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Ecological Factors Influencing the Infection Levels of Salmonids by *Acanthocephalus opsariichthydis* (Acanthocephala: Echinorhynchidae) in Lake Yunoko, Japan

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Ecological factors influencing the infection levels of salmonids by *Acanthocephalus opsariichthydis* in Lake Yunoko, Japan, were analysed. The most important factor is the feeding habits of the definitive host. Brook trout, *Salvelinus fontinalis*, were heavily infected with this parasite as they fed on the intermediate host, *Asellus hilgendorfi*. By contrast, Biwa salmon, *Oncorhynchus rhodurus*, and kokanee, *O. nerka*, preyed mainly on fish and plankton, respectively, and hence, they were infected to a lesser extent with this parasite. The overlapping habitats of the definitive and intermediate hosts were noted. These are the factors accelerating greater contact between both the hosts. Most brook trout inhabited the littoral zone, to which *A. hilgendorfi* were restricted. However, Biwa salmon and kokanee were widely dispersed in the lake. A close distributional relationship between plant materials and *A. hilgendorfi* was also suggested.

Introduction

The acanthocephalans of the family Echinorhynchidae often exhibit broad specificity toward fish definitive hosts. A number of hosts are recorded in the literature for some species of this family. *Echinorhynchus salmonis* has been found in 57 species and subspecies (PETRUSHEVSKI and SHULMAN, 1958) and *Acanthocephalus anguillae* in 36 species (PETROCHENKO, 1956).

CHUBB (1964) reported differences in the occurrence of *A. clavula* (=*E. clavula*) among four species of fishes in Llyn Tegid (Bala Lake), Merionethshire. He attributed them to the difference in the feeding of the fishes on *Asellus meridianus*, the intermediate host of the parasite, except for pike, which appeared to acquire the infections not by feeding on the isopod but by the secondary process of eating already infected fishes. The feeding habits are primary factors since natural infection occurs when a fish ingests an intermediate host containing an infective larva. The intermediate hosts for species of the Echinorhynchidae are amphipod or isopod crustaceans, and hence, carnivorous fishes are more readily infected with echinorhynchid acanthocephalans through ingestion than are hervivorous and omnivorous fishes. However, there must be additional factors influencing the infection levels rather than just the feeding habits. For example, factors promoting greater contact between definitive and intermediate hosts would lead to heavier

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infections.

The present study was intended to elucidate those factors that influence the levels of acanthocephalan infections. In initiating the study, we were justifiably concerned with the selection of a suitable site and examined several possible locations that might best serve as a study site. As a result, Lake Yunoko was chosen because of (1) the heavy infections of fishes with "*Acanthocephalus*? sp." (MATSUMOTO, 1972), (2) the availability of ecologically different fish populations, (3) its small size, and (4) its location close to the laboratory of the Nikko Branch of the National Research Institute of Aquaculture with appropriate facilities. MATSUMOTO first noted the acanthocephalan infections of salmonid fishes in this lake and reported that the isopod, *Asellus hilgendorfi,* harvored the parasite larva. The acanthocephalan was identified as *Acanthocephalus opsariichthydis* YAMAGUTI, 1935, and its life cycle was confirmed by the present authors (unpublished).

Materials and Methods

Lake Yunoko (36°47′N, 139°25′E) is a small lake located in Tochigi Prefecture, measuring approximately 900 m long, 400 m wide, and up to 15 m in depth (Fig. 1). This lake has no inlet streams, and its water is supplied by springs. At the outlet, there is a big waterfall, which prevents upstream fish migration. A belt of submerged plants fringes the margin of the lake. For detailed descriptions of the lake see JIBP-PF RESEARCH GROUP OF LAKE YUNOKO (1975).

The following salmonids were selected for the study: brook trout, *Salvelinus fontinalis*; Biwa salmon, *Oncorhynchus rhodurus*; and kokanee, *O. nerka*. Fishes were collected with nylon gill nets at monthly intervals during the period July 1978 to June 1979. A fleet of gill nets composed of four 10-m by 2-, 4-, 6-, and 8-m panels of each of five mesh sizes was set along the bottom at Station A, and a 10-m by 10-m gill net of the same mesh sizes was employed at Station B (Fig. 1). During the winter, however, fishes could not be sampled at Station B because of the ice-cover of the lake. The nets were laid for 5-h periods in the summer or overnight in other seasons, after which they were lifted and brought to the laboratory. When the fishes were removed from the nets in the summer and spring, their capture positions were recorded in order to clarify their distributions within the lake. In the summer, the stomachs were also taken and fixed in 10% formalin for food analyses. The contents were identified to the lowest possible taxon under a binocular dissecting microscope. The wet weight of respective stomach contents was recorded.

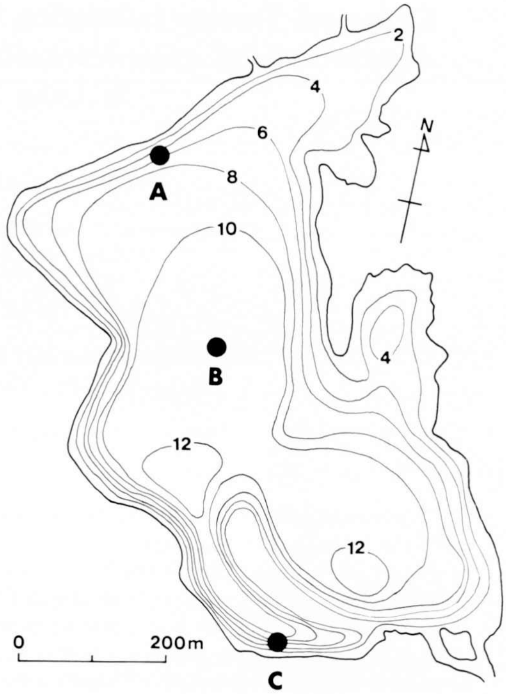

Fig. 1. Sampling stations of salmonids (A & B) and *Asellus hilgendorfi* (C) in Lake Yunoko. Depths on the contour lines are in meters.

In October 1978, *Asellus hilgendorfi* were collected with an EKMANN-BIRGE bottom sampler (0.2×0.2 m) at depths of 0.2, 1, 2, 3, 4, 6, 8, and 10 m at Station C (Fig. 1).

Throughout the text, each season is defined as: winter (January–March), spring (April–June), summer (July–September), and autumn (October–December).

Results

Occurrence of *Acanthocephalus opsariichthydis* in salmonids

Of the three species of salmonids examined, brook trout were most frequently and heavily infected with *A. opsariichthydis*. Biwa samlon were infected to a lesser extent with this parasite than brook trout, and kokanee were the least infected of these three species. This tendency appeared to be stable throughout the year (Table 1) and between host size classes (Table 2), although the sample of Biwa salmon was too small for statistical comparison of the infection levels.

Distributions of the definitive hosts

Figure 2 shows the fish distribution patterns in the summer and spring. No fishes were taken at depths greater than 4 m at Station B. This is thought to be due to the formation of un-oxygenated layer caused by the eutrophication of the lake.

Brook trout were mainly confined to the

Table 1. Seasonal occurrence of *Acanthocephalus opsariichthydis* in three species of salmonids from Lake Yunoko

Host	Season	No. of fishes		Prev-alence*	No. of worms recovered	Mean** intensity	Relative*** density
		examined	infected				
Brook trout	Summer	23	23	100	898	39.0	39.0
	Autumn	15	15	100	389	25.9	25.9
	Winter	12	10	83.3	237	23.7	19.8
	Spring	25	24	96.0	1324	55.2	53.0
	Total	75	72	96.0	2848	39.6	38.0
Biwa salmon	Summer	9	6	66.7	55	9.2	6.1
	Autumn	3	3	100	7	2.3	2.3
	Winter	0	—	—	—	—	—
	Spring	1	1	100	2	2.0	2.0
	Total	13	10	76.9	64	6.4	4.9
Kokanee	Summer	65	11	16.9	23	2.1	0.4
	Autumn	39	6	15.4	43	7.2	1.1
	Winter	3	0	0	0	—	0
	Spring	82	7	8.5	10	1.4	0.1
	Total	189	24	12.7	76	3.2	0.4

* Percentage of fishes infected.
** Mean number of worms per infected fish.
*** Mean number of worms per fish examined.

Table 2. Relationship between the occurrence of *Acanthocephalus opsariichthydis* and the size classes of three species of salmonids from Lake Yunoko

	Brook trout	Biwa salmon	Kokanee
Host size classes (Body length)			
– 9.9 cm	2, 2(100), 31, 15.5, 15.5*		3, 1(33.3), 1, 1.0, 0.3
10–19.9 cm	25, 25(100), 1329, 53.2, 53.2		111, 12(10.8), 24, 2.0, 0.2
20–29.9 cm	48, 45(93.8), 1488, 33.1, 31.0	10, 7(70.0), 21, 3.0, 2.1	73, 10(13.7), 50, 5.0, 0.7
30–39.9 cm		2, 2(100), 40, 20.0, 20.0	2, 1(50.0), 1, 1.0, 0.5
40–49.9 cm		1, 1(100), 3, 3.0, 3.0	
Total	75, 72(96.0), 2848, 39.6, 38.0	13, 10(76.9), 64, 6.4, 4.9	189, 24(12.7), 76, 3.2, 0.4

* Number of fishes examined, number of fishes infected (prevalence %), number of worms recovered, mean intensity, relative density.

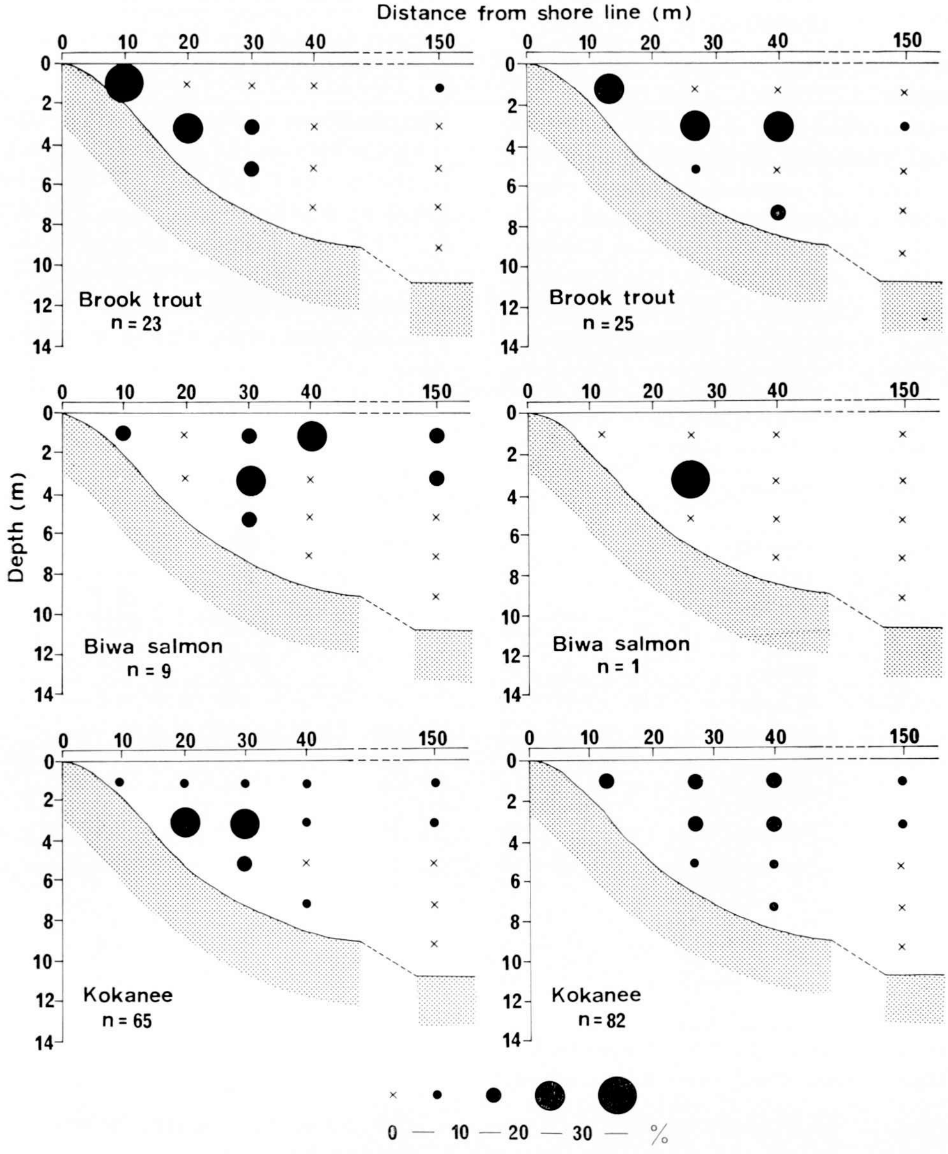

Fig. 2. Distributions of three species of salmonids in Lake Yunoko. Left: summer, right: spring.

littoral zone of the lake. Only two fishes were collected at Station B. By contrast, Biwa salmon and kokanee were widely dispersed from surface to bottom, and did not show as a restricted habitat preference as brook trout. Although exact observations were not made in the autumn, a similar distributional pattern was recognized, although in October fishes were abundant inshore probably for spawning. SHIRAISHI and TAKAGI (1955) reported that brook trout were more abundant inshore than offshore in this lake contrary to kokanee. TANAKA and SHIRAISHI (1970) also found that, although fish distributions varied with seasons, brook trout and both Biwa salmon and kokanee were mainly captured inshore and offshore, respectively. Therefore, it can be said that the brook trout is a coastal dweller, while the Biwa salmon and the kokanee are open water inhabitants.

Distribution of the intermediate host

Asellus hilgendorfi were restricted to the vegetated coastal bottom. They were most abundant at a depth of 0.2 m, decreased in number with increasing depth, and disappeared below a depth of 4 m (Fig. 3). Similar tendencies have been noted at different seasons in this lake in other papers by SHIRAISHI (1964), SHIRAISHI *et al.* (1970), SEKINE and TSUCHIYA (1972) and KITAGAWA (1974). Of these, SEKINE and TSUCHIYA suggested the seasonal vertical migration of this isopod; nevertheless, its migration range was so confined (within 3 m) that the distributional range of the isopod appears to be stable throughout the year. In addition, although we collected *A. hilgengorfi* at Station C where is far from Stations A and B, the fact that these authors obtained similar results at different sampling sites indicates no or little difference in its distributional pattern within the lake.

Feeding habits of the definitive hosts

Stomach content analysis data, expressed as the percentage of each food item of the total wet weight of food eaten, are presented in Table 3.

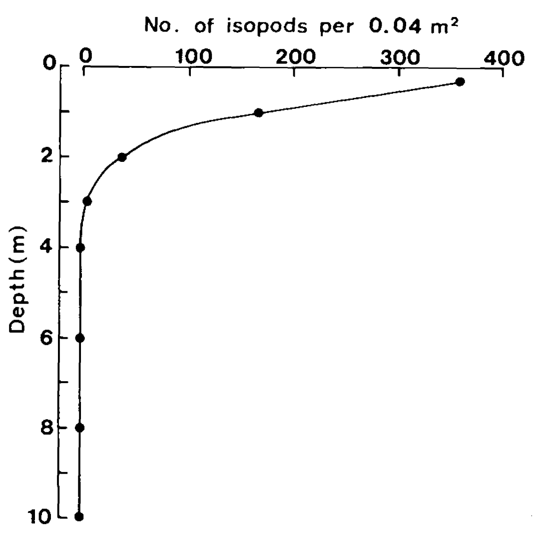

Fig. 3. Vertical distribution of *Asellus hilgendorfi* on the bottom of Lake Yunoko.

Table 3. Percentages of total wet weight of food items in the diets of three species of salmonids from Lake Yunoko

	Brook trout	Biwa salmon	Kokanee
No. of fishes examined	10	9	10
Food item			
Crustacea			
Cladocera	4.1	23.5	83.0
Asellus higendorfi	2.1	—	—
Insecta			
Chironomidae			
larvae	65.8	12.1	16.8
pupae	4.7	8.4	0.2
Hymenoptera	5.3	0.3	—
Hemiptera	—	11.9	—
Coleoptera	—	0.6	—
Arachnida			
Acarina	0.8	—	—
Gastropoda			
Physidae	15.6	—	—
Bivalvia			
Pisidium sp.	1.6	—	—
Teleostomi			
Hypomesus transpacificus nipponensis	—	43.2	—

Brook trout preyed on the widest variety of food organisms of the three species of salmonids examined. *Asellus hilgendorfi* occurred only in the diet of brook trout. The most important food component was chironomid larvae, primarily *Chironomus plumosus*, which made up to 65.8% of the total weight of food consumed. Benthos such as gastropods, sphaeriid clam *Pisidium* sp., and water mites were also ingested. Cladocerans, mainly *Daphnia longispina*, and terrestrial hymenopterans were of little importance. Although SHIRAISHI and TAKAGI (1955) found that brook trout of this lake fed heavily on *A. hilgendorfi* and trichopteran larvae, the abundance of these animals was small or null in the stomachs examined by us.

The major food item of Biwa salmon was the pond smelt, *Hypomesus transpacificus nipponensis*, a fish species that was abundant in this lake. The importance of fish in the diet of Biwa salmon has been also reported in Lake Biwa (SHIGA PREF. FISH. EXP. ST., 1942; KATO, 1978). Cladocerans and chironomid larvae and pupae were of minor importance. Terrestrial insects, largely hemipterans with a few coleopterans and hymenopterans, were also preyed on.

Kokanee fed exclusively on cladocerans which composed over 80% of the total weight of food eaten. Chironomid larvae and pupae were ingested infrequently. Similar feeding trends have been noted in several lakes (HIGURASHI, *et al.*, 1931; SAWA, 1932; OSANAI and TANAKA, 1971; MAYAMA, 1978) including the present locality (SHIRAISHI and TAKAGI, 1955).

From these results, the three salmonid species can be characterized clearly as follows: the brook trout is a benthos feeder, the Biwa salmon a fish feeder, and the kokanee a plankton feeder.

Discussion

Parasitic infection results from the contact between host and parasite. In the Acanthocephala, its contact corresponds with the feeding of the definitive host on the crustacean intermediate host containing the infective larva. This was demonstrated primarily by differences in the feeding habits of the fishes in the present study. Of the three species of salmonids examined in Lake Yunoko, brook trout were most frequently and heavily infected with *Acanthocephalus opsariichthydis*. This is caused by the fact that brook trout preyed on benthic animals including *Asellus hilgendorfi*, while Biwa salmon and kokanee fed heavily on fish and plankton, respectively.

Several other factors accelerating greater contact between host and parasite were also suggested. These are the distributions of the definitive and intermediate hosts. Most brook trout inhabited the littoral zone, to which *A. hilgendorfi* were restricted. The overlapping habitats of both definitive and intermediate hosts would promote the chancei to encounter each other. However, Biwa salmon and kokanee would have fewer chances to meet *A. hilgendorfi* than brook trout since the former two fishes were widely dispersed in the lake.

It has been suggested that piscivorous fishes become heavily infected with echinorhynchid acanthocephalans by preying on already infected fishes (CHUBB, 1964; AMIN and BURROWS, 1977; HOLMES *et al.*, 1977). The transfer of *Echinorhynchus salmonis* from one host to another has been experimentally demonstrated (HNATH, 1969). The Biwa salmon is a typical piscivorous fish in Lake Yunoko, but its parasite burden was relatively low. This may be due to the fact that this fish ingested the pond smelt. This prey fish feeds mainly on zooplankton (NAKAMURA, 1975), and does not appear to serve as a significant transport host in the lake.

Asellus hilgendorfi were found to climb both aquatic plants and fallen leaves on the coastal bottom. KADOTA *et al.* (1973) and KUBOTA (1973) reported that these plant materials were restricted to the littoral zone. SEKINE and TSUCHIYA (1972) emphasized the importance of submerged dead leaves as food of the isopod, in addition to which the submerged plants must also provide a suitable habitat. Therefore, the occurrence of submerged plants and fallen leaves is considered to be an important factor in determining the distribution of *A. hilgendorfi* and indirectly in affecting the acanthocephalan infection.

Acanthocephalan infection is essentially brought on by the feeding of the fish on the infected crustacean intermediate host. However, it is apparent that the infection is influenced by several facors such as the distributions of the definitive and intermediate hosts as well as those of the plant and animal communities. Parasitism is one aspect of the interactions of many organisms in a certain environment. Thus, to appreciate fully the parasitic infection, ecological approaches not only concerning the host and parasite relationships but also the complex biotic communities within a given regional ecosystem, including other plants and animals, would be essential. Our work performed in Lake Yunoko is still insufficient in this sense, and further detailed study is needed.

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湯ノ湖産サケ科魚類におけるハス鉤頭虫の寄生度に関与する生態学的要因

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(昭和 58 年 7 月 18 日受理)

栃木県奥日光の湯ノ湖でサケ科魚類（カワマス・ビワマス・ヒメマス）におけるハス鉤頭虫 *Acanthocephalus opsariichthydis* の寄生度に関与する生態学的要因を調査した。湖の沿岸帯底層に多く生息して底生動物を主餌料としているカワマスは，同じく沿岸帯浅水域の底土に集中分布する本鉤頭虫の中間宿主ミズムシ *Asellus hilgendorfi* を摂食する機会が多いことから，その寄生を多数受けていた。これに対し，ビワマスとヒメマスの生息域は表層かつ沖合に広がっており，それぞれ魚類と動物プランクトンを多く捕食するため，底生動物も摂るものの，本鉤頭虫の寄生数は少なかった。以上のことから，本鉤頭虫の場合も，魚における寄生度を決定する主な要因は魚類の食性における中間宿主との捕食者・被食者関係であることが確認されたほか，両者の生息域の異同が寄生度を軽減または助長させる副次的な要因として関与していることが明らかになった。

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