Dactylogyrus (Monogenea) infections on the gills of roach (*Rutilus rutilus* L.) experimentally exposed to pulp and paper mill effluent

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SUMMARY

Experimental exposure to bleached kraft pulp and paper mill effluent (BKME) at a concentration of 10% significantly reduced the abundance and mean number of species of *Dactylogyrus* on the gills of naturally infected roach, *Rutilus rutilus*, over a 3 week period. Seven *Dactylogyrus* species were recorded which differed widely in their susceptibility to the effluent. The experiment coincided with a natural spring peak in dactylogyrid infections on roach. BMKE exposure did not prevent parasite reproduction but post-larval abundance was significantly higher on control than effluent-exposed hosts. There was no evidence of a BKME-induced shift in microhabitat distribution of dactylogyrids. Elevated levels of infection with *Dactylogyrus* spp. have been recorded on roach from a Finnish lake containing relatively low concentrations of BMKE. The high exposure concentration in this experiment produced a similar reduction in dactylogyrid infections to that reported in separate studies in close proximity to Swedish pulp and paper mills. The discrepancy between the results of the Finnish and Swedish field investigations is therefore considered to be due to differences in BKME concentration between the study areas.

Key words: *Dactylogyrus* spp., roach, *Rutilus rutilus*, pulp mill effluent.

INTRODUCTION

Bleached kraft mill effluent (BKME) released following the production of pulp and paper from softwoods is known to cause a variety of lethal and sublethal toxic effects in aquatic organisms (McLeay, 1987; Owens, 1991). BKME is a complex mixture but its toxicity is generally attributed to fatty and resin acid constituents in addition to chlorinated phenols and related compounds produced during the bleaching process (Leach & Thakore, 1977; Oikari *et al*. 1985; Tana, 1988; Kennedy *et al*. 1995).

Chronic exposure to BKME can induce pathological changes in various fish tissues, particularly the gills (Lehtinen, Notini & Landner, 1984; Couillard, Berman & Panisset, 1988; Khan *et al*. 1994*a*), fins (Lindesjöö & Thulin, 1990, 1994; Barker, Khan & Hooper, 1994) and liver (Lehtinen *et al*. 1984; Axelsson & Norrgren, 1991; Khan *et al*. 1994*a*). These symptoms, combined with immunosuppression and physiological disturbances (Andersson *et al*. 1988; Barker *et al*. 1994; Jokinen, Aaltonen & Valtonen, 1995; Jeney *et al*. 1996) are indicative of chronic stress.

Recently, evidence has been accumulating of an association between BKME exposure and an increase in the prevalence and abundance of fish parasites, particularly ectoparasitic protozoans and monogeneans (Lehtinen *et al*. 1984; Lehtinen, 1989; Axelsson & Norrgren, 1991; Khan *et al*. 1994*b*). A higher abundance and species diversity of *Dactylogyrus* spp. was recorded during 1985–89 on the gills of roach, *Rutilus rutilus*, from a lake in central Finland receiving effluent from a pulp and paper mill 15 km upstream, when compared to an uncontaminated reference lake (Koskivaara, Valtonen & Prost, 1991; Koskivaara & Valtonen, 1992). The same increase in abundance of dactylogyrids was observed on roach experimentally transferred from the reference lake to the polluted one (Bagge & Valtonen, 1996).

However, studies in Sweden by Thulin and coworkers (reviewed by Khan & Thulin, 1991) appear to provide contradictory evidence of a *decrease* in ectoparasite infections associated with environmental pollution by pulp and paper mill effluent. Ectoparasitic copepods *Achtheres percarum* on perch, *Perca fluviatilis*, and *Caligus lacustris* on perch and roach increased in prevalence with distance from the point of input of effluent from a mill in Lake Vanern, neither parasite being recorded at the closest sampling site (Thulin, 1983). A second study revealed an increase in the prevalence and intensity of ectoparasitic monogeneans, *Paradiplozoon homoion* and *Dactylogyrus* sp., on the gills of roach with distance from two mills on the Baltic coast (Thulin, Höglund & Lindesjöö, 1986, 1988).

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The sample sites in these studies were all much closer to mills (maximum distance 5 km) than in Finnish investigations cited above (Valtonen, Holmes & Koskivaara, 1997) and effluent concentrations in the water would consequently have been higher. This raises the possibility that at higher concentrations BKME is directly toxic to ectoparasites such as dactylogyrids on roach and produces changes in their levels of infection that are opposite to those observed at low exposure concentrations.

This experimental study was timed to coincide with the period of rapidly increasing natural water temperatures following the spring thaw of the ice-cover on Finnish lakes. It examined the effects of exposure to a relatively high concentration of pulp and paper mill effluent on the prevalence, abundance and distribution of *Dactylogyrus* spp. on the gills of roach during the spring peak in their infections. The experiment aimed to test the hypothesis that the discrepancy between the field results of Valtonen and Thulin reflects differences in BKME exposure concentration between the study areas.

MATERIALS AND METHODS

More than 80 adult roach (*Rutilus rutilus* L.) were captured between 24 and 25 April 1993 by angling from Lake Saravesi, central Finland. Lake Saravesi is a small, eutrophic and semilotic waterbody. It is connected to Lake Vatia which is polluted by effluent from 2 paper and pulp mills. Although the water quality of Lake Saravesi had previously been adversely affected the lake was not considered to be under effluent-induced stress at the time of sampling (Valtonen *et al*. 1997). The fish were transported to a field laboratory and maintained for 1 week in a 2000 litre tank supplied with filtered water from a nearby uncontaminated river connecting 2 freshwater lakes at the ambient water temperature.

Untreated BKME from a pulp and paper mill at Pietasaari on the west coast of Finland was stored at −25 °C. The mill used pine (47 %) and birch (53 %) as the raw materials, producing 438000 tonnes/year (t/y) of bleached pulp and 60000 t/y of unbleached pulp at the time of this investigation. The bleaching sequence was D/CEDED for pine and DE(o)DED for birch, where C is chlorine, D is chlorine dioxide, E is alkaline extraction and o is oxygen.

Twenty-two roach were selected randomly from the holding tank and examined at the beginning of May for *Dactylogyrus* species as described below. This 'pre-treatment' group provided information on the infection status prior to the experiment. On 3 May 1993, 60 roach were divided randomly between four 70 litre polyethylene experimental tanks situated within a single large 2000 litre tank. The large tank was continuously supplied with river water and served to maintain a natural water temperature in the 4 experimental tanks. The smaller tanks were also supplied with filtered river water and were additionally aerated.

A static dosing methodology was employed with a single replacement of pulp mill effluent. On 4 May the water flow to the experimental tanks was stopped and BKME was added to 2 of the tanks to an initial concentration of 5 % of the tank water volume. After 12 h further effluent was added to the same tanks to achieve a final concentration of 10 % in each. After 10 days exposure the 4 experimental tanks were flushed with clean filtered river water for approximately 5 h. The water flow was then stopped and fresh paper mill effluent added to the same 2 treatment tanks to a concentration of 5 % and then, after 12 h, to 10 % of the tank water volume. This was carried out to maintain a relatively constant composition of BKME in experimentally treated tanks. The fish were fed on commercial pellet food up to 1 day prior to transfer to experimental tanks and during the flushing of tanks on day 10, but not during the exposure. Water temperature was monitored daily.

The total exposure period was 3 weeks, during which time the water temperature increased from 5 °C to almost 17 °C. On 24 May fish were pooled from the 2 tanks within each treatment, transferred to clean filtered water and maintained until dissection at 4 °C to limit any further changes in their parasite fauna. Twenty-five effluent-exposed and 25 control roach were selected at random and examined as described below for *Dactylogyrus* spp.

Each fish was killed and 4 gill arches, numbered 1 to 4 from the outermost to innermost, were removed from the left and right sides. Each gill arch was separated into 4 equal quarters or sectors numbered 1 to 4 from dorsal to ventral. The soft parts of each sector were isolated on a slide using a scalpel, covered with a cover-glass, and examined immediately under a light microscope (×100–400 magnification). All *Dactylogyrus* specimens were identified according to Gusev (1985) and counted. The length, weight and sex of each fish were recorded.

The proportions of fish infected with each *Dactylogyrus* species were compared between the control and effluent-exposed groups using 2×2 contingency tables analysis, applying Fisher's exact test when any expectation was less than 5. Differences in dactylogyrid abundance (mean number of parasites per host examined) between the groups were analysed by the Mann–Whitney U-test. For parasite infracommunity analysis each fish was treated as a single replicate within each treatment group. *Dactylogyrus* infracommunities were quantitatively compared between hosts within and between treatment groups by calculating the percentage similarity (PS) based on the proportions of each parasite species: $PS = (\Sigma \text{minimum}\, p_{ia}, p_{ib}) \times 100\,\%$, where p_{ia} and p_{ib} are the proportions of species i on hosts a and b, respectively.

Table 1. Prevalence of *Dactylogyrus* species and post-larvae on the gills of pre-treatment, control and BKME-exposed roach, *Rutilus rutilus*, and probabilities (*P*) from contingency tables analysis of differences between control (C) and exposed (E) groups being due to chance

(Number of fish in parentheses.)

	Prevalence (%)			
	Pre-treatment (22)	Control (25)	BKME-exposed (25)	P_{CE}
D. crucifer	100	96·0	88·0	—
D. micracanthus	95·5	100	60·0	***
D. nanus	90·9	88·0	68·0	—
D. fallax	81·8	72·0	20·0	***
D. similis	81·8	56·0	16·0	**
D. caballeroi	72·7	64·0	48·0	—
D. suecicus	36·4	44·0	8·0	**
Post-larvae	59·1	100	76·0	*

— $P > 0·05$; * $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.

The data were pooled across fish within each treatment and the Mann–Whitney U-test was used to compare the microhabitat distribution of dactylogyrids according to gill arch and sector between control and BKME-exposed roach.

RESULTS

Parasite prevalence

Dactylogyrids were present on the gills of all roach examined. A total of 7 species were found on pre-treatment fish and also in the control and effluent-exposed groups at the end of the experiment (Table 1). However, the proportion of fish infected with each of the *Dactylogyrus* species was lower amongst effluent-exposed than control fish and significantly different for 4 species (χ^2, $P < 0·01$ in all cases). The greatest difference in prevalence between treatments was for *D. fallax* which was present on 72% of control roach but only 20% of the effluent-exposed fish. However, the most commonly recorded dactylogyrids on effluent-exposed roach, *D. crucifer* and *D. nanus*, did not differ in prevalence between the treatments (χ^2, $P < 0·05$).

Dactylogyrid reproduction occurred during the experiment and was reflected in an increase in the prevalence of post-larvae in both control and effluent-exposed groups when compared to pre-treatment fish. However, post-larval prevalence was significantly higher among control than effluent-exposed roach (Fisher's exact test, $P = 0·011$).

Parasite abundance

There was a significant positive correlation between host length and the total number of adult *Dactylogyrus* on roach prior to the experiment (Spearman $r = 0·475$, $P < 0·05$). However, mean host length did not differ significantly between control and BKME-exposed groups ($t = 1·42$, 48 D.F., $P > 0·1$).

The data for pre-treatment, control and effluent-exposed groups were combined and parasite intensities on each fish were pooled across gill arches and sectors to compare the dactylogyrid infections between gills of the left and right sides. The intensity of each *Dactylogyrus* species, the total number of adult dactylogyrids and the intensity of post-larvae were significantly correlated between left and right sides (Spearman *r*, $P < 0·001$ in all cases) and the data were therefore pooled across sides for subsequent analysis of abundance. The ratio of female to male roach was 3:1 amongst all fish combined. However, there were no significant differences between sexes in the abundance of adult dactylogyrids either prior to the experiment or amongst control or effluent-exposed roach (Mann–Whitney U, $P > 0·05$ in all cases).

The abundance of all *Dactylogyrus* species was lower among effluent-exposed roach when compared to the control fish and significant differences in abundance were recorded for 5 of the 7 species (Table 2; Mann–Whitney U, $P < 0·01$ in all cases). The mean number of *Dactylogyrus* species per host was also significantly lower in the BKME-exposed group than among control fish (Mann–Whitney U, $P < 0·001$ in both cases; Fig. 1A).

Frequency distributions of parasite intensities were markedly different between the 2 treatment groups (Fig. 1B). Whilst the variance to mean ratio (v:m) indicated an overdispersed distribution of dactylogyrids in both groups, the degree of overdispersion was higher among effluent-exposed roach (v:m = 37·0) than among control fish (v:m = 24·0), despite the significantly lower dactylogyrid abundance in this group.

The abundance of post-larvae was only 5·6/fish prior to the experiment but increased to 91·4/fish in the BKME-exposed and over 110/fish in the control group (Table 2). There was no correlation between host length and the numbers of post-larvae in either group (Spearman *r*, $P > 0·05$ in both cases) but an interesting pattern emerged when considering the numbers of post-larvae and of adult *Dactylogyrus* on individual fish.

In the effluent-exposed group most roach harboured relatively few adult dactylogyrids or post-larvae. However, those fish carrying the greatest adult worm burdens following the exposure period also harboured the greatest numbers of post-larvae (Fig. 2; Spearman $r = 0·616$, $P < 0·01$) with post-larval intensities exceeding those recorded in the control group. In contrast there was no correlation between adult and larval parasite numbers on control roach ($r = 0·310$, $P > 0·05$). When BKME-exposed fish were divided according to post-larval numbers

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Table 2. Abundance (standard deviation) of each *Dactylogyrus* species, all adult *Dactylogyrus* and post-larvae and mean number of *Dactylogyrus* species on the gills of pre-treatment, control and BKME-exposed roach, *Rutilus rutilus*

(Probabilities (*P*) from Mann–Whitney U-tests of differences between control (C) and exposed (E) groups being due to chance. Number of fish in Table 1.)

	Abundance (standard deviation)			
	Pre-treatment	Control	BKME-exposed	P_{CE}
D. crucifer	12·8 (10·2)	10·4 (12·5)	5·0 (4·9)	—
D. micracanthus	46·0 (35·7)	62·2 (38·3)	12·2 (20·1)	***
D. nanus	7·8 (6·8)	7·6 (7·0)	3·1 (4·2)	**
D. fallax	2·4 (2·0)	2·7 (2·8)	0·6 (1·7)	***
D. similis	3·1 (4·5)	1·7 (2·2)	0·4 (1·1)	**
D. caballeroi	2·9 (3·3)	3·4 (5·1)	1·4 (2·1)	—
D. suecicus	0·9 (1·7)	0·8 (1·2)	0·1 (0·4)	**
All *Dactylogyrus*	75·9 (48·3)	88·7 (46·1)	22·8 (29·1)	***
Post-larvae	1·5 (2·0)	110·3 (57·3)	91·4 (149·3)	*
No. of species	5·6 (1·2)	5·2 (1·1)	3·1 (1·6)	***

— $P > 0·05$; * $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.

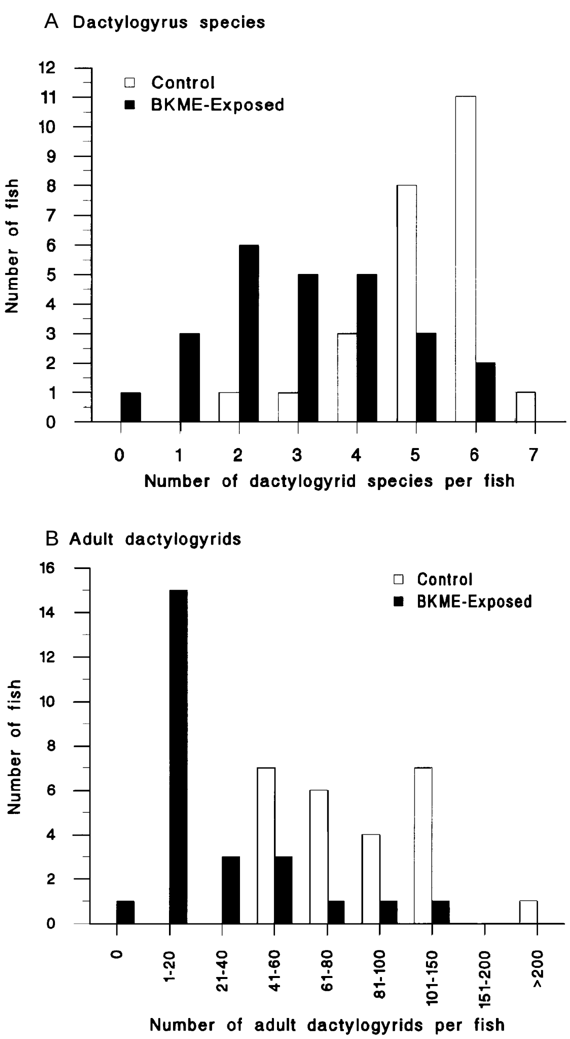

Fig. 1. Frequency distributions of (A) *Dactylogyrus* species number and (B) adult *Dactylogyrus* intensities on control and BKME-exposed roach, *Rutilus rutilus*.

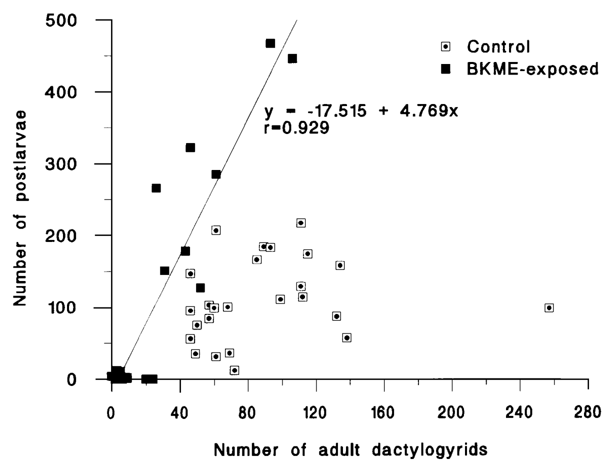

Fig. 2. Relationship between the numbers of adult *Dactylogyrus* and of dactylogyrid post-larvae on control and BKME-exposed roach, *Rutilus rutilus*.

into 2 groups, low intensity (0–12 post-larvae/fish) and high intensity (127–467), a marked difference was apparent between groups in *Dactylogyrus* species composition (Fig. 3). *D. micracanthus* dominated the infracommunities of roach on which large numbers of post-larvae were recorded, whilst this species was only the fourth most abundant on fish with few or no post-larvae.

Similarity coefficient

The mean percentage similarity (±S.E.) between the *Dactylogyrus* infracommunities of control and BKME-exposed roach was low (45·1±5·4). However, an even lower similarity (35·3±5·5) was recorded between different hosts within the effluent-exposed group illustrating the considerable variability in their *Dactylogyrus* infracommunities. It

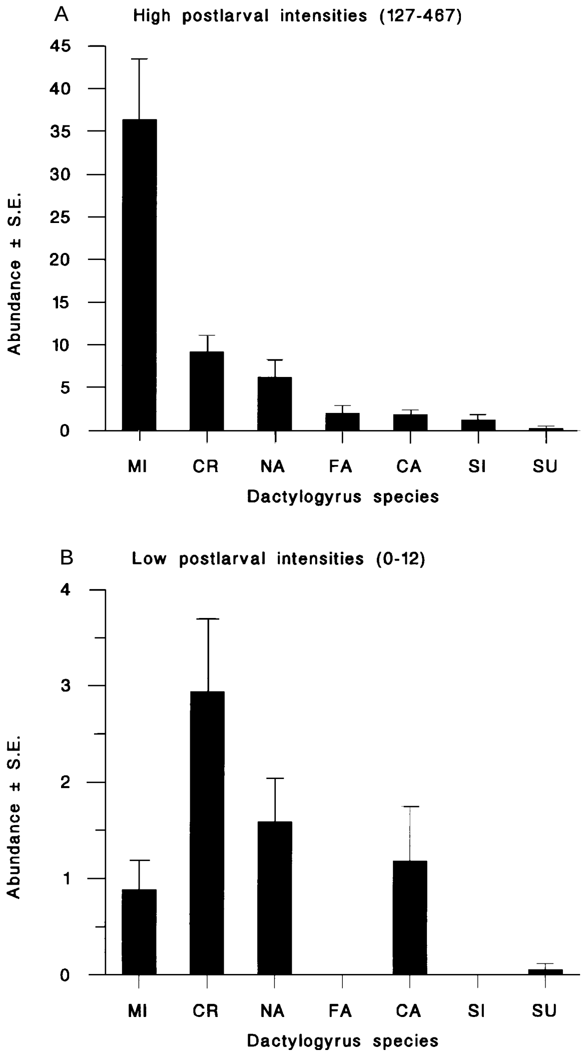

Fig. 3. Comparison of abundances of *Dactylogyrus* species between BKME-exposed roach, *Rutilus rutilus*, harbouring (A) high and (B) low intensities of dactylogyrid post-larvae. MI, *D. micracanthus*; CR, *D. crucifer*; NA, *D. nanus*; FA, *D. fallax*; CA, *D. cabelleroi*; SI, *D. similis*; SU, *D. suecicus*.

Table 3. Preferred gill arch (i.e. arch with maximum abundance) for 7 *Dactylogyrus* species and post-larvae on control and BKME-exposed roach, *Rutilus rutilus*

Dactylogyrus species	Control	BKME-exposed
D. crucifer	1	1
D. micracanthus	1	2
D. nanus	3	1
D. fallax	2	2
D. similis	2	2
D. caballeroi	4	4
D. suecicus	4	4
Post-larvae	1	1

Table 4. Comparison between control and BKME-exposed roach, *Rutilus rutilus*, of dactylogyrid microhabitat distribution according to gill arch and sector using Mann–Whitney U-test and probabilities (*P*) of differences observed being due to chance

(Total numbers of parasites are given (*N*).)

Dactylogyrus species	*n*	Location	U	*P*
D. crucifer	384	Arch	14650·5	—
		Sector	13077·0	**
D. micracanthus	1846	Arch	224007·0	—
		Sector	234179·5	—
D. nanus	428	Arch	5668·0	**
		Sector	6403·5	—
D. fallax	83	Arch	504·0	—
		Sector	467·5	—
D. similis	121	Arch	168·0	—
		Sector	192·5	—
D. caballeroi	119	Arch	963·5	**
		Sector	1131·5	*
D. suecicus	24	Arch	19·0	—
		Sector	28·5	—
Post-larvae	974	Arch	97013·0	—
		Sector	95582·0	—

— $P > 0{\cdot}05$; * $P < 0{\cdot}05$; ** $P < 0{\cdot}01$.

contrasted markedly with the high degree of similarity amongst control fish (73·8±3·3).

Parasite distribution

The data for each fish were pooled across left and right sides to examine the effect of pulp mill effluent exposure on the microhabitat distribution of dactylogyrids. Although the 7 *Dactylogyrus* species were recorded on all 4 gill arches, each species exhibited a preference for a particular gill arch and sector. The preferred gill arch (i.e. that with maximum abundance) differed between treatments for only 2 *Dactylogyrus* species (Table 3).

The parasite data were pooled across fish within each treatment and the Mann–Whitney U-test was used to compare the distribution of dactylogyrids according to gill arch and sector between control and BKME-exposed hosts (Table 4). Three of the 7 *Dactylogyrus* species, *D. crucifer*, *D. nanus* and *D. cabelleroi*, differed significantly in distribution according to gill arch between control and effluent-exposed roach ($P < 0{\cdot}01$ in each case). *D. caballeroi* also differed between treatments in distribution according to sector ($P < 0{\cdot}05$).

Post-larvae were most abundant on the middle sectors of gill arches 1 and 4 of control roach and of arch 1 alone on effluent-exposed fish. However, their distribution did not differ significantly between treatments (Table 4, $P > 0{\cdot}05$ for arch and sector).

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DISCUSSION

Experimental exposure to bleached kraft pulp and paper mill effluent (BKME) at a concentration of 10% significantly reduced the abundance and mean number of species of *Dactylogyrus* on the gills of naturally infected roach, *Rutilus rutilus*, over a 3 week period. Of the 7 *Dactylogyrus* species that were present, the prevalence of 4 species and abundance of 5 species were significantly lower among effluent-exposed roach compared to unexposed control fish. *D. micracanthus*, *D. crucifer* and *D. nanus* were the most prevalent and abundant species in each treatment group and were also found to dominate the dactylogyrid infracommunities of roach sampled from the same lake (Lake Saravesi) in previous studies (Koskivaara *et al*. 1991; Koskivaara, Valtonen & Vuori, 1992; Koskivaara & Valtonen, 1992).

The composition of the effluent in this experiment was similar to that discharged into Lake Vatia, central Finland, from a pulp and paper mill in the city of Äänekoski during the parasitological investigations of Koskivaara *et al*. (1991, 1992) and Valtonen *et al*. (1997). However, the situation in Lake Vatia represented a subchronic exposure of fish to BKME at a concentration well below that in the present study, estimated to have been less than 2% at the time the study of Jokinen *et al*. (1995) (K. Granberg, personal communication). The higher abundance and species diversity of *Dactylogyrus* spp. on roach from this lake was considered to reflect the indirect effects of poor water quality on the immune system of the fish host, allowing the parasites to proliferate. Roach captured from an uncontaminated reference lake and held in cages in Lake Vatia developed a reduced antibody-mediated immune response (Jokinen *et al*. 1995).

From 1985 onwards the biological treatment of effluent and, subsequently, a reduction in the use of chloro-bleaching has produced a fairly rapid improvement in the water quality of Lake Vatia (Granberg, 1992; Granberg *et al*. 1994). This has been reflected in a decline in the peak abundance of dactylogyrids on roach, confirmed experimentally when roach caught from an uncontaminated lake were transferred to Lake Vatia (Bagge & Valtonen, 1996).

At the exposure concentration in this experiment BKME would have had a pronounced effect on the physiology and biochemistry of roach. Jeney *et al*. (1996) reported a significant increase in cortisol and blood glucose in addition to a significant decrease in leucocrit and total plasma protein in roach exposed for 72 h to undiluted BKME. Although these effects might be considered to favour the proliferation of ectoparasites this did not occur. The concentration of BKME in this experiment clearly exceeded the threshold of toxicity to adult *Dactylogyrus*. This produced changes in levels of infection with dactylogyrids that were consistent with those recorded by Thulin and coworkers in close proximity to Swedish pulp and paper mills (see Khan & Thulin, 1991).

However, susceptibility to the effluent differed markedly between dactylogyrid species. *D. micracanthus*, the most abundant species in this study, showed the greatest decline in abundance following effluent exposure. In contrast, there was no significant difference between control and BKME-exposed roach in the prevalence or abundance of *D. crucifer* and *D. caballeroi* or in the prevalence of *D. nanus*.

The experiment was timed to coincide with the seasonal increase in *Dactylogyrus* infections on roach peaking in May and June (Koskivaara *et al*. 1991). BKME-exposure did not prevent the reproduction of dactylogyrids. Indeed, post-larval abundance significantly increased during the experiment on both exposed and control fish. Although the lower abundance of post-larvae on effluent-exposed than control fish appears to indicate at least an inhibitory effect of BKME on dactylogyrid reproduction, the picture is more complicated when the intensities on individual fish are examined.

There was a significant positive correlation between the numbers of adult dactylogyrids and of post-larvae in the effluent-exposed group. At the end of the treatment period the majority of roach exposed to BKME harboured low numbers of adult *Dactylogyrus* and no or few post-larvae. However, greater intensities of adult worms were recorded on 8 of the 25 fish and these same hosts were also infected with large numbers of post-larvae. This pattern is unlikely to reflect differences between hosts in their resistance to infection as no correlation between adult and post-larval *Dactylogyrus* intensities was observed on control fish. *D. micracanthus* was dominant on BKME-exposed fish with high post-larval intensities but rare on fish with few or no post-larvae. This suggests that the majority of the post-larvae were of *D. micracanthus* and that they hatched from eggs laid directly onto the gills of the host by adult *D. macracanthus* rather than from eggs released into the water.

The absence or low occurrence of post-larvae on the majority of effluent-exposed roach indicates that lethal toxicity of BKME to the adult worms occurred rapidly and before they were able to reproduce. However, those dactylogyrids that survived appear to have produced greater numbers of offspring than worms in the control group. The increase in reproductive output could be a stress response in *Dactylogyrus* induced by BKME-exposure. In a stressed environment females of a terrestrial isopod, *Porcellio scaber*, started to reproduce earlier and at a lower body weight than at a reference site (Donker, Zonnevald & van Straalen, 1993). Although the number of young produced per female was lower at the stressed sites the reproductive allocation, in terms of weight of young relative to that of the mother, was higher. Experimental studies have demonstrated an increased rate of fragmentation (i.e. reproduction) in enchytraeid worms, *Cognettia sphagnetorum*, forced to inhabit metal-contaminated soil (Sjogren, Augustsson & Rundgren, 1995).

The microhabitat distribution of 3 of the 7 *Dactylogyrus* species differed significantly between treatments. However, the preferred gill arch (i.e. the arch with maximum abundance) was the same in control and BKME-exposed groups for 2 of these species. The experiment was carried out at a time when dactylogyrids undergo natural changes in their distribution on the gills of roach (Koskivaara *et al*. 1992) and the differences between treatments were unlikely to be due to the effects of BKME.

In conclusion, the results of this experimental study support the hypothesis that discrepancies between ectoparasite levels of roach from Lake Vatia in Finland and the effluent area of Swedish pulp mills are due to differences in BKME exposure concentration between the study areas. The low concentrations in Lake Vatia were not directly toxic to dactylogyrids but caused changes in the host immune response that favoured parasite proliferation. The high experimental dose in this study resulted in mortality of the parasites and produced the same reduction in levels of infection as recorded close to the effluent discharge point of Swedish mills. The mechanisms of toxicity of BKME to *Dactylogyrus* are unknown, although disturbance of ionoregulation that has been recorded in fish could possibly also occur in this parasite.

Interest in the potential role of parasites as biological indicators of water quality has increased in recent years (Khan & Thulin, 1991; MacKenzie *et al*. 1995; Valtonen *et al*. 1997) and ectoparasite burdens of fish have been proposed as a sensitive index of BKME contamination (Khan *et al*. 1994). However, caution would be required in applying an index based on dactylogyrids due to the contrasting response at high and low exposure concentrations and the variability between species in their susceptibility to BKME.

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