Ecological morphotaxometry of trematodes of garfish (Teleostomi: Belonidae) from Gangetic riverine ecosystem in India. II. Correlation of seasonality and host biology with distribution pattern of *Cephalogonimus yamunii* n.sp.

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Abstract The seasonality influence on the biology and distribution dynamics of *Cephalogonimus yamunii* n.sp. in *Xenentodon cancilla* (Teleostomi: Belonidae) was reflected during 2 years' investigations. The highest infection prevalence appeared to be in late summer. Size, weight, and sex-biased population dynamics of trematode was well marked in Gangetic riverine ecosystem. The biostatistical non-parametric Mann–Whitney χ^2 test values were significant for dissolved oxygen and magnesium. The distribution of infection data on Poisson series ruled out overdispersion because good agreement was observed ($P < 0.01$).

Keywords *Xenentodon cancilla* ·
Cephalogonimus yamunii n.sp. · Seasonal impact ·
Poisson series · Overdispersion

Introduction

The survival, establishment and transmission dynamics of parasites in hosts are influenced by climate change, short term or long term alike. Since primary and intermediate consumers in the aquatic food web play a very significant role in transferring the developmental stages of trematodes from one host to the other, therefore, presence of biota is primarily responsible for the seasonal transmission of parasites in host to host as well as dynamics in aquatics to terrestrial or terrestrial to aquatics through the intermediate hosts. The varied patterns of distribution of helminths by body weight and size of fish were analyzed (Chauhan et al. 1981; Malhotra 1982, 1989; Banerjee 1991) in several Indian fishes (*Heteropneustes fossilis*, *Clarias batrachus*, *Eutropiichthys vacha*, *Rita rita*, *Mastocembelus armatus*, *Arius fulcaris*, *Lutjanus malabaricus*, *Sardinella longiceps*, *Sebastes schlegeli*, and *Tor tor* etc.). The aspects of temperature dependent host–parasite rejection response (Gairola 1989) were the subject of detailed investigations in earlier studies, mainly because of variability in response of life cycle stages to sudden changes in ambient temperature. The parasite-mix is affected by seasonal change only if the abundance of an obligatory intermediate host varied seasonally, thus making dietary habits responsible for access to helminth invasions in the body of a fish. As depth increases, seasonal effect declines (Collard 1970), because of migration and predation by epipelagic fish. Therefore, the attributes of sex and immunocompromised state of fish (Saha et al. 2002), that enhanced host susceptibility to helminth infections, gained priority (James and Llewellyn 1967; Bower and Woo 1979). The indirect influence of breeding or other physiological attributes of fish in recruitment and establishment of parasitic helminths, just after monsoon season or after or during breeding season have been taken

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into account in several earlier investigations (Dobson 1961; Kennedy 1968, 1969). The authors have highlighted ecological distribution patterns as a critical factor to support the contention of raising a new species, besides morphotaxometric assessment of worms, as presented in the earlier communication (Upadhyay et al. 2012).

Materials and methods

Common and angling netting methods were applied for the collection of live fish, *Xenentodon cancilla* ($N = 1,063$) from fresh water riverine ecosystems of river Yamuna (Kakraha Ghat), Allahabad, UP ($81^{\circ}49'06.28''\text{E}$ (Lon), $(25^{\circ}24'53.24''\text{N}$ (Lat), 74 m (Alt)). All the hosts were brought to laboratory for further investigations. The collected hosts were separated sex-wise, freshly weighed, measured their total and standard length. The collected worms were processed for morphometric analysis as mentioned in Upadhyay et al. (2012).

Results

Season and sex

The period of highest infection prevalence appeared to be late summer (June: female, 71.73 % and July: male, 69.23 %). On the contrary, the season of highest mean intensity were the period of maximum change in water temperature, i.e. autumn (September; male, 30.0), as well as winter (January: female, 20.0; November: female, 18.26; male, 20.0).

Monthwise population dynamics of flukes in fresh water fish showed significantly different sexwise distribution pattern. The infection prevalence exhibited differentiable range of 4.55–55.56 % and 7.14–71.73 % between male and female fish, respectively, during 2008–2009 (Table 1). The infection prevalence in the two sexes was also different in both the sexes during 2009–2010, i.e. 9.09–69.23 % in male fish and 18.0–47.7 % in female fish, (Table 1). But no sexwise difference in mean intensity

Table 1 Monthwise distribution data of *Cephalogonimus yamunii* n.sp. in *Xenentodon cancilla* during 2008–2010

Months	Host examined		Infection prevalence (%)		Mean intensity	
	Male fish	Female fish	Male fish	Female fish	Male fish	Female fish
2008						
July	9	14	55.56	7.14	12.0	5.0
August	7	21	14.28	14.28	10.0	10.0
September	22	10	4.55	20.0	30.0	15.5
October	7	13	28.57	7.69	4.0	8.0
November	13	35	53.85	65.71	20.0	18.26
December	18	23	33.33	52.17	13.33	15.08
2009						
January	15	36	6.67	19.44	15.0	20.0
February	11	10	27.27	10.0	13.33	4.0
March	15	11	6.67	9.09	1.0	1.0
April	32	20	15.62	30.0	4.4	3.18
May	43	38	34.88	42.1	2.28	1.87
June	28	46	50.0	71.73	4.5	4.27
July	26	44	69.23	47.7	5.44	4.81
August	26	38	46.15	47.39	8.67	8.11
September	14	33	42.86	27.27	8.0	13.56
October	9	19	55.56	26.31	5.0	7.4
November	16	18	18.75	38.89	4.33	5.14
December	13	7	23.07	25.0	7.66	4.5
2010						
January	7	13	28.57	30.77	18.5	17.0
February	8	17	37.5	47.06	21.0	14.87
March	11	11	9.09	45.45	21.0	17.6
April	28	27	39.28	33.33	4.18	3.67
May	44	50	18.18	18.0	2.75	4.11
June	43	43	28.93	32.56	3.11	5.36

Fig. 1 Sexwise association in polar area curves depicting (a) infection prevalence versus DO (mg/l), and (b) mean intensity versus magnesium (mg/l) by *Cephalogonimus yamunii* n.sp. in *Xenentodon canchilla* during 2009–2010. Red region male fish; blue region female fish. (Color figure online)

i.e. 1.0–30.0 in male and 1.0–20.0 in female fish occurred during 2008–2009 (Table 1), or during 2009–2010 i.e. 3.11–21.0 in male and 3.67–17.6 in females. As is illustrated in Results (Upadhyay et al. 2012, Communicated), the association of hydrobiological attributes like DO (Fig. 1a) and magnesium (Fig. 1b) could also be established differentially, sexwise, depicted by polar area curves. The non-parametric test, Mann–Whitney test χ^2 values were also significant for the two hydrobiological factors (DO, $\chi^2 = 0.55$; Mg^{++} , $\chi^2 = 0.50$). The distribution of infection data on Poisson series ruled out overdispersion because good agreement was observed ($P < 0.01$, Table 2).

Size of fish

The consistent findings of the 2 years studies summarily reflected positive change of events in the correlation of infection data corresponding to the augmented size of fish, as illustrated in Figs. 2a, 3a, and Table 3. The significance of correlation of infection with fish length was depicted by the analysis of variance (Table 4). The highest infection prevalence, 44.0 % (37.5 % in male, 45.77 % in female fish) and highest mean intensity, 16.33 (16.17 in male, 16.37 in female fish) was estimated during 2008–2009 (Table 3) in the largest group of >25.1 cm. However, peak infection prevalence, 39.25 % (36.37 % in male, 41.27 % in female fish) was recorded in the length of 20.1–25.0 cm and peak mean intensity were estimated 8.74 (8.5 in male, 8.85 in female fish) in the highest length class, >25.1 cm during 2009–2010 (Table 3). These findings explained that the larger fish (>20.1 cm) had greater infection than the smaller ones (<15.0–20.0 cm).

The functional linear interrelationship between infection prevalence and mean intensity in male and female fish during 2008–2009 (Fig. 2a) and 2009–2010 (Fig. 3a) exhibited statistically significant positive interrelationship. The equational forms of such interrelationships *vis-a-vis* size of fish, *X. canchilla* are summarized in Table 5.

Weight of fish

The consistent findings of the 2-years (2008–2010) investigations for change of events in the correlation of infection data corresponding to the weight of fish were illustrated in Figs. 2b, 3b, and Table 3.

The 2-years (2008–2010) investigations represented the highest infection prevalence in medium weight class of fish, 36.19–42.11 % during 2008–2009 and 36.48–38.91 % during 2009–2010. However, peak mean intensity, 20.67 during 2008–2009 and 11.44 during 2009–2010 were encountered in the heavier fish that weighed more than 75.1 g. The functional linear regression equation showed that the mean intensity was higher in heavier fish of both the sexes. However, dispersal of infection (infection prevalence) was lower in heavier female *X. canchilla* (Fig. 2b) during 2008–2009. The Infection prevalence and mean intensity higher in heavier female fish during 2009–2010 (Fig. 3b). However, infection prevalence was inversely proportional to the weight of male fish (Fig. 3b) during 2009–2010.

Discussion

Season and sex of fish

The findings of this study were closest to those of Dhole et al. (2010) on trematodes in fish, to show highest infection prevalence (23.91 %) in summer period, and highest mean intensity (1.81) during winter period. The results of Al-Kandari et al. (2000) to conclude summer peak in cercarial emergence of a variety of trematodes in Kuwait Bay that synchronized with the life history patterns of second intermediate host, mainly intertidal fish and crustaceans, were in close conformity to the findings of peak prevalence (71.73 %) in female fish in June, 2009 during the current study. The authors are in agreement with the host fish being under stress of spawning during summer

Table 2 Poisson series of *Cephalogonimus yamunii* n.sp. in *Xenentodon cancella* during 2008–2010

No. of worms	Infected fishes	Poisson series*
0	704	68.68
1	51	188.15
2	54	257.71
3	40	235.32
4	23	161.03
5	35	88.30
6	19	40.31
7	8	15.78
8	8	5.40
9	8	1.64
10	22	4.50×10^{-1}
11	6	1.12×10^{-1}
12	10	2.56×10^{-2}
13	5	5.40×10^{-3}
14	3	1.06×10^{-3}
15	8	1.93×10^{-4}
16	3	3.30×10^{-5}
17	3	5.32×10^{-6}
18	9	8.10×10^{-7}
19	4	2.47×10^{-7}
20	10	3.38×10^{-8}
21	2	4.40×10^{-9}
22	5	5.48×10^{-10}
24	1	7.45×10^{-12}
25	6	8.17×10^{-13}
28	2	8.54×10^{-16}
30	1	7.37×10^{-18}
31	3	6.51×10^{-19}
32	1	5.57×10^{-20}
33	1	4.63×10^{-21}
34	1	3.74×10^{-22}
35	2	2.92×10^{-23}
36	2	2.22×10^{-24}
40	1	5.70×10^{-29}
42	1	2.48×10^{-31}
62	1	6.28×10^{-57}

* $P < 0.01$ (significant)

period, being the reason suggested therein. Notably, the host fish *X. cancella* spawned during June as well, in fresh waters of Gangetic ecosystem at Allahabad. It was experimentally demonstrated by Saha et al. (2002) that, with the decrease in IgM levels (male fish, winter period (October–December): 2.5–3.0 mg/ml; summer period (April–May, 4.5–12.0 mg/ml); Female fish, winter period: 4.0–5.0 mg/ml; summer period: 5.0–7.0 mg/ml), a decline in immune activities of common carp were recorded during winter period. Several fishes exhibited suppressed immune

Fig. 2 a, b Sex-wise distribution of infection data by *Cephalogonimus yamunii* n.sp. with a size, b weight of *Xenentodon cancella* 2008–2009. Black region No. of host infected, white region No. of host examined

responsiveness to antigen in winter (Avtalion 1969; Rijkers et al. 1980; Wishkovsky and Avtalion 1987), and this influenced declined defence against parasitic helminths. Suzuki et al. (1996) took into account water temperature induced cyclic changes in Plasma IgM levels, that increased in summer and declined in winter, thus influencing seasonally differentiable patterns of prevalence and mean intensity. Sanchez et al. (1993) illustrated decreased IgM levels in winter in *Oncorhynchus mykiss*, and thus enhanced parasitic invasion was a clear possibility. Loot et al. (2007) also illustrated that the number of parasite species significantly increased during summer within the two habitats (upstream and downstream), investigated by them. It was also emphasized that, in addition to the effect of the weirs, parasite diversity of gudgeon was influenced by season, with parasite diversity being higher during summer. This result was explained by these authors by changes in water temperature along the seasonal gradient. In view of Karvonen et al. (2005), the parasite assemblages could also be affected by seasonal host movements (e.g., spawning movements), increasing the degree of social

Fig. 3 a, b Sex-wise distribution of infection data by *Cephalogonimus yamunii* n.sp. with **a** size, **b** weight of *Xenentodon cancilla* 2009–2010. Black region No. of host infected, white region No. of host examined

interactions of the host, and consequently, the probability of parasite transmission. Therefore, the active influence of sudden change in water temperature between autumn and winter, as illustrated in simultaneous communication by the present authors in Upadhyay et al. (2012, communicated), was apparent in the current study to conclude heaviest mean intensity by fish flukes during winter period (Table 1).

Size of fish

A positive correlation of infection by *C. yamunii* n.sp. with the length of *X. cancilla* during 2008–2010 has been illustrated in the freshwater of River Yamuna at Allahabad. As mentioned in the foregoing text, the fish being under stress of spawning during May–September (Jhingran 1991), the larger fish had greater exposure to infection than in the smaller ones, as they contributed more to production of reproductive entities during this period, hence the resistance of body declined to enhance greater susceptibility to trematodes infections. Besides physiological reasons, the dietary habit variations in this predatory fish and possibly because of being in greater contact with the intermediate hosts that harbored infective stages of helminths; heavier intensity was recorded during the following autumn and winter periods. The observed survival of copepods (intermediate hosts of *C. yamunii* n.sp.) in the riverine body was another significant observation for the higher infection in larger size fish than the smaller ones. The preference of diet or feeding, as one of the important

Table 3 The distribution data of infection of *Cephalogonimus yamunii* n.sp. by different size (cm) and weight (g) classes of *Xenentodon cancilla* during 2008–2010

<i>Xenentodon cancilla</i>	Size (cm) (%) and (MI)				Weight (g) (%) and (MI)			
	<15.0	15.1–20.0	20.1–25.0	>25.1	<25.0	25.1–50.0	50.1–75.0	>75.1
2008–2009								
Male	0.00 (0.00)	26.96 (6.52)	34.29 (8.50)	37.50 (16.17)	22.89 (4.32)	32.63 (9.19)	26.47 (9.89)	25.00 (23.5)
Female	0.00 (0.00)	26.92 (4.10)	43.28 (8.31)	45.77 (16.37)	27.03 (2.20)	39.13 (5.38)	47.48 (10.6)	15.39 (19.2)
2009–2010								
Male	16.67 (2.00)	30.77 (8.00)	36.37 (5.50)	28.57 (8.50)	31.25 (8.40)	35.23 (5.32)	37.65 (6.00)	25.58 (11.2)
Female	0.00 (0.00)	21.21 (4.43)	41.27 (7.82)	26.81 (8.85)	0.00 (0.00)	38.03 (7.48)	39.71 (5.67)	25.81 (10.7)

Table 4 Significance of distribution of *Cephalogonimus yamunii* n.sp. in relation to fish size during 2008–2010, by one way ANOVA

	2008–2009		2009–2010	
	Male fish	Female fish	Male fish	Female fish
Size vs. infection prevalence	$F_{1,2} = 25.091$ $S_{0.100}$	$F_{1,2} = 140.771$ $S_{0.005}$	$F_{1,2} = 4.900$ $S_{0.100}$	$F_{1,2} = 12.315$ $S_{0.025}$
Size vs. mean intensity	$F_{1,2} = 6.742$ $S_{0.100}$	$F_{1,2} = 6.509$ $S_{0.100}$	$F_{1,2} = 1.974$ $S_{0.250}$	$F_{1,2} = 188.189$ $S_{0.005}$

Table 5 The linear regression trends of infection of *Cephalogonimus yamunii* n.sp. by different size and weight classes of *Xenentodon cancilla* during 2008–2010

	2008–2009		2009–2010	
	Male fish	Female fish	Male fish	Female fish
Size vs. infection prevalence (%)	$Y = -47.78 + 3.41X$ $r = 0.96, P < 0.025$	$Y = -63.43 + 4.34X$ $r = 0.99, P < 0.005$	$Y = -2.79 + 1.45X$ $r = 0.84, P < 0.20$	$Y = -63.43 + 4.34X$ $r = 0.99, P < 0.025$
Size vs. mean intensity	$Y = -18.74 + 1.25X$ $r = 0.88, P < 0.10$	$Y = -19.85 + 1.27X$ $r = 0.88, P < 0.10$	$Y = -3.26 + 0.44X$ $r = 0.71, P < 0.40$	$Y = -12.27 + 0.83X$ $r = 0.99, P < 0.001$
Weight vs. infection prevalence (%)	NS	$Y = 42.52 - 0.18X$ $r = 0.51, P < 0.10$	$Y = 41.43 - 0.17X$ $r = 0.74, P < 0.005$	$Y = 11.93 + 0.20X$ $r = 0.49, P < 0.40$
Weight vs. mean intensity	$Y = 0.63 + 0.12X$ $r = 0.52, P < 0.40$	$Y = -4.82 + 0.23X$ $r = 0.99, P < 0.001$	NS	$Y = -1.66 + 0.12X$ $r = 0.93, P < 0.025$

NS nonsignificant

regulatory factor than the sexual maturity, immunity as well as metabolic physiological activity (Whitehurst and Lindsey 1990) for the dispersal of helminths infections, has been available in the literature. The significant positive correlation found between size and infection was supported by the findings of Banerjee (Banerjee 1991) for *Neascus vetestai* for constantly higher infection prevalence and mean intensity in larger size of fish. The findings of the present investigation resembled the report of Davis and Huffman (1978) in greater invasion of trematodes in larger fish than smaller ones. The conclusions of Olurin and Somorin (2006) illustrating greater susceptibility to infection in longer fish were significantly closer to the findings of current study. The richness of parasites in higher size class of *X. cancilla* was also supported by the previous findings (Polyanski 1961; Poulin and Rohde 1997; Morand et al. 2000; Simkova et al. 2001). The dietary and filter feeding behavior of *X. cancilla* was responsible for the copepods intermediate arthropod host to influence increased abundance of infection in larger fish. These findings on dietary influence were also supported by the reports of Pulkkinen et al. (1999) and Ryce et al. (2005).

Weight of fish

There was a positive correlation between the body weight of *X. cancilla* with establishment of *C. yamunii* n.sp. during the parasitological investigations. The functional linear regression equations illustrated that the mean intensity was higher in heavier fish of both the sexes (Table 5). However, infection prevalence was lower in heavier female *X. cancilla* (Fig. 2b) during 2008–2009. The infection prevalence and mean intensity were higher in heavier female fish during 2009–2010 (Fig. 3b), however, infection prevalence was inversely proportional to the weight of male fish (Fig. 3b) during 2009–2010. Therefore, maximum establishment of trematode *C. yamunii* n.sp. in heavier *X. cancilla* during the

breeding period were encountered due to their dietary habit and ingestion of more secondary or intermediate hosts (Khalil 1971; Poulin and Morand 2004) as well as decreased immunity. Since healthy male fish, *X. cancilla* was stronger to defend the existence of parasites, *C. yamunii* n.sp. Therefore, this resulted in the reduced infection prevalence during 2009–2010. Simultaneously, the fish with heavier body mass owing to their dietary habits consumed greater quantity of food, therefore, had greater potential to engulf more secondary hosts, thereby, indirectly more endo-parasites. Therefore, larger bodied carnivores had slower life histories (Gittleman 1993), which could affect patterns of parasite richness because lower host mortality rates increased the ability of parasites to become established in host populations (Anderson and May 1979; Thrall et al. 1993; De Leo and Dobson 1996). The 2 years continuous investigations corroborated the findings of Torres et al. (1977), who reported heavier parasitic load in *Tilapia mariae* with increased weight, and hence, the greater susceptibility of parasitization (Olurin and Somorin 2006).

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