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Live-Storage of *Picea abies* for Two Summers after Storm Felling in Sweden

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After recent severe storm fellings in Sweden, as harvest, transport, and storage capacities were insufficient, interest in live-storage (leaving windthrown trees in the stand) increased. This study follows windthrown Norway spruce (*Picea abies* (L.) Karst.) trees during 20 months, i.e. two summers, of live-storage in southern Sweden. Moisture content, blue stain, and storage decay were compared in trees from a site with all trees windthrown and a site with scattered windthrows. After the first summer of live-storage, the quality losses were small. After 20 months, the trees had dried significantly and had numerous infestations of blue stain and storage decay. Trees from the site with scattered windthrows were of better quality compared to trees from the site with all trees windthrown. Live-storage is a suitable method for one year of storage, but the second year losses in wood quality are considerable.

Keywords blue stain, MC, Norway spruce, storage decay, windthrown
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1 Introduction

Sweden has recently been exposed to two severe storm fellings, storm "Gudrun" that blew down 75 million m^3 of wood in 2005, and storm "Per" that blew down 12 million m^3 of wood in 2007. After both storms, harvest, transport, and wood storing capacities were insufficient, and alternative storage methods were discussed. Efficient storage methods are needed both to ensure wood quality and to secure future industrial supply.

A great threat to wood quality after storm felling is drying out. In addition to quality decrease in itself, drying facilitates infestation by wood living fungi. The growth of blue staining fungi (spread by air or bark beetles) becomes a problem as soon as trees are felled, while storage decay can be a minor problem in the first season, and is more so in subsequent seasons (Tamminen 1979). Damaged sawlogs and pulpwood decrease in economic value (Uusvaara and Löyttyniemi 1977).

Live-storage of trees is defined as "storage of downed trees in the position they fell without separating the trunk from its associated stock" (Bücking et al. 1997). The method has been used and studied after storms both in Sweden and Denmark and in central Europe (Trägårdh and Butovitsch 1935, Butovitsch and Spaak 1939, Nilsson 1974, Moltesen and Grenaa Kristensen 1982, Eisenbarth 1995, Bücking et al. 1997, Da Silva Perez et al. 2004). The knowledge of the method during current Swedish conditions is however limited. Live-storage is mainly used after severe storms, when huge volumes of wood need to be protected at the same time as resources are limited. By keeping the tree in contact with soil, the possibility of a water supply for the survival of the tree increases, even if the tree is downed and the roots are damaged. Using live-storage makes it possible to give priority in harvesting to vulnerable stands, while other stands can be live-stored and harvested later.

Before 2005, Swedish experiences with this method were limited to storm fellings 35 years ago and earlier. There is a need for more current investigations since both the state of the forest and the bark beetle (primarily *Ips typographus* L.) populations have changed. After the storm Gudrun, the interest in live-storage was resumed. In a study from 2007, Jonsson concludes that live-storage over one vegetative period is a good alternative storage method for southern Sweden if transport and storage capacities are insufficient. After the storm Gudrun, the windthrown Norway spruce (*Picea abies* (L.) Karst.) trees in that study were still in good condition after the first summer even if they had dried to some extent. Windthrows at a mesic site where all trees were windthrown were drier compared to moist sites and sites with scattered windthrows. Jonsson found limited blue stain occurrence in seven out of 40 windthrown trees and limited storage decay in one of the 40 trees. This study did not cover the condition of the trees during a second year of live-storage. This would be of interest in order to understand the limitations of the method if very large-scale needs for live-storage should arise in future. The present study was conducted in the same area as Jonsson (2007) and with similar methods but over a longer period of time (two summers).

A German study (Eisenbarth 1995, Bücking et al. 1997) also shows that live-storage of windthrown Norway spruce and Scots pine (*Pinus sylvestris* L.) works well the first summer after the storm felling; almost all trees retained high quality. Furthermore, the summary of European experiences after the 1999 storm, put together in the Technical guide from CTBA (2004), is that live-storage of Norway spruce works well for one summer. On the other hand, a Danish study found that the moisture content (MC) in live-stored spruce trees had decreased to below 50%, a critical level for wood damage (Liukko 1997), by July the summer after a storm in 1981 (Moltesen and Grenaa Kristensen 1982).

Swedish prediction functions for live-storage were constructed after the storm in 1969 (Nilsson 1974). Nilsson showed good prognosis for Norway spruce the first summer, but the second year the wood quality decreases strongly throughout the summer. Eisenbarth (1995) and Bücking et al. (1997) also showed that live-storage for a second summer is risky in Germany. Only 35–65% of their studied trees (Norway spruce and Scots pine) could be graded into the highest quality classes after the second summer following a storm felling. Moltesen and Grenaa Kristensen (1982) showed that damages to windthrown trees increased the second summer after storm felling in Denmark. Conditions that might affect live-stored trees differ between the more southern parts of Europe and Sweden why corresponding Swedish results would be interesting. No recent Swedish studies on live-storage for more than one summer have however been found.

Both CTBA (2004) and Nilsson (1974) list the current size of the bark beetle population as one of the important factors for successful live-storage. A large population increases the risk for blue stain, as bark beetles are vectors for the fungi causing blue stain. Bark beetles in a storm damaged area have favourable conditions the years following the storm felling because of greatly increased access to breeding material, i.e. windthrown and damaged trees. The second year, the beetle populations have had time to multiply. This means that the prerequisites for successful live-storage decrease with time, both as a consequence of declining tree vitality and increased risk for bark beetle attack. Immediately after the storm Gudrun in 2005, populations of bark beetles were low in Sweden, much lower than

Fig. 1. The roots of one of the windthrown Norway spruce trees in Site B (with scattered windthrows).

after the Swedish storm in 1969, for example (National Board of Forestry 2006). According to the National Board of Forestry (Svensson 2007) the population of *Ips typographus* increased 4–5 times from spring 2005 to spring 2006.

The objective of this study was to investigate how wood quality of storm felled and live-stored Norway spruce trees changed over two summers of live-storage in southern Sweden. On four occasions during 20 months, windthrown trees on a site with all trees windthrown and a site with scattered trees windthrown were compared for MC, blue stain infestations, and infestations of storage decay.

2 Material and Methods

2.1 Experimental Sites

The windthrown Norway spruce trees (*Picea abies*) in this study were felled by the storm Gudrun on January 8–9, 2005. The experimental area was located on mesic ground (assessed groundwater table 1–2 m below ground level; Lundin et al. 2001) in a storm damaged forest at Asa, Småland, in southern Sweden. The age of the Norway spruce dominated stand was around 60 years and the site index was G27–28. The site index shows the height of the trees at an age of 100 years. Half of the studied trees were located at a site with almost all trees windthrown and exposed to sun (Site A), while the other half were at a site with scattered and shaded windthrown trees in an otherwise relatively intact forest (Site B).

2.2 Experimental Trees and Wood Analyses

At each of the Site A and B, 40 windthrown trees were selected. These were full grown, non-damaged and relatively easy to access in the damaged forest. The trees lay on the ground or on other felled trees, were non-broken, and still had root contact (some of the roots were still connected with the soil). For each tree, diameter, height, length, sun exposure, root contact, and root disk radius were recorded. Mean values are in Table 1. All root disks were situated vertically in relation to the ground. An example of the roots from one of the trees can be seen in Fig. 1.

On four sampling occasions, late August and late November 2005, and early June and early September 2006, disks were cut from the trees. These occasions corresponded to approximately 8, 11, 17, and 20 months of live-storage. On each

Table 1. Characteristics (mean values) for the windthrown Norway spruce trees in Site A (with all trees windthrown) and Site B (with scattered windthrows), respectively.

	Site A	Site B
Tree diameter, m	0.25	0.28
Tree height, m	23	25
Root contact, %	23	26
Root disk radius, m	1.02	0.98
Sun exposure	Yes	No

sampling occasion, disks were cut from 10 trees at Site A and 10 trees at Site B. The disks, 50-mm thick, were cut from the trees with a chain saw at intervals of three meters, starting at an imagined felling cut (approximately 250–300 mm above ground level) and ending where the diameter of the tree fell below 100 mm. The upper side and underside of the disks relative to the ground were noted as they were situated in the fallen trees. The disks were placed in plastic sacks and transported to the laboratory.

Disks were weighed with bark before they were put back in plastic sacks and frozen until further analyses. After thawing, disks were visually analysed for occurrence of blue stain and storage decay in the section surface. Fungal infestations (blue stain and storage decay) were described as the approximate number of inoculations on each disk, total percent extension, location in relation to the upper and undersides of the windthrown tree, and depth (from surface to grain) of the inoculations. Infestations smaller than 1% of the disk surface were ignored. Root rot (*Heterobasidion* spp.) was also ignored. After the fungi analysis, the disks were dried in 103°C for 90 h to constant weight. They were weighed again and the wet-based moisture content (MC) of the disks was calculated as the weight of the water in the wood divided by the total weight of the green wood (Eq. 1).

$$MC_{wet\_based} = \frac{weight_{green\_sample} - weight_{dry\_sample}}{weight_{green\_sample}} \quad (1)$$

At the same time as the disks were cut, wood cores 30 mm deep and 10 mm in diameter were drilled from the sapwood with a drilling machine perpendicular to the grain. Cores were taken close to every other sampled disk on both the under and upper side of the fallen tree starting at the imagined felling cut. The bark was removed from the cores and each core was immediately placed in a small plastic bag that was then sealed. Wood cores were weighed in the laboratory in paper bags on a scale tared for the bag. Cores were dried in the bags at 100°C for 24 hours, cooled down in a dessicator, and once again weighed on a tared scale. MC of cores was calculated in the same way as for disks.

2.3 Statistical Calculations

Mean values, standard deviations, and regression analyses were calculated using Microsoft Excel. Analysis of Variance, General Linear Model (ANOVA, GLM), and two-sample t-tests were performed in MINITAB (Minitab Inc.).

3 Results

The trees in the study remained in relatively good condition during the first summer and autumn of live-storage, both regarding moisture content (MC) and fungal infestations. At the beginning of the second summer, the MC was lower and both blue stain and storage decay were found. After the second summer the trees were even drier and more infested with fungi.

3.1 Moisture Content

The MC in trees from Site A and Site B differed significantly at all four sampling occasions ($p<0.001$, except November 2005 when $p=0.004$). For Site A, the MC had decreased significantly ($p<0.001$) between November 2005 and June 2006 as well as between June 2006 and September 2006. For Site B, the MC decreased significantly between November 2005 and June 2006 ($p<0.001$). Otherwise, the MC developments were not significant ($p>0.05$). Generally, the MC was lowest in the lowest disks and increased with height in the trees, before the last one or two disks

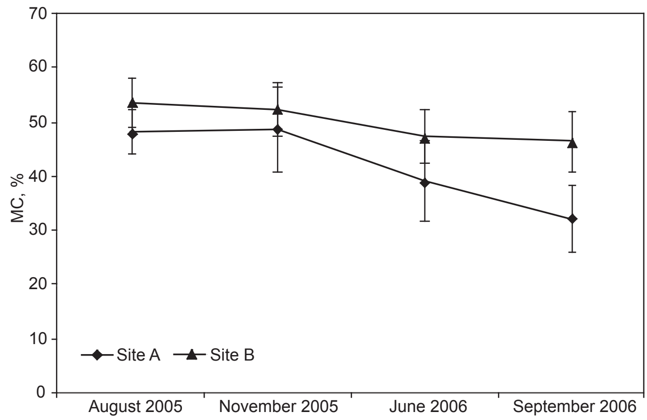

Fig. 2. Development of moisture content (MC) with standard deviation in the windthrown Norway spruce trees, in Site A (with all trees windthrown) and Site B (with scattered windthrows), respectively, during 20 months of live-storage after storm Gudrun in January 2005. The MC is measured on disks from the trees.

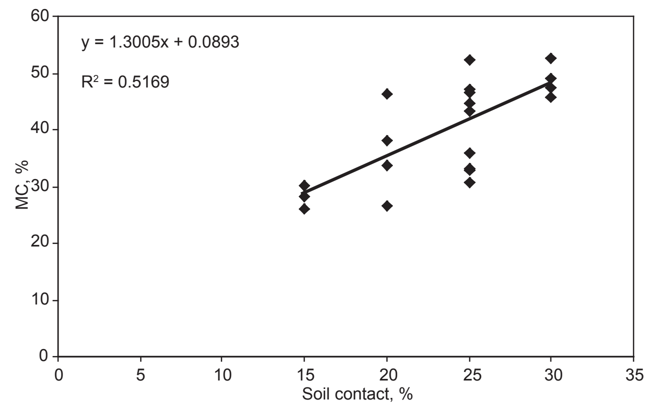

Fig. 3. Regression between the degree of soil contact and moisture content (MC) in the windthrown trees in September 2006, 20 months after storm Gudrun (n=20).

slightly decreased again. In August 2006, after 20 months of live-storage, some individual disks had MCs as low as 22–24%. The development of MC in the trees during 20 months of live-storage is shown in Fig. 2.

MC of individual trees was poorly explained by the degree of root contact in August 2005 ($R^2=0.101$), November 2005 ($R^2=0.049$), and June 2006 ($R^2=0.023$). In September 2006 the correlation was somewhat better ($R^2=0.517$), with a higher degree of root contact resulting in higher MC, see Fig. 3.

The sapwood MC in wood cores showed similar development as MC in disks. On average the sapwood MC was 8% higher than MC in disks, except for September 2006 when the disks showed 4% higher MC than the cores. This result mainly depended on very dry cores from the area with all trees windthrown (Site A). The underside of the logs was drier than the upper side at all samplings except the September 2006 sampling in the site with all trees windthrown (Site A). In this case, the MC did not differ between sides. The difference between underside and upper side for the whole experimental period was significant for both Site A ($p=0.022$) and Site B ($p<0.001$). The differences in sapwood MC (upper and underside added) between Site A and Site B was significant at all four sampling occasions ($p<0.001$, except for November 2005 when $p=0.015$). The changes in sapwood MC between the sampling occasions was significant ($p<0.001$) for November 2005 to June 2006, and June 2006 to September 2006, in Site A, and June 2006 to September 2006 in Site B. Development of sapwood MC is in Fig. 4.

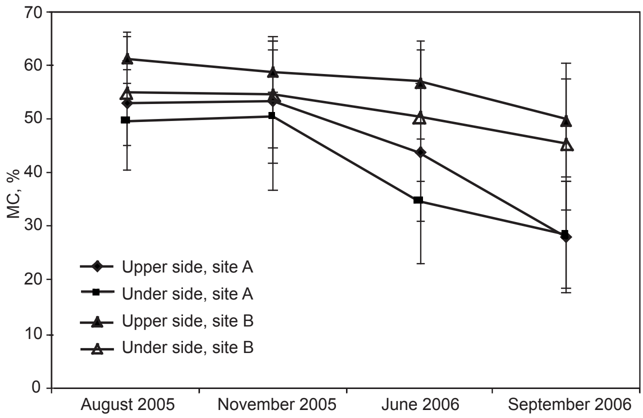

Fig. 4. Development of sapwood moisture content (MC) with standard deviation in the upper and underside of the windthrown Norway spruce trees in Site A (with all trees windthrown) and Site B (with scattered windthrows), respectively, during 20 months of live-storage after storm Gudrun in January 2005. The MC is measured on cores from the trees.

Table 2. Percentage of disks infested with blue stain and storage decay and mean percentage extension on disks at the different sampling occasions after the storm Gudrun in January 2005 in Site A (with all trees windthrown) and Site B (with scattered windthrows), respectively. Figures in brackets show standard deviation.

	Site	n	Blue stain Infested disks, %	Blue stain Mean extension on disks, %	Storage decay Infested disks, %	Storage decay Mean extension on disks, %
August 2005	A	58	0	–	0	–
	B	60	2	2.0 (–)	0	–
November 2005	A	53	9	2.8 (1.4)	0	–
	B	52	0	–	0	–
June 2006	A	72	17	3.3 (3.9)	14	5.9 (8.1)
	B	72	1	3.0 (–)	11	4.4 (2.6)
September 2006	A	68	91	8.7 (10.2)	62	10.1 (17.7)
	B	75	71	5.8 (11.9)	47	3.1 (6.9)

3.2 Blue Stain and Storage Decay

Blue stain infestations in the windthrown trees increased in the second summer of live-storage compared with the first summer (see Table 2). Both percentage of infested disks and average extension of blue stain in the disks increased, even if the blue stain extension differed considerably between individual disks. In September 2006, disks infested with blue stain were found in every sampled tree. In June 2006, the blue stain inoculations in the trees were more frequent on the underside facing south. In September 2006, no difference could be seen, as the blue stain inoculations were so numerous and widespread. The depth of the blue stain in September 2006 varied between 8 and 104 mm, with the deepest infestation in a disk from Site A.

No storage decay was observed until the second summer of live-storage (see Table 2). Trees from Site A were infested to a greater extent than trees from Site B. The observed storage decay was evenly distributed over the tree height, possibly slightly more common in the first disk of the trees. In September 2006, all sampled trees but one had disks infested with storage decay.

4 Discussion

In this study, the windthrown and live-stored trees survived the first summer of live-storage with acceptable wood quality. Already in June of the second summer, the quality had decreased. Quality continued to worsen until September of the second year, indicating that the method was less effective in the second year of live-storage.

Since the MC in living Norway spruce (*Picea abies*) is about 58–62% (Tamminen 1964), the windthrown trees had already dried somewhat during the first summer, even if they looked fresh. The decrease in MC continued between November of the first year and June of the second year, and throughout the second summer. The MC in the trees from Site B were higher than in trees from Site A, but also decreased to below 50% between November of the first year and June of the second year. Since the MC had decreased significantly by June of the second year, it is clear that there is a risk for drying and wood damage directly after the winter of the second year of live-storage. At MCs below 50%, the risk for storage damage increases (Liukko 1997). As in Jonsson (2007), the windthrown trees generally showed lower MC in the first disk at the imagined felling cut, and MC increased with tree height. But this study also showed that the MC often decreased in one or two disks at the top of the tree, probably because the smaller diameter facilitates drying.

The MC development of the wood cores, which only measure the outer sapwood, was similar to that seen in disks. The higher MC in the cores (as compared to the disks) depends on the dryer heartwood, which is included in the disks but not in the cores. However, in September 2006, after 20 months of live-storage, the cores from the area with all trees windthrown (Site A) were drier than the disks. This indicates considerable drying of the outer sapwood compared to the whole stem during the second summer of live-storage. Many of the cores even had a MC several percent below the fibre saturation point, which is around 26% for Norway spruce sapwood (Tamminen 1964). The sapwood MC in Site B was much higher than the MC in Site A, especially after 20 months of live-storage. The trees in Site B were shaded, which seems to be very important for the prevention of sapwood drying. The surprising difference in MC between the upper side and the underside of the windthrown trees that was seen after one summer of live-storage by Jonsson (2007) was observed in all samplings in this study as well. The exception was in the site with all trees windthrown (Site A) after 20 months, where the under and upper side were equal. The lack of difference on this sampling occasion could probably be explained by the lack of shade from standing trees, which resulted in rapid drying on the upper side at this site. Otherwise, the differences between upper and underside are difficult to explain.

The drying mechanisms of wood are very complicated and not studied in detail in this study. Neither is the relation between drying in the inner and outer part of the stem. Since some of the studied trees even dried below the fibre saturation point, it is also plausible that aspiration of the pits have occurred and further complicated the drying.

Earlier Swedish studies (Nilsson 1974, Jonsson 2007) have not shown the correlation between MC in windthrown trees and degree of root contact that others (Venn and Spilling 1972, CTBA 2004) have stated to be important for successful live-storage. After live-storage for 20 months, the trees in this study did show some correlation between MC and root contact. This correlation was not observed at earlier samplings in this study. It is possible that the importance of degree of root contact increases over long periods of live-storage.

It was obvious that the second summer of live-storage resulted in more fungal infestations in the trees. Both blue stain and storage decay were found in more disks and with greater percent extension in each disk than in the first year. In the first year, only a few disks with blue stain, and no disks with storage decay were found. Storage decay is usually of little importance until at least the second year of storage (Tamminen 1979). In this study, it appeared in June of the second year. The increase in blue stain in the second year is probably due to a combination of drier wood, longer exposure to the fungi, and increased population of *Ips typographus* in the storm damaged area.

After 20 months of live-storage, almost every tree was infested with both blue stain and storage decay. Blue stain and storage decay, as well as drying, decreases the wood quality. Since the economic value of pulpwood and saw logs decreases with damage (Uusvaara and Löyttyniemi 1977), this is undesired for both the forest owner and the forest industries. If possible, the trees should be harvested and processed or stored with protection (water sprinkling or equivalent) before these damages occur.

In this study root rot (*Heterobasidion* spp.) was ignored. The root rot is not a result from the storm felling as it establishes in the standing tree before it is windthrown. The aim was to isolate effects from the storm felling. This means that the actual quality losses due to root rot in the windthrown trees are not included in the results which might underestimate the overall quality losses of the wood.

Sites with scattered and shaded windthrows in otherwise intact forest are more suitable for live-storage compared to sites with all trees windthrown. The trees in Site B in this study (scattered windthrows) better preserved MC and were less infested with both blue stain and storage decay. The importance of stand characteristics for live-storage have been shown by Jonsson (2007) and Bücking et al. (1997) who, except for the importance of shade, also conclude that moister ground is more suitable. In this study, the ground was mesic, which is common in Sweden. It is possible that the results would have been different at a moister site. Almost all windthrown trees have individual conditions for live-storage; different types of stand, different root conditions, different weather conditions, etc. This makes it very difficult to exactly predict how each tree will respond to live-storage. The results of this study correspond to the specific sites studied in these specific years, with the prevailing weather conditions, bark beetle population, etc. During the first summer of live-storage in this study, 2005, the climate generally was cooler and with more precipitation compared to the average. This might have contributed to the limited drying of the windthrown trees the first year. On the contrary, the second year, 2006, the climate was warmer and drier compared to normal which in turn might have affected the quality losses seen in this period. The effect of the climate can however not be distinguished from other factors in this study. It must also be remembered that live-storage is a method to be used only during extreme conditions. There is always a risk for both wood damage and propagation of noxious wood living insects when trees are left in the forest.

The results confirm earlier findings from both Sweden (Trägårdh and Butovitsch 1935, Nilsson 1974, Jonsson 2007) and more southern parts of Europe (Eisenbarth 1995, Bücking et al. 1997, Da Silva Perez et al. 2004), that live-storage is a possible method for preserving wood quality during one vegetative period. This is despite varying conditions regarding climate, bark beetle populations, forest types etc. in the different studies. The poorer results for the second summer also agree with European studies (Moltesen and Grenaa Kristensen 1982, Eisenbarth 1995, Bücking et al. 1997) as well as the older Swedish study conducted by Nilsson (1974). In addition, the decrease in wood quality after 20 months of live-storage in this study probably continued for several weeks before the second winter arrived. A future need for two years of live-storage might be possible after for example a storm even more severe than the Swedish storm Gudrun in 2005. But hopefully, one year of live-storage provides sufficient time for the harvesting, transport, and storage of windthrown forests even after a severe storm.

The conclusions from this study are that live-storage of Norway spruce in southern Sweden effectively preserved wood quality during the first summer and autumn after a storm felling, even if some drying occurred. By the second summer, the drying and fungal infestations were considerable. Site B (with scattered windthrows) showed higher MC and less blue stain and storage decay, and was therefore more suitable for live-storage than Site A (with all trees windthrown). Live-storage is a possible storage method for one year after a storm felling. The second year the method is less suitable.

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