Journal of Fish Biology (1993) 43, 621-632

Seasonal studies of the biology of *Achtheres percarum* in perch, *Perca fluviatilis,* from four Finnish lakes over a 3-year period

E. T. VALTONEN*, H. TUUHA* AND O. N. PUGACHEV**

**Department of Biology, University of Jyväskylä, Finland, and **Institute of Zoology, Russian Academy of Sciences, St Petersburg, Russia*

(Received 30 October 1992, Accepted 18 January 1993)

Achtheres percarum infection on the gills of perch *Perca fluviatilis* was studied from four lakes in central Finland in monthly or bimonthly samples of fish during a 3-year period. The highest prevalence and intensity of infection (30%, 0.7 copepods/fish) were found in the oligotrophic, unpolluted Lake Peurunka and the lowest (6%, 0.1 copepods/fish) in the eutrophic and polluted Lake Vatia. According to hierarchical loglinear models the prevalence of A. *percarum* infection was related to the lake, but not to the year. However, when logit models were constructed such that two ' seasons ' (' cold ' and ' warm ' periods) were included, it was apparent that the year also influenced the prevalence of *A. percarum,* but only during the ' warm ' period of the year. *Achtheres percarum* had an age dependent relationship only in Lake Peurunka, where the infection increased with increasing age of the fish. Some developmental stages of *A. percarum* parasitizing the gills of perch are described. Data on the seasonal occurrence of *A. percarum* developmental stages are given and it is suggested that at least two generations are produced annually.

Keywords: *Achtheres percarum; Perca fluviatilis;* Finland; prevalence; intensity; seasonality.

I. INTRODUCTION

The parasitic copepod *Achtheres percarum* Nordmann, 1832 is distributed throughout the Palaearctic region nearly as widely as the perch *Perca fluviatilis* (L.) one of its principal hosts. It does not occur, however, to the east of the Lena River in Siberia. Another host species of *A. percarum* is pike-perch *Stizostedion lucioperca* (L.), which occurs in the study area at the northern border of its distribution.

Although some data on the infection of *A. percarum* are available, seasonal and host age-related occurrence are not well known. However, this copepod may have significant pathological effects on the fish host: for example, on the speed of the sedimentation of the red blood cells and on the number of red blood cells of fish (Stepanova & Vjuskova, 1985).

Tuuha *et al.* (1992) demonstrated that the lake condition, season and year had important influences on ergasilid copepods of perch and roach *Rutilus rutilus* (L.) from the present study area in central Finland. The four interconnected lakes differed in water quality and pollution levels. When analysing the occurrence of three ergasilid species using logit models it was found that the prevalence of *Ergasilus briani* Markevich, 1932 on roach depended on season only, with higher prevalences in summer, but that of *E. sieboldi* Nordmann, 1832 on perch was mainly dependent on the lake type, being most frequent in

0022-1112/93/010621 +12 $08.00/0

the oligotrophic lake, whereas both lake type, year and season affected the prevalence of *Neoergasilus japonicus* Harada, 1930. These observations demonstrate the flexibility of parasitic crustaceans to respond to environmental conditions in a variety of different ways, and provided the incentive for examining the results obtained from our studies of *Achtheres percarum* on perch using loglinear models.

Loglinear models provide a useful technique for evaluating the effects of a number of different but interrelated factors on parasite populations. The models are also necessary because Shulman *et al.* (1974) and Ieshko *et al.* (1982) did not find any clear correlation between the trophic status of the lake and the occurrence of *A. percarum*. By contrast, Anikieva (1982) in a lake in Karelian Russia found that perch from an area affected by pulpmill effluents lacked *A. percarum,* although the copepod did occur on perch from the unpolluted area of the same lake.

The present paper reports the results of seasonal studies of the biology of *Achtheres percarum* in perch from four interconnected Finnish lakes over a 3-year period using hierarchical loglinear and logit models for analysis. Some developmental stages of *A. percarum* are also described.

II. STUDY AREA

The Kymijoki water system opens into the Gulf of Finland (Fig. 1). Lakes Vatia, Saravesi and Leppävesi are eutrophic. Lake Vatia is polluted by the effluents of paper and pulp mills 15 km upstream and traces of these pollutants are also detected in Saravesi and Leppävesi. Lake Peurunka is oligotrophic and unpolluted. More detailed descriptions of the lakes are given by Halmetoja *et al.* (1992).

Lake Peurunka is deep and it has the maximum water retention (3-4 years). In Lakes Vatia, Saravesi and Leppävesi the water is changed at 3, 4 and 32 days, respectively (see also Brummer-Korvenkontio *et al.,* 1991). The lakes are ice-covered from about 20-25 November until 10 May of the following year. The highest water temperatures are at the end of July and the beginning of August (18-20° C). Daily water temperatures at a depth of 4 m in oligotrophic Lake Peurunka are given in Koskivaara *et al.* (1991). The summer of 1987 was cooler than that of 1986. The mean water temperatures at a depth of 4 m in 1987 in May, June, July and August were 5.4, 12.7, 15.6 and 14.9° C, and, in 1986, 6.9, 13.6, 18.0 and 19.9° C, respectively.

Waters from the oligotrophic Lake Peurunka flow into the polluted Vatia. Obstacles for fish migration between the lakes are a dam built in the 1960s in connection with the fish farm between the oligotrophic and the polluted lake, strong rapids between the polluted and the first eutrophic lakes and an electricity power station between the two eutrophic lakes (Fig. 1).

At least 14 freshwater fish species occur in all of the lakes, of which roach and perch are the most common overall. The eutrophic lakes have also been stocked with zander *Stizostedion lucioperca* (L.) during the 1980s. No drastic differences in the relative abundances of roach and perch between the lakes have been reported (Granberg *et al.,* 1987*a,b).*

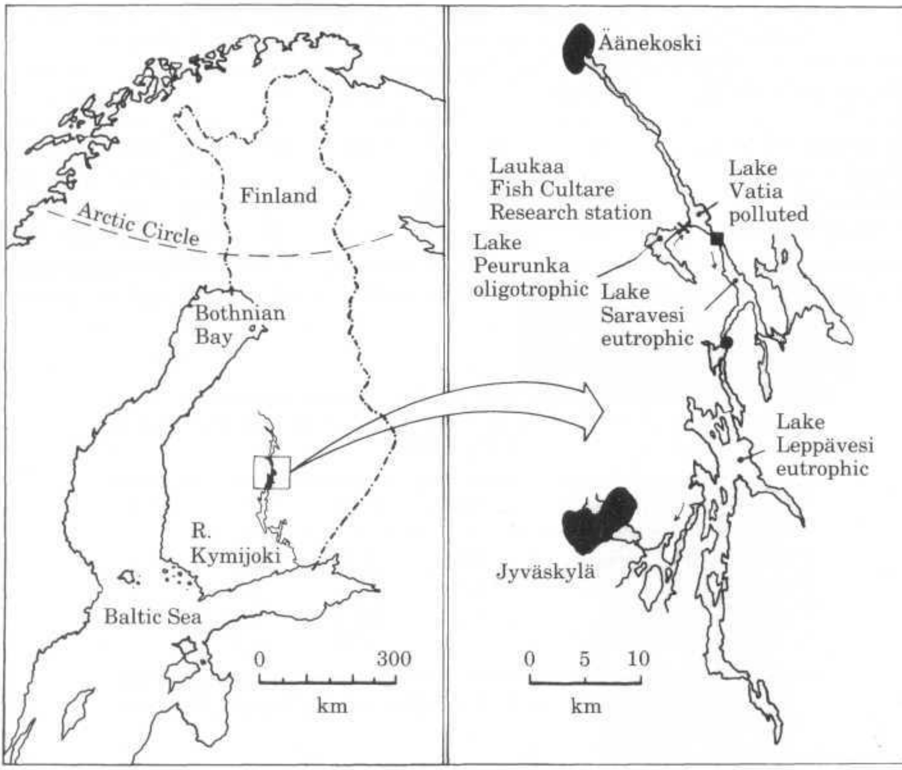

FIG. 1. The four lakes studied in central Finland. Obstacles for fish migration are: ×, dam; ■, strong rapids, and ●, electricity plant.

III. MATERIALS AND METHODS

From the four lakes 866 perch were studied. The fish were caught from three lakes between August 1985 and August 1988 and from Lake Leppävesi between February 1986 and November 1987. About 15 specimens of each species were collected monthly during the open water period and bimonthly during the period of ice-cover. Fish, caught mainly by angling and ice-fishing, were measured, weighed, sexed and aged. Living fish were brought to the laboratory and were examined within 5 h for ectoparasites.

A total of 292 of *Achtheres percarum* specimens were found and 131 specimens sampled randomly throughout the year were measured from cephalon (without antennae, and maxillipeds) to abdomen. Different stages of young individuals were also identified. When interpreting the developmental stages, the data were compared with developmental stages of *Salmincola californiensis* (Kabata & Cousens, 1973). In this work chalimus II and III stages were grouped together. Males and females could be distinguished in the chalimus IV stage. A third group was composed of adult males and females of which females were divided to those with eggs (gravid) and without eggs.

In order to analyse the factors which influence the prevalence of *Achtheres* infection hierarchical loglinear models and logit models were constructed (see Cox, 1970; Tuuha *et al.*, 1992; Halmetoja *et al.*, 1992). Each year was divided into two periods using water temperature over 10° C as a criterion for the 'warm' period (June-September) and defining the rest of the year as the 'cold' period. Statistical analyses were performed with SPSS-X and SYSTAT statistical software.

TABLE I. Occurrence of *Achtheres percarum* on perch *(Perca fluviatilis)* in four lakes studied between August 1985 and August 1988 in central Finland

Type and name of lake	No. fish	%	*x*	max	Σ	Time studied
Oligotrophic Peurunka	295	30	0.7	10	207	Aug. 1985-Aug. 1988
Polluted Vatia	125	6	0.1	2	13	Aug. 1985-Nov. 1987
Eutrophic Saravesi	265	13	0.2	4	53	Nov. 1985-Aug. 1988
Eutrophic Leppävesi	185	8	0.1	2	19	Feb. 1986-Sep. 1987

Prevalence (%), intensity of infection (copepods/fish), maximum number per fish, and total number of copepods found are given.

TABLE II. Prevalences of *Achtheres percarum* infection (%) on perch *(Perca fluviatilis)* from four lakes in central Finland in 1985-1988

Type and name of lake	1985	1986	1987	1988
Oligotrophic Peurunka	39.5	27.1	26.7	31.8
Polluted Vatia	12.0	—	8.5	
Eutrophic Saravesi	—	10.9	19.6	7.9
Eutrophic Leppävesi		6.4	9.3	

Monthly samples throughout 1986 and 1987; only four samples per annum during 1985 and 1988.

IV. RESULTS

Prevalence and intensity of infection was highest (30%, 0.7 copepods/fish) in the oligotrophic Peurunka and lowest (6%, 0.1 copepods/fish) in the polluted Vatia (Table I).

Achtheres prevalences in 1986 and 1987, when fish samples were collected evenly throughout the year, and in 1985 and 1988 when only 4-monthly samples each year were examined, the highest prevalences were always found in the oligotrophic Peurunka (Table II).

There was no statistically significant age-related variation in prevalence except in eutrophic Saravesi where infection increased with age of perch [G=18.3, d.f. = 5, P=0.003 (Fig. 2)].

Prevalences of *A. percarum* peaked during the period July to September each year (Fig. 3) but did not show any clear pattern through the remainder of each year. The highest recorded monthly prevalence (78%) was in September 1985 in oligotrophic Lake Peurunka.

Figure 4 shows the prevalences of *A. percarum* in the four lakes in 1986 and 1987, and the same data divided into warm (June-September) and cold (October-May) periods.

Hierarchical loglinear models were used to examine the interactions between the year, the lake and the occurrence of *A. percarum*. Among nine models, from a fully saturated one which fitted perfectly the observed frequencies of infected and uninfected fish, to an independent model, two simplest models were chosen from those which fitted the data statistically. Model 1: constant+year+

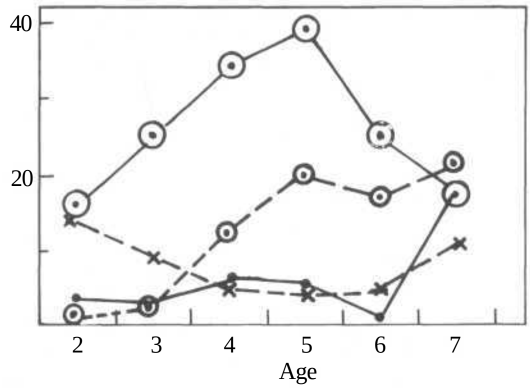

FIG. 2. Prevalences of *Achtheres percarum* infection according to the age of perch (years) in oligotrophic Lake Peurunka, —⊙—; eutrophic and polluted Lake Vatia, —●—; eutrophic Saravesi, - -⊙- -, and Leppävesi, — × —, in 1985-1988.

Achtheres+lake+year . *Achtheres*+*Achtheres* . lake (*G*=8.6, d.f. = 6, *P*=0.2). This model showed that when changes occurred in different lakes between the years the changes were in parallel, that is, in the same direction in each instance. This provided the basis for reducing model 1 to model 2: constant+year+ *Achtheres*+lake + *Achtheres* . lake, which was the simplest model of those fitting the data (likelihood ratio *G*-test= 11.1, d.f. = 7, *P*=0.133). Dropping the interaction term *Achtheres* . year from model 1 did not decrease the fitness of model 2 significantly (*G*=2.56, d.f. = l, *P*>0-05). Model 2 could be simplified so that there were no differences in *A. percarum* prevalences between the years. However, when 18 logit models were constructed, where prevalences of *A. percarum* were explained by the lake, the year and also the season, the simplest model (3) which fitted the data was: *Achtheres*+*Achtheres* .lake+*Achtheres* .year+ *Achtheres* . season+*Achtheres* . lake . season+*Achtheres* . year . season (*G*= 12.4, d.f. = 6, *P*=0.054). This means, however, that the year was an important factor and was influencing the *Achtheres* infection, because of the interaction between the season and the year.

The co-occurrence of the two parasitic copepods, *A. percarum* and *Ergasilus sieboldi* (see Tuuha *et al.*, 1992) did not differ significantly from random in any of the lakes (likelihood ratio *G*-test, the lowest probability=0.204).

Some chalimus and adult stages of *A. percarum* from Finland are illustrated (Fig. 5). Figure 5(a) provides a lateral view of the early chalimus stage (=chalimus II and III of Kabata & Cousens, 1973) with minimal development of appendages showing second maxillae and maxillipeds, and frontal filament. There is no distinct division between forebody and hindbody, no segmentation, no swimming legs. The mean length of this stage was 0.842 mm (Table III). A lateral view of a later chalimus stage with a slight division in the cephalon segment is seen in Fig. 5(b). The first antenna is clearly seen. A dorsolateral view of the female chalimus stage IV [Fig. 5(c)] shows the more elongated and cylindrical second maxillae with bulla. Maxillipeds with hooks with a waist behind the maxillipeds to form a division between the cephalothorax and trunk. The frontal filament and bulla are still present. The lateral view of an adult male [Fig. 5(d)] shows forebody and hindbody, with maxillipeds extending forward,

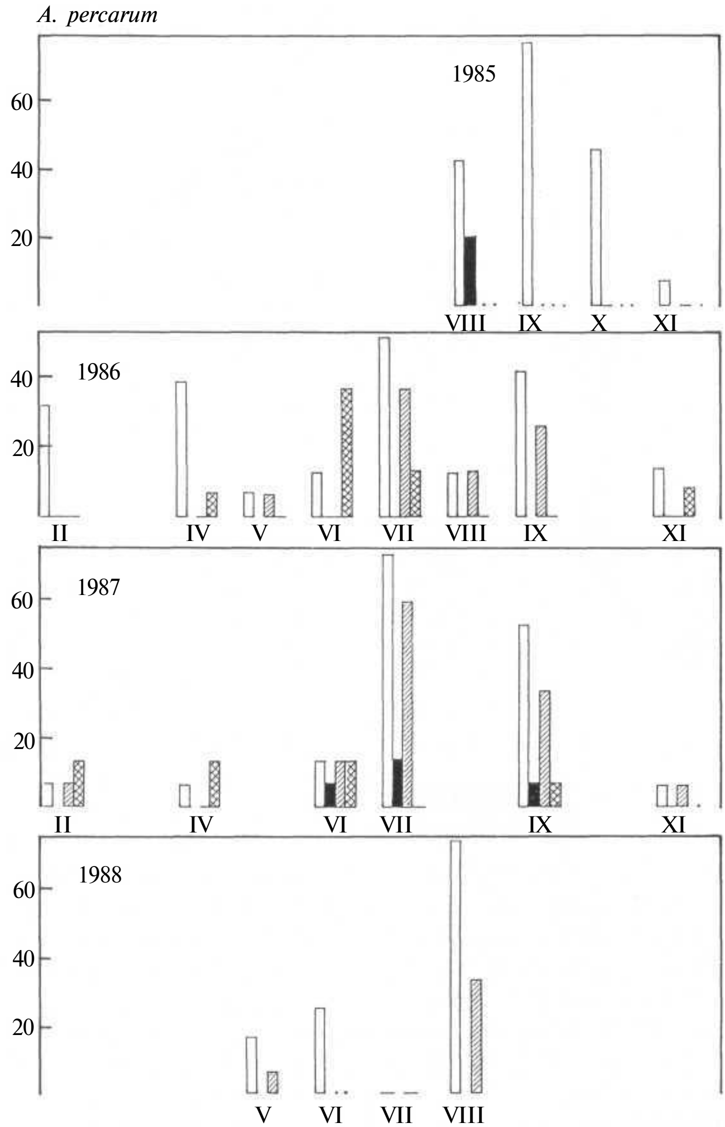

FIG. 3. Monthly prevalences of *Achtheres percarum* infections on perch *(Perca fluviatilis)* in four central Finnish lakes between August 1985 and August 1988. Number of fish in monthly samples from each lake is on average 15. □, Lake Peurunka (oligotrophic); ■, Lake Vatia (polluted, eutrophic); ▨, Lake Saravesi (eutrophic); ▩, Lake Leppävesi (eutrophic). The gap on the *x*-axis means that no fish were studied.

more so than in the female. The first antenna is three segmented. The mean lengths of chalimus IV females and males were 1.288 and 1.111 mm, respectively. Younger chalimus larvae were found only during a limited period in July-August and chalimus IV stages, both males and females, during July-October (Fig. 6). The majority of adult *A. percarum* males on perch gills were found in July-September, with one specimen in February 1987 (Fig. 6). Their mean length was 1.348 mm as compared to adult females, 2.405 mm (Table 3). The proportion of

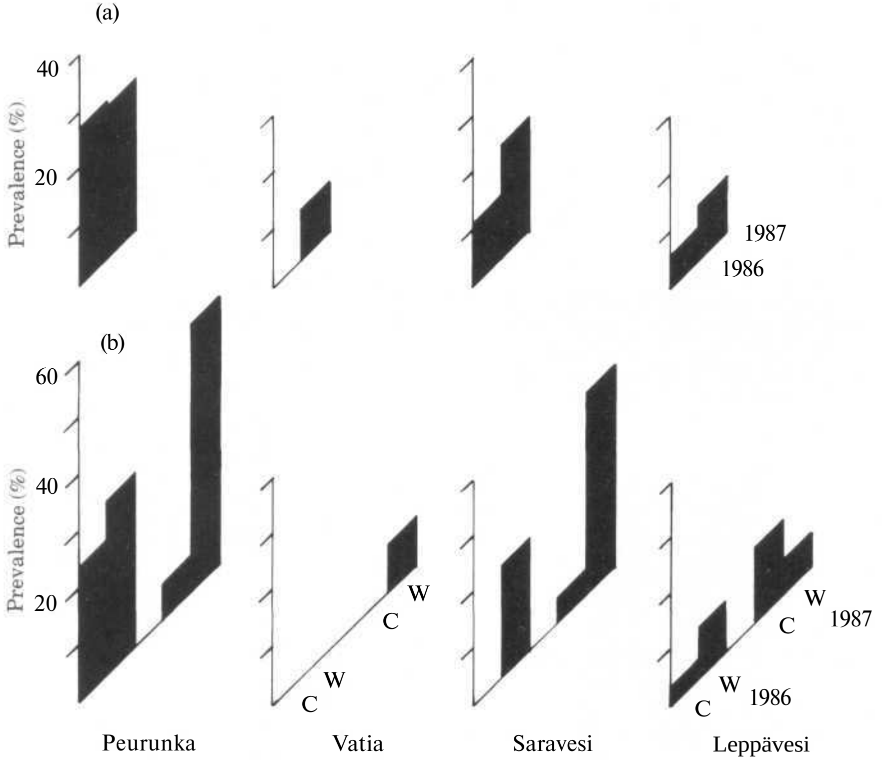

FIG. 4. *Achtheres percarum* prevalences in the four lakes studied in central Finland in 1986 and 1987 (a) and also divided according to the ' warm ' and ' cold ' periods of each year (b).

adult males was 27.7% (n = 119). Adult females were located on perch gills throughout the year; 45% of the total during June to September, 55% from October to May. The largest adult females were encountered in February-May period, when the mean length was 2.585 mm (S.D. 0.254); in July-August they were smallest, 2.086 mm (0.417) whilst in September-November the average size was 2.326 mm (0.341). Gravid females were found during the period May-September, although in 1987 two gravid females were also found in November. Biggest mature females were found in May, 2.48 mm (0.41) after which the monthly mean length was about 2.2 mm up to September.

V. DISCUSSION

Achtheres percarum infects both perch and pike-perch (Harding & Gervers, 1956; Markevich, 1956; Fryer, 1969; Gusev *et al.,* 1987). However, the prevalence on each of these species of fish varies from lake to lake: in Russian Karelia, in Lake Sjamozero, perch showed low prevalences (13%), whereas pike-perch had high prevalences (69%) (Shulman *et al.,* 1974); by contrast, in lakes Kimasozero, Luvozero and Njukozero, perch had high prevalences (24, 48 and 42%), but pike-perch were absent (Ieshko *et al.,* 1982).

In Lake Vigozero Ryback (1982) found that after introducing pike-perch into the lake in 1948 onwards, the *A. percarum* prevalence increased being 60% in

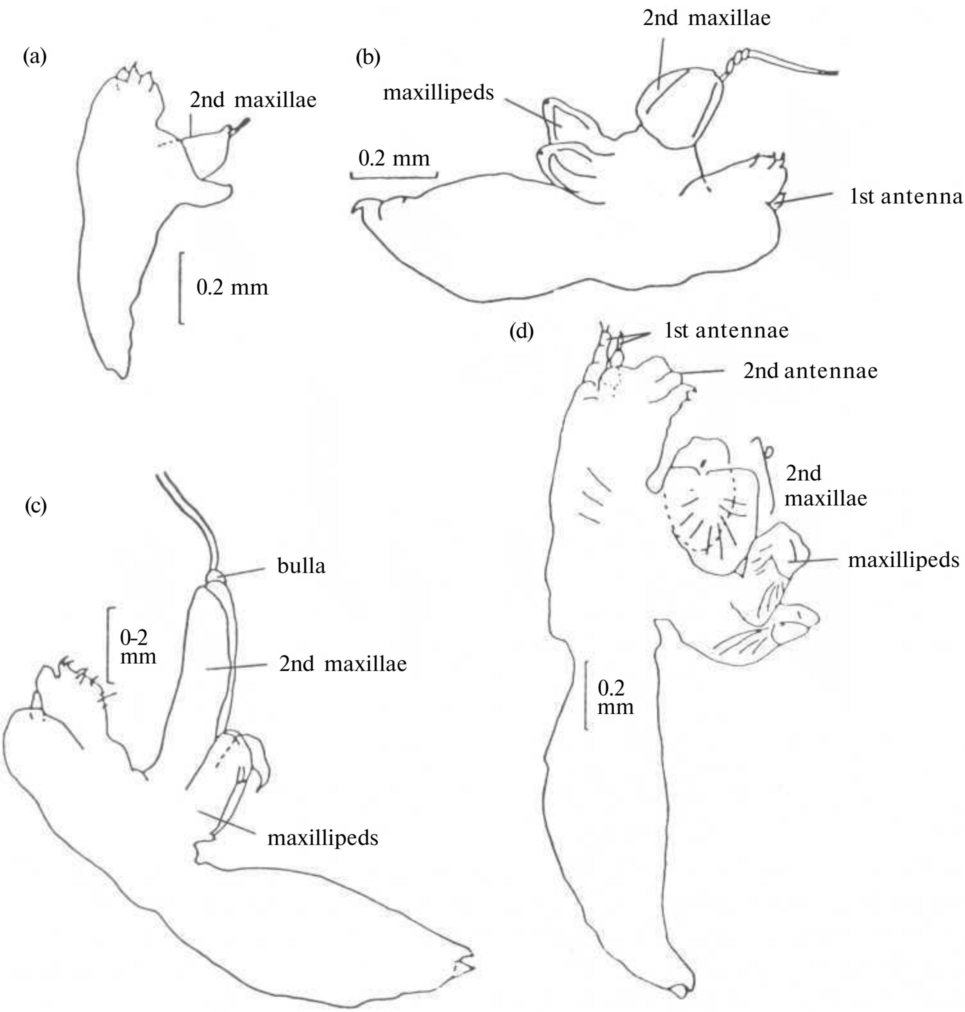

FIG. 5. Developmental stages of *Achtheres percarum* found on the gills of perch from Central Finland, (a) An early chalimus, (b) more advanced chalimus, (c) chalimus IV female, (d) adult male.

pike-perch in 1965. Pike-perch disappeared from many lakes in Central Finland some decades ago the reason being unknown. In the present area it was restocked successfully into the polluted and the two eutrophic lakes in the 1980s. Owing to a dam between Lakes Vatia and Peurunka the pike-perch are not able to enter the oligotrophic lake. The highest prevalence during the current study of *A. percarum* was on perch in the oligotrophic lake, compared to the other three lakes.

Both the hierarchical loglinear models and logit-models showed that the lake had an influence on prevalence of *A. percarum*. The highest prevalence in Lake Peurunka could be related to the lack of pike-perch in this lake, but there may be other reasons, for instance differences in rate of water flow through the lakes, water depths and the influence of organochlorine compounds on the larval stages. To discover which of these or other factors are relevant

TABLE III. Length of developmental stages of *Achtheres percarum* on the gills of perch *(Perca fluviatilis)* from Central Finland between August 1985 and August 1988

	n	Mean length (mm)	S.D.	Range
Gravid females	32	2.273	0.339	1.640-3.116
Adult females	38	2.405	0.377	1.416-2.952
Adult males	23	1.348	0.155	1.056-1.584
Chalimus IV female	20	1.288	0.24	0.931-1.886
Chalimus IV male	9	1.111	0.160	0.936-1.320
Juvenile chalimus	8	0.842	0.156	0.624-1.080

Copepods were measured from cephalon to abdomen, without including antennae and maxillipeds.

requires experimental studies. However, there are no dramatic differences in the abundance of perch between the lakes (Granberg *et al.,* 1987*a,b).* Although hierarchical loglinear models showed that year had no effect on the occurrence of *A. percarum,* this was not so when using logit models which included ' cold ' and ' warm ' periods as explanatory variables. The influence of year, as shown by model (3) appeared owing to the cold and warm periods, for example in Lake Saravesi which had a higher prevalence in 1987 due to the peak prevalence in the warm period (see Fig. 4). In Lake Peurunka a similar influence of the year was evident through the high prevalence in the warm period of 1987.

The high prevalences of *A. percarum* in 1987 (for the year, and warm period) can be related to the cooler summer of 1987 on the hypothesis that the parasite prefers cooler water temperatures during summer. High temperatures prevailed in the early summer of 1986. This view is supported by the fact that when the water temperature reached 22° C in July 1988, the highest during the 1980s, no *A. percarum* were found in any of the three lakes studied (Fig. 3), although high prevalences were found in August 1988 when the water temperature varied from 15.6 to 18.8° C. The same result, that factors including the lake, the year and the season which influenced *A. percarum,* was also shown to apply to *Neoergasilus japonicus* in these lakes (Tuuha *et al.,* 1992). Only season influenced *E. briani* prevalences and only lake *E. sieboldi* prevalences. It may be hypothesized that parasitic copepod species with a series of larval stages and a direct life cycle are very adaptable in relation to both general climatic and local environmental factors resulting in considerable variation of patterns of occurrence in space and time.

Cressey & Collette (1970) found competition between parasitic copepod species on fish, but this was not so in the present study. Co-occurrence of the two species, *A. percarum* and *Ergasilus sieboldi,* on the gills of perch did not differ from random in any of the lakes studied (see also Tuuha *et al.,* 1992).

The developmental stages of *A. percarum* have not been described in detail. Nordmann (1832) noted a free living nauplius with two pairs of legs while Claus (1862) described one nauplius and two chalimus stages. We have described some stages parasitizing the gills of perch, referring to the life cycle of *Salmincola californiensis* described by Kabata & Cousens (1973) as a model.

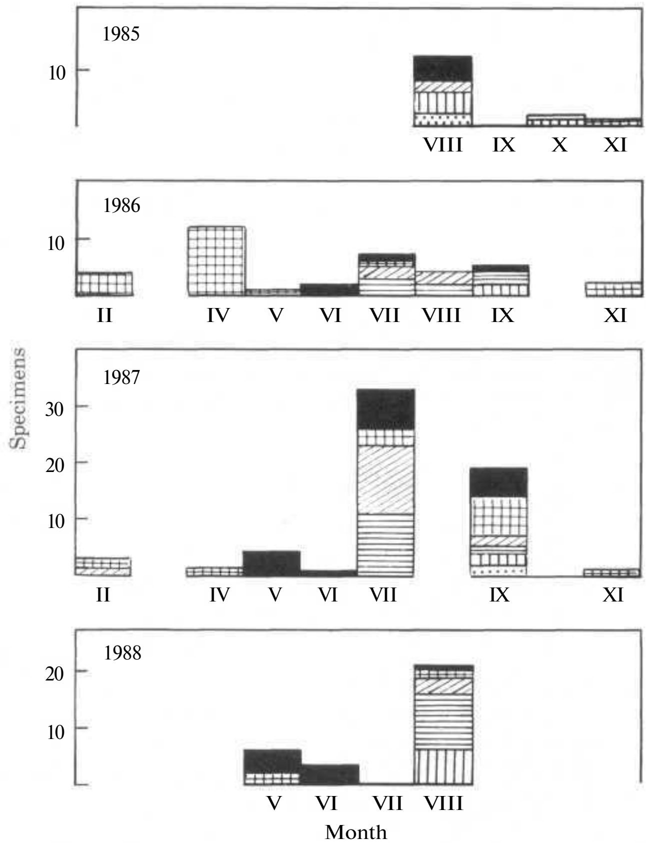

FIG. 6. Monthly occurrence of *Achtheres percarum* developmental stages on the gills of perch from central Finland. Results are pooled from the four lakes and are given yearly. The gaps on the *x*-axis means that fish were not studied that month. Number of copepods studied are indicated on *y*-axis. ■, Gravid females; ⊞, adult females; ▨, adult males; ▤, chalimus undetermined; ▥, chalimus IV females; ⁙, chalimus IV males.

However, an experimental study is required to provide a detailed description of all stages.

The population of *A. percarum* overwintered as adult females, apart from one male found in winter. Females responded to increased water temperature more quickly than ergasilids (see Tuuha *et al.,* 1992), because already in May 1987 and 1988, when water temperatures increased from 3.5 to 8°C and 1.2 to 8.3°C, respectively, gravid females were recovered. The first chalimus stages were found in July, at the time when intensity of infection by all stages was highest. All the developmental stages seen in this study were found on perch during July to September. The generation which overwintered and reached maturity in May-June produced a second generation of adults during late summer and autumn. Their progeny formed the majority of the overwintering immature males and females. The two *A. percarum* generations suggested for central Finland is supported by the experimental data of Kabata & Cousens (1973) who stated that the development of *Salmincola californiensis* males on sockeye salmon

(*Oncorhynchus nerka* Walbaum) was rapid, taking 5 days, and that of females 2 weeks.

This work was financed by the Environmental Board of the Academy of Sciences in Finland. We are most grateful to Aarre Valkonen, Olavi Järvinen, Pekka and Juha Manninen for providing us with live fish throughout the years, to Markku Julkunen and Dr Jouni Taskinen for their assistance in constructing loglinear models. Dr Geoff Boxshall (Natural History Museum, London) has helped us interpret the developmental stages of *A. percarum* and Dr J. C. Chubb has made many valuable comments and suggestions on the manuscript and checked its English.

References

Anikieva, L. V. (1982). The use of helminthological data for estimating of water reservoir state. In *Ekologia parasiticheskich organizmov v biogeocenozach Severa*, pp. 72—83. Petrozavodsk. (In Russian).

Brummer-Korvenkontio, H., Valtonen, E. T. & Pugachev, O. N. (1991). Myxosporea parasites in roach, *Rutilus rutilus* (L.), from four lakes in Central Finland. *Journal of Fish Biology* **38**, 1-14.

Claus, C. (1862). Uber den Bau und die Entwicklung von Achtheres percarum. *Zeitschrift fur Wissenschaftliche Zoologie* **11**, 287-308.

Cox, D. R. (1970). *The Analysis of Binary Data*. London: Methuen.

Cressey, R. & Collette, B. B. (1970). Copepods and needlefishes: a study in host-parasite relationships. *Fishery Bulletin. Fish and Wildlife Service, United States* **68**, 341-342.

Fryer, G. (1969). The parasitic copepods *Achtheres percarum* Nordmann and *Salmincola gordoni* Gurney in Yorkshire. *Naturalist (Hull)* **910,** 77-81.

Granberg, K., Hakkari, M. & Palomäki, A. (1987*a*). Limnological studies of the watercourse Äänekoski in 1986. *Reports of the Institute for Environmental Research, University of Jyväskylä*. (In Finnish).

Granberg, K., Hynynen, J., Meriläinen, J. J., Mäkelä, H., Palomäki, A. & Bibiceanu, S. (1987*b*). Limnologial studies of the watercourse Äänekoski in 1987. *Reports of the Institute for Environmental Research, University of Jyväskylä*. (In Finnish).

Gusev, A. V., Poddubnaya, A. V. & Avdeeva, V. V. (1987). Parasitic crustaceans. In *Key to the Parasites of Freshwater Fishes of USSR* (Bauer, O. N., ed.), pp. 378-524.

Halmetoja, A., Yaltonen, E. T. & Taskinen, J. (1992). Trichodinids (Protozoa) on fish from four Central Finnish lakes of differing water quality. *Aqua Fennica* **22**, 59-70.

Harding, J. P. & Gervers, W. K. (1956). Occurrence *of Achtheres percarum* Nordmann in English waters. *Nature (London)* **117,** 664.

Ieshko, E. P., Malakhova, R. P., Golitzina, N. B. (1982). Ecological peculiarities of fish parasite fauna formation at river Kamennaja system lakes. In *Ekologia parasitich-eskich organizmov v biogeocenozach Severa*, pp. 5-25. Petrozavodsk. (In Russian).

Kabata, Z. & Cousens, B. (1973). Life cycle of *Salmincola californiensis* (Dana, 1852) (Copepoda: Lernaeopodidae). *Journal of the Fisheries Research Board of Canada* **30,** 881-903.

Koskivaara, M., Valtonen, E. T. & Prost, M. (1991). Seasonal occurrence of gyrodactyl-ids on the roach (*Rutilus rutilus)* and variations between four lakes of differing water quality in Finland. *Aqua Fennica* **21**, 47-55.

Markevich, A. P. (1956). *Parasitic copepods of fishes of the USSR*. Kiev: Izdatelstvo Akademia Nauka Ukr. SSR. (In Russian).

Nordmann, A. von (1832). *Mikrographische Beiträge zur Naturgeschichte der wirbellosen Thiere*. Vol. 2, I-XVII 1-150. Berlin: G. Reimer.

Ryback, V. F. (1982). Fish parasite fauna formation of Vigozero reservoir. In *Ekologia parasiticheskich organizmov v boigeozenozach Severa*, pp. 59—72. (In Russian).

Shulman, S. S., Malakhova, R. P. & Rybak, V. F. (1974). *Comparative Ecological Analysis of Fish Parasites of Karelian Lakes*. Leningrad: Nauka. (In Russian).

Stepanova, G. A. & Vjuskova, L. A. (1985). *Achtheres percarum* infection in pike-perch from Volga river delta. In *Proceedings of a Symposium on Parasitic Fish Diseases, Astrahan 1985* (Bauer, O. N., ed.), p. 133. Leningrad: Nauka.

Tuuha, H., Valtonen, E. T. & Taskinen, J. (1992). Ergasilid copepods as parasites of perch *Perca fluviatilis* and roach *Rutilus rutilus* in central Finland; seasonality, maturity and environmental influence. *Journal of Zoology* **228,** 405-422.