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Timothy D. Schowalter

The impact of various factors on seed production in a Douglas-fir (*Pseudotsuga menziesii*) seed orchard in western Oregon was examined by monitoring the fate of seeds in thirty cones, stratified into three crown levels, on each of ten trees during the 1984 growing season. Cones were examined monthly between April and September for mortality or evidence of insect damage. In September, a sample of mature cones was collected and completely dissected. Each seed was examined for extractability, insect damage, or unexplained abortion.

Abortion of immature cones was found to start early in the growing season and had a substantial impact on seed production. A newly discovered cone-feeding weevil (*Lepesoma lecontei*) caused a large proportion of this abortion. Unexplained cone abortion (possibly frost damage), empty and aborted seed, Douglas-fir cone gall midge (*Contarinia oregonensis*) and Douglas-fir seed chalcid (*Megastigmus spermotrophus*) were other major causes of seed loss. Crown stratification was found to be

important for an accurate estimate of the importance of these various seed loss factors.

A basis for an inventory-monitoring system for Douglas-fir seed production is suggested based on early monitoring of immature cones, identifying specific seed loss factors, stratified crown sampling, and an adequate sample size.

IMPACT OF INSECTS ON SEED PRODUCTION IN A DOUGLAS-FIR SEED ORCHARD IN OREGON

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Scott A. Dombrosky

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Redacted for Privacy

Chairman Department of Entomology

Redacted for Privacy

Dean of Graduate School

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IMPACT OF INSECTS ON SEED PRODUCTION IN A DOUGLAS-FIR SEED ORCHARD IN OREGON

INTRODUCTION

Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) is the most common coniferous tree species in the western halves of Oregon, Washington and British Columbia. This tree is highly prized for its growth form, quality wood and a relatively fast growth rate. Douglas-fir comprises 50% of all of the standing timber in the western United States and of a much higher percentage of timber in the coastal region. The range for Douglas-fir includes most of the western United States and Canada and parts of Mexico (Harlow and Harrar 1976).

Foresters have shown a strong preference for planting Douglas-fir in their reforestation efforts. They will often plant this species where it had not been grown previously--a tendency referred to as "Douglas-fir chauvinism". This, together with the large annual cut of *P. menziesii*, has caused a very high demand for Douglas-fir seed.

Originally, foresters would rely upon natural seeding for regeneration of forest stands. However, good seed crops are rare in this species, occurring only every two to seven years. Thus, competing vegetation would often get a better start and exclude Douglas-fir from the site.

Artificial regeneration techniques were developed to overcome the problems associated with natural seeding. Two artificial regeneration techniques were developed: direct seeding and the planting of seedlings. Direct seeding is the spreading of seed over a site, often from aircraft. It is a poor regeneration method in most areas due to stand stocking problems brought about by seed predators and inconsistent seed distribution. The most common regeneration technique in use today for Douglas-fir is the planting of seedlings at specific spacings.

Seed for the artificial regeneration of forest stands is obtained from four different sources--natural forest stands, individual trees of superior phenotypes, seed production areas, and seed orchards (Zobel and Talbert 1984). The greater the control exerted over the parentage of the resulting seed, the greater the potential genetic gain in the seed. In natural forest stands, cones are collected by the public or by contracted crews often without regard to the quality of the source tree. This leads to little or no genetic gain. Trees of superior phenotypes, also known as "plus" trees, are trees which are judged to be superior in quality in comparison to other trees in the stand. Seed collected from these trees will usually give a moderate amount of genetic gain. Seed production areas are small groups of trees judged to be superior in quality in comparison to other trees in the stand. Once identified, these areas are thinned of inferior trees and fertilized. Seed production areas will usually give genetic gain on a par with "plus" trees.

Seed Orchards

The greatest amount of genetic gain is obtained from seed collected in seed orchards. Seed orchards are plantations of trees of superior phenotypes or genotypes which are managed intensively for the mass production of seed of the greatest genetic gain in as little time as possible (Zobel and Talbert 1984). These orchards are established by collecting cuttings from trees of superior phenotypes and grafting them onto established root stock, or by making specific crosses from these superior trees and planting the resultant seed or grafting the resultant seedlings onto existing root stock. These orchards are often isolated from forest stands to reduce pollen contamination from unmanaged trees.

Large amounts of money are invested in the development and maintenance of seed orchards. Seed orchards are cultured for greater cone crops. Maintenance costs are incurred from fertilization, pruning, mowing, and pest control for insects, mammals, and weeds. Cone collection is often labor intensive, adding additional costs to the seed.

Progeny from the seed of these orchards are planted in forest plantations or nursery plots and observed to see if the desired traits have been transmitted. Parent trees that produce poor progeny are removed from the orchard--a process known as roguing.

The first seed orchards in the Pacific Northwest were established in the late 1950's and early 1960's. Very few orchards were established at first (less than 12). With the advent of more intensive forestry practices in the 1970's, interest in genetically superior trees increased, leading to an increase in the number of seed orchards. Today, there are 61 seed orchards with a total area of approximately 700 hectares (1700 acres), in the Pacific Northwest. Most of these orchards are partially or totally devoted to producing Douglas-fir seed. Ownership is about evenly divided between government and private industry. The United States Forest Service is the largest owner with 16 seed orchards (Wheat and Bordelon 1980).

Because of the high value placed on Douglas-fir seed, \$650-2200/Kg (\$300--\$1000/pound) depending on the genetic gain (W.K. Randall pers. comm.), its loss to any factor is of major concern to seed orchard managers. There are a number of insects which are known to destroy large amounts of Douglas-fir seed each year. These include 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)), the fir coneworm (*Dioryctria abietivorella* (Grote)), and the western conifer seed bug (*Leptoglossus occidentalis* Heidemann). Descriptions and life histories of the major seed and cone insects have been provided in several publications (Keen 1958, Furniss and Carolin 1977, Ruth 1980, Hedlin et al. 1981). Miller (1980) provided a summary of current knowledge and management techniques used in Douglas-fir seed orchards.

Cone and Seed Insects

Early work focused on the identification, biology, and habits of individual species (Hussey 1955, Hedlin 1960, 1961; Clark et al. 1963, Johnson 1963b, Koerber 1963a). The greatest effort was put into the study of chemical control of the various seed and cone insects, especially *C. oregonensis* (Hedlin 1962, 1964, 1966; Johnson 1962a, 1963a, 1963c, 1964; Koerber 1963b, Johnson and Rediske 1965, Buffam and Johnson 1966, Johnson and Meso 1966, Johnson and Zingg 1967). A few studies examined the impact of individual insect species on Douglas-fir seed losses (Radcliff 1952, Hussey 1956, Buffam and Johnson 1966, Krugman and Koerber 1969). These studies did not attempt to determine relative impact of various factors occurring at different times during the development of cones and seeds and did not evaluate the important cone mortality factors occurring before cones reach maturity.

Douglas-fir Reproductive Cycle

Because of the high degree of phenological synchrony between the host Douglas-fir and its insect pests, it is necessary to understand the Douglas-fir reproductive cycle. The reproductive cycle of Douglas-fir takes approximately 17 months to complete (Owens 1976) with some geographical and individual variation. The cycle begins in the spring of the first year with the initiation of potential reproductive buds within the current year's vegetative buds. As the vegetative buds burst and elongate, the reproductive buds develop and, by early summer, become distinguishable based upon characteristic structural differences. The reproductive buds remain dormant during the winter and early, the next spring, meiosis and pollen development occur. In April, the reproductive buds burst and "flowering" occurs. At this time the immature seed cones are in an upright position on the stem. Soon the scales open so that the conelet may receive pollen from the male (pollen) cones. After pollination, the scales close and the immature seed coness rotate into a pendant position. Fertilization soon occurs and the cones continue to enlarge until early summer. The seed embryos develop within the cones, maturing in late August. The cones shed their seeds throughout September.

Douglas-fir cone gall midge (Diptera:Cecidomyiidae)

The Douglas-fir cone gall midge is a dipteran in the family Cecidomyiidae. The range of this insect overlaps that of Douglas-fir. In the western coastal region, *C. oregonensis* is considered the major destroyer of Douglas-fir seed, sometimes damaging 50-70% of the seed crop (Buffam and Johnson 1966). Occasionally the figure may approach 100% of a seed crop in an orchard (Hedlin et al 1981). This insect causes seed loss by making the seed unextractable from the cone and by interfering with the fertilization of the seed.

Adult Douglas-fir cone gall midges emerge from silken cocoons in the litter layer in the early spring at the time when the cone scales open up to receive pollen. This allows the female midge to oviposit at the base of the scales within the cones. The eggs soon hatch and the larva begins to feed on the tissues within the cone scales, each larva forming its own chamber. The feeding behavior of the *C. oregonensis* larvae causes galls to form which usually will fuse to the seed coat (Johnson and Heikkenen 1958). This renders the seed virtually unextractable. Larvae continue to develop within the cones, going through three instars. In the fall, they drop to the litter layer below their host tree, where they overwinter in cocoons (Johnson

1962a, Pettinger and Johnson 1962). Pupation occurs in late winter and early spring, although some larvae may extend diapause for one or more years (Miller and Hedlin 1984).

Damage by _C. oregonensis_ is easily recognized. The galls are usually very prominent and the seeds difficult to remove from the scales. The most common methods for examining cones for cone gall midge damage are complete cone dissection or longitudinal slicing of cones.

Much of the recent interest in _C. oregonensis_ has focused on prediction of population levels. Miller et al. (1984) found that damage by the cone gall midge was significantly related to the cone crop size the year before, with more damage occurring in years following heavy cone crops. This study also found that fluctuations in the cone crop size seemed to limit cone insect populations. Miller and Hedlin (1984) found no relationship between cone crop size and induction of diapause of the cone gall midge. Miller (1984a) found that the most important factor affecting larval _C. oregonensis_ population densities was the number of eggs per cone, with a number of gall midge mortality factors reducing larval populations.

The reproductive behavior of _C. oregonensis_ was studied by Miller and Borden (1984). Emergence times and rates, mating behavior and ovipositional behavior were observed. They suggested that an oviposition deterrent may occur on infested cones. Evidence for the use of a sex pheromone by the cone gall midge was also obtained, corroborating an earlier study (Miller and Borden 1981). In another recent study, Schowalter (1984) found that the distance over which _C. oregonensis_ located cones on an isolated Douglas-fir tree was greater than the distance across many seed orchards.

The information gained from the above studies has obvious implications for monitoring and predicting gall midge populations. Prediction is essential to development of an integrated pest management program for cone and seed insects. A pest management system for _C. oregonensis_ has been developed in British Columbia (Miller 1984b). This system utilizes a process of sampling conelets to estimate the average number of gall midge eggs per conelet, based on a sequential sampling scheme, and uses chemical control measures if deemed necessary by the sampling. This pest management system is the only one currently in use for any seed and cone insect in the Pacific Northwest.

Douglas-fir Seed Chalcid (Hymenoptera:Torymidae)

The Douglas-fir seed chalcid is a small (3-4 mm) yellowish wasp of the family Torymidae. This insect is another major destroyer of Douglas-fir seed and frequently destroys between 2 and 15 percent of the seed crop (Hedlin et al. 1981). The wasp occurs throughout the range of Douglas-fir.

Adult Douglas-fir seed chalcids emerge from mid-April to late May at the time when the cones are beginning to turn pendant. Mated females oviposit by inserting their ovipositors through the cone scales into the seed below; usually only one egg is depositer per seed. The eggs hatch in just a few days. The larvae pass through five instars during which time they totally consume the contents of the seed. A sizable percentage of the population may diapause for an additional year or longer (Annila 1982).

Damage by this insect is very difficult to detect because the infected seed resembles a normal healthy seed. This has allowed this insect to be introduced around the world in shipments of Douglas-fir seed (Hussey 1954). To detect infestation, X-rays of the seeds may be made or seeds may be opened to reveal the insect within. Seeds which have been infested also are evident by clean-cut circular holes left by the emerging adults.

Fir coneworm (Lepidoptera:Pyralidae)

The fir coneworm is a pyralid moth with a range that includes the northeastern and western United States and most of Canada. D. abietivorella attacks most coniferous species, including Douglas-fir. The economic importance of this insect is not well established though it appears that substantial, but usually sporadic, losses of Douglas-fir seed occur due to the coneworm (Hedlin et al. 1981).

The life cycle of the coneworm is variable and not completely known. Part of the population may overwinter as eggs. After these eggs hatch, the larvae feed through spring to early summer and then pupate in cocoons on the ground from July to September. Adults emerge in late summer, mate and lay eggs. An alternative life cycle is for *D. abietivorella* to overwinter in cocoons as prepupae, pupate in the spring and emerge as adults in late spring. Eggs are then oviposited and the resultant larvae feed through the summer (Hedlin et al. 1981).

The larva feeds directly on the seeds. From the time of hatching until pupation, fir coneworm larvae chew their way through the cone, feeding upon everything in their path--seeds, scales and bracts. *D. abietivorella* also damages trees by infesting twigs and graft unions. Cones infested by this insect may be identified by an abundance of coarse dark frass and webbing on the outside. Cones may also be sliced longitudinally or dissected scale by scale to detect fir coneworm larvae or larval mines filled with its characteristic frass. Most of the current work on *D. abietivorella* involves developing monitoring methods utilizing sex pheromones.

Douglas-fir cone moth (Lepidoptera:Olethreutidae)

Another important lepidopterous pest of Douglas-fir seed is the Douglas-fir cone moth, a member of the family Olethreutidae. The range of the cone moth covers that of Douglas-fir. *B. colfaxiana* is a more persistent pest in the dry interior regions of the West but can cause large amounts of damage, although sporadically, in the coastal regions (Hedlin et al. 1981).

Cone moths overwinter within the cones as prepupae in pitch covered cocoons. Adult moths emerge at the time of pollination of the host trees. They fly primarily at night and lay their eggs singly on the cone bract. The larva begins feeding on the scale tissues, then moves on to the area around the cone axis where it feeds mainly on seeds (Nebeker 1977). The larva continues to feed until mid-summer at which time it pupates. The pupa may diapause for up to four additional years (Hedlin 1960, Hedlin et al. 1981).

Infestation by *B. colfaxiana* is often difficult to determine by external inspection, especially in large cones. Cones can be sliced longitudinally or dissected scale by scale to detect cone moth larvae or its characteristic frass which is fine grained, light in color and pitchy.

Currently, investigators are looking into the use of *B. colfaxiana* sex pheromones for population monitoring. While the existence of a sex attractant in female cone moths has been known for some time (Hedlin and Ruth 1968), isolation and field testing did not occur until recently (Weatherson et al. 1977, Hedlin et al. 1983).

Factors which influence cone moth populations from year to year, such as diapause and cone crop size, have also been studied within the last few years. Miller et al. (1984) found that the amount of cone moth damage was related to the previous year's crop size in the interior region, but not in the coastal region. Diapause was studied by Sahota et al. (1982, 1985) who reported pharate adult diapause and the morphological characteristics necessary to distinguish 1-year-diapause individuals from 2-year-diapause individuals. This distinction has an important pest management implication: the ability to estimate the population size coming out of diapause in a given year. Hedlin et al. (1982) reported that diapause was negatively correlated to cone crop size in the year after larval feeding. Hedlin et al. (1982) also found that two weather parameters (mean maximum temperature and mean daily temperature) were correlated to cone crop size while none were correlated to diapause induction.

Western conifer seed bug (Hemipera:Coreidae)

The western conifer seed bug may be another major destroyer of Douglas-fir seed. This insect is a member of the family Coreidae. The conifer seed bug will feed on the seed from almost all commercially important coniferous tree species. Its range includes most of western North America from British Columbia to Mexico and as far east as Nebraska. The economic importance of the conifer seed bug has yet to be determined, although studies have shown that the bug can cause considerable damage (Krugman and Koerber 1969, Hedlin et al. 1981).

L. occidentalis overwinter as adults in spots sheltered from the cold. In the early spring, as temperatures rise, the adults become active and begin feeding on male pollen cones, developing female conelets, and one year-old-cones. After mating the females lay eggs in rows along the bottom sides of needles. The eggs soon hatch and the nymphs begin feeding on the seeds within the developing cones. The nymphs pass through five instars before reaching maturity in the late summer. The adults continue to feed until cold weather causes them to take shelter for the winter (Koerber 1963a).

The western conifer seed bug feeds by positioning itself on the surface of a cone and inserting its stylets through the cone scales into the seed below.

Saliva is injected into the seed and the partially digested contents are then ingested. This feeding technique causes both mechanical damage from the action of the stylets and physiological damage from the saliva. Damage by this insect is difficult to detect. Seeds that are fed upon before the seed coat hardens shrivel to resemble naturally aborted seed, whereas seed fed upon after the seed coat hardens looks like normal seed. The most common method of detection is by X-ray examination to reveal characteristic damage patterns (Krugman and Koerber 1969). Very few studies concerning the conifer seed bug have been published. This is partially a result of the great difficulty in identifying *L. occidentalis* damage.

Pests of Immature Cones

Pests that cause conelet abortion in coastal Douglas-fir seed orchards are not well known. In the southern United States, insect induced conelet abortion has been shown to greatly reduce seed production (Debarr and Ebel 1974, Debarr and Kormanik 1975, Ebel and Yates 1974, Goyer and Nachod 1976). Two insect species are known to cause Douglas-fir conelet abortion by feeding on buds and young conelets. These are the western spruce budworm (*Choristenura occidentalis* Freeman) and a large weevil (*Lepesoma lecontei* (Casey)).

Western spruce budworm (Lepidoptera:Tortricidae)

Western spruce budworm is a lepidopteran of the family Tortricidae. This insect ranges across most of the western United States feeding on both Douglas-fir and true firs (*Abies* spp.). *C. occidentalis* is considered one of the most destructive defoliators in the west, and feeds primarily on buds and foliage. Western spruce budworm is one of the major factors causing conelet abortion and seed loss in the interior Douglas-fir region. Shearer (1984) found that *C. occidentalis* killed up to 5% of the potential Douglas-fir cones and as much as 16% of the seed in natural Douglas-fir stands in Montana. While this insect has been observed feeding in Douglas-fir cones in the coastal region, its impact on seed production has not been measured.

C. occidentalis overwinters as a first instar larva in silken shelters on the bark of trees. In the spring, the larvae begin feeding on buds, both vegetative and reproductive, and needles. Pupation occurs in early summer and emerging adults lay eggs in late summer. Larvae then hatch but do not feed before constructing their winter shelters.

The western spruce budworm feeds on cones by eating out broad holes on the surface of the cones and later continues to bore deeper into the cone eating all tissues in its path. Early season feeding by this insect can cause conelet abortion. Infestation by _C. occidentalis_ can usually be detected by large gouges in the surface of the cones or by the presence of the larvae. Much further study is needed to quantify the impact of this insect on potential seed loss.

Lepesoma Weevil (Coleoptera:Curculionidae)

Very little is known about the weevil _Lepesoma lecontei_. This is a large (~15 mm) mottled coppery-brown and gray beetle of the family Curculionidae. The life cycle of this insect is not known. The larva may be a root feeder like other members of this genus (Furniss and Carolin 1977). Adults are flightless and appear to be more abundant on the lower branches. These insects feed on the cones from the time they are still in the swelling buds until well after they turn pendant. They chew deep notches in the cones occasionally severing buds and young cones from the twig. Cones that survive this feeding are often misshapen and probably less productive. Schowalter (1986) found that this insect caused about 6% of the cones on seed orchard trees to abort. The importance of this insect varies within the coastal zone; as some seed orchards report high numbers of the weevils while others report none (Schowalter 1986).

Inventory-monitoring System

An inventory-monitoring system (IMS) is a management technique by which seed orchard seed production can be predicted and evaluated on a continuing basis. The techniques used were first developed for red pine (*Pinus resinosa* (Ait.)) and further modified and used in the southern pine seed orchards to offset poor seed production (Bramlett et al 1977). In such a system, a small percentage of the trees within the seed orchard is sampled to predict the total seed and cone potential for the orchard. This allows prediction of the amount of harvestable seed at cone maturity. Subsequent sampling through the summer can be used to evaluate seed orchard performance, providing a measure of the amount of seed loss and allowing for readjustment in predicted seed harvest (Bramlett 1984). The information gained from an IMS will permit more efficient seed orchard management.

Conventionally, IMS is broken down into four phases: cone efficiency, seed efficiency, extraction efficiency, and germination efficiency. Cone efficiency is the ratio of the number of healthy mature cones compared to the original number of flowers on the tree. Seed efficiency is the ratio of healthy filled seeds to the total number of seeds from healthy mature cones. Extraction efficiency is the percentage of the healthy seeds removed from the cones. Germination efficiency is the percentage of extracted seed which germinate in the nursery. Overall, these are considered the seed orchard to nursery efficiency (Bramlett and Godbee 1982).

Currently, IMS has been used extensively in the pine seed orchards of the southeastern United States but has recently been used in the seed orchards of the Pacific Northwest (Bartram et al. 1983). A recent survey of seed orchard managers (Overhulser et al. 1985) indicated a strong interest in developing IMS for this region. Bartram et al. (1983) quantified Douglas-fir seed orchard efficiencies in British Columbia for the first time. Biological and operational efficiency standards were also established for seed orchards in British Columbia.

Relative Importance of Cone and Seed Insects

Few studies have examined the relative importance of seed and cone insects. Volney (1984) studied the within-cone distribution of insects in a seed production area and found strong patterns of association between the cone gall midge and the cone moth. These two insects were distributed such that competition with the seed chalcid was reduced. Schowalter et al. (1985) studied the geographic distribution and impact of the various seed and cone insects. They found that the cone gall midge and the seed chalcid were the most destructive species overall, that damage varied significantly by physiographic provinces, and the damage by all species increased from the northern to southern provinces. These findings that relative seed loss to the insect complex varies geographically demonstrate the need for inventory monitoring as a basis for seed orchard pest management.

Shearer (1984) studied the effects of insects on Douglas-fir cone and seed production in four natural stands in Montana. This study differed from others in that the impact of insects on conelet abortion was measured in addition to loss of seed in mature cones. Shearer found that cone mortality substantially reduced the seed potential. Western spruce budworm was implicated in a substantial seed loss. Seed loss varied between years and locations but was a fairly large percentage of the total potential seed. Thus, monitoring damage to cones and seed from the conelet stage on is very important in illuminating the real impact of insects on total seed loss and in establishing a useful inventory monitoring system for Douglas-fir.

OBJECTIVES

The purpose of this study was to assess the relative impact of insects and other factors on seed production in a Douglas-fir seed orchard. Three objectives were identified:

(1) Measure the impact of various factors on cone abortion and test for differences in impacts among trees and crown strata.

(2) Measure the impact of various factors on seed loss at cone maturity and test for differences in impacts among trees and crown strata.

(3) Recommend an inventory monitoring system for management of Douglas-fir seed production.

PROCEDURES

The site for this study was the Beaver Creek Seed Orchard, located 10 kilometers south of Philomath, Oregon. This 20 ha facility is operated by the United States Forest Service. It is a clonal seed orchard that was initiated in 1966 for the purpose of producing Douglas-fir seed, with maximum genetic gain, for reforestation in the Oregon Coast Range.The orchard trees were 8-12 meters in height and 12-28 centimeters D.B.H.

Due to the cone crop failure predicted for 1984, the entire Beaver Creek Seed Orchard was surveyed, from ground level, in March, 1984, to identify cone producing trees. Of the approximately 2400 trees in the orchard, ninety had cone buds, and only 25 trees had the minimum of 50 buds considered necessary for this study. Trees with fewer than 50 cones usually are not harvested (W.K. Randall personal communication). From these trees, ten trees were randomly selected for study. Many of these trees were seriously stressed due to graft incompatability. Cone production on these trees may have been a response to this stress.

Because of differences found in the distribution of the cone gall midge and cone moth between crown strata (Kozak 1963) the crowns were divided vertically into thirds, and each stratum was sampled separately, as described by Miller (1984b). Initially, the number of whorls on each tree was counted and divided by three to determine the boundaries for each stratum. However, the lower boundary of the top third was generally established at about 7 meters because of limited access from 5 meter ladders. The boundary of the lower and middle strata was set accordingly at 4-5 meters, allowing for about 2 meters below the canopy.

The number of whorl branches was counted for each crown stratum. The number of cones was counted on six whorl branches in each stratum. Total cone potential for each tree was estimated at the "flowering" stage (April), the pendant stage (June) and at cone maturity (early September) by multiplying the average number of cones per whorl branch in each crown level by the number of whorl branches in that crown level and adding totals for the three strata together. Non-whorl branches were not used in this estimate. Winjum and Johnson (1964) found that fewer than 10% of the cones on a tree were produced on these branches.

Within each crown level, ten flowers were randomly selected in April and marked with a ribbon and subsequently observed at three to four week intervals throughout their development. Aborted, chewed or missing conelets were recorded.

In early September, the surviving cones were harvested and a sample of four cones per stratum per tree was dissected scale by scale. An account of each seed in each sampled cone was made by scoring seed as aborted, normal, or damaged by insects.

Total cone potential for the study trees was estimated as described above. This figure was then used to calculate total seed potential for each tree. The average cone potential was multiplied by the average number of seeds per cone for each stratum for each tree. Seed losses to different factors were then deducted based on average damage for each stratum and tree.

Percentage data were transformed using the arcsine square-root transformation to produce a more homogeneous variance for model I analysis of variance (ANOVA). Data were also analyzed using regression analysis, correlation analysis and analysis of covariance using a linear model. Differences were considered statistically significant at the α=0.05 level.

RESULTS

Considerable abortion occurred before cone maturation. Most of this abortion occurred from mid-April to mid-June (Figure 1). Average cone potential/branch declined 34% from 14.3 at flowering in mid-April to 9.2 in mid-June and 7.8 at maturity in September (Figure 1). The early decline was significant at the 0.01 level. Cone abortion from mid-June to September was not significant. Thus, the bulk of conelet abortion occurred in early to late spring with conelet numbers remaining fairly constant from late spring to cone maturity.

This substantial loss of immature seed cones between April and June is also reflected in the cone densities by crown strata (Figure 2). The differences in intercept between the regression lines shows that the largest difference in the number of cones/branch occurs between April and June. Again, little change is seen in cone population between June and September.

Both the highest number of cones/branch and the highest percentage of immature seed cones aborted were in the bottom strata while the lowest percentage of conelet abortion occurred in the upper crown stratum (Figure 2). The rate of cone loss was significant and was constant among crown levels.

The numbers of immature seed cones and the abortion

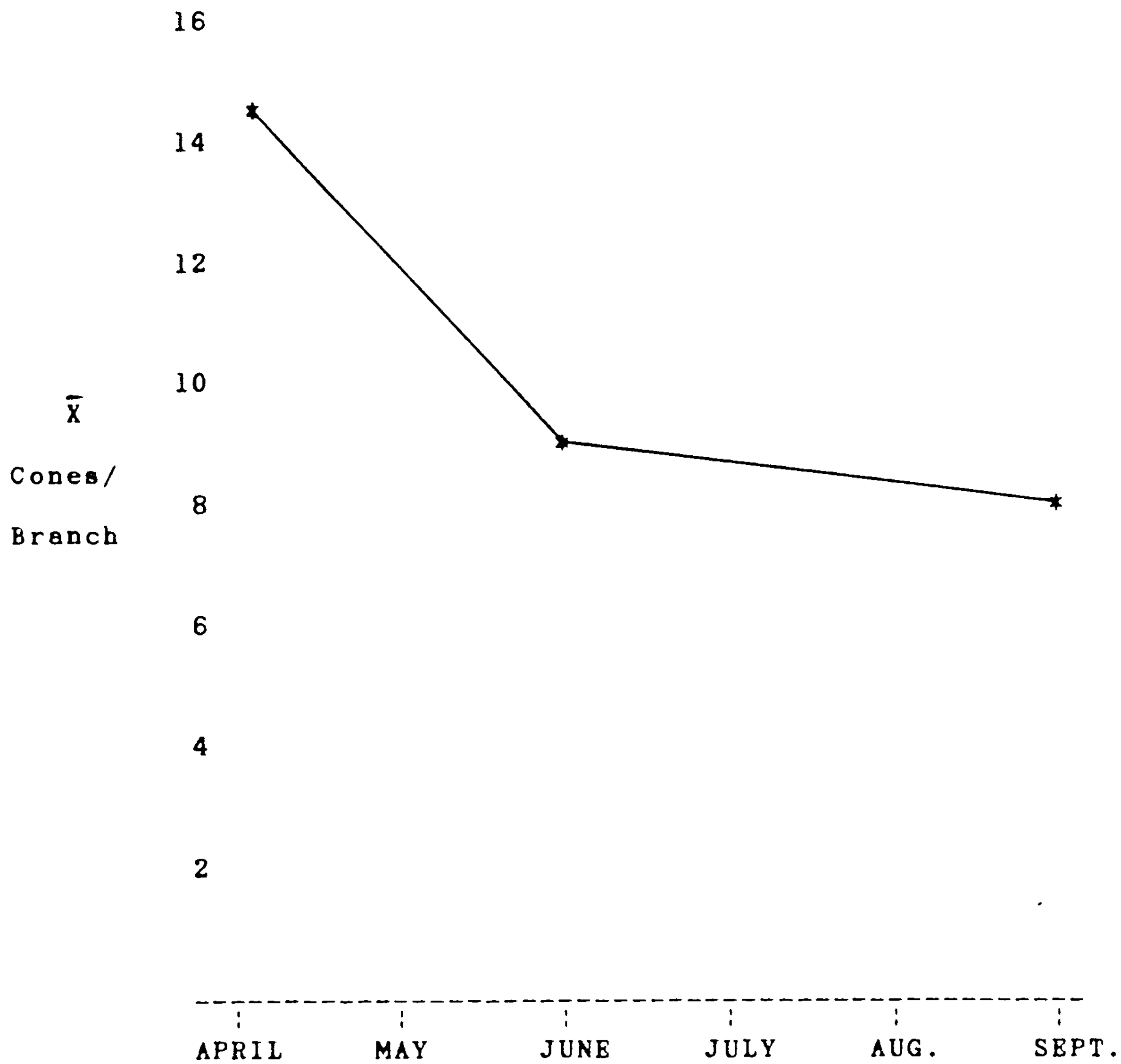

Figure 1: Cone population densities during growing season.

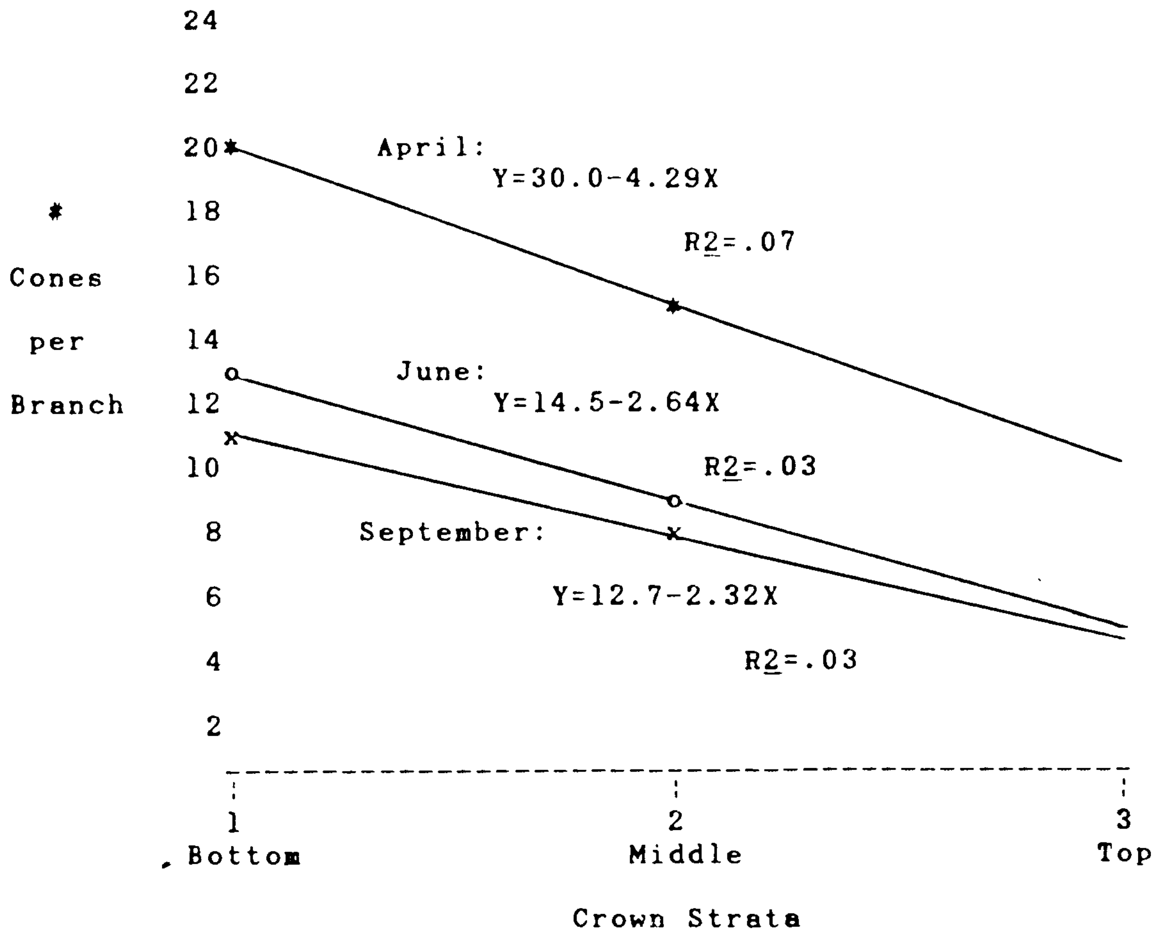

Figure 2: Regression of the number of cones/branch by crown strata for the months of April, June, and September. Based on 10 study trees at the Beaver Creek Seed Orchard, 1984.

rates by crown strata are shown in Tables 1 and 2. Very little abortion had occurred in April. However, significant crown strata differences in cone number and cone abortion are evident. Abortion increased substantially by May, but differences in conelet abortion in May were not significant.

Note that for April a greater percentage of the cones in the bottom crown stratum was chewed (19%) compared to the middle crown stratum (10%) and the upper crown stratum (4%). The differences in the percentage of cones chewed were significant. This chewing reflected feeding by the weevil L. lecontei. The same crown level pattern for percent of cones chewed also appeared in the May data, though at a greater level of chewing: 32% for the bottom, 19% for the middle, and 6% for the upper crown. However, the differences between the crown strata in the number of cones chewed by May were not significant.

The percentage of live/chewed cones for both April and May decreased from the bottom to the top crown strata. The differences between crown strata were significant while the differences between crown strata during May were not. The percentage of live/chewed cones remained nearly constant from April to May.

A high percentage of the cones aborted in April had been chewed: 78% of the cones aborted in the bottom crown stratum and all of the cones aborted in

Table 1: Cone condition survey for April 1984. Mean percent (/S.D.) by crown strata and test statistics for crown level comparison.

Strata	Cones n (/S.D.)	Live Unchewed % (/S.D.)	Live Chewed % (/S.D.)	Aborted Unchewed % (/S.D.)	Aborted Chewed % (/S.D.)	Total Chewed % (/S.D.)	Total Abort % (/S.D.)
Bottom	55.7	80	17	1	3	19	3
	(20.7)	(24.0)	(21.6)	(9.9)	(4.3)	(23.7)	(4.8)
Middle	50.8	90	10	0	<1	10	<1
	(26.7)	(9.7)	(33.6)	(0)	(1.1)	(3.4)	(1.1)
Top	31.2	96	4	0	0	4	0
	(9.07)	(8.2)	(8.3)	(0)	(0)	(8.3)	(0)
F-ratio	3.59	4.17	3.12	1.71	4.67	3.76	6.20
Tail-prob	0.04	0.20	0.03	0.06	0.02	0.04	0.01

Table 2: Cone condition survey for May 1984. Mean percent (/S.D.) by crown strata and test statistics for crown level comparison.

		Live		Aborted		Total	Total
	Cones	Unchewed	Chewed	Unchewed	Chewed	Chewed	Abort
Strata	n	%	%	%	%	%	%
		(/S.D.)	(/S.D.)	(/S.D.)	(/S.D.)	(/S.D.)	(/S.D.)
Bottom	10	60	14	8	18	32	26
		(31.9)	(21.2)	(14.8)	(30.1)	(35.5)	(16.4)
Middle	10	66	11	15	8	19	23
		(29.5)	(22.8)	(23.2)	(14.0)	(27.3)	(23.6)
Top	10	76	3	18	3	6	21
		(24.2)	(9.5)	(22.0)	(6.7)	(13.5)	(24.2)
F-ratio		0.78	0.92	0.64	1.52	2.39	0.10
Tail-prob		0.50	0.52	0.50	0.20	0.11	0.96

the middle crown stratum. Again, the pattern of chewed and aborted cones occurring primarily in the bottom crown stratum was evident for April and was significant. This pattern of chewed cones being aborted was substantially reduced in May, though a large percentage of the aborted cones still had been chewed (69% in the bottom, 34% in the middle and 14% in the top).

Unchewed/aborted cones were very rare in April, making up only 2% of the total cones and 17% of the aborted cones overall. Significant differences in the number of unchewed/aborted cones did not occur between crown strata in April. This pattern was reversed in May when 57% of all aborted cones were unchewed; 13% of the total cone population were unchewed/ aborted. The percentage of all cones which were unchewed and aborted was 8% in the bottom crown stratum, 15% in the middle and 18% in the top. However, these differences between crown strata were not significant.

Very few of the cones that had been chewed in April actually aborted. This can be seen by dividing the percentage of cones which were chewed and aborted by the total percentage of chewed cones, which gave 14% in the bottom and 2% in the middle crown stratum. However, by May, the percentage of chewed cones which had aborted increased greatly to 56% in the bottom crown stratum, 42% in the middle and 50% in the top.

A height gradient also existed in April for the percentage of live/unchewed cones which decreased from 96% in the top crown stratum to 80% in the bottom. The differences between the strata were significant In May, the same pattern still existed but at a lower magnitude and was no longer significant.

Between tree differences in the percentage of cones chewed were significant for both April and May (Tables 3 and 4). The percentage of live/chewed cones ranged from 1% to 42% in April and 0% to 50% in May. Both months showed significant between-tree differences.

The percentage of live/unchewed cones was fairly high in both April (91%) and May (67%) with significant between tree differences occurring for both months. The total number of cones on the 6 sample branches/crown level also varied greatly from tree to tree but was not significantly different.

Abortion was low in April and differences between trees in the percentage of cones aborted were not significant. This is also true of the percentage of cones aborted/unchewed and aborted/chewed. Abortion was high in May for some trees (66% for tree #9) while in others abortion was very low (0% in tree #8 and 3% in tree #4). The difference was significant. Aborted/chewed conelets (range 0% to 53%) also differed significantly. Aborted/unchewed cones (range 0% to 37%)

Table 3: Cone condition survey for April: Tree means (/S.D.) and significance statistics.

Tree #	Cones/18 Brnchs #	Live Unchewed %	Live Chewed %	Aborted Unchewed %	Aborted Chewed %	Total Chewed %	Total Abort %
1	96	88 (12.7)	10 (14.2)	0 (0)	2 (2.6)	12 (14.5)	2 (2.6)
2	174	95 (7.3)	4 (7.3)	1 (0.9)	1 (0.9)	5 (7.3)	2 (1.8)
3	94	80 (25.3)	20 (25.3)	0 (0)	1 (4.5)	21 (25.3)	1 (4.5)
4	140	91 (8.5)	9 (8.5)	0 (0)	0 (0)	9 (8.5)	0 (0)
5	101	97 (3.9)	1 (4.0)	0 (0)	2 (2.6)	3 (4.0)	2 (2.6)
6	126	77 (20.2)	23 (19.1)	0 (0)	1 (1.3)	24 (20.2)	1 (1.3)
7	141	92 (15.0)	8 (15.0)	0 (0)	0 (0)	8 (15.0)	0 (0)
8	263	94 (4.4)	6 (3.9)	0 (0)	0 (0)	6 (4.4)	0 (0)
9	108	54 (34.0)	42 (25.8)	0 (0)	4 (16.1)	46 (34.0)	4 (16.1)
10	127	91 (4.2)	5 (2.1)	2 (2.8)	1 (2.1)	6 (4.2)	3 (4.8)
Avg.		91	7	<1	1	8	1
F-ratio:	2.15	2.92	3.19	0.93	0.61	3.41	0.55
Tail-prob.:	0.07	0.02	0.01	0.52	0.77	0.01	0.82

Table 4: Cone condition survey for May: Tree means (/S.D.) and significance statistics.

Tree #	Total Cones #	Live Unchewed %	Live Chewed %	Aborted Unchewed %	Aborted Chewed %	Total Chewed %	Total Abort %
1	30	47	10	37	7	17	44
		(20.8)	(17.3)	(30.6)	(16.3)	(22.9)	(23.1)
2	30	60	0	40	0	0	40
		(26.5)	(0)	(26.5)	(0)	(0)	(26.5)
3	30	43	50	3	3	53	6
		(15.3)	(20.0)	(5.8)	(5.8)	(20.8)	(5.8)
4	30	93	3	3	0	3	3
		(5.8)	(5.8)	(5.8)	(0)	(5.8)	(5.8)
5	30	93	0	3	3	3	6
		(5.8)	(0)	(5.8)	(5.8)	(5.8)	(5.8)
6	30	53	27	7	13	40	20
		(40.4)	(25.2)	(11.6)	(11.6)	(36.1)	(20.0)
7	30	80	0	7	13	13	20
		(0)	(0)	(16.3)	(11.6)	(11.6)	(0)
8	30	100	0	0	0	0	0
		(0)	(0)	(0)	(0)	(0)	(0)
9	30	30	3	13	53	56	66
		(26.4)	(5.8)	(23.1)	(34.8)	(40.4)	(30.6)
10	30	73	0	23	3	3	26
		(15.3)	(0)	(29.4)	(5.8)	(5.8)	(15.3)
Avg.		67	13	9	10	19	23
F-ratio:		4.93	5.86	2.16	3.50	3.41	4.70
Tail-prob.:		0.00	0.00	0.07	0.00	0.01	0.00

did not differ significantly.

The fate of seeds at cone harvest is shown in Tables 5 and 6. Overall, cones contained an average of 83.4 seeds. Of these seeds, only 7%, or about 6 seeds per cone were normal healthy seeds. By far, the greatest loss of seed (71%) was attributed to empty (seed coat intact) and aborted (seed coat shriveled) seed. Damage known to be insect induced amounted to 21% of the seed with another 1% lost to other or unknown factors. Of the seed lost to insects, the greatest amount of seed mortality was attributable to the Douglas-fir cone gall midge. This insect destroyed 11% of the seed in mature cones. The Douglas-fir seed chalcid was second in importance, destroying 7% of the seed. Other insects encountered were the Douglas-fir cone moth which destroyed 1% of the seed and the fir coneworm which destroyed another 2% of the seed. In addition, 1% of the seed was destroyed by fungi, mechanical damage, the western conifer seed bug, or unidentified factors.

The total number of seeds/cone differed significantly between crown strata with cones from the top stratum of the tree having the highest number of seeds/cone (88.5) compared to the middle (83.3) and bottom (77.4). The percentage of healthy seeds per cone also showed significant differences between crown strata. While cones from the bottom and middle crown

Table 5: Fate of seed in mature cones: crown strata means (/S.D.) and test statistics.

Crown elev.	Norm. Seed %	Empty/ Aborts %	Gall Midge %	Seed Chal-Cid %	Cone Moth %	Cone Worm %	Other Factors %	Tot. Seed
Bottom	5 (1.9)	72 (7.2)	7 (5.1)	11 (2.6)	1 (0.6)	3 (6.2)	1 (0.7)	77.4
Middle	5 (2.4)	71 (7.6)	14 (5.3)	7 (2.7)	1 (3.2)	1 (1.1)	1 (1.3)	83.3
Top	10 (4.9)	68 (8.9)	11 (4.8)	5 (4.1)	1 (3.5)	3 (6.7)	1 (0.9)	88.5
Avg.	7	71	11	7	1	2	1	83.4
F-ratio	4.32	1.34	7.18	6.98	0.14	0.89	0.04	3.49
Tail-prob.	0.02	0.27	0.00	0.00	0.90	0.52	1.00	0.03

Table 6: Fate of seed in mature cones: tree means (/S.D.) and test statistics.

Tree #	Norm. Seed %	Empty/ Aborts %	Gall Midge %	Seed Chal-Cid %	Cone Moth %	Cone Worm %	Other Factors %	Tot. Seed
1	5 (2.1)	57 (5.7)	13 (8.2)	21 (6.0)	2 (4.9)	0 (0.7)	2 (1.2)	70.2
2	19 (6.8)	60 (11.1)	15 (8.1)	4 (1.5)	1 (2.1)	0 (1.1)	1 (1.1)	85.3
3	5 (4.9)	76 (8.9)	7 (4.8)	10 (4.1)	0 (3.5)	1 (6.7)	0 (0.9)	102.0
4	<1 (0.7)	74 (9.4)	12 (4.5)	8 (3.1)	0 (0)	4 (7.7)	1 (1.3)	78.8
5	9 (3.4)	55 (10.5)	22 (5.4)	4 (3.9)	0 (4.1)	6 (9.1)	2 (1.4)	80.8
6	3 (1.8)	88 (2.7)	3 (2.3)	0 (0.5)	3 (0.7)	0 (0)	1 (0.5)	89.2
7	7 (0)	69 (0)	7 (0)	15 (0)	1 (0)	0 (0)	2 (0)	112.0
8	4 (3.1)	90 (8.8)	3 (3.6)	1 (1.3)	1 (3.6)	0 (0)	1 (0.8)	79.5
9	3 (0)	68 (0)	17 (0)	13 (0)	0 (0)	0 (0)	0 (0)	72.0
10	13 (6.7)	72 (5.2)	3 (2.9)	7 (1.4)	0 (0)	4 (9.1)	1 (0.6)	95.7
Avg.	13	71	11	7	1	2	1	83.4
F-ratio	13.06	13.03	8.49	20.05	0.56	1.06	1.53	5.50
Tail-prob.	0.00	0.00	0.00	0.00	0.82	0.41	0.17	0.00

strata averaged 5% normal seeds, the cones from the top crown stratum averaged 10% normal seeds. The percentage of empty/aborted seeds varied little between crown strata (range 68% to 72%) and had no apparent pattern. Crown strata differences for this factor were not significant.

Seed mortality due to the Douglas-fir cone gall midge varied among the crown strata (bottom=7%, middle=14%, top=11%). These between crown strata differences were significant.

A distinct crown-level gradient was observed for the Douglas-fir seed chalcid. Seed mortality to this insect decreased from lower to upper strata (bottom=11%, middle=7%, top=5%). These differences were significant.

Seed destroyed by the Douglas-fir cone moth, the fir coneworm or by other factors did not show any pattern or any significant differences between crown strata.

The average total seeds/cone varied significantly between trees (range 70.2 to 112). The percentage of healthy seeds/cone also differed significantly. Overall, healthy seeds averaged 7% but ranged from <1% to 19%. The percentage of empty/aborted seed ranged from 55% to 90%. These differences were significant.

Significant differences also occurred by tree in the percent of seed lost to the Douglas-fir cone gall midge and the Douglas-fir seed chalcid. Damage to the gall midge ranged between 3% and 22%, a significant difference The seed chalcid destroyed 0% to 21% of the seed. This difference was significant.

The fir coneworm and the Douglas-fir cone moth both caused sporadic and low seed mortality between trees. Mortality ranged from 0% to 6% for the coneworm and 0% to 3% for the cone moth. These differences were not significant. Mortality due to other factors also showed no significant differences between trees.

The percentage of seeds destroyed by the seed chalcid and the percentage of healthy seed per cone were linearly related to crown strata: $Y=0.135-0.029X$, where $Y=$ % of seed loss to seed chalcid and $X=$ crown stratum (1=bottom, 2=middle, and 3=top); $Y=0.017+0.025X$, where $Y=$ % healthy seed and $X=$ crown stratum (as above). Low R-square values (0.08 for the seed chalcid and 0.07 for healthy seeds) reflected considerable variation about the regression lines. The slopes of these equations were significant.

The correlation matrix for the different seed mortality factors is shown in Table 7. Most of the correlations were low and non-significant. However, empty/aborted seed was significantly correlated to all factors except cone moth and total number of seeds/cone. Total seed was significantly correlated with seed chalcid and with total seed. Correlation coefficients were less than 0.10.

The number of cones per stratum was analyzed as a covariate influencing insect abundance, as suggested by the resource concentration hypothesis (Kareiva 1983). Analysis of covariance showed no significant relationship between the number of cones/stratum and occurrence of the gall midge, seed chalcid or healthy seed.

The average number of potential cones/whorl branch was highest in the bottom crown strata (18 cones/branch) and decreased with increasing crown elevation (middle= 17 and top=9) (Table 8). The difference between the lower two crown strata and the top crown stratum is significant.

Multiplying cones/whorl branch by whorl branches/strata yielded the number of potential cones in each crown level. The highest cone potential was in the middle crown followed by the bottom crown strata. The difference in the number of potential cones between these two strata was not significant. The upper crown stratum was significantly different from the other two crown strata. After subtracting April and May conelet abortion, each of the bottom two crown strata still had significantly more cones than the top crown stratum. Cone efficiency, in April, was 0.99 overall with the bottom crown stratum having the lowest cone efficiency. Cone efficiency, in May, was 0.77 overall. Again, the bottom crown stratum had the lowest cone efficiency

Table 7: Correlation Matrix of % seed loss for the various factors affecting seed from mature cones. Values are coefficients of determination, sign for direction of correlation and significance level.

.	Norm.	Gall Midge	Seed Chal-cid	Cone Moth	Cone worm	Other Fact.	Total Seed
Gall Midge	.03						
Seed Chalcid	-.05	-.01					
Cone Moth	.00	.04	-.01				
Fir coneworm	-.01	.00	.00	-.01			
Other Factors	.00	.03	.03	.00	.01		
Total Seed	.10**	.00	-.06*	-.02	-.01	.00	
Empty/Aborted	-.18**	-.45**	-.13**	-.05	-.08*	-.08*	.00

*Significant at 0.05 level; **Significant at 0.01 level; otherwise not significant.

and the top had the highest.

Total potential seed production on sample trees was 587,000 overall, with 207,000 in the bottom stratum, 222,000 in the middle and 159,000 for the top crown (Tables 9-12).

The mortality tables for Douglas-fir seed presented in Tables 9-12 can be used to identify the key mortality factors. Overall, seed efficiency was poor (6.1%), increasing from 4.5% in the bottom crown to 5.3% in the middle and 9.3% in the top. As a result of the higher seed efficiency for the top crown, the total production of harvestable seed was greatest in the top even though seed potential was much higher in the bottom and middle crown strata at the beginning of the season.

The percent mortality to each factor based on total potential seed is shown in Tables 9-12. The largest loss category was empty/aborted seed (57.5%), reflecting unidentified factors such as insufficient pollination. If the overall unexplained conelet abortion rate (13.1%) is deducted from weevil-damaged conelets (9.7%), then other major seed mortality factors, in order of importance, were unexplained conelet mortality, likely due to frost (13.1%), conelet mortality due to weevils (8.4%), seed loss to gall midge (7.8%) and seed loss to seed chalcid (4.7%). The relative importances of these factors varied among crown strata.

Seed survival was highest in the top crown stratum

Table 8: Gross cone potential and cone efficiency estimates.

Strata

	Bottom	Middle	Top
Avg. # cones/branch	17.54	16.63	8.89
# Branches	147	158	177
Total # potential cones	2578	2627	1574
% April abortion	3	<1	0
Cone survival (Apr.)	2501	2616	1574
Cone efficiency	.97	.99	1.00
% May abortion	24	23	21
Cone survival (May)	1908	2014	1243
Cone efficiency	.76	.77	.79

Table 9: Mortality table for Douglas-fir seed in the bottom crown level on 10 study trees at the Beaver Creek Seed Orchard, 1984.

Stage	# Surviving	Mortality Factor	Seed Loss	% of Total Seed Loss
Cone "Flowering"				
-Early abortion (April)	207,000	Weevil	5169	2.5
		Other	1034	0.5
-Late abortion	201,000	Weevil	30085	14.5
		Other	14040	6.8
Seed Development				
	156,000	Empty/ Abort	123746	59.8
		Gall Midge	9230	4.5
		Seed Chalcid	10951	5.3
		Cone Moth	2034	1.0
		Coneworm	2347	1.1
		Other	1095	0.5
Seed Maturity	7,040			

Table 10: Mortality table for Douglas-fir seed in the middle crown level on 10 study trees at the Beaver Creek Seed Orchard, 1984.

Stage	# Surviving	Mortality Factor	Seed Loss	% of Total Seed Loss
Cone "Flowering"				
-Early abortion (April)	222,000	Weevil	487	0.2
		Other	0	0.0
-Late abortion	222,000	Weevil	16836	7.6
		Other	33229	15.0
Seed Development	171,000	Empty/ Abort	128425	57.8
		Gall Midge	21261	9.6
		Seed Chalcid	9602	4.3
		Cone Moth	514	0.2
		Coneworm	857	0.4
		Other	1715	0.8
Seed Maturity	9,180			

Table 11: Mortality table for Douglas-fir seed in the top crown level on 10 study trees at the Beaver Creek Seed Orchard, 1984.

Stage	# Surviving	Mortality Factor	Seed Loss	% of Total Seed Loss
Cone "Flowering"				
-Early abortion (April)	159,000	Weevil	0	0.0
		Other	0	0.0
-Late abortion	159,000	Weevil	4122	2.6
		Other	28540	18.0
Seed Development				
	126,000	Empty/ Abort	84850	53.5
		Gall Midge	15736	9.9
		Seed Chalcid	6798	4.3
		Cone Moth	1762	1.1
		Coneworm	3777	2.4
		Other	1259	0.8
Seed Maturity	11,710			

Table 12: Mortality table for Douglas-fir seed on 10 study trees at the Beaver Creek Seed Orchard, 1984.

Stage	# Surviving	Mortality Factor	Seed Loss	% of Total Seed Loss
Cone "Flowering"				
-Early abortion (April)	587,000	Weevil	5656	1.0
		Other	1034	0.2
-Late abortion	581,000	Weevil	51043	8.7
		Other	75809	12.9
Seed Development				
	454,000	Empty/ Abort	337624	57.5
		Gall Midge	45833	7.8
		Seed Chalcid	27682	4.7
		Cone Moth	4538	0.7
		Coneworm	7261	1.2
		Other	4084	0.7
Seed Maturity	29,000			

(7.4%), twice the survival attained in the bottom crown stratum (3.5%). The middle stratum had the lowest survival (2.7%).

The total number of trees, cones/tree, and cones/crown level /tree required for a predetermined level of precision (Southwood 1966) is shown in Table 13. The number of samples required for standard errors (E) of .10 and .20 are shown. The fewest samples required is for empty/aborted seed (73 trees, 2 cones/tree for E=.10; 21 trees, 0.5 cones/tree for E=.20). This reflects the low variance between trees and between crown strata.

The two most damaging insects, the gall midge and the seed chalcid require approximately the same number of cones/tree at each level of sampling precision. However, the seed chalcid requires approximately twice the number of sample trees as the gall midge due to the high between-tree variance for the seed chalcid.

Estimates for the percentage of healthy seeds/cone require a sampling intensity similar to that for gall midge. Cone moth, coneworm, and seed destroyed by other factors require substantially more samples, especially the number of cones/tree. This is due to the sporadic nature of the damage by these insects within and between trees. The number of samples required for estimating weevil damage is quite high (781 trees, 584 cones/tree for E=.10). Unchewed/ abortion (frost damage) requires fewer samples (379 trees, 157 cones/tree for E=.10).

Table 13: Minimum number of samples required for estimates to be within a predetermined standard error (E), based on data from 10 study trees at the Beaver Creek Seed Orchard, 1984.

E=.10

Factor	Trees (#)	Cones/ Tree (#)	Cones/level/tree (Bot./Mid./Top) (#)
Normal Seeds	565	52	15 / 22 / 25
Empty/Aborted	73	2	1 / 1 / 2
Gall Midge	312	51	59 / 13 / 19
Seed Chalcid	620	49	15 / 15 / 25
Cone Moth	605	895	52 /945 /627
Coneworm	1020	706	368 /468 /523
Other	207	148	33 /124 / 75
Cone Abortion (Weevil)	781	584	92 /390 /1111
Cone Abortion (Other)	379	157	133 /198 /758

E=.20

	Trees (#)	Cones/ Tree (#)	Cones/level/tree (Bot./Mid./Top) (#)
Normal Seeds	144	13	4 / 6 / 6
Empty/Aborted	21	0.5	.25 /.25 / .5
Gall Midge	79	13	15 / 3 / 5
Seed Chalcid	158	12	4 / 4 / 6
Cone Moth	151	224	13 /236 /157
Coneworm	255	177	92 /117 /131
Other	52	37	8 / 31 / 19
Cone Abortion (Weevil)	195	146	23 / 98 /278
Cone Abortion (Other)	95	39	33 / 50 /190

DISCUSSION

Decline in the seed potential for a Douglas-fir seed orchard begins early in the growing season in the form of conelet abortion. Conelet abortion has a substantial impact on seed potential, accounting for approximately 23% of the seed lost at the Beaver Creek Seed Orchard during 1984. This seed loss has been uncounted by most seed orchard managers. Conelet abortion has been recognized and many of its causes identified, including late frost (Timmis 1976), drought, and physiological problems within the trees, such as graft incompatibility. However, insects as a cause of conelet abortion has not been recognized in coastal Douglas-fir seed orchards. Insects that caused conelet abortion were responsible for as much as 8.4% (corrected for the unexplained abortion rate) of the seed lost in this study or about 43% of the conelet abortion overall. Annual variation in the importance of these insects must be assessed. However, the data from this study indicate that the weevil, *L. lecontei*, and frost are the major causes of conelet abortion in Douglas-fir. The relative importance of *L. lecontei* may increase as techniques for frost protection are incorporated into seed orchard management.

Although this weevil has now been implicated in conelet mortality, seed loss also may have occurred in conelets which were not aborted but were damaged in ways that reduced their seed potential. This potential reduction in the number of seeds/cone should be studied so that seed loss due to *L. lecontei* can be accurately estimated for the inventory-monitoring system. Damage by this previously unrecognized cone pest in this study places it on the same scale of importance as other well known seed and cone pests of Douglas-fir such as the gall midge and seed chalcid, at least during 1984.

This weevil and its damage were most abundant in the bottom crown stratum of the trees, possibly because the weevil prefers shade. Control of this insect may be as easy as banding the trees with sticky traps. However, more information is needed on the life history, habits and impact of this insect on seed loss.

More information is needed on other causes of conelet abortion so that seed loss can be accurately ascribed to factor. Though a number of causes of conelet abortion are known, an accurate method of identifying the cause of abortion is needed to make the inventory-monitoring system work properly. Other insects may be identified as causes of conelet abortion. The western spruce budworm, while not common or important during this study, has been shown to be an important agent of conelet abortion in other areas in other years (Shearer 1984). Although an IMS can be used to assess the need for, and success of, pest control measures, its use requires adequate information on causes of seed loss.

The importance of stratification of the crown can be seen in the results of this study. Significant crown strata effects were found for the number of conelets/branch, weevil damage in April and April conelet abortion. Apparent trends for other factors also might have been significant if more samples had been taken. Thus, stratification will provide more accurate prediction of the cone potential for the seed orchard and for more accurate estimates of conelet abortion and damage, relative to unstratified data.

Stratification also demonstrated significant crown level effects on the impact of the various factors affecting seed loss in mature cones. The percentages of healthy seed, gall midge damaged seed, seed chalcid damaged seed and total seed per cone all showed significant between-crown-strata differences. Winjum and Johnson (1964) also found that the seed potential for cones is greatest in the top of the crown, and Kozak (1963) previously reported crown level effects on seed loss to the cone gall midge. Only biased estimates of seed production will be provided if the crown level differences in importance of the various factors are not addressed in an inventory-monitoring system.

The high between-tree-variances found for the majority of factors affecting seed production indicates the need to sample an adequate number of trees. The estimated number of samples required for adequate precision are relatively high. These estimates are based on one seed orchard for one year and may not reflect sample requirements for future years in other seed orchards with different levels of cone production or different effects of mortality factors. They do indicate the intensity of sampling that may be required to achieve the required precision for IMS. The sample size would most appropriately be based on data for the more important factors such as gall midge, seed chalcid, healthy seeds and total seeds per cone. Managers must determine the best sampling intensity for their specific seed orchard based upon the degree of precision they require and the cost for sampling they are willing to accept.

For the most part, only weak correlations occurred between the various factors affecting seed from mature cones. Empty/ aborted seed had mainly negative correlations with the other factors, especially the gall midge. Total number of seeds/cone had a significant correlation with the number of normal seeds. Thus, the larger the seed count in a cone the more healthy seed. Overall, because of the low correlations found, none of these factor would be a good indicator of the importance of any other factor.

Seed efficiencies found in this study were extremely low. These low seed efficiencies reflected the amount of empty/ aborted seed. The reasons for failure of seed to develop are not known but may reflect physiological factors (especially resource allocation to seed production), frost, poor pollination or undetected insect damage. Empty/aborted seed is the major seed loss among seed orchards (Schowalter et al. 1985). More information is needed on the possible causes of empty and aborted seed, especially methods for identifying specific causes, in order to account for these factors in an inventory-monitoring system. A reduction in the amount of empty or aborted seed could substantially increase the amount of normal seed produced.

The gall midge and the seed chalcid were the most important seed destroying insects and caused substantial seed loss. The cone moth and coneworm caused fairly low and variable losses of seed among the different strata and study trees. These results were consistent with results of a region-wide survey of Douglas-fir seed orchards in 1983 (Schowalter et. al. 1985). While the amount of insect caused seed loss is not nearly as great as that for empty/aborted seed, this study shows that a management program that reduced the amount of insect damage could have increased the production of normal seed by up to 300%.

CONCLUSIONS

The results of this study indicate that the weevil, *L. lecontei*, can be a major pest causing seed and cone loss in Douglas-fir seed orchards. Therefore, it is important that more information on the life history, habits and impact of this insect be obtained and that this insect should be monitored in addition to other important and well known cone and seed insects.

The results of this study suggest a basis for an effective inventory-monitoring system:

1. Because seed loss through immature seed cone abortion starts early in the season, monitoring should begin as soon as the reproductive buds become distinguishable from the vegetative buds.

2. Specific causes of seed loss should be identified so that the need for or success of control programs can be assessed properly. Future research should focus on identification of factors causing unascribed seed loss.

3. Because of significant differences in damage levels in the different crown strata, stratified sampling is necessary to accurately estimate the importance of various seed loss factors.

4. An adequate number of cones/tree, cones/crown level/tree, and trees/orchard is required for precise

estimates of cone and seed efficiencies and of the importance of the various factors affecting seed loss. These sample numbers should be based upon the precision required for the orchard and the funding available for sampling. However, this study indicated that approximately 12 cones from each of 100 trees are necessary to predict seed losses to cone gall midge, seed chalcid, and as empty/aborted seed at a 0.2 standard error level of precision.

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