CONE AND SEED INSECTS IN DOUGLAS-FIR, *PSEUDOTSUGA MENZIESII* (MIRB.) FRANCO, SEED ORCHARDS IN THE WESTERN UNITED STATES: DISTRIBUTION AND RELATIVE IMPACT

T.D. SCHOWALTER

Department of Entomology, Oregon State University, Corvallis, Oregon, USA 97331

M.I. HAVERTY and T.W. KOERBER

U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA 94701

Abstract

Can. Ent. 117: 1223–1230 (1985)

Douglas-fir cones were collected from 17 seed orchards in California, Oregon, and Washington in the fall of 1983. Cones were completely dissected and seed losses ascribed to the Douglas-fir cone gall midge (*Contarinia oregonensis* (Foote)), the Douglas-fir seed chalcid (*Megastigmus spermotrophus* (Wachtl)), the Douglas-fir cone moth (*Barbara colfaxiana* (Kearfott)), and the fir coneworm (*Dioryctria abietivorella* (Groté)). There appear to be great differences between orchards, but overall *C. oregonensis* and *M. spermotrophus* collectively destroyed approximately 70% of the filled seed. Physiographic province significantly ($P<0.05$) explained variation in damage by all insect species between seed orchards. In general, damage by all species increased from northern provinces to southern mountainous provinces. Damage by *C. oregonensis* and *B. colfaxiana* appeared to be related to land use or management factors, as well.

Résumé

En automne de l'année 1983, des cônes de sapins Douglas ont été receuilli de 17 graineteries en Californie, en Oregon et au Washington. Les cônes ont été complètement disséqué et les pertes de graines sont attribuées aux moucherons d'écorce des pins Douglas (*Contarinia oregonensis* (Foote)), aux guêpes grainières des pins Douglas (*Megastigmus spermotrophus* (Wachtl)), aux mites des cônes Douglas (*Barbara colfaxiana* (Kearfott)) et aux vers de cônes (*Dioryctria abietivorella* (Groté)). Des différences semblent exister d'une graineterie à une autre, mais au total *C. oregonensis* et *M. spermotrophus* ont détruit ensemble environ 70% de la graine pleine. La province physiographique expliqua avec signification la variation ($P<0{,}05$) des dégâsts causés par toutes les sortes d'insectes entre les diverses graineteries. En général, les dégâts causés par toutes les espèces augmentèrent des provinces nordiques aux provinces montagneuses du sud. Les dégâts causés par *C. oregonensis* et par *B. colfaxiana* paraissent aussi être liés à l'utilisation de la terre ou aux facteurs administratifs.

Introduction

As reforestation efforts and demand for genetically superior seed increase in the western United States, the need for information on factors influencing seed availability will increase. Insects are known to be capable of annually decimating seed crops in seed orchards, seed production areas, and natural stands. The most destructive species reported to affect Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seed production adversely west of the Cascades are the Douglas-fir cone gall midge (*Contarinia oregonensis* (Foote)), the Douglas-fir cone moth (*Barbara colfaxiana* (Kearfott)), the fir coneworm (*Dioryctria abietivorella* (Groté)), the western conifer seed bug (*Leptoglossus occidentalis* Heidemann), and the Douglas-fir seed chalcid (*Megastigmus spermotrophus* (Wachtl)). This insect complex frequently destroys over half of the Douglas-fir seed crop (Hedlin *et al.* 1981; Meso 1979).

Most available information on Douglas-fir cone and seed insect impact has been obtained from natural stands or seed production areas (Clark *et al.* 1963; DeMars 1964; Hedlin 1961, 1964; Johnson 1962; Johnson and Heikkenen 1958; Meso 1979; Volney

1984; but see Miller 1980, 1983). Furthermore, most previous studies have generally focused on individual insect species at specific sites. The study reported herein constitutes the first comprehensive survey of the impact of insects on cones and seeds in producing Douglas-fir seed orchards in the western United States. The objectives of this study were (1) to assess the severity of damage caused by each species of Douglas-fir cone and seed insect at each seed orchard, (2) to assess the geographic distribution of the various species, (3) to identify seed orchard site characteristics that may be related to differing levels of insect damage, and (4) to establish a basis for examining annual variation in seed loss. This information will be useful in identifying priority research and development needs for pest management in Douglas-fir seed orchards and may aid foresters in selecting seed orchard sites to minimize insect impact on seed crops.

Methods

Of the 46 Douglas-fir seed orchards in California, Oregon, and Washington (Anonymous 1982; Wheat and Bordelon 1980), only 17 produced a harvestable cone crop in 1983 (Fig. 1). We obtained in late August, 1983, at least 10 mature cones from each of at least 10 trees in 16 of these orchards, and 10 cones from each of the 4 cone-producing trees in the McDonald Seed Orchard. No attempt was made to make a statistically random sample. Our cone sample represented most or all of the cone-producing trees at each seed orchard. The data are confounded by orchard management practices. For example, 3 seed orchards (Mason, Rochester, and Schroeder) were treated with insecticides to control cone and seed insects, and the cones collected at South Sound were only from trees judged to have a collectable seed crop as determined in a preharvest sample of the number of filled seed exposed per half-cone (Dobbs *et al.* 1976).

Cones were identified by parent tree and orchard and air-dried in a greenhouse in Corvallis, Oregon. A random sample of 10 dried cones from each tree, from the above sample, was completely dissected, and each potential seed from all seed scales, except the 4–6 infertile scales at either end of the cone, was evaluated according to the following categories: seed aborted before development (i.e. flat or undeveloped), seed fused to the scale by gall tissue (*C. oregonensis*), seed at least partially consumed and pitch mixed with frass (*B. colfaxiana*), seed at least partially consumed and no pitch mixed with frass (*D. abietivorella*), and extractable seed. Extractable seeds from each tree were pooled and subsequently X-rayed, and the percentages of *M. spermotrophus*-infested seed, empty seed, seed with a partially destroyed embryo and/or endosperm, and filled seed were determined.

The mean number and percentage of seed per cone ± 95% confidence interval in each category and the percentage of extractable seeds ± 95% confidence interval in each category were used to assess the relative importance of each insect species at each seed orchard. Preliminary examination of the data suggested that site-related factors influenced seed losses attributable to each insect species. Differences between geographical and land use factors were tested by analysis of variance on arscine–square-root-transformed percentages.

Results

The average number of potential seed per cone over all 17 seed orchards was approximately 64 (Table 1). The fate of the potential seed varied considerably from orchard to orchard. In many places (Badger Hill, Beaver Creek, Rochester, and McDonald) more than 40% of the seeds failed to develop, possibly due to inadequate pollination (Table 1). In only 7 of the locations (Denny Ahl, Eola Hills, Research Center No. 2, Rochester, Schroeder, Sequim, and South Sound) did *C. oregonensis* gall less than 40% of the developed seed (Table 2). There were few cases (Mason, Mosby, and Sixes) where the Lepidoptera, *B. colfaxiana* and *D. abietivorella*, accounted for destruction of more than 20%

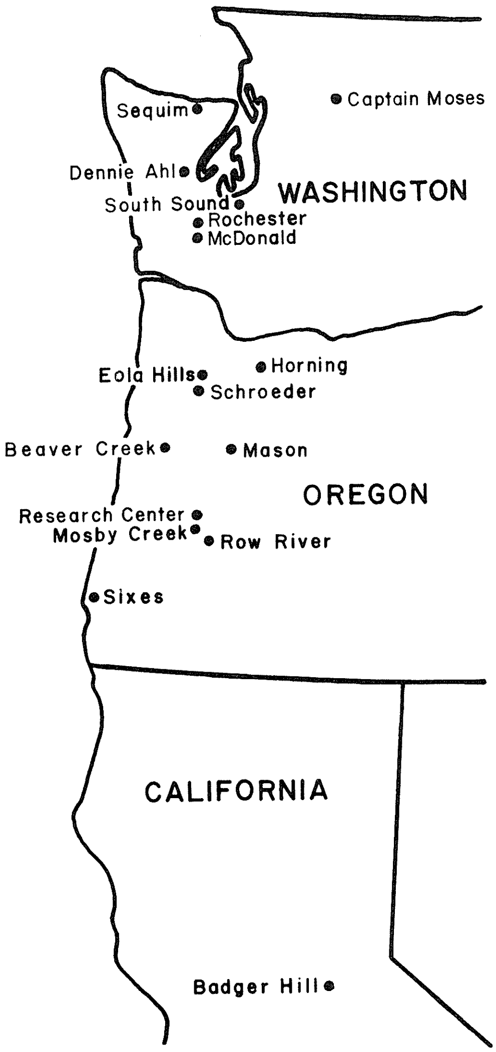

FIG. 1. Location of Douglas-fir seed orchards sampled for seed loss to insects in 1983.

of the developed seed (Table 2). In all seed orchards except Denny Ahl, over 40% of the extractable seed was unfilled (Table 3). Of the remaining extractable seed, *M. spermotrophus* infested, on the average, about the same percentage of the seeds (20%) as there were filled seeds (21%) in each cone (Table 3). Seeds with defective embryos or those apparently fed upon by *L. occidentalis* constitute a fairly small percentage of the extractable seed (Table 3), although some aborted seed (Table 1) may represent *L. occidentalis* damage. The cumulative effect of insects is clearly reflected in the number of filled seed per cone (number of extractable seed/cone times proportion of seed that are filled) (Table 3). Only a few seed orchards, for example Dennie Ahl, Eola Hills, and South Sound, had seed yields that would warrant harvesting of the crop unless the demand for seed was great (Table 3).

Significant differences in seed loss to insects were observed between physiographic provinces defined by Franklin and Dyrness (1973) (Table 1 and 4). Seed losses to all 4

Table 1. Site classification and number of potential seeds in Douglas-fir cones of 17 seed orchards in the western United States in 1983

Orchard*	Physiographic province†	Adjacent land use	Number aborted ovules‡	Number seeds destroyed by‡			Number extractable seed‡	Total number potential seed
				C. oregonensis	*B. colfaxiana*	*D. abietivorella*		
Badger Hill	Sierra Nevada	Forest	33.5 (6.8)	13.3 (6.5)	1.9 (1.9)	4.1 (2.7)	10.7 (8.8)	63.5
Beaver Creek	Coast Range	Forest	31.6 (5.8)	21.5 (7.2)	3.3 (1.8)	1.6 (1.4)	5.7 (2.1)	63.7
Capt. Moses	Northern Cascades	Forest	10.4 (4.2)	29.6 (7.3)	2.0 (1.0)	2.3 (0.8)	13.3 (5.0)	57.6
Danny Ahl	Olympic Peninsula	Forest	6.5 (2.0)	17.5 (5.9)	0.2 (0.3)	0.3 (0.4)	32.8 (8.4)	57.3
Eola Hills	Willamette Valley	Nonforest	23.1 (7.6)	6.1 (3.9)	1.3 (0.7)	0.6 (0.5)	39.7 (9.7)	70.8
Horning	Western Cascades	Forest	10.2 (4.3)	45.0 (10.3)	2.2 (2.3)	5.0 (1.9)	6.0 (3.6)	68.4
Mason	Western Cascades	Forest	9.3 (4.7)	35.7 (6.7)	6.2 (1.5)	7.6 (2.8)	3.3 (3.0)	62.1
McDonald	Coast Range	Forest	30.6 (19.8)	29.7 (20.8)	4.3 (1.0)	2.2 (1.7)	4.7 (4.5)	71.5
Mosby Creek	Western Cascades	Forest	23.6 (3.8)	24.0 (5.6)	4.7 (1.7)	5.7 (2.3)	6.8 (3.4)	64.8
Res. Ctr. 1	Willamette Valley	Nonforest	11.0 (3.8)	23.1 (8.3)	2.5 (1.5)	8.0 (4.3)	17.6 (7.7)	62.2
Res. Ctr. 2	Willamette Valley	Nonforest	20.6 (4.4)	12.6 (4.7)	2.0 (1.4)	3.9 (2.3)	22.7 (7.4)	61.8
Rochester	Puget Trough	Nonforest	37.6 (9.8)	8.9 (5.4)	0.3 (0.4)	0.1 (0.2)	14.3 (7.2)	61.2
Row River	Western Cascades	Forest	24.9 (4.8)	31.9 (5.8)	1.9 (0.9)	3.1 (1.8)	2.4 (1.7)	64.2
Schroeder	Willamette Valley	Nonforest	13.4 (5.5)	6.7 (3.7)	0.8 (1.3)	0.8 (0.7)	41.1 (7.3)	62.8
Sequim	Olympic Peninsula	Nonforest	7.5 (5.0)	6.2 (4.8)	0.1 (0.1)	0.2 (0.2)	53.1 (8.7)	67.1
Sixes	Coast Range	Forest	11.7 (4.4)	30.7 (9.3)	6.1 (3.4)	5.6 (2.1)	6.6 (4.2)	60.7
South Sound	Puget Trough	Nonforest	24.2 (3.1)	13.2 (2.8)	0.7 (1.1)	0.2 (0.4)	41.4 (3.3)	79.7
Overall means§			19.4	20.9	2.4	3.0	18.8	64.7

*Data derived from 10 cones from each of 10 trees except at Res. Ctr. 2 (11 trees), Mason (15 trees), and McDonald (4 trees).
†Defined by Franklin and Dyrness (1973).
‡Mean (95% confidence interval).
§Overall mean is simply the average of the mean numbers for the 17 seed orchards.

Table.2. Percentage of developed (non-aborted) seed destroyed by 3 species of insects or extractable* in Douglas-fir cones from 17 seed orchards

Orchard	Seed destroyed by *C. oregonensis*	*B. colfaxiana*	*D. abietivorella*	Extractable
Badger Hill	48.8 (19.7)	6.0 (6.7)	11.5 (5.7)	33.7 (17.5)
Beaver Cr.	64.0 (9.3)	10.0 (5.8)	4.0 (2.8)	22.0 (6.7)
Denny Ahl	34.4 (11.9)	0.6 (1.0)	0.5 (0.7)	64.5 (12.7)
Capt. Moses	61.8 (11.2)	4.2 (2.2)	4.8 (1.8)	29.2 (11.0)
Eola Hills	11.8 (6.9)	2.8 (2.0)	1.2 (0.9)	84.2 (8.1)
Horning	75.4 (10.7)	4.3 (4.6)	9.3 (3.8)	11.0 (7.4)
Mason	66.8 (9.0)	11.7 (2.9)	14.9 (6.3)	6.6 (8.0)
McDonald	70.4 (24.5)	10.5 (5.9)	4.2 (3.2)	14.9 (13.0)
Mosby	57.6 (6.0)	11.5 (4.3)	13.5 (4.9)	17.4 (9.1)
Res. Ctr. 1	43.7 (13.6)	4.8 (3.1)	15.6 (8.5)	35.9 (18.0)
Res. Ctr. 2	28.8 (10.4)	5.1 (3.8)	9.0 (5.8)	57.1 (18.0)
Rochester	17.7 (10.0)	0.6 (0.8)	0.2 (0.3)	81.5 (10.4)
Row River	80.1 (6.9)	5.4 (3.1)	6.7 (3.5)	7.8 (7.4)
Schroeder	11.2 (5.6)	1.5 (2.4)	1.3 (1.1)	86.0 (6.6)
Sequim	10.0 (7.5)	0.2 (0.3)	0.3 (0.4)	89.5 (7.4)
Sixes	61.6 (14.8)	13.3 (10.3)	11.1 (3.9)	14.0 (8.6)
South Sound	21.6 (4.4)	1.7 (2.4)	0.3 (0.5)	76.4 (5.4)
Overall mean†	45.0	5.5	6.4	43.0

*Mean (95% confidence interval). Aborted ovules not considered in the total.
†Overall mean is the average of the mean percentages for the 17 seed orchards.

Table 3. Percentage of extractable seed from Douglas-fir cones which were filled, unfilled, infested with *Megastigmus spermotrophus*, and projected number of extractable, filled seed from each of 17 seed orchards in the western United States

Orchard	Percentage of extractable seed* Filled	Unfilled†	*M. spermotrophus*	Other‡	No. of extractable filled seed per cone§
Badger Hill	10.0 (2.2)	64.9 (4.3)	19.2 (3.7)	5.9 (0.8)	1.1
Beaver Creek	15.8 (1.7)	46.9 (3.2)	33.7 (4.3)	3.6 (1.0)	0.9
Capt. Moses	27.4 (3.9)	54.7 (5.0)	2.5 (0.7)	15.4 (2.5)	3.6
Denny Ahl	67.6 (2.2)	24.2 (2.5)	5.7 (1.5)	2.5 (0.5)	22.2
Eola Hills	27.6 (2.8)	49.7 (3.3)	21.8 (2.8)	1.0 (0.2)	11.0
Horning	11.9 (3.8)	58.3 (7.2)	12.4 (2.9)	16.4 (6.9)	0.7
Mason	25.2 (5.2)	53.1 (6.5)	10.8 (2.8)	10.9 (5.8)	0.8
McDonald	7.8 (6.2)	53.7 (13.9)	38.5 (12.1)	0.0 (0.0)	0.4
Mosby Creek	12.2 (2.4)	51.0. (3.2)	34.4 (3.5)	2.4 (1.2)	0.8
Res. Ctr. 1	6.2 (1.2)	60.2 (3.3)	29.5 (3.7)	4.1 (1.2)	1.1
Res. Ctr. 2	10.1 (2.2)	62.8 (2.6)	25.0 (1.7)	2.1 (0.4)	2.3
Rochester	53.3 (3.8)	44.7 (4.0)	0.5 (0.2)	1.5 (0.3)	7.6
Row River	6.3 (2.4)	43.7 (4.5)	46.9 (5.3)	3.1 (1.4)	0.2
Schroeder	8.7 (1.9)	72.7 (3.8)	16.8 (3.4)	1.8 (0.3)	3.6
Sequim	11.6 (2.1)	85.5 (2.4)	2.4 (0.4)	0.5 (0.2)	6.2
Sixes	14.7 (3.7)	64.9 (4.3)	19.3 (4.1)	1.1 (0.5)	1.0
South Sound	32.8 (1.5)	53.3 (1.7)	11.7 (1.0)	3.2 (0.5)	13.6
Overall mean‖	20.5	55.6	19.5	4.4	4.5

*Mean percentage (95% confidence interval) based on percentages from each of 10 trees per seed orchard. Four trees only at McDonald, 11 at Res. Ctr. 2, 15 at Mason.
†No evidence of embryo or endosperm, yet seed coat is fully formed.
‡Seed obviously fed upon by western conifer seed bug or defective embryos.
§Number of extractable seed per cone × proportion filled.
‖Overall mean is the average of percentages from all 17 seed orchards.

Table 4. Percentage of developed Douglas-fir seed lost to insects in Douglas-fir seed orchards in physiographic provinces in California, Oregon, and Washington

Physiographic* province	N	*Contarinia oregonensis*† %	*Barbara colfaxiana*† %	*Dioryctria abietivorella*† %	*Megastigmus spermotrophus*† %
Olympic Peninsula	2	22.2 (17.3) a	0.4 (0.3) a	0.4 (0.1) ab	4.1 (2.3) ab
Puget Trough	2	19.7 (2.8) a	1.2 (0.8) ab	0.3 (0.1) a	6.1 (7.9) ab
Northern Cascades	1	61.8 b	4.2 bc	4.8 abc	2.5 a
Coast Range	3	65.3 (4.6) b	11.3 (1.8) d	6.4 (4.0) bc	30.5 (10.0) c
Willamette Valley	4	23.9 (15.5) a	3.6 (1.7) b	6.8 (6.9) bc	23.3 (5.4) c
Western Cascades	4	70.0 (9.9) b	8.2 (3.9) c	11.1 (3.8) c	26.1 (17.5) c
Sierra Nevada	1	48.8 b	6.0 c	11.5 c	19.2 bc

*Defined by Franklin and Dyrness (1973).
†Mean (standard deviation); means in the same column followed by the same letter do not differ at the 0.05 level by Duncan's new multiple range test on arcsin–square-root transformed data.

species were lowest in the Olympic Peninsula and Puget Trough. Highest seed losses were in the Coast Range and Western Cascades for *C. oregonensis*, *B. colfaxiana*, and *M. spermotrophus* and in the Western Cascades and Sierra Nevada for *D. abietivorella* (Table 4). These trends may be confounded to an unknown extent by land use or management factors. Seed losses to *C. oregonensis* and *B. colfaxiana* were significantly lower in the largely agricultural and intensively managed Puget Trough, Willamette Valley, and the coastal portion of the Olympic Peninsula surrounding Sequim, relative to the largely forested provinces ($F_{1,15}$ = 42 and 9.7, respectively). However, a 2 × 2 factorial analysis of variance including physiographic province and land use as main effects showed no difference at the 0.05 level for *C. oregonensis* and no land use effect at the 0.05 level for the other species.

We also examined the possibility that cone production in surrounding forests influenced cone and seed insect impact in seed orchards. Cone production data for natural stands and seed production areas in 1982 and 1983 showed no differences between physiographic provinces in either year (Erickson *et al.* 1982, 1983; California Department of Forestry unpubl. data).

We examined association between the species so that future studies can assess the importance of species interactions to seed losses in Douglas-fir seed orchards. Percentage seed losses to the 4 insect species were significantly ($P<0.05$) correlated (Table 5). *Contarinia oregonensis* activity was significantly and positively correlated with *B. colfaxiana*, *D. abietivorella*, and *M. spermotrophus* activities. *Barbara colfaxiana* activities were significantly and positively correlated with *D. abietivorella* and *M. spermotrophus*. Activities of *D. abietivorella* were not significantly correlated with *M. spermotrophus*.

Discussion

This study represents the first comprehensive survey of seed-destroying insects in Douglas-fir seed orchards in the United States. The Douglas-fir cone gall midge and the Douglas-fir seed chalcid were the major insect pests in 1983. The Douglas-fir cone gall midge trapped a considerable proportion of the developed seed in the cone by galling the seed coat to the cone scale. Although many of these galled seeds were empty, Johnson and Heikkenen (1958) and Miller (1983) found that galling apparently inhibits seed development. Seed chalcid larvae feed only on fertilized seeds. Over all of the orchards this insect destroyed nearly half of the filled seed (Table 3). Hence, the 2 species together destroyed about 70% of the filled seed. The Douglas-fir cone moth, the fir coneworm, and the western conifer seed bug accounted for the destruction of a relatively small proportion of the seeds, although it is possible some aborted seeds and unfilled seeds were the result of seed bug feeding.

Table 5. Correlation coefficient and significance level* for Douglas-fir seed losses to *Contarinia oregonensis, Barbara colfaxiana, Dioryctria abietivorella*, and *Megastigmus spermotrophus* in 17 seed orchards in the western United States

	C. oregonensis	*B. colfaxiana*	*D. abietivorella*
B. colfaxiana	0.70***		
D. abietivorella	0.57**	0.67***	
M. spermotrophus	0.48**	0.53**	0.36NS

*Correlation coefficient and significance levels: **≤0.05, ***≤0.01, NS = non-significant.

Site-related factors strongly influenced the importance of these insects. Important geographic differences in abundance were found for all 4 major species. The increasing importance of *C. oregonensis* from northern provinces to southern mountainous provinces in this study differs from (or may complement) earlier assertions of decreasing importance of this species from wet coastal areas to dry interior areas (Hedlin *et al.* 1981). A similar trend for *B. colfaxiana* within this region may also complement a general increase in importance of this species from coastal to inland areas (Hedlin *et al.* 1981). The increasing importances of *D. abietivorella* and *M. spermotrophus* from northern to southern provinces have not been reported previously.

Our results also suggested previously unreported relationships between insect activity and land use variables. The significantly higher seed losses to *C. oregonensis* and *B. colfaxiana* at seed orchards adjacent to forested land, compared with those surrounded by agricultural lands, appear to support the view that these species disperse into seed orchards from neighboring forests (Hedlin *et al.* 1981; Miller 1983; Ruth 1980; Schowalter 1984). However, this relationship is confounded by the fact that the seed orchards within agricultural zones are also generally younger and more intensively managed than are the orchards within forested zones. Further studies will be necessary to assess the relative importance of these variables for insect activity.

The strong associations between Douglas-fir cone- and seed-destroying insects and site-related factors identified in this study have important implications for seed orchard management. Although future studies will be necessary to evaluate factors influencing annual variation in insect activity, our results indicate that seed losses to insects generally increased from north to south and from agricultural to forested zones in 1983. These data can contribute to seed orchard management by indicating potential seed losses to insects at a given site and thereby facilitate insect population management and site selection for future seed orchards.

Acknowledgments

This research was supported jointly by the Oregon Agricultural Experiment Station (Paper No. 7330) and the U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station. We thank the many individuals associated with the U.S. Forest Service, the U.S. Bureau of Land Management, the Oregon State Forestry Department, Barringer and Associates, Boise Cascade Corp., Crown-Zellerbach Corp., Georgia-Pacific Corp., and the Weyerhaeuser Co. for providing cones used in this study. J. Martin provided cone crop data from 1982 and 1983 for California. We especially want to thank G.E. Miller, J.A. Schenk, R.R. Silen, and H.O. Yates III for critically reviewing the manuscript and the many people who had the dreadful task of dissecting the cones and manipulating the data.

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(Date received: 1985 02 20; date revision received: 1985 05 15; date accepted: 1985 05 16)