CHAPTER 7

Fruit Maturity Influences on Apple Maggot Capture and Optimum Between-Tree Trap Placement

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Introduction

The apple maggot (AM), Rhagoletis pomonella Walsh (Diptera:Tephritidae), is a native North American fruit fly which, until the 1980s, had been confined largely to the eastern United States and eastern Canada. For more than a century, it has been a key pest of cultivated apple in these areas where, if left untreated, it is capable of infesting 100 percent of the apple crop (Reissig et al. 1984) (Chapter 2). The geographical range of this pest has slowly extended to the western United States, with the first
confirmed reports of infestations occurring in Oregon and Washington in 1979, and in northern California in 1983 (AliNiaze & Penrose 1981; Dowell 1985). Its establishment on the West Coast threatens apple growers with a new key pest, along with additional pest control costs and possible quarantine restrictions on exported fruit (Chapter 1).

Because of the low economic injury level for AM—one maggot can ruin an apple—more pesticide is applied to control AM in eastern apple-growing regions than against any other single apple pest (Reissig 1988). Control of AM is accomplished with a number of organophosphates that are highly effective. Typical materials include azinphosmethyl, diazinon, phosmet, and zolcne (Fisher & Penrose 1981). Historically, calendar-based spray programs were used for AM control. Cover sprays were begun according to adult emergence and were repeated at 10- to 14-day intervals for the remainder of the season (Neilson et al. 1976; Reissig & Tette 1979).

The availability of effective sticky traps to monitor fly movement supported development of integrated pest management (IPM) strategies which determine the need and timing of control tactics, based on the presence and biological attributes of the fly (Nielsen et al. 1976; Reissig & Tette 1979; Stanley et al. 1987). Timing control measures to the presence of AM provide a commercially acceptable level of control while often halving the number of treatments required (Reissig & Tette 1979; Stanley et al. 1987).

Sticky traps have also allowed for widespread monitoring of AM populations in nonorchard habitats. In parts of Canada, Oregon, and Washington nonorchard monitoring supports local eradication and containment programs to protect commercial apple orchards by minimizing immigration pressure (AliNiaze 1988; Brunner 1987; Neilson et al. 1976) (Chapter 1). In California, sticky traps supported an eradication program to eliminate AM from its northern portion (Dowell 1985). See Chapter 1.

The effectiveness of IPM and eradication/containment programs relies on the ability of the traps to determine the presence of the fly to time control strategies properly. Any reduction in trap efficiency, such as improper placement or late deployment of traps, may result in inaccurate information on adult activity and subsequent control failures. The most commonly used traps to detect AM adults are either yellow sticky panels or red sticky spheres (Whalton & Croft 1984). The yellow sticky panel uses an olfactory attractant (ammonium acetate and protein hydrolysate) and a visual attractant to capture flies. The red sticky sphere relies on visual stimuli in the form of a potential oviposition and mating site to attract flies (Prokopy 1968). The importance of these traps for AM management is re-
fleeted in the tremendous number of studies in the literature evaluating the reliability and sensitivity of traps in AM monitoring systems in the eastern United States and, increasingly, in the West (Chapter 5).

**Population Monitoring and Trap Efficiency**

AM trap evaluations in the East have concentrated on two primary aspects: (1) the efficacy of trap types for timing insecticides and (2) the relative efficiency (or sensitivity) between trap types for monitoring AM in commercial and abandoned orchards. In general, acceptable levels of control are achieved when either trap type is used to time insecticide applications (Neilson et al. 1976; Neilson, Knowlton, and Whitman 1981; Reissig 1975; Reissig & Tette 1979; Reissig et al. 1984; Trottier et al. 1974; Prokopy & Hauschild 1979). Various studies have reported on the relative efficiency of these traps for monitoring the presence and abundance of AM from different geographical regions and different periods of the growing season (Neilson, Knowlton, and Whitman 1981; Drummond, Groden, and Prokopy 1984; Reissig 1974b, 1975; Prokopy & Hauschild 1979).

With the introduction of AM to the West a new round of trap comparison studies was begun to find the trap most appropriate for western conditions. In contrast to eastern studies, evaluations in the West emphasized monitoring performance to support eradication and containment programs in nonorchard habitats where western AM populations are found. In Washington state, Brunner (1987) compared red spheres and yellow panels in mixed stands of hawthorn and apple hosts characteristic of many areas harboring AM populations and concluded that there were no significant differences in performance. He recommended using yellow panels for AM monitoring. Davis & Jones (1986) reported red spheres were not attractive to Utah AM populations found in cherry and hawthorn and also recommended yellow panels for AM surveys. In contrast to these studies, AliNiazee, Mohammed, and Booth (1987) compared trap types in an unmanaged apple orchard in Oregon where he found red sphere and yellow panel combination traps and red sphere traps alone superior to all other traps for capturing AM, particularly at low population levels. Another study conducted in southern Oregon and northern California also found red spheres superior to yellow panels for capturing AM in residential apple trees and unmanaged orchards (Murphy unpublished data). Neither eastern nor western studies provide conclusive evidence as to the trap
most effective for monitoring AM under most conditions. These studies do suggest the relative effectiveness of trap types may vary under different biotic and abiotic conditions, such as host composition, habitat, and climate.

**AM Movement Patterns and Capture Frequency**

The attractive range of the yellow panel and the red sphere is, at best, limited to a few meters from the location of the trap (Johnson 1983). Thus, the frequency of Ah4 capture depends largely on the number of flies near the trap. Any factor that affects the distribution pattern of flies within or among their hosts is likely to directly affect fly capture. Drummond, Groden, and Prokopy (1984) demonstrated that trap position within the tree canopy is critical for maximizing trap efficiency. Such factors as fruit and foliage density, tree fruit distribution, and canopy height influence fly orientation and movement within the tree canopy, and trapping efficiency depends on trap placement relative to these factors. Mark-recapture techniques used to study AM dispersal have also found several factors affect AM dispersal patterns between apple trees as measured by the capture rate on sticky traps. Data from these studies indicate fly dispersal is uneven among orchard trees and is influenced by the presence or absence of fruit, crop size, and apple cultivar (Neilson 1971; Maxwell & Parsons 1968).

The type of cultivar appears to be associated with the number of flies trapped in apple trees. Early bearing cultivars that mature during peak fly emergence generally have the highest capture rates followed by mid- and late maturing cultivars (Neilson, Knowlton, and Whitman 1981; Maxwell & Parsons 1968; Dean and Chapman 1973). Prokopy, Moericke, and Bush (1976) and Reissig (1974a) demonstrated that AM flies are strongly attracted to the odor of ripe apple relative to unripe and nonhost fruit and that this attraction occurs over a considerable distance. Laboratory evaluations of AM behavioral response to fruit chemicals have found AM can detect differences in the sugar content of fruit and respond with increased ovipositional activity and egg laying as sugar content increases (Girolami et al. 1984; Dean & Chapman 1973). Data from these studies indicate that in the eastern United States AM flies have a strong behavioral preference for mature fruit: mature fruit is identified as a potential key factor affecting variations in the spatial pattern of AM capture rate among apple trees.
AM Preference for Mature Fruit in the West

A major obstacle for AM surveys in California, as well as for other AM-infested regions, is the limited attractive range of sticky traps. To insure fly detection during surveys, traps are placed in a large proportion of hosts within infested areas which result in substantial costs for the placement and maintenance of these traps. In 1987 research was begun in California to evaluate the potential of reducing the number of traps needed for AM survey programs without reducing the probability of detecting AM flies. Unlike much of the Northwest, California has few hawthorn trees or susceptible cultivars of crabapple; thus, monitoring AM occurs primarily in apple trees found in residential backyards and abandoned orchards. The predominance of apple trees hosting AM in California and the attraction of AM to ripe fruit reported in the East, suggest this behavior may be exploited to enhance the efficiency of AM survey programs in the West. Specifically, the objectives of our study were to: (1) determine if traps placed among mature apple fruit significantly increased the rate of AM capture relative to unripe fruit and (2) evaluate the potential of reducing trap densities by preselecting trees with the greatest fruit maturity for monitoring.

The study site in an unmanaged apple orchard in southern Oregon near the California border was a heterogeneous habitat consisting of 88 apple trees of various cultivars unevenly distributed. The site was chosen for its approximation to northern California habitats where AM populations are found. AM adults were monitored using one yellow sticky panel and one red sphere trap hung within each tree of the orchard. Maturity of apple fruit was monitored by estimating the average percent sugar content within each tree using a hand-held refractometer. The number of flies trapped and the maturity of tree fruit were recorded weekly throughout the season. To quantify the relationship between capture rate and fruit maturity, trees that bore fruit were initially split into three equal groups based on the time of season their fruit ripened (reached 12 percent sugar content). Early, mid-, and late-maturing tree types were defined as trees whose fruit ripened during the first, second, and third 5-week period of the season respectively.

AM capture rate with respect to time of fruit ripeness

The response of AM to the tree-type categories during the season indicated trees whose fruit ripen earliest have higher AM capture rates than
trees with later ripening fruit, Early maturing tree types caught twice the number of AM as either mid- or late-maturing tree types. Trees without fruit were relatively unattractive to flies, with captures only recorded during peak fly emergence. The rate of capture among tree types bearing fruit though, was not consistent throughout the season (Fig. 7.1). During the season’s first 10 weeks, the proportion of flies caught during each sample week was significantly greater on the early tree-types than the other two
tree-type categories. For the remaining 5 weeks, no significant differences were found in the proportion of flies caught among the tree-type categories. Overall, trees in the early tree-type category were found to catch flies earlier in the season, and greater numbers of trees within this category caught one or more flies during each sample period compared with later-ripening tree types. Results confirmed that western AM populations prefer ripe apples as do Eastern populations, and the relative numbers of flies caught on trees with ripe fruit is greatest early in the growing season, diminishing as the season progresses.

The AM preference for mature fruit has implications for AM surveys. Assuming trap catch is a measure of relative fly density among apple trees, our data indicate flies aggregate on trees with mature fruit. Thus, concentration of AM sticky traps among these trees should result in a greater probability of fly detection and a higher overall capture rate than traps placed in any other group of trees. Our data indicate placing traps among trees with immature or no fruit could reduce trap efficacy. During the state-wide AM eradication project in California, the placement of traps relied on randomly selecting a large proportion of apple trees within an infested area. Our data suggest the efficiency of AM surveys conducted in regions
with large numbers of apple trees may be increased by placing traps on trees with relatively mature fruit, where there is the greatest fly activity, and eliminating the placement of traps with little or no AM activity.

Quantifying AM preference for different levels of apple maturity

Based on these initial conclusions, we further analyzed the data to estimate fly preference for different levels of apple maturity, rather than categorizing tree types according to apple ripeness. The preference of AM for different maturity levels was then used to compare the efficiencies of a conventional pest survey to a modified program of optimizing trap placement. For the AM preference analysis, trees were placed into one of eight maturity categories, depending on the sugar content of their fruit. The number of apple trees and the number of AM caught within each maturity category were recorded each week during the season. Estimation of AM preference for each fruit maturity category was derived, using a selective predation model. Selective predation models are most often used to quantify the relative preference shown by a population of predators toward different types of prey. Preference estimates derived from the model may be used to predict the proportion of prey types that should be attacked (Chesson 1978, 1983) regardless of the relative densities or numbers of prey types. Wilson (1977) and Wilson & Gutierrez (1980) demonstrated that a similar technique can be used to explain and to predict the relative preference of phytophagous insects for host fruit of different age classes. This model was used in the present study to estimate AM preference for the different maturity categories of fruit (Murphy, Wilson & Dowell 1990).

As the season progressed, the density of flies varied in the orchard and the fruit within trees shifted to higher maturity categories as their fruit matured. To account for these changes, AM preference estimates were initially derived for each of three 5-week periods during the season. Within each period, the number of trees in each fruit maturity category were weighted to fly density. The preference estimates for each period were then collapsed to provide a set of composite estimates of AM preference. The composite estimates indicate the relative preference of AM for different maturity categories when all categories are simultaneously available to flies. To test how well the resulting model described the distribution pattern of fly capture among maturity categories, a partial verification was performed by testing the predicted distribution of fly catch against the observed fly catch during different periods of the season (Murphy, Wilson &
Dowell 1990). No significant differences were found between the predicted and observed distribution pattern during the three 5-week time periods. Based on these results, we conclude that the distribution pattern of fly capture among apple trees is a function of the physiological maturity of the tree fruit. The preference model predicts increasing AM preference for apples as their maturity increases, and suggests the highest capture rate, and therefore the most efficient monitoring of AM, will be attained by placing traps on trees with the most mature fruit (Fig. 7.2).

Application of AM preference model

To illustrate how the model may be used to increase the efficiency of detecting and monitoring flies during AM surveys, we compared two methods of trap placement during a hypothetical AM survey among two habitat types. The first method was based on a conventional program where traps were randomly placed in 50 percent of the available hosts in each habitat type. The second method used a modified program where the preference model was used to determine which trees should contain traps based on the maturity of their fruit. We compared each method in two types of habitats during two time periods, one early and the second late in the growing season. Figure 7.3 depicts the expected distribution of apple maturity among trees within the two habitats during both time periods of the season. Residential and abandoned trees (nonorchard habitats) usually consist of mixed cultivars and characteristically have a wide range of fruit maturity. Commercial orchards (orchard habitats) often consist of a single cultivar, but due to differences in environmental conditions and management practices within the orchard some variation in fruit maturity results.
Figure 7.3. A hypothetical distribution of tree fruit maturity for an early and late period of the growing season for (a) non-orchard habitats and (b) orchard habitats.

Figures 7.4a and 7.4b depict the proportion of the catchable fly population which should be captured when traps are randomly distributed at increasing densities, and the proportion of flies that should be caught at increasing trap densities when trees with the most mature fruit are monitored preferentially. The catchable fly population is defined as the potential fly catch when 100 percent of trees contain AM traps. For the conventional method, when 50 percent of the trees are randomly selected for trap placement in either the orchard or non-orchard habitats, on average one half of the catchable fly population will be captured. In nonorchard habitats using a modified trapping program, the required trap density needed to capture a comparable number of flies varies as the season progresses. Early in the season when most fruit are immature, the small proportion of trees with higher maturity will be strongly attractive to flies. Selection of 15 percent of trees with the most mature fruit captures 50 percent of the catchable fly population (Fig. 7.4a). Later in the season, as the maturity of
all tree fruit increases, more trees become attractive to flies, and the density of traps must be increased to 32 percent to capture the same number of flies. A similar situation occurs in orchard habitats, but the narrower range of fruit maturity results in trees having similar attractiveness to flies and

Figure 7.4. The proportion of trees with traps required to capture half the catchable fly population when trees are randomly selected, and when trees with mature apples are selected in (a) non-orchard and (b) orchard habitats. Arrows indicate the proportion of trees that must have traps to capture half the catchable fly population.
requires greater trap densities. Twenty-five percent of trees early in the season require traps to achieve 50 percent fly capture (Fig. 7.4b). Late in the season, as all tree fruit become increasingly attractive to flies, 38 percent of trees must have traps to capture half the catchable fly population.

Conclusion

From our example, placement of traps with respect to AM preference for apple maturity can substantially increase the efficiency of AM surveys by reducing trap densities while maintaining the same, or greater, overall capture rate. The benefits of using a modified AM survey program are greatest early in the season when the disparity in attractiveness is greatest between mature and immature fruit, and among stands of mixed cultivars with a wide range of apple maturity. As the growing season progresses, the apple crop matures and relative benefits diminish, approaching the efficiency of conventional programs.

Besides using the preference model as a decision-making tool for optimizing the placement of traps among groups of trees, the information derived from the model may have other benefits. Estimating the attraction of mature fruit to flies may provide valuable information on fly attack patterns among trees within an orchard. Trees predicted to have greater fly activity are likely to be more susceptible to AM damage; thus, action thresholds may be established for individual maturity categories of tree fruit. This may allow control measures to be applied selectively to apple trees determined to be susceptible to attack, rather than applying control measures on an orchardwide basis. Use of cultivars that mature at peak AM emergence as a trap crop may also aid in pest-control strategies. Planting these cultivars between the orchard and where feral or ornamental hosts provide sites for AM reinfestation would allow for early fly detection and a site for applying control measures to reduce fly densities before reaching the orchard.

Results of the preference model are encouraging for AM survey and pest control programs conducted in the West, but certain potential limitations should be noted. Optimizing the placement of traps requires the sampling of the maturity of each tree’s fruit. Although this may be accomplished quickly and easily with a hand-held refractometer, the time and labor required will offset some of the benefits of reducing trap densities during AM surveys. Furthermore, although the model was generated using
a large sample of trees over a large area, the distribution of trees was continuous. Thus, the model may not accurately describe AM capture distribution for discontinuous **groups of** trees during surveys.

**Literature Cited**


Maxwell, C. W., & E. C. Parsons. 1968. The recapture of marked apple maggot adults in several orchards from one release point. J. Econ. Entomol. 61:1157-9.


______. 1974b. Field tests of traps and lures for the apple maggot. J. Econ. Entomol. 67:484-486.


