DECAY RESISTANCE AND EXTRACTIVE CONTENT OF SECOND-GROWTH PORT ORFORD CEDAR (*CHAMAECYPARIS LAWSONIANA*) WOOD

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Abstract. Port Orford cedar (*Chamaecyparis lawsoniana*) has a reputation for being resistant to fungal attack, but much of the work to support this premise used older growth material (80-100 yr old). Given the tendency for the heartwood from the second growth of some species to be less durable, we evaluated the decay resistance of Port Orford cedar heartwood from 12 trees in laboratory soil block tests using *Postia placenta* and *Gloeophyllum trabeum* as the test fungi. Weight losses ranged from as little as 1.1 to more than 60% with most blocks experiencing weight losses between 11 and 24%. Heartwood was resistant to attack by *G. trabeum* but proved to be very susceptible to *P. placenta* and was only moderately resistant to this species. These results suggest that the durability rating of second-growth Port Orford cedar merits a re-evaluation.

Keywords: Port Orford cedar, decay resistance, *Postia placenta, Gloeophyllum trabeum.*

INTRODUCTION

Port Orford cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.) grows in a narrow range along the west coast of the US in northern California and southern Oregon. The wood of this species is straight-grained and has excellent resistance to chemicals (Stillinger 1953). As a result, it has been used domestically for battery cell separators. It is also exported to Japan for use in house construction. A root disease once threatened the commercial viability of the species. However, there are now resistant seedlings and there is a steady supply of smaller-diameter logs available in some markets. Port Orford cedar heartwood has been reported to be resistant to fungal attack (Humphrey 1918; White 1922; Scheffer and Morrell 1998; Morrell et al 1999; Liu 2004; Tunnicliffe, undated), and a laboratory study of material collected from Oregon and California mills showed that the materials exhibited moderate to high decay resistance in laboratory soil block tests (Morrell and Sexton 1987). These tests, however, were performed on boards cut from older trees (>80-100 yr old), and there are

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no data on the durability of materials cut from younger, second-growth trees.

Although the use of naturally durable heartwoods is an attractive option for many wood users, there are some concerns about potential differences between so-called old-growth and second-growth wood of the same species. Clark and Scheffer (1983) showed that heartwood cut from old-growth redwood trees tended to be more durable than that cut from second-growth trees. A number of researchers have shown that extractives content tends to be lower in heartwood from second-growth heartwood of the same species, and this translates into potentially less durable materials. Heartwood decay resistance in most species also decreases from the heartwood–sapwood boundary toward the pith (Scheffer and Cowling 1966; Taylor et al 2002). Thus, older, larger trees are potentially more likely to contain higher proportions of more durable heartwood. Changes in extractive content that affect resistance to biological attack could have important implications for those planning on more aggressive management of these durable species.

The objective of this work was to evaluate heartwood extractives content of second-growth Port Orford cedar heartwood in relation to its resistance to attack by two brown rot fungi.

MATERIALS AND METHODS

Disks (150 mm thick) were cut from the butt and tip of 12 randomly selected Port Orford cedar logs ranging in age from 15 to 38 yr old as determined by ring counts of the butt sections at a mill located near Canyonville, OR. It was not possible to determine the exact source of each log. The sapwood zone on each disk was determined by observing wetting patterns, and this zone was marked, allowing it to be eliminated from testing. The disks were air-dried at 20-24°C to a stable moisture content prior to processing, and a single radial strip (20 mm wide [tangential] × 20 mm thick [longitudinal]) was sawn from each disk (Fig 1). These strips were sawn in half radially to produce two edge-matched pieces 10 mm wide (tangential). One strip was used for evaluating extractives content, and the other was used to assess resistance to fungal attack.

Extractive Content Determination

The second radial sample was cut into blocks that were labeled from the pith outward in the case of heartwood and from the bark inward in sapwood. Therefore, the radial position of each individual block could be compared with the matched sample exposed to the decay fungi. The blocks were cut into matchstick-sized pieces and then further decreased in size using a Kleco 4100 Kenetic Pulverizer (Garcia Manufacturing, Visalia, CA). The resulting material passing a 40-mesh screen was collected and conditioned to constant weight. Samples of wood powder (≈1.0-1.7 g) were weighed and enclosed in heat-sealable polyester filter bags (mesh size 25 μm; ANKOM Technology, Macedon, NY) that were conditioned to constant weight. The bags were weighed, which allowed the bag weight to be subtracted from the wood weight. The bags were placed in a large beaker containing 1.5 L of the desired solvent and covered with aluminium foil to minimize solvent loss. The samples were first extracted for 24 h in ethanol–toluene (1:2 v/v) at room temperature. The samples were thoroughly rinsed with 95% ethanol before being placed in 1.5 L of ethanol for 24 h at 60°C. The samples were then drained, thoroughly rinsed with hot water, and then placed in a hot water bath for 24 h at 90°C. Finally, the samples were extracted in 1.5 L of toluene at 60°C for 6 h before being dried to a constant weight and weighed according to ASTM Standard D 1105 (ASTM 2011). Previous tests had shown that the mesh mass was not affected by the extraction procedures. As a result, mass at the end of the test (accounting for the mesh weight) was subtracted from the original wood weight to determine total extractives content on a wt/wt % extract-free basis.

The extractives content data were plotted and compared with the fungal weight losses data by position and fungus.

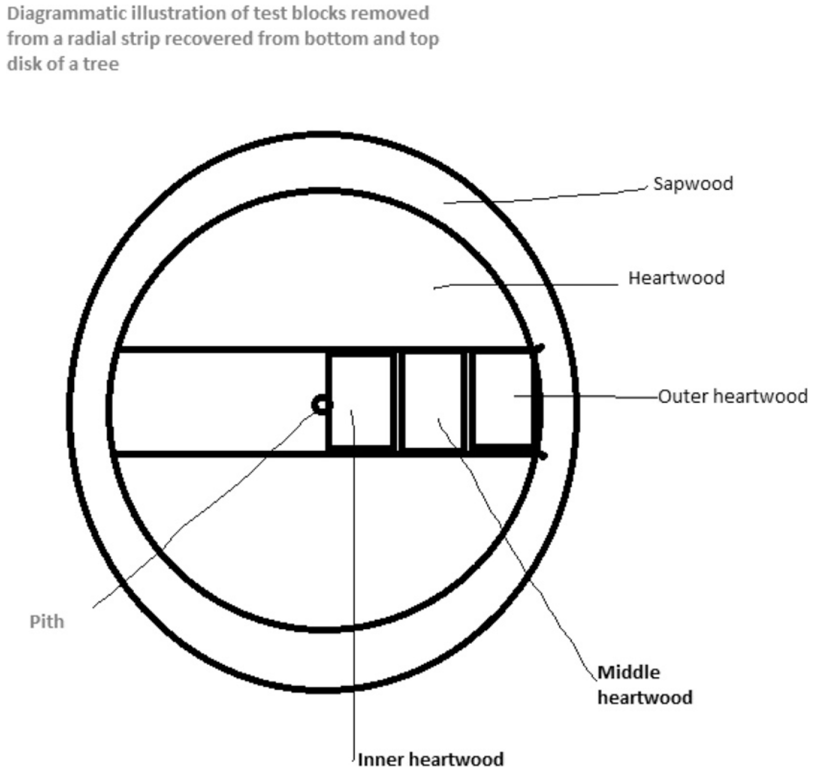

Figure 1. Cutting pattern for sampling blocks from Port Orford cedar log sections.

Decay Tests

A total of 262 edge-matched test blocks (20 × 10 × 20 mm [radial, tangential, longitudinal]) were cut at 20-mm increments from the pith to the outer heartwood. The number of edge-matched blocks recovered from each disk varied per tree from 3 pairs (for top disks) to 10 pairs (bottom disk) depending on the width of the heartwood. The number of blocks varied with tree diameter. The procedures followed those described in AWPA (2012), except for smaller test block dimensions. The blocks were oven-dried to constant weight at 50°C and then weighed prior to being sterilized by exposure to 2.5 mrad of ionizing radiation from a cobalt 60 source.

Decay chambers were prepared by half-filling 454-mL French squares with moisture forest loam and placing a western hemlock feeder strip on the soil surface. The bottles were then loosely capped and autoclaved for 45 min at 121°C.

After cooling, the bottles were inoculated with 2- to 3-mm-diameter malt agar disks cut from the actively growing edges of cultures of the test fungus. The fungi evaluated in this study were *Postia placenta* (Fr.) M. Larsen et Lombard (Madison 698) and *Gloeophyllum trabeum* (Pers. ex. Fr.) Murr. (Isolate Madison 617). *Postia placenta* was shown to be the most aggressive fungus on Port Orford cedar in previous tests (Morrell and Sexton 1987). The agar plugs were placed on the edges of the wood feeder strips, and then the jars were loosely capped (to allow air exchange) and incubated for 10-14 da until the feeder strip was thoroughly covered with fungal mycelium. The sterile test blocks were then placed, cross-section down, on the surfaces of the feeder strips, and the bottles were loosely capped and incubated at 28°C for 12 wk.

At the end of the incubation period, the blocks were removed, scraped clean of adhering mycelium, and weighed to determine wet weight. The blocks were then oven-dried (50°C) and weighed. The difference between initial and final oven-dry weight was used as a measure of the effect of fungal exposure.

RESULTS AND DISCUSSION

The sampled trees ranged in age from 15 to 38 yr, as represented by the number of growth rings in cross-sections of the bottom disk, and were 292-453 mm in diameter at the butt. This sample was selected at random from the log deck and could have originated from anywhere in the growing region. Thus, variations in growth rate and sapwood thickness would be consistent with the inherent variability among trees of the same species.

Extractive Content

The mean extractive content for the heartwood from the butt disk was 4.03% compared with 3.15% in the top disk; however, concentrations varied widely among trees (Table 1). Extractive levels might be expected to vary between tip and butt because the woods formed at different times and could potentially contain different amounts of stored carbon compounds that would be converted into extractives at the time of heartwood formation (Taylor et al 2007). Overall, average extractives levels tended to decline with distance from the pith in samples cut from the butts of the trees and declined and then rose abruptly in samples cut from the tip of the tree (Fig 2). This trend is the opposite of that seen in other species such as coast redwood (*Sequioa sempervirens*) or teak (*Tectona grandis*) (Sherrard and Kurth 1933; Rudman and DaCosta 1959) but

Table 1. Extractives content at selected distances outward from pith in cross-sections cut from tip and butt of 12 Port Orford cedar logs.

		Extractives content by position (% wt/wt)[a]												
Tree no.	Tip/butt	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm	18 cm	20 cm	22 cm	24 cm	Avg.
1	Butt	4.8	4.6	4.6	3.9	4.1	6.7	5.3	4.4	4.4	2.5	4.7	2.5	4.38 (1.13)
2		5.6	4.0	3.7	4.1	3.7	4.6	3.8	2.1	2.8	2.9	—	—	3.73 (0.98)
3		4.9	3.0	4.1	3.4	2.9	3.2	2.3	3.2	—	—	—	—	3.38 (0.80)
4		3.5	3.3	5.9	3.2	3.0	3.2	3.1	2.6	3.3	—	—	—	3.46 (0.95)
5		4.3	4.1	4.2	3.4	5.3	4.2	3.9	6.7	1.8	4.6	—	—	4.25 (1.25)
6		3.9	2.1	4.6	4.6	4.3	4.8	5.4	4.6	2.5	2.0	—	—	3.88 (1.22)
7		4.3	3.9	4.0	4.3	3.0	4.4	2.9	2.6	—	3.2	—	—	3.62 (0.70)
8		4.0	4.4	4.0	4.8	3.2	3.7	4.3	3.8	3.2	2.7	—	—	3.81 (0.63)
9		4.2	3.4	4.0	7.7	7.7	7.2	4.0	3.0	3.6	—	—	—	4.98 (1.95)
10		4.5	5.0	4.2	4.6	4.8	7.0	8.0	6.3	3.5	3.7	3.1	—	4.95 (1.54)
11		7.7	9.3	7.6	2.7	4.5	1.9	2.5	—	—	—	—	—	5.17 (2.99)
12		2.6	2.8	3.9	3.0	4.0	3.1	1.9	2.0	2.4	—	—	—	2.86 (0.74)
Avg.		4.5	4.1	4.6	4.1	4.2	4.5	4.0	3.8	3.1	3.1	3.9	2.5	4.03 (0.72)
1	Tip	4.2	4.7	4.1	3.3	2.8	2.6	—	—	—	—	—	—	3.61 (0.84)
2		4.1	4.0	4.1	2.6	2.6	—	—	—	—	—	—	—	3.48 (0.80)
3		4.6	5.4	4.6	3.6	3.1	3.1	—	—	—	—	—	—	4.05 (0.93)
4		2.4	2.1	2.2	2.6	—	—	—	—	—	—	—	—	2.33 (0.22)
5		2.5	4.0	4.7	4.6	3.4	3.7	—	—	—	—	—	—	3.82 (0.82)
6		3.2	4.6	3.6	3.3	2.9	—	—	—	—	—	—	—	3.52 (0.65)
7		4.5	4.0	4.2	3.6	4.2	—	—	—	—	—	—	—	4.10 (0.33)
9		3.8	4.0	4.5	3.7	2.6	2.8	—	—	—	—	—	—	3.57 (0.73)
10		3.2	2.8	4.1	3.4	3.0	2.5	3.7	—	—	—	—	—	3.24 (0.54)
11		4.2	4.0	3.0	3.0	3.3	—	—	—	—	—	—	—	3.50 (0.57)
12		4.4	2.3	3.6	3.4	—	—	—	—	—	—	—	—	3.43 (0.87)
Avg.		3.7	3.8	3.9	3.4	3.1	2.9	3.7	—	—	—	—	—	3.15 (1.12)

[a] Values were rounded to 0.1% for convenience. Averages represent means of all samples extracted from a given tree. Figures in parentheses represent 1 standard deviation. Boxes with a hyphen signify no sample available for testing.

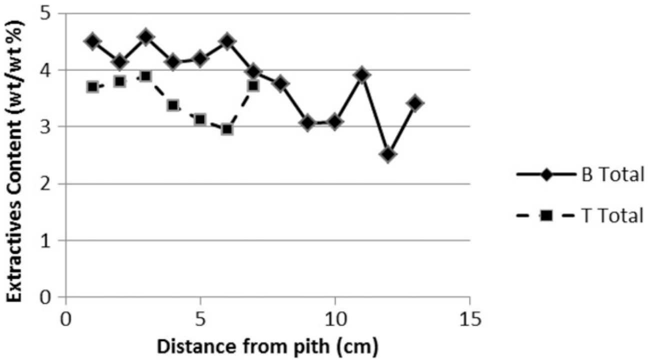

Figure 2. Extractives content with distance from pith of radial sections cut from tip and butts of 12 Port Orford cedar logs.

resembles the resin content distribution in the butt log in many coniferous species (Panshin and De Zeeuw 1970). It has been suggested that extractives content tends to increase from the pith to the sapwood as a result of the cambium maturing; however, no such trend was observed in this study (Taylor et al 2002). Extractive levels are generally correlated with increased heartwood durability for species that are naturally durable (Hawley et al 1924). McDaniel (1989) reported extractive levels in Port Orford cedar heartwood of approximately 5.2% (wt/wt) in samples subjected to sequential extractions in hexane, acetone, and acetone–hexane–water. These results were slightly higher than those found in this study. Clearly, small differences in levels of specific extractive components could have major effects on durability, but the large number of samples in this study precluded detailed analysis of every extract for specific compounds. Further tests to compare extractives content of old- and second-growth trees would be required to determine if the levels found in these samples were representative of the general population.

Decay Tests

Weight losses in blocks exposed to the two brown rot fungi also varied widely among individual samples, but there were several overall trends (Table 2). Weight losses tended to be much higher in blocks exposed to *P. placenta* than in those exposed to *G. trabeum*. This result is consistent with previous tests on Port Orford cedar (Morrell and Sexton 1987). The former species is a common inhabitant of the decomposition community in the Pacific Northwest and is often found in the heartwood of other species (Duncan and Lombard 1965). *G. trabeum* tends to be a more frequent colonizer of wood exposed

Table 2. Weight losses of blocks cut from selected distances from pith along radial sections cut from tips and butts of 12 different Port Orford cedar logs and evaluated in a soil block test.

	Wood weight loss (%)[a]			
	P. placenta		*G. trabeum*	
Distance from pith (cm)	Butt	Tip	Butt	Tip
2	35.3 (21.4)	27.0 (18.4)	14.6 (4.4)	15.0 (5.0)
4	38.2 (21.30	36.1 (22.6)	14.3 (3.0)	14.2 (3.9)
6	39.9 (24.1)	37.7 (20.7)	15.1 (4.2)	15.9 (3.7)
8	43.7 (21.9)	29.0 (16.5)	15.5 (3.2)	16.3 (4.9)
10	45.8 (22.6)	43.1 (21.5)	16.5 (4.7)	14.5 (2.5)
12	46.0 (19.6)	—	17.9 (4.8)	—
14	50.8 (14.2)	—	18.1 (6.0)	—
16	54.9 (2.0)	—	14.5 (4.3)	—
18	29.7 (38.9)	—	21.5	—

[a] Values represent means, whereas figures in parentheses represent 1 standard deviation. Hyphen denotes no samples from that location.

out of soil contact. Weight losses in blocks exposed to *P. placenta* tended to increase with distance from the pith, except for the very outermost samples. The overall trend is consistent with the decline in extractive levels observed in the adjacent samples. Weight losses were also slightly lower in samples cut from the tip of the tree and exposed to *P. placenta*, although the differences were slight. Weight losses also tended to vary somewhat among trees, but wood from most trees was highly susceptible to attack by *P. placenta* (Table 2). The scale described in ASTM 2017 (ASTM 2001) for assessing natural durability states that woods are considered highly resistant to decay when weight losses are below 10% and are considered resistant when weight losses are between 11 and 24%. Only one tree had heartwood that would be classified as resistant to decay based on the *P. placenta* results, whereas all would be classified as resistant to *G. trabeum* (Table 3). Extractives content in the one tree that was resistant to *P. placenta* was similar to that found in the other trees exposed to this fungus. Interestingly, weight losses for wood taken from the tip of two trees and exposed to *P. placenta* would be considered resistant to decay, although the number of replicates tested was small. The heartwood samples tested in these experiments would be considered moderately resistant to *P. placenta*.

Relationship between Extractives and Weight Loss

Although extractives content is generally correlated with resistance to fungal attack in naturally durable species, plots of individual results for fungal-associated weight loss and extractive content were poorly correlated for both fungi (r^2 of 0.0068 and 0.00104 for *P. placenta* and *G. trabeum*, respectively) (Fig 3). It would be interesting to further quantify the levels of specific extractive compounds to determine if there was a better relationship between these compounds and decay resistance.

The generally limited decay resistance of Port Orford cedar was perplexing given its performance in previous field tests in which this species produced results similar to Alaska cedar and western redcedar (Morrell et al 1999). However, the results were similar to those found with this species in previous exposures to *P. placenta*. The results illustrate the difficulty in assigning durability ratings using laboratory tests because of the potential for selected fungi to be tolerant of the heartwood extractives. In this instance, the tolerance of *P. placenta* is important because this fungus is frequently reported in decaying building components and, therefore, might be more important in terms of performance. It might also suggest that Port Orford cedar would perform best in aboveground

Table 3. Weight losses of blocks cut from butt and tip sections of 12 Port Orford cedar logs and exposed to either *G. trabeum* or *P. placenta* in soil block test.[a]

	Butt section weight loss (%)			Tip section weight loss (%)		
Tree	Repetitions	*P. placenta*	*G. trabeum*	Repetitions	*P. placenta*	*G. trabeum*
1	7	41.5 (27.2)	13.3 (1.5)	3	11.1 (17.3)	15.3 (1.7)
2	7	50.4 (4.7)	17.1 (5.3)	3	13.6 (2.1)	24.9 (24.2)
3	6	59.4 (3.6)	18.5 (4.3)	3	28.3 (2.2)	12.8 (2.3)
4	5	39.5 (20.7)	12.5 (3.9)	3	55.4 (1.4)	11.9 (0.2)
5	8	55.8 (5.8)	15.5 (3.7)	3	37.2 (18.7)	27.3 (11.6)
6	8	53.2 (8.8)	17.4 (5.7)	5	24.8 (10.6)	9.4 (2.3)
7	7	49.2 (19.2)	17.2 (3.7)	4	36.3 (25.3)	12.3 (2.3)
8	9	35.4 (19.0)	19.2 (5.4)	—	—	
9	7	58.9 (4.8)	18.6 (3.5)	5	45.7 (18.7)	17.7 (2.1)
10	9	11.7 (19.5)	10.2 (3.0)	5	21.8 (17.3)	14.8 (3.4)
11	5	29.6 (25.5)	15.3 (3.7)	3	58.8 (5.7)	18.6 (1.8)
12	7	28.0 (20.1)	16.5 (6.0)	3	54.4 (7.4)	15.8 (5.8)

[a] Values represent means, whereas figures in parentheses represent 1 standard deviation. Hyphen denotes no samples from that location.

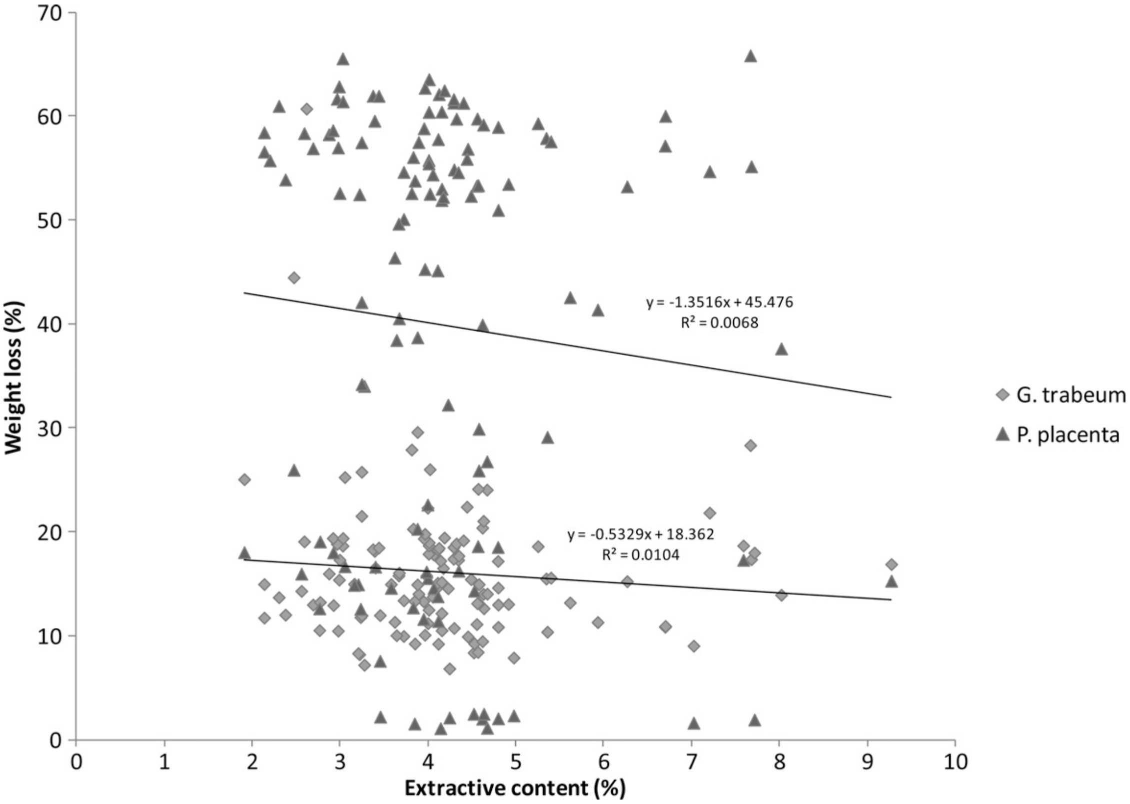

Figure 3. Weight losses of Port Orford cedar heartwood blocks exposed to *P. placenta* or *G. trabeum* vs extractives content showing the poor correlation between decay resistance and durability for the material studied.

applications in which the risk of fungal attack is much lower.

CONCLUSIONS

The Port Orford cedar evaluated in this study was classified as resistant to attack by *G. trabeum* but only moderately resistant to attack by *P. placenta*. These results suggest that the second growth of this species merits further study to better understand the implications of second growth on overall reputation for the durability of this species.

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