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Organic farming research project report submitted to the Organic Farming Research Foundation:

Project Title:

Bird and arthropod predation of codling moth in apple orchards

FINAL PROJECT REPORT

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Photo 1. Chestnut-backed chickadee feeding nestlings in the Deer Park apple orchard where the first year of this project's research was conducted.



Photo 2. Adult chestnut-backed chickadee (*Parus rufescens*) removing fecal sac from the cavity nest in an apple tree. This species is the the same genus as great tits (*Parus major*) and blue tits (*Parus caeruleus*), which were responsible for eating up to 95% of the overwintering codling moth larvae experimentally exposed in British apple orchards (Solomon et. al., 1976).

INTRODUCTION

Codling moth is a serious worldwide pest of apples and pears, and is becoming an increasing problem in walnuts, prunes, and a few varieties of plums. Birds have been shown to be part of the system that reduces codling moth numbers. As early as 1746, Roesel published an account on the codling moth, recognizing birds as beneficial:

(Codling moth) conceal themselves so thoroughly as scarcely to be found by men; but the woodpeckers and similar birds know how to discover quickly their retreats.

In 1911, McAtee, a USDA researcher, reported that 36 bird species were important codling moth predators, which conclusion was determined by examining the stomach contents of birds and by other methods. Between the 1950's and 80's, researchers documented 50% to 99% predation of codling moth by indigenous bird species in Canada, Britain, Poland and New Zealand (MacLellan, 1959; Mailloux and LeRoux, 1960; Solomon et al., 1976; Zajac, 1979; Wearing, 1975 a).

Codling moth eggs are laid on the leaves or fruit, and upon hatching, the minute larvae bore into fruit, where, after about 10 to 40 days of feeding, they emerge at maturity and seek sheltered places, such as holes or cracks in the trees or ground, or crevices under bark scales, in which to spin their cocoons. Here they either pupate in a couple of weeks, or, if winter is near, postpone pupation until the following spring (Flint, 1991). This research project was designed to study the effects of birds on codling moths at the overwintering diapausal stage, i.e. when the insects are in cocoons and concealed under bark during the coldest part of the year.

Organically approved practices exist to reduce codling moth populations, but few of these practices are effective on the overwintering diapausing stage, when the insect is in its cocoon form. Conventional management of codling moth using pesticides has its own apparent problems and no long term solutions. Applications of a pyrethroid can produce secondary pest outbreaks of the two-spotted spider mite in apples (Flint, 1991). Cross resistance by the pest insects to other materials is occurring in the U.S., where moth populations originally resistant to guthion are also showing resistance to pyrethroids (Stockwin, 1998).

Some insects are known to be important natural enemies of the codling moth in its diapausing stage. Two imported wasp species are documented to parasitize larval cocoons¹. Certain ants and beetles have been known to prey upon the diapausing larvae and earwigs are thought to be important predators of this stage (Jaynes and Marucci, 1947; Wearing, 1975a and 1975b; Hagley and Allen, 1988).

The question of whether bird predation was occurring in Central California coastal apple orchards was answered with a preliminary survey. Apple trees in ten organic orchards were examined for signs of bird predation. Usually a small hole on a piece of bark with an empty cocoon underneath was observed (Figure 1). Forty percent predation was thought to be taking place.

¹ Mills of U.C. Berkeley discussed his work with codling moth parasites from Kazakhstan at the UCCE Walnut Grower's meeting in Hollister in February, 1996.

METHODS & RESULTS

Predation Trials

Year one methods. Replicated trials were located in two dry-farmed organic apple orchards in the fall and winter of 1996. Deer Park orchard contained 7 acres of Pippin and Red Delicious apple trees, 72% of which were present, and was adjacent to mixed evergreen vegetation on two sides. Happy Valley orchard was 3 acres of mostly Pippin trees, with a few Red Delicious and European Pears (68% tree cover) located on a one hundred acre tract with an extensive pear orchard and mixed evergreen habitat surrounding the parcel (Figure 2).

Codling moth larvae were obtained from UC Berkeley, where the insects were raised in conditions comparable to the fall equinox. The cool temperatures and short day lengths present in the lab physiologically triggered the larvae into a long diapause instead of a quick pupation into moths.

In the first year, the larvae were placed directly on the trees to spin cocoons. The insects were put on the trunks or branches at a height where codling moth are typically found, and were covered with a plastic cup until they had spun cocoons in crevices of tree bark or under bark scales. One or two codling moths were exposed and compared with one or two caged (excluding birds) and screened (excluding insects) codling moths per tree.

In order to determine what the effects of bird predation looked like, the literature was consulted. The New Zealand researcher noted that the bird called Silvereye makes a characteristic neat, round hole in the cocoon during feeding, or rips open one side (Wearing, 1975a). One of the Canadian researchers stated that Downy and Hairy Woodpeckers each leave distinctive beak marks on the bark when attacking codling moths (MacLellan, 1971). The following description of predation is excerpted from a British study:

The marks of (codling moth) predation by (British) birds are often plain to see: rounded holes going directly into the bark, oblique beak-marks and the scars of recently removed flakes of bark; and usually the greater part of the cocoon, or at least its underside, remains attached to the tree (Solomon et al, 1976).

It was assumed that cocoons that were partially or totally missing must have been attacked by a large predator, such as a bird, since a small predator would not be able to remove pieces of the cocoon without repeated effort, and for no obvious purpose. A small rip in the cocoon was counted as arthropod attack. If a predaceous arthropod was found on top of a cocoon and the larva was either dead or missing, the moth's demise was attributed to an arthropod predator. Mortality was attributed to a pathogen if the larva inside the cocoon was covered with fungal hyphae, or if the larva looked melted, as if it were decaying.

Year One Results. Nineteen percent and 11% codling moth cocoons appeared to be attacked by birds in the exposed trials at Deer Park and Happy Valley orchards respectively. Eleven percent and 4% codling moths appeared to be preyed on by arthropods in the caged trials, and 11% and 11% moth larvae were diseased in the screened trials at Deer Park and Happy Valley orchards, respectively.

Year Two Methods. For the cool season trials of 1997-98, Happy Valley orchard was again utilized and a new abandoned 9-acre orchard containing mixed varieties of apples in the Bonny Doon area was used. The Bonny Doon orchard, abandoned for at least 10 years, had 38% coverage of apple trees interspersed

with invading shrubs, herbs and grasses, several ancient redwood stumps and was surrounded by native mixed evergreen habitat (Figure 2).

The procedure for placing codling moth in the orchards changed in the second year because of a larvae crop failure at UC Berkeley in the early fall. The next batch of codling moth would not have been at the proper stage until the weather had turned cold, so methods used by British researchers were employed. The larvae were placed on apple logs indoors where temperatures allowed the insects to actively spin secure cocoons. Once properly outfitted, the codling moths and their logs were placed in the trees. Each tree contained the same treatment, either all exposed or all caged; the screened trials were discontinued because of the increased incidence of disease. The numbers of larvae placed on each tree increased to a median of 13.5 codling moths, which was equal to a naturally occurring amount found in some of the orchards.

Bird predation was scored the same as in year one if the cocoons were mostly missing, completely nu'ssing, or if the bark chip covering the cocoon had a bird peck through it to the codling moth. An additional technique was used by rating a cocoon with rips or holes larger than 2.0 mm as bird predation. The cutoff of 2.0 mm was made since distinguishing between 1.7 mm (the smallest bird peck found in bark chips) and 2.0 mm in winter field conditions could not be accurately done. Larval mortality was attributed to arthropods if the cocoon had a hole smaller than 2.0 mm, or if it contained a parasitoid. Disease was scored the same as the previous year.

Year Two Results. Very high total predation was recorded in the exposed treatments: 83% mortality in Happy Valley orchard, and 99% mortality at the abandoned orchard, of which 77% and 91% respectively were caused by birds, and the remainder by arthropods and diseases. Even though there appeared to be some accidental bird predation under the cages, there was a statistically significant difference (Chi-square $p < 0.001$) between the exposed and caged moth data at each orchard, which suggested that bird predation was occurring in the exposed trials (Figure 3 & 4).

Arthropod predation and disease impacted the larvae in the two treatments in Happy Valley at about the same rates, with 5% and 2% in the caged trials and 5% and 1% in the exposed trials, respectively. A greater influence was exerted on the caged than the exposed treatments in the abandoned orchard, where 12% and 18% versus 5% and 3%, were recorded, respectively. The wasp parasitoid, *Liotryphon caudatus*, was found inside one of the caged cocoons at Happy Valley orchard, presumably a descendant from an earlier UC Berkeley release of these parasitoids.

Year Three Methods. The abandoned Bonny Doon orchard was used for predation trials in the winter months of 1998-89. A new technique for placing the codling moth in the orchard was used to save time. The larvae were put in trays that were lined with brown paper and strewn with pieces of apple bark chips. After the larvae spun cocoons between the paper and the bark, the paper was cut and trimmed to the size of the chip. These bark chips were subsequently nailed to the apple trees at an average of nine per tree, twelve trees in all. Half the codling moth were exposed to all predators and the other half were caged.

Year Three Results. Birds accounted for 83% predation in the exposed trials and no predation under the cages; arthropods 2% predation in the exposed and 4% under the cages. The results showed statistically significant differences (Chi-square $p < 0.001$) between the exposed and caged trials (Figure 5).

Bird Surveys

Year one and two methods. Bird surveys were conducted in the orchards approximately once per month from November through July of year one in order to determine which birds were most likely responsible for codling moth predation. All birds present in the orchards were noted, but only the insectivorous species were reported (for example, raptors were not counted). Bird surveys were conducted about once per month from September through May in year two. The insectivorous songbird data was used in the analysis of foraging guilds, species diversity, abundance and in an index of diversity.

Year one and two results. The relative importance of the thirty-one insectivorous bird species present in all three orchards was assessed in relation to foraging guilds. Figure 6 shows the average number of insectivorous bird species per survey in all the orchards that periodically or continuously forage in trees. Table I lists the other insectivorous aerial and ground foraging species recorded in the three orchards. Six species in Figure 6, and two species in Table I had been documented by McAtee in 1911 to be found with codling moths in their stomachs (scrub jay, American robin, downy woodpecker, Brewer's blackbird, bushtit, black-headed grosbeak, Pacific sloped flycatcher, California towhee). Four different bird species (see Figure 6) recorded in the three orchards were found to be predators of codling moth by either McAtee (1911) or other researchers around the world (European starling, ruby-crowned kinglet, northern flicker, oak titmouse). Some of the remaining bird species present in the orchards are related to important codling moth predators indigenous to other locations globally.

TABLE I
AERIAL AND GROUND FORAGING GUILDS OF INSECTIVOROUS
BIRD SPECIES RECORDED IN EXPERIMENTAL ORCHARDS

Aerial forager	Ground forager
Pacific sloped flycatcher ^a	California towhee ^a
ash-throated flycatcher	spotted towhee
olive-sided flycatcher	dark-eyed junco
black phoebe	white-crowned sparrow
barn swallow	song sparrow
violet-green swallow	fox sparrow

Note and source: ^a Bird species found with codling moth in their stomachs. McAtee, 1911.

Insectivorous bird species diversity is shown in Figure 7. Differences in species diversity between the abandoned orchard and the managed orchards was significant (Mann-Whitney $p < 0.05$), suggesting that bird species diversity is greater in the abandoned orchard. Differences between all the orchards were also significant (Kruskal-Wallis $p < 0.05$). The fewest total number of bird species (15) was recorded in Happy Valley orchard, while the greatest total number (23) was documented in Bonny Doon orchard.

The abundance of insectivorous birds in the abandoned orchard was significantly higher than both managed orchards (Figure 8) (Mann-Whitney $p < 0.05$), and the differences between all orchards were significant (Kruskal-Wallis $p < 0.05$). The lowest abundance of birds (114) was recorded in Deer Park orchard, and the most (172) was noted in Happy Valley Orchard in year two.

Insectivorous bird species diversity as related to habitat at Happy Valley and Deer Park orchards do appear to be distinct. An increasing gradient of species diversity is seen at Happy Valley in year one (Figure 9), from the transects closest to the disturbed habitat of coyote brush to the transects neighboring the higher quality oak woodland habitat. The trend of increasing species diversity at Happy Valley in year two is not as distinct. At Deer Park orchard, transect one seems to have higher species diversity and it is

adjacent to quality habitat (Figure 10). Habitat influences were not graphed for Bonny Doon orchard since it was surrounded by unmanaged grasslands and forests and semi-rural and rural roads which seem to equally influence the insectivorous bird species on all sides, and so the effect of habitat could not be determined.

Two bird species were observed nesting in cavities of apple trees during the experimental trials. A pair of chestnut-backed chickadees nested in the Deer Park orchard in the spring of 1996, and a pair of downy woodpeckers nested in the Happy Valley orchard in the spring of 1997.

DISCUSSION

The results of this study show that birds, and to a lesser extent, arthropods can be important allies in reduction of codling moth in apple orchards. No predators were directly observed feeding on the codling moth, but of the 31 insectivorous bird species recorded in all three orchards, 12 had been documented by researchers around the world to attack the pest. Some of the remaining bird species present in the orchards are related to important codling moth predators indigenous to other locations globally. These known bird predators and/or their related family members presumably were attacking the codling moth in the caged treatments of the experimental orchards.

Diet is an important component in whether a bird species is predator or not. Bird diets consist of both animal and plant materials, and some birds, such as downy woodpeckers, have been recorded by Martin et al. (1951) to consume over three-quarters of their diet from a variety of arthropods in a year. Figure 11 shows the specialized tongue a woodpecker species uses to extract its arthropod prey. Birds such as American robin were reported to consume arthropods chiefly in the spring when they are feeding their fast growing young, although they continue to feed on a multitude of insects throughout the year (Martin, Zim and Nelson 1951). A few birds such as scrub jays are listed in the UC IPM Apple and Pear guide (Flint, 1991) as pest species, even though they have been reported to consume one quarter of their diet in arthropods (Martin, Zim and Nelson, 1951). All three species were previously reported to have codling moths in their stomachs in McAtee's 1911 study, and all three were present in the author's experimental orchards. Some birds may prefer other arthropods over codling moth or they may use foraging strategies that do not detect this pest, but the percent arthropods in a bird's diet indicates the potential importance as a predator of codling moth.

Birds occupy distinct foraging guilds in the orchards and impact codling moth differently as a result. The majority of the California and spotted towhees' time is spent foraging in low-lying bushes or on the ground, and it is this type of forager that may be impacting codling moth diapausing in the ground litter. Aerial foragers, such as the Pacific slope, olive-sided and ash-throated flycatchers, may be consuming the adult codling moth on the wing. Some bird species are almost continuously foraging in the trees, such as ruby-crowned Kinglet, downy woodpecker, oak titmouse, and chestnut-backed chickadee (Ehrlich, Dobkin and Wheye, 1988). Others forage both in the trees and on the ground, including scrub jay, American robin, European starling, Steller's jay, and northern flicker. These part- and full-time tree foraging species are the most likely predators of the experimental codling moth trials of this research project.

Just as foraging strategies define a species presence in part of the orchard, so do nesting and roosting requirements. Cavity nesters, such as downy woodpecker, chestnut-backed chickadee, and oak titmouse, require either a new site to excavate every year or need a previously hollowed-out cavity. Dead limbs of apple trees, more abundant in the abandoned orchard, may actually be preferred to live wood, as

they are more easily drilled. American robins require a site to build a cup nest and bushtits need a location to hang their sac-like nest. Two-thirds of the insect-loving bird species found in the experimental orchards nest in the region, while the other one-third migrate to breed. All require roosting sites in or within reasonable flying distance of the orchards. When a bird's basic requirements are met nearby or within an orchard, it is more likely to be present.

Year-round presence in the orchards is not a factor in whether birds are effective codling moth predators. Both resident and non-resident species were present in the experimental orchards to impact the overwintering codling moth. Non-residents are specialists and take advantage of predictable periods of local food abundance. The ruby-crowned kinglet is present in the orchards from fall to the spring just when diapausing codling moth is most abundant, and the ash-throated flycatcher appears in the orchards in the spring and summer when the adult codling moths are flying. The chestnut-backed chickadee, oak titmouse, downy woodpecker, American robin, and jay species, among others, are present year-round to impact the codling moth. These results are consistent with other research in apple orchards around the world. Migrating birds were primarily responsible for predation in British, Polish and New Zealand orchards (Glen and Milsom 1978; Zajac, 1979; Wearing, 1979), while resident birds were the key predators in Canadian orchards (MacLellan, 1959).

More insectivorous bird species were recorded in the abandoned orchard, which had a higher diversity of annual grasses, herbs and shrubs, than were observed in the managed orchards. Abundance of insectivorous birds in the abandoned orchard was more than in the managed orchards. These findings of increased species diversity and abundance are consistent with Chakravarthy's (1988) report that bird species richness increased when a farm contained a diversity of plants and insects within and surrounding it. Thus maintaining diverse habitats may attract birds to orchards and thereby encourage predation of codling moth.

Species diversity of insectivorous birds appeared to be influenced by habitat quality at Happy Valley and Deer Park orchards in year one (Figures 9 & 10). What plant species' are present, what the habitat structure is, and what the percent vegetative cover is, all influence the local diversity of birds (Gill, 1989). The food value, nesting and roosting sites in quality habitat especially the oak woodland community (Bakker, 1972) at Happy Valley, is undoubtedly attractive to the birds, which seemed to come into the orchard more often from this locality in year one. These findings of habitat influence, though somewhat inconclusive, are in line with MacLellan's report (1961) that downy and hairy woodpeckers are more plentiful in orchards near native forests.

Birds' behavioral responses of increasing predation as density of the pest increases may be occurring in these orchards. Predation was much lower in the first year when only one or two larvae were exposed per tree, as opposed to the second year, when the number of larvae per tree increased to an average of 14 per tree. Predation increased substantially from averages of 15% to 84%, as the number of prey increased. Many other factors may explain this relationship, but Canadian, European, and New Zealand researchers have also documented bird behavioral responses to increases in codling moth population (MacLellan, 1971; Solomon and Glen 1979; Thiem and Sy, 1938; Zajac, 1979; Wearing and McCarty, 1992).

Birds' foraging responses can be influenced by surrounding types and amounts of food. Maximum foraging was not reported in high yielding mealworm prey patches by the European Great tit; the birds periodically checked low yielding patches which then resulted in an easy switch when the density of the high yielding patch dropped (Smith and Sweatman, 1974). Additionally, maximum foraging responses may

only occur when the nutritional quality of the food source is adequate, and there is enough cover from avian predators (Stiling, 1992). Zajac (1979) found that codling moth predation was influenced by artificially increasing the amount of food available to birds, in both orchards with high initial pest numbers and in conventional orchards with few numbers. The combined amounts of codling moth and supplemental food present in the Polish orchards resulted in more intensive foraging by the birds (Zajac, 1979). Food quality and abundance may be important factors in density dependent predation of the author's experimental orchard, and some bird species may be more inclined than others to this phenomenon depending on foraging strategies.

Significant predation differences between the codling moth treatments were not detected in year one due to a large amount of unknown moth mortality, probably caused by early winter pupation during the trials. Also in year one, no recorded significance was possibly related to the density-dependent phenomenon that resulted in little predation on the few codling moths present per tree. In year two, significant differences in the trials were found. Significance in year two was influenced by the lack of winter pupation, and the density dependent phenomenon that resulted in increased predation on the larger numbers of codling moths per tree.

The ecotone between orchard edges and habitat may be an important area for bird predation because of the increased number of codling moth typically found there in both organic and conventional systems². Recruitment of codling moth from locations outside the orchards increases the populations along the border area, as does the use of pheromones³. When pheromones are applied, the center of the orchard is saturated, but the scent is not as strong on the edges, where the codling moth populations can build. Thus orchard edges would benefit from density-dependent predation by bird species.

Bird species population dynamics may or may not be affected by conventional or ecologically based management; bird predation of arthropods in other parts of the world has been documented in both systems. Songbird species density in a conventionally managed prune orchard was shown by Geupel and King (1998) to be about equal to the biointensively managed orchard, and to have a lower index of diversity and higher abundance. Predatory birds consumed codling moth in conventional Canadian, British and Polish research apple orchards (MacLellan, 1959; Solomon et al., 1976; Zajac, 1979), where pesticides were used on part or all of the study sites, and were also present in a New Zealand research orchard where ryania (a botanical pesticide) was used (Weaning, 1979). The results of this author's research in organic orchards of the Central Coast should be transferable to conventional orchards in the region.

Ants, wasps, beetles, spiders, and earwigs were potential predators and parasitoids present in the experimental orchards. Spiders and earwigs were found on the tree bark, as were the ants. Beetles were usually present in the ground litter and were occasionally found on the lower section of the trunk. None of these natural enemies, except a wasp species, were the known moth larvae predators or parasites, although some were implicated either by their close proximity to dead larvae, or the size of holes in the empty cocoons.

Arthropod predation and disease may be amplified when birds are excluded. The increase in mortality caused by arthropods and disease as seen under the cages in the abandoned orchard (refer to Figures 4 & 5) appears to result from excluding birds as the primary predators that were suppressing the

² Personal communication with D. Thompson, Representative for 3M Incorporation's codling moth pheromones, February 1999.

³ Codling moth pheromones are synthetic substances that mimic the scent secreted by the female codling moth to attract a mate. The scent is so pervasive, especially in the middle of the orchard where it is less windy, that the male is confused, which results in less codling moth pressure.

secondary mortality agents. This reduction of competition and replacement of the bird niche by the arthropods and pathogens was not seen in the Happy Valley orchard (Figure 3), perhaps because the diversity in this managed orchard was not as great and does not support as many mortality mechanisms. Happy Valley orchard had sparse ground cover in year two compared to the abandoned orchard which had wild radish, milk and Italian thistle over 6 feet tall. These results concur with Alfieri and Schmidt's (1986) report that the number of natural codling moth enemies was less in an orchard with no ground cover than with one that was well-vegetated (with cover crops). Thus, arthropod predation and disease may best serve as back-up mortality agents when bird predation is low, such as in an orchard surrounded by miles of monoculture, where diversity of secondary mortality agents is high because of a cover crop and interplantings of native plant species.

CONCLUSION

Bird and arthropod predation has been shown to be part of an orchard system that can reduce codling moth, rather than completely controlling this pest. Many of the bird species recorded in the surveys are known to consume codling moth diapausing on trees, especially those that are arboreal foragers. Birds impact the codling moth during the wintering stage when pesticides are least effective, and may be instrumental in reducing the higher codling moth density on the edges of conventional or organic orchard. These insectivorous bird species appear to increase in diverse orchards and in orchards near native habitat. Arthropods and disease seem to impact the codling moth in diverse orchards, chiefly when birds are not present. By conserving habitat in and around the orchard which supplies diverse food, reproductive, and cover resources, growers can provide favorable conditions for birds, arthropods, and disease whose prey or host includes codling moth.

RECOMMENDATIONS

Apple growers should conserve native bird habitat adjacent to their orchards, and increase habitat by planting native shrubs and trees within and surrounding the orchards. Leaving a few dead limbs in the apple trees, that are manicured so as not offer hiding places for overwintering codling moth, will furnish woodpeckers with excavation nest sites. Placing nest boxes in orchards will supply downy woodpeckers with roost sites during the winter (Ehrlich, Dobkin and Wheye 1988), and will provide chestnut-backed chickadees nest sites in the spring.

Small orchards surrounded by native habitat report more fruit damaged by birds than larger orchards adjacent to native habitat ⁴. Most birds are not pests in apple orchards. One of the few exceptions is the house finch, which has a diet high in plant material and probably is not a codling moth predator. Another exception is the scrub jay, which is both a known predator of codling moth, and can be a pest during apple season. The benefits of the scrub jay should be weighed against the damage it can cause to the fruit- every diapausing female moth consumed by a jay will not produce an average of 60 progeny that could damage fruit. If either bird species is a problem in a small orchard, bird netting can effectively protect the crop in the summer as the apples mature.

⁴ Growers discussed bird damage to apple crops at a Community Alliance with Family Farmers' Lighthouse Farm Network meeting in Watsonville in March 1999. Smaller orchards seem to be impacted more by birds, possibly due to the larger ratio of edge to orchard area.

By creating or conserving native plant habitat, growers will encourage bird predation, and pesticide use will be reduced. There will be less need for pesticides in conventional orchards due to the increased impact on codling moth populations, especially on the edges of the orchards where moth populations are generally higher. Decreasing pesticide use will result in less chemical residues on food, less air and water-borne chemicals in the environment, less pesticide exposure to birds, and less destruction of beneficial arthropods in orchards.

FIGURE 1. REMNANTS OF A CODLING MOTH COCOON ATTACKED BY A BIRD



This turn-of-the-century drawing shows an inner bark surface with the outlining remains of a codling moth cocoon and a hole in the bark made by a Woodpecker species.

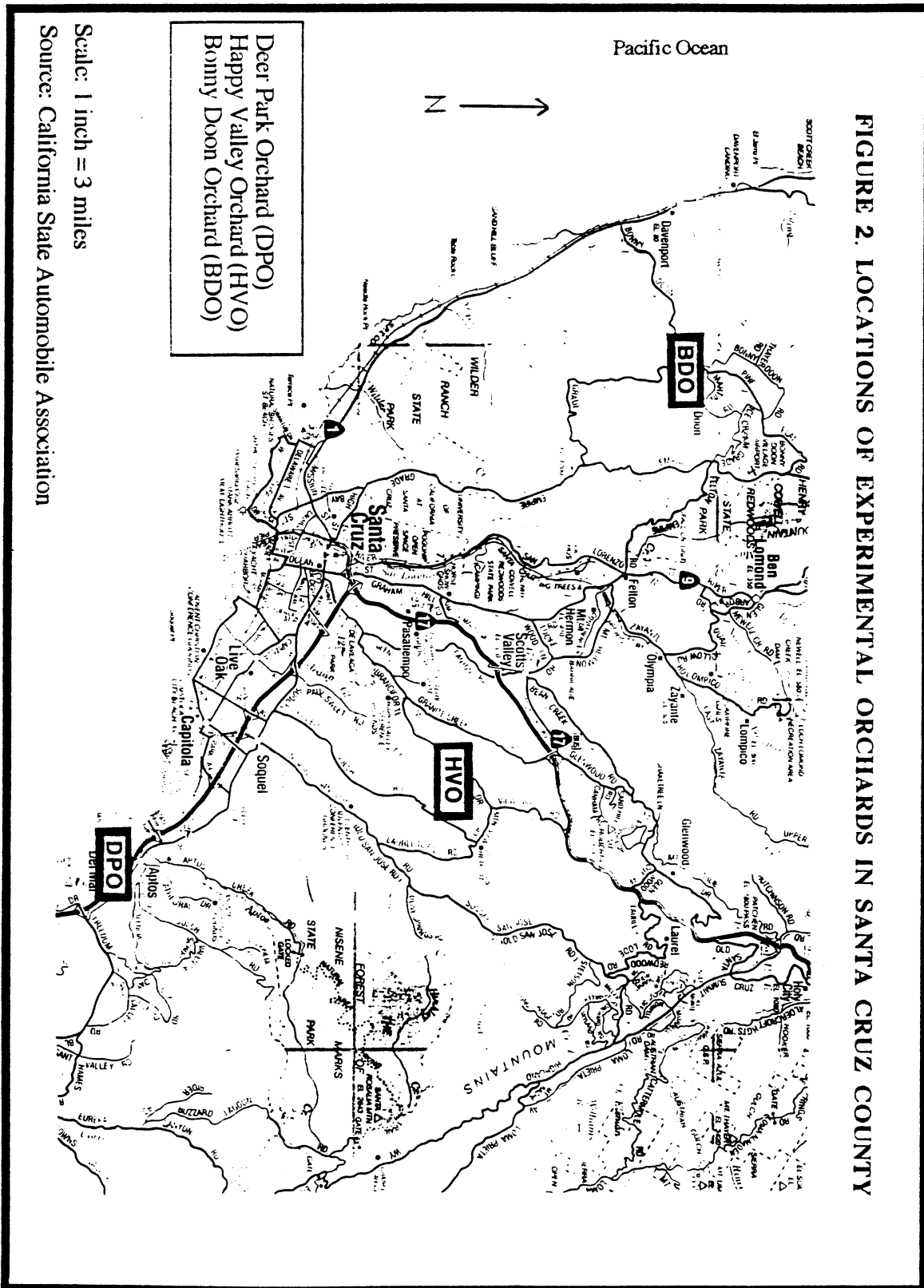
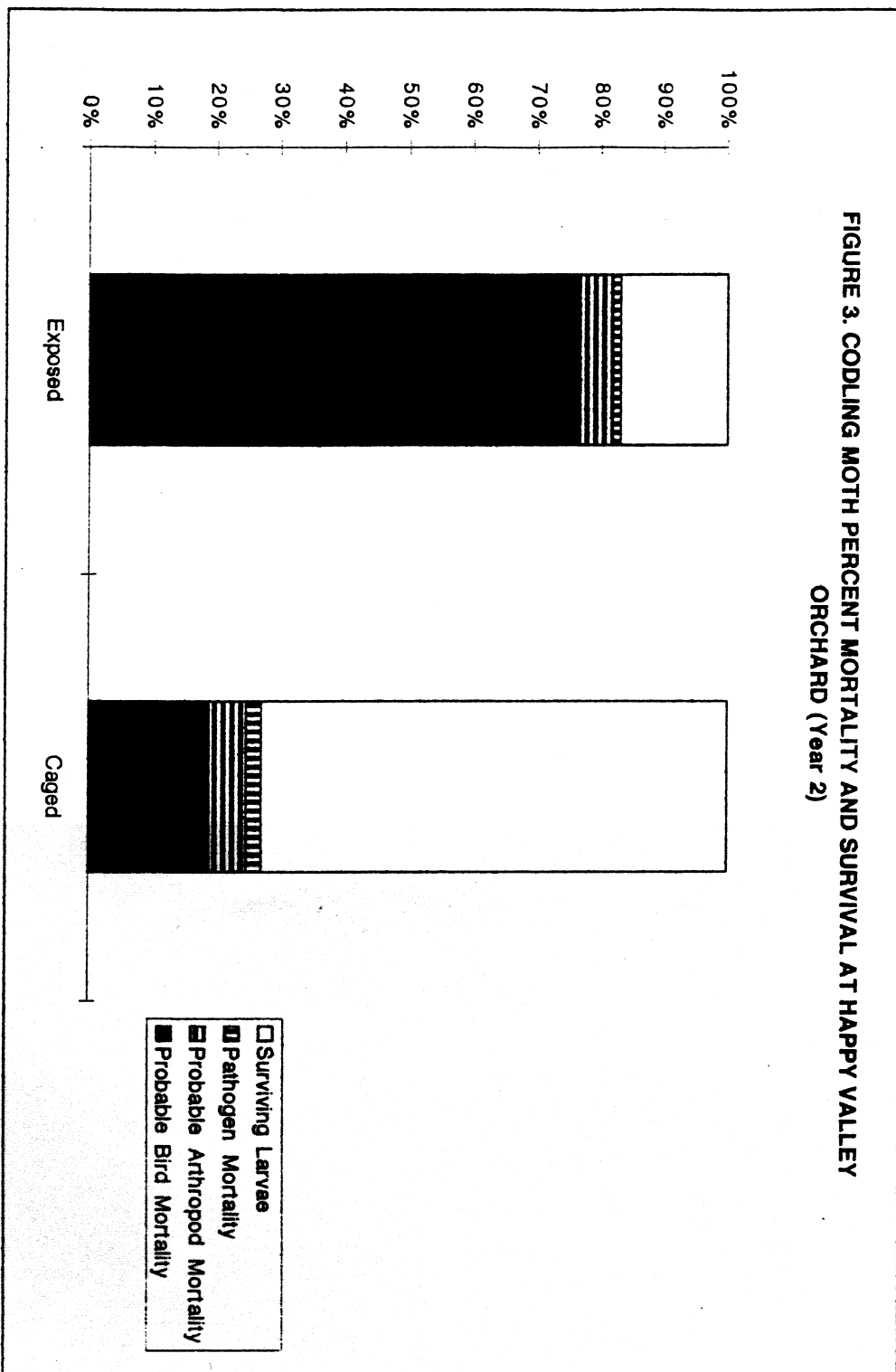


FIGURE 3. CODLING MOTH PERCENT MORTALITY AND SURVIVAL AT HAPPY VALLEY ORCHARD (Year 2)

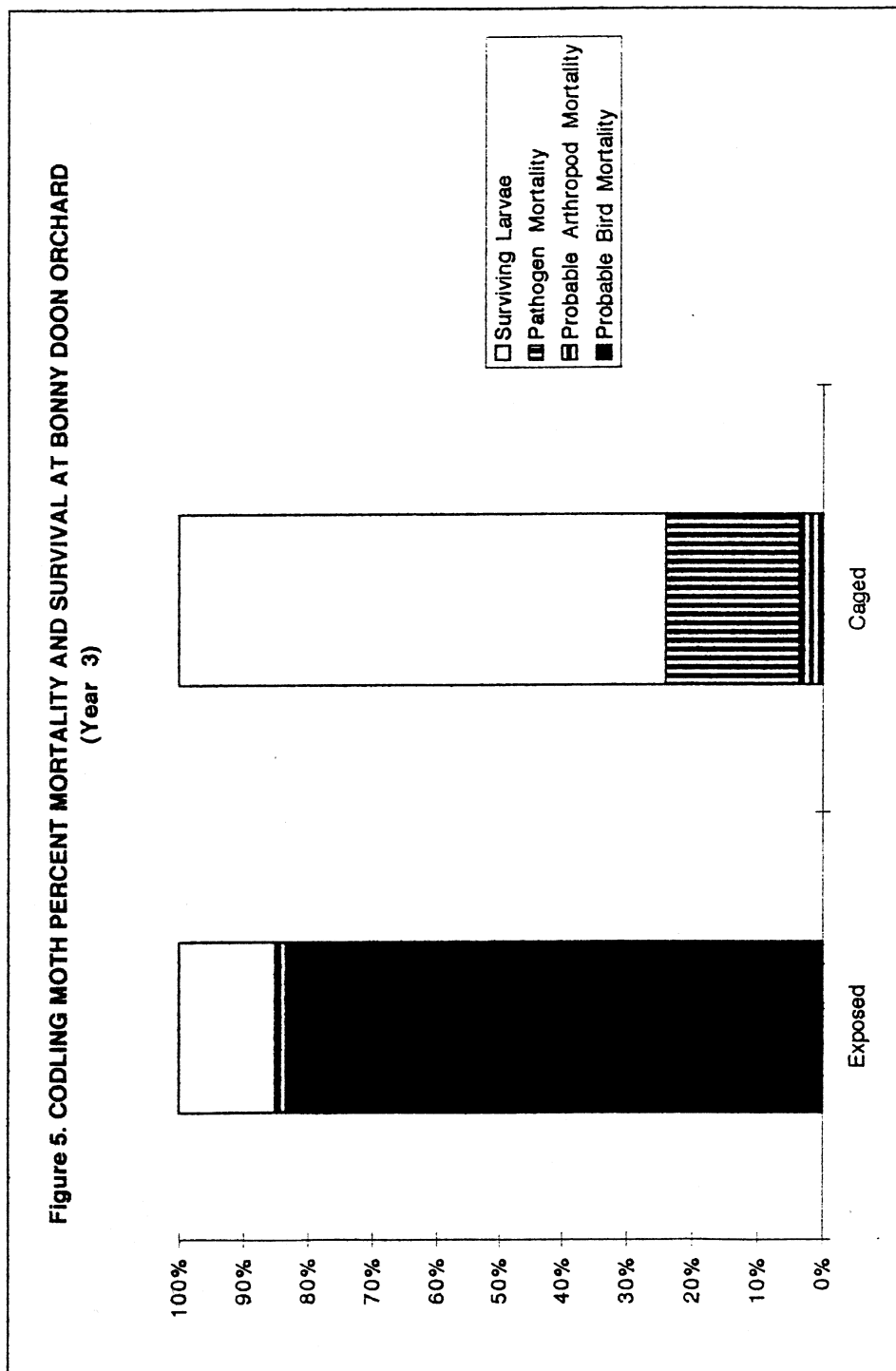


Mortality and survival outcomes are significantly different for exposed and caged treatments;
 chi-square test ($\chi^2 = 51.06$, and $\chi^2_{0.001, 1} = 10.83$).

**FIGURE 4. CODLING MOTH PERCENT MORTALITY AND SURVIVAL AT BONNY DOON ORCHARD
 (Year 2)**

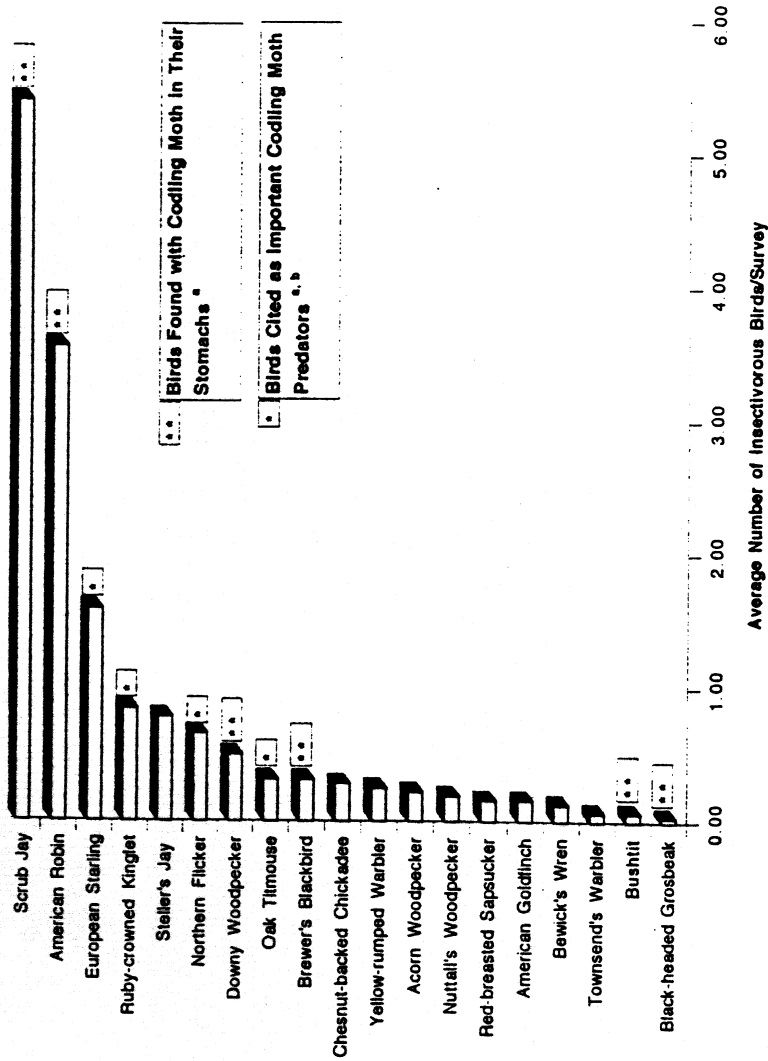


Mortality and survival outcomes are significantly different for exposed and caged treatments; chi-square test ($X^2 = 16.69$, and $X^2_{0.001, 1} = 10.83$).



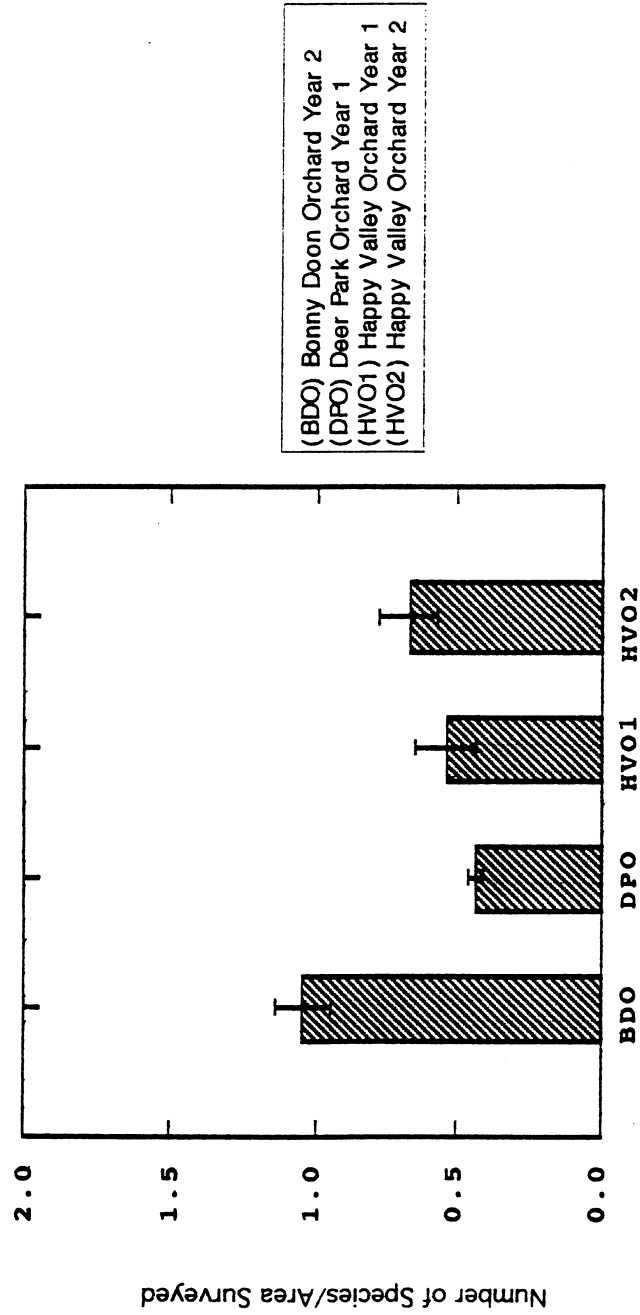
Mortality and survival outcomes are significantly different for exposed and caged treatments; chi-square test ($X^2 = 40.68$, and $X^2_{0.001, 1} = 10.83$).

FIGURE 6. AVERAGE NUMBER OF INSECTIVOROUS BIRDS/SURVEY THAT PERIODICALLY OR CONTINUOUSLY FORAGE IN TREES IN THREE EXPERIMENTAL ORCHARDS (Years 1 & 2)



Sources:
 * McAtee, 1911. pp. 237-246.
 b MacLellan, 1958. pp. 18-22; Malloux and LeRoux, 1960. pp. 45-56; Stairs, 1985. pp. 323-324; Solomon et al., 1976. p.342; Weating, 1979. p. 190.

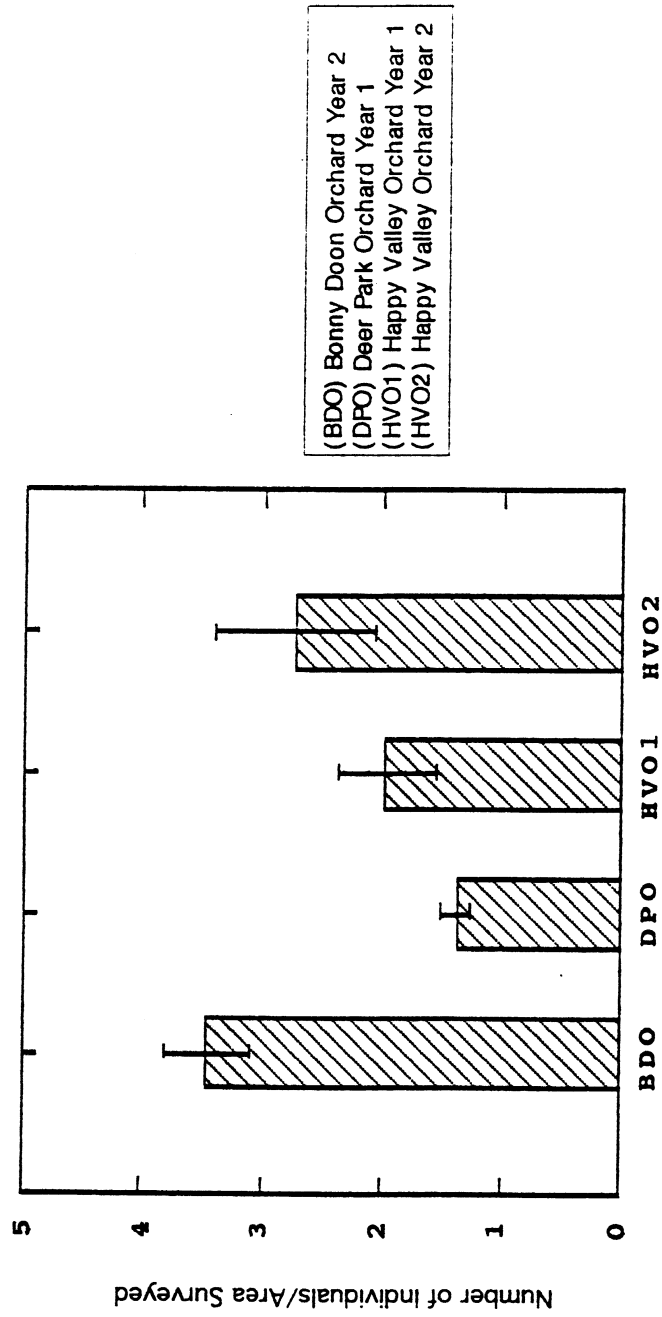
FIGURE 7. INSECTIVOROUS BIRD SPECIES DIVERSITY IN ORCHARDS



(BDO) Bonny Doon Orchard Year 2
 (DPO) Deer Park Orchard Year 1
 (HVO1) Happy Valley Orchard Year 1
 (HVO2) Happy Valley Orchard Year 2

Bird species diversity is significantly different between the abandoned orchard (BDO) and the other managed orchards combined; Mann-Whitney test ($U = 69.5$, and $U_{0.05(14,18)} = 56$), and between each individual orchard [Kruskal-Wallis test ($H_0 = 10.37$, and $X^2_{0.05,3} = 7.82$)].

FIGURE 8. ABUNDANCE OF INSECTIVOROUS BIRDS IN ORCHARDS



Abundance of birds is significantly different between the abandoned orchard (BDO) and the other managed orchards combined [Mann-Whitney test ($U = 62$, and $U_{0.05(1),18} = 56$)] ; and between each individual orchard [Kruskal-Wallis test ($H_0 = 8.35$, and $X^2_{0.05,3} = 7.82$)].

FIGURE 9. INSECTIVOROUS BIRD SPECIES DIVERSITY AS RELATED TO HABITAT AT HAPPY VALLEY ORCHARD (Year 1)

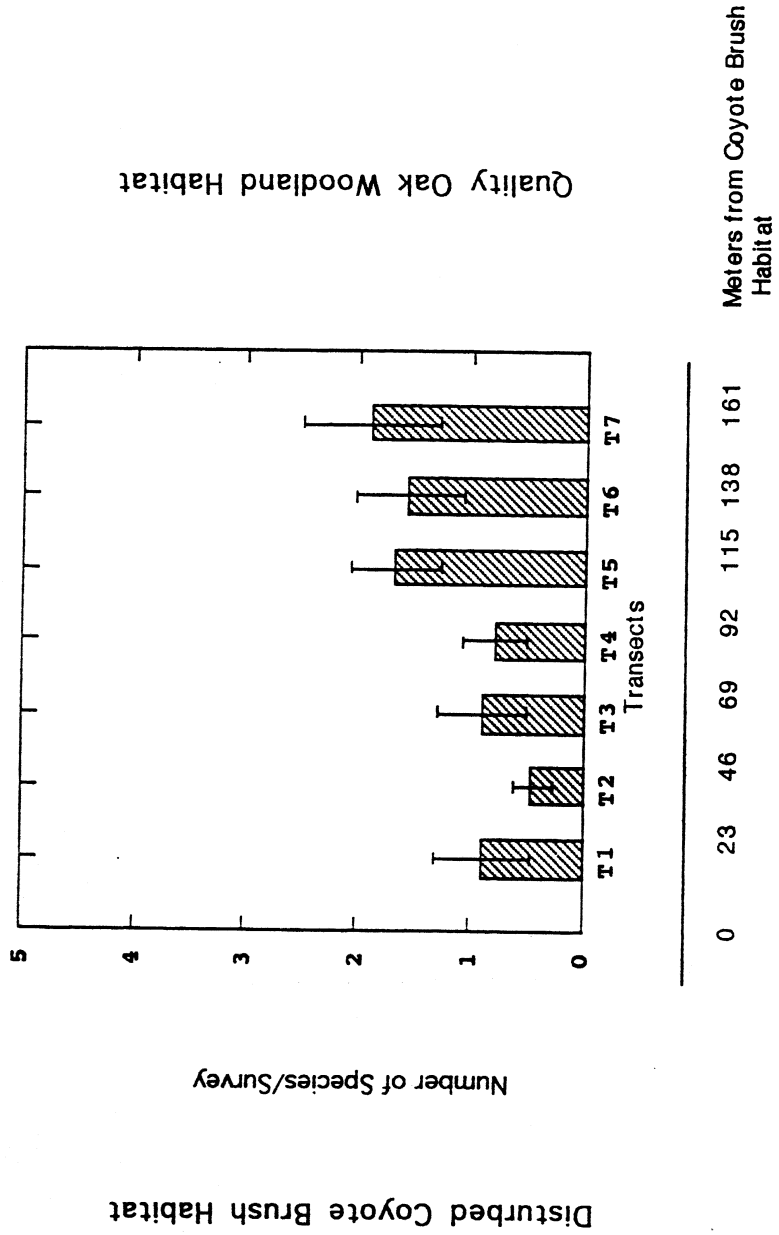


FIGURE 10. INSECTIVOROUS BIRD SPECIES DIVERSITY AS RELATED TO HABITAT AT DEER PARK ORCHARD (Year 1)

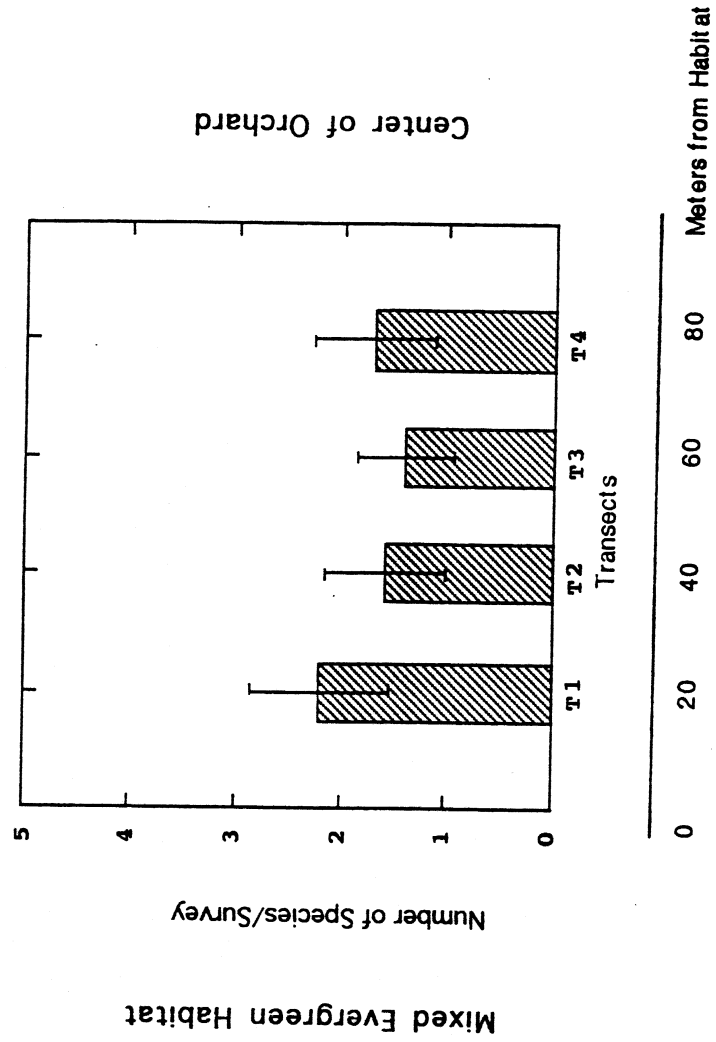
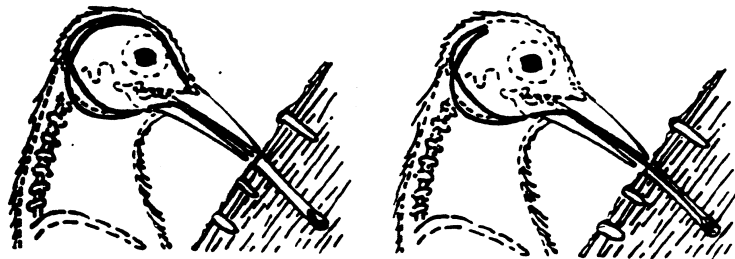


FIGURE 11. WOODPECKER FEEDING STRATEGY



How exactly do Woodpeckers obtain their prey? After locating an insect, with its tongue retracted around the skull (left), a Woodpecker extends its tongue into a crevice (right). Its long tongue is coated with sticky saliva that helps to retain the prey. Although this bird is probably extracting a bark beetle larvae and not a codling moth, the process is the same.

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