

The Temporal and Spatial Distribution of Filbert Weevil Infested Acorns in an Oak Woodland in Marin County, California¹

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Abstract: Two-hundred shoots contained within randomly selected locations from each of thirty-six coast live oak, *Quercus agrifolia*, trees were sampled to determine the abundance and spatial distribution of acorns infested by the filbert weevil, *Curculio occidentis* in northern California during 1989. The seasonal abundance of infested acorns was highest at 30 percent during mid-September. Overall, 25 percent of all acorns observed on sample trees revealed signs of boring insect activity. Slightly higher infestation rate of 38 percent was obtained from laboratory dissections of field collected acorns (n = 501). Of those acorns dissected in the laboratory found to contain insect larvae, 70 percent contained *C. occidentis* and 30 percent contained the filbertworm, *Melissopus latiferreanus*. Although acorns were numerous on the sunny side of the tree, infested acorns were more abundant on the shady side. The differential distribution of acorns spatially within trees, acorn survivorship, and the impact of insect and other animal acorn predators on acorn production are discussed.

The sweeping branches of a large regal oak is a vision common to all of us. As a single tree or forest stand, our native oaks play an important role in wildlife and human ecologies. In California there are 18 species of oaks, 10 of which reach tree size (Tucker 1980; Griffin and Muick 1990). The total acreage for California's oak species has been estimated at 15-20 million acres (Plumb and McDonald 1981). For thousands of years, native oaks have been a prominent and persistent floral feature in California. Unfortunately, it now appears many of our oak woodlands have been drastically reduced and are poorly regenerating (Mayer and others 1986; Bolsinger 1987; Muick and Bartolome 1987).

Because of poor regeneration and dwindling oak habitats in California, there is renewed interest in factors that restrict or inhibit acorn development. Acorns have many predators, including insects, birds, and mammals (Brown 1980; Griffin 1980; Koenig 1980). However, while acorns are still on the tree, the filbert weevil, *Curculio occidentis* (Casey) (Coleoptera: Curculionidae) and filbertworm, *Melissopus latiferreanus* (Walsingham) (Lepidoptera: Olethreutidae) can play a signifi-

cant role in the reduction of the acorn crop. The filbert weevil is the more commonly found insect within infested acorns (Brown and Eads 1965). Acorns of all our native oak species are attacked by both filbert pests during the summer and autumn months. Both insects have a single generation per year. However, the filbert weevil can hibernate for several years in the soil as a pupa while the filbertworm overwinters in a single season as a larva (Furniss and Carolin 1977). Acorn crop reduction due to these insects has been reported as high as 80 percent for some locations (Keen 1958; Furniss and Carolin 1977).

These insect species attack acorns differently. The female filbert weevil, after cutting a small hole, deposits her eggs inside of acorns. Filbertworm larvae must bore into acorns unaided by the adult female. The boring into acorns by these insects often results in the oozing of large amounts of sap from acorns. This sap contains a bacterial infection known as dripping nut disease and is commonly associated with insect ovipositional activity on acorns (Hildebrand and Schroth 1967).

The following study was undertaken to quantify the seasonal abundance and spatial distribution of boring insects inside acorns for coast live oaks, *Quercus agrifolia* Née in northern California. The study objectives were: 1) to record the seasonal appearance of insect infested acorns, and 2) to determine the spatial distribution of infested acorns within tree crowns. The reasons for selecting these objectives were the lack of information on the timing of insect attack of acorns and how insects spatially exploit acorns within trees. The reasons for selecting coast live oaks as the host tree included its prominence and importance to wilderness and urban habitats along the coastal belt of California from Baja California Norte to Mendocino County (Griffin and Critchfield 1972). In addition, information gathered from studying this oak may add insight into our understanding of other insect phenologies on more threatened oak species.

MATERIAL AND METHODS

The location for this study was Sky Oaks, Marin County, California. The study area is a 8,000 hectare water shed containing Mount Tamalpais and is maintained and operated by the Marin Municipal Water District. The specific site used for the study was a 22 hectare valley called Bon Tempe meadow. This site is primarily a native oak woodland, composed of coast

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live oak, *Quercus agrifolia*. Historically, the meadow was grazed by cattle up until 1932. The meadow, on a south facing slope at approximately 213 meters above sea level, now contains approximately 300 coast live oaks as old as 60 years and varying in height from seedlings to 15 m sized trees. The reasons for using this site over other locations included 1) abundance of coast live oak trees, 2) cooperation by the Marin Water Municipal District, 3) past evidence of filbert weevil and filbertworm activity, and 4) close proximity to the University of California, Berkeley campus.

A 3 by 3 factorial model was used to assess the spatial patterning of acorns within trees. The three vertical locations created within trees were low, mid, and upper crown. Three horizontal locations, northeast, south, and northwest were also created. The total number of sampling locations created from this design was nine. Each of the nine sampling locations was replicated four times resulting in a total of 36 trees being used for the study. This 3 by 3 spatial sampling design was used over 4 by 4 or 4 by 3 designs which use traditional compass designations (north, east, south, and west) because the smaller number of sampling locations enhances significance testing of mean counts for biological systems which are highly variable. Other researchers have shown acorn numbers to vary greatly between trees and years (Carmen and others 1987). In addition, using only three horizontal positions (northeast, south, and northwest) instead of four still allows for sunny versus shady side of tree comparisons.

Individual coast live oak trees were selected from the approximately 300 which occurred at Bon Tempe meadow. The criteria use for selecting trees were: 1) size between 4 - 8 meters, 2) level ground under tree, 3) symmetrical crown, and 4) high potential for producing acorns. High potential of acorn production was determined in March by using only those trees which produced large numbers of catkins. It was assumed trees with high numbers of catkins also produced high numbers of acorns. Average height ($\pm$ SD) of sample trees was 5.8 ± 1.5 m and average DBH ($\pm$ SD) at one meter above the ground was 124.8 ± 46.9 cm.

One of the nine possible sampling locations was randomly assigned to each of the 36 trees. Using a 5.5 m ladder, 200 shoots were selected (non randomly) in the center of each sampling location for all trees and labelled for future observations. These shoots were visited once a month from April through December 1989 to collect data on 1) number of female flowers, for April only 2) total number of acorns, 3) number of insect scarred acorns, and 4) number of acorns showing insect oviposition scars and dripping sap.

To better gauge the relative abundance of filbert weevil and filbertworms in acorns on sample trees, 100 acorns were collected from six non-sample trees during each field visit from July to November (501 total acorns). The collection process of these acorns was non random and basically consisted of collecting easily accessible insect scarred acorns at ground level. These field collected acorns were brought back to the laboratory for dissection and insect species determination. It was assumed that the frequency of filbert weevil and filbertworms found in the

dissection of non-sample tree acorns would be similar to frequency found for sample trees.

Acorn production, survivorship, and infested acorn counts were graphed through time using Julian Day as the x-axis. Means for undamaged and infested acorns counts among spatial locations were analyzed for significant differences using the Duncan multiple comparisons test (PROC GLM, SAS Institute 1985). Since it was not possible to differentiate filbert weevil ovipositional scarring from filbertworm in the field, all insect scarred acorn data from sample trees was pooled. Differences in the proportions of insect species from laboratory dissected acorns were analyzed using Chi-Squared tests (PROC FREQ, SAS Institute 1985).

RESULTS AND DISCUSSIONS

From the laboratory dissection data, 38 percent of all acorns contained insect larvae. Seventy percent of those acorns containing larvae were filbert weevils and 30 percent were filbertworms. This difference in species composition was significant ($X^2 = 138.9$, $df=1$, $P < 0.0001$). Filbert weevil numbers varied from 1 to 5 within acorns. While filbertworm numbers varied from 1 to 3. However, 12 acorns contained both filbert weevil and filbertworm larvae inside the same nut. Other researchers have shown that it is not uncommon for acorns to be infested by one or more species of insect, even within the same acorn (Kearby, Christisen, and Myers 1986). However, increasing numbers of insects inside acorns probably decreases the success of acorn germination and seedling survival. Griffin (unpublished data³) has found that insect infested acorns, although they may germinate, rarely produce vigorous seedlings. Since filbert weevils were found to be more than two time more common than filbertworms, I will restrict my discussion comments to filbert weevils only.

The number of survived acorns declined steadily, almost logarithmically, throughout the season (fig. 1a). The peak period for acorn survival was 60 percent in May (Julian Day 178). By late-December, less than 1 percent of acorns remained on trees. Infested acorns became noticeable on trees soon after adult filbert weevil emergence from the soil in mid-July (fig. 1b). The percentage of infested acorns was seasonally highest at 30 percent by mid-September. Overall, 25 percent of all acorns on sample trees showed external signs of containing beetle larvae. This figure compares favorably to the 38 percent infested rate found from laboratory dissections. Acorn insect infestation rates have been found to vary considerable among sites and years, as much as 80 percent, throughout California (Brown and Eads 1965; Koenig unpublished data⁴).

³ Data on file, Hastings Reservation, University of California, Carmel Valley, California.

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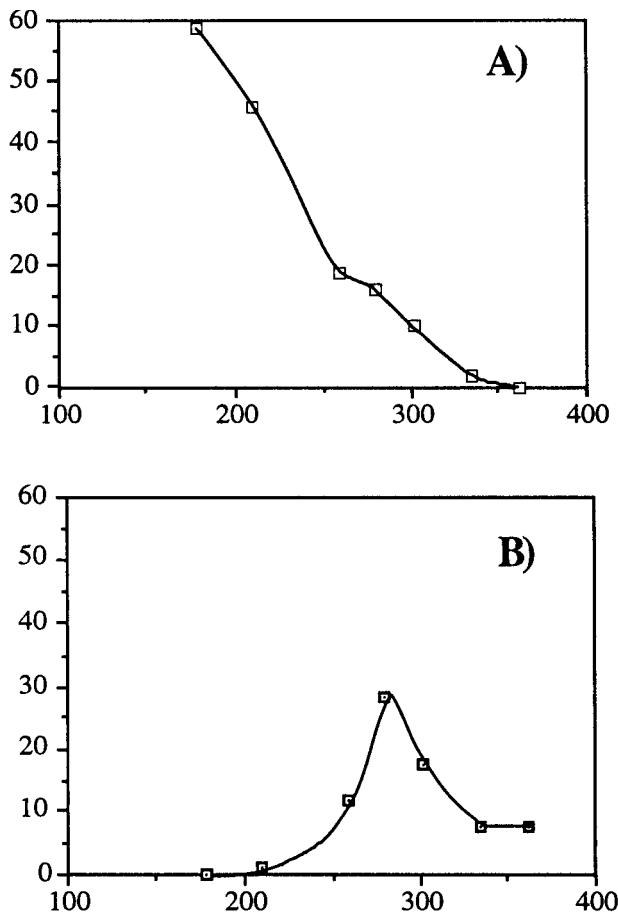


Figure 1—The percentage of survived acorns (A) and damaged acorns (B) from 36 coast live oaks at Sky Oaks, Marin County, California, 1989. Pooled data from observations of 200 shoots per tree. The time axis is expressed in Julian Day.

From the data, it appeared that insects had little impact on acorn survival. Even at peak abundance in mid-September (Julian Day 280), infested acorns only amounted to one third of the acorn crop. However, by this time, only 20 percent of the original acorns from May (Julian Day 178) still remained on trees (figs. 1a and 1b). Other vertebrate predators of acorns (e.g., rodents, deer, woodpeckers, etc.) apparently also had little impact on the acorn production since even before the autumn masting period (mid-July, Julian Day 210) less than 20 percent of the crop remained on trees. The greatest mortality of acorns, approximately 25 percent, occurred during mid- June (Julian Day 210). In June, beetle oviposition activity has not yet commenced and the immature acorns are not developed enough for consumption my vertebrate acorn predators. These results suggest that other factors (i.e., weather, soil condition, or tree physiological condition) impact the survival of immature acorns in early summer.

Vertically within the crown, significantly more undamaged acorns were concentrated in the lower two crown levels ($F = 4.42$, $df = 2, 31$, $P < 0.05$, Table 1). The differences among crown levels was as great as four-fold. This result is not surprising, the crown of oaks is asymmetrically biased with more foliage in the lower two levels. With more foliage in the

lower crown you would expect greater numbers of acorns. Insect damaged acorns appeared to be evenly distributed throughout the crown.

Horizontally, significantly more undamaged acorns were found in the south location (table 1). Surprisingly, significantly more infested acorns were found on the northeastern side of trees. These data suggest that the filbert weevil is not exploiting the acorn resource on trees to its fullest. Field observations at the time of sampling provided a possible explanation for this differential partitioning of acorns and weevils.

While conducting the study, it was noticed that acorns on the west side of trees (most exposed to the sun) appeared split, as if bursting from within. These acorns were dripping sap and probably contained dripping nut disease as well as insect larvae. The oviposition stings by weevils and cynipid wasps (Cynipidae) is presumed to be the means of entry of this bacteria pathogen into acorns (Hilebrand and Schroth 1967). As these acorns burst open in late summer, they were soon invaded by ants, wasps, other microbial pathogens, and possibly parasites. It is possible that the fermentation gases produced by the drippy nut disease expand when heated causing the damage seen. Drippy nut disease has been shown to require temperatures of about 29° C for development. These high temperatures are not uncommon on the sunny sides of oaks especially during the late summer. For conifers, significant temperature differences have been shown between sunny and shady sides of individual pine cones (Schaefer 1963). Perhaps the adult female filbert weevil can detect changes in temperatures for varying sides of a tree. Such behavior could enhance larval survival and explain the clumped spatial patterning of infested acorns observed in the field.

The results of this study have important applied implications for pest monitoring and acorn yield studies. Realistically, oaks are sometimes treated for acorn insect pests in urban areas of California. Knowing that filbert weevil infested acorns are

Table 1—Spatial distribution of total and infested acorns within tree crowns at Sky Oaks, Marin County, California, in 1989¹.

Within-tree Parameters	Total acorns		Infested acorns	
	n ²	$\bar{X}/100$ shoots $\pm$ SEM ³	n	$\bar{X}/100$ shoots $\pm$ SEM ³
Vertical Stratum				
Upper	60	1.2 $\pm$ 0.3 a	60	0.6 $\pm$ 0.2 a
Mid	60	8.0 $\pm$ 1.5 b	60	2.4 $\pm$ 0.5 b
Low	60	8.7 $\pm$ 2.6 b	60	1.8 $\pm$ 0.4 b
Horizontal Stratum				
NE	60	4.6 $\pm$ 0.9 a	60	2.4 $\pm$ 0.5 a
S	60	8.7 $\pm$ 2.7 b	60	1.6 $\pm$ 2.8 ab
NW	60	4.6 $\pm$ 1.4 a	60	0.8 $\pm$ 1.4 b

¹Pooled data from monthly inspections of 200 shoots/tree (n=36) for August through December.

²n, number of vertical (3) or horizontal (3) sampling locations times four replicates times five visits.

³Means followed by the same letter within each column and parameter are not significantly different ($P < 0.05$; Duncan multiple range test [SAS Institute 1985]).

concentrated on the shady side of oaks, can significantly reduce pest monitoring time and help locate larval populations within the crown. More accurate pest monitoring decisions often can reduce the use or need of pesticides, which already overburden many of our environments. Currently, acorn yield studies are based on visual ranked categories or timed counts acorn counts (Graves 1980; Carmen and others 1987). For the current study, flower counts in March proved to be a good predictor of immature acorn numbers in mid-summer (fig. 2). However, additional data from larger trees and from other species will be needed to fully evaluate the usefulness of this acorn yield model.

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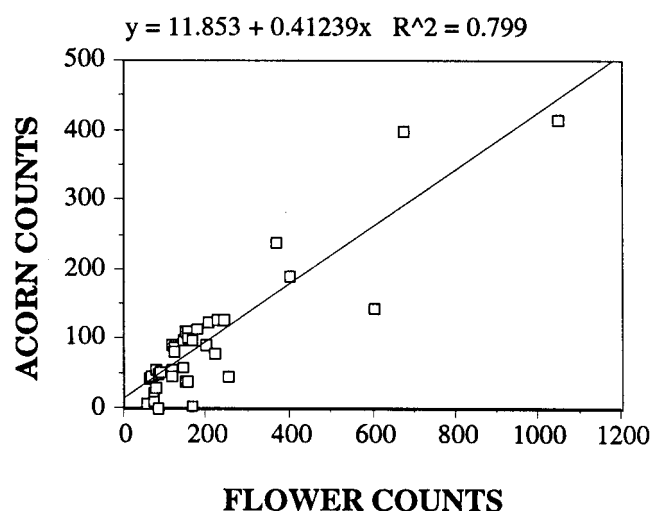


Figure 2—Regression plot of acorn and female flower counts. Data points represent flower counts from 200 shoots for each of 36 coast live oaks from Sky Oaks, Marin County in April 1989 correlated with acorn counts taken from the same shoots and trees in May 1989.

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