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ORIGINAL ARTICLE

The importance of debarking in mitigating the leaching of pollutants from common Swedish tree species submerged in water

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Abstract Sprinkling wood with water is a common method for protecting wood during storage, yet the polluted runoff generated by the log yard is a major drawback. To study bark's ability to leach pollutants from logs, the *Picea abies, Pinus sylvestris,* and *Betula pubescens* wood species were submerged with and without bark for 6 weeks. The water was analysed during the study for total organic carbon, phosphorus, nitrogen, colour, pH, and distillable phenols. The results showed that the leaching from carefully debarked wood is lower than that of both gently debarked wood and intact wood. Storing carefully debarked logs is a viable method for reducing pollutants in log yard runoff.

Keywords Wood storage · Sprinkling · Leaching · Total organic carbon · Phosphorus

Introduction

In Sweden, the most common method used to protect wood from deterioration due to drying and biological degradation during storage is sprinkling logs with water to keep the essential moisture at sufficiently high levels. A central drawback of this method, however, is the runoff resulting from sprinkling the logs; to ensure wood protection, the safety margins used when sprinkling often result in large runoff volumes. Recycling the sprinkling/runoff water can be used to reduce the amount of runoff. According to the latest figures, for example, 39% of the larger Swedish sawmills recycled runoff in 2001 [1]. One further possibility for reducing runoff is climate adaptation of the sprinkling system [2]. The amount of runoff can be considerably reduced with this method, although not completely eliminated. In spite of these methods, the runoff volume is still considerable in many locations.

Log yard runoff is often polluted, as soluble compounds from the wood leach into the water [3], which is not always purified before it is discharged. In addition, pollutants in log yard runoff may originate from buildings, equipment, and additional sources at the log yard itself [3, 4]. The level of pollutants in log yard runoffs varies considerably, for example, between different sites with different species, handling systems, and equipment, and is often high [5]. Organic material and phosphorus constitute two of the main pollutants [5, 6] that cause oxygen depletion and eutrophication in the receiving watercourses. Some of the organic compounds are also potentially toxic to living organisms in the water [5]. To minimise the industry's impact on their surrounding environment, it is advantageous to reduce these pollutants as much as possible.

It is likely that a majority of the pollutants originate from the bark, as it is more porous than the wood and also contains higher concentrations of certain polluting elements, especially the inner bark [7]. For example, the concentrations of nitrogen and phosphorous in the inner bark of Scots pine (*Pinus sylvestris*) have been found to be more than four and ten times greater than those of the stem wood [8].

In Sweden, logs are normally stored with the bark intact, and the bark is removed when the logs are processed further. Removing the bark from the logs before storage and then sprinkling would produce less polluted runoff and would be a more straightforward method of mitigating the problems associated with log yard runoff, such as pollution,

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eutrophication, and oxygen depletion, than the possibly costly and technically difficult other mentioned methods of runoff purification [9, 10]. In addition, storing logs without bark has other advantages, such as the increased energy value of the bark and a more exact scaling and grading of the logs [11, 12]. Storage of logs without bark is currently used sparingly in Sweden, mainly due to the fear of wood deterioration. However, Jonsson [11–13] has shown that the wood quality can be adequately preserved over normal periods (from 3 to 6 weeks) of sprinkled storage when the bark is removed from the logs.

The impact of debarking or not debarking on runoff quality has not been properly studied, and further research is required. Runoff quality from sprinkled logs with and without bark was compared in the previously mentioned studies. Jonsson [11, 12] found confusing results, and no significant differences were seen, possibly due to a weak experimental design. The experimental design was improved in Jonsson's later study [13], but still no significant differences were reported. The runoff from Norway spruce (*Picea abies*) logs without bark had lower concentrations of organic material and a higher pH value, yet the phosphorus and nitrogen concentrations were higher than in the runoff from logs with bark. Additionally, Halldin and Eriksson [14] have reported higher concentrations of phosphorus when submerging debarked logs in water compared to logs with bark (Norway spruce, Scots pine). One plausible explanation is that the remnants of the extremely nutritious inner bark are left exposed on the debarked logs rather than the less nutritious outer bark that is exposed in intact logs. It is possible that the technique and precision of the debarking method is much more important than has previously been thought.

In this study, pieces of wood submerged in water were used to simulate leaching from sprinkled wood during storage. Pieces of the three most common Swedish species, Norway spruce, Scots pine, and Downy birch (*Betula pubescens*), were stored in buckets of water for 6 weeks. Wood pieces with bark, wood pieces gently and carefully debarked, and pure bark were compared. The water was analysed during the storage period for total organic carbon, phosphorus, nitrogen, colour, pH, and distillable phenols.

Materials and methods

Experimental wood

The wood used in the experiment was felled in late March 2009 outside Uppsala in Sweden (59°51′30″N, 17°39′0″E) and stored in the freezer (−18°C) until the study began in late April 2009. Approximately 30-year-old trees of Norway spruce, Scots pine, and Downy birch were used. Wood pieces with bark (only sapwood) were cut from the outer part of the logs, approximately 140 × 130 × 40 mm. One-third of the pieces were left with the bark intact, one-third were carefully debarked with a knife to remove all of the bark, and the remaining one-third of the pieces were more gently debarked with a knife to leave the inner bark on the wood. Pure bark was used as the 4th type of bark treatment in the experiment. In practice, the carefully debarked pieces had small remnants of (inner) bark remaining and the gently debarked pieces had most of the inner bark and small remnants of the outer bark. The gently debarked spruce wood had more inner bark remaining compared to the pine and birch. The bark from each carefully debarked wood piece was collected and put into net textile bags, forming the pure bark sample for the experiment. Due to the debarking process, the bark was divided into smaller parts.

Experimental setup

The wood pieces were placed into plastic buckets; two pieces with the same bark/debarking treatment were placed in each bucket. Each combination of species (Norway spruce, Scots pine, and Downy birch) and bark treatment (wood with bark, closely debarked, gently debarked, and pure bark) was replicated in triplicate (three buckets of each combination). As a reference, three buckets without any wood or bark were used. The two pieces of wood (or bark from two pieces of wood) in each bucket were held in place with a 1-kg stone. The buckets were then filled with 10 l of tap water and placed in a fluorescent-lit room at 16°C (to imitate the average temperature of a Swedish summer) and at 80% relative humidity (to prevent unnecessary evaporation from the buckets). The 39 buckets were left for 6 weeks to simulate wood storage. Adding deionised water compensated for the water losses due to evaporation. The average compensation needed per bucket during the 6 weeks of storage was 1500 ml.

After 3 weeks, some mould and bacterial growth was visible on the water surface of the buckets. This growth was removed from all the buckets once or twice a week until the experiment was finished.

Water sampling

After 1, 2, 4, and 6 weeks, water samples were taken from each of the experimental buckets. The samples were placed in 150-ml plastic bottles, cooled with iced packs, and transported to the laboratory the same day. The water losses from the buckets due to the sampling were not compensated. At the start of the experiment, five random samples were also taken from the tap water used to fill the buckets.

All the water samples were analysed for TOC (total organic carbon, SS-EN 1484 [15]), P (total phosphorus, ISO 15681 [16]), N (total nitrogen, ISO 13395 [17]), and colour (SS-EN ISO 7887 [18]). In addition, the distillable phenols (Skalar 497-001) in the tap water samples were analysed at the beginning of the experiment and in the samples from the buckets after 6 weeks of storage. The analyses were performed by ALcontrol Laboratories in Linköping, Sweden. The pH of the water in the buckets was analysed while sampling directly at the experimental site with a pH Pen JENCO model 610. This procedure was followed for all of the pH analyses, except those of the tap water at the start of the experiment, which were analysed by ALcontrol Laboratories according to SS 028 122 [19].

Results

The concentrations of the analysed substances (i.e., TOC, P, N, distillable phenols, and the colour value) in the water samples increased over the 6 weeks of submerged-water storage, while the pH value decreased. The spruce wood, with or without bark, and the spruce bark generally produced more polluted water (higher concentrations of the analysed substances) than did the pine and birch. The concentrations of TOC and the colour value were significantly higher for the spruce than for the pine ($p < 0.001$ and $p = 0.009$), and the P concentrations were significantly higher in the spruce water than that of the pine ($p < 0.001$) and birch ($p = 0.001$). The concentrations of TOC and P, pH and colour values for the leaching experiment can be seen in Figs. 1, 2, 3. In general, the closely debarked wood produced significantly less polluted water than did the other treatments (Table 1). The gently debarked wood produced significantly less polluted water for the spruce as well. In addition, the pure bark from the spruce and pine also created less pollution from P. Other significant differences can be seen in Table 1.

The means of the concentrations/values of TOC, P, colour, pH, and phenols in the tap water used at the start of storage and in the reference treatment can be seen in Table 2. The phenol concentrations after the storage period can be seen in Table 3.

The N concentrations in the samples from the different wood treatments were generally low. Although they sometimes did increase over time, most of the samples had

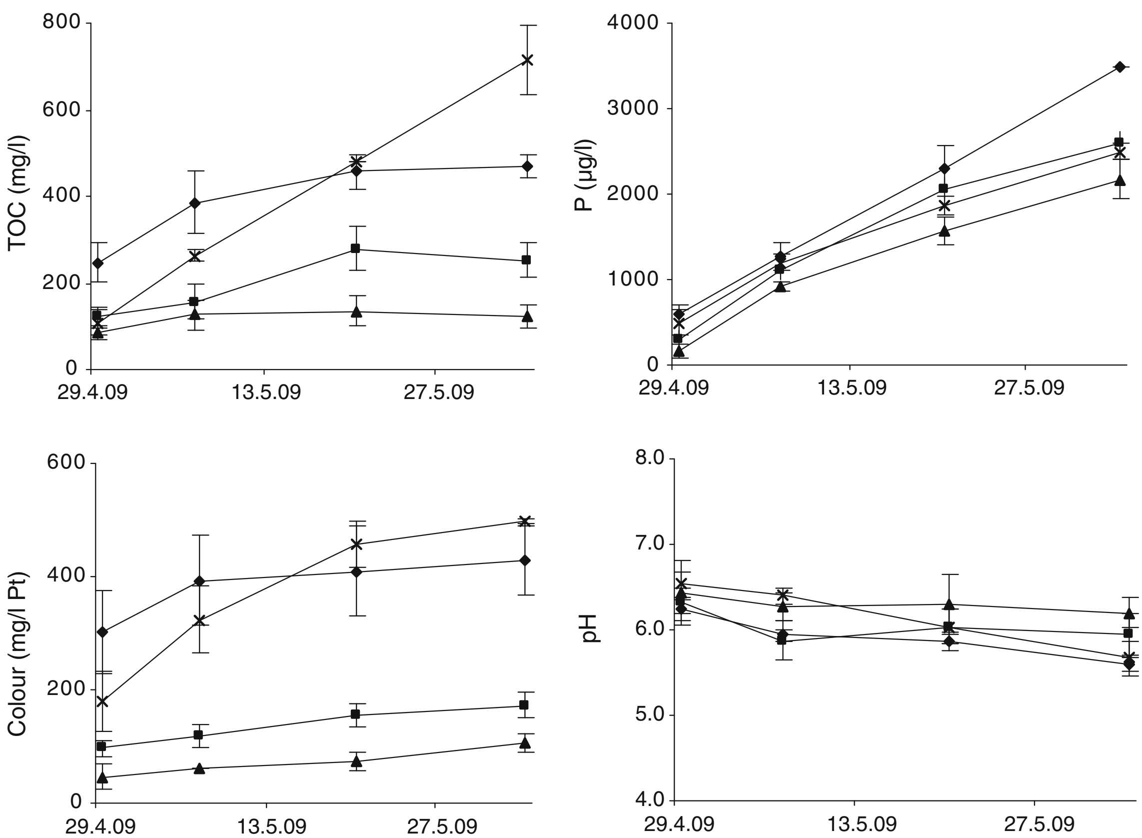

Fig. 1 The concentrations of total organic material (TOC) and phosphorus (P), colour values and pH values of the water from the different wood/bark storage methods for the Norway spruce (*Picea abies*) over 6 weeks of storage. *Error bars* show standard deviation. Dates are shown on the *x*-axis. *Filled triangle* carefully debarked wood, *filled square* gently debarked wood, *filled diamond* wood with bark, *times symbol* bark

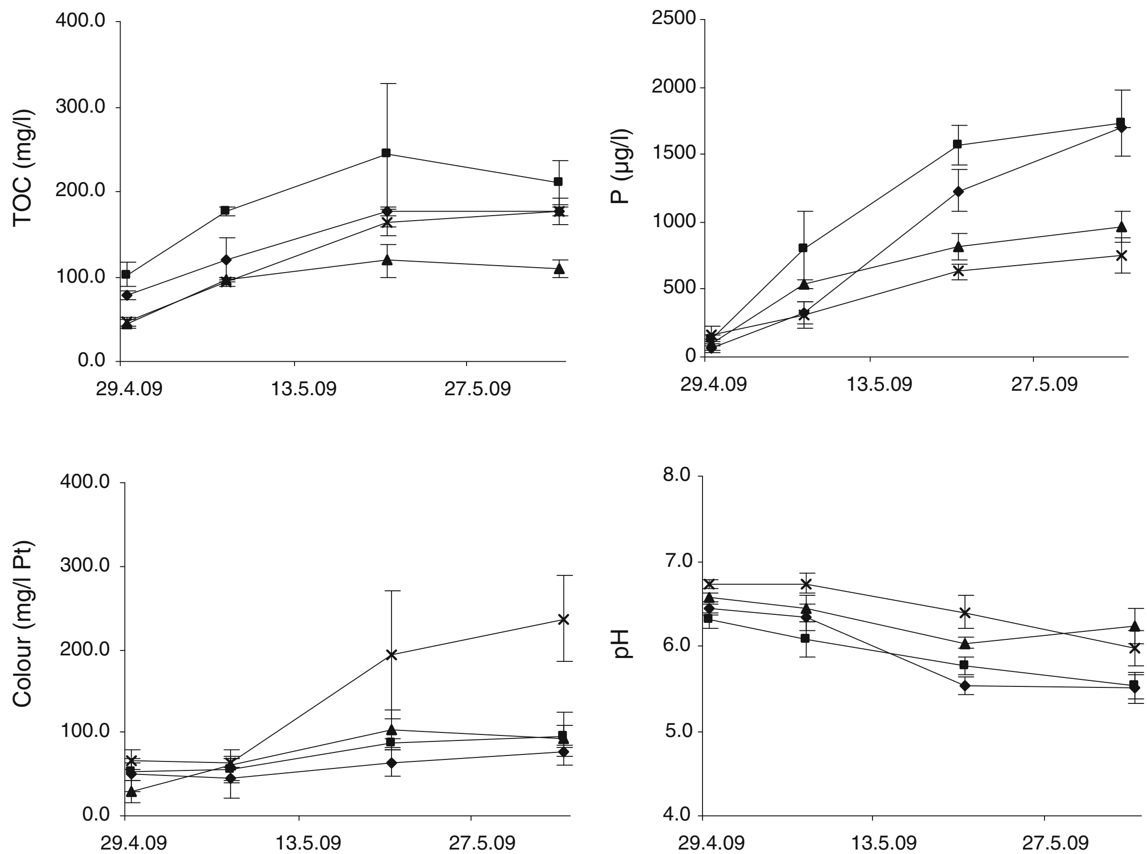

Fig. 2 The concentrations of total organic material (TOC) and phosphorus (P), colour values and pH values of the water from the different wood/bark storage methods for the Scots pine (*Pinus sylvestris*) over 6 weeks of storage. *Error bars* show standard deviation. Dates are shown on the *x*-axis. *Filled triangle* carefully debarked wood, *filled square* gently debarked wood, *filled diamond* wood with bark, *times symbol* bark

N concentrations below that of the tap water (1200 µg/l). Analysing the N was technically troublesome, as the high TOC concentrations led to the need for dilution; in 37% of the samples, the N concentrations fell below the level of detection. Therefore, further presentation and discussion of the N concentrations is omitted.

Norway spruce

For the spruce (Fig. 1), concentration differences could be seen between the four wood/bark treatments (see Table 1). For TOC and colour, in particular, it was obvious that the wood with bark led to higher concentrations/values than either the gently or the closely debarked wood. The leaching rate from the pure bark did not decline over time in the same manner as it did for the other treatments. At the end of the storage period, this bark had given rise to the most polluted water with respect to the TOC and colour. The P concentrations from the wood with bark were also higher, especially at the end of the period, but otherwise the differences in the P were less clear than those in the TOC and colour. The differences in the pH values between the treatments were even smaller (Table 1). The concentration of phenols in the water with the pure bark at the end of the storage was much higher than those of the other treatments (Table 3).

Scots pine

The leaching from the pine (Fig. 2) was lower than that of the spruce, and the differences between the storage treatments were generally smaller. However, the P concentrations for the pine showed clearer differences between the treatments (Fig. 2) than did the spruce, with higher concentrations from the pine with bark and the gently debarked pine. For both P and TOC, the highest leaching occurred from the gently debarked wood. It was also noted that the TOC leaching from both the pine bark and the pine wood with bark was higher than that of the closely debarked wood but lower than that of the gently debarked wood. The colour values did not show any clear differences, except for the pure bark, which gave rise to visibly darker water in the second half of the storage period than did the other treatments. In contrast, the pure bark gave rise to the highest

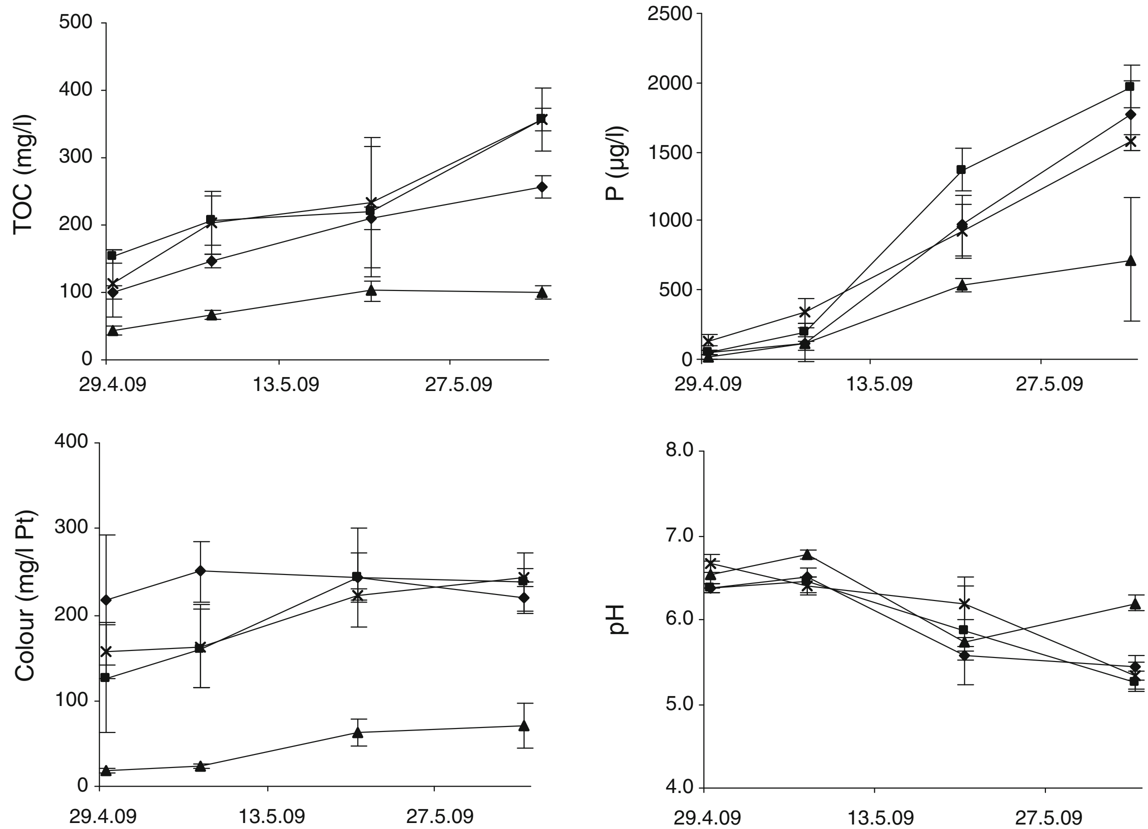

Fig. 3 The concentrations of total organic material (TOC) and phosphorus (P), colour values and pH values of the water from the different wood/bark storage methods for the Downy birch (*Betula pubescens*) over 6 weeks of storage. *Error bars* show standard deviation. Dates are shown on the *x*-axis. *Filled triangle* carefully debarked wood, *filled square* gently debarked wood, *filled diamond* wood with bark, *times symbol* bark

mean pH levels over the storage period. The concentration of phenols at the end of the storage period was much higher in the water with the pure bark when compared to the other treatments (Table 3).

Downy birch

The closely debarked birch wood gave rise to significantly less polluted water with respect to the TOC, P, colour, and phenols than did the other treatments. The gently debarked birch gave rise to the most polluted water with respect to the TOC, P, and phenols (Fig. 3). Otherwise, the differences between treatments were difficult to distinguish.

Discussion

Consistent with earlier findings [20], the leachates from the Norway spruce wood and bark caused more polluted water than did the Scots pine and Downy birch. Within the analysis of the different species, significant differences were found between the debarking methods, showing their vital importance for the amount of pollutants created when submerging wood and bark in water. For all of the tree species in the study, removing the bark completely from the wood produced lower overall concentrations of pollutants. It is well known that extracts from bark can be toxic to living organisms [21–23]. Concerning the remnants of inner bark on the wood (as in the gently debarked wood), the spruce differed from the pine and birch. The gently debarked treatment did not cause more polluted water for the spruce, while it did for the pine and birch. This difference between the species was perhaps unexpected, as comparing the three species in the study showed that the gently debarked spruce wood pieces had more inner bark remaining on the wood than did the pine and birch. The results indicated that the inner bark is of great importance to the leaching of pollutants from pine and birch, but not from spruce.

For all the species and analysed substances (with the exception of the colour value for the pine), there was less leaching from the carefully debarked wood. The higher P leaching from debarked logs found by Halldin and Eriksson [14] and Jonsson [13] was not observed in the present study. The P leaching was also lower from the pure bark of the spruce and pine in this present study. When interpreting

Table 1 *p* values for the comparisons (using an ANOVA model) of the concentrations of total organic carbon (TOC) and phosphorus (P), colour values, and pH values of the four treatments ($n = 12$ for the four sampling times combined) within each tree species

Species	Comparison	*p* value			
		TOC	P	Colour	pH
Picea abies	Wood with bark × wood closely debarked	0.002	<0.001	<0.001	0.022
	Wood with bark × wood gently debarked	0.043	0.005	<0.001	n.s.
	Wood with bark × bark	0.007	0.002	0.002	n.s.
	Wood closely debarked × wood gently debarked	n.s.	n.s.	0.024	n.s.
	Wood closely debarked × bark	<0.001	n.s.	<0.001	0.032
	Wood gently debarked × bark	<0.001	n.s.	<0.001	n.s.
Pinus sylvestris	Wood with bark × wood closely debarked	0.012	0.007	n.s.	0.006
	Wood with bark × wood gently debarked	n.s.	n.s.	n.s.	n.s.
	Wood with bark × bark	n.s.	0.002	0.005	0.039
	Wood closely debarked × wood gently debarked	<0.001	0.003	n.s.	0.008
	Wood closely debarked × bark	0.009	n.s.	0.005	n.s.
	Wood gently debarked × bark	n.s.	<0.001	0.005	n.s.
Betula pubescens	Wood with bark × wood closely debarked	<0.001	0.006	<0.001	<0.001
	Wood with bark × wood gently debarked	0.006	n.s.	n.s.	n.s.
	Wood with bark × bark	0.006	n.s.	n.s.	n.s.
	Wood closely debarked × wood gently debarked	<0.001	0.002	<0.001	<0.001
	Wood closely debarked × bark	<0.001	0.020	<0.001	<0.001
	Wood gently debarked × bark	n.s.	n.s	n.s.	n.s.

n.s. not significant = $p \geq 0.05$

Table 2 The mean values of the concentrations/values of TOC, P, colour, pH, and distillable phenols in the tap water at the start of storage and in the reference treatment (without wood) after 1 week (1 w), 2 weeks (2 w), 4 weeks (4 w), and 6 weeks (6 w) of storage

	Tap water/before storage	Reference 1 w	Reference 2 w	Reference 4 w	Reference 6 w
TOC (mg/l)	2.5	5.8	23	36	17
N (μg/l)	1200	1003	690	627	630
P (μg/l)	<5	<5	6.3	11	21
Colour (mg/l) Pt	<5	6.7	5.0	15	6.7
pH	8.3	7.7	7.5	7.1	7.3
Phenols (mg/l)	<0.002	n.a.	n.a.	n.a.	0.008

$n = 5$ for tap water and $n = 3$ for the reference treatment

n.a. not analysed

Table 3 The mean concentrations of distillable phenols for the different treatments after 6 weeks of wood storage ($n = 3$)

Picea abies	Distillable phenols (mg/l)	*Pinus sylvestris*	Distillable phenols (mg/l)	*Betula pubescens*	Distillable phenols (mg/l)
Wood with bark	0.373	Wood with bark	0.293	Wood with bark	0.129
Wood closely debarked	0.157	Wood closely debarked	0.157	Wood closely debarked	0.094
Wood gently debarked	0.210	Wood gently debarked	0.297	Wood gently debarked	0.200
Pure bark	0.767	Pure bark	0.757	Pure bark	0.167

the results from the bark samples in the present study, the smaller volume of the bark samples compared to the wood samples may have caused underestimation of the leaching. Due to the debarking process, the pure bark samples were also divided into more pieces, possibly accelerating the leaching. In practice, the results may be considered reasonable, as when the bark is left intact on the logs, the wood beneath is likely to barely affect the leaching. The surface area of the bark also differed between the bark samples and the wood samples with bark, possibly being one source of uncertainty in the interpretation of the results. Even if it was considered to be of minor importance it is possible that this larger surface area contributed to overestimation of the leaching from pure bark. The setup in this study with pieces of wood instead of whole logs as is the case at a normal log yard is also a source of uncertainty. For example, the amount of exposed heartwood (none in this study) and sapwood might differ from reality.

Generally, N concentrations are low in these types of water [5, 6], and in this study they were often well below the level of detection. Nitrogen is often mentioned when discussing possible environmental problems, but investigations on leaching from wood and bark can focus on other substances. Of the substances analysed in this study, TOC and P are the substances requiring the most attention regarding possible environmental impact.

The experimental setup of wood submerged in the same water for 6 weeks allowed some microbial growth in the buckets. Any visible mould or other growth was removed, and as all the buckets were treated identically, the effect on the results was negligible. The evaporation from the buckets, mainly due to air circulation in the experimental room that was needed to create a constant temperature, was replaced with deionised water, and no accumulation of substances occurred from the replaced water. The changes in the concentrations of the analysed substances in the reference treatments (Table 2) were small when compared to the wood/bark treatments, showing that the changes in the wood/bark treatments were relevant for the different treatments.

To conclude the results from this study, closely debarked wood (Norway spruce, Scots pine, and Downy birch) gave rise to the least polluted leachates, compared to the other bark/wood treatments. For the spruce, this finding also applied to the gently debarked wood. Additionally, the spruce gave rise to higher concentrations of leached pollutant substances analysed than did the pine and birch. According to the results of this study, using carefully debarked logs for storage and sprinkling is the best method for improving the quality of runoff water. The higher concentrations of pollutants from the gently debarked wood (for the pine and birch) illustrate the importance of the debarking method and the need for proper debarking in practice. Irrigating debarked logs is an interesting and promising alternative to other methods that have been suggested [24, 25] for industries trying to reduce pollutants in log yard runoff.

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