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Long term durability of the heartwood of seven common softwood species in above ground conditions

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Long term durability of the heartwood of seven common softwood species in above ground conditions

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ABSTRACT

The natural durability for wood in above ground use has been evaluated based on results after 11 years of exposure in a test site situated at the Danish Technological Institute in Taastrup, Denmark. Selected results for seven common softwood species exposed horizontally are reported. The test results cover samples with direct rain exposure (use class 3 of the European standard EN335-1:2006) and samples under cover (use class 2). Furthermore, results from sorption experiments on the original sample material employing Dynamic Vapour Sorption (DVS) equipment are shown. The purpose of this paper is to examine basic moisture properties of the wood species and correlate them with their observed long term performance.

The results show that natural durability for above ground use depends on a combination of sample type and wood species. This study shows that the relative durability of wood species, i.e. the long term performance of one species compared with others, can be heavily influenced by sample type. Based on the observed moisture behaviour in the first 5 years of exposure, the risk of decay is evaluated and correlated to the observed decay in the first 11 years of exposure. By comparing the results of covered and uncovered samples, the response of the different wood species to water vapour is concluded to be unimportant compared to the response to liquid water exposure for uncovered samples.

Keywords: natural durability, softwood, field test, above ground, moisture, decay, DVS

1. INTRODUCTION

The natural durability of wood is of great importance for structures, where wood is exposed outdoor without chemical protection to enhance the performance. It is well known that the natural durability varies with wood species and method of exposure, e.g. orientation, ground contact, rain exposure, etc. The durability evaluation of wood species is most often based on results from stakes in ground contact, however, the durability classification derived from such field tests is not always valid for above ground use as demonstrated by e.g. Rapp et al. (2006).

This study reports selected results from field tests initiated in April 2000 at a test site in Taastrup, Denmark, previously described by Lindegaard and Morsing (2003). The original purpose of these tests was to investigate the performance of a number of common softwood and hardwood species in different exposure scenarios. The field tests are still running, and this study reports results gathered so far for seven softwood species, whereas future studies will examine the results of all exposed wood species more closely. The methods of exposure correspond to use class 3 (outdoor, uncovered, above ground) and use class 2 (outdoor, covered, above ground) of

EN335-1:2006. Two different sample types are used in use class 3; lap-joints (according to ENV 12037:1996) and boards.

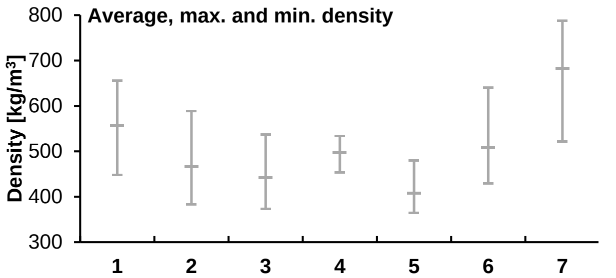
The purpose of the present study is to examine the basic moisture properties of the original sample material to see if the wood properties could be correlated with the observed long term performance.

2. EXPERIMENTAL METHODS

The material reported in this study covers heartwood of the following seven common softwood species: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), Nordmann fir (*Abies nordmanniana*), European larch (*Larix decidua*), and Siberian larch (*Larix sibirica*). Of these species, the heartwood of Scots pine, Douglas fir and European and Siberian larches contain significant amounts of extractives (Hillis 1987). The density at c. 12 % moisture content of the seven softwood species is shown in Table 1. Also included in this study is Scots pine sapwood as reference material for the observed decay.

Table 1: Wood species utilized in this study and their densities at 12 % moisture content

	Wood species	Range [kg/m^3]	Av. [kg/m^3]
1	Scots pine	448-656	557
2	Norway spruce	383-589	466
3	Sitka spruce	374-537	442
4	Douglas fir	453-534	497
5	Nordmann fir	364-480	408
6	European larch	430-641	508
7	Siberian larch	521-788	682



In April 2000, boards measuring 20 x 90 x 1200 mm^3 (thickness x width x length) were exposed at the test site. The samples reported in this study cover both horizontal boards which were directly exposed to the weather (uncovered boards) and boards exposed to outdoor conditions under a roof, see figure 1. Ten boards of each wood species for each method of exposure were produced and tested.

Figure 1: Covered (left) and uncovered (right) boards exposed at the test site.

At the same time, lap-joints measuring 38 x 85 x 300 mm^3 (thickness x width x length) were produced according to ENV12037:1996 and exposed outdoor. These contain a moisture trap as seen in figure 2. Ten lap-joints of each wood species were produced and tested.

Figure 2: Lap-joints after 3 years of exposure

During the time of exposure, the degree of decay of both boards and lap-joints has been assessed annually according to ENV12037:1996 where the conditions of the samples are classified between 0 (sound) and 4 (failure) based on the extent and severity of decay. ENV12037:1996 is a test method for evaluating the durability of treated wood, but is used in this study to evaluate natural durability. This is because there are no European test methods for evaluating the natural durability of wood above ground (Råberg et al. 2005). Since the start of the field tests, ENV12037:1996 has been superseded by the standard CEN/TS 12037:2004 which includes a revised scale for evaluation. Nonetheless, all evaluations in this study have been done according to ENV12037:1996 in order to compare the results.

Besides the decay evaluation, the mass of all samples has been regularly measured during the first five years of exposure in order to assess average moisture contents (MC). Specimens of the original sample material for all tests have been stored in a dark room for later comparison between exposed and unexposed material.

In order to evaluate the basic moisture relations of the different wood species, part of the unexposed original sample material was grinded to powders with a max. particle size of 1 mm. The sorption isotherms of these different powders were established by using 20 mg of each powder in a Dynamic Vapour Sorption (DVS) equipment of the type Advantage 2 from Surface Measurement Systems, London, UK. A more detailed description of this equipment was given by Engelund et al. (2010).

3. RESULTS AND DISCUSSION

The average MC of the covered boards, uncovered boards and lap-joints for the different wood species is shown in figures 3, 5, and 6. In these figures, the grey area marks regions of temperature and MC with a negligible risk of biological decay. Conditions of 20 % MC and 5 °C are used as threshold for risk of biological decay. Thus, if the MC is below 20 % or the temperature below 5 °C the risk of biological decay is assumed negligible. A value of 20 % MC is used, even though the evidence for such low moisture threshold is very weak according to some researchers (Carll and Highley 1999) and is more likely found in range of the fibre saturation point (Wang and Morris 2011). In this study, the "region of low risk of biological decay" seen in figures 3, 5, and 6 is bounded by the more conservative and traditional threshold of 20 % MC and 5 °C.

Figure 3 illustrates the variation in MC and outside temperature during the first five years of exposure for uncovered boards. The climate in Denmark is seen to result in high MC during winters (low temperatures) and lower MC during summers (high temperatures). During most of the time of exposure, either MC or temperature falls below the threshold condition for decay. Therefore, only for brief periods during autumn or spring are conditions right for decay with MC above 20 % and temperature above 5 °C.

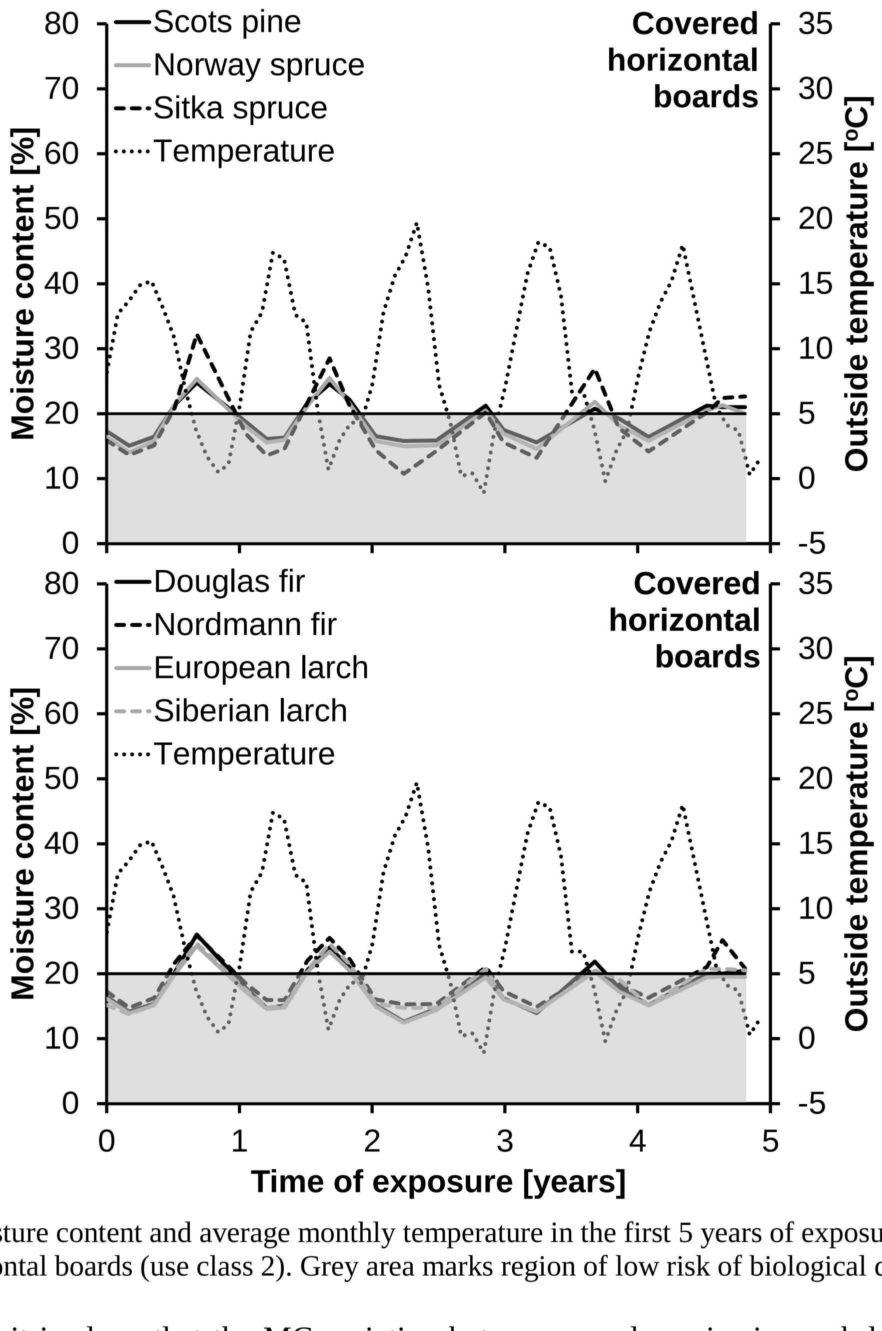


Figure 3: Moisture content and average monthly temperature in the first 5 years of exposure for covered horizontal boards (use class 2). Grey area marks region of low risk of biological decay.

From figure 3 it is clear, that the MC variation between wood species is much less significant than for uncovered boards and lap-joints seen in figures 5 and 6. The sorption isotherms shown in figure 4 illustrates that under constant climatic conditions, the MC variation between the selected species is indeed insignificant. However, differences in water vapour permeability between wood species may result in variation in average moisture content when samples are exposed to a variable outdoor climate. Such variation is seen in figure 3, but the magnitude of variation is much smaller than for uncovered wood samples in figures 5 and 6. It is therefore concluded that possible differences in water vapour permeability between species is of much less influence than the response to direct liquid water exposure for the cold and humid climate found in Denmark.

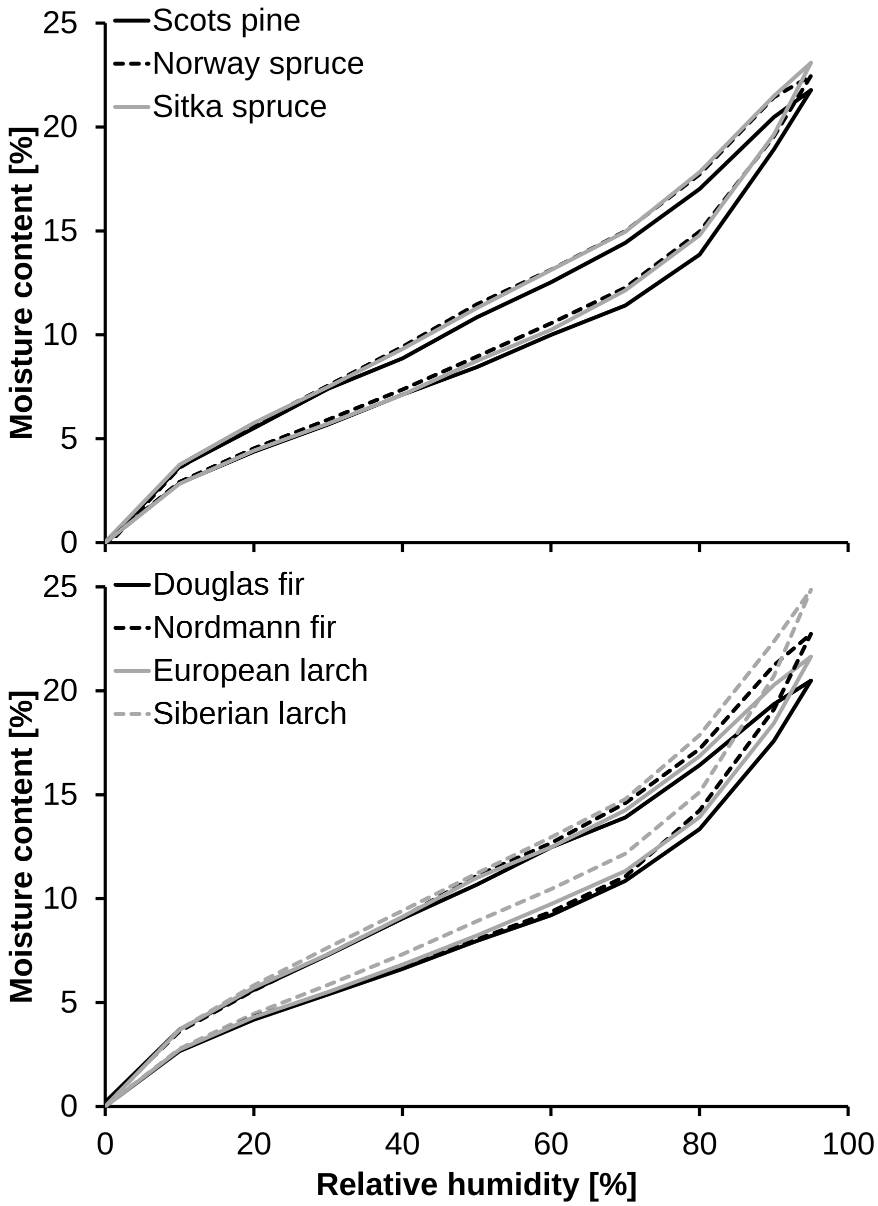


Figure 4: Sorption isotherms for the seven species of softwood. Note that the adsorption isotherm ends at 95 % RH which is the starting point for the desorption isotherm. Thus, the latter is not a true desorption isotherm, but a scanning curve (Engelund et al. 2010).

The moisture variation in uncovered boards depends heavily on wood species as illustrated in figure 5. The MC of Douglas fir and European larch is quite similar with a difference less than 1.5 % MC. For the other wood species, the average MC is greater during winter periods and more or less similar in summer periods.

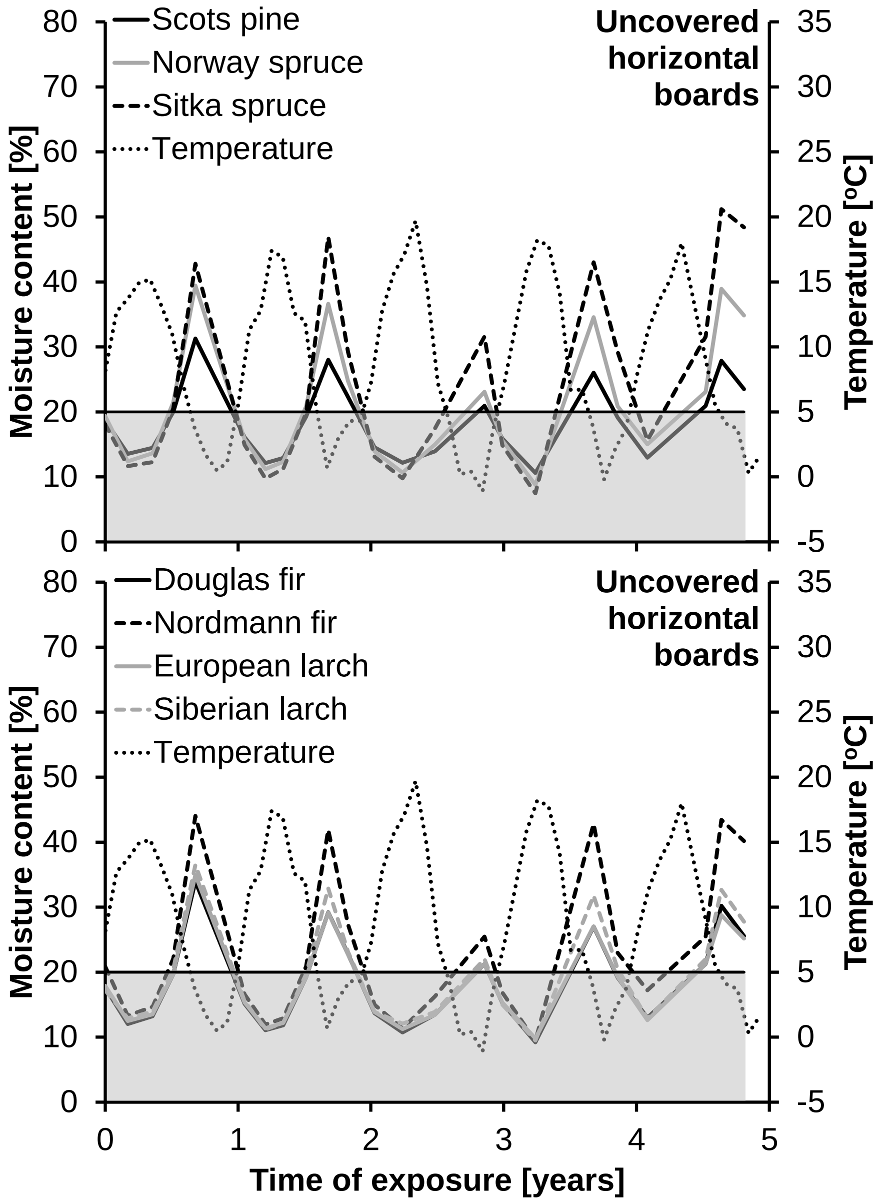


Figure 5: Moisture content and average monthly temperature in the first 5 years of exposure for uncovered horizontal boards (use class 3). Grey area marks region of low risk of biological decay.

The MC for lap-joints shown in figure 6 generally attains levels within 3 % MC lower than for uncovered boards at the points of registration. This might seem a little surprising considering the artificial water trap found in lap-joints. The difference in geometry between sample types and the fact that the MC reported are average values for the entire specimens might, however, mask the effect of water traps. Nevertheless, deviations in MC between uncovered boards and lap-joints are seen for Norway spruce, Scots pine and Sitka spruce. Lap-joints of Norway spruce have on average 10 % higher MC than boards during winters, whereas Sitka spruce lap-joints have on average 8 % lower MC than boards during winters. Thus, these wood species respond markedly different between lap-joints and boards.

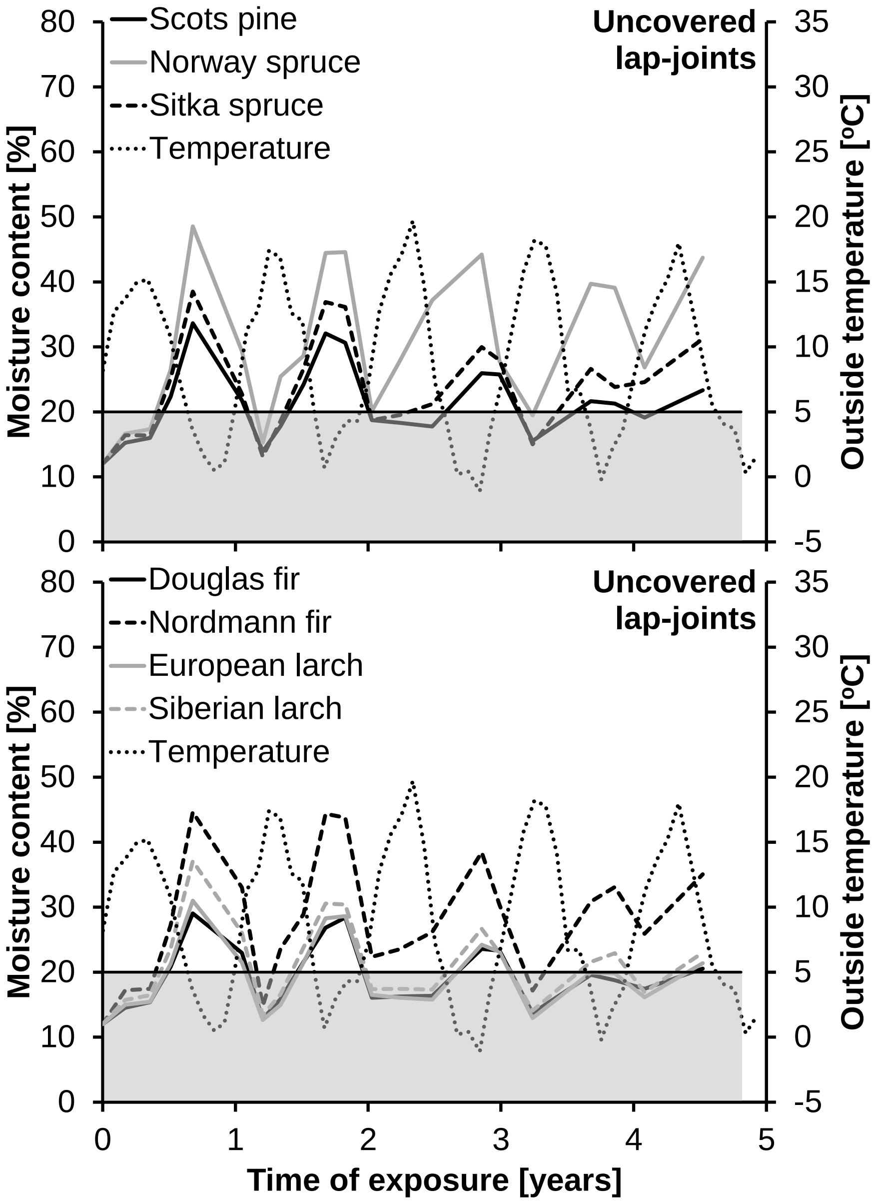


Figure 6: Moisture content and average monthly temperature in the first 5 years of exposure for uncovered lap-joints (use class 3). Grey area marks region of low risk of biological decay.

The moisture behaviour for uncovered boards and lap-joints of Sitka spruce and Norway spruce is compared in figure 7. The shift in MC variation between uncovered boards and lap-joints must be related to inherent moisture properties of the wood species, however, the nature of these properties has not yet been resolved.

The moisture behaviour of the different wood species is important for the risk of biological decay and hereby durability. Furthermore, the protective action of extractives in the wood can aid the durability. Nonetheless, the moisture behaviour illustrates which wood species are in greatest risk of biological decay. The level of risk is, however, not related to the highest level of average moisture content. Rather, it is the duration of the periods of favourable conditions for biological decay which influence the durability. Thus, the Norway spruce lap-joints are not necessarily more prone to biological decay because of their higher moisture content but because of the longer periods with favourable conditions for decay, see figure 7.

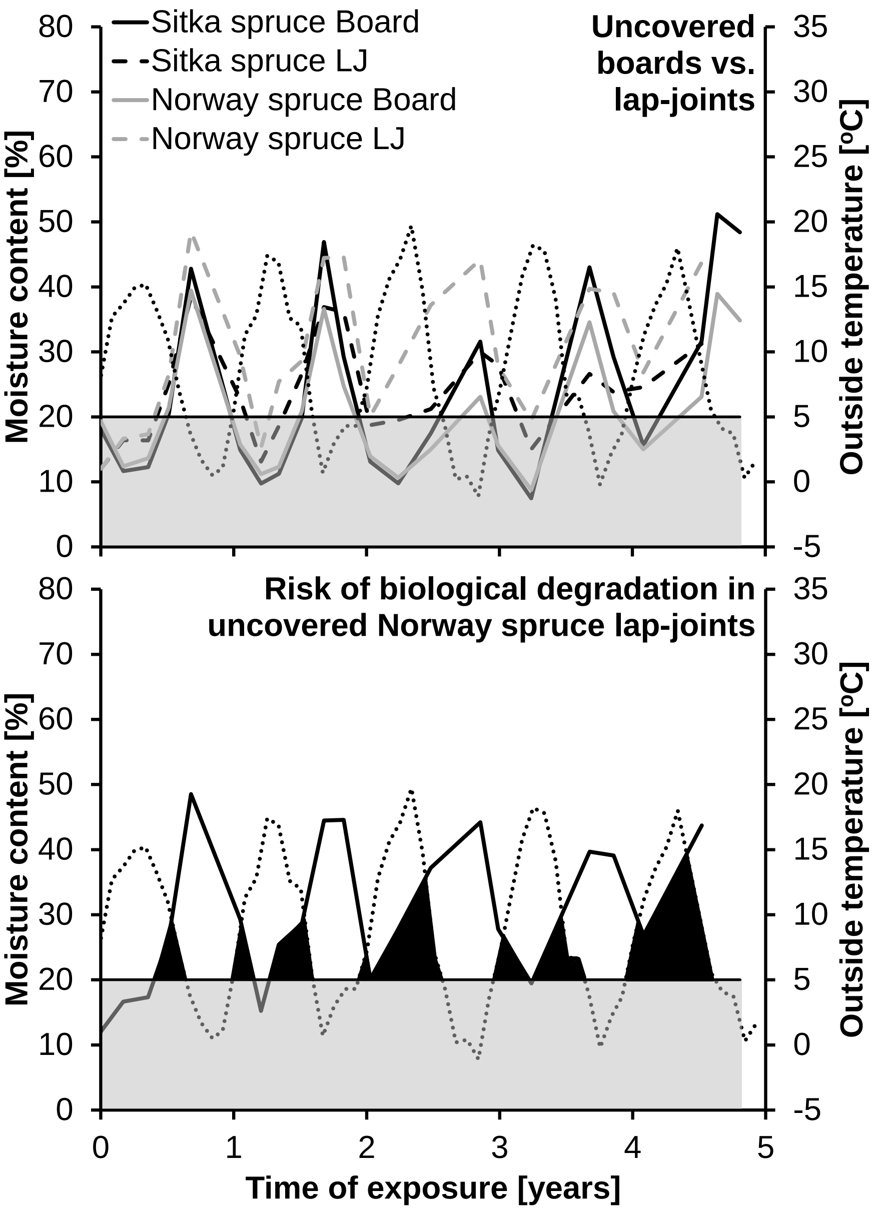


Figure 7: Moisture content and temperature for uncovered boards and lap-joints of Sitka spruce and Norway spruce (top). Illustration of periods of increased risk of biological decay (black areas) in uncovered Norway spruce lap-joints (bottom).

In these tests, the moisture content and climatic conditions have not been monitored frequently enough to justify a more detailed analysis of the accumulated time of conditions favourable of decay. Rather, the moisture behaviour in response to similar climatic conditions between species can be evaluated and compared with the variation in observed biological decay. The latter is illustrated by the decay index for uncovered boards and lap-joints in figure 8 for all 11 years of exposure. For covered boards, the decay index after 11 years of exposure has not risen above 1 (defined as discolouration only) for any of the wood samples.

Some of the decay curves in figure 8 show an occasional decreasing decay index, which is an inherent problem of using a subjective classification scale, i.e. different people may evaluate the same samples differently. This problem was also noted by Lobb et al. (2011). The decay curves nonetheless illustrate variations in durability between the seven softwood species. Douglas fir, Scots pine, European larch and Siberian larch are generally found to be more durable than the rest of the wood species with the previous being the most durable. This is in accordance with the durability class of these three species in ground contact as listed in EN350-2:1994, see table 2.

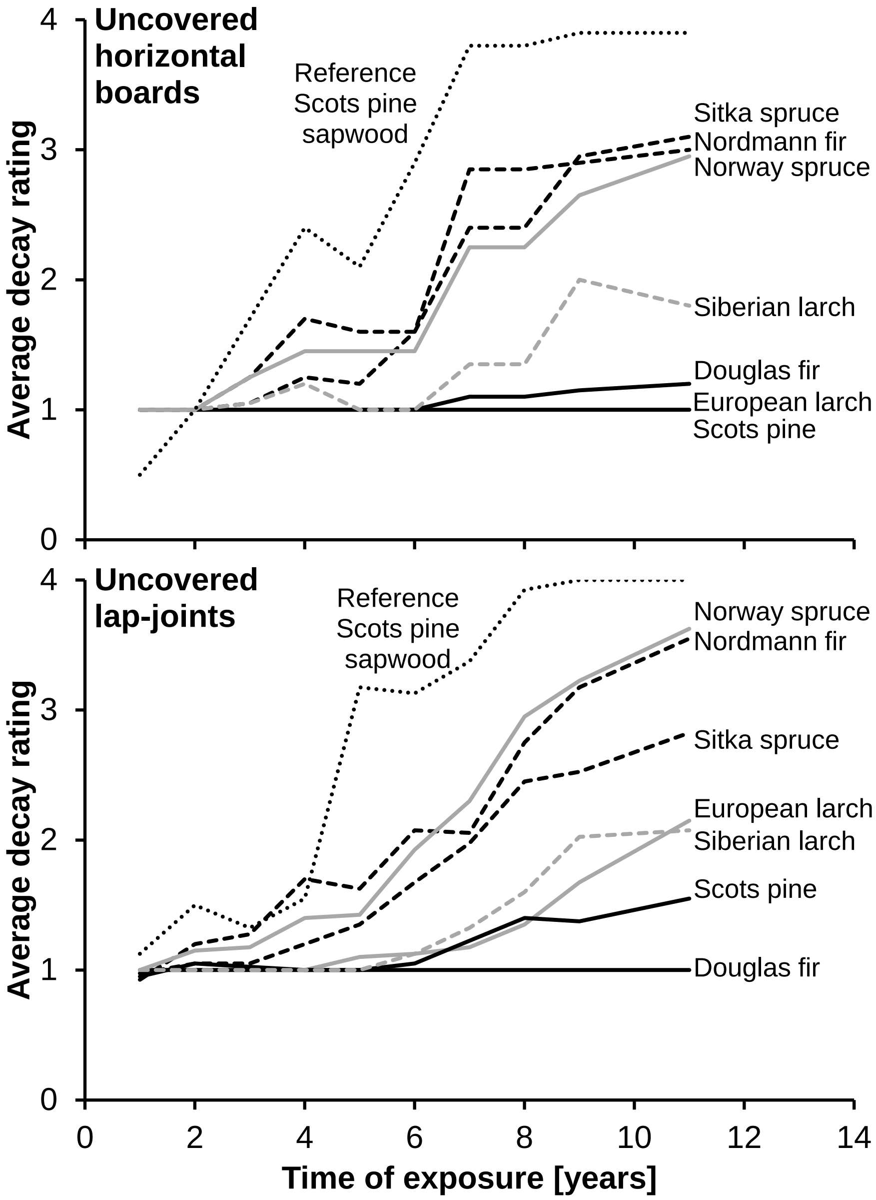


Figure 8: Decay index vs. years of exposure for uncovered boards (top) and lap-joints (bottom).

The observed decay differs between uncovered boards and lap-joints. The three most durable species are Douglas fir, European larch and Scots pine. Douglas fir boards show slight decay after 11 years whereas the index for boards of the other two species has not risen above 1. Lap-joints of European larch and Scots pine, on the other hand, show some decay after 11 years of exposure, whereas the index of Douglas fir lap-joints is 1. The Siberian larch show similar decay patterns for boards and lap-joints and is in general less durable than the three most durable species. Even less durable are the species Nordmann fir and Sitka spruce, which show similar decay behaviour in the first 6 years of exposure in boards and lap-joints. After this period, the decay is generally faster in boards than lap-joints. For Norway spruce, the decay is faster in lap-joints than in boards. Therefore, the method of exposure yields different decay behaviour in the various species.

The variation between wood species in rate of decay can be partly related to their moisture behaviour, in particular the duration of periods of increased risk of biological decay. For instance, the difference in decay between the most and least durable species in figure 8 is reflected in the moisture behaviour seen in figures 5 and 6. The least durable species are exposed to longer periods of increased risk of decay than the most durable species. The four most durable species in figure 8, i.e. Douglas fir, Scots pine, European and Siberian larch, all contain significant amounts of extractives, which can enhance the durability by acting as a biocide but also by regulating the MC.

Table 2: Wood species listed after durability class when in ground contact according to EN350-2:1994, along with the observed decay in samples after 11 years of exposure.

Wood species	Durability class (EN350-2)	Decay after 11 years exposure
Douglas fir	3 “moderately durable”	Slight attack (discoloration)
European larch Scots pine Siberian larch	3-4 “slightly to moderately durable”	Slight to moderate attack Slight to moderate attack Moderate attack
Norway spruce Nordmann fir	4 “slightly durable”	Severe attack to failure Severe attack to failure
Sitka spruce	4-5 “not durable to slightly durable”	Severe attack

The durability classes listed in table 2 refer to wood in ground contact. As stated in EN350-2:1994, the durability classification for above ground use might differ, which has been illustrated by Rapp et al. (2006). So far this study has not produced enough data to assign durability classifications to the different wood species. This could for instance be done by adapting the performance criteria of EN350-1:1994 to above ground use. Hereby, a durability class 5 would correspond to an average life time of less than 20 % longer than the average life time of the reference samples, whereas the upper performance criterion of class 4 would correspond to less than 100 % longer life time. For class 3, the upper performance criterion will be an average life time of less than 200 % longer than the references. Since the reference samples failed within 7-8 years for both boards and lap-joints, the upper and lower limits of class 4 would be 8.5-9.5 years and 14-16 years, respectively. It is expected that the Norway spruce and Nordmann fir samples will fail within the next 3-5 years, corresponding to a durability class of 4. Sitka spruce on the other hand, will presumably fail later than these two species corresponding to a durability class of 3-4. Thus, the results indicate that Sitka spruce has similar or better durability in above ground use than Norway spruce and Nordmann fir. This is opposite the durability classification shown in table 2.

For the more durable wood species reported in this study, a longer test period is needed to evaluate their performance. Nonetheless, the results so far indicate that the durability of European larch is similar to or better than Siberian larch, dependent on the method of exposure. The method of exposure used in above ground testing is seen to affect the decay rates of the species differently, and this might also affect the durability classification. Therefore, the usefulness of testing the durability above ground with lap-joints in accordance with ENV12037:1996 (now superseded by CEN TS12037:2004) might depend on how well these simulate the behaviour of the intended construction. For instance, the behaviour of decking might be better simulated by uncovered boards than lap-joints.

The purpose of this study was to correlate moisture properties of the different wood species with the observed long term performance in outdoor exposure. Several additional experiments will be conducted to determine if the observed decay or at least the risk of decay could have been predicted. In particular, the response to liquid water of the species seems of high importance in this respect.

4. CONCLUSIONS

The results show that durability of wood exposed above ground depends on a combination of sample type and wood species. Based on the moisture behaviour, the risk of decay was evaluated and found to be somewhat correlated to the decay actually observed.

The response of the wood species to water vapour was deemed unimportant compared with the response to liquid water exposure for uncovered samples. Future experiments will show if the decay or risk of decay could have been predicted based on this response.

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