EFFECTS OF ROTENONE TREATMENT ON MAYFLY DRIFT AND STANDING STOCKS IN TWO NORWEGIAN RIVERS

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ABSTRACT

In Norway, the salmon parasite *Gyrodactylus salaris,* has spread to 40 rivers and caused a drastic reduction in the stocks of Atlantic salmon (*Salmo salar* L.). In order to eradicate the parasite, a total of 24 rivers has so far been treated with rotenone (0.5-1.0 ppm rotenone solution). Drift and standing stocks of Ephemeroptera from stretches treated with rotenone were compared with untreated stretches and with the faunal composition before rotenone treatment.

Rotenone treatment induced an immediate catastrophic drift and caused high mortalities. The different species varied with respect to the degree and timing of their response to rotenone. *Baetis* species were rapidly affected: A great number of dead individuals appeared in the drift samples at the start of the treatment, but then subsequently declined. The response was more slow in the genus *Heptagenia,* and a few larvae of *Ephemerella* occurred in the drift samples.

A significant reduction in standing stocks of most mayflies: *Ameletus inopinatus, Baetis rhodani, B. subalpinus, B. fuscatus/scambus, Metretopus borealis* and *Heptagenia* spp. was found in newly rotenone-treated stretches. However, *Ephemerella aurivillii* and *Cloeon simile* survived the treatment in high numbers. Thus, the species composition was altered during the first few months, but a fast recolonization of the mayfly fauna took place on the rotenone-treated stretches. Within one year, all the abundant species registered before the treatment occurred again in high numbers.

INTRODUCTION

The salmon parasite, *Gyrodactylus salaris* Malmberg 1957, was probably introduced to Norway with infested parr/smolt of Atlantic salmon (*Salmo salar* L.) in the early 1970s, and has since then spread mainly through the stocking of fish from infested salmon hatcheries. Populations of salmon parr have been severely reduced in infested rivers (Johnsen and Jensen 1986, 1991, 1992). Norwegian fishery authorities are attempting to prevent any further spread of *G. salaris* and to exterminate the parasite in as many infested rivers and hatch-

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eries as possible. So far the parasite has been found in 40 Norwegian rivers, and rotenone treatments have been accomplished in 24 rivers.

Knowledge of the toxic effect of rotenone on the benthos in Norwegian rivers, and on mayflies in particular, was lacking. The use and effect of rotenone in fishery management in North America and Scandinavia have been dealt with by Soleman (1950), Almquist (1959), Tobiasson (1979), Fox (1985) and Næss et al. (1991). Haley (1978) and Ugedal (1986) also provide literature reviews. Rotenone is highly toxic to fishes (Marking and Bills 1976) and some insect larvae (Fukami et al. 1969). However, its full effects on insects and other aquatic invertebrates is not well documented since most studies primarily have been concerned with fish. Among the more detailed field studies concerning toxic effects of rotenone on benthos are Chandler (1982), Koksvik and Aagaard (1984), Dudgeon (1990) and Dolmen et al. (1995). These field studies and also laboratory studies (Engstrom-Heg et al. 1978) have documented some taxon-specific responses to the poison.

Ephemeroptera are usually an abundant part of the benthic community in Norwegian salmon rivers. Among 45 species recorded in the country, *Baetis* spp. are especially abundant in running waters. The present study documents the influence of rotenone on drift and abundance of mayflies in two Norwegian rivers.

MATERIAL AND METHODS

The Study Area and the Rotenone Treatment

The rivers Ogna and Rauma are situated in Central Norway (Fig. 1). The river Ogna with a lowland catchment area of 571 km^2, has a length of 65 km, and an average annual discharge of 22 m^3/s. It flows into the fjord Trondheimsfjorden. The rotenone treatment was carried out on 4 July 1993. At Støafossen, 18 km from the river outlet, rotenone solution (Gullviks rotenone) was continuously emptied into the river, giving a rotenone concentration of 0.5-1.0 ppm for approximately five hours. Locally, the concentration of rotenone was probably higher, up to 2-5 ppm. Backwaters, small ponds and all tributaries where anadromous fish could ascend were also treated with rotenone.

The total catchment area of the river Rauma is 1240 km^2, and the river drains mountain areas. The river empties into the Romsdalsforden near the town Åndalsnes, and the annual discharge at the river mouth is 42 m^3/s. Atlantic salmon can ascend 42 km upstream, and the lower 45 km of the river were treated with rotenone on 26-28 September 1993 (PK-PW rotenone). Several ponds, two small lakes and three neighbouring streams were also treated with rotenone. The concentration of rotenone in water was calculated to be 0.5-1.0 ppm both in lakes and rivers, but locally it was probably higher. The river was exposed to rotenone for 7 hours, and the lowermost part was exposed on three successive days.

Sampling Methods

In the river Ogna, drift samples were taken at 1 h intervals in four periods before the rotenone treatment started, and at 0.5 h intervals continuously during the rotenone treatment period. The samples were taken from one location (st. 2) in a central part of the rotenone treated river stretch (Fig. 1). We used a 2.5 m long tube (opening 10 cm diam.) and a single net (70 cm, 0.25 mm mesh size). The opening of the drift sampler was raised about 5 cm above the substratum. All animals in the drift net were first examined for dead/living animals and then preserved in 70 % ethanol. All mayflies in a 10% subsample for each time interval were counted and identified.

Two benthic kick-samples (Frost et al. 1971), using a square framed net (opening 25x25 cm, mesh size 0.5 mm), were taken at four locations in the river Rauma and at three locations in the river Ogna. Each kick sample was carried out for one minute's duration. Additional qualitative benthic samples (e.g. z-sample, see Dolmen 1992) were taken from two small lakes or ponds

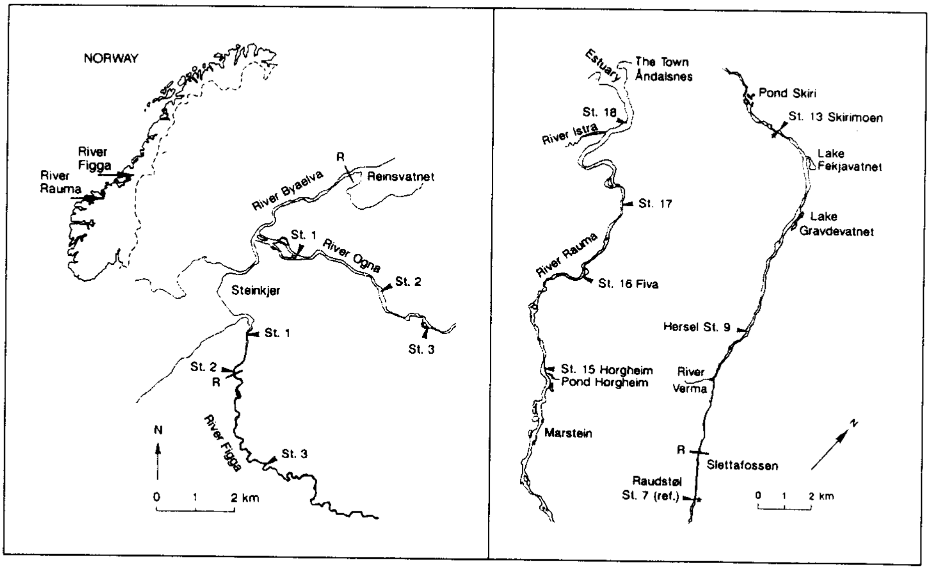

Fig. 1. Map of the lower parts of the rivers Ogna and Figga, showing the position of the sampling locations and the locations of rotenone application (R). The positions of the rivers Ogna and Rauma in Norway are shown at top, left.

near the river (Fig. 1). Samples were taken on 12 dates during the three years preceeding the rotenone treatment, and on 16 dates during the three years following the treatment. Mayflies were picked from the samples and preserved in 70 % ethanol. The animals were later sorted out in the laboratory and identified to species where possible.

RESULTS

Rotenone Effects on Mayfly Drift

A dramatic increase in drift densities was recorded following rotenone application, and the effect was still apparent during the five hours of treatment. Before rotenone was applied, the drift densities of mayflies were low (0.1-0.3 larvae per m^3). A slight indication of rotenone in the water was noticed at 14.00 p.m., resulting in an increase in drifting larvae from 0.3 to 4.7 individuals per m^3. About one hour later, the full concentration of rotenone was reached (approximately 0.5- 1.0 ppm) as indicated by skimming water and the smell of rotenone. The total drift density of mayfly larvae peaked after 30-60 minutes, and increased from 4.7 to 97-125 individuals per m^3 followed by a decline in drift densities during the next few hours (Fig. 2). The total drift rates declined with time during the treatment and monitoring period of five hours ($r^2 = -0.805$, $n = 10$, $p < 0.001$).

The different species varied with respect to the degree and timing of their response to rotenone. Most *Baetis* species were rapidly affected: a great number of dead individuals appeared in the drift samples at the start of the treatment and then the number subsequently declined. The response was slower in *Baetis muticus* and in the genus *Heptagenia* (Fig. 3). For the species *B. rhodani*, *B. fuscatus/scambus* and *H. sulphurea* there was a significant decline in drift densities during the rotenone treatment period (*B. rhodani*: $r^2 = -0.648$, $n = 10$, $p < 0.001$, *B. fuscatus/scambus*: $r^2 = -0.506$, $n = 10$, $p < 0.01$, *H. sulphurea*: $r^2 = -0.681$,

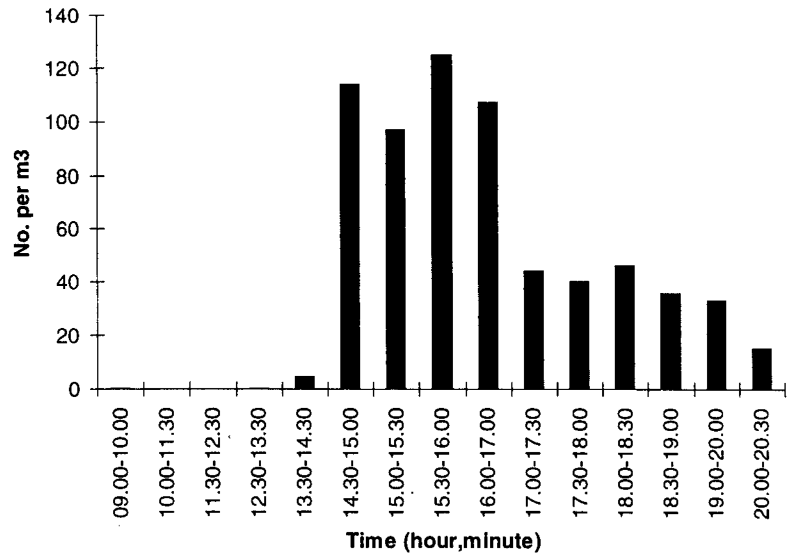

Fig. 2. Total drift densities (N/m³) before and during rotenone treatment of the river Ogna. The rotenone solution reached the station at approximatly 14.00

$n = 8$, $p < 0.01$). A few larvae of *Ephemerella mucronata*/sp. occurred in the drift samples through the whole treatment period, but their numbers did not decline with time ($r^2 = 0.037$, $n = 9$, $p = 0.310$).

About 95-99% of the drifting larvae were dead, especially *Baetis* spp. However, among living larvae *Ephemerella mucronata*/sp. was most common, although some living *Heptagenia sulphurea* were also found. The composition of rotenone-induced drift was markedly different from the ephemeropteran benthic community structure. *Heptagenia* sp./*sulphurea* comprised 60 % of the total mayfly drift, but only 19.3 % of mayfly benthic standing stock as indicated by kick samples. In the benthic samples baetid mayflies were clearly dominant (78 %), while in the drift samples they only made up 37.8 % (Table 1).

Rotenone Effects on Mayfly Standing Stocks

In the river Ogna, the mayfly fauna was almost eradicated from the treated stretches. One day after the application of rotenone, only a few specimens of *Heptagenia sulphurea* and *Ephemerella mucronata* was found alive in kick samples (Fig. 4). However, one and a half months after the treatment, the dominant species *Baetis rhodani* and *Ephemerella* sp. were common, and six species were detected compared with eigth species four days before the treatment.

In the river Rauma, 14 species of Ephemeroptera were found in the benthic samples in the investigated period. A significant reduction in standing stocks of most mayflies: *Ameletus inopinatus, Baetis rhodani, B. subalpinus, B. fuscatus/scambus, Metretopus borealis* and *Heptagenia* spp. was found on newly rotenone-treated stretches. The abundance of mayflies was reduced by 12-81% (between locations) during the month after the rotenone application, compared to the month before the rotenone treatment in late September 1993. In particular, baetid mayflies were strongly affected. *B. rhodani,* the most dominant species in the river, was absent from the samples in the autumn of 1993 and the spring of 1994 (Fig. 5). However, there was a

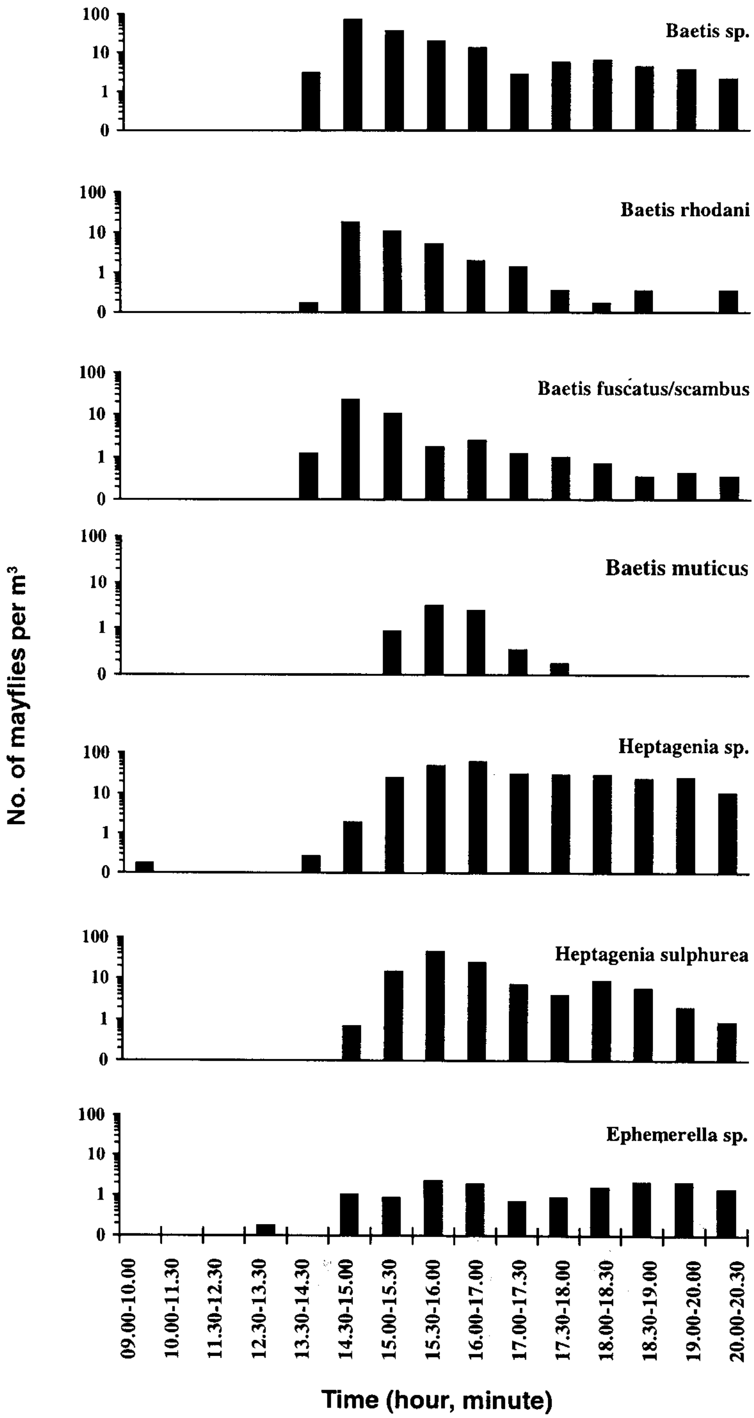

Fig. 3. Drift densities (N/m³) of mayfly species before and during the rotenone treatment period in the river Ogna.

Table 1. The composition (%) of mayfly species in drift samples taken during the rotenone treatment, and the composition in benthic samples taken four days before the treatment.

Species	% in drift	% in benthos
Baetis spp.	24.7	7.4
Baetis rhodani	5.8	55.7
Baetis fuscatus/scambus	6.2	9.3
Baetis muticus	1.1	2.6
Baetis subalpinus	0.0	3
Heptagenia sp.	42.9	3.7
Heptagenia dalecarlica	0.0	1.5
Heptagenia sulphurea	17.1	14.1
Ephemerella mucronata/sp.	2.3	2.2
Caenis horaria	0.0	0.4

recolonization of numerous small larva in October 1994, and in 1995 and 1996 the species was as abundant as in the years preceeding the treatment. Its seasonal variation in abundance was also quite similar to that at the reference station (Fig. 5). Other baetid mayflies, as well as *A. inopinatus* died as a result of the rotenone application, and were absent from the river samples in the following month. However, they all recolonized the river stretches in 1994, and *A. inopinatus* was already numerous in May 1994 (Fig. 5). *E. aurivillii* was found alive in high numbers both during and after the rotenone treatment, and there was no significant reduction in larval standing stock (Fig. 5). The species occurred in especially high numbers during the year after the rotenone treatment. *Heptagenia sulphurea* also survived the treatment, as did the lentic species *Cloeon simile* in the pond Horgheimdammen (Fig. 6). These

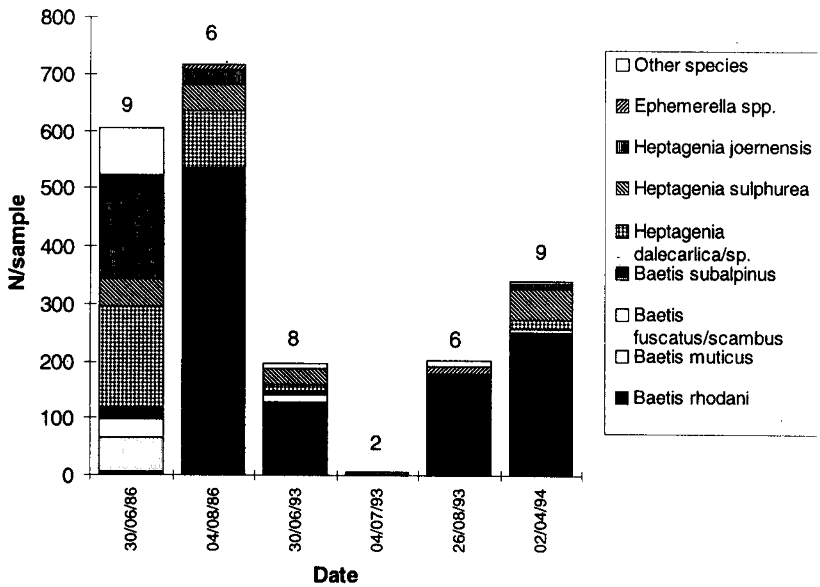

Fig. 4. The composition and abundance of mayfly species (N/sample) in the river Ogna before and after rotenone treatment. Pooled data from two locations. Number of species are given over each bar.

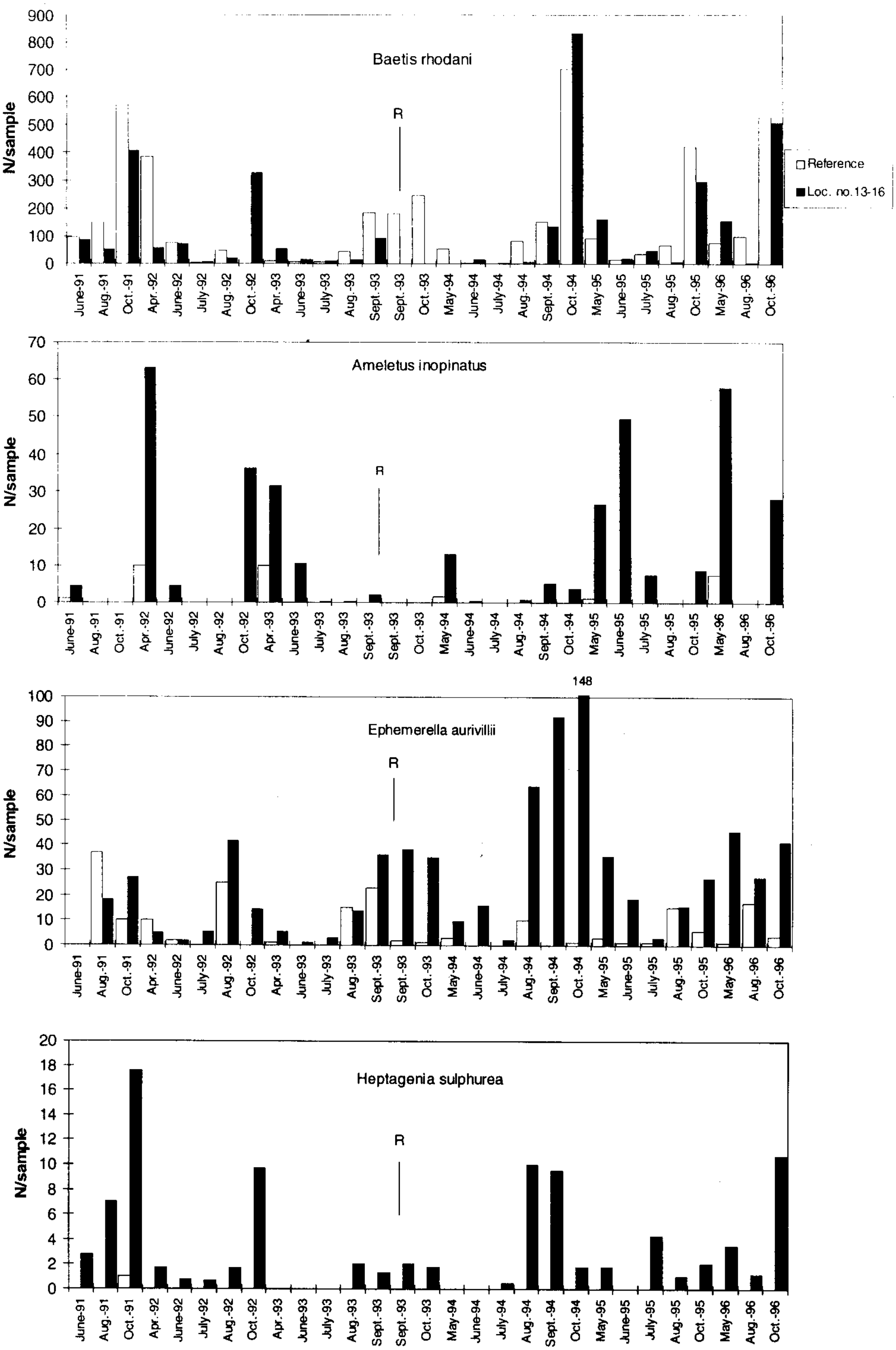

Fig. 5. Density of *Baetis rhodani, Ameletus inopinatus, Ephemerella aurivillii* and *Heptagenia sulphurea* in samples from the river Rauma before and after rotenone treatment (R).

results indicate that there is considerable variability in the effects of rotenone on different mayfly species.

At the localities exposed to rotenone, the overall mayfly fauna changed little compared to the three years preceeding the treatment (Table 2). *B. rhodani* was the dominant species in both periods (1991-1993 and 1994-1996). There was an increase in the abundance of *E. aurivillii* after the treatment, and a slight decrease in the abundance of *A. inopinatus* and *H. sulphurea*. Several species appeared sporadically in the samples both before and after the rotenone treatment: *Baetis subalpinus*, *B. fuscatus/scambus*, *Parameletus chelifer* and *Metretopus borealis*. A total of 12 species were observed in the samples during the three years before the rotenone treatment compared to 11 species during the three years after. Both the Shannon-Weaner diversity index and eveness were lower after the treatment. However, there was also a reduction in the mayfly diversity at the reference station (Table 2), so at least part of the reduction on the rotenone-treated stretches was probably not due to the poison. Among the more uncommon species, *H. dalecarlica* and *Paraleptophlebia werneri* were only detected in the period before the treatment, while *Leptophlebia vespertina* and *Cloeon simile* were observed only in the period following the treatment. Overall, total mayfly abundances did not change much in the long term as a result of the rotenone application.

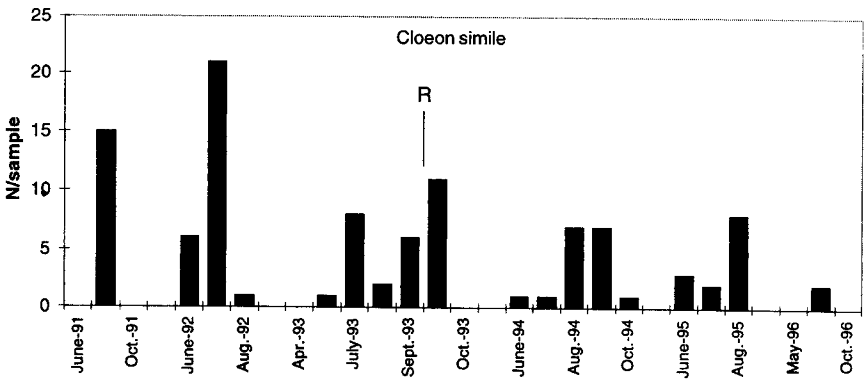

Fig. 6. Density of *Cloeon simile* in the pond Horgheimdammen before and after rotenone treatment (R).

DISCUSSION

The effects of rotenone on Scandinavian lotic mayflies is poorly known. This study shows that rotenone application induced an immediate catastrophic drift of mayflies, and caused large-scale mortality. Daytime drift densities before the rotenone application were low. The drift densities peaked 30-60 minutes after rotenone exposure, and were much higher than normal drift densities (cf. Brittain and Eikeland 1988). The different species differed in their tendency to enter the drift: most baetid mayfly species were particularly sensitive to rotenone. After a peak early in the treatment period, they decreased in densities. Others, like *Baetis muticus*, *Heptagenia* spp. and *Ephemerella* spp. were more slow in their response. Drift densities of *Ephemerella* did not decrease with time, and several specimens were found alive in drift samples. Different species of mayflies must therefore have widely different tolerances to rotenone, either for physiological reasons or as a result of ecological and/or behavioural differences between species. Koksvik and Aagaard (1984) describe taxon-specific effects of rotenone on lentic chironomids. In two Papua New Guinea streams, Dudgeon (1990) also found increasing drift densities after rotenone application. Baetid mayflies were particularly affected, and baetid densities decreased with time, as was also seen in the river Ogna. Leptophlebiid mayflies, by contrast, were found less sensitive to rotenone in Dudgeon's study (1990). Catastrophic drift in the Papua New Guinea streams comprised mainly living animals, in contrast to our findings in the river Ogna. However, Dudgeon does not give any data on the concentration of rotenone used and the time of exposure. Laboratory studies have indicated that tolerances vary greatly within single orders or families (Engstrom-Heg et al. 1978, Chandler and Marking 1982). Coleoptera, Hemiptera, Gastropoda and Bivalvia seem to have a high tolerance to rotenone (Engstrom-Heg et al. 1978). The pearl mussel (*Margaritifera margaritifera*) is also highly resistant to rotenone (Dolmen et al. 1995). Among ephemeropterans Engstrom-Heg et al. (1978) found Baetidae to be very sensitive and Heptageniidae and Ephemerella to be relatively unaffected. This agrees with our findings. Total mortality occurred after 6 ppm-hours of rotenone exposure in *Baetis* spp., in contrast to 72-144 ppm-hours in *Ephemerella* spp. (Engstrom-Heg et al. 1978). However, exposure to rotenone in laboratory studies does not necesserely mimic the way in which species respond to the poison in running water. As pointed out by Dudgeon (1990), the initial response to rotenone is behavioural, but we do not know whether the insects are drifting in response to detection of rotenone or as a result of its toxic effects. In the river Ogna, however, rotenone clearly had a toxic effect on most mayflies, causing high mortalities. The effects of rotenone at the species level may, moreover, depend on the microhabitat use of a species and also in the timing of the rotenone treatment versus life history events. The early instars of several mayfly species live in the hyporheic (Ward 1992, Williams 1984) and will not be exposed to rotenone as easily as later instars dwelling in the uppermost substrate. This may also be the case in later instars of *Baetis muticus* and *Heptagenia sulphurea,* which are more cryptic in their behaviour than *Baetis rhodani* and *Baetis subalpinus* for instance.

Reports on the short-time effects of rotenone treatment of rivers on standing-stocks of macroinvertebrates give highly different pictures. Some investigations have found a large temporary reduction in standing stocks of invertebrates (Binns 1967, Cook and Moore 1969, Arnekleiv 1997, Arnekleiv et al. 1997), while others report small or insignificant reductions (Dudgeon 1990, Morrison 1977). This depends probably both on the rotenone concentrations used and the design of investigations. In the river Ogna mayflies were almost eradicated from the rotenone treated stretches for some weeks. Dispite a higher total exposure to rotenone in the river Rauma (up to 10 ppm-hours in the river Ogna, versus 15-25 ppm-hours in the river Rauma) the mayfly fauna seemed less affected in the river Rauma. This can be due to several factors: The effects of rotenone are positively correlated by temperature (Meadows 1973, Gilderhus et al. 1986). The temperature was considerably higher during the rotenone treatment in Ogna in July (13.6 °C) compared to that in Rauma during the treatment in September (5.0-6.0 °C). Species composition and seasonal life history events were also different in July and September. In addition different types of rotenone were used in the two rivers.

In both rivers, however, we observed a rapid recolonization after the rotenone treatment. *Ameletus inopinatus* occured with large nymphs in May 1994 after the rotenone treatment in late September 1993. *Baetis rhodani* recolonized the treated stretches with small nymphs the following autumn. Within one year, all the abundant species registered before the treatment, again occurred in large numbers. Binns (1967) made similar observations when treating a river in Wyoming with emulsified rotenone: the invertebrate population was drastically reduced by the rotenone treatment, but within one month it had to a large extent been built up again. Drift was probably an important source in the recolonization of the rivers Ogna and Rauma, since both rivers have long stretches of different biotopes upstream of the rotenone treated reaches (cf. Brittain and Eikeland 1988, Mackay 1992). However, we do not have detailed information about the mechanisms of recolonization in these rivers. Engstrom-Heg et al. (1978) state that there is a strong tendency for the more sensitive insects to be highly mobile and/or to have short life cycles, and thus to repopulate depleted areas rapidly through drift, migration and oviposition. This is in parti-

Table 2. Relative abundance and diversity of mayfly species at the reference station and at three locations (pooled data) in the river Rauma before (12 dates) and after (16 dates) rotenone treatment in 1993.

1991-1993 (before r.)				1994-1996 (after r.)		
Loc. no. 7, reference	**Mean**	**± SE**	**% of total**	**Mean**	**± SE**	**% of total**
Baetis rhodani	131.46	50.88	90.63	172.50	51.29	96.02
Ephemerella aurivilli	10.21	3.57	7.04	3.88	1.35	2.16
Ameletus inopinatus	1.67	1.12	1.15	0.72	0.47	0.40
Baetis subalpinus	1.17	0.87	0.80	2.16	1.32	1.20
Parameletus chelifer	0.42	0.34	0.29	0.00	0.00	0.00
Heptagenia sp.	0.08	0.08	0.06	0.00	0.00	0.00
Baetis fuscatus/scambus	0.04	0.04	0.03	0.03	0.03	0.02
Siphlonurus sp.	0.00	0.00	0.00	0.38	0.34	0.21
Total	145.04	51.75	100.00	179.66	50.92	100.00
No. of species	7			6		
Shannon-Wener H'	0.169			0.092		
Eveness J'	0.200			0.118		

1991-1993, before rotenon				1994-1996, after rotenon		
Loc. no. 13, 15, 16	**Mean**	**± SE**	**% of total**	**Mean**	**± SE**	**% of total**
Baetis rhodani	113.86	34.04	72.7	147.14	41.87	71.94
Ephemerella aurivilli	14.32	2.97	9.14	38.89	10.32	19.01
Ameletus inopinatus	12.50	3.99	7.98	11.3	2.99	5.52
Siphlonuridae	9.53	6.26	6.08	0.01	0.01	0.01
Heptagenia sulphurea	2.14	0.93	1.37	1.81	0.77	0.88
Siphlonurus sp.	1.76	1.56	1.13	1.56	1.27	0.76
Heptagenia sp.	1.34	0.75	0.86	1.56	0.88	0.76
Paraleptophlebia werneri	0.58	0.43	0.37	0.00	0.00	0.00
Baetis subalpinus	0.24	0.13	0.15	0.41	0.22	0.20
Parameletus chelifer	0.08	0.06	0.05	0.11	0.11	0.06
Baetis sp.	0.08	0.06	0.05	0.57	0.56	0.28
Metretropus sp./*borealis*	0.08	0.08	0.05	0.01	0.01	0.01
Baetis fuscatus/scambus	0.07	0.04	0.04	0.01	0.05	0.01
Heptagenia dalecarlica	0.03	0.03	0.02	0.00	0.00	0.00
Metretropus borealis	0.01	0.01	0.01	0.00	0.00	0.00
Parameletus sp.	0.00	0.00	0.00	0.11	0.11	0.06
Siphlonurus lacustris	0.00	0.00	0.00	0.19	0.13	0.09
Cloeon sp.	0.0	0.00	0.00	0.01	0.01	0.01
Cloeon simile	0.00	0.00	0.00	0.01	0.01	0.01
Leptophlebia vespertina	0.00	0.00	0.00	0.01	0.01	0.01
Ephemerella sp.	0.00	0.00	0.00	0.76	0.49	0.37
Total	156.61	39.55	100.00	204.52	47.5	100.00
No. of species	12			11		
Shannon-Wiener H'	0.443			0.390		
Eveness J'	0.376			0.311		

cular the case for *Baetis rhodani* and *Ameletus inopinatus*, which are good swimmers and have an univoltine life cycle in Central Norway (Arnekleiv 1996). Experimental studies of recolonization of disturbed reaches by stream macroinvertebrates have given periods from a few days to approximately four months (Reice 1985, Malmquist et al. 1991, Tikkanen et al. 1994).

Heptagenia sulphurea, Ephemerella aurivillii and *Cloeon simile* all survived the rotenone treatment. In laboratory experiments the two former species were also the most rotenone-tolerant mayfly species (Engstrom-Heg et al. 1978). Many pond-dwelling insects, including Leptophlebiid mayflies, are known to tolerate oxygen deficiency (Brittain and Nagell 1981, see also Macan 1973). The reason why the lentic species *Cloeon simile* also survived the treatment is possibly that it can also tolerate low oxygen levels. However, the highest numbers of surviving individuals was found in *E. aurivillii*. This species even appeared more numerous the year following the rotenone treatment compared to the year before. The altered interspecific competition and lack of predators evidently gave *E. aurivillii* increased opportunity.

This study demonstrated a taxon-specific response to rotenone among mafly species. A significant reduction in standing stocks of most species was found in newly rotenone-treated streches. At least three species survived the treatment. A relatively fast recolonization of the mayfly fauna took place on the rotenone-treated stretches. Overall, total mayfly abundances did not change in the long term as a result of the rotenone treatment of the river Rauma. However, further investigations are needed to evaluate recolonization mechanisms and the long-term effects on the population biology and genetics of mayfly species.

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REFERENCES

Almqvist, E. 1959. Observations on the effect of rotenone emulsives on fish food organisms. Rep. Inst. Freshw. Res. Drottningholm 40: 146-160.

Arnekleiv, J. V. 1996. Life cycle strategies and seasonal distribution of mayflies (Ephemeroptera) in a small stream in central Norway. Fauna norv. Ser. B 43: 19-30.

Arnekleiv, J. V. 1997. Short-time effects of rotenone treatment on benthic macroinvertebrates in the rivers Ogna and Figga, Steinkjer municipality. Vitenskapsmuseet Rapp. Zool. Ser. 1997, 3: 1-28. (In Norwegian).

Arnekleiv, J. V., D. Dolmen, K. Aagaard., T. Bongard and O. Hanssen. 1997. Effect of rotenone treatment on the bottomfauna of the Rauma and Henselva watercourses, Møre and Romsdal. Part I: Qualitative investigations. Vitenskapsmuseet Rapp. Zool. Ser. 1997, 8: 1-48. (In Norwegian).

Binns, N. A. 1967. Effects of rotenone treatment on the fauna of the Green River, Wyoming. Fish. Res. Bull. 1: 1-114.

Brittain, J. E. and T. J. Eikeland. 1988. Invertebrate drift. A review. Hydrobiologia 166: 77-93.

Brittain, J. E. and B. Nagell. 1981. Overwintering at low oxugen concentraitons in the mayfly Leptophlebia vespertina. Oikos 36: 45-50.

Chandler, J. H. (Jr.) and L. L. Marking. 1982. Toxicity of rotenone to selected aquatic invertebrates and frog larvae. Prog. Fish. Cult. 44: 78-80.

Cook, S. F. (Jr.) and R. L. Moore. 1969. The effects of rotenone treatment on the insect fauna of a California stream. Trans. Amer. Fish. Soc. 98: 539-544.

Dolmen, D. 1992. Dammer i kulturlandskapet - makroinvertebrater, fisk og amfibier i 31 dammer i Østfold. NINA Forskningsrapport 20: 1-63. (In Norwegian).

Dolmen, D., J. V. Arnekleiv and T. Haukebø. 1995. Rotenone tolerance in the freshwater pearl mussel (*Margaritifera margaritifera*). Nordic J. Freshw. Res. 70: 21-30.

Dudgeon, D. 1990. Benthic community structure and the effect of rotenone piscicide on invertebrate drift and standing stocks in two Papua New Guinea streams. Arch. Hydrobiol. 119: 35-53.

Engstrom-Heg, R., R. T. Colesante and E. Silco. 1978. Rotenone tolerances of stream-bottom insects. N. Y. Game J. 25: 31-41.

Fox, R. C. 1985. Rotenone use for fisheries management. California Department of Fish and Game. 243 pp.

Frost, S., A. Huni and W. E. Kershaw. 1971. Evaluation of a kicking technique for sampling stream bottom fauna. Can. J. Zool. 49: 160-173.

Fukami, J. I., T. Shisido, K. Fukunaga and J. E. Casida. 1969. Oxidative metabolism of rotenone in mammals, fish, and insects, and its relation to selective toxicity. J. Agr. Food Chem. 17: 1217-1226.

Gilderhus, P. A., J. L. Allen and W. K. Dawson.1986. Persistence of rotenone in ponds at different temperatures. North Amer. J. Fish. Mgmt. 6: 129-130.
Haley, T. J. 1978. A review of the literature of rotenone. J. Environ. Pathol. Toxicol. 1: 315-337.
Johnsen, B. O. and A. J. Jensen. 1986. Infestations of Atlantic salmon (*Salmo salar*) by *Gyrodactylus salaris*, in Norwegian rivers. J. Fish Biol. 29: 233-241.
Johnsen, B. O. and A. J. Jensen. 1991. The *Gyrodactylus* story in Norway. Aquaculture 98: 289-302.
Johnsen, B. O. and A. J. Jensen. 1992. Infection of Atlantic salmon, *Salmo salar* L., by *Gyrodactylus salaris*, Malmberg 1957, in the River Lakselva, Misvær in northern Norway. J. Fish Biol. 40: 433-444.
Koksvik, J. I. and K. Aagaard. 1984. Effects of rotenone on the benthic fauna of a small eutrophic lake. Verh. Int. Ver. Limnol. 22: 658-665.
Macan, T. T. 1973. Ponds and lakes. London. George Allen and Unwin Ltd. 148 pp.
Mackay, R. J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Can. J. Fish. aquat. Sci. 49: 617-628.
Malmquist, B., S. Rundle, C. Brönmark and Erlandson, A. 1991. Invertebrate colonization of a new, man-made stream in southern Sweden. Freshw. Biol. 26: 307-324.
Marking, L. L. and T. D. Bills. 1976. Toxicity of rotenone to fish in standardized laboratory tests. U.S. Fish Wildl. Serv., Invest. Fish Control 72: 1-11.
Meadows, B. S. 1973. Toxicity of rotenone to some species of coarse-fish and invertebrates. J. Fish Biol. 5: 155-163.
Morrison, B. R. S. 1977. The Effects of Rotenone on the Invertebrate Fauna of Three Hill Streams in Scotland. Fish. Mgmt. 8: 128-139.
Næss, T., K. E. Naas and O. B. Samuelsen. 1991. Toxicity of rotenone to some potential predators on marine fish larvae. An experimental study. Aquacult. Eng. 10: 149-159.
Reice, S. R., 1985. Experimental disturbance of species diversity in a stream community. Oecologia 67: 90-97.
Soleman, V. E. F. 1950. History and use of fish poisons in the United States. Can. Fish Cult. 8: 3-16.
Tikkanen, P., P. Laasonen, T. Muotka, A. Huhta, and K. Kuusela. 1994. Short-term recovery of benthos following disturbance from stream habitat rhabilitation. Hydrobiologia 273: 121-130.
Tobiasson, G. 1979. The use of rotenone in Sweden. Inf. Inst. Freshw. Res., Drottningholm 10: 1-33. (In Swedish).
Ugedal, O. 1986. A review of the litterature concerning the effects of rotenone in freswater ecosystems. DN-Reguleringsundersøkelsne 1986-14: 1-52. (In Norwegian).
Ward, J. V. 1992. Aquatic Insect Ecology. 1. Biology and habitat. John Wiley and Sons, Inc. New York. 438 s.
Williams, D. D. 1984. The hyporheic zone as a habitat for aquatic insects and associated arthropods, pp. 430-455 in V. H. Resh and D. R. Rosenberg (eds.), The Ecology of Aquatic Insects. Praeger, New York.