The Effects of the Filbert Weevil (*Curculio occidentis*) and the Filbertworm (*Cydia latiferreana*) on Garry Oak (*Quercus garryana*) Acorn Germination on Vancouver Island.

An undergraduate research project
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ABSTRACT

Garry oak trees (*Quercus garryana*) and their associated ecosystems are among the most diverse and endangered landscapes in B.C. Garry oak acorns are susceptible to two insect species, the Filbert weevil (*Curculio occidentis*) and the Filbertworm (*Cydia latiferreana*). The objective of this study was to determine the effects of the Filbert weevil and the Filbertworm on Garry oak acorn germination on Vancouver Island. In the fall of 2005 a total of 1,985 Garry oak acorns were collected from 8 locations: three sites in Victoria, two sites in Nanaimo, two sites in the Comox Valley, and from Hornby Island. The acorns were observed for species-specific insect exit-hole damage, planted in potting soil, labeled as either insect-damaged or undamaged, then watered and observed for germination until December. The acorns were then removed from their containers, inspected, and insect damage was recorded. Five of the 8 sites indicated a trend that undamaged acorns were more likely to germinate than insect-damaged acorns. For example, the highest percent germination was 99% of undamaged acorns and 84% of insect-damaged acorns at one site in Courtenay. The highest total insect abundance based on insect exit holes, was 1.3 insects per acorn at the other Courtenay site. At this same site 66% of all acorns contained insects; this was the highest prevalence of insects of all 8 sites. The weevil is generally more abundant and prevalent than the moth; however, there is considerable variation in prevalence and abundance of insects between sites, likely reflecting site differences in tree stand age, soil type, and seasonal moisture levels. This study demonstrates conclusively that acorns damaged by insect larvae germinate into Garry oak tree seedlings. However, it also appears to indicate that the Filbert weevil and the Filbertworm negatively affect Garry oak acorn germination on Vancouver Island.

INTRODUCTION

Garry oak trees and their associated ecosystems are among the most diverse landscapes in British Columbia (Capital Regional District Environmental Services, 2002). They contain 694 identified plant species and 151 vertebrate species composed of 104 species of birds, 33 mammals, 7 amphibians, and 7 reptiles. Also, more than 800 species of insects and mites, as well as many other invertebrates, have been reported in primary association with Garry oak trees (Fuchs, 2001). Many of these species are considered endangered or at risk. For example, the B.C. Conservation Data Centre (CDC) lists as at risk: 3 mammals (including Townsend's big-eared bat, *Corynorhinus townsendii*), 14 birds (including Lewis's woodpecker, *Melanerpes lewis*), 2 reptiles (including the Sharp-tailed snake, *Contia tenius*), 23 insects (including the Island blue butterfly, *Plebjus saepiolus*), 1 earthworm, 74 vascular plants (including Golden paintbrush, *Castilleja levisecta*), and 3 mosses (including Twisted oak moss, *Syntricha laevipila*) associated with Garry oak ecosystems. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has ranked the same 3 mosses and 2 reptiles, as well as 24 vascular plant, 4 insect, and 7 bird species, as at risk. Garry oak ecosystems are considered critically imperiled by the CDC (Capital Regional District Environmental Services, 2002), primarily due to the over-development of their park-like landscape, the introduction of exotic species, and their limited and patchy distribution.

Garry oak ecosystems are found in western North America from California to southwestern British Columbia (Figure 1). Garry oak ecosystems are thought to have arisen 7,000-10,000 years ago (Garry Oak Ecosystem Recovery Team, 2003b), attaining their maximum distribution 5,000-8,000 years ago in the warm, dry period following the

Pleistocene glaciation. As the climate has shifted to more cool, wet weather the range of Garry oaks has decreased, potentially contributing to the patchy distribution of Garry oak ecosystems seen today (Erickson, 1993). In Canada, Garry oak ecosystems are found only in British Columbia, at two locations on the mainland (in the Fraser Valley) and on the east coast of Vancouver Island from Victoria to the Comox Valley, as well as on some Gulf Islands (Cloutier, 1950) (Figure 2).

Over the last 150 years there has been a substantial decline in Garry oak ecosystem habitat (Erickson, 1993; Fuchs, 2001; Garry Oak Ecosystem Recovery Team, 2003b). In the greater Victoria area more than 95% of land that was formerly Garry oak meadows and woodlands, has been developed (Capital Regional District Environmental Services, 2002). While development often leaves the large Garry oak trees standing, the ecosystem as a whole is destroyed. Also, the introduction of exotic and invasive species, of which 173 have been identified, such as Scotch broom (*Cytisus scoparius*), which alters the soil nutrients, and English ivy (*Hedera helix*), which chokes the plants that it grows around, have disrupted Garry oak ecosystems and caused declines in species richness and in habitat availability (Garry Oak Ecosystem Recovery Team, 2003a). The Coast Salish regularly burned Garry oak ecosystems, before European settlement, in order to maintain blue camas (*Camassia quamash*) as a major food source (Pojar and Mackinnon, 1994; Fuchs *et al.*, 2000). Subsequent fire suppression has allowed conifers, particularly Douglas fir (*Pseudotsuga menziesii*) which were killed in these fires, to invade and dominate where Garry oak ecosystems were formerly abundant, by overtopping, shading, and killing the shade-intolerant, mature Garry oaks (Fuchs *et al.*, 2000; Fuchs, 2001; Courtin and Peter, 2001; Devine and Harrington, 2004).

Figure 1. Garry oak distribution in North America.
GOERT website Courtesy of the govt. of B.C. (2003b)

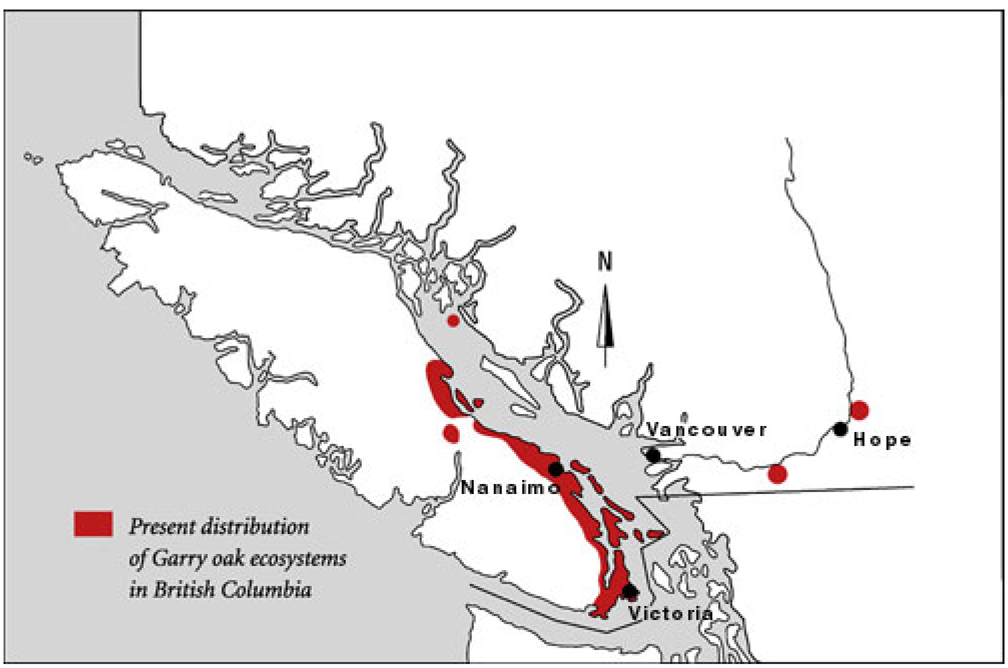

Figure 2. Garry oak distribution in Canada. GOERT website. Courtesy of the govt. of B.C.(2003b)

Garry oak (*Quercus garryana* (Douglas)) is a member of the Family Fagaceae and it is the only oak tree native to British Columbia. Garry oaks are capable of growing in a wide variety of locations, from sea level up to 200m elevation in B.C., and are often found growing in rocky terrain along the coastline (Stein, 1990; Brayshaw, 1996). Garry oaks have a very long, deep taproot which allows them to withstand both drought and flood conditions that are not tolerated by many other native tree species, which out-compete the slow-growing Garry oaks on better sites (Stein, 1990). They are monoecious, with both male and female flowers on the same tree (Stein, 1990; Fuchs, 2001). They begin to produce acorns at 20-25 years old. Flowers are wind-pollinated from March to June, depending on latitude and elevation (Fuchs, 2001). Acorns mature over the summer and fall from the tree in late August to November (Stein, 1990). With sufficient moisture Garry oak acorns begin to grow right away, producing a long radicle (taproot) in the fall, but no leaves/shoots until the following spring (Stein, 1990, Fuchs, 2001). One mature Garry oak tree may produce thousands of acorns, though acorn production varies by year for each tree, and in some years a mature tree may produce no acorns at all.

In order for Garry oak ecosystems to continue to be part of our landscape it is necessary for the oak trees to replace themselves. There are many problems facing Garry oak regeneration. Other shrubs and trees that grow more quickly than Garry oak seedlings, which can take about 10 years to reach 1m in height, can out-compete Garry oaks, which results in loss of Garry oak ecosystem habitat. Garry oak seedlings, with their tender new leaves, are consumed by black-tailed deer (*Odocoileus hemionus*) and other vertebrate herbivores. Insects, such as the Oak leaf phylloxeran (*Phylloxera glabra*) and the Jumping gall wasp (*Neuroterus saltatorius*), also cause damage to the leaves of

Garry oaks, including scorching and premature leaf fall (Duncan, 1995; Fuchs, 2001; Garry Oak Ecosystem Recovery Team, 2003b). In some instances, with repeated defoliation of a particular tree, the tree may die (Edmonds *et al*., 2000).

Acorns, which are vital to the dispersal and regeneration of Garry oaks (Courtin and Peter, 2001), are also food for a variety of animals. Black-tailed deer (*Odocoileus hemionus*), black bears (*Ursus americanus*), the native red squirrel (*Tamiasciurus hudsonicus*) and the introduced eastern grey squirrel (*Sciurus carolinensis*) in Victoria, the deer mouse (*Peromyscus maniculatus*) and other rodents, introduced eastern cottontail (*Sylvilagus floridanus*) and many birds including Steller's jays (*Cyanocitta stelleri*) consume Garry oak acorns (Stein, 1990; Fuchs *et al*., 2000; Fuchs, 2001). On the positive side, Steller's jays are considered to be one of the main dispersal agents of Garry oak acorns in B.C. (Fuchs *et al*., 2000, Fuchs, 2001).

Throughout North America, Europe, the Mediterranean, and Asia, oak tree acorns have been shown to be host to a diversity of specialized insect predators (Lewis, 1992). These predators include members of all four of the largest insect orders: The Lepidoptera (moths), Coleoptera (beetles), Diptera (flies), and Hymenoptera (wasps). Weevils (Coleoptera), particularly in the family Curculionidae, are generally considered the most damaging insects worldwide, as many are obligate acorn feeders (Oliver and Chapin, 1984; Ricca *et al*., 1996). These are followed, in terms of damage, by moth larvae, particularly *Cydia spp.* (Lewis, 1992; Fukumoto and Kajimura, 1999; Post *et al*., 2001; Maeto and Ozaki, 2003), gall wasps of the family Cynipidae (Moffett, 1989; Fukumoto and Kajimura, 1999), and flies of the genus *Resseliella* (Branco *et al*., 2002; Bellocq *et al*., 2005). In Japan, for example, studies have found *Curculio sikkimensis, C.*

dentipes, C. distinguendus, and *C. robustus* along with a cynipid wasp, and moth larvae of *Pammene nemorosa, Cydia danilevski, Cydia glandicolana, Cydia amurensis,* and *Characoma ruficirra* in acorns of three oak species (Fukumoto and Kajimura, 1999; Fukumoto and Kajimura, 2001; Maeto and Ozaki, 2003). Studies in the United States, of oak acorn insects, have focused mainly on the northern red oak (*Quercus rubra*), the live oak (*Q. virginiana*), and the white oak (*Q. alba*). In these studies 2 gall wasp species, 2 species of moth, and 12 species of weevil, 9 of which are curculionids, have been investigated (Gibson, 1982; Oliver and Chapin, 1984; Galford, 1986; Crocker *et al*., 1987; Post *et al.,* 2001; Miller and Schlarbaum, 2005). The acorns of the Engelmann oak (*Quercus engelmannii*) and the coast live oak (*Q. agrifolia*), in western North America, are host to a variety of larval insect species, including two species of moth; *Valentinia glandulella* and *Cydia latiferreana*; and many species of curculionid beetles, particularly *Curculio occidentis* (Dunning *et al*., 2002).

Garry oak acorns are also known to be susceptible to two of these insects, the Filbert weevil (*Curculio occidentis*) and the Filbertworm (*Cydia latiferreana*), which may consume all or part of the acorn kernel (Stein, 1990; Rohlfs, 1999; Fong, 1999; Fuchs 2001). A previous study by Fong (1999) has shown that these two insects are present from Victoria to the Comox Valley at infestation levels of 48% to 84%. A three year study in Victoria also demonstrated infestation rates of 51% to 81% for these two insect species combined (Rohlfs, 1999).

Very little research has been done on the insects that inhabit Garry oak ecosystems in B.C. (Fuchs, 2001). The female Filbert weevil lays eggs in the young acorns between June and September, and the larvae grow inside the acorn, as the acorn grows, consuming the acorn until it falls from the tree in the fall. The larvae then emerge from the acorn by chewing holes in the shell. They over-winter in the soil as larvae and pupate in the spring. The Filbertworm is a moth of the Family Tortricidae. The female moth lays her eggs on the outside of the acorn and on branches. When the eggs hatch the larvae enter the acorn through the micropyle and begin feeding. Larval stages grow inside the acorn starting about mid-July, and emerge from the acorn in the fall, by chewing an exit hole in the acorn shell. The Filbertworm also over-winters in the soil as a larva and pupates in the spring (Rohlfs, 1999).

In a study of the Filbertworm and the Filbert weevil in acorns in the Victoria area 42% of healthy acorns and 11.5% of damaged acorns had the potential to germinate into viable seedlings (Rohlfs, 1999). Other studies have shown up to 75% germination of "fresh" acorns, but the quality, in terms of insect damage, of the acorns in these samples is unknown (Stein, 1990).

This study aims to determine the effects of the Filbert weevil (*Curculio occidentis)* and the Filbertworm (*Cydia latiferreana*) on Garry oak acorn germination on Vancouver Island. The primary objective was to determine the difference in percent germination of insect damaged vs. undamaged acorns throughout the range of Garry oaks on Vancouver Island. The second objective was to determine whether Garry oak tree seedlings with insect-damaged cotyledons grow as well as acorns with whole cotyledons. The prevalence and abundance (*sensu* Bush *et al*., 1997), of the Filbert weevil and the Filbertworm, were also determined at 8 locations spanning the range of Garry oaks on southeastern Vancouver Island.

MATERIALS AND METHODS

Study sites - Acorns were collected by hand from three sites in Victoria, two sites in Nanaimo, two sites in the Comox Valley, and from Hornby Island (Figure 3) in September and October of 2005. Site 1 in Victoria is a rocky, shallow-soil site on the southern slope of a hill. The area includes Beckwith Park, with well-used walking paths between rocky outcrops. Site 2 in Victoria is on campus at the University of Victoria. It is a flat, deep-soil site with the Garry oak trees surrounded by maintained lawn and cement pathways. Site 3 at Bow Park in Victoria is a small stand of Garry oaks. It is a slightly sloping, south facing, deep-soil site in a residential subdivision. Site 4 in Nanaimo is on coastal bluffs at Pipers Lagoon Park. It is a rocky, shallow-soil site with well used walking paths. Site 5 in Nanaimo is in a riparian zone, on a slope down to the water with relatively deep soil, and is bordered by Highway 19, some maintained grass, and a parking lot. Site 6 in the Comox Valley is a flat, deep-soil site with the Garry oak trees surrounded by farm land with a gravel driveway running between the trees. Site 7 in the Comox Valley is a cemetery on a south-facing hill with somewhat shallow soil. It is not a rocky site but, is completely surrounded by paved roads on three sides and housing on the fourth. Parts of this site are maintained grass while other areas are overgrown grass and shrubs. Site 8 on Hornby Island includes Helliwell Provincial Park and along Central Rd. on the South side of the island. This coastal area is predominantly sloping and somewhat rocky.

Research protocols - In order to test how the weevil and the moth affect the germination of Garry oak acorns, acorns were divided into those with obvious insect damage (exit holes, frass) and those with no obvious insect damage. The acorns with insect damage

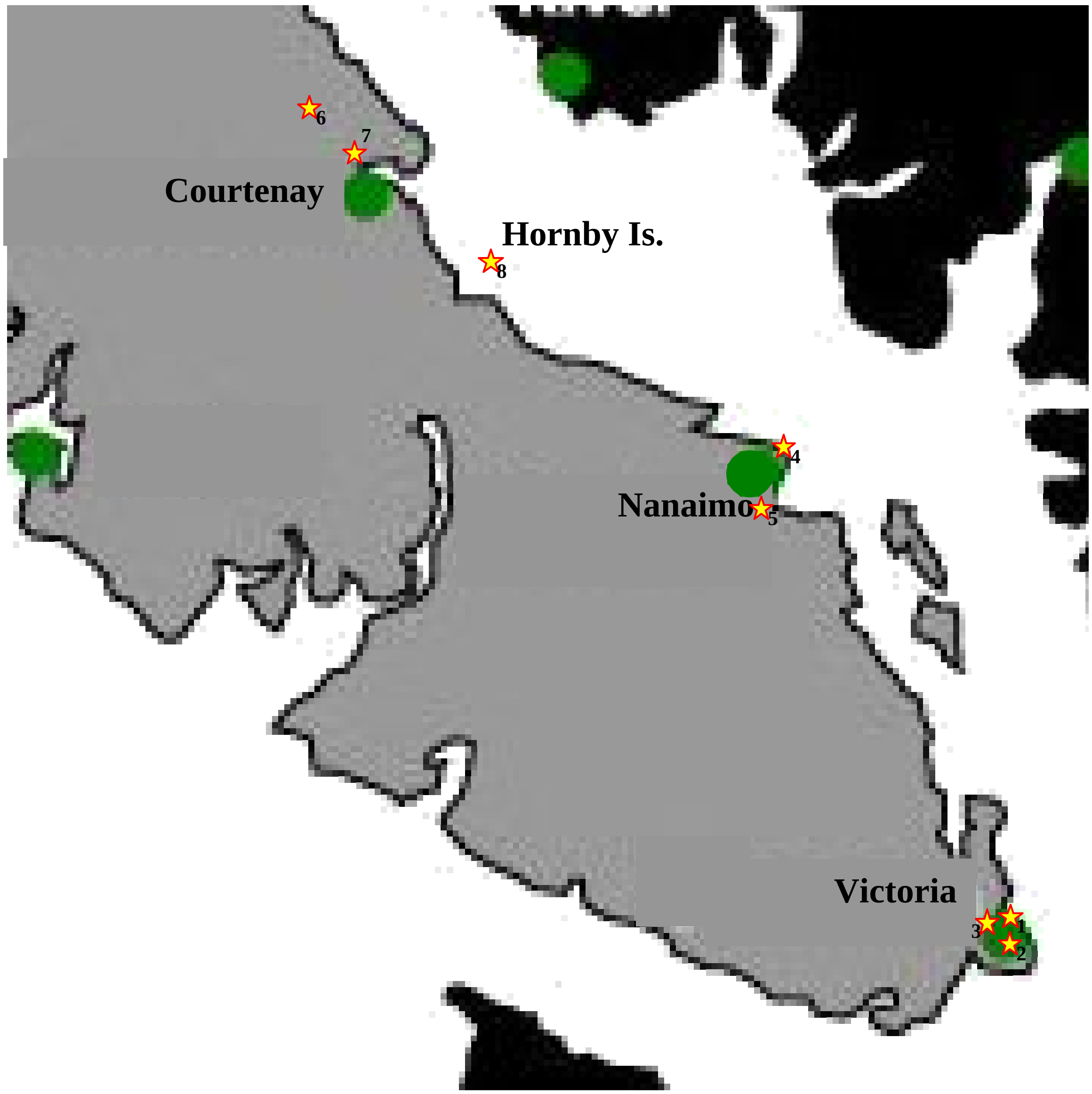

Figure 3. Map of Southeastern Vancouver Island, showing location of the 8 study sites where Garry oak acorns were collected.☆
(Original map accessed November 21, 2005 from www.villageisland.com/ map_sayward.html)

were planted in potting soil in individual clear, semi-sealed plastic containers, for easy observation of germination and to observe when an insect emerged from the acorn. Any weevil or moth larvae that emerged were placed in semi-sealed, clear containers with some moist soil for observation. The acorns with no obvious insect damage underwent a float test; those that sank in a bucket of water were considered most likely to germinate (Hyde-Lay, 2002). Those that floated may have had some internal or non-visible damage and were examined again in December for signs of insect damage and then placed in the appropriate category. All these acorns with no visible external damage were planted in potting soil in individual open seed trays. The soil was kept moist throughout the winter and the containers were kept at room temperature with natural light until the end of December. At the end of December ungerminated acorns were removed from their containers, re-evaluated, and any insect damage was recorded. Germinated acorns were moved out to a small greenhouse where they were kept and watered during final evaluation and recording of insect damage. Measurements of root and shoot length were taken with a ruler to the nearest mm +/- 2mm. Acorns with damage from sources other than the two insect species under study, such as rot/fungus or squirrel damage, were not included in the final data analysis.

Analysis - The prevalence (percentage of acorns infected with a particular species of insect) and mean abundance (the average number of insects likely to be found in one acorn) of each insect species was determined at each of the 8 study sites. Data on both insect species was pooled for all of the other statistical analysis. A 2x2 contingency table, $\alpha=0.05$, was used to evaluate each site and determine if there was a statistically significant relationship between the number of acorns germinated and the number of acorns with insect damage (Zar, 1999). Seedling mean root length and mean shoot height were compared using a t-test to determine whether there was a difference between those with insect-damaged and those with undamaged cotyledons at each location (Triola, 1998).

RESULTS

A total of 1,985 acorns were collected from all 8 sites from September 4th to October 9th, 2005 (Appendix 1). Site 2, the University of Victoria site, had the highest number of acorns collected at 468. Of these, 126 were undamaged, 214 were insect-damaged and the remainder (128) had other damage, such as squirrel damage. These latter acorns were not included in this study. At the University of Victoria site 72 of the undamaged acorns germinated and 59 of the insect-damaged acorns germinated. The Headquarters Rd. site (site 6) in Courtenay had the highest number of undamaged acorns collected with 327 of the 370 acorns collected having no damage and only 32 acorns having insect damage. This site also had the highest number of germinated acorns with 324 undamaged acorns and 27 insect-damaged acorns germinating (Appendix 1; Figure 4). The Courtenay Cemetery site (site7) had the highest number of insect-damaged acorns with 249 of the 375 acorns collected having insect damage and only 98 acorns having no damage. At this site only 49 undamaged acorns and 95 insect-damaged acorns germinated.

Only 4 sites: the Headquarters Rd. Courtenay (site 6), the Old Highway site in Nanaimo (site 5), the University of Victoria Campus in Victoria (site 2), and the Courtenay Cemetery (site 7) had sufficient acorn germination to allow for statistical analysis (more than 20 individuals in each category). Three of these sites, Headquarters

Rd., the Old Highway, and the University of Victoria had significantly more undamaged acorns germinate than insect-damaged acorns (X^2=23.488, P<0.001, X^2=26.111, P<0.001, and X^2=28.049, P<0.001 respectively). The hypotheses tested were: H_o: There is no relationship between germination and insect damage, and H_A: There is a relationship between germination and insect damage with the data suggesting that insect-damaged acorns are much less likely to germinate than undamaged acorns (Appendix 1). There was not a statistically significant relationship between germination and insect damage at $\alpha = 0.05$ at the Courtenay Cemetery site (2x2 contingency table, $X^2 = 3.592$, d.f. = 1, P <0.10). However, at this site is a statistically significant relationship at $\alpha = 0.10$, in that the acorns with insect damage are less likely to germinate. At the Hornby Island site (site 8), though there were few acorns to compare, there was a significant relationship with insect-damaged acorns being much less likely to germinate than undamaged acorns (2x2 contingency table, $X^2 = 18.158$, d.f. = 1, P <0.001). For the other three sites, Bow and Beckwith Parks in Victoria (sites 3 and 1 respectively) and Pipers Lagoon in Nanaimo (site 4), no significant relationship was found between insect damage and acorn germination (Appendix 1).

The Courtenay Cemetery (site 7) had the highest number of weevil-damaged acorns, with 140 acorns having weevil exit holes, and the highest number of acorns with both weevil and moth exit holes at 55 acorns. The Courtenay Cemetery site also had the highest number of weevil-damaged acorns that germinated (53) and the highest number of acorns with both weevil and moth damage to germinate at 16 acorns of the 95 insect-damaged acorns that germinated. The University of Victoria (site 2) had the highest number of moth-damaged acorns, with 95 acorns having moth exit holes. Of these, 27

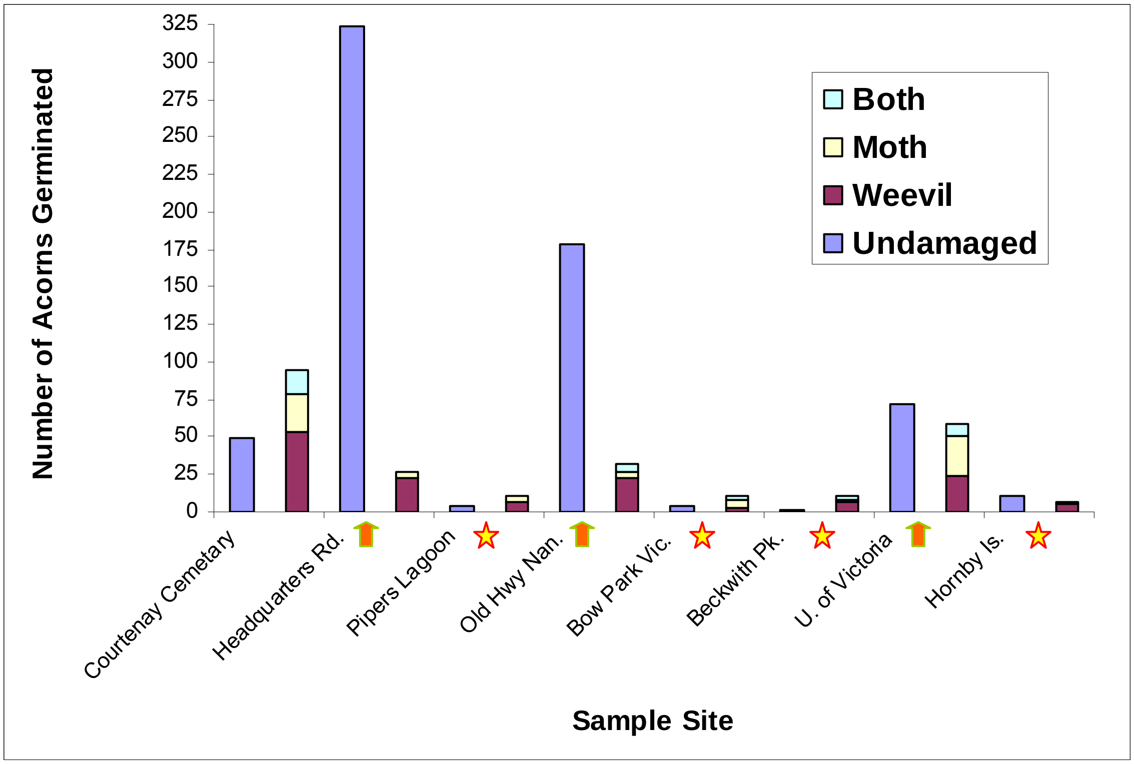

Figure 4. Comparison of the numbers of germinated acorns showing insect-damaged and undamaged acorns at each site. ☆ Small sample sizes. ⇧ Statistically significant difference.

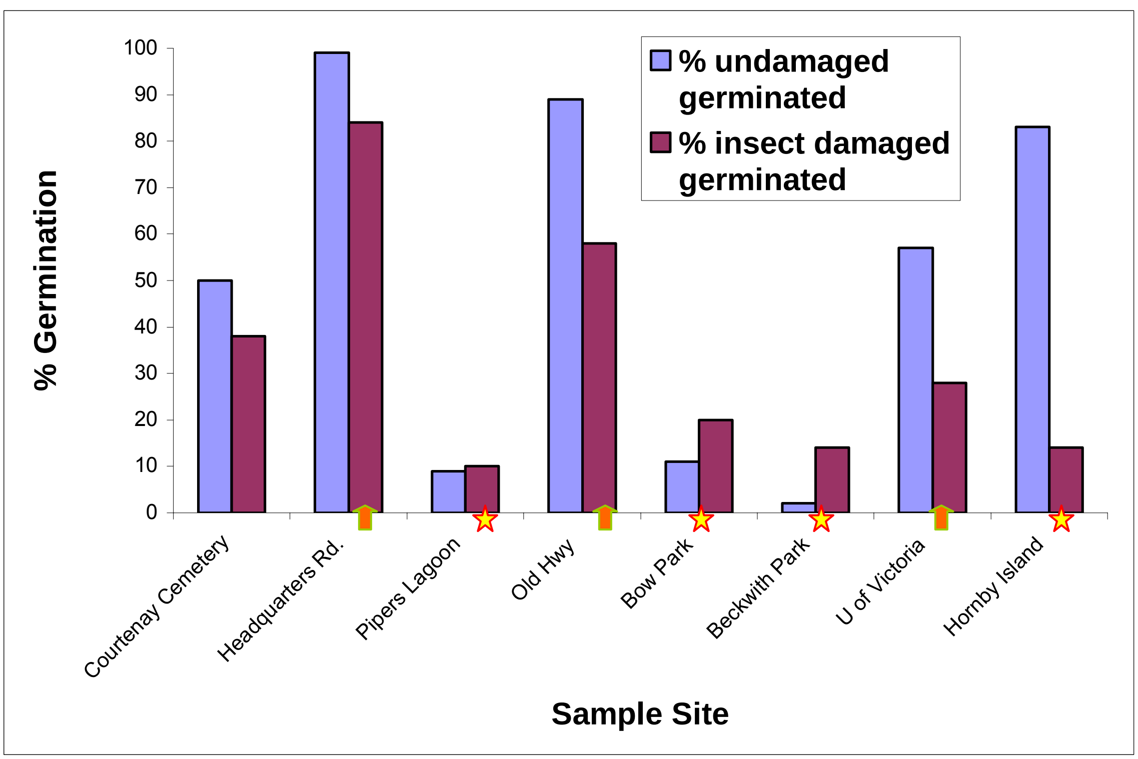

Figure 5. Comparison of the percent germination of insect-damaged acorns versus undamaged acorns at each site. ☆ Small sample sizes. ⇧ Statistically significant difference.

moth-damaged acorns germinated of a total of 59 insect-damaged acorns that germinated. Bow Park (site 3) had the lowest number of weevil-damaged acorns (23 of 55 insect-damaged acorns), while Headquarters Rd. (site 6) had the lowest number of moth-damaged and both insect damaged acorns (6 and 1 respectively out of 32 insect-damaged acorns) (Appendix 1; Figure 4).

Five of the eight sites show higher percent germination of undamaged acorns than insect-damaged acorns: Courtenay Cemetery, Headquarters Rd., Old Hwy, UVic, and Hornby Island (Figure 5). The Pipers Lagoon, Bow Park, and Beckwith Park sites had low percent germination with very few (20 or less) acorns germinating in each category (insect-damaged or undamaged). All three of these sites show slightly higher percent germination of insect-damaged acorns. The highest percent germination of both insect-damaged acorns and undamaged acorns was observed at Headquarters Rd. in Courtenay, with 99% germination of undamaged acorns and 84% germination of insect-damaged acorns (Appendix 1; Figure 5).

While six sites appear to have longer mean root length of acorns with undamaged cotyledons (Figure 7), only four sites had sufficient germination to allow for statistical analysis (more than 20 seedlings with roots). At all four of these sites (the Courtenay Cemetery (site 7), Headquarters Rd. (site 6), the Old Hwy (site 5), and the University of Victoria (site 2)), the mean root length indicates that seedlings with insect-damaged cotyledons have, on average, significantly shorter roots than seedlings with undamaged cotyledons (t_{calc} =3.801, $P<0.0005$; t_{calc} = 2.422, $P<0.025$; t_{calc} =1.810, $P<0.05$; t_{calc} =4.903, $P<0.0005$ at these four sites respectively) (Appendix 2; Figures 6, 7). The hypotheses tested were H_o: Insect damaged acorns mean root length is larger than or

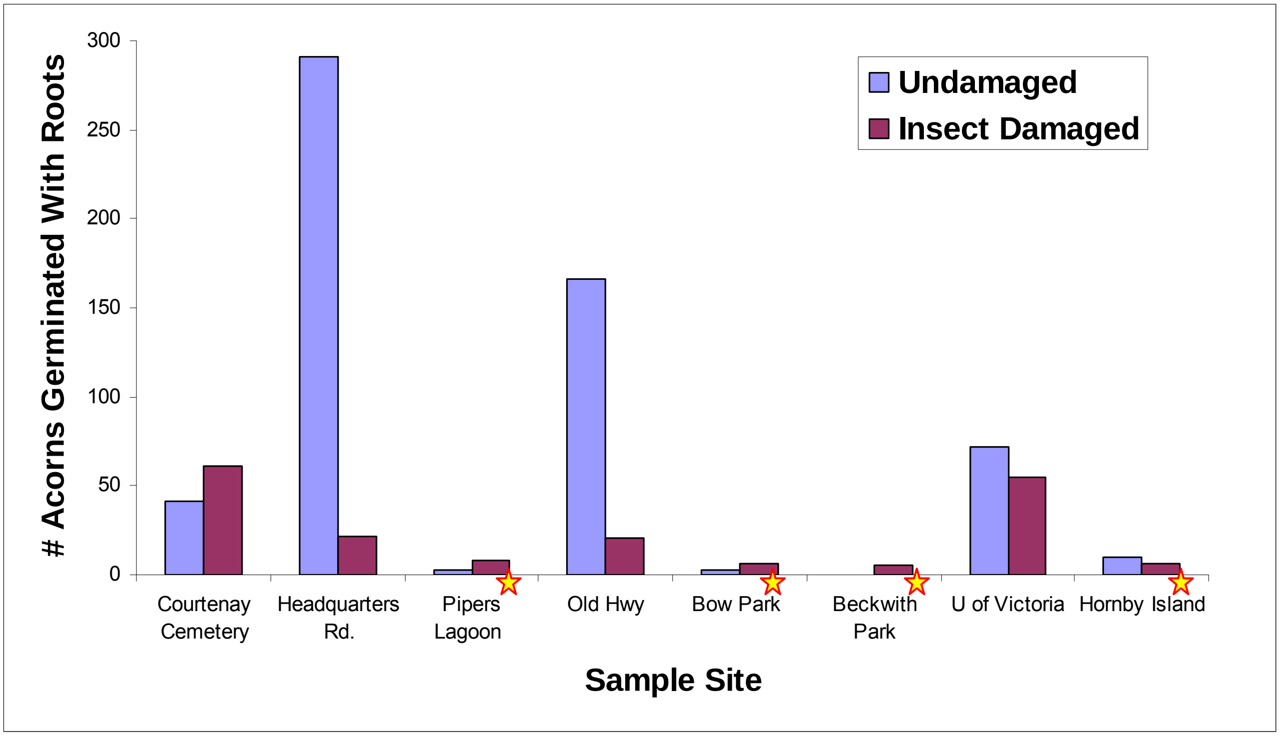

Figure 6. Comparison of the number of undamaged and insect-damaged acorns germinated at each site. ☆ Small sample sizes, less than 20.

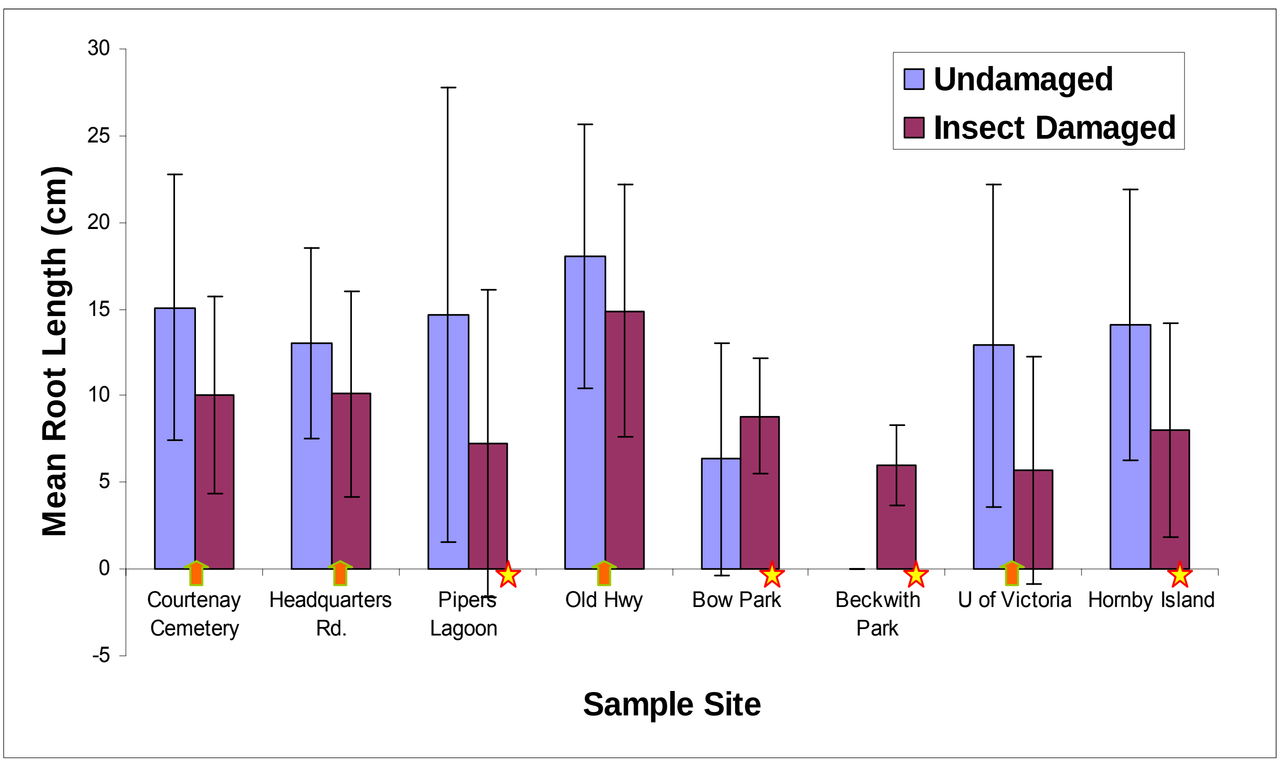

Figure 7. Mean root length of germinated acorns by insect damage and site. ☆ Small sample size.
⇧ Indicates a statistically significant difference; shorter average root length in insect-damaged acorns.

equal to undamaged acorns mean root length, (there is no significant difference), and H_A: Insect damaged acorns mean root length is shorter than undamaged acorns mean root length. The other four sites (Pipers Lagoon, Bow Park, Beckwith Park, and Hornby Island) had insufficient germination data to draw any conclusions with sample size less than 20 (Appendix 2; Figures 6, 7).

Mean shoot length for each site was also analyzed, and while mean shoot length was greater for seedlings with undamaged cotyledons at 6 sites, only two sites Courtenay Cemetery (site 7) and the Old Highway (site 5), had sufficient germination to allow for statistical analysis (more than 20 seedlings with shoots). Statistical analysis of both these sites indicates that there was no significant difference between mean shoot height of seedlings with insect-damaged cotyledons and those with undamaged cotyledons. However, at the University of Victoria and the Hornby Island locations, there is a significant difference in shoot length with 'undamaged' seedlings shoots being longer on average than 'insect-damaged' seedlings shoots. For example, for acorns from the University of Victoria (site 2) mean shoot length for seedlings with undamaged cotyledons was 12.12 cm compared to a mean shoot length of only 6.82 cm for seedlings with insect-damaged cotyledons (t_{calc}=3.197, $P<0.005$). However, this relationship is very weak due to small sample sizes (Appendix 3; Figures 8, 9).

The prevalence and abundance were calculated for each site. Abundance based on the number of insects collected was lower at all sites than abundance based on insect exit holes (Appendices 4, 5; Figure 10). The abundance of weevil larvae (the number of weevils you can expect to find in one acorn), based on either the number of exit holes or the actual number of weevils collected, was higher at all sites than the abundance of moth

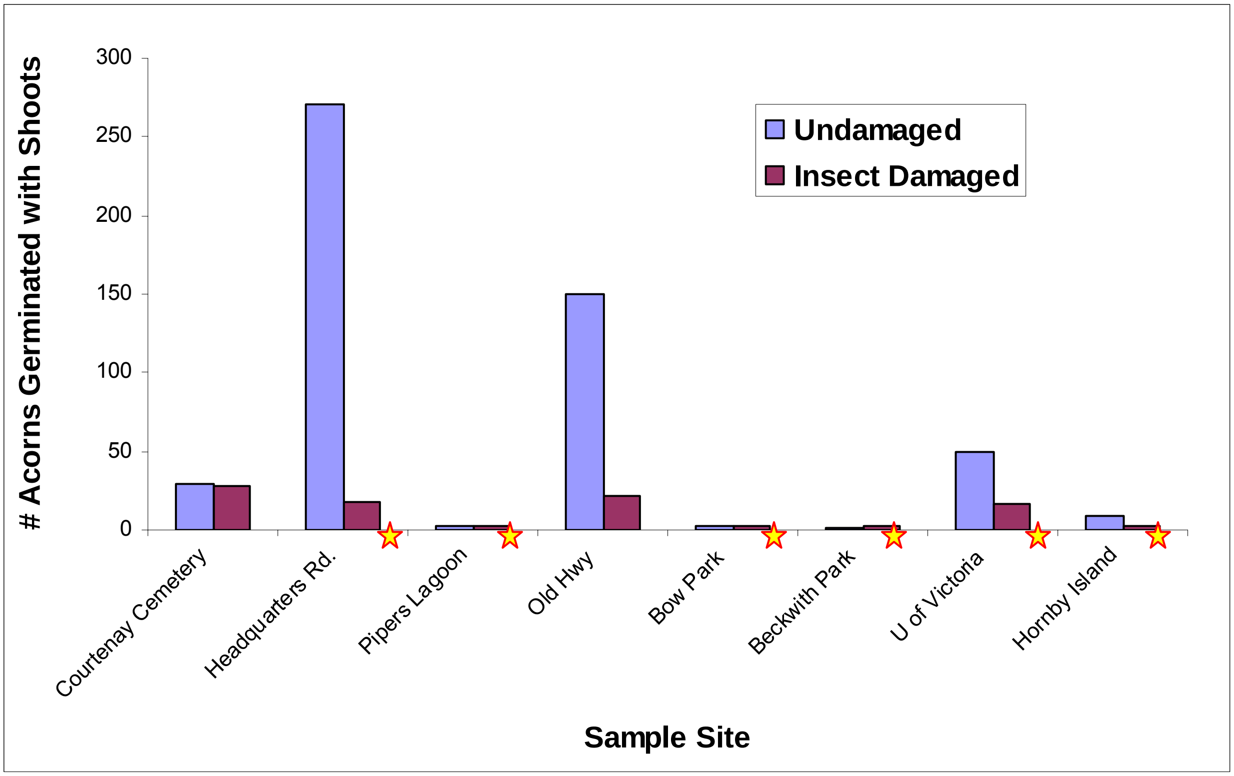

Figure 8. Comparison of the number of acorns germinated with shoots at each site.☆ Small sample sizes, less than 20.

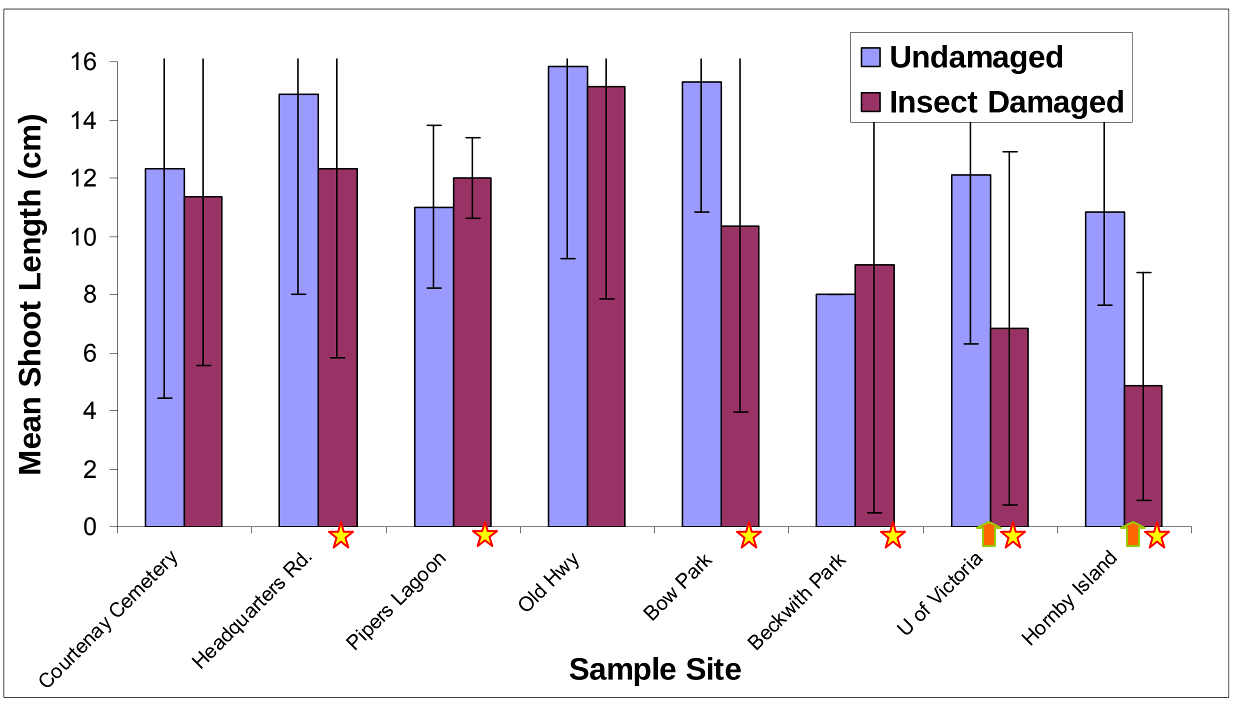

Figure 9. Mean shoot length of germinated acorns by insect damage and by site.
☆ Small sample size. ⇧ Indicates a statistically significant difference.

larvae, except for the Old Highway site in Nanaimo which only yielded a total of two moth larvae and no weevils.

Based on the number of insects collected, total insect larvae abundance was high (more than 0.5 insects per acorn) at the Courtenay Cemetery site and at Pipers Lagoon in Nanaimo. Total insect larvae abundance was low (less than 0.1 insects per acorn) at the Headquarters Rd. site in Courtenay and the Old Highway site in Nanaimo. Based on the number of insect exit holes the total insect abundance was high at all sites except for Headquarters Rd. site in Courtenay and the Old Highway site in Nanaimo. The highest abundance of weevils by either method was found at the Courtenay Cemetery site (by insects = 0.741, by exit holes = 0.992) (Appendices 4, 5). Hornby Island also had high weevil abundance (based on insect exit holes = 0.788) (Appendix 4; Figure 10). The lowest weevil abundance by either method was found at the Headquarters Rd. site in Courtenay (by insects = 0, by exit holes = 0.081 (Appendices 4, 5) with the Old Highway in Nanaimo site also having low weevil abundance based on the number of insects collected (=0) (Figure 10). The highest abundance of moth larvae based on number of insects was Pipers Lagoon (0.365), with Headquarters Rd. having the lowest abundance of moths (0) by the same method (Appendix 4). The highest abundance of moth larvae, based on the number of exit holes, occurred at Courtenay Cemetery (0.331) and Bow Park (0.325), with the lowest abundance of moth larvae occurring at Headquarters Rd. (0.024) and the Old Highway (0.061) (Appendix 5; Figure 10).

Prevalence, the percentage of total acorns infected with insects, was only calculated based on insect exit holes (Appendix 6). Overall prevalence of insect larvae was high at Courtenay Cemetery (66%), Hornby Island (64%), and Pipers Lagoon (59%),

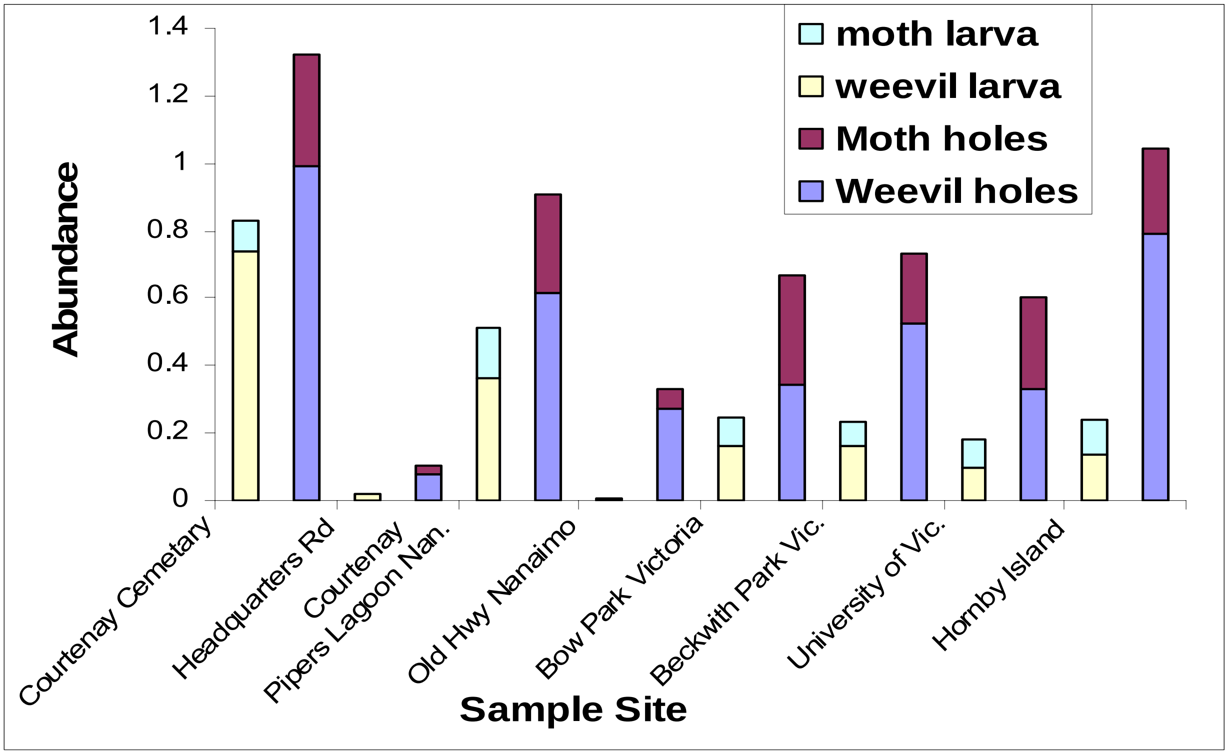

Figure 10. Abundance based on number of insects collected vs. based on number of insect exit holes, by site.

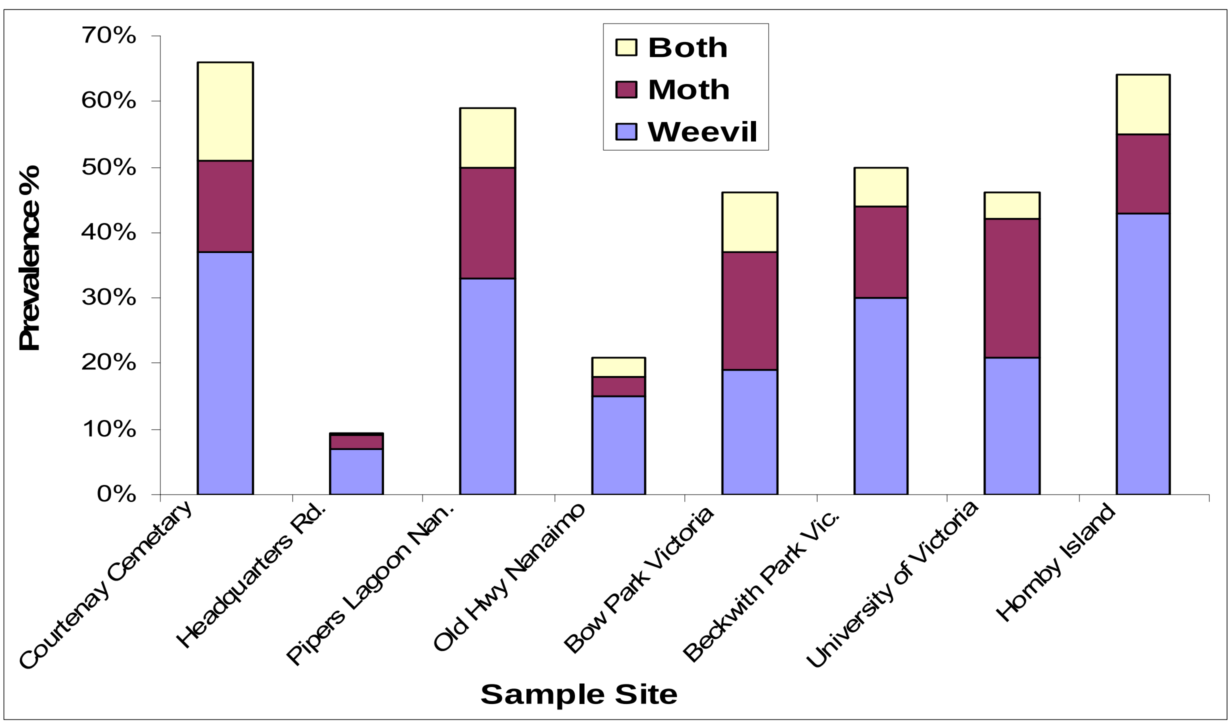

Figure 11. Prevalence of Filbertworm and Filbert weevil larvae based on the number of insect exit holes observed for each, by site.

and lowest at the Headquarters Rd. site (9%) (Figure 11). The prevalence of weevil larvae is higher than the prevalence of moth larvae at all sites, with the exception of the University of Victoria site for which the prevalence of the two insects is equal (25%). The prevalence of weevils is highest at the Courtenay Cemetery and Hornby Island locations, with 52% of all acorns sampled containing weevil(s) at both of these sites. Weevil prevalence was lowest at the Headquarters Rd. site (7%). The prevalence of moths is high at Courtenay Cemetery (29%), Bow Park (27%), and Pipers Lagoon (26%), and low at the Headquarters Rd. (2%) and Old Highway (6%) sites. The moth and weevil co-occurred in 15% of acorns at the Courtenay Cemetery site; however, the prevalence of both insect species occurring in one acorn is generally low for all 8 sites, with the lowest prevalence of both insect species infecting one acorn occurring at the Headquarters Rd. site (0.30%).

The maximum number of insect holes found in one acorn was 7 (from the Courtenay Cemetery site); this acorn had 5 round weevil larva exit holes and 2 oval moth larva exit holes. The maximum number of weevil holes in one acorn was 6 (again at the Courtenay Cemetery site). The maximum number of moth holes in one acorn was 3 (at the Bow Park and University of Victoria sites) (Appendix 7).

DISCUSSION

***Garry oak acorn germination* -** Four of the sample locations (Courtenay Cemetery (7), Headquarters Rd. (6), the Old Highway (5), and The University of Victoria (2)) had high acorn crops in 2005. The Headquarters Rd. site in Courtenay had significantly more undamaged acorns (324) than insect-damaged acorns (27) germinate. This site had the highest acorn germination of all the samples. One of the factors that could have contributed to this was the age of the trees; the trees at this site were the youngest included in the study, possibly not more than 40 years old. Also, the local environment could play a role. At the time of collection the site was quite moist relative to other sites, possibly reducing acorn death due to desiccation (Stein, 1990). Finally, this site had very few Filbertworm and Filbert weevil larvae and very little acorn damage was observed from these two insects.

Studies by Gibson (1982), Oliver and Chapin (1984), and Miller and Schlarbaum (2005) on other oak species and by Rohlfs (1999) and Fuchs *et al*. (2000) on Garry oaks, demonstrate that weevil and moth larval acorn herbivory has a negative effect on acorn germination. Of the 4 sites that had sufficient germination to allow for statistical analysis (Headquarters Rd. Courtenay, Old Highway site in Nanaimo, UVic Campus in Victoria, and Courtenay Cemetery), all but one (Courtenay Cemetery) show that the acorns with insect damage were significantly less likely to germinate than were undamaged acorns. At 5 of the 8 sites acorns with insect damage were less likely to germinate than were undamaged acorns. These 5 sites show higher percent germination of undamaged acorns than of insect-damaged acorns reflecting similar results to those found in literature. For example, Phillips *et al*. (1995) found that 89% of intact blue oak acorns germinated. Hopper *et al*. (1985) and Branco *et al*. (2002) also found that up to 90% of undamaged northern red oak acorns and cork oak acorns germinated, respectively. Generally, undamaged Garry oak acorns are expected to have about 80% germination (Stein, 1990), which is comparable to the results in this study for the sites with abundant acorn crops in 2005. Leiva and Fernandez-Ales (2005) found that 44% of holm-oak acorns with insect damage from *Cydia fagiglanda* and *Curculio elephas* were viable and 59% of undamaged acorns were viable. Rohlfs (1999) found that 11.5% of insect-damaged and 42% of undamaged Garry oak acorns had the potential to germinate. This is much lower than the percent germination observed in the present study at the four abundant acorn crop sites, where a maximum of 99% of undamaged and 84% of insect-damaged acorns germinated (Headquarters Rd.) and minimums of 50% undamaged acorns (Courtenay Cemetery) and 28% insect-damaged acorns (University of Victoria) germinated. Potential reasons for the generally higher germination at the Courtenay Cemetery, Headquarters Rd., Old Highway, and University of Victoria sites (besides more acorns being produced in 2005 at these sites) could involve local climate. These sites appeared to be more moist than the other four sites, and as acorns need to maintain more than 30% moisture in order to germinate (Stein, 1990), these sites may have maintained more viable acorns.

For the 4 sites with poor/low acorn crops in 2005 (Pipers Lagoon, Bow Park, Beckwith Park and Hornby Island) the low percent germination of 11.5% insect-damaged acorns (Rohlfs, 1999) is in the range of insect-damaged acorn germination for this study. Pipers Lagoon in Nanaimo had a low of 10% insect-damaged acorns germinating and Bow Park in Victoria had a high of 20% of insect-damaged acorns germinating. The low number of germinated acorns from these sites may be due to many factors including low sample numbers for these four sites and desiccation of acorns prior to collection, as these locations appeared to be extremely dry at the time of collection. Also, Leiva and Fernandez-Ales (2005) found that larger acorns (>1.5g dry weight) were more likely to germinate in Holm-oak. Though acorn size was not measured in the present study, this could be a factor in the low percent germination at these four sites. The Pipers Lagoon site, which had low acorn production in 2005, was observed to have had an abundant acorn crop in 2004. Yearly variation in acorn crops is common, with low crops and high, or mast, crops cycling randomly (Phillips *et al*., 1995; Maeto and Ozaki, 2003). Perhaps, at the sites with low acorn production in 2005, percent germination will be higher in better acorn crop years. Another possible reason for low acorn germination of the samples from these 4 sites is that some of the acorns collected from these sites may have been old non-viable acorns from 2004. Since so few acorns at these sites were available to collect, acorns were actively hunted for, instead of just collecting all those that were readily apparent. Thus, all acorns that were found were collected regardless of apparent age marks (discolouration) or obvious emptiness (split or extremely light).

***Comparison of root and shoot length between seedlings with insect-damaged cotyledons and those with undamaged cotyledons* -** Though mean root length of seedlings with undamaged cotyledons appears to be higher for 6 of the 8 study locations, only 4 sites had more than 20 acorns with roots. These were the same 4 sites with abundant acorn production and relatively high percent germination. These sites, Courtenay Cemetery, Headquarters Rd., the Old Highway, and the University of Victoria, have significantly longer mean root length for acorns with undamaged cotyledons than for acorns with insect-damaged cotyledons. This may be due to the insect damage reducing the nutrients available for root production, resulting in shorter roots. This indicates that the insect damage to cotyledons affects early seedling growth and development. This tantalizing result has not been conclusively demonstrated in any other studies on Garry oak trees. However, in cork oak, *Q. suber*, it has been shown that seedling growth and survival were significantly reduced in acorns with *Curculio elephas* exit holes (Branco *et al*., 2002). Future studies should carefully examine this difference in root lengths by also dividing the acorns that produced only roots from those which produce roots and shoots. This could be important because seedlings with leaves have an alternate source of energy, other than just the cotyledons, which may have affected their root length.

Six sites appear to have higher mean shoot length for seedlings with undamaged cotyledons. However, there appears to be no significant difference in mean shoot height between seedlings with insect-damaged cotyledons and seedlings with undamaged cotyledons. Due to the small number of acorns that produced shoots for most sites, further study of seedling development in response to insect-damaged cotyledons, with larger sample sizes, is recommended prior to drawing any conclusions about the effects of insect damage on seedling shoot height. The short duration of this experiment may have minimized the effects of damaged cotyledons on seedling growth. The seedlings with damaged cotyledons may also have lower start up reserves (for spring) than those with undamaged cotyledons once they are no longer dependant on the cotyledon so they may have lower survivorship and growth in future years (Phillips *et al*., 1995; Rohlfs, 1999; Post *et al*., 2001). Therefore, over a longer time period perhaps mortality of seedlings with insect-damaged cotyledons would occur and the shoot height and root length differences would become more pronounced. Or perhaps over a longer duration the seedlings would no longer be dependant on the cotyledons for nutrients and therefore would show growth and survival relative to soil and climate (external conditions) independent of damaged or undamaged cotyledons. Other studies have shown that significant differences in shoot height and root length are observable after only 28 days of seedling growth under different experimental treatments of oak acorns (Hopper *et al*., 1985). Therefore, a short interval of time may be appropriate to observe growth differences between insect-damaged and undamaged Garry oak acorns as the seedlings are directly dependant on the cotyledons for growth.

Filbert weevil and Filbert worm abundances - The actual number of insects collected was lower at all sites than abundance based on insect exit holes. This was likely as a result of collecting the acorns from the ground, as impact with the ground has been proposed as a trigger for the larva to emerge from the acorn for both insect species (Fong, 1999; Fukumoto and Kajimura, 1999; Rohlfs, 1999). Therefore, it is likely (and supported by the presence of insect exit holes during acorn collection) that some larvae had already left the acorns to over-winter in the soil, before the acorns were collected.

Measures of abundances based on the number of exit holes for weevils is presumed to be relatively accurate because weevil larvae are thought to remain within the acorn that their egg was originally oviposited into, chewing out of this acorn only when their development is complete (Rohlfs, 1999; Leiva and Fernandez-Ales, 2005). However, it is possible that in acorns with multiple weevil larvae, one insect will chew an exit hole and other larvae may use that same hole (Oliver and Chapin, 1984), making it possible that the estimate of weevil abundance based on exit holes is lower than reality. Measures of abundance for the moth larvae, based on insect exit holes, however, are complicated by their reported behaviour of chewing into and out of several acorns over the course of their larval stage (Rohlfs, 1999). This could lead to overestimates of actual moth larvae abundance in each sample if the estimate is based on exit holes. Also, some larval insects that were found from the acorns collected over the course of this study could not be attributed to one site or another, so the abundance based on insect numbers is not particularly accurate and it is likely lower than it should be for many, if not all, sites.

Fong (1999) found maximum abundances of *Curculio occidentis* and *Cydia latiferreana* in Garry oak acorns on Vancouver Island to be 0.079 and 0.087 insects per acorn, respectively. These values are considerably lower than the maximum abundances found for the 8 sample sites in the present study calculated by either the number of insects collected or by the number of species-specific insect exit holes. This could reflect differences in acorn crops between 1998 and 2005. In 2004 it was observed that Garry oak trees at many locations on Vancouver Island produced a mast crop, which may explain the high insect abundances observed in the 2005 acorn samples.

***Filbert weevil and Filbertworm prevalences* -** Without dissecting the acorns there is no way of knowing how many insects came from any one acorn; therefore, prevalence could not be calculated based on the actual number of insects collected and was instead calculated based on species-specific insect exit holes. Leiva and Fernandez-Ales (2005) also used insect exit holes to calculate prevalence levels in their study of *Cydia fagiglanda* and *Curculio elephas* in Holm-oak. They found a maximum of 72% infestation and an average of 16.6% infestation per tree (Leiva and Fernandez-Ales, 2005). Branco *et al*. (2002) found an average of 17-68% of *Quercus suber* acorns were infested by *Curculio elephas* and *Cydia splendana*, which is similar to the prevalence, of the two insect species combined, found in this study. Fong (1999) found that the Filbert weevil and the Filbertworm are present at infestation levels of 48-84% from Victoria to the Comox Valley on Vancouver Island. Rohlfs (1999) study in Victoria found that percent infestation ranged considerably among her sample sites and also between years with a minimum of 24.29% to a maximum of 91.39% infestation by the two insect species combined. In the present study it was found that prevalence of the two insect species combined was extremely variable, ranging from 9% (Headquarters Rd.) to 66% (Courtenay Cemetery).

Surprisingly, prevalence, based on insect exit-holes, for all 8 sample sites seems to be lower than the published values for the prevalence of these two insect species in Garry oak acorns. This could be explained by the relatively low numbers of acorns produced by Garry oaks in 2005. Variability of acorn production between trees at one site has been associated with variability in insect prevalence within sites (Dunning *et al*., 2002; Leiva and Fernandez-Ales, 2005). Though variation within sites was not taken into account in the present study, it could explain at least partially the prevalences of *Curculio occidentis* and *Cydia latiferreana* that were observed. It has been proposed that in mast years the adult insects are easily able to find acorns; therefore, they distribute their eggs to many acorns resulting in one larva per acorn. In years with low acorn production however, the adult insects are unable to find many of the acorns. This results in higher numbers of insect larvae per acorn (high abundance) in fewer acorns (low prevalence) (Miller and Schlarbaum, 2005). As 2005 was a low acorn crop year for at least 4 of the sample sites included in this study, as well as for many other Garry oak stands, which were not included in this study because insufficient numbers of acorns were found, low acorn production appears to be the general trend on Vancouver Island in 2005. Perhaps this idea, of poor acorn-finding ability by ovipositing insects in non-mast years affecting larval distribution in acorns, is supported by the results of the present study, which clearly shows one acorn frequently containing more than one insect larva, with many acorns containing no insects at all.

Courtenay Cemetery had the highest number of insect-damaged acorns, the highest number of insect-damaged acorns that germinated, the highest number of weevil-damaged acorns, and the highest number of acorns with damage from both insect species. The relatively older age of this site may explain these results. This site has more than 20 mature Garry oak trees which are large and may be approximately 120 years old. The long-term stability of this site may have allowed the insects to become well established. The site is central to a large area, of more than $4km^2$, with scattered Garry oak trees that are mainly less than 1km away from another Garry oak tree or stand. This distribution probably enhances the dispersal of the Filbert weevil and the Filbertworm adults. The Filbert weevil, particularly, is a weak flier (Lewis, 1992; Rohlfs, 1999) and the small size of both insects may limit their dispersal. Therefore, the relatively close proximity of trees in this area may enhance the insect's dispersal. The Courtenay Cemetery, being a relatively old cemetery, is a low traffic area, which means that the soil is not compacted to prevent larvae from burrowing in to the ground to over winter or prevent adults from emerging in the spring (Rohlfs, 1999). Also, moisture has been shown by Ricca *et al*. (1996) to be a critical factor affecting survival of weevils in acorns and this site was relatively damp at the time of acorn collection.

The Courtenay Cemetery site also illustrates the general trend of weevil damage being more common than moth damage, with 140 weevil-damaged but only 54 moth-damaged acorns collected from this site. Maeto and Ozaki (2003) found that, *in Quercus crispula*, *Curculio* spp. infested 25-70% of acorns, while *Cydia glandicolana* infested only 3-24% of acorns. Rohlfs (1999) also found, in the sites she studied, that the Filbert weevil attacks more acorns than the Filbertworm. The exception to this trend, of weevils being more prevalent, occurred at the University of Victoria site which had the highest number of moth-damaged acorns collected. This could reflect either a high relative number of moth larvae or a relatively low number of weevil larvae.

Low weevil larvae numbers could be a result of grounds maintenance and high pedestrian traffic on the University lawn which could compact the ground and reduce the number of weevils that survive and emerge as adults. This scenario should, however, affect both insect populations in an equivalent manner, so at least two other factors could contribute to explaining the relatively equal samples of weevil-damaged and moth-damaged acorns at this site. One possibility involves the introduced Grey squirrels that are abundant at the University of Victoria campus. It has been suggested that squirrels can be extremely specific in their foraging behaviour and it has been demonstrated that they select acorns with insects inside for increased nutritional value (Steele *et al*., 1996). Therefore it may be possible that the squirrels preferentially eat acorns with weevil larvae in them, thus lowering the population numbers of the weevils relative to the moths. Another possibility involves the insect's dispersal. Lewis (1992) and Rohlfs (1999) found that dispersal is limited in the Filbert weevil, while the moth distribution is relatively even throughout both a single tree and an entire stand. The acorns collected from the University of Victoria campus were collected from two isolated trees in the middle of a large field, and perhaps, while it is easy for the moths to disperse to these trees, it is harder for the weevils to find the trees in an open area, thus reducing the weevil population numbers at these two trees.

The maximum number of moth exit holes found in one acorn was 3 and the maximum number of weevil exit holes was 6; both of these acorns still germinated. This is comparable to a maximum of 5 Filbert weevil larvae in one acorn and 3 Filbertworm larvae in one acorn of the coast live oak (Lewis, 1992). Miller and Schlarbaum (2005) found a maximum of 8 *Curculio* spp. larvae in a single northern red oak acorn. Weevils were found to be more abundant but appear to be less damaging individually, because one acorn can support more than 6 weevil larvae (though whether or not those larvae survive to adult stage is unknown, as the larvae may be too small to mature). Overall, Filbert weevil larvae appear to do more damage due to their greater numbers, while moths appear to do more damage individually, simply based on the fact that it does not appear as though an acorn is able to support more than 3 moth larvae. There are, however, generally fewer moth larvae so they usually do less damage overall (except at the University of Victoria site).

Conclusions and future studies - This study demonstrates conclusively that acorns damaged by insect larvae can germinate into Garry oak tree seedlings making damaged acorns potentially important to Garry oak regeneration. Also, a single acorn can contain multiple larvae of one species of insect and even both species of insects and sometimes still germinate. Overall, 5 of 8 sites show the trend of higher percent germination of undamaged acorns than insect-damaged acorns. This study found higher percent germination of Garry oak acorns than Rohlfs (1999) for both insect-damaged and undamaged acorns from sites with abundant acorn crops in 2005. The percent germination of insect-damaged acorns was similar to literature values (for example, Rohlfs, 1999; Leiva and Fernandez-Ales, 2005) for acorns from sites with low/poor acorn crops in 2005. Various environmental factors, such as desiccation, in combination with the effects of the insects, likely influence Garry oak acorn germination.

The highest abundance and prevalence were found for the Courtenay Cemetery sample with 1.3 insects per acorn (based on insect exit holes), which is higher than published abundance for the Filbert weevil and the Filbertworm, and 66% of all acorns containing insects, which is lower than published infestation rates for these two insects. High abundance and low prevalence may be a result of the adult insect's inability to find acorns in low acorn crop years such as 2005. Weevils were found to be more prevalent than moths at all but the University of Victoria site (where 25% of collected acorns were infested by weevils and 25% by moths). Local environmental conditions, such as soil compaction, dispersal distances, seasonal moisture levels, mast *vs*. low acorn crop years, and the age of the Garry oak stand all may interact to determine Filbert weevil and Filbertworm distribution and abundance. Future studies should look at how well seedlings with insect-damaged cotyledons survive relative to their undamaged counterparts and at the timing of germination – whether or not insect exit holes speed up or slow germination rates. The Filbert weevil and the Filbert worm do reduce the germination potential of Garry oak acorns. However, their impact on Garry oak tree regeneration is likely minimal in comparison to the effects of herbivory by mammals, such as squirrels and deer, local environmental factors, such as desiccation, and general habitat alteration accelerated by humans.

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Appendix 1. Summary data table of statistical analysis examining differences in germination of insect-damaged vs. undamaged Garry oak acorns at 8 sampling locations.

	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
Site:	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
Date Collected 2005	Sept 23 rd	Oct 9th	Sept 8th	Oct 1st	Sept 4th	Sept 4th	Sept 4th, Oct 1st	Sept 19th
Number of Acorns:								
Collected	375	370	170	261	117	158	468	66
Germinated	144	351	14	210	15	12	131	16
Undamaged*	98	327	44	200	36	48	126	12
Undamaged Germinated*	49	324	4	178	4	1	72	10
Insect Damaged*	249	32	100	55	55	80	214	42
Insect Damaged Germinated*	95	27	10	32	11	11	59	6
Weevil Damaged	140	25	56	39	23	48	99	28
Moth Damaged	54	6	29	8	22	22	95	8
Both Weevil & Moth Damaged	55	1	15	8	10	7	20	6
Weevil Damaged Germinated	53	22	6	22	3	6	24	5
Moth Damaged Germinated	26	5	4	4	5	2	27	1
Both Weevil & Moth Damaged Germinated	16	0	0	6	3	3	8	0
* used in calculations for statistics: 2x2 contingency table, df=1,α=0.05								
X^2critical= 3.841 X^2_{Calc}=	3.592	23.488	0.018	26.111	0.66	3.531	28.049	18.158
P-value	<0.10	<0.001	<0.90	<0.001	<0.50	<0.10	<0.001	<0.001
Reject H_o	no, close	yes	no ♦	yes	no ♦	no ♦	yes	yes ♦

H_o: No relationship between germination and insect damage

H_A: Relationship between germination and insect damage -> data suggests that insect-damaged acorns are much less likely to germinate than undamaged acorns

♦ indicates sample size of less than 20 used for statistical analysis.

	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
Total % Germination	38	95	8	81	13	8	28	24
% undamaged germinated	50	99	9	89	11	2	57	83
% insect damaged germinated	38	84	10	58	20	14	28	14
% weevil damaged germinated	38	88	11	56	13	13	24	18
% moth damaged germinated	48	83	14	50	23	9	28	13
% both damaged germinated	29	0	0	75	30	33	40	0
Site conditions at collection	Damp	Damp	Dry	Damp	Dry	Dry	Damp	Dry
Site relative acorn production	Abundant	Abundant	Low	Abundant	Low	Low	Abundant	Low

Appendix 2. Summary data of root length for seedlings with insect-damaged Cotyledons and undamaged cotyledons.

Site:	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria	2	8
	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
# Acorns with Roots:								
Undamaged	41	291	3	166	3	0	72	10
Insect Damaged	61	22	8	21	6	5	55	6
Mean Root Length(cm):								
Undamaged	15.1	13.07	14.67	18.06	6.33	0	12.92	14.1
Insect Damaged	10.03	10.09	7.25	14.9	8.83	6	5.7	8
Statistics: $\alpha=0.05$								
degrs. freedm.	100	311	9	185	7	0	125	14
critical t-value	1.645	1.645	1.833	1.645	1.895	x	1.645	1.761
calculated t-value	3.801	2.422	1.099	1.810	0.781	x	4.903	1.619
Reject H_o	yes	yes	no ♦	yes	no ♦	x ♦	yes	no ♦
P-value	<0.0005	<0.025	<0.25	<0.05	<0.50	x	<0.0005	<0.05

♦ indicates sample size of less than 20 used for statistical analysis.

H_o: Insect damaged acorns mean root length is larger than or equal to undamaged acorns mean root length, (there is no significant difference)

H_A: Insect damaged acorns mean root length is shorter than undamaged acorns mean root length

Appendix 3. Summary data of shoot length for seedlings with insect-damaged Cotyledons and undamaged cotyledons.

	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
Site:	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
# Acorns with Shoots:								
Undamaged	29	271	2	150	3	1	50	9
Insect Damaged	28	18	2	21	3	2	17	3
Mean Shoot Length(cm):								
Undamaged	12.31	14.9	11	15.82	15.33	8	12.12	10.83
Insect Damaged	11.36	12.33	12	15.14	10.33	9	6.82	4.83
Statistics: $\alpha=0.05$								
degrs. freedm.	55	287	2	169	4	0	65	10
critical t-value	1.645	1.645	2.920	1.645	2.132	x	1.645	1.812
calculated t-value	0.5171	1.5444	0.4472	0.4337	1.1119	x	3.197	2.675
Reject H_o	no	no ♦	no ♦	no	no ♦	x ♦	yes ♦	yes ♦
P-value	<0.50	<0.10	<0.75	<0.50	<0.25	x	<0.005	<0.025

♦ indicates sample size of less than 20 used for statistical analysis.

H_o: Insect damaged acorns mean shoot length is larger than or equal to undamaged acorns mean shoot length, (there is no significant difference)

H_A: Insect damaged acorns mean shoot length is shorter than undamaged acorns mean shoot length

Appendix 4. Abundance of the Filbertworm and Filbert weevil larva based on the number of larva actually collected, by site.

	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
Site:	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
Total # of Acorns	375	370	170	261	117	158	468	66
# weevil larva	278	7	62	0	19	26	47	9
Weevil Abundance	0.741	0.019	0.365	0	0.162	0.165	0.1	0.136
# moth larva	34	0	25	2	10	11	38	7
Moth Abundance	0.091	0	0.147	0.008	0.085	0.07	0.081	0.106
Total # insects	312	7	87	2	29	37	85	16
Insect Abundance	0.832	0.019	0.512	0.008	0.248	0.234	0.182	0.242

Appendix 5. Abundance of the Filbertworm and Filbert weevil larva based on the number of insect exit holes observed for each, by site.

	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
Site:	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
Total # of Acorns	375	370	170	261	117	158	468	66
# weevil holes	372	30	105	71	40	83	156	52
Weevil Abundance	0.992	0.081	0.618	0.272	0.342	0.525	0.333	0.788
# moth holes	124	9	49	16	38	33	127	17
Moth Abundance	0.331	0.024	0.288	0.061	0.325	0.209	0.271	0.258
Total # insect holes	496	39	154	87	78	116	283	69
Insect Abundance	1.323	0.105	0.906	0.333	0.667	0.734	0.605	1.045

Appendix 6. Prevalence of the Filbertworm and Filbert weevil larva based on the number of insect exit holes observed for each, by site.

	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
Site:	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
# of Acorns:								
Total	375	370	170	261	117	158	468	66
with insect holes	249	32	100	55	55	80	214	42
with weevil holes	195	26	71	47	33	57	119	34
with moth holes	109	7	44	16	32	32	115	14
with holes of both spp.	55	1	15	8	10	9	20	6
Preval. of insects	66%	9%	59%	21%	47%	51%	46%	64%
Preval. of weevils	52%	7%	42%	18%	28%	36%	25%	52%
Preval. of moths	29%	2%	26%	6%	27%	20%	25%	21%
Preval. of both	15%	0.30%	9%	3%	9%	6%	4%	9%

Appendix 7. Numbers of insect exit holes found in one acorn by site.								
Site:	7 Courtenay 6		4 Nanaimo 5		3	1 Victoria 2		8
	Courtenay Cemetery	Headquarters Rd.	Pipers Lagoon	Old Hwy	Bow Park	Beckwith Park	U of Victoria	Hornby Island
Max # of insect holes found in one acorn	7	2	6	4	3	5	4	4
Germinated? Y/N	Y	Y	N	N	Y	Y	Y	N
Max # of weevil holes found in one acorn	6	2	5	4	3	4	4	3
Germinated? Y/N	Y	Y	N	N	N	N	Y	N
Max # of moth holes found in one acorn	2	2	2	1	3	2	3	2
Germinated? Y/N	Y	Y	N	Y	Y	N	Y	N
Max # of both holes found in one acorn	7 W5,M2	2 W1,M1	6 W4,M2	3 W2,M1	3 W2,M1	5 W4,M1	3 W1,M2	4 W1,2,3;M3,2,1
Germinated? Y/N	Y	N	N	Y	N	Y	Y	N

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