BOREAL ENVIRONMENT RESEARCH 3: 63–73 ISSN 1239-6095
Helsinki 7 July 1998

Impact of forestry practices on ecology of algal communities in small brooks in the Nurmes experimental forest area, Finland

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Holopainen, A.-L. & Huttunen, P. 1998. Impact of forestry practices on ecology of algal communities in small brooks in the Nurmes experimental forest area, Finland. *Boreal Env. Res.* 3: 63–73. ISSN 1239-6095

The effects of clear felling, ditching and site preparation on the species composition, biomass and production of algae in forest brooks have been studied in 1982–93 as a part of the Nurmes Project in Finland. After clear felling and site preparation the primary factors causing change in species composition of algae were the increased nutrient content and colour of water. As the effects of site preparation started to wear off the nutrient content and temperature of the water returned towards the original level, a new response was seen in species of algae. Immediately after ditching and clear felling the biomasses of Volvocales and Cryptophyceae rose and reached their maximum in the following open water season, while the proportion of diatoms in the biomass decreased. A protective forest zone between the brook and the area affected by the intervention appeared to be highly effective in preventing changes in the water quality.

Introduction

It is now recognized that the efficient felling and site preparation techniques used in forestry until the late 1980s had the effect of altering the water quality and biota of the lakes and rivers, especially in terms of illumination conditions, water temperatures and enhanced concentrations of organic matter, nutrients and metals (e.g. Borman *et al*. 1968, Grip 1982, Ahtiainen 1992, 1993, Binkley and Brown 1993). Less attention has been paid to its biological effects (*see* Bergqvist *et al.* 1984, Holopainen *et al.* 1991, Huttunen *et al.* 1993, Rönkkö *et al.* 1988).

This report presents results regarding spatial and temporal changes in the algal flora, biomass and production capacity of the brooks as a consequence of clear felling, ditching and site preparation in four drainage basins in the Nurmes experimental area over the period 1982–1993. The results are based on observations made in July and August of each year.

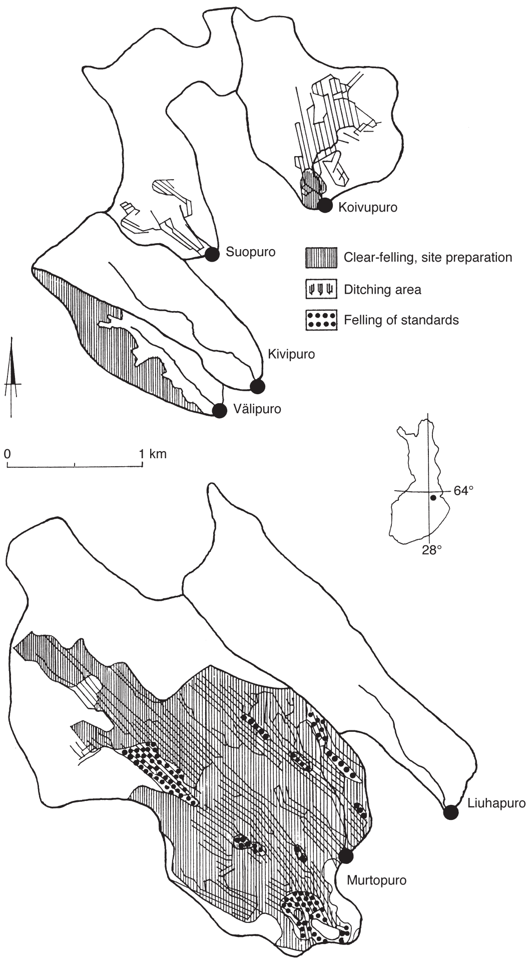

Fig. 1. The drainage basins studied in the Nurmes project, after the commencement of forestry practices. Experimental plots Murtopuro, Suopuro, Koivupuro and Kivipuro. Reference brooks Kivipuro and Liuhapuro.

Material and methods

The research started in 1982 as a part of the Nurmes Project beginning in 1978 (Ahtiainen *et al*. 1988). Monitoring of the brooks is continuing. Forestry practices were carried out in four drainage basins, and another two remained untouched throughout the duration of the project. Clear felling (mainly using forest harvesters) was carried out in 1982–1983, and the mineral soil was ploughed and the mires ditched and mounted in summer 1986. In Kivipuro a strip of forest was left between the clear felled area and the nearby brook, and in Suopuro a buffer zone was left between the ditches and the brook. The areas of land on which the forestry practices were carried out varied from 13% to 58% of the drainage basin. The biology of the brooks in their natural state had been studied one year before any forestry practices were undertaken and has now been monitored for 11 years since the felling took place.

Study area and the experimental plots

The experimental plots are situated in two separate areas in Eastern Finland (63°52´N, 28°35´E), in the drainage basins of the brooks Murtopuro and Liuhapuro in the district of Valtimo and Suopuro and the brooks Koivupuro, Välipuro and Kivipuro in Sotkamo (Fig. 1). The drainage basins are small (0.5–4.9 km) and fairly similar in altitude (179–246 m a.s.l.) and land gradient (Ahtiainen *et al*. 1988). The brooks are approx. 0.5–1.5 m wide and 0.5–1 m deep at the sampling points and their length varies between 300 and 1 500 m. Their mean annual discharges are in the range 9.1–17.3 l s^{-1} km^{-2}. The highest annual runoff during the calibration period, 1979–82, was in the Liuhapuro basin, 462 mm a^{-1}, and the lowest in Kivipuro basin, 328 mm a^{-1} (Seuna 1988). The proportion of mires varies between 32–70%, being lowest in the Kivipuro basin and highest in Suopuro, which rises from a small lake.The main tree species growing alongside the brooks are birch and pine, although Murtopuro runs through spruce forest and the Koivupuro basin is characterized by birch-dominated forest. The brooks also run underground for part of their length, or are covered by mosses, Kivipuro in particular being only sporadically visible at the surface. The banks of the brooks are moss-covered.

The drainage basins had remained for the most part untouched by forestry practices up until the winter of 1982–83, the only exception being an area of 3 ha in the Koivupuro basin that had been felled in the early 1970s and small amounts of felling, ditching and fertilization carried out near the upper reaches of Murtopuro and Liuhapuro at about the same time.

Clear felling and site preparation

The clear felling of 286 ha of forest in the Murtopuro basin in winter 1982–83 was followed by the ditching of 198 ha, mounting of 49 ha and ploughing of the mineral soil on 80 ha in summer 1986. New pine seedlings were planted in the area in the summer of 1987. Similarly an area of 30 ha in the Kivipuro basin clear felled in the summer of 1983, was ploughed in summer 1986. In this case a protective strip of unfelled forest 10–50 m wide was left between the felling site and the brook.

Ditching

The ditching of 32 ha of forest in the Koivupuro basin in 1983 and clear felling of 6 ha was followed in summer 1986 by mounting and ditching of an additional 4 ha, after which fertilizer was applied to an area of 6 ha in 1989. Pine seedlings were planted in summer 1987. Ditching was carried out in the Suopuro basin in summer 1983 and a buffer zone was left between the ditches and the brook.

Two drainage basins, Liuhapuro in Valtimo and Välipuro in Sotkamo, were left untouched throughout the study period, to serve as reference areas for studying the annual changes taking place in the brooks under natural conditions.

Sampling and analyses

Water samples were taken weekly from all brooks between May and September 1982, every second week in 1983–92 and once a month from 1993 onwards. Sampling sites were located about 50–100 m away from the weir constructed for the measurement of discharge. Total sample of approx. 5 litres consisted of 7–10 separately taken samples of 0.5 l each, which were combined, mixed and used for subsampling for the determination of water chemistry (M. Ahtiainen and P. Huttunen unpubl.), primary production, species composition and biomass of algae. The physicochemical analyses were performed in the laboratories of the Environmental Centre of Northern Karelia and the Karelian Research Institute, University of Joensuu. The sampling procedures and analyses are described in more detail by Ahtiainen *et al.* (1988) and Holopainen *et al.* (1988).

Primary production was measured *in vitro* using the ^{14}C method under constant conditions (Kusnetsov and Romanenko 1967, Goldman *et al.* 1969). The samples of algae were stored in Lugol solution, to which 18% formalin was added later to ensure preservation. The algae visible within a standard surface area of a 50 ml sample in a precipitation cuvette were identified and counted under an inverted microscope. Dissolved organic carbon (DOC) was determined by the high-temperature combustion method (Salonen 1979). The methods are described in detail by Holopainen *et al.* (1988).

The correlations of algal species with water quality parameters were examined by canonical correspondence analysis (CCA) using the CANOCO computer program (Ter Braak 1987, 1990).

Results

Preliminary results of this study were published earlier in Holopainen *et al.* 1988, 1991, Holopainen and Huttunen 1992 and Huttunen and Holopainen 1993.

Before any forestry practices had been carried out the water in all the brooks was cold, with mean temperatures in July and August in the range 8.1–11.9 °C (Table 1), and fairly acid throughout the open water season, pH 3.9–6.5. It was also markedly brown in colour, 50–700 mg l^{-1} Pt, and had a high content organic matter, 13.9–52.1 mg l^{-1} (Ahtiainen 1992). Concentrations of phosphorus and nitrogen compounds were relatively high during the low runoff period, and total phosphorus was high in July and August, especially in Murtopuro and Kivipuro (Table 1).

Clear felling and site preparation (Murtopuro)

Primary production in Murtopuro in July and August remained higher than in the natural state for three years after felling. The maximum value, 86.1 mg C $m^{-3}d^{-1}$, seven times higher than before site preparation, was reached in the first summer (Table 2). The nutrient content of the water similarly rose after felling, and remained high until 1988 (Table 1). In 1983–85, total phosphorus was five times higher than in the natural state and phosphate phosphorus eight times higher, while total nitrogen had doubled.

Primary production decreased again in 1986,

Table 1. Mean water temperature, total phosphorus, phosphate phosphorus, total nitrogen, DOC and suspended solids in the brooks Murtopuro (clear felling and soil preparation), Koivupuro (ditching and supplementary ditching, Suopuro (ditching with a protective zone) and Kivipuro (felling with a protective zone) in July and August 1979–82 (calibration period), 1983–85, 1986–88, 1989–91 and 1992–94.

Brook	Period	t °C	Tot.P µg l^{-1}	PO$_4$-P mg l^{-1}	Tot.N mg l^{-1}	DOC	Suspended solids
Murtopuro	1979–82	9.9	34.8	17.8	507	20.3	0.9
	1983–85	13.4	217.6	142.5	1 291	60.9	1.9
	1986–88	16.8	136.7	38.2	1 022	28.1	91.5
	1989–91	14.2	28.7	7.6	530	28.1	2.8
	1992–94	13.0	29.3	8.9	493	26.9	3.0
Koivupuro	1979–82	8.1	16.8	5.3	328	24.0	1.6
	1983–85	14.2	58.8	16.4	768	26.9	7.0
	1986–88	12.7	35.6	12.4	584	22.6	3.4
	1989–91	13.4	19.6	6.7	523	24.6	1.8
	1992–94	11.3	18.9	5.6	530	25.1	2.1
Suopuro	1979–82	11.9	15.8	2.4	514	23.7	3.5
	1983–85	13.9	48.6	5.1	1 084	32.3	14.6
	1986–88	12.8	24.0	6.5	611	31.1	4.9
	1989–91	13.2	16.3	2.4	556	33.9	2.1
	1992–94	12.2	15.8	3.7	645	29.0	4.6
Kivipuro	1979–82	10.5	43.4	12.8	613	30.5	2.6
	1983–85	9.7	37.4	9.6	677	37.9	0.8
	1986–88	9.0	26.3	9.9	556	31.1	0.6
	1989–91	9.3	24.9	7.0	639	39.4	0.8
	1992–94	8.6	25.7	6.4	611	37.7	0.7

Table 2. Mean primary production (prod., mg C $m^{-3}d^{-1}$) and algal biomass (bm, mg m^{-3}) in the brooks Murtopuro (clear felling and soil preparation), Koivupuro (ditching and supplementary ditching, Suopuro (ditching with a protective zone) and Kivipuro (felling with a protective zone) in July and August 1982–93.

	Murtopuro		Koivupuro		Suopuro		Kivipuro	
	prod.	bm	prod.	bm	prod.	bm	prod.	bm
1982	6.4	36	35.3	16	23.4	235	15.3	76
1983	86.1	1 660	50.7	1 640	60.7	984	10.4	41
1984	23.0	433	83.3	507	52.6	209	5.5	13
1985	46.6	295	124.5	336	16.0	61	45.4	9
1986	33.3	51	26.7	169	27.8	276	1.6	16
1987	43.7	265	113.5	225	168.5	64	3.1	16
1988	87.6	289	91.1	153	29.1	59	41.4	18
1989	125.1	–	123.8	–	138.4	–	27.0	–
1990	25.8	277	28.3	161	13.2	46	1.1	2
1991	31.4	219	33.2	60	7.7	98	2.8	1
1992	19.7	204	33.8	162	22.0	80	4.3	44
1993	14.5	68	12.6	50	8.9	42	1.1	5

in conjunction with site preparation, although it was still somewhat higher than in a natural state (Table 2). The decisive factor was the turbidity of the water caused by pronounced outwash of suspended solids from the drainage basin. Suspended solids in fact increased immediately after soil preparation and remained extremely high for three years, during which the mean content was 91.5 mg l^{-1}, i.e. 70 times higher than the initial value (Table 1). Production capacity rose again in the two years after soil preparation, reaching maximum values in 1989. It was still more than double the initial figure in the late summer of 1993, eleven years after clear felling (Table 2).

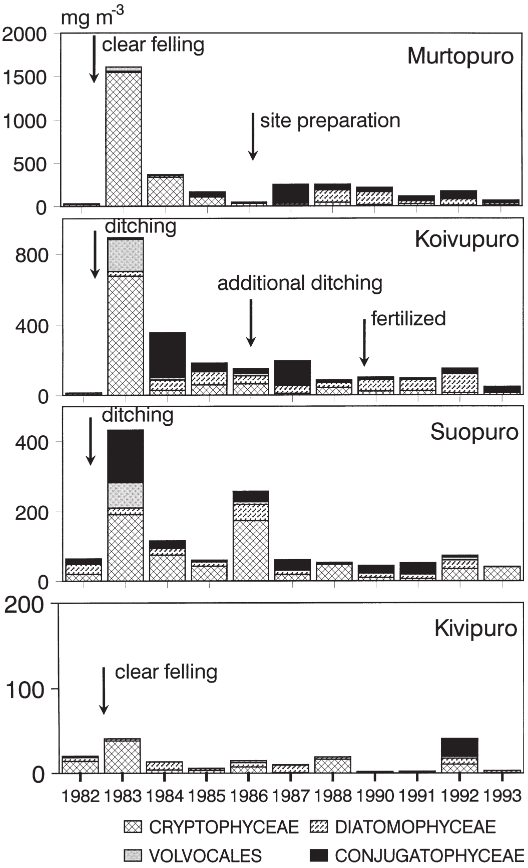

Fig. 2. Biomasses of Cryptophyceae, Diatomophyceae, Volvocales and Conjugatophyceae in Murtopuro, Suopuro, Koivupuro and Kivipuro in July and August 1982–93. Note that the scale for biomass varies from one brook to another.

Having been initially fairly low (mean = 36 mg m^{-3} in July and August 1982), algal biomass for Murtopuro rose immediately upon clear felling and reached maximum values the following year, 1 660 mg m^{-3}. This implied a 46-fold increase in late summer biomass. The biomass was low during site preparation in 1986 (Fig. 2), but rose again afterwards and was still double the initial level in 1993 (Table 2). Although positive correlations were obtained between algal biomass and both total phosphorus and total nitrogen, DOC explains the variance in algal biomass in Murtopuro (Table 3).The number of algal species increased together with biomass after the forestry practices in Murtopuro. The initial number of species was fairly low, only 21 taxa (species or genera) identified (Holopainen *et al.* 1988). Typical entities were the Cryptophyceae *Cryptomonas* spp. and *Chroomonas* spp. and representatives of the Pennales diatoms, including *Eunotia* spp. The Cryptophyceae made up almost half of the total biomass and diatoms approx. 38%. Considerable changes took place in 1983–85, following clear felling (Fig. 2). The Cryptophyceae, largely *Cryptomonas* spp., and the Volvocales green algae *Chlamydomonas* spp. increased in quantity and the

Table 3. Correlations of algal biomass with total phosphorus, total nitrogen and DOC in the brooks Murtopuro (clear felling and soil preparation), Koivupuro (ditching and supplementary ditching, Suopuro (ditching with a protective zone) and Kivipuro (felling with a protective zone). Number of samples varied from 32 to 38 in each brook.

	Murtopuro	Koivupuro	Suopuro	Kivipuro
Tot. N	$r = 0.49$ $P = 0.002$	$r = 0.71$ $P < 0.001$	$r = 0.14$ $P = 0.383$	$r = -0.02$ $P = 0.907$
Tot. P	$r = 0.48$ $P = 0.002$	$r = 0.66$ $P < 0.001$	$r = 0.13$ $P = 0.415$	$r = 0.27$ $P = 0.089$
DOC	$r = 0.72$ $P < 0.001$	$r = 0.46$ $P = 0.003$	$r = -0.13$ $P = 0.412$	$r = -0.04$ $P = 0.805$

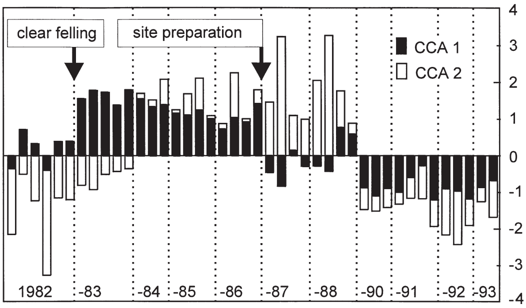

Fig. 3. CCA scores for the algal flora and water quality variables in Murtopuro in the summers of 1982–93. The significant explanatory variables were total phosphorus ($r = 0.93^{***}$), total nitrogen ($r = 0.79^{***}$) and water colour ($r = 0.72^{***}$) on axis 1 and water temperature ($r = 0.78^{***}$) on axis 2.

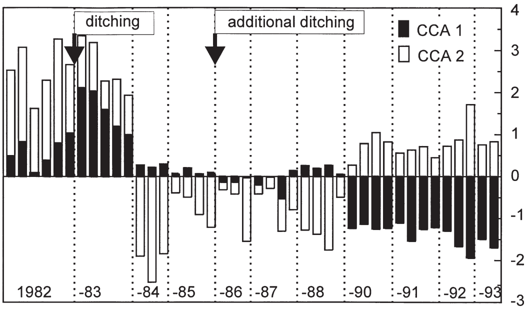

Fig. 4. CCA scores for the algal flora and water quality variables in Koivupuro in the summers of 1982–93. The significant explanatory variables were total phosphorus ($r = 0.81^{***}$) on axis 1 and pH ($r = 0.59^{**}$) and ammonium nitrogen ($r = 0.65^{**}$) on axis 2.

proportion of the previously typical diatoms diminished, to account for less than 5% of the total biomass (Huttunen *et al.* 1990).

The number of species of algae increased somewhat after clear felling, and had trebled compared with the situation in a natural state by the time site preparation was completed. The number of Conjugatophyceae in particular increased considerably in the summers of 1987 and 1988, remaining high until 1991. Other algae to benefit from site preparation were *Mougeotia* spp., *Cosmarium punctulatum*, *Penium spinospermum*, *Roya obtusa* var. *montana*, *Hyalotheca dissiliens* and representatives of the genera *Closterium* and *Staurastum*. These accounted for about 51% of the total algal biomass in 1986–88 (Fig. 2). It was only later, in 1988–91, that the diatoms increased in number.

The CCA results suggest that the primary factors causing the change in algal species in Murtopuro were the increased nutrient content of the water and the alteration in water colour (Fig. 3), although the higher water temperature was also significant immediately after site preparation, in 1987–88. In 1990–93, as the effects of site preparation on water quality began to wear off, the nutrient content and temperature of the water in the brooks fell once again and a further response was seen in the number of species of algae. The principal explanatory variables on CCA axis 1 for Murtopuro were total phosphorus ($r = 0.93^{***}$), total nitrogen ($r = 0.79^{***}$) and water colour ($r = 0.72^{***}$), while the main variable on axis 2 was water temperature ($r = 0.78^{***}$, Fig. 3).

Ditching, clear felling and supplementary ditching (Koivupuro)

Primary production in Koivupuro increased during the three years following ditching and felling, having trebled by the third year, just before the supplementary ditching work (Table 2). Possibly because of the turbidity of the water, the maximum production in this brook was reached only in the third year, although the maximum in the brook beside the clear felling area was reached immediately in the following summer. Concentration of the suspended solids in late summer was seven times higher during three years following clear felling compared to the natural state (Table 1). Primary production in the brook decreased during supplementary ditching and mounting, but rose again in the subsequent years. The highest production was recorded in 1989, when the water was warm. Fertilization of a small area of the drainage basin may also have contributed to the high production. The production returned more or less to its initial level in 1990. In Koivupuro total phosphorus and phosphate phosphorus rose immediately after ditching and remained high until 1988, while the nitrogen content continued to be high until 1993 (Table 1).

Algal biomass in Koivupuro in the late summer increased more than 100-fold in the year immediately after ditching (Fig. 2, Table 2), and was still enhanced 21-fold after three years. No separate response to the later supplementary ditching could be observed due to the already high biomass.

Even after 11 years the algal biomass was three times that recorded in the natural state. The changes in algal biomass in Koivupuro is explained by the total nitrogen content of the water (Table 3).

The algal flora in Koivupuro was altered in 1983–85 as a response to the ditching and the small area of clear felling that took place in the same year. The biomasses of Volvocales and Cryptophyceae rose immediately and were at their maximum in the following open water season, while the proportion of diatoms in the biomass decreased (Fig. 2). The primary cause of the change in species composition directly after was the increase of total phosphorus in the water, as shown by the status of this variable as the principal one on CCA axis 1 ($r = 0.81^{***}$) (Fig. 4).

The supplementary ditching in the Koivupuro basin was followed by an increase in the proportions of Conjugatophyceae and in their species diversity. Species encountered after ditching were *Closterium acutum*, *Mougeotia* spp. and *Penium spinospermum*. Later responses included increases in diatoms (*Eunotia* spp. and *Frustulia* spp.) and in the chrysophyte *Synura*. The number of species of algae increased to some extent immediately after ditching, about twice as many species or genera being encountered as had been found initially. The most important abiotic factors for the trends in the algal flora were the pH (pH 5.6) and ammonium (NH_4 18.1 $\mu g\ l^{-1}$) content of the water immediately after ditching and the nutrient content and lowering of the pH in more recent years. Significant negative correlations were found between CCA axis 2 and both pH ($r = -0.59^{**}$) and ammonium nitrogen ($r = -0.65^{**}$) (Fig. 4).

Ditching with a protective zone (Suopuro)

The production capacity of algae and biomass increased for about two years after ditching in the Suopuro basin having a protective zone left between the ditched area and the brook (Table 2). However, even at its maximum, the production of algae was only three times higher than in a natural state and biomass four times higher (Table 2). Correspondingly, total phosphorus, phosphate phosphorus and total nitrogen were above the initial level for six years (Table 1). Also, unlike the other brooks, Suopuro sometimes had high algal production capacity and biomass values on later occasions (Fig. 2), possibly due to floodwater from a small lake in its drainage basin.

Amounts of Cryptophyceae, Volvocales and Conjugatophyceae increased in the first year after ditching, including more abundant occurrences of *Hyalotheca dissiliens* and *Gymnozyga moniliformis* among the Conjugatophyceae, although their biomass remained fairly low throughout. In subsequent years, with the decline in the amounts of Volvocales, the diatom biomass increased (Fig. 2). Thus the effects of ditching were only discernible for two years when a protective zone was provided, the change in the algal flora being brought about largely by the increase in nutrients at first and the lowering in water acidity at a later stage.

Clear felling with a protective zone (Kivipuro)

Clear felling in the Kivipuro basin with a protective zone left between the felled area and the brook had only a mild impact on the brook. The production capacity of algae was low during the first two years after ploughing, increasing somewhat in the third year, but this pattern may simply be attributable to differences between the years, as similar changes were also seen in the reference brook Välipuro. Thus the protective zone may be said to effectively shield the brook from the potential hydrological effects of felling and soil preparation.

Discussion

Before forestry practices, the brooks were all very similar in terms of water quality and algal communities (Holopainen *et al.* 1988), although the water of Välipuro was somewhat darker in colour than in the other brooks (M. Ahtiainen and P. Huttunen unpubl.). No obvious water quality or biological changes were observed in the reference brooks over the period 1982–93.

Removal of the shading effect of the trees as a result of felling naturally implied a change in illumination conditions in the open stretches of the brooks. The water of Murtopuro as it passed the clear felled area, for example, was found to be 3.5 °C warmer on average in late summer, while the ditching carried out beside Koivupuro and Suopuro increased temperatures by 6.2 °C and 1.6 °C respectively. No warming of the water was detected in Kivipuro, however, where a protective zone of forest was left between the brook and the clear felled area. The felling and ditching also affected water quality in the brooks, increasing the concentrations of nutrients and organic matter, while the leaching of iron led to a rise in colour values (M. Ahtiainen and P. Huttunen unpubl.). These water quality changes were less pronounced in the drainage basins where a protective zone was left beside the brook.

The alterations in the water quality of the brooks brought about by the forestry practices described here had a considerable impact on the production of algae. Illumination improved upon the removal of the tree canopy, and the water became warmer. In this sense illumination conditions would seem to be one of the decisive factors regulating production in such brooks, as also shown experimentally, where it was found to be more significant than an increase in nutrients (Hill and Knight 1988). Likewise, the present increase in nutrient content in the water of Kivipuro, where a protective zone was left between the felling site and the brook, did not affect the algal flora or the production capacity of algae.

Water temperature is able to affect the occurrence of algae in flowing water as well as in standing water, for as Lam (1981) indicates, a temperature of at least 12 °C is required for algal biomasses to increase in flowing water. The present results suggest that water temperatures in Murtopuro, Koivupuro and Suopuro in the late summer are high enough for production of algae, and temperature does emerge alongside the nutrient content of the water as a crucial factor explaining the changes in the algal community. Binkley and Brown (1993) note that if forestry practices are to be carried out in an optimal manner a protective zone should be able to restrict the change in water temperature to below 2 °C.

Water colour values rose as a consequence of the forestry practices and the turbidity of the water increased as a response to the outwash of suspended solids. The latter effect was less marked after clear felling, however, than after ditching, as the solid matter content of the water in Koivupuro was more than three times that in Murtopuro. Turbidity in Koivupuro was so pronounced at its maximum that the enhanced illumination, increased nutrient content of the water, and higher water temperature did not lead to any immediate increase in biological production, but only after the decrease of tubidity three years later. Van Nieuwenhuyse and LaPerriere (1986) also noted that turbidity effectively reduces the production of lagae, and Krogstad and Løvstad (1989) showed that algal biomasses decrease as illumination conditions deteriorate. A similar effect was also found in Murtopuro, where algal production declined markedly and algal biomasses decreased at the time of site preparation.

The fact that both nutrient concentrations and DOC increased in the brooks in areas where forestry practices had been carried out prove a significant nutrient loading from the drainage basin and a continuation of outwash for some time afterwards, more than ten years in the case of some treatments (Ahtiainen 1992, M. Ahtiainen and P. Huttunen unpubl.). Significant correlations were observed between algal biomass and total phosphorus, total nitrogen and DOC after clear felling in the Murtopuro basin and ditching in Koivupuro, although DOC explained the changes in biomass better in Murtopuro than in Koivupuro. The total nutrient ratios suggest that total nitrogen content was the limiting factor for growth of algae in Murtopuro from the time of felling up to 1988 (Forsberg *et al.* 1978), and nitrogen content also best explain the changes in algal biomass in Koivupuro.

Rises in water temperature, nutrient content and DOC will also increase bacterial production in the water of brooks (Holopainen and Huttunen 1992). The increase in bacterial production in Murtopuro noted over the period 1983–89 was nevertheless small, whereas in experiments carried out in Alaska an increase in soluble phosphate phosphorus affected not only the periphytic algae in the river but also bacterial production (Peterson *et al.* 1985).

As water quality in brooks such as these changes, conditions become more favourable for heterotrophic algae. According to Sepers (1977), DOC is an appropriate source of carbon for some algae, while Haffner *et al.* (1980) and Salonen and Hammar (1986) report that *Cryptomonas* and

Chlamydomonas algae are able to make use of soluble organic matter. DOC increased markedly, especially in Murtopuro after the nearby clear felling, and at this time *Cryptomonas* flagellates formed the main component of the algal biomass. These algae appear to be able to adapt to new conditions by altering their metabolism. A statistically significant correlation was found between algal biomass and DOC in Murtopuro.

Clear felling may have had an immediate impact on the algal community of Murtopuro, as the *Cryptomonas* flagellates, which seem to favour turbid water with a high humic content (Rosen 1981), emerged as the only dominant group (Holopainen *et al.* 1991). Similarly, the biomass of these algae increased after ditching, but their proportion of the total biomass was smaller than after clear felling (Fig. 2). Bergqvist *et al.* (1984), studying lakes in Sweden, also noted that forestry practices tend to increase the biomass of Cryptomonas flagellates, although the effect was less marked in those lakes than it was in the present brooks. Cryptophyceae are also common in water with high humic content due to loading from peat mining areas (Marja-aho and Koskinen 1988).

The first response of algal species in the brooks after the forestry practices was that the communities became dominated by few species, and it was only later that an increase in species number occurred. Likewise, Peterson *et al.* (1985) observed in nutrient addition experiments in flowing water that the number of the common species increased while the rarer species were eliminated altogether. Clear felling did not make conditions any more favourable for algae growing on the surface on the brook bed in Murtopuro, which led Rönkkö and Simola (1988) to regard conditions in these acid, brown water brooks as too extreme for diatoms growing on the surface of brook bottoms, in spite of the increase in available nutrients.

The increase in the number of Conjugatophyceae species and their biomass after site preparation is in accordance with the observation by Morgan (1987) of a spread of the same genera in brooks after a rise in pH and nitrogen content. Many of these species are of large size and do not float particularly well, so they could be considered as periphytic algae. It is algae breaking away from the sediment surface that frequently cause the most pronounced fluctuations in the algal communities of brooks (Moore 1977, Jones and Barrington 1985).

Repeated clear felling and site preparation with short intervals can cause major changes in algal biomasses, species diversity and production. The first forestry measure carried out at each study site, either clear felling or ditching proved sufficient to produce a radical change in the adjacent brook. Successive treatments in the same area increased the changes in algal flora that persisted for the next ten years or so. Production capacity and algal biomass in Murtopuro are still double what they were in a natural state following clear felling in 1982 and site preparation in 1986, and those in Koivupuro, where ditching and felling took place, are still more than three times their initial values. Seven years have now elapsed since the last intervention at either of these sites, but there are still some biological parameters that show no sign of a return to normal. Ten years is obviously too short a time to expect such brooks to regain their natural characteristics, and they are evidently condemned to remain in an altered state until the forest closes in again and the ditches silt up.

A protective zone between the brook and the area affected by the intervention would be highly effective in preventing unwanted effects. Thus the production and biomass of algae in Suopuro returned almost to their natural levels within a couple of years after small-scale ditching in the drainage basin, and the changes occasioned by clear felling in the Kivipuro area remained minor in extent.

This research programme spanning more than ten years provided a wealth of new information on the effects of forestry practices on the hydrobiology of forest brooks and on the duration of these effects. It would now be important to carry out further research into the extent and duration of the impact of forestry on watercourses by focusing on small lakes and rivers and more complex lake systems. It is also obvious that evaluation of the environmental implications of the currently recommended forest management techniques is a matter of some urgency. The new instructions regarding the width of a protective zone, for instance, are not based on research findings, nor do the guidelines yet take sufficient account of the environment of the whole drainage basin when considering the management of forest areas.

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Received 15 April 1997, accepted 11 February 1998