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Can Durability of New Zealand Grown Redwood (*Sequoia sempervirens*) be Predicted by NIR?

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EXECUTIVE SUMMARY

Coast redwood (*Sequoia sempervirens)* produces an attractive appearance-grade timber and is a durable material for both ground-based and above-ground situations. New Zealand-grown young redwood material has poorer and greater variability of durability than old growth United States wood.

The objective of this report is to evaluate progress towards the improvement in redwood durability aided by the use of NIR. This report contains both a summary of local and international literature, plus a critical analysis of recent redwood NIR studies.

New breeding stock can be used to enhance both growth rate and durability, but these breeding programmes are largely in their infancy. Due to the considerable time lag required to test trees for durability, new methods are being sought to give early indications of this trait. During the last two years a non-destructive near-infrared (NIR) spectroscopy method has been tested for assessing the deterioration of samples, alongside standard laboratory tests.

Conclusions reached are:

1. The durability of plantation-grown redwood has been shown in tests to be variable. The current official rating as “moderately durable” out of ground contact will remain until convincing test results are obtained from scientific ground-contact and service tests that meet the requirements of Standards NZ.
2. The NIR tests provided “proof of concept” for the approach, but to progress there needs to be:
    a. Further testing with higher numbers of heartwood samples (at least 500 - 1000) and a wider range of material (ages – up to 50 years; regions – at least five regions) to generate a more robust model for prediction. At this stage, maintaining genetic diversity of redwood in New Zealand is important, so testing should not be restricted to just a few genotypes.
    b. Development of a standard testing protocol for assessing young standing trees using 5-mm increment cores so that future work can build up a robust database (at age 10 years).
    c. Phenotypic screening of genetic material to identify genotypes with desirable characteristics, including durability.

3. For selection of improved genotypes, two “fast” test methods are available:
    a. Fungal Cellar tests in which small stakes are exposed in ground contact to soil fungi indoors under a controlled environment. Comparative results can be expected in about three years. Stakes of the same biological age must be used.
    b. Development of a hand-held NIR tool for predicting durability at point-of-sale. This could use the same algorithm used for assessing standing trees, provided the prediction model is expanded by including more samples and validated in robust trials involving ground-contact samples.

4. Improving the Durability Rating for new breeds will necessitate selection and deployment ***and ground-contact and service tests***, which will take at least 50 years. These tests need to be complemented with service tests of various kinds around the country. Thus the prospect of modifying the durability rating in NZ Standards for redwood in the near future are bleak because:
    a. established ground-contact tests involving redwood are currently insufficient to warrant such a re-classification, and

b. “improved” breeds will take a long time to become predominant in the forest resource.

What are the implications for FFR members?

This is a bold move to raise the acceptance of redwood in local and overseas markets. While a laudable goal, it will take a lot of time and the co-operation of redwood growers because there are several steps to be completed along the way:

1. Validation of the NIR method for assessing durability in place of the traditional ground-contact field tests. This will include further work to make the model robust.
2. Screening of heartwood durability by redwood breeders at an early age (ideally 10 years) on the assumption that early rankings will persist through time as heartwood develops. (This will also have to be validated at some point.)
3. Improved durability is a worthwhile goal and will require industry to work together with the appropriate research and genetic improvement to achieve it. It is also challenging as it will take some time and tenacity to maintain the momentum.

INTRODUCTION

Adapted from (http://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/tree-grower-february-2007/redwoods-an-overview/)

Redwoods were first introduced into New Zealand in the 19th century with high expectations they would enhance the New Zealand landscape and provide sought-after timber. The outcome of early plantings, mainly in the central North Island, was disappointing. The giant trees at Whakarewarewa are the remnants of extensive areas of planting in 1901, and even these struggled in their early years, protected by companion planting of larch, until they eventually claimed the site. The reason for the early failures is not entirely clear, but is likely to include poor site selection, planting without shelter, weed competition, and perhaps a lack of suitable mycorrhizae.

The outcome of subsequent plantings in the 1920s and 1940s was similar, with patchy areas of survival which contain some very impressive trees. It also became clear that the local timber did not match the quality of the old growth redwood that was being cut at that time in California. As a result, redwoods fell from official favour. Meanwhile farm foresters continued to plant redwoods on their own properties. This has resulted in some very fine stands, and clearly demonstrated that with proper attention redwoods will grow very well in New Zealand, with potential to provide durable timber for both outdoor and interior uses.

Adapted from (http://www.nzredwood.co.nz/redwood-uses-and-markets/)

Redwood is an “appearance wood” and is sought after for interior panelling, cladding, decking, and fencing. Demand for redwood appears to be consistent regardless of the level of new building activity, as it is used as much in renovation as it is in new buildings. The price of redwood logs has been twice that of Douglas-fir and nearly three times that of pine logs in California. Although the forestry and wood processing industries in California are facing a serious downturn, prices for redwood logs have remained high.

It has been used for weatherboards with some success[1], but some locally grown redwood is too soft for exposed decking. Its low strength means that it would need to be either supported by joists at closer centres or be thicker than radiata pine decking. Surface erosion on decking is likely to be worse than on uncoated weatherboards and would produce a very rough surface on lower density boards within five years. Its variable durability would also make it marginal for use as decking because a few failures in less than 15 years – the minimum requirement [2] – could be expected in exposed situations and in areas where there is a higher decay hazard, e.g., poorly ventilated or constantly damp areas (Dave Page, *pers. comm.*).

Natural Durability

Natural durability is a feature of the heartwood of many species. Very often, durability ratings are initially given based on material from natural forests, which can be inappropriate for plantation material which is generally younger and faster grown. The rating allocated at a species level is normally “high”, “medium” or “low” for indoor and outdoor situations separately, but this rating does not acknowledge the high variability which is a feature of all wood properties. Timbers of trade are often attributed with the characteristics (density, stiffness, durability) of the original natural forests which may be several hundreds of years old, without regard to the fact that properties including natural durability can be highly variable both within and between species and highly dependent on growing conditions. The decay resistance of heartwood is highly variable in young coast redwood (*Sequoia sempervirens*), with large differences among trees and from inner to outer heartwood [3], as in other species [4, 5]. The heartwood of young growth trees is less resistant to decay and more variable, with the outer heartwood zone consistently more resistant than the inner heartwood. These differences in natural durability can result in premature failure when the wood is exposed to high decay situations. Unfortunately those “old growth” properties are not necessarily transferred to plantations of the same species when grown as exotics on much shorter rotations.

To utilise the natural durability of plantation redwood heartwood effectively, a rapid method of sorting the heartwood according to decay resistance is desirable. Over the last century numerous laboratory and field test methods generally provide only “pass/fail” durability criteria based on limited sampling. There is a danger in adopting durability ratings assigned in one continent (e.g. USA) to another where the material is of different age and genetics.

Ground-contact and above-ground field exposure tests have been used to evaluate durability for over 50 years in New Zealand, and stake and post tests continue to be the primary test method for products intended for use in ground contact. There are several factors that can interact to affect the results of these tests. Perhaps the most important of these factors are site conditions and duration of the test. It has long been recognised that deterioration is more rapid in warm, moist climates than in cool or dry climates. In New Zealand, these tests typically last at least 7 years of exposure in regional tests to ensure that a range of fungal and climatic environments are covered. Durability ratings have been assigned on the basis of the average results from “long-term” field stake tests maintained by Scion and its predecessors[6].

For evaluation of products intended for use in contact with the ground, extended durability evaluations conducted at a single site may not be adequate for estimation of durability in more severe climates. A practical solution would be to require data from at least one test site that has previously demonstrated a severe deterioration hazard. Even in severe decay hazard climates, excellent performance of stakes after a few years is not a reliable indicator of long term durability [7].

The system used in New Zealand places natural durability into classes, with class 1 being the most durable and class 4 being the least (Appendix 2). These levels are based on long-term field tests established across the country, and an assignment of a Durability Class can be made in no less than seven years (Dave Page *pers comm*.). The selection of test material must be representative of material available on the market.

Accelerated laboratory tests like the Sutter Block test and Fungal Cellar tests have often been used, mainly to compare preservative treatments. However, as these environments are unnatural, the results can only be used comparatively [8]. Long term field tests, for example, [9], are well established for testing durability in ground contact.

Redwood in New Zealand

Redwood is a valued species for use in appearance grade applications, such as decking, exterior siding and interior panelling, because of its dimensional stability. It is also valued for certain exterior-use applications because of its natural durability. Young-growth redwood is less durable (categorised as “moderately resistant” rather than “resistant or very resistant”), and also exhibits greater shrinkage and swelling than old-growth redwood [10].

Differences in natural durability and dimensional stability between old-growth and young-growth could be accounted for by changes in the extractives found in the heartwood and changes in the microfibril angle in the S2 layer of the cell wall, respectively. Differences in extractive content in the heartwood would be related to the age of the tree, since durability increases across the heartwood from pith to bark.

In New Zealand, ground contact stake tests indicate that locally grown redwood heartwood has variable durability and is likely to be unreliable in moderately high decay hazard situations. Redwood has not been well represented in New Zealand trials and has been omitted from several of the local publications on durability, and suffers a consequent disadvantage. Appendix 1 lists the total numbers of existing tests and the ages of the source material. Test results to date place New

Zealand-grown redwood in natural durability Class 3, (moderately durable). There has been considerable variation both between and within tests, and hence it should still be regarded as unreliable in moderate-high decay hazard situations (Dave Page *pers comm.*). In low-moderate decay hazard uses such as weatherboards, decay does not appear to be a problem. The service life of uncoated weatherboards is likely to be limited by erosion and distortion but could be improved with well-maintained surface coatings. As weatherboards it should meet the durability requirements of NZ Standards [2], and surface coatings will improve its service life in exposed situations (Dave Page *pers. comm.)*.

Due to a lack of scientific data on redwood durability in New Zealand, it is not well represented in local literature (Appendix 3).

For tree breeders interested in durability, a sound scientific approach would require screening of potential stock at a relatively early age – preferably well under 10 years – before multiplication in nurseries and establishment in forests.

ASSESSING REDWOOD DURABILITY WITH NEAR INFRARED (NIR) SPECTROSCOPY

Near infrared (NIR) spectroscopy provides a potential rapid, non-destructive method for the routine estimation of wood properties. The technology is particularly well suited to tree improvement programmes where large numbers of samples must be analysed, but it can be utilised in any forestry application where the rapid provision of wood property data is required [11]. NIR spectroscopy, with its relative low-cost instrumentation and rapid spectra collection (with little or no sample preparation), is ideally suited for quantitative analysis, and is particularly applicable to process monitoring and quality control applications.

In recent years there has been an increasing focus on applying NIR to wood quality, particularly in tree improvement programmes, where in the past the destructive measurement of wood properties has been prohibitively expensive and may irreversibly damage breeding stock. The use of non-destructive sampling has become increasingly attractive [12-17]. NIR is a so-called secondary method which requires a primary reference method to establish a relationship between NIR spectra and the (wood) property of interest. From a sampling design viewpoint, the calibration equations can be improved by increasing the number of samples and by assessing a wider span of values. The quality of the calibration equation closely depends on the choice of experimental design (training samples) and also on the accuracy of the reference methods.

NIR spectroscopy can be applied to samples ranging in size from milled chips representing whole trees, to sections of wooden strips cut from increment cores [18-20]. NIR data, combined with powerful calibration models, such as Principal Component Analysis (PCA) and Partial Least Squares (PLS) has the potential to measure chemical components in wood and predict performance properties.

Even more recently, several studies have investigated the ability of NIR to assess the advancement of wood decay by correlating spectra against wood loss of laboratory samples[18-24].Typically, PLS regressions between the data sets of wood decay tests (x values) and the NIR spectra yield high correlations and low root mean square errors of prediction (RMSEP) using cross validation [22, 25-28]. This has been applied to both softwoods and hardwoods to examine decay resistance of heartwood [4, 21-23, 26]. As with field tests, the results show that durability in many species increases with tree age and distance from the pith.

Overall, NIR spectroscopy has proved to be an accurate and fast method for the non-destructive prediction of wood decay natural durability, which might be highly relevant for intensive tree breeding programmes and for efforts to optimise wood utilisation. The use of increment cores for these types of tests is also increasing [29, 30].

In order to progress NIR for durability assessment, certain criteria **must** be met:

1. Establish a robust correlation between NIR readings of wood samples and wood durability from standard tests.
2. In tree breeding for durability, develop efficient test procedures for standing trees and confirm a degree of juvenile:mature correlation.
3. For testing timber, employ calibrated hand-held units and a robust correlation.
4. To influence species durability ratings, establish long-term wood durability field tests (in varied environments) of improved genotypes.

These will be discussed separately below.

Correlation between NIR Readings and Wood Durability

In 2011, a NIR spectroscopy study was conducted by FFR on heartwood samples of New Zealand-grown coast redwood [32]. The study investigated if a robust relationship could be developed between NIR readings and durability – as determined by in vitro decay testing of heartwood blocks with fungal cultures. The methodology as described below is adapted from Jones *et al* [31].

- Coast redwood trees were sampled from stands from three different forests; Kinleith Forest in the Waikato (70 years old), Mangatu Forest in Gisborne (38 years old), and Rotoehu Forest in the Bay of Plenty (22 years old)[31].
- A further 13 trees were included from the Mangatu sawing study [32] and samples from six 70-year old stems from Kinleith.
- The trees in each forest stand were of different age and seedlots, so the effects of site and genetics are confounded, but the stands did provide a wide range of tree age and New Zealand and Californian seedlots.
- The stand inventories showed the Kinleith Forest stand had a stocking of 550 s/ha, basal area of 150.9 m^2/ha, mean DBH of 59.1 cm, mean top height of 44.9 m.
- The Mangatu Forest stand [32] had a stocking of 398 s/ha, basal area of 107.6 m^2/ha, mean DBH of 58.5 cm, mean height of 32.8 m.
- Wood discs were cut from the ends of the 6-m butt log for six trees at Kinleith Forest and 13 trees at Mangatu Forest, and at breast height for 32 trees at Rotoehu Forest.
- The wood basic density and heartwood content were measured, and heartwood blocks of dimensions 25 × 15 × 50 mm (tangential, radial, longitudinal directions) were cut in series from the inner to outer heartwood of radial strips from each disc. The heartwood blocks were measured for NIR spectra using a Bruker MPA spectrometer. Fungal cultures of two Brown-rot and one White-rot fungi were used in Sutter Block tests in standard pure-culture fungi tests [21, 33, 34] and weight loss was recorded on 306 heartwood samples.
- Due to time and cost restraints, no ground-contact tests were included.

The correlation coefficients for two NIR methods (line camera - transverse measurements- and Bruker MPA – radial transverse measurements) were of the order of 50% to 58%. Huge differences were observed in predicted weight loss against measured weight loss (of the order of 25%). This is normal for laboratory tests [8], which is why large numbers are preferred to the tests to allow better comparisons. Since durability is rated by actual weight loss in field stake tests, the results can only be considered encouraging, and sufficient only to rank genetic material. It has been observed in the past that weight loss can vary significantly between sites (presumably due to differences in microsite and fungal flora – and possibly sample age and genetics), and this is the reason that field tests are mandatory for allocating Durability ratings.

Comment on Scion Work to Date.

a) Developing a rapid lab test is attractive because it is much quicker and more cost effective than field tests. However, common pure-culture fungi are used under controlled conditions, unlike the complex fungal flora in nature (which differ according to site and environment). The extent to which the rapid tests are indicative of field tests is open to debate for the reasons outlined above.

b) Three hundred samples are too few to arrive at anything other than an indicative result. Protocols have moved beyond the days of such small sample sets – there really should be at least 500 independent samples, covering the range of target material (sites and ages – Geoff Downes, *pers comm.*; Laurie Schimleck, *pers. comm.)*.

c) The work to date shows a reasonable NIR correlation with weight-loss data, which serves as proof-of-concept [28]. More work is needed to develop a robust correlation (covering more ages and sources). The study was very worthwhile, showing high promise as a screening mechanism for genetic material.

The results are of interest to breeders, proving that NIR may be a useful screening tool. However, for scientific credibility the underlying relationship should be based on a larger sample size (e.g. >500 samples).

Correlation between Juvenile and Mature Wood

Tests on young material are assumed to be indicative of the properties of mature wood. This is a reasonable premise and one on which breeders rely heavily.

It is well known from field tests that heartwood durability in many species (redwood included) increases with tree age and distance from the pith. Old growth redwood (>200 years) in the USA is rated as "resistant to very resistant" to heartwood decay because the outer heartwood tends to be very old. Young growth is from 8 to 200 years old. The extent to which this applies in New Zealand is not well documented. (Dave Page *pers. comm*.). In the US there is evidence that their "young growth" (up to 200 years old) may have lower durability than the old growth [35], so it is logical to assume that this would also apply in New Zealand to a greater or lesser extent.

In the marketplace, questions around the durability of US young growth durability have encouraged some companies to explore the use of preservative treatments. However, the industry is reluctant to recommend treatment as it wishes to retain the "durable" "natural" and "chemical free" image (Alan Preston, Director of Apterus Consulting, *pers comm.*). This may change in future and acceptable treatment may be developed.

The prospect of improving the durability of new genetic stock is a distinct possibility [5, 36], and the fact that NIR can give comparative results between genotypes suggests that a protocol should be developed soon for NIR screening. The age at which heartwood starts in redwood is young, so there is a strong possibility that assessment could be made on 5-mm increment cores from 10-year-old stems. The age is important as durability increases with age, and samples need to be of comparable age for screening purposes. Standard decay tests involve specified sample sizes, so a small experiment needs to be undertaken to correlate weight loss in standard samples with NIR assessments on the heartwood of increment cores from the same material so that future non-destructive sampling can be done on standing trees.

In the context of breeding, juvenile:mature correlations are fundamental. There are no current data on durability in this regard, but it is reasonable to expect that material selected for durability early in life (and heartwood in redwood starts well before 10 years) will retain a significant advantage into the future. Additional work is needed to describe the process of heartwood development over time, as it is possible that there are differences between genotypes in the rate of heartwood formation. This would require a long-term and systematic work programme to develop more durable breeding stock, and even longer to impact on the official Durability Class for redwood. An outline of steps is:

- Improve the durability prediction algorithm by undertaking more NIR/decay studies on 10-year-old material (200 samples).
- Establish a protocol for assessing heartwood durability from 5-mm increment cores of young redwood material for which Sutter block or Fungal Cellar test results are obtained. Indicative results of using 10-mm increment cores on cypresses have been somewhat promising [28], so trials would be necessary to establish the best approach for selecting the core sections to be assessed – presumably the outer heartwood at a standard age – 10 years?
- Undertake initial scoping trials on 5-mm increment cores from 10-year-old material before using the Kuser trials (10 cores/breed/site).

Testing Wood Quality of Individual Timber Boards

The increasing pressure to rapidly evaluate and commercialise durable wood products from plantations is challenging our ability to interpret the results of short-term durability tests. The current process of subjectively interpreting data by averaging results is vulnerable to the pressure for rapid commercialisation where data may be reviewed by organisations whose members are not familiar with the intricacies of wood product durability evaluations. Ground-contact testing of products used in structurally critical above-ground members may be necessary until appropriate above-ground test methods are developed.

The idea of testing timber before sale is attractive, since boards are variable and the level of durability required will vary with use (ground contact or above ground). NIR has proved to be a potential tool for “grading” individual boards, but to be adopted it will require much more comprehensive testing, algorithm development and validation. As boards can come from all ages of material, sites and positions within the heartwood zone, calibration samples (300 - 500) for field testing should contain a wide mix of sample types. The expectation is that NIR screening will identify a wide range of durability levels, and ground-contact tests will be necessary to validate the results and generate “cut-off” levels. This will take at least seven years to complete.

Wood Durability Field Tests

The extent of field testing in New Zealand is documented in Appendix 1 (courtesy of Dave Page).The number of test sites is very limited (only three ground-contact sites in the North Island), but the material is diverse (up to 80 years old). Due to the variability observed, they confirm the Durability Rating of 3 (Moderately Durable), and are therefore unreliable in high hazard situations.

Existing ground-contact tests confirm a Durability Rating of 3 (Moderately Durable). Some failures could be expected after 15 years (minimum requirement [2]). If the industry is serious about improving the Durability Rating, more support should be given to the establishment of wider ranging tests (sites, material) to demonstrate the benefits of breeding for durability and persuade authorities to change the Durability Rating.

CONCLUSIONS

1. The durability of plantation-grown redwood has been shown to be variable and its average level is unproven and will remain so until convincing test results are obtained from official ground-contact stake tests, currently maintained by Scion, and recommendations are made to NZ Standards.
2. NIR methods have been developed to the “proof of concept” stage, and the next moves are:
    a. Extend the sampling to obtain a more robust model.
    b. Deploy the method on young breeding material (e.g. Kuser clones) to start the improvement process, and avoid spending effort on non-durable stock without a good reason.
    c. There is a shorter-term prospect of developing a timber test for assigning durability classes to timber boards.
3. To improve the Durability Rating for redwood will necessitate the aggressive selection and deployment ***<u>and ground-contact testing</u>*** of genotypes selected on the basis of early tests, which will take around 50 years, assuming they are widely adopted by industry. Thus the prospects of modifying the durability rating in New Zealand Standards for redwood in the near future are bleak because:
    a. Ground-contact test results are currently insufficient to warrant such a re-classification. Under the present system a case has to be made based on scientific data (assessment of material after at least seven years in tests – Dave Page, *pers comm*.).
    b. “Improved” breeds will take a long time to become predominant in the forest resource.

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APPENDICES

Appendix 1: Summary of Redwood Durability Tests To August 2012

Durability tests of redwood (*Sequoia sempervirens*) as at August 2012 courtesy of Dave Page, Scion)

Test	Site	Type	Year in	Av. life (years)	Comments
10	Whakarewarewa	Stakes	1962	4.0	Ex 50-year-old FRI trees
86	Whakarewarewa	Stakes	1999	7.8	Ex 80-year-old trees from Scion
86	Waitarere	Stakes	1999	5.9	
86	Whakarewarewa	Stakes	2001	3.3	Ex 35-year-old trees from Tokoroa
86	Waitarere	Stakes	2001	5.1	
98	Whakarewarewa	Stakes	2007		Three sets of material from Southland 70 & 43 year old, few stakes failed
98	Waitarere	Stakes	2007		
FT22	Whakarewarewa	Lap joints	2007		
BU17	Devonport	W. boards	1979		Stained, weathered, minor decay after 17 years.
BU19	Mystery Creek	W. boards	1978		Painted, sound after 11 years.
BU37	Whakarewarewa	W. boards	1987		Uncoated, weathered, sound after 24 years.
BU41	Welcome Bay	Log home	1986		Sound after 25 years
BU41	Masterton	Log home	1999		Sound after 12 years

Discussion of Redwood Tests

The initial stake test (1962) placed New Zealand-grown redwood in natural durability Class 3, (moderately durable). The second test with wood from the same source, some 30 years later, indicated that redwood should be in Class 2 (durable). However, the third set of stakes was more durable than the first and supported the initial classification. This just goes to illustrate the issue variability in relatively small samples. Overall, locally grown redwood has been shown to be quite variable in durability in ground-durability tests. Even though stakes from 80-year-old trees appear to be more durable on average than the other sets tested, the first failures occurred in that group after only 2-3 years. Therefore redwood is likely to be unreliable in moderately high decay hazard situations or in exposed situations where a long service life is required, e.g., exposed exterior structural situations. The reasons for the high variability are not clear, although this is not unusual in species with a Class 3 durability classification.

In low decay hazard situations such as weatherboards, New Zealand-grown redwood should meet the requirements of NZS 3602:2003 (NZ Standard for Timber and Wood-Based Products for Use in Building). The service life of uncoated boards is likely to be limited by erosion and distortion, but could be improved with well-maintained surface coatings.

Appendix 2: New Zealand Durability Requirements

Taken from Table 1 of the official website of the New Zealand Farm Forestry Association http://www.nzffa.org.nz/specialty-timber-market/information-resources/structural-specialty-timbers/nzs-3602-durability/#Table1 - Requirements for solid timber to achieve a (minimum) 50-year durability performance

NZS 3602 Ref No.	Wood-based building components	Species or type	Level of treatment(2) to NZS 3640
	C – Members protected from the weather but exposed to ground atmosphere (see section 108 of NZS 3602)		
1C.1	Jack studs, subfloor braces, bearers, wall plates, floor joists to the subfloor, blocking, subfloor wall studs, wailings and battens, wall studs and nogs, diagonal boards	Larch	None
		Cypress(6) sapwood	H1.2
		Cypress(6) heartwood	None
1C.3	Interior flooring, suspended ground floors	Cypress(6) heartwood	None
		Cypress(6) sapwood	H1.1
		Matai heartwood	None
		Matai sapwood	H1.1
		Rimu heartwood	None
		Rimu sapwood	H1.1
		All Eucalyptus species	None
		Tawa	H1.1

D – Members protected from the weather but with a risk of moisture penetration conducive to decay (see section 109 of NZS 3602)

Roof members (in or associated with)

1D.1	Sarking and framing not protected from solar driven moisture through absorbent cladding materials(8)	Larch Cypress(6) heartwood Cypress(6) sapwood	None None H1.2
1D.3	Enclosed skillion roof framing and associated roof members	Larch Cypress(6) heartwood Cypress(6) sapwood	None None H1.2
1D.4	Valley boards and boards supporting flashings or box gutters and flashings to roof penetrations and upstands to roof decks(10)	Larch Cypress(6) heartwood Cypress(6) sapwood	None None H1.2

Wall members (in or associated with)

1D.5	Framing and other members within or beneath a parapet except in situations detailed in 1D.13 (i.e. framing and other members in exterior walls including boundary joists, where monolithic claddings are fixed directly to the framing and do not comply with E2/AS1)	Larch Cypress(6) heartwood Cypress(6) sapwood	None None H1.2
1D.6	Framing and other members within enclosed decks or balconies(9) (See figure 1 NZS 3602)	Larch Cypress(6) heartwood Cypress(6) sapwood	None None H1.2
1D.7	Framing and other members supporting enclosed decks or balconies where failure is potentially life threatening, such	Larch	None

	as when the support is enclosed post and beam construction	Cypress[6] heartwood Cypress[6] sapwood	None H1.2
1D.8	Framing and other members supporting enclosed decks or balconies[9] (See figure 1 NZS 3602)	Radiata pine and Douglas fir	H1.2
1D.14	All other exterior wall framing and other members including exterior and boundary joists[9][11] except those clad in masonry veneer covered by 110.2(c) NZS 3602[12]	Radiata pine and Douglas fir	H1.2
	E – Members not exposed to weather or ground atmosphere and in dry conditions (see section 110 of NZS 3602)		
1E.1	All roof trusses, including gable end trusses, roof framing, ceiling and eaves framing, purlins and battens excluding skillion roof framing, and sarking described in 1D.1	Larch Cypress heartwood Cypress sapwood	None None H1.1
1E.2	All midfloor framing excluding boundary joists but including associated ceiling framing	Larch Cypress heartwood Cypress sapwood	None None H1.1
1E.3	Unlined buildings except those not allowed in 110.2(f) of NZS 3602	Larch Cypress heartwood Cypress sapwood	None None H1.1
1E.4	Timber framing (including boundary joists) in exterior walls clad with masonry veneer complying to SNZ HB 4236 on a single storeyed building but with restrictions set out in 110.2(b) and in figure 3 of NZS 3602	Larch Cypress heartwood Cypress sapwood	None None H1.1
1E.5	Internal walls excluding those supporting decks and balconies	Larch Cypress heartwood Cypress sapwood	None None H1.1
1E.7	Interior flooring	Cypress heartwood Cypress sapwood Matai heartwood Matai sapwood Rimu heartwood Rimu sapwood Beech heartwood	None H1.1 None H1.1 None H1.1 None

Beech sapwood	H1.1
Eucalyptus heartwood	None
Eucalyptus sapwood	H1.1
Tawa	H1.1

NOTE
(2) Throughout Appendix 2, timber treated to a higher level than the minimum satisfies the minimum requirements.
(5) H3.2 refers to preservative treatments outlined in NZS 3640
(6) Cypress species include *Cupressus macrocarpa* (macrocarpa), *C. lusitanica* (Mexican cypress) and *Chamaecyparis lawsoniana* (Lawson's cypress). Refer to AS/NZS 1148.
(8) Timber shakes and shingles, and similar absorbent claddings, absorb moisture that can be driven in frame cavities by evaporation. Unless the cavities are adequately drained and ventilated, continuing condensation caused by solar driven transfer increases the moisture content in the cavities and timber framing, requiring a higher level of timber treatment to resist decay.
(9) Such as joists, lintels, wall plate and double top plates, studs, together with parapets, enclosed balustrades, boxed columns and chimneys.
(10) Any metal flashing shall be separated from the treated timber with building paper.
(11) Exposed ends of joists shall be protected by a boundary joist.
(12) Refer to table 1 row 1E.4 NZS 3602.

Requirements for solid timber to achieve a 15-year durability performance

NZS 3602 Ref No.	Wood-based building components	Species or type	Level of treatment
A - Members exposed to exterior weather conditions and dampness (see section 111 of NZS 3602)			
2A.1 2A.2 2A.3	Weatherboards Base battens Fascia, barge and coverboards	Larch heartwood	None
		Cypress[4] heartwood	None
		Redwood heartwood	None
		Western red cedar heartwood	None
2A.5 2A.6	Exterior joinery, including window frames, sills, and sashes, exterior door frames, sills and doors Timber reveals for aluminium windows	Redwood heartwood	None
		Western red cedar heartwood	None
		Cypress[4] heartwood	None
2A.7	External stairs, stair handrails and balustrades, verandah floors, unroofed decking (which can easily be replaced)	Cypress[4] heartwood	None

		Rimu heartwood	None
		Eucalyptus[(6)] heartwood	None
		Beech heartwood (silver, red, hard)	None
B – Members protected from the weather and dampness (see section 111 of NZS 3602)			
2B.1	Non-load bearing interior wall framing	Larch	None
		Cypress[(4)] heartwood	None
2B.2	Stair treads, risers and handrails	Larch	None
		Cypress[(4)]	None
		Rimu	None
		Eucalyptus[(6)]	None
		Beech - silver, red, hard	None
		Tawa	None

NOTE
(2) Throughout Appendix 2, timber treated to a higher level than the minimum satisfies the minimum requirements.
(4) Cypress species include *Cupressus macrocarpa* (macrocarpa), *C. lusitanica* (Mexican cypress) and *Chamaecyparis lawsoniana* (Lawson's cypress). Refer to AS/NZS 1148.
(6) Eucalyptus species include *E. botryoides, E. saligna, E. globoidea, E. obliqua, E. pilularis.*

Note: For more information about Hazard Classes download *NZ Hazard Class and Timber Treatment Summary Table* from the NZ Wood website.

Appendix 3: Hazards that Effect the Durability of Wood

Adapted from (http://www.nzwood.co.nz/how-wood/treatment-and-durability/hazards/)

Hazards: Insects, Fungal Decay, Other Fungi, Bacteria, Chemical and Physical Hazards

Biological hazards

Insects

Wood boring insects (and to a lesser extent, termites) are a potential hazard to dry wood in New Zealand buildings. *Anobium punctatum* (Furniture beetle) has been identified as the principal hazard to interior finishing timbers and framing.

When radiata pine was accepted as timber framing in the mid 1950s, the preservative treatment was exclusively to combat the potential risk of wood borer.

From the 1990s, untreated machine stress grade high temperature dried radiata pine was also accepted as an alternative, since it had been shown that machine gauged, high temperature kiln dried radiata pine was much less susceptible to borer attack than rough sawn, air dried framing. It was also accepted that the susceptibility of untreated radiata pine to *Anobium* attack had been somewhat overstated in the past.

More recently and as a consequence of the "leaky building crisis", timber framing is now more likely to have had a preservative treatment to reduce the risk of decay if leaks in the building envelope occur, although untreated framing is still acceptable for some limited applications and building designs such as single storey brick veneer houses with a wall cavity and built with eaves.

Fungal Decay

Until recently, fungal decay of timber building components in New Zealand was not considered to be a significant biological hazard. It was mainly confined to occasional incidences of dry rot (*Serpula lacrymans* – the true dry rot fungus), or decay of poorly maintained exterior cladding, or decay of native timbers used in poorly ventilated sub-floor situations. Since the "leaky building crisis", decay has become the main perceived biological hazard for framing, although the timber is required in-service to have a moisture content of < 20%, which is too low for the fungal decay.

Two broad types of decay are relevant to timber in buildings, brown rots and white rots. The main distinction is that brown-rotted wood is usually various shades of orange or orange brown to dark brown and the dried decayed wood has extensive cuboidal cracks.

White rots produce a white/cream fibrous decay and are less common in softwoods than hardwoods. Brown rots are a threat when the wood moisture content exceeds 25-30 % for lengthy periods of time.

White rots prefer a somewhat higher moisture content. True dry rot (the term is often misused) is relatively rare, but the fungus has the ability, once established, to attack wood with moisture contents below 25%. It thrives in alkaline conditions, e.g. when wood is in close proximity to cement-based products (concrete blocks, mortar etc).

When conditions are particularly wet – wood moisture contents in excess of 60% – soft rot decay may occur. This type of decay appears initially as a gradual erosion of the wood from the outside, characterised by grey/black discolouration, particularly of the late wood (the dense rings) in softwood timber. When the decay becomes advanced, the wood substance becomes quite brittle and the dried wood surface develops fine cuboidal cracks.

Other Fungi

Mould fungi frequently colonise the surface of damp wood, whether preservative treated or not. White, pink, orange, green and black moulds may be encountered, the colour being that of the mycelium and spores which the fungus produces. Although they have negligible effect on wood strength, several moulds pose a serious health hazard when in a closed or poorly ventilated environment.

Timber treatment will not relieve this potential risk, and it is critical that building design and construction provide for adequate ventilation where moisture may be encountered. Perhaps the most serious is *Stachybotrys ata*, which can produce highly toxic spores. It preferentially grows on damp wood fibre products (building paper, fibre-cement building components), rather than solid wood.

Sapstain is not a health or strength issue but it is often present when timber has not been seasoned or dried properly. It occurs as blue-black discolorations which may penetrate deeply into the wood. Like moulds, this group of fungi have negligible effect on wood strength, although under appropriate, wet conditions, some can develop as softrot.

Bacteria

In the last 20 years there have been different types of bacterial degrade patterns documented. As with soft rot, this type of degrade tends to be associated with timber with a high moisture content that is in ground contact or even immersed in water, e.g. water cooling tower slats.

Chemical Hazards

Most timber species exposed to strong acids and alkalis will be detrimentally affected. A notable exception is redwood. Strong acids and alkalis result in separation of wood fibres or changes to the wood structure with an effect similar to chemical pulping.

The contact of some preservative treated wood with iron fastenings such as screw spikes with CCA -treated railway sleepers (cross-ties) are an example of chemical degradation. This is referred to as ‘iron rot’.

Some timber species may also be discoloured by reaction between naturally occurring timber tannins and metals, e.g. uncoated nails.

Physical Hazards

Some timbers, such as pine species, of low to medium density are ”soft” and are susceptible to physical abrasion which will wear away timber surfaces. Species that are more dense are better suited to applications such as flooring where weighty objects or the heels of shoes will not leave imprints on the timber surface.

Exposure of timber surfaces to sunlight (UV rays) can lead to bleaching, yellowing and roughness of timber surfaces. The UV rays alter the cell structure in the surface wood cells. Western red cedar is commonly used as a cladding material, and over time will grey and develop surface checking.

Prolonged wetting and drying cycles (swelling and shrinkage) of wood will also lead to deformation of wood which is seen as warping (twist and bow), splitting and cracking (checking) of timber. Different timber species or products may be more resistant to moisture and therefore appear to be more dimensionally stable. The failure of paint coatings or films may also allow moisture ingress into wood, and open wood joints as timber takes up moisture and swells. The maintenance and renewal of paint coatings is important and can significantly affect the overall long-term performance of a wood product in service.