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SEED MATURITY IN WHITE FIR AND RED FIR

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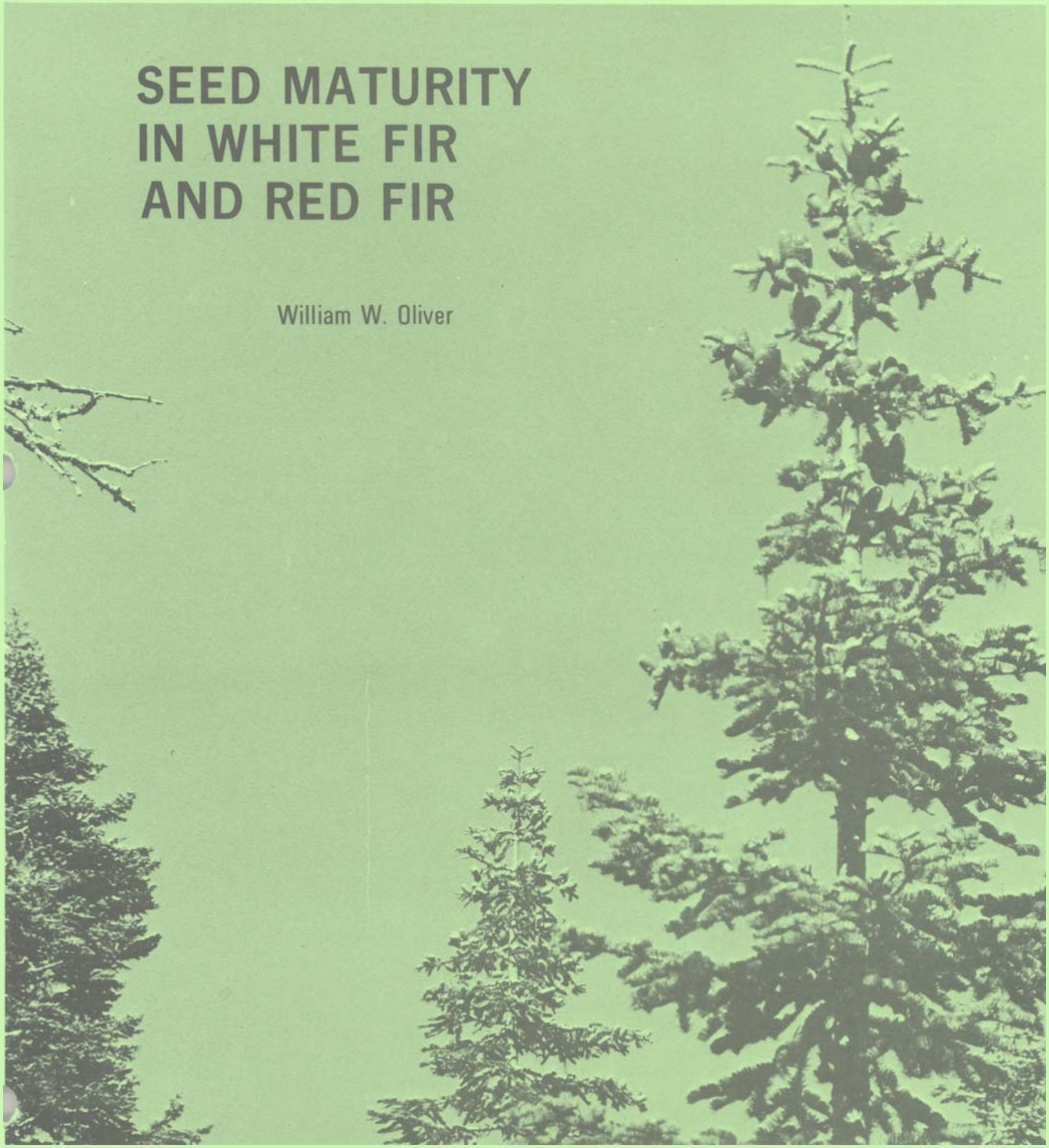

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SUMMARY

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Oxford: 232.218:232.312.1 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].
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Low viability of white fir and red fir seeds often is the result of collecting immature seeds. Seed handlers need to know when acceptable seed viability is reached in the maturing cone. For this they need easily measured cone and seed characteristics that indicate this point has been reached. In this study, several cone and seed characteristics were evaluated as maturity indices for white and red fir. A limited test of artificially ripening white fir cones was also made.

Cones from six white fir and eight red fir trees on the west slope of the southern Cascade Range in northern California were collected biweekly in 1967. Collections began on August 15 and ended October 9–3 days before seed fall began. Cone specific gravity and several other cone and seed characteristics were measured for each collection, and seed germination was tested on both freshly harvested and stratified seeds.

White fir and red fir cone specific gravities were similar in pattern. Both held nearly constant until mid-September, but then dropped rapidly until seed fall began on October 12. In contrast, white fir and red fir seed germinability exhibited different patterns. There was little difference in pattern, however, between freshly harvested and stratified seeds of the same species. No seeds of either species germinated from cones collected in mid-August. White fir seed germinability increased rapidly in collections made up to mid-September and then tended to level off. Red fir seed germinability, however, tended to increase steadily for collections made up to the beginning of seed fall. In both firs, stratifying seeds affected germination capacity very little, but increased germination rate profoundly.

In 1968, biweekly cone collections were repeated in red fir and the vigor of red fir seedlings from stratified seed was tested. Both ovendry weight and proportion of healthy seedlings increased significantly until mid-September, and then nonsignificantly until seed fall began on October 8.

A limited test of artificially ripening white fir seeds was successful. Cones collected in mid-September–4 weeks before seed fall–and stored in a cool, moist environment for 4 weeks yielded seed which germinated as completely and speedily as stratified seeds from mature cones. This result supports the observation by others that maturation of seeds of many true firs can be completed independently of the tree. Storing immature white fir cones 2 weeks beyond beginning of seed fall boosted both speed and completeness of germination beyond that of stratified seeds from mature cones. This suggests that white fir requires some after-ripening for maximum germinability.

Many cone and seed characteristics were observed in an attempt to find a simple, effective index of cone and seed ripeness. Specific gravity was significantly correlated with nearly all measures of seed germination in both firs. Results indicate that white fir cones can be collected when cones average about 0.96 specific gravity–a point reached about 3½ weeks before seed fall began. A firm recommendation is more difficult to make for collecting red fir cones. Unlike that of white fir, red fir seed germinability continued to increase up to the beginning of seed fall. Nevertheless, we may conclude that red fir cones should not be picked if their average specific gravity exceeds 0.75–reached about 2 weeks before seed fall began in this study. To obtain a reliable estimate of average cone specific gravity at least three cones from each of four trees should be measured.

A method combining several seed characteristics seems more direct and simpler than using cone specific gravity as an index of seed maturity. White and red fir cones should be ready for harvest when

1. Seed wings are uniformly brown with a deep magenta edge.
2. Seeds are free or only loosely attached to cone scale.
3. Embryos are uniformly pale yellow-green.
4. Embryos entirely fill embryo cavities.

The ratio of embryo length to the length of the embryo cavity was the single most useful index of seed maturity found. Future studies should aim towards verifying this characteristic as a seed maturity index for all conifers.

The demand for white fir *(Abies concolor* Gord. & Glend.*)* and red fir *(A. magnifica* A. Murr*)* seeds increases each year in response to increasing demands for planting stock. Often, forest nurseries cannot fill all requests for true fir seedlings.

Low viability of the seed is a major problem. Lanquist (1946) concluded that the relatively low germination he found in these two species probably was the result of seed immaturity. He warned that germinative capacity of seed is so vitally affected by time of cone harvest that this time must be selected with extreme care, especially when cones are collected on logging operations or on any down trees. To help solve this problem, forestry research must determine when acceptable seed viability is reached in the maturing cone, and find some easily measured characteristics of the cone or seed that indicate this point.

This paper explores the usefulness of cone specific gravity and several other cone and seed characteristics as maturity indices of white and red fir seeds, and reports a limited test of artificial ripening of white fir cones.

METHODS

Seeds tested in 1967 came from six white and eight red fir trees in a mixed stand at 6,000 feet elevation on the Latour State Forest. The Forest lies on the west slope of the Cascade Range, 37 miles east of Redding, California. The trees were vigorous, full-crowned specimens ranging from 48 to 92 years of age and from 14 to 28 inches d.b.h.

At least four cones were collected at random from each tree. Five biweekly collections began on August 15 for red fir and on August 17 for white fir. The last collection was on October 9 for both species–3 days before seed fall began.

In 1968, some tests were repeated on red fir because five of the eight sample trees had good repeat cone crops. Four nearby trees of similar size and age with abundant cones were selected for additional sampling. This time cones were collected at four biweekly intervals beginning on August 23 and ending September 30–8 days before red fir began casting seed.

At each collection, cones of each species were sealed in plastic bags immediately, and specific gravity was determined within 24 hours by the weight displacement method. The cones were grouped, then, into specific gravity classes, using an interval of 0.04 for white fir and 0.05 for red fir.

Testing Fresh Seeds

Germinability of freshly-harvested seed should measure its physiological maturity at time of collection. Therefore, at each collection (1967) half the cones in each specific gravity class were broken open, and the seeds were removed by hand. All insect-infested, broken, and aborted seeds were discarded; only seeds that appeared sound were kept for testing. Germination testing was begun within 24 hours of collection on four 100-seed samples of each specific gravity class. The seeds were kept moist during extraction and cleaning to prevent the possibility of inducing dormancy through drying of the seed coat (Kozlowski 1971). The samples were placed on a moist medium of two parts vermiculite and three parts sand in petri dishes placed in a darkened room held at 24 degrees C. for 100 days.

At the end of the 100-day germination period for each collection date, I attempted to determine the number of filled seeds in the ungerminated remainder. But many seeds had been destroyed by molds during the long germination test, and distinguishing between originally filled and empty seeds was difficult. Therefore, germination results are presented as a proportion of all seeds used in the test. Germination of stratified seeds is reported similarly to aid in comparing results.

Testing Stratified Seeds

Germination testing of fresh seeds may measure physiological maturity at time of cone collection but results do not represent the germination that can be expected in practice, because fresh seeds are not usually planted. Therefore, the remaining half of the cones of each specific gravity class at each collection were processed by methods similar to those used by commercial nurseries. Soon after specific gravity was determined, the fresh cones were spread on open racks in a well-ventilated room held at 24 degrees C. until the cones from all collections were completely dry. The cones were broken by tumbling, cone scales removed, seeds dewinged, and all apparently unsound seeds discarded. Four 100-seed samples from each specific gravity class collected on each collection date were stratified for 4 weeks at 2 degrees C. Following stratification, germination was tested by the methods used for fresh seeds, except that this test ran for only 30 days.

Seedling Vigor Tests

Germination is only the first step in producing a healthy seedling. Many hazards which can be lethal to seedlings with poor vigor must be overcome in the first few months. Red fir seedling vigor was tested in 1968 as follows: As seeds germinated in the germination test they were planted in flats containing two parts vermiculite and three parts sand. Planting was arranged in four randomized blocks with each block containing seed taken from one petri dish from each collection-date–specific-gravity class combination. The seedlings were grown in a greenhouse held at 25 degrees C. The test terminated 6 weeks after the end of the 30-day germination test. At the end of the test, seedlings were categorized as healthy, dead, or having the seed coat still adhering to the cotyledons (an indication of poor vigor). Healthy seedlings were carefully lifted from the flats, washed, and the ovendry weight determined.

Artificial Ripening Trial

Since true fir cones become fragile as they approach maturity, methods of artificially ripening seed from immature cones have been explored. Storing seed in cones placed in a cool, moist environment has increased germination of Douglas-fir *(Pseudotsuga menziesii* Mirb. Franco*)* (Silen 1958; Rediske 1961), noble fir *(Abies procera* Rehd.*)* (Rediske and Nicholson 1965; Edwards [1]) and grand fir *(A. grandis* [Dougl.] Lindl.*)* (Pfister 1966). Accordingly, in this study, the response of white fir and red fir cones to a similar treatment was tested.

Three additional cones from each sample tree were collected on August 17 and September 14 for white fir and on August 15 and September 12 for red fir. (Artificial ripening was not tested on the September 12 collection of red fir cones, however; these were found to be necessary to complete the seed maturity studies because of the low percentage of sound seed.) The cones were dipped in a water suspension of 50 percent Captan [2] and all, except the O week treatment, placed in individual, tightly-sealed plastic bags in a refrigerator at 10 degrees C. for the following time periods:

August 15 and 17 collections	*September 14 collection*
4 weeks	4 weeks
8 weeks	6 weeks

After each of the prescribed storage periods one cone from each tree was removed, the cones were air dried, seeds were removed and cleaned, and germination was tested for 30 days, duplicating the procedure described above for stratified seeds.

Other Observations

During hand extraction of seeds from fresh cones, five possible indices of seed maturity, other than cone specific gravity, were examined–seed wing color, firmness of attachment of the seeds to the cone scale, megagametophyte consistency, embryo color, and the ratio of embryo length to the length of the embryo cavity. Cone and seed wing colors were recorded by using Munsell (1952) color ratings. The firmness of attachment of the seeds to the cone scale was noted as firm, moderately firm, or loose. Megagametophyte consistency was recorded as milky or firm.

The ratio of embryo length to the length of the embryo cavity was measured on at least 50 filled seeds of each specific gravity class for each collection date. The seeds were broken open lengthwise and lengths were measured to the nearest 0.5 millimeter. The ratio of embryo length to the length of its cavity seems to be a better measure than embryo length alone because use of the ratio eliminates variability caused by differences in seed size. As the embryo was measured, morphological development and color of the cotyledons were noted.

[1] Edwards, David George Warrilow. *Investigations on the delayed germination of noble fir.* 1969. (Unpublished Ph.D. thesis on file at Univ. of Wash., Seattle, Wash.)

[2] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

RESULTS AND DISCUSSION

Cone Specific Gravity

In 1967, white fir and red fir cone specific gravities were similar in pattern *(fig. 1)*. The range for both species held almost constant in collections from mid-August through the end of the month. By mid-September average values had dropped slightly to 0.99 for white fir and 0.96 for red fir. The drop was not statistically significant, [3] however, until the end of September, when average values were 0.76 for white fir and 0.75 for red fir. On October 9, just 3 days before seed fall began, the average specific gravity had fallen to 0.57 for white fir and 0.60 for red fir.

In 1968, the pattern of red fir cone maturity was different. Average cone specific gravity had dropped significantly by the September 3 collection, nearly 3 weeks earlier than in 1967. Values continued to drop, but at a rate slightly lower than in 1967. By September 31, the average specific gravity of 0.66 was nearly identical to that of the year before at the same date.

[3] Differences between means exist at the 5 percent level of probability.

In both years, the between-tree variation in cone specific gravity in sample trees of each species was narrow until the values dropped significantly. While average specific gravity was dropping rapidly, the range in values widened. As cones reached their minimum values at the beginning of seed fall, the range tended to narrow again. Analyses of variance indicated that the pattern of decreasing cone specific gravity differed between trees.

Seed Germination, by Collection Date

Fresh Seeds

None of the seeds of either species collected in mid-August germinated, nor were any seeds living at the conclusion of the 100-day germination test. Fourteen percent of the white fir seeds in the late August collection germinated *(table 1)*. Seed collected in mid-September showed a further significant increase in germination, this time to 30 percent. Germination remained at this level for the succeeding collections.

Red fir seed germinated in a slightly different pattern *(table 1)*. Germination increased steadily to 11

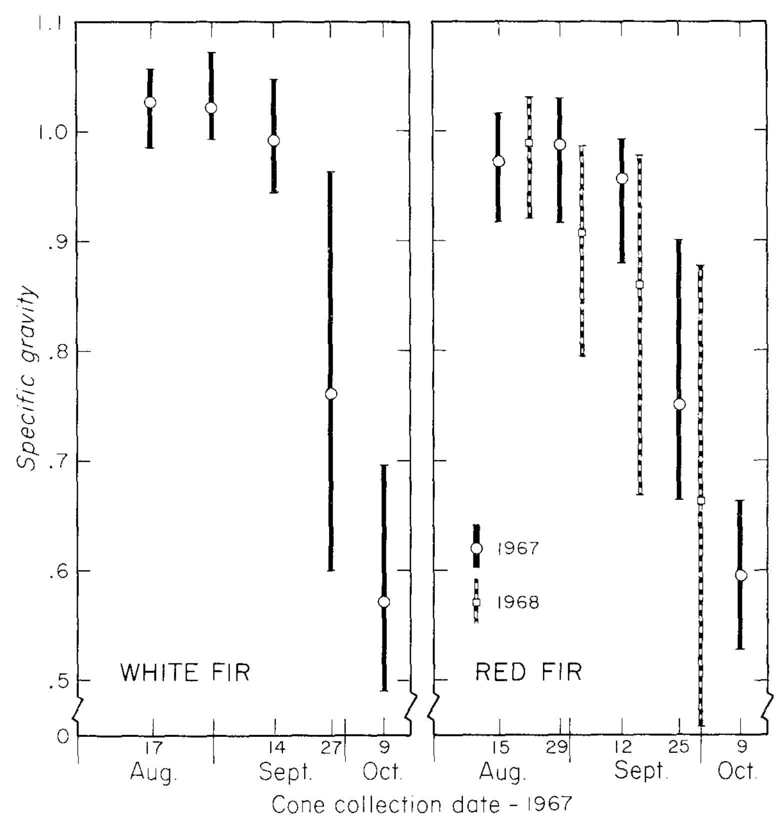

Figure 1–Cone specific gravity decreases rapidly as beginning of seed fall approaches.

Table 1–*Germination of both fresh and stratified seeds of white and red fir by collection date, 1967*[1]

Collection date	Fresh seed		Stratified seed	
	Total germination	Peak germination	Total germination	Peak germination
	Pct	*Days*	*Pct.*	*Days*
WHITE FIR				
August 17	0		0	–
August 31	14	68	17	8
September 14	30	54	26	11
September 27	33	52	36	9
October 9	31	52	39	8
RED FIR				
August 15	-	-	0	-
August 29	6	86	5	10
September 12	11	82	8	18
September 25	10	68	20	18
October 9	19	58	17	8

[1] Means not significantly different at 5 percent level are bracketed.

percent for the mid-September collection, remained at this level for the late September collection, then jumped to 19 percent for seed collected just before seed fall began. Variation in the data was high, however, preventing these differences from being statistically significant.

For seedling production, germination rate (the time required for germination) is as important as percent germination. In some situations, such as direct seeding, it is more important. The measure used here is the number of days required to reach peak germination. Peak germination is the maximum value found by dividing the cumulative germination percent on any one day by the number of days required to reach this percent. It differs from the measure proposed by Czabator (1962) in that percent germination is based on the total seeds used in the test rather than on filled seeds only.

Germination of fresh seeds was sluggish for all collections. In white fir, peak germination was not reached until the 68th day for the late August collection. The mid-September collection took 54 days to reach its peak value, a significant decrease. Germination rate, like percent germination, did not improve in later collections.

Again, the peak germination pattern differed in red fir. Peak germination was reached on the 86th day for the late August collection, and remained about constant through the mid-September collection. Peak germination for the late September collection was reached in 68 days, a significant decrease. It decreased again, but nonsignificantly, in the early October collection.

Stratified Seeds

Germination of stratified seeds of both species followed the general pattern for fresh seeds. Again, no seeds germinated from cones collected in mid-August. Germination from white fir cones collected in late August was 17 percent. It increased steadily with each succeeding collection date until it reached 39 percent for the early October collection. High variance within collections prevented these means from being significantly different, however.

Red fir seed germination was tested both in 1967 and in 1968. In both years, germination tended to increase with increasing cone maturity up to late September. But, in both years, the variation within collections was so great that except for the mid-August collection in 1967, collection means were not significantly different.

After mid-August, germination rate was unaffected by date of cone collection. Stratified white fir seeds took about 9 days to reach peak germination. Red fir took 14 days in 1967 and 26 days in 1968 to reach peak germination.

Stratification had little effect on germinative capacity. Results were similar to those for fresh seeds of each collection. The capacity of white fir (U.S. Forest Service 1948) and red fir seeds [4] to germinate fairly well without stratification has been reported previously. Nevertheless, fresh seed germination was higher than expected considering that these seeds had been tested for 100 days, a time period that led to

[4]See footnote 1.

more severe problems with mold than were encountered in the 30-day test.

It is likely that greater mortality from mold in the fresh seed test was offset by continued maturation and subsequent germination of the fresh seeds in the germination medium. Krugman (1966) hypothesized that maturation of sugar pine seed consists of two distinct periods: First, an early period in which the cones continue to provide organic materials necessary for seed maturity; and second, a period of continued maturation (often confused with "after ripening") after the accumulation of organic materials has been completed. Krugman concluded that during this second period the cone is not needed. Extracted seed will mature if simply stored in a moist medium.

Rediske and Nicholson (1965) reached a conclusion similar to Krugman's from their work on noble fir, except that they were uncertain whether the cone was necessary, not having tested extracted seeds. Stratified seeds were obtained from cones allowed to air dry. Maturation ceased when the cone dried, eliminating the second maturation period and cutting short the first period in earlier collections. Tests of neither fresh nor stratified seeds accurately measured physiological maturity at time of collection, but the stratified seed test may have been the more accurate of the two.

In the present study, in contrast to its lack of influence on percent germination, stratification had a pronounced effect on germination rate. Peak germination of stratified seeds was reached 47 days earlier in white fir and 60 days earlier in red fir than it was in the corresponding fresh seed tests. The pattern prominent in fresh seed (greater germination rate for seed samples whose collection dates approach the beginning of seed fall) was not seen in stratified seed.

It is difficult to explain why germination rates in stratified seed tests did not show this pattern. The study design may have been partly responsible. The seeds in all collections for stratified seed tests were cleaned at the same time. Thus, the cone (and seed) drying period was shorter for cones collected on dates closer to the beginning of seed fall. This may have resulted in elimination of more seeds of poor vigor from the earlier collections than from the later ones. Such low-vigor seeds would be expected to germinate sluggishly, and their absence may have affected the data pattern.

Seed Germination and Cone Specific Gravity

The correlation of seed germination with cone specific gravity was examined in the data according to specific gravity classes. The relation of germinative capacity to cone specific gravity was distinctly different in the two species, but similar in fresh and stratified seeds of the same species. Germination percentages for both fresh and stratified white fir seeds rose rapidly to about 30 percent, whereas cone specific gravity values dropped to 0.96. Germination of fresh seeds remained near 30 percent whereas corresponding cone specific gravities dropped further. Germination of stratified seeds, however, tended to increase gradually to about 45 percent for seed samples representing the lightest specific gravities *(fig. 2).*

Germinative capacity of red fir was linearly related to cone specific gravity. The relationship was nearly identical for fresh and stratified seeds. Germination

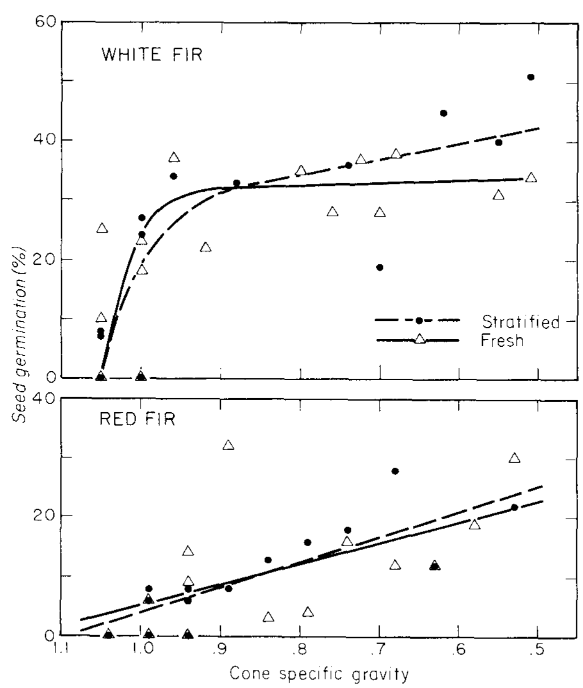

Figure 2–The relation between germinative capacity and cone specific gravity differed in the two species. In white fir, germinative capacity increased rapidly for successive classes of specific gravity, then tended to level off. In red fir, germinative capacity increased gradually.

Table 2–*Correlation coefficients of seed germination for both fresh and stratified seeds on cone specific gravity*

Species	Fresh seeds		Stratified seeds	
	Total germination	Days to peak germination	Total germination	Days to peak germination
White fir	0.66**	0.64*	0.79**	0.55*
Red fir	.57*	.84**	.84**	.40

* Statistically significant at 5 percent level.

** Statistically significant at 1 percent level.

values rose gradually to about 25 percent for both fresh and stratified seeds from cones with the lightest specific gravities *(fig. 2).*

Required time to peak germination, like germinative capacity, was curvilinearly related to cone specific gravity in white fir and linearly related in red fir. The absolute values and curve shapes for rate were different, however, from those for capacity.

In white fir, germination rate for both fresh and stratified seeds rose rapidly to the point where cones reached a specific gravity of about 0.96, and then leveled off for lower cone specific gravities *(fig. 3).* Values for fresh white fir seeds leveled off at about 50 days; for stratified seeds, at about 9 days.

Time to peak germination for fresh red fir seeds steadily shortened from more than 90 days at cone specific gravity of 1.00 to 52 days for seeds in cones with specific gravities of 0.53. For stratified seeds, it dropped from 22 days to 10 days throughout the same range of cone specific gravities *(fig. 3).*

Over-all, when comparing both fresh and stratified seeds, I found little difference between species in the ability of cone specific gravity to predict seed germination *(table 2).* But for stratified seeds only, cone specific gravity seems to predict germination rate of white fir slightly better than it does red fir. Information for stratified seed is the more relevant because in planting operations, seeds are routinely stratified.

For stratified seeds of both firs, cone specific gravity predicted germinative capacity much better than it did germination rate. The weak correlation between cone specific gravity and germination rate may be an

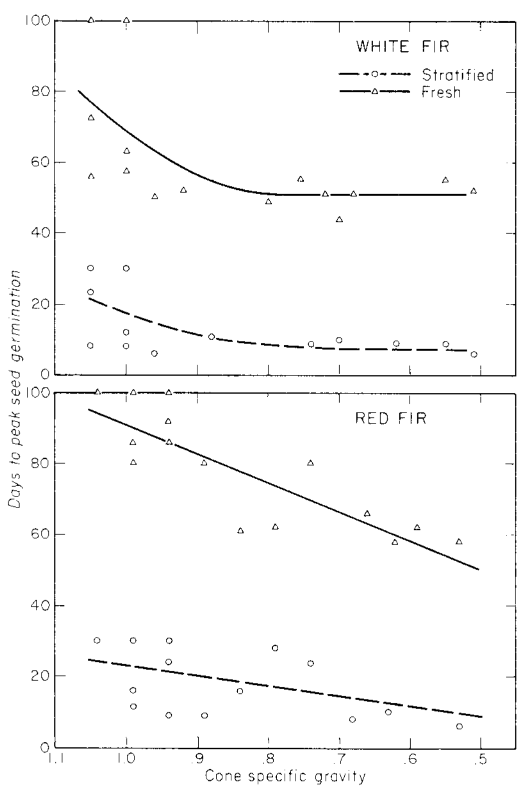

Figure 3 – The relation of time required for peak germination also differed between species. In white fir, the time dropped, then leveled off. In red fir, time decreased steadily throughout the range of specific gravity encountered.

artifact of the study procedure, as discussed previously.

Multiple regression analyses showed that seed collection date was a better predictor of seed germination than was cone specific gravity. For practical purposes, then, prediction of seed fall would be helpful. During a 4-year period, Cram and Worden (1957) found date of white spruce *(Picea glauca* [Moench] Voss*)* seed fall to be closely related to date of pollen shed. Using this kind of information requires, however, a degree of advance planning often not possible. And as Krugman (1966) points out, collection dates can be a less valuable indicator than cone specific gravity because of the variation in rate of seed maturation among localities, among trees, and even among individual cones on the same tree.

Red Fir Seedling Vigor

A higher proportion of healthy seedlings and larger seedlings was produced by seeds from cones collected closer to seed fall (October 8, 1968), as follows:

	Healthy seedlings [5]	
	(Dry weight/ 100 gm.)	*(Proportion pct.)*
Seed collection date:		
August 22	0	0
September 3	2.47	55
September 16	3.26	83
September 30	3.70	86

Both the proportion of healthy seedlings and their ovendry weights were significantly correlated with cone specific gravity. Cone specific gravity contributed 43 percent of the variation in proportion of vigorous seedlings and 38 percent of the variation in their ovendry weight.

Artificial Ripening of White Fir Seeds

None of the seeds from cones of either species collected in mid-August and subjected to four artificial ripening treatments germinated, nor were any seeds living at the end of the test.

Seeds from cones collected on September 14 germinated. The longer the artificial ripening treatment, the greater the percent germination and the greater the germination rate of white fir seeds, as follows:

[5] Means not significantly different at 5 percent level are bracketed.

Length of ripening treatment	*Total germination (pct.)*	*Time to peak germination* [6] *(days)*
0 weeks	31	12
4 weeks	38	7
6 weeks	47	4

In this test, cones collected in mid-September–4 weeks before seed fall began–and stored in a cool, moist environment for 4 weeks yielded seed which germinated as completely and speedily as stratified seed from mature cones. This result agrees with the observation of Rediske and Nicholson (1965) that the maturity of seed, when stored in cones in a cool, moist environment, seems to be associated with calendar date rather than with maturity at time of collection. By early September–nearly 5 weeks before seed fall began–the seeds apparently had reached the second period of the maturing process in which maturation can be completed independently of the tree (and possibly independently of the cone). This stage corresponds to the beginning of the rapid drop in cone specific gravity. Furthermore, the maturation rate of the seeds in the detached cones was the same as that of the seeds in the cones left on the trees even though their environments were radically different.

Two weeks of additional storage in cones boosted both total and peak germination for the artificially ripened seeds above that of stratified seeds from mature cones. This suggests that white fir requires some after-ripening for maximum germinability. Probably no more than 2 weeks of after-ripening is required. Seeds from cones stored 6 weeks (2 weeks beyond date when seed fall began) germinated more completely and in less time than any of the seeds tested by Lanquist (1946).

Other Maturity Indices

Many cone and seed characteristics were noted, but no single effective index of cone and seed ripeness was discovered.

Cone Characteristics

By the end of August the white fir cones had reached their mature size and were yellow-green in color. Munsell color varied from 7.5GY 8/8 to 2.5GY 8/6. The cones remained yellow-green through mid-September before turning straw-colored by the end of

[6] Means not significantly different at 5 percent level are bracketed.

the month. At the last collection–October 9– the cones were mature, and ranged in color from a dull greyish-yellow to a bright yellow-brown (5Y 6/4 to 7.5YR 7/8).

The red fir cones had reached their mature size by the time of the first collection in mid-August. In later collections the cones had shrunk in size slightly from curing. In mid-August the red fir cones ranged in color from bright yellow-green to yellowish olive (2.5GY 7/6 to 5Y 6/8). Changes in color were subtle until late September when the cones ranged from greenish yellow to bright yellow-brown (5Y 7/6 to 7.5YR 6/8). At the beginning of seed fall all cones were bright yellow-brown.

Cone color varied mostly with collection date, but specific gravity had some effect. At each collection, cones in the lighter specific gravity classes tended to be yellower or browner than cones in the heavier classes. Nevertheless, the variation between trees was too great and color descriptions too difficult to make cone color an effective index of maturity. Many investigators have reached a similar conclusion (Finnis 1950; Maki 1940).

Seed Characteristics

At the first collection in mid-August, seeds of both species were firmly attached to their cone scales, the megagametophyte had a milky consistency, and the embryo was transparent and difficult to see *(table 3)*. The color of the seed wings of both species was dark red (2.5R 4/10). By late August, the seed wings had turned magenta (5RP 5/6 to 4/12) and a brown streak appeared on the wings of the white fir seeds. The embryo in both species had lengthened noticeably, also, then occupying over half the length of its cavity in the megagametophyte. Red fir embryos, though still mostly transparent, were tinged with yellow on the cotyledons.

By mid-September, white fir seed wings had turned mostly brown except for the outer edge which remained deep magenta. Brown streaks appeared on many red fir seed wings, especially those in the lighter specific gravity classes. By then the megagametophytes of both species had firm consistency, and white fir embryos had a yellow tinge. The embryo in both species had grown rapidly, occupying nearly the entire cavity.

In late September, 2 weeks before seed fall began, seeds of both species were only loosely attached to their cone scales. The entire embryo was pale yellow-green and filled its cavity entirely. The seed wings were brown, edged with deep magenta.

Little change was noted in the last collection except that seeds were free of their scales.

Like the cone characteristics, these seed characteristics varied both with collection date and specific gravity, but collection date had greater influence.

APPLICATION

For both white fir and red fir, seeds collected later in the season germinated faster than those collected earlier. And more seeds in the later collections germinated than those in the earlier ones. Red fir seeds collected closer to seed fall also produced heavier and healthier seedlings. White fir seeds matured rapidly until cones reached an average specific gravity of about 0.96–about 3½ weeks before seed fall began in this study. Germination and seed characteristics changed little thereafter. Therefore, little loss of seed quality will result from collecting white fir cones with a specific gravity of 0.96 or less.

Red fir seed, on the other hand, tended to mature at a constant rate throughout the range of cone specific gravity. As a result, a firm specific gravity recommendation for cone collection is more difficult to make for red fir. Nevertheless, from the results of this study it seems that seed collected from cones with a specific gravity more than 0.75—the value reached about 2 weeks before seed fall began in 1967–will be of poor quality.

The differing patterns of seed maturity can be important to the seed harvester. White fir cones can be collected within 3½ weeks of seed fall with only a negligible loss of seed quality. Red fir cones, on the other hand, should be picked as close to beginning of seed fall as possible, since the later the picking the better the seed quality. Proper timing in the collection of red fir cones is especially important because even mature seed is often of poor quality.

Seed maturity patterns have been reported for grand fir (Pfister 1967) and noble fir (Rediske and Nicholson 1965; Franklin 1965; Edwards [7]). Even though grand fir is closely related taxonomically to white fir and, similarly, noble fir to red fir, the pat-

[7] See footnote 1.

Table 3–*Sequence of changes in white and red fir seed characteristics observed in collections from mid-August to just before the beginning of seed fall (October 12)*

Collection date	Seed wing color	Cone scale attachment	Megagametophyte consistency	Embryo color	Ratio of embryo length to cavity length	Germination of stratified seeds
					Percent	*Percent*
			WHITE FIR			
August 17	Dark red	Firm	Milky	Transparent	–	0
August 31	Deep magenta with brown streak	Firm	Milky	Transparent	54	17
September 14	Mostly brown with deep magenta edge	Firm to loose	Firm	Yellow tinge	96	26
September 27	Brown with deep magenta edge	Loose	Firm	Pale yellow-green	100	36
October 9	Brown with deep magenta edge	Free	Firm	Pale yellow-green	100	39
			RED FIR			
August 15	Dark red	Firm	Milky	Transparent	–	0
August 29	Deep magenta	Firm	Milky	Yellow tinge	59	5
September 12	Deep magenta with brown streak	Firm to loose	Firm	Pale yellow-green	98	8
September 25	Mostly brown with deep magenta edge	Loose	Firm	Pale yellow-green	96	20
October 9	Mostly brown with deep magenta edge	Free	Firm	Pale yellow-green	99	17

terns of seed maturity in grand and noble fir did not show the same contrasts evident between white and red fir. Grand fir germination increased steadily up to seed fall; noble fir germination leveled off prior to seed fall.

Fortunately, harvesting white fir cones within 4 weeks of seed fall and artificially ripening the seeds appears possible. Seeds thus treated may be of better quality than those harvested from mature cones if artificial ripening extends 2 weeks beyond beginning of seed fall. This artificial ripening treatment was not attempted for red fir cones. Probably it would be successful, however, as a similar treatment has been successful for noble fir (Edwards [8]; Rediske and Nicholson 1965), grand fir (Pfister 1966), and Douglas-fir (Rediske 1961; Silen 1958).

The artificial ripening treatment used here–refrigerated storage in individual bags–may not be practical for commercial operators. But storing cones in burlap sacks outside in the shade can be successful if the climate is cool. This was the artificial ripening treatment given noble fir, grand fir, and Douglas-fir cones. The major problem mentioned by all investigators is the deleterious effect of mold, which can be controlled only by keeping the sacks well ventilated.

These recommendations must be considered tentative because they are based solely on seed for immediate germination. Most seed is stored for several years, but little is known about the storing qualities of artificially ripened seed.

Cone specific gravity can be an index of seed maturity. But the variation among trees and among cones on the same tree is large, especially when the cones are actively drying–the stage when specific gravity normally would be determined. Results of sampling in this study indicate that at least three cones from each of four trees should be measured to obtain a reliable estimate of cone specific gravity.

A prediction method combining several seed characteristics seems more direct and simpler than measuring cone specific gravity. Taken individually, most seed characteristics examined in this study were little better than cone specific gravity as predictors. Several characteristics taken together, however, seem to offer an easy and effective index of seed maturity. White fir and red fir cones should be ready for harvest when

1. Seed wings are uniformly brown with a deep magenta edge.

[8] See footnote 1.

2. Seeds are free or only loosely attached to cone scale.
3. Embryos are uniformly pale yellow-green.
4. Embryos entirely fill embryo cavities.

Several of these seed characteristics have been recommended as indices of seed maturity for other species. Seedwing color and cone scale attachment are suggested as maturity indices for grand fir (Pfister 1967).

The ratio of embryo length to cavity length was the single most useful index of seed maturity found. It is a logical morphological characteristic easily seen and quantified in the field, and variation within a collection was lower than that of any other characteristic observed. At the earliest recommended collection time for white fir–3½ weeks before seed fall begins–94 percent of the embryos entirely filled their cavities. For red fir the earliest collection time is 2 weeks before seed fall begins. At that time 84 percent of the embryos entirely filled their cavities. Embryo length has been recommended as an index for Douglas-fir (Finnis 1950; Ching and Ching 1962). It seems probable that the embryo length/cavity length ratio would be an effective index for all conifers. Future studies should aim towards verifying and quantifying this characteristic as a seed maturity index for other conifers.

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1974. **Seed maturity in white fir and red fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-99)

White fir and red fir seed collected over a 2-month period in northern California was tested for germination of fresh and stratified seed. Ratio of embryo length to embryo cavity length was found to be the most useful index of seed maturity for white and red fir. Cone specific gravity also was correlated with nearly all measures of seed germination. Data suggest that red fir cones should be collected as close to beginning of seed fall as possible. White fir cones should be collected within 3½ weeks of seed fall. White fir cones collected 4 weeks before seed fall can be artificially ripened, however. These cones yielded seed which germinated as completely and speedily as stratified seed from mature cones.

Oxford: 232.218:232.312.1 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].
Retrieval Terms: Abies concolor; Abies magnifica; germination tests; cone collection; Latour State Forest; California.

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