Spatial distribution of ectoparasites on the gills of the mullet, *Liza macrolepis*: the effects of pollution

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Abstract Spatial distribution of ectoparasites on the gills of the mullet *Liza macrolepis* collected from two sites, the unpolluted reference site (Site I) and the heavily polluted North western arm of Visakhapatnam harbour (Site II), was analysed. Of the various ectoparasite species found on the gills of the mullet, only *Ancyrocephalus vanbenedeni* (Monogenea) and *Dermergasilus varicoleus* (Copepoda), occurred commonly at both the sites with more or less high prevalence and mean intensity. *A. vanbenedeni* at site I preferred gill arch 1 and posterior most and central sections, whereas at site II, it showed preference for gill arch 3, and posterior and proximal sections of the gill. *D. varicoleus* is highly specific in site selection. It preferred gill arch 1 and the anterior and distal parts at both the sites. *Ergasilus rostralis* favoured gill arch 3 and anterior and proximal sectors, a safe place providing absolute protection from the environmental pollution. It is concluded that the distribution of various ectoparasites on the gills of *L. macrolepis* is determined by the force of ventilation water current, the behavioral response of the parasite to the stress induced by pollution and the surface area of gill arches.

Keywords Ectoparasites · Spatial distribution · Mullet · *Liza macrolepis* · Gosthani estuary · Pollution

Introduction

The ecological niche concept, defined as the microenvironment of a particular species, taking into consideration all aspects of physical, chemical and biological factors that influence the survival and reproductive success of individuals (Pianka 1981), has been investigated intensively by several scientists. Most of the work on ecological niche deals with fish parasites with emphasis on ectoparasites of gills, due to their relatively easy accessibility and suitability to address ecological questions like interspecific competition, spatial partitioning etc. (Llewellyn 1956; Rhode 1977a, b, 1979; Lebedev 1978). A great deal of work has been carried out on microecology (Niche restriction) of ectoparasites of fishes covering marine and freshwater fishes from different geographic regions (Rhode 1977a, b, 1979, 1980, 1981, 1982, 1989, 1994; Rhode and Watson 1985; Rhode and Hobbs 1986; Geets et al. 1997; Hanek and Fernando 1978; Koskivaara et al. 1992; Lambert and Maillard 1975; Ramasamy and Ramalingam 1989; Ramasamy et al. 1985; Dzika 1999; Lo and Morand 2000, 2001; Yang et al. 2006; Blazek et al. 2008; Soyulu et al. 2010; Tripathi et al. 2010). Various hypotheses such as intra and interspecific competition, ventilating water currents and optimisation of reproductive strategy have been put forward to explain the microhabitat restriction and niche specificity. According to Rhode (1994), site segregation was not a result of selection for stabilizing segregation of competing species but has the adaptive function of maintaining intraspecific contact in low density populations, whereas Holmes (1973) supported the hypothesis that continued competitive interaction between parasite species in evolutionary lines leads to niche diversification.

Experimental work by Paling (1968) and Hughes and Morgasn (1973) showed that the degree of infection of gills

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is directly related to ventilation volume and the pattern of current flow over the gills. According to Jeanette et al. (2010) intrinsic factors such as haptoral phenotypes also play an important role in the site selection.

The microhabitat of ectoparasites also varies according to the parasite species, its developmental stage or phase of parasite population, the host fish species and extent of immune response of the host. In addition, abiotic factors of the aquatic environment also play a significant role in site selection (Koskivaara et al. 1991; Buchmann and Bresciani 1998; Buchmann and Uldal 1997). But most of the studies in this direction were undertaken on fish collected from wild or culture operations. So far no data is available whether environmental stress caused by pollution has any impact on the spatial distribution of parasites on the gills of fishes. In this context the mugilids, which are euryhaline and survive well under severe stressful environmental conditions and serve as suitable hosts for ectoparasite species, offer ideal models to study the affect of pollution on site selection of ectoparasites on the gills.

The work presented herein deals with the distribution of ectoparasites in various gill sections of the mullet, *Liza macrolepis* (Smith), obtained from two localities: the unpolluted waters represented by Gosthani estuary and the polluted region of the north-western arm of Visakhapatnam harbour where the waters are subject to heavy pollution due to influx of effluents from industries, domestic sewage and other anthropogenic activities. The goal of the study was to determine whether environmental pollution causes any shift in the microhabitat preference of the gill parasites.

Materials and methods

Samples of mullets were collected from two stations, the unpolluted Gosthani estuary (Site I) and the polluted north-western arm of Visakhapatnam harbour (Site II). Altogether 60 *L. macrolepis* were examined, 35 from site I and 25 from site II. Considerable difficulty was experienced for sampling of mullets at Site II because of restrictions imposed on fishing in the area and the scarcity of fish. The investigations were carried during the month of December when the mullets carried heavy infections. Total length was measured for each fish. Gills were excised and placed in separate petri dishes containing sea water and examined under the microscope. For each examined host, the parasite numbers on each gill arch of the right and left sides were recorded. The gills were numbered 1–4 beginning with the one immediately below the operculum. For the study of microhabitat preference, each gill was divided into 12 sections including 4 sections (anterior, anterior medial, posterior medial, and posterior) along the antero-posterior axis of the gill (longitudinal partitioning) and 3 horizontal

divisions (proximal, central and distal). These divided each gill arch into 12 microhabitats offering a total of 96 sections in each fish (Fig. 1). Additionally the preference of parasites for either external (upper face) or internal (inner face) hemibranch was recorded. Statistical tests such as Student's *t* test for paired comparisons and simple analysis of variance (ANOVA) for multiple comparisons were performed where ever required to test the significance of differences in the distribution of parasites for the particular region under consideration. The parasite counts were log transformed $y = \text{Log}(x + 1)$ for this purpose. Prevalence and mean intensity were calculated following Bush et al. (1997).

Results

The study was based on analysis of site preferences of ectoparasites of 60 specimens of the mullet *L. macrolepis* including 35 from Gosthani estuary (size 8.0–14.3 cm) and 25 from the Harbour arm (size 5.4–10.5 cm). Only infected fish were selected for the study, a total of 1590 ectoparasites from Site I and 757 from Site II were recovered, giving the mean intensity of infection 45.5 and 30.3, respectively.

Fig. 1 Schematic diagram of gill arch showing different arbitrary sections

Ectoparasites of the mullet

L. macrolepis from Site I (Gosthani estuary) was infested by 6 species of ectoparasites including one species of monogenean *Ancyrocephalus vanbenedeni* (Parona and Perugia 1890) and 5 species of copepods, namely *Dermergasilus varicoleus* Ho, Jayarajan and Radhakrishnan 1992; *Ergasilus rostralis* Ho, Jayarajan and Radhakrishnan 1992; *Nipergasilus bora* (Yamaguti 1939); ergasilid n. gen. and *Caligus platytarsis* Basett-Smith, 1898. At Site II, infections were noted with four species including the monogenean *A. vanbenedeni*, and the copepods *D. varicoleus*, *E. rostralis* and *Mugilicola mugilis* Pillai and Jayasree, 1978. Overall, the prevalence and mean intensity of monogeneans and copepods were much higher at Site I compared to Site II (Table 1). Of the various parasite species only *A. vanbenedeni* and *D. varicoleus* were of common occurrence at both the sites. Infection with *E. rostralis* was low at Site I and moderately high at Site II. *N. bora*, ergasilid n. gen and *C. platytarsis* were restricted to Site I and *M. mugilis* to Site II.

Microhabitat differences, site and gill preference at sites I and II

At both the sites neither the total parasites nor any individual parasite species showed a significant difference between the parasite numbers on right and left sets of gills. All parasite species showed slightly higher percentage values for the right side gill arches but the Student's *t* test employed showed the difference in values to be insignificant ($p > 0.05$) (Table 2). The two species *A. vanbenedeni* and *D. varicoleus*, which are of common occurrence at both the localities, were selected for detailed analysis of spatial distribution on the gills.

A. vanbenedeni

Altogether, 1424 individuals of *A. vanbenedeni* were recovered from the 35 fish examined from Site I. The right side gills harboured higher number of parasites (53.2 %) compared to the left side ones (46.8 %). Paired comparison of the numbers of parasites on the right and left sets of gills using Student's *t* test however, revealed no significant differences ($p > 0.05$). Among the 4 gills arches, the parasite most preferred the 1st gill arch, followed by the 3rd gill arch and the 2nd gill arch and least the gill arch 4 (Table 3). However, the difference in the parasite counts between the four gill arches was not significant ($p > 0.05$), but was significant ($p < 0.05$) between the 1st and the 4th gill arch. Among the 4 gill sections, the numbers of parasites were found to be maximum on the posterior most section (30 %), followed by the anterior medial (26.4 %), anterior (24.1 %) and posterior medial sections (19.5 %) in descending order. Along the vertical axis of gills, a preference for central section (50 %) followed by distal (35.7 %) and proximal Sects. (14.4 %) was also seen. However, differences between the central and distal sections were not significant. Between external and internal faces of the gill, majority parasites (82.4 %) were found on the external face.

At Site II, infection with *A. vanbenedeni* was much less compared to Site I. A total of 757 individuals were obtained from the gills of the 25 fish examined. No difference was found in the numbers of the monogeneans on the right and left gills. The maximum number was found on gill arch 3 (30.6 %), followed by gill arch 1 (25.6 %), gill arch 4 (22.3 %) and gill arch 2 (21.6 %); the gill arch 2 carried the least number of parasites (Table 4). No preference for any section of gill was noted; the parasites were uniformly distributed on all sections except for a marginal

Table 1 Prevalence (Pr %) and mean intensity (MI) of infections with different ectoparasite species in *L. macrolepis* from Gosthani estuary (Site I) and NW arm of harbour (Site II)

Ectoparasite species	Gosthani estuary (Site II) (n = 35)		NW arm of harbour (Site II) (n = 25)	
	Pr (%)	MI	Pr (%)	MI
Total ectoparasites	100	45.5	100	30.3
<i>A. vanbebedeni</i>	88.6	45.9	96	24.5
Copepods	71.4	6.7	76	8.9
<i>D. varicoleus</i>	42.9	8.1	72	3.8
<i>E. rostralis</i>	14.3	1.2	28	14.0
<i>N. bora</i>	11.4	1.3	0	0
Ergasilid n.gen	5.7	1.5	0	0
<i>C. platytarsis</i>	45.7	1.6	0	0
<i>M. mugilis</i>			1.2	1.0

Table 2 Distribution of Ectoparasites on the right and left sets of gill arches of *L. macrolepis* at sites I and II

Ectoparasite	Site I (n = 35)		Site II (n = 25)	
	Right gills	Left gills	Right gills	Left gills
Total ectoparasites (%)	856 (53.8)	734 (46.2)	441 (58.2)	316 (41.8)
<i>A. vanbenedeni</i> (%)	757 (53.9)	647 (46.1)	348 (59.1)	240 (40.9)
<i>D. varicoleus</i> (%)	72 (59.5)	49 (40.5)	37 (54.4)	31 (45.6)

Table 3 Distribution of ectoparasite species on different gill sections of *L. macrolepis* from Gosthani estuary

Ectoparasite species	Gill no.					Longitudinal section				Face		Vertical section		
	1	2	3	4	Total	Ant.	Ant. med	Post. med.	Post.	Ext.	Int.	Prox.	Cent.	Distal
Total parasites	519	354	448	269	1590	404	409	292	485	1324	266	219	764	607
%	32.7	22.2	28.0	16.9		25.4	25.8	18.3	30.5	83.2	16.8	13.9	48.0	38.1
<i>A. vanbenedeni</i>	472	302	403	247	1424	343	376	277	428	1174	250	205	710	509
%	33.1	21.2	28.3	17.3		24.1	26.4	19.5	30.0	82.4	17.6	14.4	50.0	35.7
Copepods	47	52	45	22	166	61	34	14	57	150	16	18	52	06
%	28.3	31.3	27.1	13.3		36.7	20.5	8.4	34.3	90.4	9.6	10.8	31.3	57.8
<i>D. varicoleus</i>	39	32	30	20	121	50	21	7	43	107	14	4	30	87
%	32.2	26.4	24.8	16.5		41.3	17.4	5.8	35.5	88.4	11.6	3.3	24.8	71.9
<i>E. rostralis</i>	1	3	2	0	6	3	2	1	0	5	1	3	2	1
%	16.7	50.0	33.3	0		50.0	33.3	16.7	0	83.3	16.7	60.0	33.3	16.7
<i>N. bora</i>	1	1	2	0	4	0	0	1	3	4	0	2	1	1
%	25.0	25.0	50.0	0		0	0	25.0	75.0	100.0	0	50.0	25.0	25.0
Ergasilid n. gen	0	1	1	1	3	0	0	0	3	3	0	3	0	0
%	0	33.3	33.3	33.3		0	0	0	100.0	100.0	0	100.0	0	0
<i>C. platytarsis</i>	6	12	8	1	27	7	10	5	5	26	1	5	18	4
%	22.2	44.4	29.6	3.7		25.9	37.0	18.5	18.5	96.3	3.7	18.5	66.7	14.8

Table 4 Distribution of ectoparasite species on different gill sections of *L. macrolepis* from NW arm of Harbour

Ectoparasite species	Gill no.					Longitudinal section				Face		Vertical section		
	1	2	3	4	Total	Ant.	Ant. med.	Post. med.	Post.	Ext.	Int.	Prox.	Cent.	Distal
Total parasites	190	160	237	170	757	198	193	176	190	657	100	356	305	96
%	25.1	21.1	31.3	22.5		26.2	25.5	23.2	25.1	86.8	13.2	47.0	40.3	12.7
<i>A. vanbenedeni</i>	151	127	179	131	588	141	135	145	167	517	71	273	266	49
%	25.6	21.6	30.4	22.3		24.0	23.0	24.6	28.4	87.9	12.1	46.4	45.2	8.3
Copepods	39	33	58	39	169	58	57	31	23	140	29	83	40	46
%	23.1	19.5	34.3	23.1		34.3	33.7	18.3	13.6	82.8	17.2	49.1	23.7	27.2
<i>D. varicoleus</i>	30	20	15	3	68	23	15	15	15	65	3	2	24	42
%	44.0	29.4	22.1	4.4		33.8	22.1	22.1	22.1	95.6	4.4	2.9	35.3	61.8
<i>E. rostralis</i>	8	11	43	36	98	34	41	16	7	72	26	78	16	4
%	8.1	11.2	43.9	36.7		34.7	41.8	16.3	7.1	73.5	26.5	79.6	16.3	4.1
<i>M. mugilis</i>	1	2	0	0	3	0	2	0	1	3	0	3	0	0
%	33.3	66.7	0	0		0	66.7	0	33.3	100.0	0	100.0	0	0

increase in numbers in the posterior section. The distribution was almost similar on proximal and central sections 46.4 and 45.2 %, respectively) and very low distally (8.3 %). The difference is significant ($p < 0.05$).

Dermergasilus varicoleus

Altogether 121 individuals of *D. varicoleus* were recovered from the 35 fish examined from Site I. As regards their occurrence on different gill arches, they were most abundant on gill arch 1 (32.2 %), followed by gill arch 2 (26.4 %), gill arch 3 (24.8 %) and least on gill arch 4 (16.5 %), the difference being insignificant ($p > 0.05$) (Table 3). Some preference to anterior section (41.3 %) and the distal section (35.5 %) of the gill arch was also evident. Most of them were found clasping the distal gill filaments such that the egg cases were visible hanging outside the gill filaments.

At Site II the trend observed for *D. varicoleus* was similar to that noted at Site I. It showed maximum percentage on gill arch 1 > 2 > 3 > 4 and the least number (4.4 %) was found on gill arch 4 (Table 4). The difference was significant among 4 gill arches and also between gill arches 1 and 4 ($p < 0.05$). Among various vertical sections, it was most abundant on the anterior most region (33.8 %) and was equally distributed among the other three regions (22.1 % on each section). In comparison with the results at site I, in general there appears to be a microhabitat shift of the copepod towards anterior side from the posterior section. The distribution of the copepod along the vertical axis of the filament showed a similar trend as in Site I and occurred in maximum numbers distally (61.8 %). Majority of copepods were also found on the external face of the gill arches (95.6 %).

Caligus and *ergasilids*

Of the remaining species of copepods, only *E. rostralis* occurred at both the localities, infections with *C. platytarsis* and the ergasilid n. gen were found only at Site I. Twenty-seven individuals of *C. platytarsis* were obtained from 35 *L. macrolepis* of Site I. They showed preference for gill arch 2 (44.4 %), gill arch 3 (29.6 %), gill arch 1 (22.2 %) and lastly gill arch 4 (3.7 %) in descending order. Maximum numbers were present on anterior median and central sections.

The few numbers (three out of six) of *E. rostralis* present at Site I showed preference for the proximal section. On the other hand as many as 98 *E. rostralis* were obtained from Site II, which showed preference for gill arches 3 and 4 and anterior medial and anterior sections and proximal part of the gill arch. The copepod ergasilid n. gen though less prevalent showed site specificity for

proximal regions of gill filaments; they were found to hook and pierce on the gill arches and gill rakers.

Discussion

It is evident from the present study that the various species of ectoparasites of the mullet, although colonized all sections of the gill apparatus, showed preference for a certain niche. Also some shift in the microhabitat selection of ectoparasites occurred in the fish from polluted zones.

A. vanbenedeni exhibited most preference for attachment to gill arch I and some affinity for posterior most and central sections of gills. In teleost gills, the force of ventilation current is considered to be less in the proximal region of primary lamellae than in the distal (Hughes 1966). *A. vanbenedeni* probably prefers the central zone due to a possible balance of situation in this zone relative to the other two extreme zones. A similar distribution was observed by Rajagopalasamy and Natarajan (1987) for *Ancylo-discoides* sp. on *Liza tade* except that it showed preference for the middle sector along the anterior posterior axis rather than the posterior section. Preference for gill arch 1 was also reported for *A. vanbenedeni* (Rawson 1977), *A. mogurndae* on *Siniperca chuatsi* (Nie 1996) and for *Metamicrocotyla cephalus* and *Microcotyle mugilis* on *Mugil cephalus* (El Hafidi et al. 1998) and many species of ectoparasites (Llewellyn 1956; Paling 1969; Pilcher et al. 1989 and Ramasamy and Ramalingam 1989; Dzika and Szymanski 1989; Rubio-Godoy 2008).

At site II, *A. vanbenedeni* however, showed preference for gill arch 3 with some affinity towards posterior most and proximal sections. A probable reasoning for the microhabitat shift at Site II is that these niche provide increased protection from pollutants. Only few studies are available dealing with the impact of adverse environmental conditions in site selection of ectoparasites on fish gills. The results of these studies are not uniform, some recording a shift in spatial selection under adverse environmental conditions, others reporting no such change. For example, Drovskikh and Torba (1988) reported that *Dactylogyrus intermedius* and *D. wegneri* on *Carrasius carrasius* changed their positions on the gills in conditions of prolonged oxygen deprivation. In the case of the thermophilous species *Gyrodactylus markakulensis*, it is reported that 94 % of parasites occurred on the fins in warm months but preferred the gill apparatus during cold months when conditions for survival were not favourable (Blazek et al. 2008). Similarly, Koskivaara et al. (1991) found gyrodactylids to be more frequently attached on the gills when environmental conditions were not suitable for parasites. In contrast, Bagge and Valtonen (1996), in an

experimental study on the influence of paper and pulp mill effluents on the gill distribution of *Dactylogyrus crucifer* and *D. manus* on *Rutilus rutilus*, found no change. Yang et al. (2006), in a study on microhabitats of monogeneans viz., *Polylabris mamaevi* and *Tetrancistrum nebulosi* on gills of *Siganus fuscus* from caged versus wild-caught hosts, found that differences in resources in net cages and wild populations did not influence the parasite distribution on the gills. However, it is evident from results of the present analysis and other studies that effects of adverse environmental conditions or stress on site selection of gill parasites vary depending on the species of the parasite, the extent of interaction between the host, pathogen and the environment and the nature and degree of pollution, which may shift the parasite to a safer niche or totally eliminate it.

As for the microdistribution of parasitic copepods, the ergasilid *Dermergasilus varicoleus* on mullets from Gosthani estuary showed a clear preference for gill arch I and anterior most section on the arches, with a strong affinity towards terminal (distal) ends and very little for proximal sector of gill filaments. Similar preference for gill arch I has been reported for *Lamproglana chinensis* (Sproston et al. 1950), *Ergasilus versicolor*, *Branchiella oblongo* and *Ergasilus funduli* (Rawson 1997) and for *Clavella adunca* (Pilcher et al. 1989). Hanek and Fernando (1978) however, observed no clear preference for any arch by copepods on *Lepomis gibbosus* though they occurred most often on anterior or posterior sections of hemibranchs as observed in the present study.

It appears that for *D. varicoleus*, the location of gill arch and the force of respiratory current are the deciding factors. It prefers gill arch I, the anterior most region and the distal section, showing its capability to withstand great water flow. Hughes (1966) and Wootten (1974) observed that almost throughout the respiratory cycle, main force of respiratory current falls upon the outer surfaces of hemibranchs. According to Rajagopalasamy and Natarajan (1987) attachment on the terminal sector enhances the egg strings in copepods to swing freely in the opercular cavity and facilitates the egg hatching.

D. varicoleus is highly specific in its microhabitat preference as it was restricted to the same niche even in the highly contaminated waters of Site II. It appears the parasite has adapted and modified to restrict itself to particular niche.

For *E. rostralis*, the infection was very low at site I, whereas at Site II, the parasites were quite abundant and showed preference for gill arch 3, anterior medial section and proximal sector. Similar habitat restriction to gill arch 3 was reported for *Ergasilus lizae* on *Mugil cephalus*. (Rawson 1977) and *Ergasilus* sp. on *Liza tade* (Rajagopalasamy and Natarajan 1987). However, Fernando and Hanek (1976) noted no affinity for any gill arch by

Ergasilus caeruleus. *E. rostralis* too, appears to be highly site specific and probably due to its niche selection, it is capable of withstanding pollutants more than *D. varicoleus*, which is less abundant in polluted waters as compared to *E. rostralis*.

Infection with *C. platytarsis* occurred only at Site I and was not found at Site II. At Site I, the parasite showed preference for middle gills but more for gill arch II and anterior medial and central sections. Similar preference for the central region has been reported by Rawson (1977) for the caligoid *Branchiella oblonga* on *M. cephalus*. Martens and Morand (1995) reported that *Caligus* sp. on rabbit fish from the Kenyan coast was absent on gill arch IV and showed no preference for other gill arches and areas. They attributed this wide microhabitat to the mobility of *Caligus*.

At both stations, difference between infection on the right and left side gills was insignificant for all parasites, since no difference occurs in water flow over both sides (Paling 1968). Similar observations have been reported for glochidia on ruffe (Wootten 1974) and various monogeneans (Ramasamy et al. 1985; Agrawal and Mishra 1992; Martens and Morand 1995; Turgut et al. 2006). However, Wootten (1974) observed significant difference in numbers of Monogenea—*Dactylogyrus* and *Metamicrocotyla cephalus* on right and left gill sets of *Mugil cephalus*.

We found a significant difference in the occurrence of parasites between external and internal hemibranchs at both stations. Results similar to ours have been reported by Hanek and Fernando (1978) and Ramasamy et al. (1985).

To conclude it seems that the distribution of various ectoparasite species on the gills of *L. macrolepis* is governed by (1) the gill currents (2) the behavioural response of the parasite towards pollutants and (3) the surface area of the gill. The relative importance of these factors varies in different parasite species depending on their mode of host invasion and extent of host–parasite and parasite–parasite associations.

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