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INFECTION DYNAMICS OF *SCHISTOCEPHALUS SOLIDUS* (MULLER, 1776), IN THREE-SPINED STICKLEBACK, *GASTEROSTEUS ACULEATUS* L. IN AIRTHREY LOCH, SCOTLAND

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ABSTRACT

Infection of *Schistocephalus solidus* in three-spined stickleback, *Gasterosteus aculeatus* was investigated for over a two year period from Airthrey Loch, Scotland. Altogether 1301 fishes were sampled. A total of 1327 *S. solidus* plerocercoid worms were extracted from the visceral cavity of 385 fish. The prevalence was 29.55%, mean intensity (3.44) and abundance (1.01). Monthly prevalence and abundance showed significant difference in two years. Infection in female (14.68%) was higher than male fish (5.99%). The highest infection was recorded in autumn and spring. There are two waves of infection, the first wave operates from July to October and second starts in February and ends in June. The growth of *S. Solidus* in the fish is influenced by a rise in water temperature in summer. In natural environment, probably different biotic and abiotic factors may affect the transmission of *S. solidus* and thus may affect the prevalence and intensity of infection. Such factors could influence the survival of coracidia, or abundance of suitable copepod at a given time. The growth of plerocercoid in the fish host may be influenced by factors both internal and external to the fish host. It is concluded that *S. solidus* was moderately established in second intermediate host *G. aculeatus* in Airthrey Loch

Keywords: *Schistocephalus solidus*, *Gasterosteus aculeatus*, infection dynamics, freshwater loch,

INTRODUCTION

Schistocephalus solidus is a pseudophyllidean tapeworm with three host life cycle. The free swimming coricidea are ingested by freshwater copepod, the first intermediate host. In the copepod, coricidia develops into the infective stage in almost 2 weeks. Then it is ready to be transmitted to second intermediate, the fish *G. aculeatus.* In fish worm grow to large size and mass of plerocercoid may account for sometimes equaling or exceeding host mass (Hopkins and Symth, 1951, Clark, 1954, Arme and Owen, 1967). Nearly 40 species of piscivorous birds (Smyth, 1962), such as gulls and herns and other vertebrates like Baltic ringed seal *Phoca hispida botnica* (Gmelin) are intended definitive host (Chubb *et al*., 1995). In the final host, worm becomes reproductively mature within 2-3 days and in the next 7 days all eggs are produced and the worm dies. The plerocercoids of *S. solidus* are commonly found in the visceral cavity of *G. aculeatus*, in Britain and throughout its geographical range (Barber, 2007).

Heavy infection results in the death or predation of the fish (Pennnycuick, 1971b) and change in the behavior of the host (Holmes and Bethel, 1972). The seasonal variation and occurrence of *S. solidus* in *G. aculeatus* as well its effects on the behavior, pathology and growth of the host have been reported by many researchers (Arme and Owen, 1967; Chappell, 1969a,b; Pennycuick, 1971a; Curtis, 1981). The influence of parasitism on stickleback physiology has been investigated by Pascoe and Cram (1977), Pascoe and Woodworth (1980). Infection of *G. aculeatus* with *S. solidus* (Seed, 1984) and Scanning electron microscopy (SEM) of this parasite from different geographical location has been described by Chubb *et al.* (1995). A significant difference in the infection of three-spined stickleback with *S. solidus* has been reported in two lakes in Alaska (Heins *et al*., 2002). Another study, Dorucu *et al*. (2007) found a significant difference in the relationship between plerocercoid mass and lifetime eggs output of *S. solidus* recovered from singly and multiple infected *G. aculeatus*. *Schistocephalus solidus* has effects on stickleback reproduction (Macnab *et al*., 2009). Epizootic of *S. solidus* appear to depend on particular and at times on, rare set of circumstances (Heins *et al*., 2010). Mortality of the host during winter is a major factor which reduces transmission and influences the population dynamics of *S. solidus* (Heins *et al*., 2011). *Schistocephalus solidus* has been reported for the first time from body cavity of anadromous three-spined stickleback inhabiting Mud Lake, Alaska (Confer *et al*., 2012). While carrying out PhD project on biology of *Proteocephalus filicollis* from *G. aculeatus* (Iqbal, 1998; Iqbal and Wootten, 2013), some interesting observations on infection dynamics of *S. solidus* in *G. aculeatus* from Airthrey Loch, Scotland were obtained and these are compared with earlier studies from Britain.

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Table 1. Composition of various length classes of *Gasteosteus aculeatus* from Airthrey Loch, Scotland.

Month	LC-I	LC-II	LC-III	LC-IV	LC-V	Month	LC-1	LC-II	LC-III	LC-IV	LC-V
A93	-	20.96	30.64	46.77	01.61	-	-	-	-	-	-
M	-	04.87	41.46	60.97	02.43	-	-	-	-	-	-
J	32.50	37.50	02.50	25.00	02.50	-	-	-	-	-	-
J93	27.77	44.44	01.85	22.22	03.70	**J94**	58.33	41.66	-	-	-
A	02.59	64.93	27.27	03.89	01.29	A	50.00	40.00	07.50	-	02.50
S	02.35	37.64	45.88	12.94	01.17	S	18.86	50.94	24.52	05.66	-
O	01.53	26.15	56.92	15.38	-	O	-	50.00	50.00	-	-
N	-	46.00	44.0	10.00	-	N	01.96	49.01	39.21	05.88	01.96
D	-	50.00	39.58	10.41	-	D	-	37.50	50.00	08.33	04.17
J94	-	50.00	40.98	08.19	-	**J95**	-	35.00	55.00	10.00	-
F	-	38.23	58.88	05.88	-	F	-	32.14	53.37	14.28	-
M	-	47.97	47.97	03.37	01.36	M	-	40.62	40.62	15.62	03.12
A	-	33.33	44.44	19.04	03.16	A	-	15.00	35.00	50.0	-
M	-	12.96	29.62	55.55	02.50	M	-	08.51	40.42	48.93	02.12
J	-	02.50	40.00	55.00	02.50	J	03.63	16.36	12.72	50.99	14.30

(Values are in %; - indicates zero value)

Table 2. Infection of *S. solidus* in three samples of *G. aculeatus* in relation to sex of the host.

Sample	Fish Exam.	Infected fish prevalence, MI	Infected fish			Female: male
			Sex ?	Female	Male	
1	147	70 (47.61%) 4.81	13(18.57%)	32(45.71%)	25(35.57%)	1.28:1
2	704	140 (19.88%) 2.87	39(27.85%)	65(46.42%)	36(25.71%)	2.03:1
3	450	175 (38.88%) 3.52	64(36.57%)	94(53.71%)	17(9.71%)	5.52:1
Total	1301	385(29.59%)3.44	116(30.12%)	191(49.61%)	78(20.23%)	2.44:1

MATERIALS AND METHODS

The fish, *G. aculeatus* were sampled from Airthrey Loch, University of Stirling, Scotland (Grid Reference 806965) with the help of hand net on a monthly basis (April 1993 to June 1995). The physicochemical and biological features of the Loch are given by Iqbal, (1998), Iqbal and Wootten (2004). The fishes were brought live in loch water to the Parasitology laboratory, Institute of Aquaculture and maintained in 40liter glass aquarium at ambient water temperature. The fishes weighed were and measured and examined within 2-4 hours. The worms were extracted from the visceral cavity of the fish and relaxed in tap water. The fish collected comprised three samples; sample-1 (April-June 1993); sample-II (July 1993 to June 1994); sample –III (July 1994-June 1995). The fishes were divided into five length classes as under; LC-1 (up to 20mm); LC-II (21-30mm); LC-III (31-40mm); LC-IV (41-50mm) and LC-V (51mm<). Prevalence, abundance and mean intensity were followed after Margolis *et al.* (1981). Pearson correlation analysis was applied to verify the significance between the values of prevalence, mean intensity and abundance.

RESULTS

A total of 1301 *G. aculeatus* were sampled and examined. These fishes are represented by five length classes (Table 1). Altogether 385 fishes were infected with *S. solidus* hence, prevalence was 29.59%. A total of 1327 *S. solidus* plerocercoid worms were extracted (abundance 1.04 and mean intensity 3.44) from infected fish. Infection and mean intensity of *S. solidus* in three samples of *G. aculeatus*, according to the sex of the host is given in table 2. The female fish population was always high, compared to the male population. Similarly, female fish had higher infection compared to male in all samples.

The monthly prevalence of *S. solidus* in the fish fluctuated over the study period. In sample II and III, there was

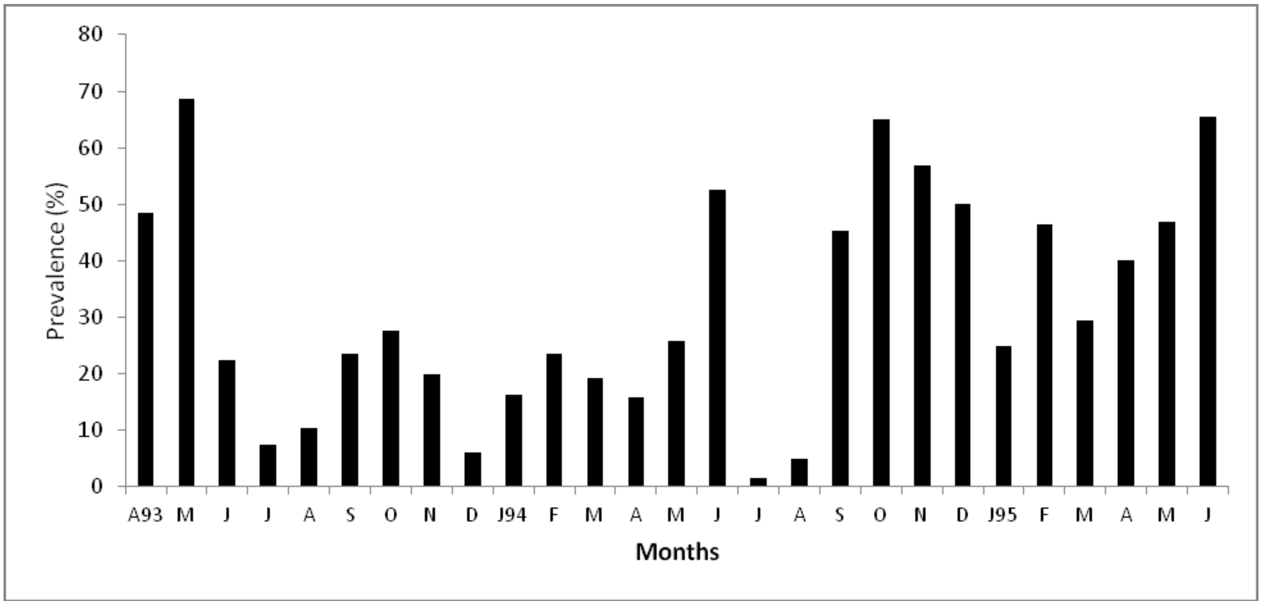

Fig.1A. Prevalence of *S. solidus* in *G. aculeatus* from Airthrey Loch Scotland.

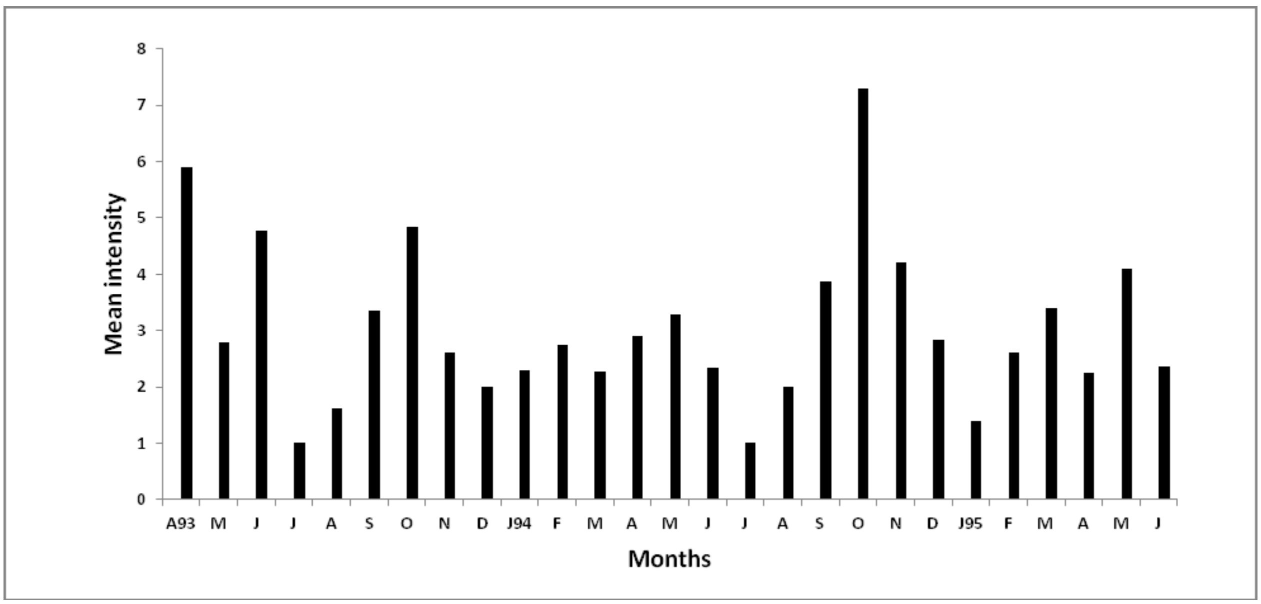

Fig.1B. Mean intensity of *S. solidus* in *G. aculeatus* from Airthrey Loch Scotland.

gradual rise in prevalence from July to October which dropped to the lowest level in December-January and increased gradually through February to May-June with some fluctuation (Fig. 1A). The mean intensity of infection showed rising trend from July to October and then gradually dropping from November to December-January which increased through spring and dropped in June in sample II and III with some fluctuation (Fig.1B). The monthly prevalence and mean intensity was not significantly correlated (P=0.18) in sample II. But was significantly correlated (P=0.02) in sample III.

The prevalence was low in summer followed by a rise in autumn and dropping in winter and high in spring. The mean intensity followed the same pattern of seasonal rise and fall as that of prevalence. Low mean intensity is observed in winter. High mean intensity from late winter to early spring in sample-II and sample-III indicates a second wave of infection. Adult fish showed high infection in the samples I, II and III (April to June). There was no significant correlation between prevalence and mean intensity in adult fish infection cases in three samples (P=0.23). Prevalence in various length classes of fish (Table 3) shows a rising trend from LC-I to LC-V in

Table 3. Prevalence (%) and mean intensity of *S. solidus* in various length classes of *Gasterosteus aculeatus* in Airthrey Loch, Scotland.

Length Class	Sample-I			Sample-II			Sample-III		
	Fish	Prev.	MI	Fish	Prev.	MI	Fish	Prev.	MI
LC-I	13	0	0	20	5.0	2.0	68	11.76	1.1
LC-II	30	20.0	3.3	279	15.05	3.21	157	38.85	3.59
LC-III	37	70.27	3.19	289	22.84	2.36	130	40.79	4.96
LC-IV	64	54.68	5.62	107	26.16	3.82	81	54.32	2.54
LC-V	03	100	2.33	9	33.33	1.0	14	64.28	1.66
Total	147	47.61	4.81	704	19.88	2.87	450	38.88	3.52

Table 4. *Schistocephalus solidus* infection in different *G. aculeatus* populations in Britain.

Locality	% population infected	Mean intensity	Max. worm /fish	Authority
Hunslet,Yorkshire	100	6.0	16	Hopkins & Smyth (1951)
Stourton,Yorkshire	-		$(5)^2$	Clark, (1954)
Farnley, Yorkshire 1962 1963-65	 100 36-96	 46.5	 138	Arme & Owen (1967)
Baildon, Yorkshire	27	1-1.6	4	Chappell (1969a)
Priddy Pool Somerset	88	4.4	106	Pennycuick (1971a)
Beaumaris,N.Wales	79	2.9	43	Seed (1984)
Stirling, Scotland 1993 1993-94 1994-95	 47.4 19.88 38.38	 4.81 2.87 3.52	 66 40 40	Present Study

sample II and sample III. However, this trend was not observed in mean intensity in these length classes. The recruitment continues from July to October as highest number of worms has been recorded in this period.

The mature *G. aculeatus* were observed in April, May and June in three samples. The fish normally mature at the age of one year. But, the fish reach sexual maturity at the age of two years. Healthy fish showed full maturation i.e. ripe ovaries and testes. Whereas, the infected fish at the same time were not mature, either they had suppressed or under developed gonads.

DISCUSSION

This is another detailed investigation of *S. solidus* infection in *G. aculeatus* from Scotland. The infected female population exceeded the male population in Airthrey Loch. The prevalence of *S. solidus* in *G. aculeatus* was high in sample I and sample III compared to sample II. The earlier studies from Britain (Table 4) reported high prevalence of *S. solidus* in *G. aculeatus* compared to the present study. Mean intensity also followed the same pattern as that of prevalence but showed some fluctuation. In Scotland, infection of *S. solidus* starts in summer and becomes high in autumn which drops to the lowest in winter and gradually rise in summer again. Monthly prevalence and mean intensity in sample II and sample III did not show any significant correlation to abiotic factors (pH, water temperature, conductivity and rain fall) of the Loch, but a significant correlation was observed in prevalence and mean intensity and pH in sample III (P=0.008). The low prevalence and mean intensity in sample II might be due to mortality of larger and heavily infected hosts during winter, as a result of infection stress and long starving winter.

In the Airthrey Loch, three-spined sticklebacks are infected in their first summer. Infection also takes place in fishes of 1 year of age, and multiple infections are common, and this is also reported by Heins *et al*. (1999). Healthy and uninfected fishes live up to 2 or sometime 3 years of age, as observed in the present study. The *S. solidus* may live in the fish host as long as two years until the death of the host and all the growth of the worm occurs during plerocercoid stage in the fish host. The water temperature has been proposed as an explanation for seasonal maturation of *Proteocephalus* sp. in their host (Kennedy, 1977). However, growth is accelerated in spring and summer. There is also fall in the mean intensity of infection during this period. The low mean intensity of infection may also reduce competition within the parasite infrapopulation at a time when metabolic requirement of individual cestode associated with growth increases.

The eutrophic nature of the Airthrey Loch (Iqbal and Wootten, 2004) may be suggested to increase the large population of infected copepod that may have influenced the high transmission of *S. solidus* in the fish. The high prevalence may be associated with warm late summer and autumn of Year I and Year II (Iqbal and Wootten, 2004) which might have acted indirectly by facilitating the copepod population to multiply. The high water temperature in Year I in Airthrey Loch may have operated by; 1) enhancing the feeding rate of *G. aculeatus*; 2) by facilitating the establishment of worms in the fish; 3) providing high biomass of infected cyclops resulting in higher population of larval worms. The parasite populations fluctuate on year to year basis as reported by Kennedy (1996) and the transmission rate of a parasite may be determined by the size of parasite population (Nie and Kennedy, 1991). The composition and abundance of suitable intermediate host in a locality may contribute to the distribution and infection level of a parasite.

The role of parasites on host reproduction and host death by predation may also be taken into consideration in infection dynamics of *S. solidus* in *G. aculeatus.* The effects of the parasite on the host are most evident when the host reproductive potential is reduced and infection results in mortality of larger host. The larger fish carry bigger parasites which are able to reproduce in the final host (Heins *et al.,* 2002). Our results are in contrast to Heins *et al.* (2010); because in our case low values of metrics for parasite population was in sample II, when the host fish population was high and vice versa in sample III. In nature probably different biotic and abiotic factors may affect the transmission of *S. solidus* at any stage of life cycle and thus could affect the prevalence and intensity of infection. Such factors could influence the survival of coracidia, or abundance of suitable copepod at a given time. Moreover, the growth of plerocercoid in fish host may be influenced by factors both internal and external to the fish host.

CONCLUSION

It may be concluded that *S. solidus* was moderately established in *G. aculeatus* population in Airthrey Loch as compared to earlier studies in Britain.

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