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Research Article

Population dynamics and diversity of Odonata (insecta) at Mini and Mahi rivers of Gujarat, India

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ABSTRACT: Population dynamics, diversity and community structure of Odonata were studied on three adjacent riparian microecosystems in Vadodara district, Gujarat, India. Population dynamics was studied by observing their population by point count method on three microhabitats (Mini River at Sankarda, Sindhrot and Mahi River at Fazalpur). In the course of a twenty-eight-week study, a total of 4783 Odonata were encountered on three microecosystems. Odonata density 9% throughout September 2014 (39th Meteorological Week) and gained its peak during October 2014 (44th Meteorological Week). A definite drop in the density was observed during November 2014 (48th Meteorological Week) and it achieved precisely 1% throughout December 2014 (51st Meteorological Week). Amongst the three microecosystems, at Fazalpur, species richness began rising from the 4th week of September (6%) and made it to its highest (11%) throughout the 4th week of October. At Sankarda, maximum absolute richness (12.61%) was recorded in 3rd week of October. At Sindhrot, the relative abundance of odonates started increasing in 3rd week of September (7%) and achieved its highest (13%) during 4th week of October. A total of twenty-five species were encountered in the terrain. The diversity index was maximum for Sankarda (2.35) followed by Fazalpur (2.27) and Sindhrot (2.01). A total of four species (Ditch Jewel (26.6%), Pigmy Dartlet (19.5%), Green Marsh Hawk (10.3%) and Senegal Golden Dartlet (8.3%) were dominant in all three microhabitats.

KEYWORDS: Damselfly, diversity, dragonfly, Gujarat, Mahi river, Mini river, population dynamics

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INTRODUCTION

The insect order Odonata comprises a few of the extremely primitive and delightful insects that forever wandered on the planet. It also comprises some of the most immense winged invertebrates ever to have existed. They are the superior invertebrate predators in any ecosystem. As predators both at immature and mature stages, they play a remarkable role in the food chain of forest ecosystems (Vashishth *et al.,* 2002).

Odonata is predatory, incomplete and amphibiotic invertebrates, which reside in all types of freshwater ecosystems both perpetual and impermanent. It comprises dragonflies (Anisoptera) and damselflies (Zygoptera), which undergo entirely diverse lifestyles in the larval and adult stages where immature stages are aquatic and adults are terrestrial (Silsby, 2001). Dragonflies have been proposed as biological indicators to assess the ecosystem health of freshwater wetlands (Suhling *et al*., 2006). Hence, odonates serve as an umbrella species in biodiversity conservation (Lambeck, 1997; Noss, 1990) and represent specific biotic wetland assemblages.

Information about the Odonata of Gujarat state is recognized by Prasad (2004), Rohmare *et al.* (2015), Rathod *et al.* (2016a; 2016b), Rathod and Parasharya (2018), Rathod *et al.* (2021), Rathod and Parasharya (2014, 2015). Recently, Dholu *et al.* (2023) published about Odonata diversity by wetland quality in Central Gujarat. There is little information available on the population dynamics of odonates in Gujarat (Rohmare *et al.,* 2016). Hence, the present study was carried out to examine population dynamics and Odonate diversity in Central Gujarat.

MATERIALS AND METHODS

General inventory of Odonata

Sampling

Odonata were collected from all the wetland sites. Photos of the odonates were taken in the field as well as in the laboratory after collection. Photos help in the identification. Those species which are difficult to identify in the field were brought into the laboratory and studied under a microscope. Deceased samples were conserved dry or wet in 70% alcohol as per requirement.

Identification

Identification of the preserved samples and their photos were done with the help of the taxonomic key given by Fraser (1933, 1934, 1936), Subramanian (2009), Nair (2011) and Kiran and Raju (2013). Confirmation of the identified species was done by a taxonomist Dr. S. S. Talmale of the Zoological Survey of India (Jabalpur, Madhya Pradesh).

Population dynamics and diversity of Odonata

Population dynamics is a study of variations in species number and changes in their figure concerning period. To examine the variations happening in their population size and diversity period, the point count method was used for sampling the area. The study was carried out on three wetland sites Fazalpur, Sankarda and Sindhrot (Figures 1 and 2) by using the subsequent census method from July to December 2014.

1. A weekly point count was completed at the fringe of Mini River at two locations during the monsoon and post-monsoon period (July to December 2014) subsequent procedure of Smallshire and Beynon (2010).
2. Odonate counts at 15 points were taken at both sites on 500 m River length.
3. Dragonfly and damselfly recorded surrounded by a 3m radius of visible grassland were counted species-wise at a fixed point.
4. Species occurring in two habitats but not recorded within a 3m radius of point count were recorded separately using 7X binoculars.
5. Odonate counts were carried out from 9:00 to 12:00 hours in the dawn (As in the morning Odonata are more active)
6. Odonata encountered in three meters area were identified with the help of identification keys provided by Fraser (1933,1934,1936), Mitra (2006), Subramanian (2009), Andrew *et al.* (2009) and Nair (2011).
7. Index of population dynamics is a variation proceeding in the figure of Odonata observed in point count. Relative abundance (%) of the species and rate of encounter or frequency of occurrence (%O and % fi) were figured out to find out species dominance and Important Value Index (Tiple *et al*., 2012; Obrtel & Holisova, 1974).
8. The species diversity Index using the Shannon-Weinner formula was figured out for every time phase (Shannon, 1948).
9. A comparison of diversity indices and community structure at two sites of the river was made.

Figure 1. Study sites (**A**). Sankarda (**B**). Sindhrot (**C**). Fazalpur.

RESULTS

Population dynamics

The population dynamics and diversity of odonates were studied on three adjacent riparian micro-ecosystems in the Vadodara district. This survey was conducted from July 2014 to January 2015 when the surroundings were damp and the Odonata population were at its peak. During the pre-monsoon period, water was present in all three sites and hence some

Figure 2. Satellite view of study site.

odonate populations thrived. Output of the studies conducted on three wetland sites Fazalpur, Sankarda and Sindhrot are presented below (Tables 1 and 2).

Population dynamics and diversity on wetland

Fazalpur

Even before the onset of the monsoon in starting of July, the Mahi River contained some stagnant water and an odonate population (4%). The first observation was taken on 9th July when the South-west monsoon had not set in. The first rain (41mm) was received on 13th July. During the initial eleven observations (monsoon period), Odonata richness varied from 1 to 4 % only but the population began to rise from the 4th week of September (R.A.6%), i.e., post-monsoon period. Relative abundance made it to its top (11%) in the 4th week of October. It required sixteen extended weeks to attain the maximum population by the end of October (44th meteorological week) but it gradually declined to 1% within the next eight weeks. The population of Odonatan stayed down by 1% in the 4th week of December 2014 (52nd Meteorological Week) and after that, Odonata was not observed in January 2015 from the Mahi River (Table 1).

Sankarda

The population of Odonata was down in the first ten observations (28th to 37th meteorological week) but from the 11th observation (3rd week of September) it began to rise, in the 3rd week of October (42nd meteorological week) maximum relative abundance (12.61%) was observed. Relative abundance turns into below 1% by the 4th week of December, (Table 1). Differing from another two microecosystems, one Odonata was observed in point count at least and some others were observed in the air at a distance, which were outside of the point count area.

Sindhrot

From 3rd week of July to 2nd week of August Odonata's Relative abundance was low but in the first two weeks of records, it was mostly related to another two microhabitats. The relative abundance of odonates started increasing in 3rd week of September (7%) and attained its highest (13%) during 4th week of October. The breakdown in population size was critical after 2nd week of December. The relative abundance of odonates was negligible as the river was highly polluted in December. Afterwards, the odonates population stayed at zero during the study period (Table 1).

Composite picture of population fluctuation of odonates of three microhabitats

A total of 4783 Odonata were observed on three microhabitats in a 28-week study. During summer, the Sindhrot site was highly polluted. However; relatively clean water was available in the Mahi River and Sankarda sites. All the sites were flooded with new rainwater in mid-July. Hence, the Odonata observed in 1st observation (9th July 2014) can be counted as a preliminary fully grown abundance. In 12-week the Odonata population gradually increased and attained about 9% (30th September 2014). It attained its highest in the 16th week (31st October 2014). A sudden drop in the population was observed from 21st November (19th week) and it attained just 1% by 19th December 2014. This sudden drop in the population was endorsed to decrease in the swamped place in all three microecosystems. The Odonata population stayed down 1% in the last two weeks of December 2014 and

Table 1. Population dynamics of odonates at weekly intervals (expressed as relative abundance (%)) at Fazalpur, Sankarda and Sindhrot

Microhabitats										
S. No.	Met. Week	Date of Observation	Fazalpur		Sankarda		Sindhrot		Total	
			No.	%	No.	%	No.	%	No.	%
1	28	09/07/2014	35	1.65	20	1.12	28	3.21	83	1.74
2	29	16/07/2014	33	1.55	24	1.34	37	4.24	94	1.97
3	30	22/07/2014	32	1.51	17	0.95	17	1.95	66	1.38
4	31	31/07/2014	34	1.60	3	0.17	0	0.00	37	0.77
5	32	06/08/2014	41	1.93	0	0.00	2	0.23	43	0.90
6	33	13/08/2014	46	2.16	6	0.34	4	0.46	56	1.17
7	34	22/08/2014	58	2.73	22	1.23	43	4.93	123	2.57
8	35	27/08/2014	69	3.25	14	0.78	10	1.15	93	1.94
9	36	05/09/2014	42	1.98	7	0.39	14	1.61	63	1.32
10	37	17/09/2014	38	1.79	11	0.62	15	1.72	64	1.34
11	38	24/09/2014	87	4.09	43	2.41	67	7.68	197	4.12
12	39	30/09/2014	142	6.68	188	10.53	95	10.89	425	8.89
13	40	05/10/2014	158	7.43	82	4.59	62	7.11	302	6.31
14	41	10/10/2014	158	7.43	82	4.59	62	7.11	302	6.31
15	42	21/10/2014	185	8.70	225	12.61	112	12.84	522	10.91
16	44	31/10/2014	234	11.01	221	12.38	119	13.65	574	12.00
17	45	06/11/2014	145	6.82	174	9.75	45	5.16	364	7.61
18	46	14/11/2014	196	9.22	213	11.93	49	5.62	458	9.58
19	47	21/11/2014	138	6.49	139	7.79	20	2.29	297	6.21
20	48	28/11/2014	66	3.10	103	5.77	28	3.21	197	4.12
21	49	05/12/2014	74	3.48	81	4.54	29	3.33	184	3.85
22	50	12/12/2014	63	2.96	66	3.70	14	1.61	143	2.99
23	51	19/12/2014	34	1.60	33	1.85	0	0.00	67	1.40
24	52	24/12/2014	18	0.85	11	0.62	0	0.00	29	0.61
25	1	01/01/2015	0	0.00	0	0.00	0	0.00	0	0.00
26	2	08/01/2015	0	0.00	0	0.00	0	0.00	0	0.00
27	3	15/01/2015	0	0.00	0	0.00	0	0.00	0	0.00
28	4	24/01/2015	0	0.00	0	0.00	0	0.00	0	0.00
29	**Total**		2126		1785		872		4783	
30	**Mean ± SD**		3.57±3.12		3.57±4.26		3.57±3.96		3.57±3.54	

was zero during January 2015. Odonata once again displayed a gradual rise in their population from February to April 2015 (Appendix), however, it is not considered for analysis here.

A slight decline in relative abundance in some weeks (Table 1) during active monsoon (30 to 41 meteorological week) was largely due to heavy rains leading to flooding of the area during preceding periods of observations.

A comparison of population fluctuation at three sites showed a similar with minor variations in relative abundance. At Fazalpur and Sindhrot, the population reached its peak during October 2014 whereas at Sankarda, the peak was reached in November (Table 2). It shows the relative abundance of total odonate observed at three sites during the study period. It clearly shows a gradual increase in the population size during monsoon and post-monsoon periods with a peak attained during October. Its population quickly declined during November and December.

Density of odonates at study sites

Amongst the three sites, odonate density was always higher at Fazalpur (which was least polluted) compared to Sankarda and Sindhrot which received industrial pollutants to some extent (Table 3). Changes in the density are indicative of changes in population size.

Table 2. Population fluctuations of odonates at monthly intervals expressed as Relative abundance (%) at Fazalpur, Sankarda and Sindhrot

S. No.	Months	Fazalpur		Sankarda		Sindhrot		Total	
		No.	R. A. %	No.	R. A. %	No.	R. A. %	No.	R. A. %
1	July	134	6.30	64	3.59	82	9.40	280	5.85
2	Aug	214	10.07	42	2.35	59	6.77	315	6.59
3	Sep	309	14.53	249	13.95	191	21.90	749	15.66
4	Oct	735	34.57	610	34.17	355	40.71	1700	35.54
5	Nov	545	25.63	629	35.24	142	16.28	1316	27.51
6	Dec	189	8.89	191	10.70	43	4.93	423	8.84
7	Jan	0	0.00	0	0.00	0	0.00	0	0.00
8	Total	2126		1785		872		4783	
9	**Mean±SD**	14.28±11.94		14.29±14.77		14.28±13.74		14.28±12.86	

Table 3. The density of odonates at the monthly interval at study sites from July 2014 to January 2015

Months	Fazalpur		Sankarda		Sindhrot	
	No.	Density/obs.	No.	Density/obs.	No.	Density/obs.
July	134	2.23	64	1.07	82	1.37
Aug	214	3.57	42	0.70	59	0.98
Sep	309	5.15	249	4.15	191	3.18
Oct	735	12.25	610	10.17	355	5.92
Nov	545	9.08	629	10.48	142	2.37
Dec	189	3.15	191	3.18	43	0.72
Jan	0	0.00	0	0.00	0	0.00

***** One observation in an area of 3 m radius equivalent to 28.26 m^2

Table 4. Correlation between mean weekly ambient meteorological parameters and total adult odonate number from July 2014 to January 2015 (n=28)

Meteorological Parameters	Fazalpur	Sankarda		Sindhrot	
	Anisoptera	Anisoptera	Zygoptera	Anisoptera	Zygoptera
MAX T (C°)	0.740**	0.584**	0.406*	0.699**	0.665**
MIN T (C°)	0.374*	0.158	-0.134	0.342	0.215
RH 1 (%)	-0.457*	-0.459*	-0.534**	-0.437*	-0.516**
Rainfall (mm)	-0.156	-0.230	-0.342	-0.096	-0.252
*Level of Significance at 5%= ± 0.374		** Level of Significance at 1%= ± 0.479			

Correlation between mean weekly ambient meteorological parameters and total adult odonates

Amongst the three ambient meteorological parameters tested, only maximum temperature showed a significantly higher moderate positive correlation ($p<1.0$, df. 26). It was the mean maximum temperature which showed the highest value r° (Table 4). The minimum temperature did not show any linear association. RH1 showed a significantly higher moderate negative correlation ($p<1.0$, df. 26) and rainfall either did not show a linear association or showed a weak negative correlation.

Amongst the two suborders, Anisoptera and Zygoptera showed significantly higher moderate positive correlation with maximum temperature ($p<1.0$, df. 26) except Zygoptera showed significant weak positive correlation at Sankarda ($p<5.0$, df. 26). Anisoptera showed significant weak positive correlation with minimum temperature at Fazalpur ($p<5.0$, df. 26). Anisoptera showed significant weak negative correlation ($p<5.0$, df. 26) and Zygoptera showed significantly higher moderate negative correlation with RH1 ($p<1.0$, df. 26) whereas Anisoptera did not show linear association and Zygoptera showed significant weak negative correlation with rainfall at Fazalpur ($p<5.0$, df. 26) (Table 5).

Table 5. Correlation between mean weekly ambient meteorological parameters and adult Anisoptera and Zygoptera numbers from July 2014 to January 2015 (n=28)

Meteorological Parameters	Fazalpur		Sankarda		Sindhrot	
	Anisoptera	Zygoptera	Anisoptera	Zygoptera	Anisoptera	Zygoptera
MAX T (C°)	0.740**	0.574**	0.584**	0.406*	0.699**	0.665**
MIN T (C°)	0.374*	0.002	0.158	-0.134	0.342	0.215
RH 1 (%)	-0.457*	-0.586**	-0.459*	-0.534**	-0.437*	-0.516**
Rainfall (mm)	-0.156	-0.376*	-0.230	-0.342	-0.096	-0.252
*Level of Significance at 5%= ± 0.374			** Level of Significance at 1%= ± 0.479			

Predominant species during different months

All four species were dominant during different months of the study period. All the species showed a bimodal pattern of population peaks.

Ditch Jewel was the most dominant species from July to October with its peak population size during August. Senegal Golden Dartlet was the second dominant species during July, August and December. Green Marsh Hawk was in the highest number from October to December though its dominant rank was third. Pigmy Dartlet was the most dominant species during November and December (Figure 3).

Population fluctuation of dominant species

The dominance of four species within the population varied during the study period, *i.e.*, from July to January (Figure 4). All four species showed a similar trend of fluctuations. The initial population of July remained stable during August showed a slight increase in September and reached to peak in October/November. At least amongst these dominant species, Anisoptera reduced to its peak population during October and Zygoptera reached its peak in November. Both the suborders showed a decline during December with the drying of the wet area and decreasing temperature. In January 2015 their population was so much reduced that it could not be detected with the counting technique used.

Relative abundance (%) of two suborders of Odonata at monthly interval

The suborders Anisoptera (dragonfly) showed a population peak during October (38.18) and Zygoptera (damselfly) showed a population peak during November (35.24) (Table 6). The overall population peaked during October (35.54). The numerical proportion of the two suborders also showed a similar trend of changes during the study period (Table 7). Both dragonflies and damselfly indicated the same trend of population variabilities as they are season-specific and have similar breeding necessities in wetlands.

13 species of Anisoptera and 10 species of Zygoptera respectively showed the highest number of species during October which were (Table 8).

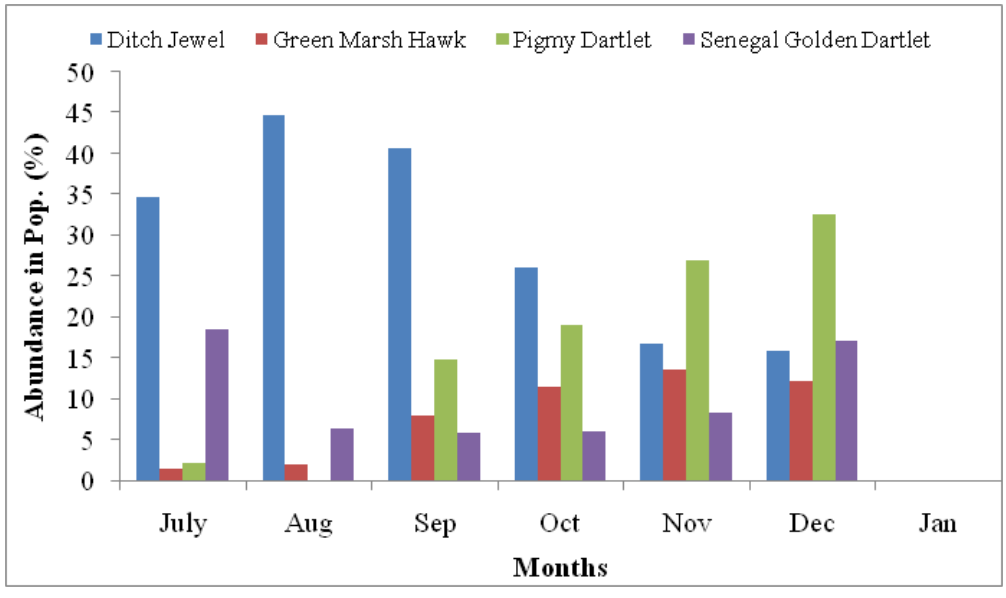

Figure 3. A comparison of the abundance of dominant species within the population.

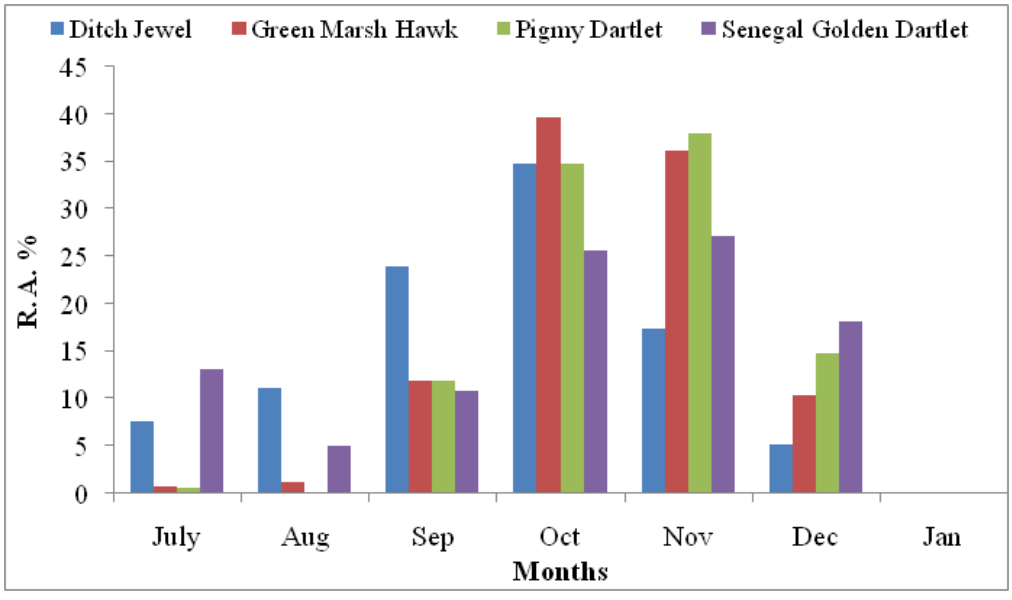

Figure 4. A comparison of population fluctuation of dominant species.

Table 6. Relative abundance (%) of two suborders of Odonata at monthly interval

S. No.	Months	Suborder				Grand Total	R. A. %
		Anisoptera (No.)	R. A. %	Zygoptera (No.)	R. A. %		
1	July	180	6.92	100	4.58	280	5.85
2	Aug	265	10.19	50	2.29	315	6.59
3	Sep	496	19.07	253	11.59	749	15.66
4	Oct	993	38.18	707	32.40	1700	35.54
5	Nov	547	21.03	769	35.24	1316	27.51
6	Dec	120	4.61	303	13.89	423	8.84
7	Jan	0	0	0	0	0	0
8	Total	2601		2182		4783	
Mean ± SD			14.28±12.96		14.28±14.24		14.28±12.86

Table 7. The numerical proportion of two suborders at monthly interval

Months	Anisoptera		Zygoptera		Total No.
	No.	Proportion	No.	Proportion	
July	180	64.29	100	35.71	280
Aug	265	84.13	50	15.87	315
Sep	496	66.22	253	33.78	749
Oct	993	58.41	707	41.59	1700
Nov	547	41.57	769	58.43	1316
Dec	120	28.37	303	71.63	423
Jan	0	0	0	0	0

Table 8. Number of species of two suborders of Odonata at monthly interval

S. No.	Months	Anisoptera	Zygoptera
1	July	6	6
2	Aug	8	6
3	Sep	9	8
4	Oct	13	10
5	Nov	11	10
6	Dec	3	8
7	Jan	0	0

Table 9. Diversity index, species richness and evenness values of odonates from July 2014 to January 2015 at the study site

Months	Diversity Index			Species Richness			Evenness		
	Fazalpur	Sankarda	Sindhrot	Fazalpur	Sankarda	Sindhrot	Fazalpur	Sankarda	Sindhrot
July	1.78	1.73	1.41	7	8	7	0.91	0.83	0.72
Aug	1.94	1.03	1.13	12	4	6	0.78	0.74	0.63
Sep	1.86	2.11	1.77	11	13	14	0.78	0.82	0.67
Oct	2.24	2.22	2.04	17	19	16	0.79	0.75	0.74
Nov	2.31	2.20	1.70	17	18	8	0.82	0.76	0.82
Dec	1.78	1.89	1.65	10	9	6	0.77	0.86	0.92
Jan	0.00	0.00	0.00	0	0	0	0.00	0.00	0.00
Total Period	2.27	2.35	2.01	21	21	17	0.75	0.77	0.71

Diversity index, species richness and evenness values of odonates

A comparison of diversity index, species richness and evenness based on the total Odonata population recorded over the entire study period shows that species richness at the Fazalpur and Sankarda sites was the same (21 species) whereas it was just seventeen (17) species at Sindhrot site. Through the species richness of Fazalpur and Sankarda, the equal value of evenness and diversity index (H′) for Sankarda was slightly higher than for Fazalpur (Table 9).

Diversity index (H′) and species richness values showed their highest values in October/November at all three sites. A comparison amongst sites showed that diversity index and species richness values were always highest for Fazalpur followed by Sankarda and Sindhrot sites. Evenness values almost similar trend but with exceptions during September and December at Sankarda village.

During October when water quality parameters were studied, values of all the parameters were highest for Fazalpur followed by Sankarda and Sindhrot.

Similarity Index of odonate species richness between sites

A total of 25 odonate species were recorded on the Mahi and Mini River complex. However, the highest species richness was only twenty-one (21), both at Fazalpur and Sankarda points. Species richness at the Sindhrot site was lowest (17). Despite having an equal number of species, the similarity index between the Fazalpur and Sankarda sites was only 0.86 indicating that both the sites had some unique species. Fazalpur and Sankarda sites had a similarity index of 0.79 with Sindhrot (Table 10).

Diversity and community structure of odonates

Diversity

The diversity and community structure of odonates were studied at Mini River at Sankarda and Sindhrot village and Mahi River at Fazalpur by monitoring their adult population from July 2014 to January 2015. A total of twenty-five species were recorded in the landscape; of which thirteen were Anisoptera and twelve were Zygoptera. Twenty-one Odonata species were encountered on Fazalpur, and twenty-one species were observed at Sankarda however minimum number (17) of species abundance was at Sindhrot (Table 12). Black-winged Bambootail (*Disparoneura quadrimaculata*) and Yellow Bush Dart (*Copera marginipes*) were unique species recorded at Fazalpur. At Sankarda, Granite Ghost (*Bradinopyga geminata*) and Little Blue Marsh Hawk (*Brachydiplax sobrina*) were unique species and Black

Table 10. Similarity Index of odonate species richness amongst three study sites

Place	Fazalpur	Sankarda	Sindhrot
Mahi	1.00	-	-
Sankarda	0.86	1.00	-
Sindhrot	0.79	0.79	1.00

Ground Skimmer (*Diplacodes lefebvrei*) was a unique species at Sindhrot (Table 11). Only one individual of a unique species was recorded only once at a specific site except Little Blue Marsh Hawk which was recorded over three weeks and Granite Ghost recorded over two weeks (Table 13).

The species diversity index (H') reflects species richness and their relative abundance. In the present study, the diversity index was highest (2.35) for Sankarda followed by Fazalpur (2.27) and Sindhrot (2.01). Overall odonate diversity of Mahi River and its tributary (Mini River) was 2.36 with 0.73 evenness. Odonata Evenness value also varied from 0.7 to 0.8 (Table 12).

Community structure

The community structure of the odonates was worked out on three aquatic microhabitats of the Vadodara district.

At Fazalpur, a total of twenty-one species were recorded of which nine were Anisoptera and twelve were Zygoptera. Black-winged Bambootail (*Disparoneura quadrimaculata*) and Yellow Bush Dart (*Copera marginipes*) (0.05%) were unique species at Fazalpur, as they were not encountered on the other 2 microecosystems. Ditch Jewel (28.46%), Green Marsh Hawk (7.34%), Pigmy Dartlet (14.72%) and Senegal Golden Dartlet (8.89% each) forming 59.4% of the community and only these four were dominant species. The remaining forty per cent of the community was formed by seventeen species (Table 11).

At Sankarda, a total of twenty-one species were recorded of which twelve were Anisoptera and nine were Zygoptera. Granite Ghost (*Bradinopyga geminate*) and Little Blue Marsh Hawk (*Brachydiplax sobrina*) were unique species. Unlike Fazalpur, the same four species were dominant, however, the values of their relative abundance were slightly different (Table 11).

Sindhrot had the least species richness (17) compared to the other two microhabitats in which nine were Anisoptera and eight were Zygoptera. Black Ground Skimmer (*Diplacodes lefebvrei*) was a unique species at Sindhrot. At Sindhrot the same four species were dominant too but the relative abundance of Ditch Jewel was 36.24%; the maximum among the 3 microecosystems (Table 11).

Data from all the microhabitats were fused and the total relative abundance of each species was figured out to obtain a compound image of the community structure of odonates of the study site (Table 11). Even though twenty-five species were observed in the location, eleven species were below one per cent in abundance. Among the four dominant species, Ditch Jewel was the most dominant both at Fazalpur and Sindhrot whereas Pigmy Dartlet was the most dominant one at Sankarda. Other two notable species were the Green Marsh Hawk and the Senegal Golden Dartlet.

A composite picture of the sites shows that Ditch Jewel was the most dominant species (26.6 %) followed by Pigmy Dartlet (19.5 %), Green Marsh Hawk (10.3 %) and Senegal Golden Dartlet (8.3 %). Another notable species was the striped Blue Dart (6.3 %) (Table 11).

Presence and index of importance of Odonate species in three Microhabitats

In 28 weeks study, species like Ditch Jewel, and Senegal Golden Dartlet were existing of 80% of the time. The Common Clubtail, Green Marsh Hawk, Three Stripped Blue Dart and Trumpet Tail existed above 60% of the time. Coromandal Marsh Dart, Pigmy Dartlet and Ruddy Marsh Skimmer were present over 50% of time. Around four species were there below 50% of the period and had less relative abundance too. Those Odonata species that indicated existence throughout a prolonged period had maximum relative abundance value too. Thus, the index of importance (I %) for such species was maximum too. Each species was given a rank based on the value of the index of importance (Table 13). The first five ranks in the odonate community at the study site were as follows: Ditch Jewel, Senegal Golden Dartlet, Pigmy Dartlet, Green Marsh Hawk and Three Striped Blue Dart.

In the present study, water was least polluted at Fazalpur followed by Sankarda and Sindhrot. However, species richness at Fazalpur and Sankarda was equal (21 species) and least (17 species) at Sindhrot (Highly polluted).

On the other hand, the diversity index was highest (2.35) at Sankarda followed by Fazalpur (2.27) and Sindhrot (2.01) due to Sankarda being the least polluted point. The evenness rate of the Odonata varied from 0.7 to 0.8 too indicating dominance of only a few species at three sites.

Table 11. Community structure of odonates on three microhabitats

S. No.	Odonates	Microhabitats							
		Fazalpur		Sankarda		Sindhrot		Total	
		No.	%	No.	%	No.	%	No.	%
1	Black Ground Skimmer	0	0.00	0	0.00	3	0.34	3	0.06
2	Blue Tail Green Darner	2	0.09	1	0.06	0	0.00	3	0.06
3	Common Clubtail	102	4.80	31	1.74	17	1.95	150	3.14
4	Crimson Marsh Glider	6	0.28	8	0.45	29	3.33	43	0.90
5	Ditch Jewel	605	28.46	352	19.72	316	36.24	1273	26.62
6	Granite Ghost	0	0.00	2	0.11	0	0.00	2	0.04
7	Green Marsh Hawk	156	7.34	211	11.82	128	14.68	495	10.35
8	Ground Skimmer	1	0.05	16	0.90	3	0.34	20	0.42
9	Little Blue Marsh Hawk	0	0.00	12	0.67	0	0.00	12	0.25
10	Long-legged Marsh Hawk	90	4.23	43	2.41	4	0.46	137	2.86
11	Ruddy Marsh Skimmer	119	5.60	103	5.77	10	1.15	232	4.85
12	Trumpet tail	161	7.57	10	0.56	0	0.00	171	3.58
13	Wandering Glider	0	0.00	41	2.30	19	2.18	60	1.25
14	Black Winged Bambootail	1	0.05	0	0.00	0	0.00	1	0.02
15	Blue Grass Dartlet	7	0.33	29	1.62	7	0.80	43	0.90
16	Common Blue Tail	22	1.03	22	1.23	0	0.00	44	0.92
17	Coromandel Marsh Dart	155	7.29	37	2.07	14	1.61	206	4.31
18	Golden Dartlet	6	0.28	86	4.82	0	0.00	92	1.92
19	Pigmy Dartlet	313	14.72	446	24.99	174	19.95	933	19.51
20	Pixie Dartlet	14	0.66	33	1.85	8	0.92	55	1.15
21	Saffron-faced Blue Dart	18	0.85	32	1.79	40	4.59	90	1.88
22	Senegal Golden Dartlet	189	8.89	150	8.40	58	6.65	397	8.30
23	Three-striped blue dart	153	7.20	120	6.72	26	2.98	299	6.25
24	Violet Striped Blue Dart	5	0.24	0	0.00	16	1.83	21	0.44
25	Yellow Bush Dart	1	0.05	0	0.00	0	0.00	1	0.02
Total		2126		1785		872		4783	

Table 12. Diversity indices of Odonata on three microhabitats

Microhabitats	Species Richness (S)	Species Diversity (H`)	Evenness (J)
Fazalpur	21	2.27	0.75
Sankarda	21	2.35	0.77
Sindhrot	17	2.01	0.71
Overall	25	2.36	0.73

DISCUSSION

Karthika and Krishnaveni (2014) showed that the diversity was also high in the Sulur wetland (Highly polluted). Since the nymphal life stage is predominant in the life cycle of a dragonfly, it is directly associated with the aquatic ecosystem therefore the effects of a polluted water system would have a direct influence on the distribution of nymphs rather than the adult dragonflies. They concluded that factors like vegetation, shade cover, presence of aquatic plants and riparian vegetation perhaps could have highly influenced the distribution of dragonflies in the particular wetlands.

The density of odonates slightly declined due to flooding in monsoon. A potential area of their habitat increased several fold leading to a decline in their density. Such a situation was reflected during point count within a fixed distance radius.

Table 13. Presence (O%) and index of importance of odonate species in three Microhabitats

S. No.	Odonates	Occurrence of Odonata in three Microhabitats			Frequency of Occurrence		R.A. %	Index importance (I %)	Rank
		Fazalpur	Sank-arda	Sindhrot	In 28 Weeks	O %			
1	Black Ground Skimmer	0	0	1	1	3.57	0.06	1.82	23
2	Blue Tail Green Darner	2	1	0	2	7.14	0.06	3.60	21
3	Common Clubtail	16	9	7	17	60.71	3.14	31.93	7
4	Crimson Marsh Glider	3	1	8	8	28.57	0.90	14.74	16
5	Ditch Jewel	24	22	21	24	85.71	26.62	56.16	1
6	Granite Ghost	0	2	0	2	7.14	0.04	3.59	22
7	Green Marsh Hawk	16	14	15	17	60.71	10.35	35.53	4
8	Ground Skimmer	1	7	3	8	28.57	0.42	14.49	17
9	Little Blue Marsh Hawk	0	3	0	3	10.71	0.25	5.48	20
10	Long-legged Marsh Hawk	12	7	2	13	46.43	2.86	24.65	10
11	Ruddy Marsh Skimmer	11	8	3	14	50.00	4.85	27.43	9
12	Trumpet tail	18	5	0	18	64.29	3.58	33.93	6
13	Wandering Glider	0	7	3	8	28.57	1.25	14.91	15
14	Black Winged Bambootail	1	0	0	1	3.57	0.02	1.80	24
15	Blue Grass Dartlet	2	7	2	7	25.00	0.90	12.95	18
16	Common Blue Tail	9	5	0	9	32.14	0.92	16.53	14
17	Coromandel Marsh Dart	16	7	4	16	57.14	4.31	30.72	8
18	Golden Dartlet	2	11	0	12	42.86	1.92	22.39	11
19	Pigmy Dartlet	14	14	13	15	53.57	19.51	36.54	3
20	Pixie Dartlet	6	8	2	12	42.86	1.15	22.00	12
21	Saffron-faced Blue Dart	6	8	9	11	39.29	1.88	20.58	13
22	Senegal Golden Dartlet	22	16	9	22	78.57	8.30	43.44	2
23	Three-striped blue dart	18	13	10	18	64.29	6.25	35.27	5
24	Violet Striped Blue Dart	3	0	4	5	17.86	0.44	9.15	19
25	Yellow Bush Dart	1	0	0	1	3.57	0.02	1.80	24

The relative abundance of odonates declined during November and December. Such a decline in their population size was related to the drying of their marshy habitat (as monsoon rain is restricted to 3 months) and a decline in mean weekly maximum temperature.

Amongst three study sites, there were four dominant species, Ditch Jewel, Pigmy Dartlet, Green Marsh Hawk and Senegal Golden Dartlet. All the dominant species were habitat generalists.

The assemblages and distribution of the benthic macroinvertebrates frequently change in response to pollution stress in predictable ways. This is the basis of the development of biological criteria to evaluate anthropogenic influences (Saha *et al.,* 2007). The responses are summarized into three distinct categories: reduced diversity, increased domination by a single or group of opportunistic species, and reduced individual size. Langer (1980) also reported increased domination by some tolerant species above two responses.

Amongst the three sites, an abundance of Zygoptera was highest at Sankarda (marshy area with full vegetation) compared to the Mahi River edge (with less vegetation) and Sindhrot (no vegetation). Subramanian (2005) revealed that shade and aquatic vegetation could favour Zygoptera more than Anisoptera.

In present study, the similarity index between Fazalpur and Sankarda was only 0.86 indicating that both the sites had some unique species. Both Fazalpur and Sankarda had only a 0.79 similarity index with Sindhrot as Sindhrot was a highly polluted point.

Wankhade *et al.* (2012) found that the similarity index of the two lakes in Puna was the same as they had similar habitat structures and water quality. However, the community

structure of odonates at the university pond was quite different as it was the least polluted.

CONCLUSION

Odonata fauna of the wetlands of central Gujarat exhibited species richness. The species diversity and richness of odonate was affected by wetland vegetation (aquatic and marginal) that could have influenced their abundance in wetlands. Disruption (pesticide use) of the system should be minimized and a favourable microhabitat should be maintained in the agroecosystem to get maximum benefits from odonates.

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