# DECAY RESISTANCE IN REDWOOD (*SEQUOIA SEMPERVIRENS*) HEARTWOOD AS RELATED TO COLOR AND EXTRACTIVES[1]

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ABSTRACT

Decay resistance and water-soluble and ethanol-soluble extractive contents were determined for redwood heartwood boards having a full range of natural color variation. Decay resistance and ethanol-soluble extractive content were greatest in the darkest boards. Water-soluble extractives varied inconsistently with board color and decay resistance. Correlation analysis showed that as much as 69% of the variation in weight loss could be accounted for by ethanol-soluble extractive concentration.

*Additional keywords*: Biodegradation, soil-block tests, extractive content.

## INTRODUCTION

In highly decay resistant species, heartwood color and natural decay resistance result from the presence of small quantities of extractable materials deposited at the time of heartwood formation that do not contribute significantly to wood strength. Decay resistance apparently is provided by different extractive fractions in different species of wood (Scheffer and Cowling 1966). In redwood (*Sequoia sempervirens*), decay resistance has been ascribed largely to water-soluble extractives (Hawley et al. 1924; Sherrard and Kurth 1933; Anderson 1961), or at least heat labile extractives (Anderson 1961), although some fungitoxicity has been reported for material removed from wood by alcohol extraction (Inst. Pap. Chem. 1946). While hot water extraction removed a considerable amount of decay resistance, the extract itself showed no fungicidal properties (Anderson 1961); hot acetone extraction had little effect on decay resistance (Anderson et al. 1962). In incense cedar (*Libocedrus decurrens*) decay resistance is associated with extractive fractions having little or no solubility in water (Anderson et al. 1963; Anderson and Zavarin 1965; Wilcox 1970), but in western red-cedar (*Thuja plicata*) the substances responsible for decay resistance are at least partly soluble in water (Scheffer 1957; Barton and MacDonald 1971). As redwood is among the most decay-resistant of domestic U.S. woods, with a reputation for long service life in many moist exposures, it is difficult to understand how a major part of its decay resistance could be due to water-soluble substances.

Redwood has a wide degree of natural variability in the shade and intensity of the color of its heartwood. Some of these color variations are recognized by graders as cause for accepting or rejecting boards in certain grade categories, suggesting that they represent or indicate variations in wood properties that might affect end use. However, little is known about actual differences in properties of wood belonging to the various color variation categories.

We were asked to survey the properties of wood belonging to various descriptive categories recognized in grading, along with

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some categories recognized by graders but not considered by the grading rules (R.I.S. 1970). Because two of the properties examined were decay resistance and extractive content, comparison of these two parameters was possible in relation to a rough measure of heartwood color, as represented by the color variation categories provided us; the results of these comparisons are reported here.

## MATERIALS AND METHODS

Boards representing the widest possible range of naturally occurring redwood [*Sequoia sempervirens* (D. Don) Endl.] heartwood colors were selected from current mill production at a number of California redwood mills. These boards were categorized into seven distinct groups by workers having extensive experience in redwood lumber grading. Because of the variety of mills visited, the samples undoubtedly included boards from both old-growth and young-growth timber—although, because sampling was done at the grading station, this information about each individual board was not available. Two boards considered representative of the entire group were selected from each group for testing.

The control group, called "normal" (see Table 1), was selected by the graders as typical of the color of the vast majority of redwood heartwood; the other color groups occurred in relatively small quantities. The names "extractive stain" and "color streaks" were chosen by the graders for want of suitable descriptive terms, although these two groups are not recognized as different from normal according to current grading standards. The group called "dark" is normally included in what is known as "medium stain." The wood immediately adjacent to and associated with "fire scars," which is approximately the color of normal sapwood, is treated as sapwood under current grading standards and is permitted only in grades that allow sapwood.

Weight loss due to decay was determined by a soil-block test using chambers prepared according to ASTM D2017 (ASTM 1970) with the exception that a soil moisture content of 170% of the soil moisture-holding capacity was employed and feeder blocks were of white fir. *Poria monticola* (from Madison 698) and *Lenzites trabea* (from Madison 617) were used as test fungi with five replicate test blocks from each board and two boards per category.

Specific gravity was determined by the maximum moisture method (Smith 1954) because of the small and variable sizes of some specimens. Concern over the amount of water-soluble substances removed by this method prompted a check of the results using the standard method for specific gravity determinations (ASTM 1970 [D143]) on a few samples where adequate material was available. Although differences were found, this check revealed no substantial systematic differences between the results of the two methods.

Wood adjacent to that supplying the soil-block specimens was ground to pass a 40-mesh screen and be retained on a 60-mesh screen. Moisture content of the ground wood was determined and, for each of two boards in each color group, a sample of the air-dry material equivalent to 10 grams of oven-dry wood was extracted consecutively with hot water followed by hot ethanol. Extraction was carried out in a Soxhlet apparatus for a maximum of 8 h in each solvent or until the extracting solvent was colorless. The extract was collected by evaporation separately from the two solvent systems. Extractive concentration was expressed as a percent of the oven-dry weight of extracted wood. Additionally, a correction was applied to account for differences in specific gravity of the boards, thus allowing the expression of extractive content on the basis of grams/cm$^3$ of green wood substance according to the equation:

$$EC_{g/cm^3} = \left[\frac{EC_{\%}}{100}\right] \times \left[\frac{\rho_G}{1 + \frac{EC_{\%}}{100}}\right]$$

where:

$EC_{g/cm^3}$ = extractive concentration in oven-dry g of extract per cm$^3$ of green wood

TABLE 1. *Weight loss and extractive content by color variation group*

| Color Group[a] | Weight Loss in Soil-Block Test | | Extractive Content (oven-dry extract as percent of extracted, oven-dry wood) | | Extractive Concentration (g oven-dry extract/cm$^3$ of green wood) | |
|---|---|---|---|---|---|---|
| | *Poria monticola* | *Lenzites trabea* | Water | Ethanol | Water | Ethanol |
| | % | % | % | % | g/cm$^3$ | g/cm$^3$ |
| 1. Normal | 41.4 | 5.4 | 11.35 | 4.22 | 0.0295 | 0.0106 |
| 2. Extractive stain | 34.0 | 14.9 | 11.12 | 3.18 | .0362 | .0106 |
| 3. Color streaks | 45.2 | 22.8 | 6.80 | 1.39 | .0238 | .0066 |
| 4. Fire scars | 34.2 | 9.8 | 12.72 | 2.86 | .0398 | .0089 |
| 5. Light stain | 20.8 | 1.4 | 9.79 | 5.29 | .0283 | .0153 |
| 6. Medium stain | 36.1 | 4.6 | 3.88 | 5.20 | .0124 | .0167 |
| 7. Dark | 18.0 | 1.4 | 11.24 | 8.12 | .0335 | .0225 |

[a] Approximately in order of increasing color intensity except that groups 2, 3 and 4 differed in color only in discrete streaks.

$EC_{\%}$ = oven-dry extractive content as percent of oven-dry weight of extracted wood

$\rho_G$ = specific gravity (maximum moisture method; oven-dry weight of wood and extract—green volume basis)

Correlation analysis was performed using the program DANIEL on the CDC 6400 computer of the U. C. Berkeley Computer Center (Daniel and Wood 1971). Statistical significance was determined by both r and F tests (Snedecor and Cochran 1974, Tables A11, A14).

## RESULTS

Table 1 shows weight loss caused by *Poria monticola* and *Lenzites trabea* and the corresponding extractive concentrations ranked (to the extent that was possible) in order of increasing darkness of heartwood color. Boards in the "dark" group had substantially greater decay resistance than those in the "normal" group. Boards in both categories were strikingly resistant to decay caused by *Lenzites trabea*. Although boards in the "dark" group are included with "medium stain" in practice, the two groups appear to have some distinctly different properties.

There was a tendency, although not perfect, for content of ethanol-soluble extractives to increase with increasing darkness of wood color. A distinct trend for water-solubles in relation to wood color was not present. Table 1 also shows that as content of ethanol solubles increased, weight loss tended to decrease, or in other words decay resistance appears to have been directly associated with the amount of ethanol-soluble extractives. The strength of this relationship is demonstrated by the results of the correlation analysis shown in Table 2, where the concentration of ethanol solubles accounts for 56 to 69% of the variation in weight loss.

Microscopical examination of boards from each color group revealed the presence of hyphae of decay fungi, in an early stage of infection, in the "dark" group, as well as in the "light stain" and "medium stain" groups, and in the fire scars.

## DISCUSSION AND CONCLUSIONS

These results suggest that more of the decay resistance of redwood heartwood observed in this study was due to its alcohol-soluble extractive content than to its water-soluble extractive content. In view of the breadth of confidence intervals necessitated

TABLE 2. *Correlation between extractive concentration (g/cm³) and weight loss (%)*

| Extract Grouping | Correlation Coefficient (r) | | Proportion of Variation in Weight Loss Accounted for by Extractive Content ($r^2 \times 100$) | |
|---|---|---|---|---|
| | *Poria monticola* | *Lenzites trabea* | *Poria monticola* | *Lenzites trabea* |
| Values from Individual Boards[a] | | | | |
| Water extract | -0.50 | -0.28 | 25% | 8% |
| Ethanol extract | -0.83**[c] | -0.75** | 69 | 56 |
| Total extract | -0.79** | -0.57* | 63 | 32 |
| Mean Values for Color Groups[b] | | | | |
| Water extract | -0.27 | -0.05 | 8 | 0 |
| Ethanol extract | -0.81* | -0.79* | 65 | 62 |
| Total extract | -0.70 | -0.39 | 49 | 16 |

[a] Residual degrees of freedom = 12

[b] Residual degrees of freedom = 5

[c] ** = Significant at 1% level
 * = Significant at 5% level

by such a small sample and of variability due to the subjectivity of color group-selection, the attainment of statistically significant correlations in these data is considered to indicate a strong relationship between these properties.

Even total extractive concentration (the sum of the concentration of water solubles and ethanol solubles for each board sampled) appeared to be a relatively good predictor of decay resistance. To the extent that it can be generalized, darkness of heartwood color also appeared to be a relatively good index of decay resistance, with the darkest boards tending to have the highest resistance.

It is clear that other factors than those considered here must have been responsible for approximately 30 to 40% of the weight-loss variation. Foremost among these factors, probably, are the subjective manner in which color groups were differentiated (with regard to the mean values for color groups), the effects of other extractive fractions, and variation in the quantity and composition of extractives within and between trees.

These results are in direct contrast to earlier data for redwood that associated decay resistance with water-soluble extractives (Hawley et al. 1924; Sherrard and Kurth 1933; Anderson 1961) and appear to be at least somewhat different from earlier results with western red-cedar (Scheffer 1957), a species similar in many properties to redwood. Although the use of correlation analysis is not a common method of analyzing the basis for decay resistance, it has been used before in similar work (Roff et al. 1963), and these results suggest that it deserves greater acceptance as a diagnostic tool in such studies. Nevertheless, some of the differences in results may be due to differences in methods. Furthermore, it would be unfair without qualification to generalize as to expected results with other fungi and exposures, since the two fungi used in this study (particularly *P. monticola*) are considered exceptionally aggressive wood destroyers.

Eades and Alexander (1934) stated categorically that decay resistance in western red-cedar could not be predicted on the basis of heartwood color. More recently, Scheffer (1957), Roff et al. (1963), and Barton and MacDonald (1971) found that dark-colored wood of western red-cedar was considerably less resistant to decay than was light-colored wood. The opposite was true for redwood with respect to the "dark" and "normal" categories in our study. Barton and MacDonald (1971) reported that dark-colored heartwood of western red-cedar contained fungi not present in lighter heartwood, which was also true of redwood in the present study. Fritz and Bonar (1931) found decay fungi in darkly discolored redwood heartwood, adjacent to advanced decay, and recommended that such discolored wood be excluded from uses where decay resistance is required; it would appear from the present results that such exclusion is unnecessary, at least where existing infections of decay fungi have been eliminated—by kiln drying, for example.

The data of this study appear to correspond with earlier results for incense cedar, another species resembling redwood, where the substances responsible for decay resistance did not reside primarily in the water-soluble fraction (Anderson et al. 1963; Anderson and Zavarin 1965; Wilcox 1970). Lack of water solubility for the substances responsible for most of the decay resistance in redwood heartwood would be more consistent with the history of durability of redwood in various wet environments than would dependence upon water-soluble, leachable substances.

The apparent differences in substances responsible for decay resistance in three otherwise similar wood species, and conflicting evidence concerning the basis for such resistance, indicate a need for further detailed research on the nature of natural durability in this important group of high-extractive-bearing western conifers, particularly with respect to redwood. Highest priority should perhaps be given to repetition of this work, using matched samples in both correlation and direct bioassay types of studies and including identification of specific compounds in each extractive fraction most responsible for observed results, along with direct assay of the extracted substances for fungitoxicity.

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## Editorial

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The opinion molders and leaders of tomorrow are in our universities today. How many of them spend four years on campus without even being aware of the research and teaching involving wood which is going on?

While we cannot and should not spend all our time as publicists, if we do not speak up for wood who will?

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