic disturbances.

Species Diversity and Abundance Pattern

A) Wetland

Wetlands present in this forest division are old and maintained mostly by irrigation department there is tremendous biotic pressure on these ecologically important habitat results in irreversible damage to breeding habitats. Wetlands habitat showed that contaminated study site has less diversity of odonates as compared to the non-polluted site. The Odonates from 3 different sites were compared and Shannon's indices were calculated as a measure of diversity within the habitat. The Shannon diversity index indicated that site I (Saikheda dam- 1.37) was relatively diverse followed by site III (Muchi dam - 1.368) and lastly the transect II (Wai dam- 1.361). The Simpson and Shannon J (evenness) indices also revealed almost the same order (Table 2).

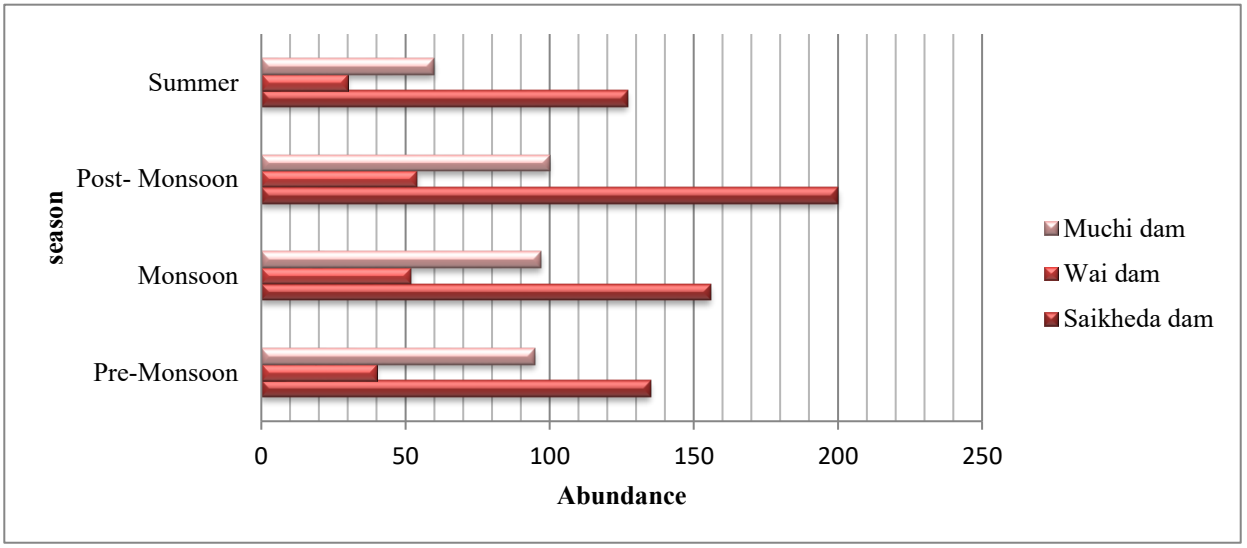
Table 2: Alpha diversity indices for different sites at Wetland habitat of Pandharkawada forest division.

Index	Site I	Site II	Site III
Shannon H'	1.37	1.361	1.368
Shannon Hmax	1.977	1.964	1.973
Shannon J	0.595	0.591	0.594
Simpsons Diversity (D)	1.6807	1.6920	1.6835
Simpsons Diversity (1/D)	0.2572	0.2579	0.2564
Hills No (HO)	1.37	1.361	1.368
Margalef R1	0.4668	0.5802	0.5116

Table 3: Distribution profiles of Odonata fauna at Wetland habitat of Pandharkawada Forest Division.

Species	Mean	Median	Range	Variation	Standard deviation
Anax guttatus	6	6	2	0.5	0.70710678
Anax immaculifrons	7.5	8	6	5.25	2.29128784
Ictinogomphus rapax	10	9.5	5	4.5	2.12132034
Brachydiplax sobrina	7.5	7.5	3	1.25	1.11803398
Brachythemis contaminate	28	31	20	63.5	7.96868872
Bradinopyga geminate	30	28	30	129	11.3578166
Diplacodes bipunctata	9.25	9	5	3.68	1.92028643
Diplacodes haematodes	3.75	3.5	4	2.18	1.47901994
Diplacodes trivialis	10.5	10.5	15	29.25	5.40832691
Lathrecista asiatica	5.75	4.5	6	6.19	2.48746859
Neurothemis fulvia	2	2	2	0.5	0.70710678
Neurothemis tullia	3	3	2	0.5	0.70710678
Orthetrum Chrysis	2.75	2.5	2	0.69	0.82915619
Orthetrum pruinosum	4.75	5.5	6	5.18	2.27760839
Orthetrum Sabina	7.25	7	7	3.68	1.92028643
Pantala flavescens	11.5	11	10	14.75	3.84057287
Potamarcha congener	5	5	4	2.5	1.58113883
Rhyothemis variegate	7	7	6	6.5	2.54950975
Tholymis tillarga	6.75	5.5	10	15.18	3.89711431
Trithemis aurora	4.5	4.5	3	1.25	1.11803398
Trithemis festiva	7.5	7	6	5.25	2.29128784
Trithemis pallidinervis	8	7.5	7	6.5	2.54950975
Aciagrion pallidum	8	8	4	2.5	1.58113883
Agriocnemis femina	5	4.5	5	3.5	1.87082869
Agriocnemis pygmaea	10.5	10	8	8.75	2.95803989
Ceriagrion coromandelianum	26.75	26.5	6	7.68	2.77263412
Enallagma parvum	2.5	2.5	3	1.25	1.11803398
Ischnura senegalensis	6.25	6.5	4	2.19	1.47901994
Pseudagrion hypermelas	9.25	9.5	4	2.19	1.47901994
Pseudagrion microcephalum	7.5	7	6	15.25	3.90512483
Pseudagrion spencei	5	5	6	5	2.23606797
Disparoneura qudrimacalata	2.5	2.5	3	1.25	1.11803398
Copera marginipes	5	5.5	5	4.5	2.12132034
Copera vittata	2.75	2.5	2	0.69	0.82915619
Lestes concinnus	4.5	4.5	3	1.25	1.11803398
Lestes umbrinus	2.25	2	1	0.19	0.43301270

Figure 3 : Species abundance plot for three different sites in Wetland habitat



B) Forest land

Forest land also provides a variety of habitats as well as favorable conditions for odonates. Adult odonates can use both sunshine and shade available in forests of this division, but removal of large areas of these natural forests to use the land for cultivation, construction of dams building houses, grazing and agriculture. One of most dangerous and unsettling effect of deforestation is the loss of odonate species due to their loss of habitat.The odonates from 5 different transects were compared and Shannon's indices were calculated as a measure of diversity within the habitat. The Shannon diversity index indicated that transect V was relatively diverse (Area containing the river and the surrounding herbs- 1.378) followed by transect III (Area predominant with teak trees- 1.377), transect I (The area with dung patches- 1.375), transect II (Dry area with shrubs- 1.354) and lastly the transect IV (The area containing stones and rocks- 1.336). The Simpson and Shannon J (evenness) indices also revealed almost the same order (Table 4).

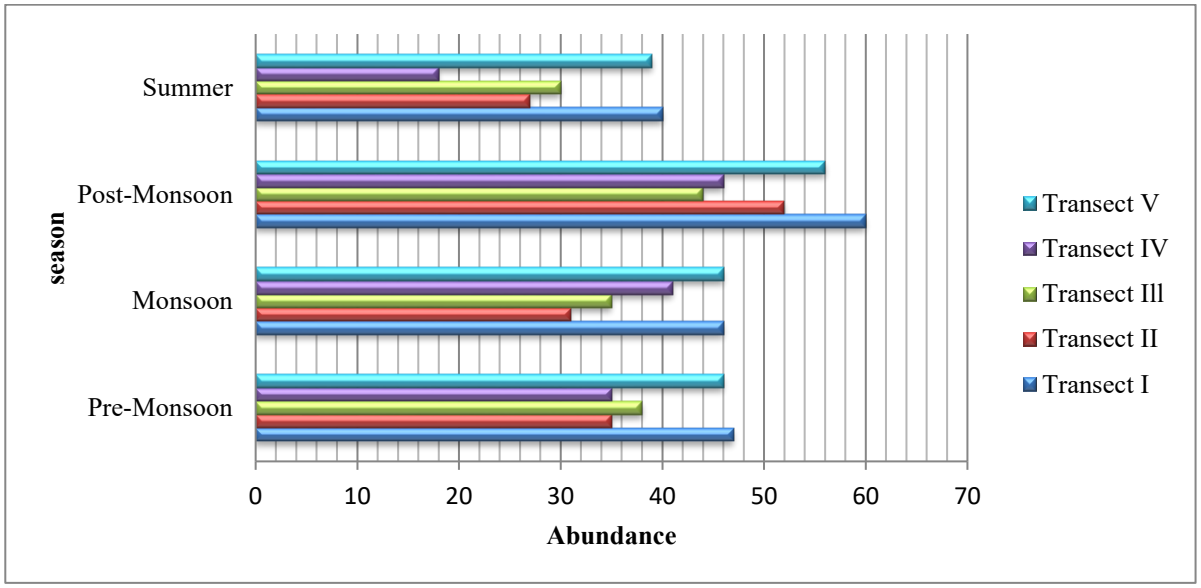
Table 4: Alpha diversity indices for different transects at Forest habitat of Pandharkawada Forest Division.

Index	Transect I	Transect II	Transect Ill	Transect IV	Transect V
Shannon H'	1.375	1.354	1.377	1.336	1.378
Shannon Hmax	1.984	1.953	1.986	1.927	1.988
Shannon J	0.5972	0.5879	0.5979	0.5801	0.5985
Simpsons Diversity (D)	0.2518	0.2622	0.2497	0.2675	0.2502
Simpsons Diversity (1/D)	3.971	3.813	4.004	3.738	3.999
Hills No (HO)	1.375	1.354	1.377	1.336	1.378
Margalef R1	0.5701	0.6028	0.6012	0,6071	0.5735

Table 5: Distribution profiles of Odonata fauna at Forest habitat of Pandharkawada forest division.

Species	Mean	Median	Range	Variation	Standard deviation
Anax immaculifrons	7.5	7	8	8.25	2.87228132
Acisoma panorpoides	10	10	10	17	4.12310562
Brachythemis contaminate	17.5	14.5	19	55.25	7.43303437
Bradinopyga geminate	9.5	8.5	7	7.25	2.69258240
Crocothemis servilia	6.5	6.5	5	3.25	1.80277563
Diplacodes nebulosa	13.75	14	7	6.69	2.58602010
Orthetrum glaucum	9.5	10	6	4.75	2.17944947
Orthetrum Sabina	7.5	7.5	3	1.25	1.11803398
Orthetrum taeniolatum	4.5	4.5	3	1.25	1.11803398
Pantala flavescens	18.75	18.5	8	9.19	3.03108891
Tramea basilaris	3.25	3.5	4	2.19	1.47901994
Trithemis festiva	20	19	22	66	8.12403840
Aciagrion pallidum	7.5	7	10	13.25	3.64005494
Agriocnemis pygmaea	10	10	4	2.5	1.58113883
Ceriagrion olivaceum	9.5	9	4	2.75	1.65831239
Ischnura nursei	7	7.5	7	6.5	2.54950975
Ischnura verticalis	8.75	8.5	6	5.69	2.38484800
Pseudagrion hypermelas	7.25	7.4	4	2.19	1.47901994
Pseudagrion rubriceps	12.5	12.5	7	9.25	3.04138126
Pseudagrion spencei	6.25	4	11	20.19	4.49305018
Copera vittate	2.25	2.5	2	0.69	0.82915619
Lestes elatus	3.75	3.5	4	2.19	1.47901994

Figure 4: Species abundance plot for five different transects in Forest habitat



C) Agricultural land

Agricultural fields adjoining this forest division are unique ecosystem that provides several services to odonates. So, different Odonates depend on these fields and their diversity also signs of good health of agro-ecosystem. But now a day agricultural landin this area are gradually decreasing due to the rapid growth of highways, housing and factories results in loss of odonate habitats. Odonata diversity also depends on the presence of chemicals and pesticides in the field. The odonates from 5 different transects from were compared and Shannon's indices were calculated as a measure of diversity within the habitat. The Shannon diversity index indicated that transect IV (Wetlands-1.384) was relatively diverse followed by transect V (Sugarcane crop- 1.381) (1.25), transect III (Soyabean crop- 1.376), transect II (Area with crops -1.359) and lastly the transect I (Area with stones and rocks -1.339). The Simpson and Shannon J (evenness) indices also revealed almost the same order (Table 6).

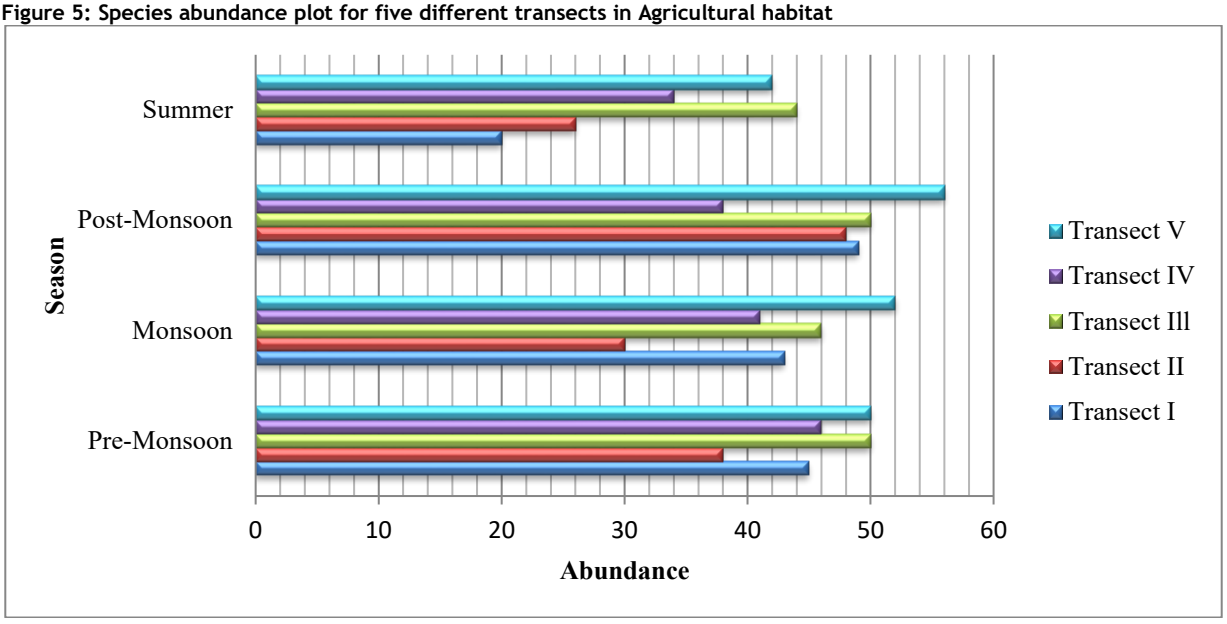
Table 6: Alpha diversity indices for different transects at Agricultural habitat of Pandharkawada forest division.

Index	Transect I	Transect II	Transect Ill	Transect IV	Transect V
Shannon H'	1.339	1.359	1.376	1.384	1.381
Shannon Hmax	1.931	1.961	1.985	1.997	1.992
Shannon J	0.5814	0.5901	0.5976	0.601	0.5998
Simpsons Diversity (D)	0.2661	0.2588	0.2516	0.2461	0.2488
Simpsons Diversity (1/D)	3.758	3.864	3.975	4.063	4.020
Hills No (HO)	1.339	1.359	1.376	1.384	1.381
Margalef R1	0.5933	0.6053	0.5646	0.5995	0.5662

Table 7: Distribution profiles of Odonata fauna at Agricultural habitat of Pandharkawada forest divison.

Species	Mean	Median	Range	Variation	Standard deviation
Anax immaculifrons	10	9.5	5	3.5	1.87082869
Brachydiplax sobrina	25.25	20.5	30	138.18	11.7553179
Brachythemis contaminate	12.41	14.5	15	22.54	4.74793288
Crocothemis servilia	9.5	9.5	11	18.25	4.27200187
Diplacodes haematodes	4.25	4	3	1.19	1.08972473
Diplacodes trivialis	12.75	12	7	7.19	2.68095132
Neurothemis tullia	2	2	2	0.5	0.70710678
Orthetrum Sabina	9.5	9.5	5	4.25	2.06155281
Pantala flavescens	11.75	10	9	13.19	3.63145976
Rhyothemis variegate	7.5	6	10	15.25	3.90512483
Tholymis tillarga	8.25	8.5	8	9.19	3.03108891
Tramea limbate	5.25	4.5	8	8.69	2.94745653
Trithemis pallidinervis	10.75	10	7	6.69	2.58602010
Agriocnemis pygmaea	6.25	5.5	8	8.69	2.94745653
Ceriagrion coromandelianum	5.75	6.5	8	9.69	3.11247489
Enallagma parvum	7	6.5	7	6.5	2.54950975
Ischnura aurora	8	7.5	13	22.5	4.74341649
Ischnura nursei	5.5	4	12	20.75	4.55521678
Ischnura rubilio	3.25	2.5	6	5.19	2.27760839
Pseudagrion spencei	9	8.5	9	10.5	3.24037034
Pseudagrion hypermelas	7.25	7	9	14.69	3.83242742
Pseudagrion rubriceps	5	3.5	11	17.5	4.18330013
Copera marginipes	19.5	21.5	15	33.25	5.76628129
Lestes elatus	4.5	3	8	10.25	3.20156211

Figure 5: Species abundance plot for five different transects in Agricultural habitat



D) Urban landscape

Changes in odonate diversity in Pandharkawada Forest Division are directly related to urbanization and pollutant concentrations in water. Results of present study suggest that increasing urbanization seems to affect odonate diversity negatively. The odonates from 3 different transects were compared and Shannon's indices were calculated as a measure of diversity within the habitat. The Shannon diversity index indicated that transect I was relatively diverse (Area containing the river- 1.379) followed by transect III (Shruby area near the Forest Rest House- 1.35), and lastly the transect II (Area containing garden- 1.328) The Simpson and Shannon J (evenness) indices also revealed almost the same order (Table 8).

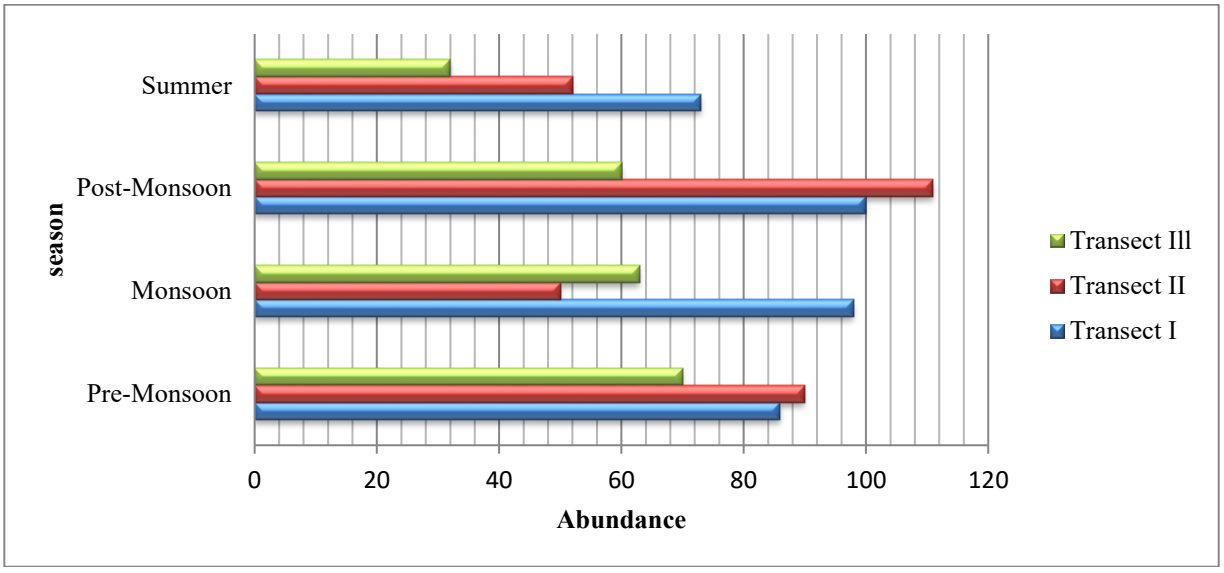
Table 8: Alpha diversity indices for different transects at Urban habitat of Pandharkawada forest division.

Index	Transect I	Transect II	Transect III
Shannon H'	1.379	1.328	1.35
Shannon Hmax	1.989	1.916	1.947
Shannon J	0.5988	0.5768	0.5861
Simpsons Diversity (D)	0.2516	0.2767	0.2633
Simpsons Diversity (1/D)	3.975	3.614	3.798
Hills No (HO)	1.379	1.328	1.35
Margalef R1	0.5104	0.5251	0.5539

Table 9: Distribution profiles of Odonata fauna at Urban habitat of Pandharkawada forest division.

Species	Mean	Median	Range	Variation	Standard deviation
Anax guttatus	5.5	4.5	5	4.25	2.06155281
Ictinogomphus distinctus	6.25	6	7	8.19	2.86138078
Ictinogomphus rapax	8.75	8	11	16.19	4.02336923
Acisoma panorpoides	8	8	2	0.5	0.70710678
Brachythemis contaminate	8.75	8.5	7	6.69	2.58602010
Bradinopyga geminate	5.75	5.5	6	4.69	2.16506350
Diplacodes nebulosa	5.25	6	5	4.19	2.04633819
Orthetrum Chrysis	5.75	5	7	7.19	2.68095132
Orthetrum glaucum	10	9	12	23.5	4.84767985
Orthetrum luzonicum	5.25	3	11	20.19	4.49305018
Orthetrum pruinosum	7.5	8	8	12.75	3.57071421
Pantala flavescens	24.75	23	11	18.69	4.32290411
Rhyothemis variegate	12.25	12.5	4	2.19	1.47901994
Trithemis aurora	5	4.5	7	6.5	2.54950975
Trithemis pallidinervis	25.25	24	31	193.69	13.9171656
Aciagrion pallidum	9.5	9.5	3	1.25	1.11803398
Agriocnemis lacteola	5.75	4	9	13.19	3.63145976
Ceriagrion coromandelianum	8.5	8.5	3	1.25	1.11803398
Ceriagrion olivaceum	7	5.5	9	12.5	3.53553390
Ischnura nursei	4	4	2	0.5	0.70710678
Ischnura senegalensis	18.75	16.5	20	61.19	7.82224392
Ischnura verticalis	7	7.5	5	3.5	1.87082869
Pseudagrion decorum	6	4.5	11	17.5	4.18330013
Pseudagrion spencei	4.75	5	5	5.19	2.27760839
Disparoneura qudrimacalata	3.25	3.5	2	0.69	0.82915619
Elattoneura nigerrima	3	3	2	0.5	0.70710678

Figure 6: Species abundance plot for three different transects in Urban habitat



DISCUSSION

The findings from the present study conducted from June 2021 to May 2022 demonstrate a significant impact of habitat type on odonate diversity in the Pandharkawada Forest Division. Wetlands, forest land, agricultural land, and urban land all contribute uniquely to odonate populations, but the pressures of human activity, such as commercial fishing, agriculture, deforestation, and urbanization, have resulted in habitat degradation and loss of species diversity. These results align with similar studies conducted in Central India, Kerala, and Assam, which also highlight the critical role of habitat quality in maintaining odonate populations (Andrew et al., 2009; Choudhury et al., 2020; Thakuria and Kalita, 2019).

Pandharkawada Forest Division has a unique diversity of flora and fauna. Presence of total of 55 odonates with 31 Anisoptera and 24 Zygoptera indicates that various biotopes of Pandharkawada forest division support good Odonate diversity. In similar kind of survey, Sharma et al. (2020) studied on the dragonfly and damselfly (Odonata) diversity in and around Vadodara, Gujarat to understand the habitat and seasonal distribution studied the Odonate diversity. According to the study, total of 38 Odonate species in 24 genera and six families were recorded. Libellulidae was the most dominant and diverse family of Odonata in this study (figure 2). Libellulidae is one of the largest and most diverse families in order Odonata with 7 genera 12 species (Chandran et al. 2021). According to Thakuria et al. (2019), there is little doubt that conditions like humidity, moisture, temperature etc. might affect insect distribution. On the basis of the present study, it is clear that the availability of Odonate species was not only dependent on seasonal fluctuation, but also on ecological and environmental conditions. In the present study, the average population density was high during the post monsoon period. It was moderately high during the pre-monsoon and monsoon season. In general, the population densities were slightly lower during the summer season. Changes in the density of population at a place or time can usually be attributed to the direct or indirect influence of some of the environmental factors such as temperature, rainfall and humidity. Water sources are also one of the important factors that influence the diversity of odonates (Chandran et al. (2021).

Wetlands in the Pandharkawada Forest Division are vital habitats for Odonates, providing breeding grounds and essential resources for survival. However, the biotic pressures from commercial fishing, domestic use lean period agriculture, open defecation around waterbodies have caused irreversible damage to these ecologically significant areas, affecting breeding habitats. A study by Bose (2019) on odonate diversity in Kerala's wetlands similarly highlighted the importance of wetland health in sustaining diversity. The comparison of Odonate diversity across the three wetland sites indicated that Saikheda Dam (H' = 1.37) was the most diverse, followed by Muchi Dam (H' = 1.368) and Wai Dam (H' = 1.361). The relatively high Shannon diversity index at Saikheda Dam reflects better environmental conditions, while contamination at other sites likely contributed to reduced diversity. Chandran et al. (2021) also documented the negative impact of pollution on odonate diversity in Kerala's wetlands. These results confirm that polluted wetlands have lower Odonate diversity, reinforcing the importance of preserving water quality to maintain biodiversity (Choudhury et al., 2020).

Forest land, with its varied microhabitats, also supports a rich diversity of Odonates. Studies by Mitra (2006) and Fraser (1933) emphasize that forested areas provide crucial microhabitats for various odonate species. The findings show that forested areas with a mix of sunlight and shade provide favourable conditions for adult Odonates. However, deforestation due to agricultural expansion, dam construction, and grazing has resulted in significant habitat loss, threatening Odonate species that depend on these ecosystems. The Shannon diversity index for forest habitats revealed that Transect V (riverine area with surrounding herbs, H' = 1.378) was the most diverse, followed by Transect III (teak-dominated area, H' = 1.377) and Transect I (dung patches, H' = 1.375). These findings align with those of Supanekar et al. (2008), who noted the importance of habitat heterogeneity in maintaining odonate diversity. Deforestation and forest land diversion poses a significant threat to these species by reducing available habitat and altering microclimatic conditions essential for their survival (Fraser, 1936).

Agricultural lands adjacent to the forest division form a unique ecosystem that supports diverse Odonate populations, indicating the health of the agroecosystem. Previous studies by Rathod et al. (2012) and Sharma and Kumar (2020) have also highlighted how agricultural ecosystems can support diverse Odonate populations, particularly in areas with minimal pesticide use. The diversity of Odonates in agricultural land depends heavily on the presence of chemicals and pesticides, which can have detrimental effects on these species. Among the agricultural transects, Transect IV (wetlands, H' = 1.384) was the most diverse, followed by Transect V (sugarcane fields, H' = 1.381), Transect III (soybean fields, H' = 1.376), Transect II (mixed crops, H' = 1.359), and Transect I (rocky areas, H' = 1.339). These results suggest that wetland areas within agricultural landscapes provide critical habitats for Odonates, while pesticide use and habitat loss due to urbanization remain significant threats to these populations (Mitra & Mitra, 2009).

Urbanization, driven by the need to accommodate a rapidly growing population, along with the resulting carbon footprints, has become a significant factor negatively impacting Odonate diversity in the Pandharkawada Forest Division. The rise in pollutant levels and the loss of natural vegetation due to urban expansion have contributed to the decline in Odonate diversity. Tiple et al. (2008) reported similar findings regarding the impact of urbanization on Odonate diversity in Nagpur, Central India. The study found that Transect I (riverine area, H' = 1.379) was the most

diverse, followed by Transect III (shrubby area near the Forest Rest House, H' = 1.35), and Transect II (garden area, H' = 1.328). The reduced diversity in urban areas highlights the adverse impact of pollution and habitat disturbance, with Odonates serving as bioindicators of environmental health (Andrew, 2013; Naik & Sayeswara, 2017).

CONCLUSION

The diversity of odonates in the Pandharkawada Forest Division is strongly influenced by habitat type and human activity. Wetlands and intact forest areas with minimal disturbance support a higher diversity of species, while habitats impacted by urbanization, agriculture, and deforestation show reduced diversity. The results of this study are consistent with previous research conducted in different parts of India and globally (Fraser, 1933; Fraser, 1934b; Fraser, 1936c), confirming that habitat quality is a critical determinant of odonate diversity.The results suggest that Odonates are highly sensitive to habitat quality, making them reliable indicators of ecosystem health (Remsburg & Turner, 2009; Letsch et al., 2016). Effective conservation strategies are essential to mitigate the negative impacts of habitat degradation and ensure the protection of odonate species. Preservation & scientific management of wetlands, sustainable agricultural practices, and restoration of forested areas will be key to maintaining healthy odonate populations. Future research should focus on the long-term effects of land use changes and climate factors on odonate diversity, as highlighted by Letsch et al. (2016) and Subramanian (2014). Continued monitoring of Odonate diversity across different habitats will provide valuable insights into the health of ecosystems and inform future conservation strategies in the region.

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