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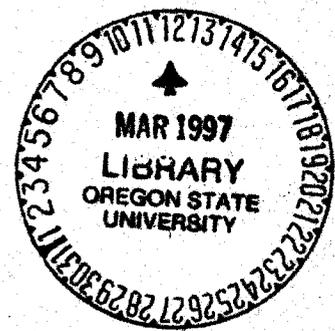
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Biology and Control of the Cherry Fruit Flies: A Worldwide Perspective



Agricultural Experiment Station
Oregon State University

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Biology and Control of the Cherry Fruit Flies: A Worldwide Perspective

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Proceedings of the International Cherry Fruit Fly Symposium
held on March 3, 1995 at The Dalles, Oregon, U.S.A.

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OBJECTIVES AND GOALS OF THE SYMPOSIUM

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For more than 25 years, cherry growers throughout the Pacific Northwest have successfully controlled cherry fruit fly with aerial applications of ultra low volume malathion. This has been an effective and inexpensive way of controlling this most important pest of sweet cherries. Due to this success, however, growers and scientists lost interest in continuing to search for alternative methods of control. Nevertheless, times are changing. The public is demanding an alternative to aerial applied pesticides.

The purpose of this symposium is to redirect the attention of growers and scientists back to cherry fruit fly. As a result of this conference we hope to stimulate new interest in the scientific community to find better and safer methods to control cherry fruit fly, methods that will be just as effective as chemical control, but more acceptable to neighboring homeowners, and less harmful to beneficial insects in our orchards.

Our plan is to review what we know about cherry fruit fly but expand the discussion to include closely related species. Hopefully, from these deliberations, ideas for new directions in research will be clear and scientists will regain an interest in focusing their attention, once again, on cherry fruit fly and its control.

Section I
Introduction

CHAPTER 1

Cherry Fruit Flies : A Worldwide Perspective

M. T. AliNiazee

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Commercially cultivated cherries comprise two species of the genus *Prunus*. These include the sour (tart or bitter) cherry, *Prunus cerasus* L., and the sweet cherry, *Prunus avium* L. A large number of cultivars of these two species are cultivated throughout the world. Commercial production of cherries is found in many countries across the globe. Major cherry producing countries include Russia, Germany, Italy, France, Turkey, and the United States. In North America, cherry production is mostly concentrated in the western states of California, Oregon, Washington, and parts of the mid-western United States, particularly Michigan, and the eastern states of New York and Pennsylvania.

Three species of fruit flies are the major threat to cherry production in the United States and Canada. These include the western cherry fruit fly, *Rhagoletis indifferens* Curran, the (eastern) cherry fruit fly, *Rhagoletis cingulata* (Loew), and the black cherry fruit fly, *Rhagoletis fausta* (Osten Sacken) (AliNiazee 1986). The former two species were considered as a single species until Curran (1932) and Blanc and Keifer (1943) erected *R. indifferens* as a separate species and distinct differences between these two species were demonstrated (AliNiazee 1973). It is now generally accepted that *R. indifferens* and *R. cingulata* are separated by allopatry and may have evolved independently on their respective native hosts and made the host shifts to cultivated cherries at different times as the commercial cherry production increased in these two geographic areas (AliNiazee 1973). *R. fausta*, the black

cherry fruit fly, is a less serious pest and is generally found in the northern areas of cherry cultivation in both eastern and western regions (see Chapter 6 for distribution maps) and at higher elevations in California (Bush 1966, AliNiazee 1997). Biology of these two pests is quite similar and is discussed in Chapter 5. *R. fausta* is more cold adapted and requires slightly longer periods of cold temperatures for diapause development. Consequently, it is more adapted to higher elevations and colder climates. Also, its emergence appears to be less well synchronized with commercial cherry production, thus making it a less serious pest.

The European cherry fruit fly, *Rhagoletis cerasi* L. is widely distributed throughout Europe and parts of Asia where cherries are grown and is regarded as the most serious pest of this crop. In addition to cultivated cherries, it infests berries of an ornamental honey suckle, *Lonicera xylosteum* which has come in handy in developing mass-rearing programs required for pursuing a successful sterile insect release program (see Chapter 11).

All four species of cherry fruit flies cause similar damage. They infest mature or maturing cherries one to three weeks before harvest by depositing individual eggs inside the fruit. Eggs hatch in 3-7 days and young maggots feed on cherry flesh, mainly around the pit. Mature larvae make breathing holes and eventually drop to the ground for pupation. The larval period varies from 1-3 weeks depending upon the temperature, pupae spend 9-10 months in the soil and emerge as adults the following spring. There is only one generation per year. Cherry fruit flies are serious pests. Fresh market cherries have zero tolerance and most growers apply preventive sprays of organophosphate insecticide to control them. Although the chemical control has been highly effective for over 40 years against these pests (AliNiazee 1986) without much indication of resistance development, the secondary pest outbreaks, destruction of beneficial insects and mites, residues and environmental contamination continue to be the major drawbacks of this one-sided approach. Alternative strategies including mass trapping and elimination of spray treatments by closely monitoring the presence or absence of flies and emergence dates using traps have been pursued both in North America and Europe with mixed results (Russ *et al.* 1973, Prokopy 1975, AliNiazee 1978, 1981). Utilization of oviposition-detering pheromone in cherry fruit fly management was envisioned by many workers (Katsoyannos 1975, Katsoyannos & Boller 1980, Boller 1981, Mumtaz & AliNiazee 1983), however, because of lack of structure identification and mass production, none of these compounds are available for commercial use. Cytoplasmic incompatibility among different populations was found in *R. cerasi* (Boller 1989). The commercial application of such techniques to develop a genetic control program is still under experimental stages and needs further investigation. Sterilized insect release method (SIRM) was successfully used in Europe against *R. cerasi*, but in North America SIRM was found to

be impractical (Brown 1978) although technical feasibility is well documented (Brown & AliNiazee 1978). An integrated pest management approach as discussed by AliNiazee (1986) appears to be ideal for this group of insects but further work needs to be done on logistics and practical utilization of such a program. Articles presented in this symposium summarize current status of pest management research on cherry fruit flies.

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Section II

**Cherry Fruit Fly Problem
and Export Restrictions**

Cherry Fruit Fly Problem in Oregon

Lynn E. Long

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Since the early 1970s control of cherry fruit fly in Wasco County has been accomplished, almost exclusively, by applications of aerial ultra low volume (ULV) malathion. Over the years, this control program has proven to be very effective. In fact, since the implementation of this program, there have been only two years where cherry fruit fly larvae were found in the fruits from Wasco County.

This success can be attributed to several factors. First, and most importantly, growers recognized the importance of a thorough, consistent control program. After the initial pesticide application, Oregon cherry growers were required to apply aerial ULV malathion at 7-day rather than 10-day intervals as is common in other areas. This is a policy that has been followed by nearly every cherry grower in Wasco County.

A second reason for success is related to the quality of the application process. Since the beginning of ULV malathion use 90 to 95 percent of the orchards have been sprayed by a single applicator. This applicator has done an excellent job of consistently covering commercial orchards. However, he has also gone out of his way to make sure that abandoned orchards and other problem areas are also sprayed, often at his own expense.

Finally, the majority of cherry orchards in Wasco County are located within a concentrated band surrounding the city of The Dalles. This facilitates consistent coverage and eliminates vacant areas between orchards where cherry fruit flies can breed on wild trees.

However, the proximity of the orchards to the city of The Dalles also presents one of

the greatest problems to cherry growers in controlling cherry fruit fly. Cherry orchards surround the city on three sides. Subsequently, there is no place for the city to grow. Urban expansion has naturally flowed to the more rural areas, including the orchard district. With the expanding population, urbanization of agricultural lands is inevitable.

It is obvious that orchard areas are beautiful, especially in the spring when trees are blooming. People imagine orchard locations to be the perfect home site situated in the beauty and peace of the country. That is, until the first plane flies over their houses spreading malathion to within inches of their property and sometimes crossing that line.

Peace and tranquility are now lost and the inhabitants fear for their health and the safety of their children and pets. They started demanding that the orchardist should change his farming practices because of their presence in the farming community. They call the Oregon Department of Agriculture and lodge a formal complaint. When traces of malathion are found on their lawns or their houses, depending on the circumstances the applicator is warned or fined.

With this scenario played out, the cherry growers are now realizing that the days of aerial ULV malathion applications are numbered. Most orchards in Wasco County are too large to be easily sprayed by ground every 7 to 10 days. Wasco County cherry orchards average 80 acres in size. Cherry orchards of 200 and 400 acres are common with one as large as 700 acres. It is unreasonable to expect that consistent, regular coverage can be obtained by ground sprayers on such large orchards.

In addition, the use of dimethoate, an insecticide with season-long residual activity, is not an alternative for fresh cherries. The majority of Wasco County's fresh fruit is sold to Japan. Japan will not allow the importation of cherries treated with this chemical. We are therefore faced with a need to find an alternative to ULV malathion before it is banned completely.

Cherry Fruit Fly in North Central Washington

Len Pugsley

Chief Wenatchee Inc., Wenatchee, WA 98801

In the late 1980s the western cherry fruit fly (WCFF) was becoming a serious problem for Wenatchee based warehouses. Although it remains a serious problem, good progress has been made to better control this pest.

By 1987, the incidence of WCFF finds in Wenatchee warehouses had risen steadily to a high of 23 for the season (Fig. 1). I was assigned to work as the fieldman for the Horticultural Pest and Disease Boards of Chelan and Douglas Counties during the same year.

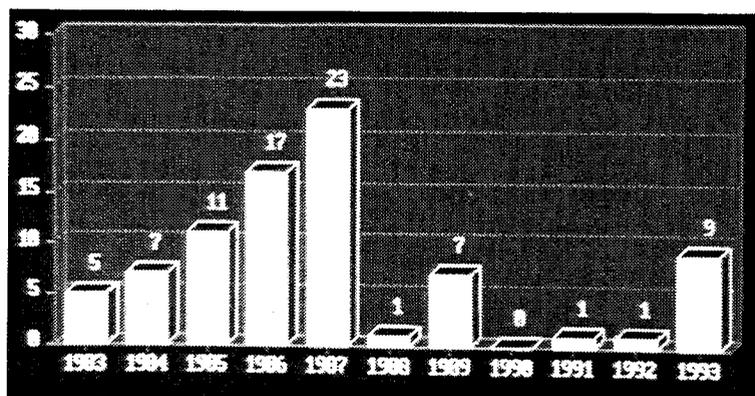


Figure 1. The western cherry fruit fly finds in Washington State Department of Agriculture inspection program over a 11 year period.

I quickly learned that many commercial orchards were in close proximity to backyard infestations or orchards that were poorly maintained. I originally believed that by controlling WCFF in backyard trees, WCFF in adjacent commercial orchards would also be controlled. With the help of jail trustees entire neighborhoods and hundreds of sites were cleaned up. However, adjacent commercial orchards remained infested. It was obvious that these problems could no longer be blamed on neighbors.

It soon became apparent that the majority of problems were initiated from internal infestations of the orchards. We then realized that most orchards experiencing larval finds had internal infestations; the flies were emerging just before harvest or during harvest (when most growers were relying on Cythion ULV) to lay eggs in cherries. At that time most growers did not realize that Cythion would do little more than knock down a population for a few days. While Cythion is an excellent fly killer, its main purpose is to kill off the population before it matures enough to mate and begin laying eggs. If the grower comes back a week later (under average weather conditions) and applies another Cythion spray, the fruit flies that emerged during that week have not matured enough to mate and are killed before egg laying.

If there is hotter than normal weather, and/or poor coverage in the orchard due to power lines, wind, or neighboring buildings, small number of flies will survive, mate, and lay eggs. If there is an outside infestation, usually up-wind from the orchard, a fertilized female can be carried in by the wind any time during that week between sprays and begin laying eggs immediately.

There is no protection for an orchard during the pre-harvest and harvest period against the fertilized female blown on the wind, other than eliminating the infestation.

While flies blown into the orchard during harvest are a serious threat, the establishment of an internal population during the post-harvest period is a much greater threat. Tim Smith has for years felt the fruit left behind after harvest was an ideal site for fruit flies during the post-harvest period. Tim has found that even in orchards where it appeared a good clean job of picking had been done, pounds of fruit can be left in the tops of trees just out of sight. These cherries left behind remain viable for fruit fly reproduction for many weeks after harvest during the time when the largest percentage of fruit flies have emerged, mated and are looking for egg laying sites. The cherries left behind provide an excellent avenue for fruit flies to become established and gain strength during that post-harvest period from year to year.

With the internal infestation emerging from straw stage through the harvest and into the post-harvest, all that is needed for an infestation of the fruit to take place is poor coverage

or a delay in insecticide application for whatever reason.

By trapping and eliminating hundreds of infested sites (located and trapped with help from Wenatchee Valley College Tree Fruit Production students), and with better understanding on the part of growers, larva finds were reduced down to a few per season within a couple years in the Wenatchee warehouses.

But we were still faced with the internal infestations that carried through from year to year in many orchards. We believed by controlling the pest during the post-harvest we could reduce the chance of developing the internal infestation. We had documented cases where traditional organophosphates had failed because the material washed off or broke down too soon, or because the pest was allowed to lay eggs before the material was applied. Once the egg has been laid, surface type materials will not harm the egg and developing larva. By the time the larva has fully developed, the material has mostly broken down or been washed off. The mature larvae drop to the ground and pupates for the remainder of that season to re-emerge the following year.

One of my earliest experiments was to remove all the fruit from a totally infested tree before the larva reached larval maturity and dropped to the ground. The single isolated tree was totally infested with at least one larva per cherry and over 150 flies caught in the sticky trap. The following year I again trapped the site and trapped 15 flies in the trap and again picked all the cherries from the tree. The third season the trap count was zero. We had eliminated the infestation preventing the pest from successfully reproducing, which again pointed towards the post-harvest period as the critical time for control (Fig. 2).

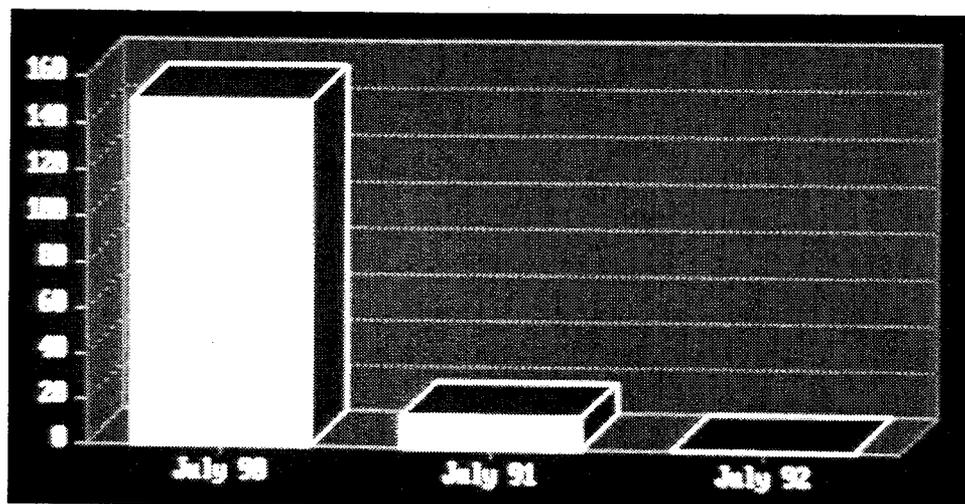


Figure 2. Effect of clean picking of fruit on trap counts over a three year period, total number of flies caught in traps at Astor Court.

Traditionally growers have looked at pest control as a season by season battle. If they make it through harvest, they are home free. We have found this is absolutely not true of cherry fruit fly. The fight for control of fruit fly should begin the day after harvest ends the season before. It is then that the stage is set for the following year.

Again, we had found traditional materials were not controlling the pest during the long post-harvest period because of their inability to hold up to rain and heat. To combat this we decided to go after the larva with a systemic pesticide. Dimethoate 2.67 EC was chosen because it was already labeled for use during the early pre-harvest. We found no work had been done with the material against larva by researchers or by the chemical companies.

We selected a small orchard site with a moderate level of fly population. Taking four samples of 100 cherries per sample we found over 98 percent infestation of the fruit with many cherries having two larvae. We then applied Dimethoate 2.67 EC at 12 fluid ounces per 100 gallons to the orchard. A week later we returned and again took four samples of 100 fruits and found a 100 percent kill of larvae in the cherries. We also found the AM-sticky traps had all but shut down. We spent over an hour checking cherries throughout the orchard to confirm our 100 percent kill.

The success of Dimethoate gave us a tool that would accomplish the same result as the picking of every cherry from the tree. It eliminated the cherry fruit fly's ability to reproduce and eliminated the internal orchard infestation if Dimethoate was used two seasons in a row.

During the 1992 season we found an abandoned 4 acre block on the northwest corner of Wenatchee. The orchard was located during the harvest period just at peak emergence with hundreds of flies visible in the trees.

An attempt was made to spray the orchard the following day but was called off when the pilot saw people walking along the canal bordering the block. He flew back to the airport and landed to find he had been turned in for spray drift. More attempts were made to spray but a wind storm passed through the area with wind speeds in excess of 40 MPH. The following day the orchard was inspected for flies and only two were found after careful searching where hundreds were found a few days earlier at a glance.

The next couple days our traps scattered downwind through the Wenatchee Valley started picking up increased numbers of flies. Many of these sites had not trapped positive for a fly before, with some sites having been trapped for two years previously with no catches. Our most distant trap sites (8 miles) picked up flies for the first time just after the wind storm. We are convinced that the CFF were carried away for that distance and beyond by the wind and believe this is the main avenue for infestation during the post-harvest period.

The following 1993 season we accurately predicted an increase in larva finds based on the spread of this infestation and the number of growers who were ignoring their post-harvest programs.

Another field test was carried out looking for a replacement for Cythion ULV where aerial application could not be used. During the testing, Pyrenone EC was sprayed at a rate of 12 oz. per 100 gallon water on June 29, 1993. Data indicated (Fig. 3) that there was a sharp knock down in fly population, but post application trapping buildup similar to sites treated with Cythion ULV was noticed.

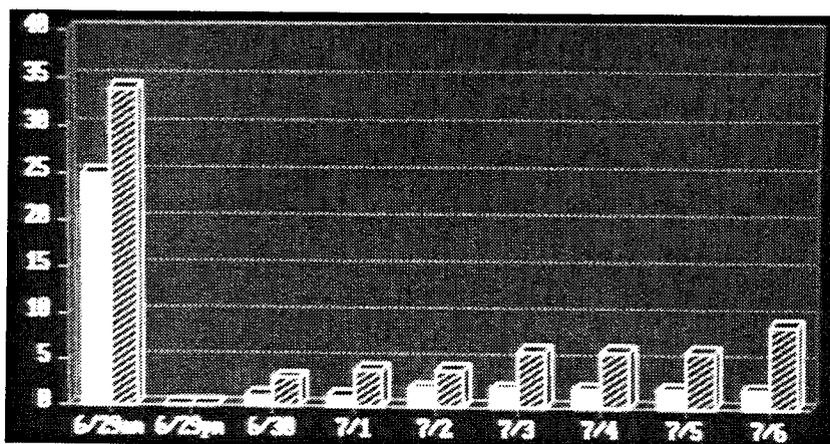


Figure 3. Effect of Pyrenone sprays on WCFE trap counts (trap 1 and 2) before and after spraying.

A most important tool for cherry growers in northcentral Washington has been the computer emergence model perfected by Tim Smith of WSU Cooperative Extension. With this model, Tim has accurately predicted the first emergence of flies in the Wenatchee Valley to the day 4 years running. The model will be re-calibrated for the Tri-cities area this season.

I believe if special attention is given to eliminating outside infestations, and a good spray program utilizing Dimethoate or PennCap-M is followed during the post-harvest period, WCFE can be reduced from a serious pest to a level where we will be able to control this fly with insecticides.

Acknowledgement

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Auvil Fruit Company; Cascadian Fruit Shippers; Chief Wenatchee Growers;
H & H Orchards; Northern Fruit Company; Stemilt Growers; and Skookum Growers.

Cherry Fruit Fly Export Restrictions, Domestic

Robert Hawkes

Administrator, Commodity Inspection Division,
Oregon Department of Agriculture, Salem, Oregon

For many years the California Department of Food and Agriculture (CDFA) has been concerned about fresh cherries being shipped into California without first being fumigated for cherry fruit fly. California officials believe cherry fruit fly does not occur within their commercial cherry production area and they are making every effort to keep it from being introduced. In order to allow for shipment of fresh cherries California issues an annual permit to allow Oregon packing companies to ship cherries under a very strict set of requirements that are overseen by Oregon Department of Agriculture (ODA) plant pest control and commodity inspection personnel. The 1994 version of the California permit is as follows.

Master Permit for the Shipment of Cherry Fruit From the State of Oregon to California

Under authority of Section 3256 (Cherry Fruit Fly Exterior Quarantine), Title 3, California Code of Regulations, permission is hereby granted to the Oregon Department of Agriculture (ODA) to authorize firms to ship Oregon grown cherry fruit to California without fumigation, subject to the requirements and conditions of this permit.

To meet the requirements for this master permit, ODA shall:

1. Maintain California approved mandatory pest control districts for control of cherry fruit fly.
2. Carry on a trapping program for adult cherry fruit flies.
3. Require the application of pesticides at specified intervals for control of cherry fruit fly.
4. Porch sampling of all incoming lots of cherry fruit arriving at firms destined as "Approved Shippers".
5. Furnish a list of approved shippers with addresses and assigned identification numbers to the California Department of Food and Agriculture (CDFA) prior to the beginning of the shipping season.
6. Pay transportation and per diem expenses of a CDFFA representative for the purpose of observing that the permit requirements are met at origin.

The following conditions are also required to maintain the validity of this master permit:

1. The cherry fruit shipped to California must be grown in commercial orchards located in approved pest control districts.
2. Each lot shall consist only of one variety of cherry and shall be at least 1,000 pounds. Each container in the lot shall be randomly sampled prior to adjusting the container weight and according to the following schedule:

Lot size in pounds	Sample size - number of cherries from each container in lot
1,000 to 19,999	5
20,000 to 39,999	4
40,000 and over on continuous belt run	2

3. The cherries in the sample shall be tested for the presence of cherry fruit fly larvae in an approved manner.
 - A. **Brown sugar procedure**
 - (1) Crush cherry fruit sufficiently to break open all of the fruit.
 - (2) Fill pan or other suitable container 1/3 full of crushed cherries.
 - (3) Add measured water to cover the cherries pouring water over crushing mechanism to wash larvae adhering to mechanism into pan.

- (4) Mix brown sugar into water at the rate of 4 to 5 quarts of sugar per 5 gallons of water (7 pounds of sugar per 5 gallons of water). Solution used should read at least +15 soluble solids on the refractometer.
 - (5) Stir mixture to dissolve brown sugar; stirring will cause foam to develop.
 - (6) Allow to set for five minutes or until foam clears up. Inspect for larvae.
- B. Hot water procedure**
- (1) Crush cherry fruit through wringer into a pan containing a 1/4 inch mesh screen liner.
 - (2) Submerge crushed cherries in a container of hot water (140-180°F - not to kill larvae).
 - (3) Agitate in water for approximately 60 seconds.
 - (4) Remove cherries and mesh screen liner, skim off excess water and debris, pour remaining water into either: (a) a Pyrex dish, or (b) a dull black pan. Larvae will settle to bottom, use light under Pyrex or over black pan to inspect for larvae.
4. Maintain identity of each container of inspected fruit with the proper identification number as issued by the ODA.
 5. The address of the packing location on the approved shipper's label that appears on the container must coincide with the address on the list of approved shippers furnished by the ODA.
 6. Vehicles transporting cherries from approved shippers to California shall be sealed under the supervision of an ODA representative. Carriers shall be sealed before leaving the State of Oregon. The seals shall not be broken except in the presence of a California Plant Quarantine Inspector after the carrier arrives in California.
 7. If any cherries received, stored, packed, or shipped by an approved shipper are found infested with cherry fruit fly, the ODA shall:
 - (a) Eliminate the grower who produced cherry fruit fly-infested cherries from participation in shipments to California of cherry fruit without fumigation for the remainder of the shipping season.
 - (b) If the shipper had no suspensions during the preceding shipping season and if the find(s) of cherry fruit fly are the first for the shipper for the current shipping season, immediately suspend the approval for the shipper to ship under this permit for a consecutive period of five packing days.
 - (c) Continue porch sampling cherries received by the suspended shipper during the suspension period and if a larva of cherry fruit fly is found a new five packing-day suspension period would begin.

- (d) At the conclusion of the five packing-day suspension period with no new larval finds, and upon agreement by the CDFA, reinstate the suspended shipper as an approved shipper.
- (e) If the shipper had a suspension(s) during the preceding shipping season or if the find(s) of cherry fruit fly are not the first for the shipper for the current season, immediately suspend the approval for the shipper to ship under this permit for the remainder of the current shipping season.

Each shipment destined to California shall be accompanied by an officially signed ODA certificate naming the approved shipper, the ID number of the lot, the number of containers in the shipment, the name and address of the consignee, and affirming that the shipment is in compliance with the requirements of this permit.

Cherry fruit shipped by approved shippers is subject to inspection upon arrival in California. Any lot found infested with cherry fruit fly shall be fumigated in the approved manner (note all fumigation requirements, especially pulp temperature) or immediately shipped out of state. The shipper of a lot found infested with cherry fruit fly by California inspectors shall be immediately suspended from shipping to California under this permit for the remainder of the shipping season by the ODA.

This master permit is valid only for the 1994 cherry shipping season and is subject to revocation at any time by the CDFA.

Over the years this has been a very successful cooperative program between CDFA, ODA and the cherry industry. A representative from the CDFA travels to Oregon each year to review the program and to discuss any problems or issues with ODA staff who in turn make certain that any concerns are corrected prior to the next shipping season.

Section III
**Cherry Fruit Fly Biology,
Ecology and Behavior**

Biology and Distribution of the Western and Black Cherry Fruit Flies

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Distribution

The western cherry fruit fly, *Rhagoletis indifferens* Curran, and black cherry fruit fly, *Rhagoletis fausta* (Osten Sacken), are found in the western United States and Canada (Bush 1966). *R. indifferens* appears almost identical to *R. cingulata* (Loew), the eastern cherry fruit fly, and was classified as the same species in the literature until recent times (AliNiazee 1973). *R. indifferens* is found in the British Columbia, Washington, Oregon, Idaho, Montana, Utah, and northern counties of California (Fig. 1, next page). Recent reports also indicate that *R. indifferens* is present in Colorado (Kroening *et al.* 1989) and New Mexico (Ward 1990). *R. fausta* is found across the northern portion of North America spanning from East to West (Fig. 1). In the West *R. fausta* has a distribution similar to that of *R. indifferens*.

Host plants

Both fruit fly species utilized native plants as hosts prior to a shift to commercial cherry. The number of native plants utilized as hosts is relatively small, suggesting a close relationship between the phenology of the plant and development of the insect. A list of

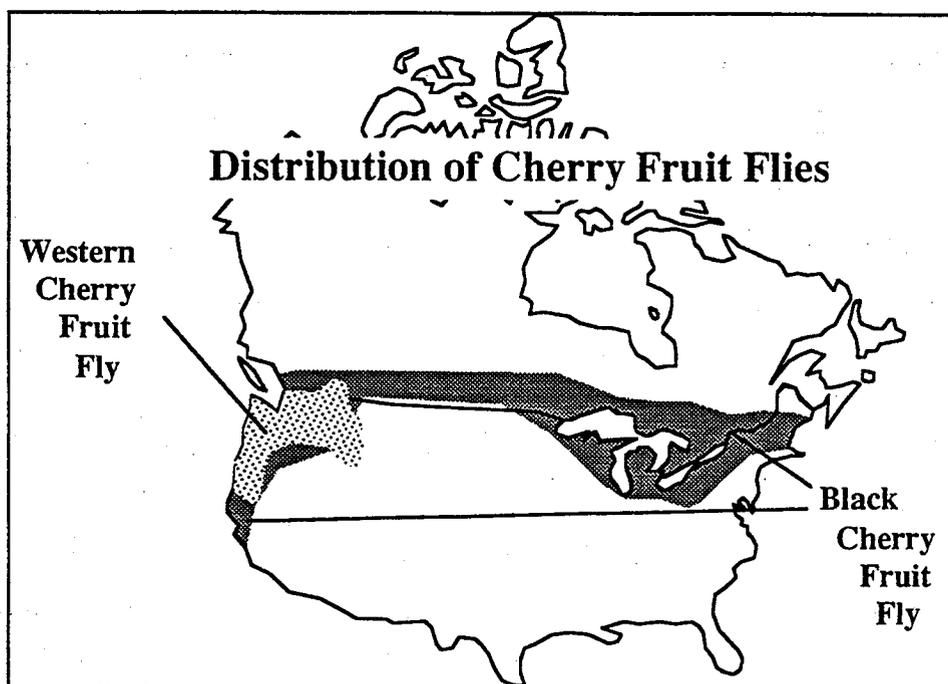


Figure 1. Distribution of the black and western cherry fruit flies in North America.

plants used as hosts by *R. indifferens* and *R. fausta* is given in Table 1. Both of the cherry fruit flies have successfully switched to commercial cultivars of cherry as hosts. In Washington, the *R. indifferens* is more common than *R. fausta* in commercial cherry and is more often reared from western bitter cherry than choke cherry (Frick *et al.* 1954).

Table 1. Plants used as hosts by fruit flies attacking stone and pome fruits in the western U.S.

Western cherry fruit fly (<i>R. indifferens</i>)	Black cherry fruit fly (<i>R. fausta</i>)	Apple maggot (<i>R. pomonella</i>)
Sweet cherry	Sweet cherry	Apple
Tart cherry	Tart cherry	Crab apple
Choke cherry	Black cherry	Hawthorn
Western pin or Bitter cherry	Western pin or Bitter cherry	Sweet cherry
	Choke cherry	Tart cherry
	Pin cherry	Pear
	Mahaleb cherry	Prune
		<i>Pyracantha</i> sp.
		<i>Cotoneaster</i> sp.

Life stages

The immature stages of both cherry fruit flies appear similar. The egg is cream colored and elongated, about 1/30 inch long (0.8 mm) and is deposited under the cherry skin and so is not visible. The larva is a creamy white, legless maggot, which is tapered at the head and blunt at the rear. It passes through three instars and grows to about 5/16 inch (8 mm) long. Larvae of both the cherry fruit fly species can be distinguished from other fly larvae of the genus *Drosophila*, sometimes found infesting cherry, by examining the posterior end of the larvae. The posterior end of the cherry fruit fly larva is round and the anal spiracles, which are not raised, have three darker lines each extending laterally from the midline. The posterior end of *Drosophila* larva has two protuberances on which the anal spiracles are found (Beers *et al.* 1993). Pupae of both cherry fruit fly species appear similar, being yellowish-brown to dark brown. The pupa looks like a large grain of wheat and is about 3/16 inch (4 mm) long.

It is in the adult stage that the two cherry fruit fly species can be easily distinguished. While the bodies are similar, generally black with white bands on the abdomen, the wings are different. They are transparent with a distinctive dark banding pattern. It is this banding pattern that allows an easy distinction between *R. indifferens* and *R. fausta* and, for that matter, from other fruit flies (Fig. 2). The adult is about 1/5 inch (5 mm) long. The female is slightly larger than the male.

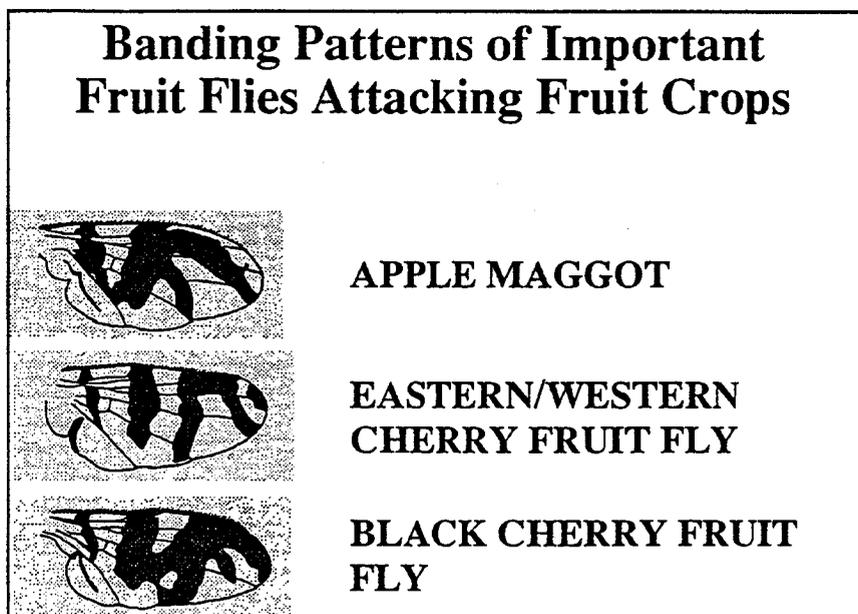


Figure 2. Distinguishing banding patterns on the wings of cherry fruit flies and the apple maggot that can be used to separate the species.

Life history

Rhagoletis indifferens and *R. fausta* have similar life histories (Frick *et al.* 1954). They complete one generation a year. Pupae overwinter in the soil and are found at a depth ranging from 1 to 10 centimeters, most being in the upper 3 centimeters (Frick *et al.* 1954, AliNiazee 1974a). Overwintering pupae are in diapause and require a chilling period before development can proceed normally (vanKirk & AliNiazee 1981). Pupal development in the spring is influenced by soil temperature. The temperature threshold for post-diapause development is about 41°F (AliNiazee 1976), and predictive models have been developed to help finding out when the first adult emergence is expected in the spring (Stark & AliNiazee 1982, Jones *et al.* 1991).

In the Pacific Northwest, adults begin to emerge in May, about four to five weeks before harvest, and are active until three or four weeks after harvest (Fig. 3). *R. fausta* adults typically begin emerging one or two weeks earlier than *R. indifferens*. The beginning of adult emergence has often been associated with the color change in cherry fruits from a straw color to pink blush, but this is not always a reliable indicator. Peak emergence often coincides with or near harvest. Adult fruit flies are capable of depositing eggs in immature fruits (green) and after cherries have turned red (Frick *et al.* 1954, Messina *et al.* 1991). The female *R. indifferens* deposits a marking pheromone on the fruit following oviposition (Prokopy 1975, Mumtaz & AliNiazee 1983). This chemical reduces the chance that multiple eggs will be laid in the same fruit making optimum use of resources.

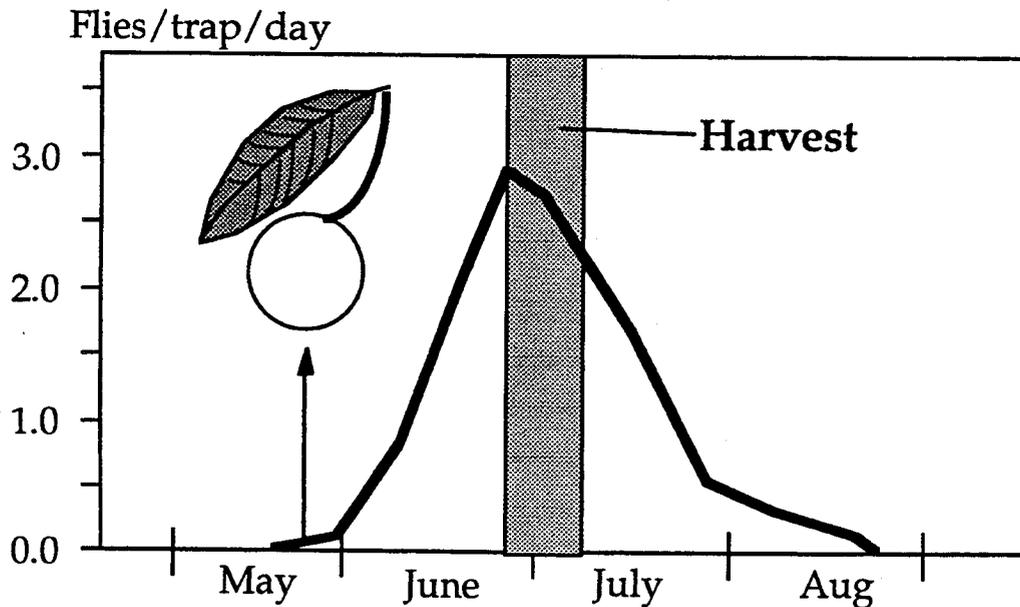


Figure 3. Emergence pattern of the western cherry fruit fly in northcentral Washington.

Adult cherry fruit flies live 16 to 40+ days, depending on temperatures, with males living longer than females. They feed on deposits on the leaves, such as honeydew and pollen or other organic material. Adult females undergo a 7- to 10-day preoviposition period before they are sexually mature. The movement of cherry fruit flies has not been extensively studied, but reported observations indicate that they tend not to be strong dispersers. After mating, adults deposit eggs under the skin of cherry fruits. Females frequently feed on juices exuding from the puncture made during egg laying. Each female can lay from 50 to 300+ eggs in a 3- to 5-week period. The optimum temperature for egg laying is between 75 and 85°F.

The eggs of cherry fruit fly hatch in five to eight days, and the larvae burrow towards the pit. Larvae are fully developed in 10 to 21 days after hatching. When nearly mature, larvae move to the fruit surface and make a "breathing hole" that they eventually use to exit the fruit and drop to the ground. They immediately burrow into the soil to pupate. A small percentage of adults emerges the same summer from the pupae without going into the diapause. This emergence must be suicidal since no known hosts are available at that time of the year. The majority of pupae enter diapause and overwinter, developing into adults the following season, but a small percentage of the pupae remain dormant for one or two years before emerging.

Management and monitoring

R. indifferens is by far the more important cherry fruit fly species attacking commercial cherry in the Pacific Northwest. Chemical applications are the primary means of providing control, and applications are made prophylactically due in part to a zero tolerance for infestation of cherries destined for California, one of the largest domestic markets. Control is directed at adult cherry fruit flies with the goal of preventing oviposition and is primarily achieved by using organophosphate or carbamate insecticides. A systemic insecticide, dimethoate, has been used in some situations to provide control of adults as well as larvae in the fruit (AliNiazee 1974b, Banham 1974, Zwick *et al.* 1975).

R. indifferens and *R. fausta* adults are attracted to certain colors, shapes, and odors (Frick 1952, Reissig 1976, AliNiazee 1978). Management programs have been proposed based on monitoring with traps (AliNiazee 1981). However, the need to detect very low levels of fruit flies and the zero tolerance of infestation based on the California quarantine have meant that these programs have not been widely adopted. Improvements in monitoring systems or a relaxation of CA quarantine restrictions would enhance opportunities for developing IPM programs in cherry.

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Behavioral Ecology of Cherry Flies

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Behavioral ecology is the study of the contribution of the behavior of an animal to its survival and reproductive success within an ecological and evolutionary framework. To put it another way, behavioral ecology is the “how” and the “why” of behavior.

Why is it important to understand something about the behavioral ecology of an insect in order to manage or control it effectively?

To maximize survival and reproductive success, most insects require nutritious food, worthy mates and suitable egg-laying sites. Knowing how insects go about satisfying each of these needs can provide clues to developing new and effective management tactics. Such knowledge can also be of great value in understanding why some approaches to insect control work better than others.

With this as brief introduction, let us have a look then at how cherry flies go about acquiring food, mates, and egg-laying sites. Let me say at the outset that a good deal, less is known about the behavioral ecology of the western cherry fruit fly, *Rhagoletis indifferens*, than is known about the behavioral ecology of several other important fruit fly pests, including the European cherry fruit fly, *Rhagoletis cerasi*; the eastern cherry fruit fly, *Rhagoletis cingulata*; the black cherry fruit fly, *Rhagoletis fausta*; and the apple maggot fly, *Rhagoletis pomonella*. Therefore, I will draw upon elements of our knowledge of the behavioral ecology of some of the other species to fill in gaps in our knowledge of western cherry fruit flies. This

presentation is not intended to be an exhaustive account of what is known. Rather, the intent is to selectively highlight those particular facets of behavioral ecology that have greatest potential relevance to cherry fly management.

Acquiring food

If cherry fruit flies are like most other species of fruit flies, they require intake of carbohydrate every day to support survival and movement capability, and protein every 3 or 4 days to develop and sustain reproductive capability. The ideal way to find out how a fruit fly goes about satisfying these nutritional needs is to study how feeding behavior is organized in time and space. In-depth studies of this sort have been carried out with apple maggot flies (reviewed in Hendrichs & Prokopy 1994) but not with cherry flies.

What do we know about cherry fly food foraging behavior, which comes largely from three studies?

In the first study, Prokopy (1976) censused the location and activities of *R. fausta* flies in a small unsprayed sour cherry orchard interspersed with hickory and apple trees and surrounded by sumac and woods. About two-thirds of all instances of observed feeding was on cherry trees. Principal food included honeydew (excrement) of aphids on foliage, extra-floral nectaries at the juncture of leaf blades and stems, bird droppings on foliage, and juice exuding from punctures in fruits made by females. One particularly striking finding was that the flies foraged for the nectar of extra-floral nectaries in a very stereotyped fashion that involved making a series of short flights upward from one leaf to another until the top of the tree was reached, at which point the flies would make long flights downward to the bottom-most leaves and begin this process over again. In the second study, Smith (1984) reported that primary sources of food for *R. cingulata* flies on wild black cherry trees were insect honeydew, bird droppings, and juice from punctured fruits but not extra-floral nectaries, which are absent from black cherry trees.

In the third study, Katsoyannos *et al.* (1986) censused the location and activities of *R. cerasi* flies in a diverse habitat of sweet cherry trees, honeysuckle bushes (the native host of this fly), gardens, and woods. As was the case with *R. fausta*, they found that the majority of activities probably associated with food finding occurred on host plants but some occurred on non-hosts.

What are the practical implications of these findings?

First, although cherry flies seem to spend a majority of time in intimate association

with host plants, many spend at least some time away from hosts, both early as well as later in their adult lives. This suggests that whatever the management strategy employed, it should be recognized that on any given day in the life of a population, at least some proportion of the population is likely to be outside of the managed area, if the managed area were to consist solely of host trees.

Second, the numerous stereotyped upward flights associated with the nectar-foraging movements of *R. fausta* suggest that trapping surfaces could be oriented in a particular way to take advantage of this behavior.

Third, synthetic equivalents of the odor of natural food could be used in traps to lure cherry flies. Indeed, recent studies have shown that apple maggot flies are strongly attracted to the odor of recently deposited bird droppings and that bacteria are the agents responsible for the production of this attractive odor (Prokopy *et al.* 1993). Chemical analysis (Heath & Prokopy, unpublished data) has revealed that ammonia is one of the principal attractants produced by bacteria associated with bird droppings, but that there also are other yet unidentified major attractive components.

Fourth, the tracking of movements of individual cherry flies in apparent search of food has suggested that cherry flies might be using visual cues of foliar surfaces as well as odor cues of food associated with foliage to guide them toward food. Indeed, experiments by Prokopy and Boller (1971) and Moericke *et al.* (1975) clearly show that *R. cerasi* and *R. fausta* adults are attracted to the green color of foliage. Even more attractive than green is yellow, which reflects energy in the same part of the visual spectrum as green leaves do but at a much higher level of intensity. Thus, yellow seems to represent to hungry fruit flies a patch of exceptionally bright foliage on which they might find food.

Acquiring mates

Existing data on the mating behavior of cherry flies under field conditions come partly from the aforementioned studies of cherry fly feeding activities. Although numbers of observed attempted copulations in the study of *R. fausta* by Prokopy (1976) were few, all that were observed occurred on sour cherry trees. None were observed on non-host plants. In that study as well as in the study of *R. cingulata* by Smith (1984), all observed copulation attempts were initiated on the foliage of host trees. None were observed being initiated on the fruit.

Studies by Katsoyannos (1982) on the mating behavior of *R. cerasi* under field and laboratory conditions are perhaps the most revealing of all. Several important conclusions can be drawn from Katsoyannos' studies.

First, mating behavior is concentrated on host plants, with certain properties of host plants (possibly attractive volatiles) serving the function of a long range pheromone in aggregating the sexes.

Second, daily activities of flies on host plants are focused on sun-lit parts of the plants, further aggregating the sexes.

Third, males emit a sex pheromone that is attractive to females over short distances of several inches, but apparently not over longer distances of several yards. Females become unresponsive to male pheromone for a period of 1-2 weeks after mating, suggesting that females in nature may willingly mate only 1-3 times during their life. Under confined laboratory conditions, however, *R. cerasi* females frequently undergo forced copulation by males because they cannot escape the advances of males. Conclusions from these studies on *R. cerasi* are similar to those of extensive field, semi-field, and laboratory studies of the mating behaviour of *R. pomonella* flies reviewed in Prokopy and Roitberg (1984). The major difference appears to be that in *R. pomonella*, the vast majority of matings in nature results from forced copulations of females that are in the process of withdrawing their ovipositors from fruit and are unable to resist the pursuits of males. There is a distinct advantage to the *R. pomonella* male that is the last one to mate with a female, as his sperms will fertilize more than 80 percent of the eggs laid (Opp *et al.* 1990).

What are the practical implications of these findings?

First, the fact that in *Rhagoletis* flies sex pheromone appears to be produced only by males, is attractive only to females, and is attractive only over short distances, suggests that the concept of mating disruption applied to behavioral control of codling moth and other tree fruit lepidopterans is not likely to be applicable to controlling cherry flies. As currently practiced, mating disruption involves release of large amounts of synthetic female sex pheromone to disrupt the mate-finding ability of males. Even if the male-produced sex pheromone of cherry flies could be chemically identified, it is unlikely that it could be put to practical use to disrupt female mating behavior.

Second, it is conceivable in concept that host plant volatile attractants that apparently act to lure males to host plants containing females could be used to trap out males and prevent mating. As has been found in extensive studies using female sex pheromones to attract and trap out male lepidopterans, however, it takes only a few untrapped males to inseminate sufficient females to give rise to damaging numbers of progeny. Hence, this is not a practical approach to cherry fly control.

Third, it is conceivable that male sex pheromone of cherry flies could be identified,

synthesized and incorporated into traps to capture females. An extensive amount of work on this approach has been conducted on tropical fruit flies, but has been fraught with much difficulty associated with identification of the numerous kinds of chemicals emitted in the sex pheromone blends of males (Millar 1995).

Fourth, the manner in which mating behavior in cherry flies is organized has much relevance to the use of the sterile insect release approach to fly management. The fact that copulations in cherry flies appear to be initiated largely or exclusively on host plants suggests that releases of sterile cherry flies can be confined to host plants. This would be a major operational and economic advantage to a sterile release program. One must be concerned, however, with the frequency with which cherry fly females mate with males in nature. If females under field conditions were to mate on a daily basis, as they apparently do in *R. pomonella* (Opp 1988), then it might require a massive overflooding ratio of sterile wild males to reduce the probability of insemination by wild males. Because there appears to be considerable variation among species of *Rhagoletis* flies in the manner in which males approach females for mating and the ability of females to fend off unwanted advances of males, any serious consideration of using sterile insect releases to control

R. indifferens ought to be preceded by detailed studies of its mating behavior under field conditions, which to date are lacking.

Acquiring egg-laying sites

Like other fruit flies that attack fruit, cherry fruit flies seeking to lay eggs appear to search for host fruit that are in prime condition to support their larval progeny to maturity. Once such fruits are found, females lay eggs singly in the fruit flesh.

How do females go about finding fruit in favorable conditions for egg-laying?

No studies of long distance orientation of females to host plant stimuli have yet been conducted on cherry flies. But in *R. pomonella* flies, there exists firm knowledge that females as well as males move upwind from tree to tree when they get a sniff of the odor of host fruit in suitable condition for egg-laying (reviewed in Aluja & Prokopy 1992). Such odor is attractive over at least 20 meters (Green *et al.* 1995). Odor of host plant leaves and woody tissue is not attractive (Prokopy *et al.* 1973). After arrival on a host tree, *R. pomonella* rely on the visual properties of host fruit (shape, size and color) to locate individual fruit; they use fruit odor to locate individual fruit only if individual fruits are highly inconspicuous visually, a rare occurrence (Aluja & Prokopy 1993). Volatiles of host fruit attractive to *R. pomonella* have been identified as several short-chain esters, particularly butyl hexanoate (summarized

in Averill *et al.* 1988). As with *R. pomonella* flies, cherry flies are known to respond positively to host fruit visual stimuli in locating individual fruit after arrival on a host tree (reviewed in Katsoyannos 1989).

Considerable work has been done on determining the characters used by *R. indifferens* females in deciding whether or not to lay an egg after arrival on a fruit. Fruit size, color, penetrability, sugar content, and water content all play a role in such decisions (Messina *et al.* 1991). The timing of *R. indifferens* fly emergence appears to be much less important than degree of fruit ripeness in determining the onset of egg-laying; importantly, there appears to be rather little decline in the acceptability of mature fruit compared with fruit in optimum stage for egg-laying (Messina *et al.* 1991). After depositing an egg, a female *R. indifferens* fly drags its ovipositor around the surface of the fruit and in so doing deposits on the fruit surface a marking pheromone (Prokopy *et al.* 1976, Mumtaz & Ali-Niazee 1983). The pheromone is a signal to the female that laid the egg as well as to other females that a developing larva is already present in the fruit and that it would be wasteful to deposit another egg in a fruit that is likely to support only a single larva to maturity.

What is the practical significance of these findings?

First, based on work done on *R. pomonella*, there is every reason to believe that host fruit produce volatiles that are attractive to *R. indifferens* flies and that such volatiles could be identified and used as long-distance attractants for luring flies to traps for monitoring or controlling populations of *R. indifferens*.

Second, the visual stimuli of host fruit that act to attract other species of *Rhagoletis* flies to individual fruit could be used to attract *R. indifferens* females to fruit-mimicking visual traps.

Third, the acceptability of ripe cherries to at least some *R. indifferens* females in search of egg-laying sites suggests that fruit remaining on trees after harvest is indeed subject to attack by late-emerging flies and could constitute a major reservoir for continuous within-orchard fly populations if not removed or treated with pesticide.

Fourth, the existence of host-marking pheromone in *R. indifferens* suggests that if such pheromone could be identified and synthesized it could be sprayed on orchard trees to deter fly egg-laying, as has been done for *R. cerasi* (Aluja & Boller 1992).

Conclusions

Studies of the behavioral ecology of several species of fruit flies have provided numerous insights into potentially useful approaches for behavioral fly control. Unfortunately,

rather little work has been done on the behavioral ecology of *R. indifferens*. Hence, at this point in our knowledge, one can only presume, but not know for certain, that patterns of resource acquisition behavior common to *R. fausta*, *R. cingulata*, *R. cerasi* and *R. pomonella* flies also are characteristic of *R. indifferens*. If this presumption proves true, then several complementary pathways (but also some constraints) exist for potential behavioral control of *R. indifferens* flies. These will be explored further in several of the following papers.

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Host Marking Pheromones in Fruit Flies

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Historic background

Investigations on host marking pheromones (HMP) of fruit flies were initiated and are still most advanced in the temperate *Rhagoletis* spp. deas and methods generated by this research have stimulated similar investigations in *Ceratitidis capitata* and *Anastrepha* spp. On the other hand it seems that *Bactrocera (Dacus)* do not produce and deposit HMPs as an oviposition-deterrent (ODP) (Prokopy *et al.* 1978).

There are three distinct periods in HMP research on *Rhagoletis*: Early observations (first report of Prokopy 1972) on basic biological characteristics of HMP in *R. pomonella* (such as influence on behavior, physiological investigations on production site etc.) were conducted in the 1970s mainly by Prokopy and others, and stimulated similar research on *R. completa* in California (Cirio 1972), *R. cerasi* in Switzerland (Katsoyannos 1975), and *R. indifferens* in Oregon (Mumtaz 1976). Comprehensive reviews have been published by Prokopy (1981), Boller (1981), and Averill and Prokopy (1989).

The second period - starting in 1975 and lasting until 1987 - covered the first field applications of HMP against *R. cerasi* extracts that achieved a degree of protection for the treated cherries of over 90 percent (Katsoyannos & Boller 1976, 1980). After 15 years of research the chemical structure of the HMP was identified in 1985 and the compound synthesised in 1987 by Swiss investigators (Hurter *et al.* 1987, Ernst & Wagner 1989).

During the same period, partial delineation of structure of HMP for *R. indifferens* was accomplished by Mumtaz and AliNiazee (1983).

The third phase started a few years ago. It focuses on the influence of HMPs on the foraging behavior of flies under laboratory, semi-field and field conditions, and addresses the basic question - how HMPs are best allocated in orchards to achieve optimum protection of the fruits? Larger field experiments with the synthetic natural pheromone of *R. cerasi* started in 1988 and continued in 1989 with a synthetic modification of the pheromone that was submitted in 1993 as the first HMP world-wide for official registration in Switzerland (Aluja & Boller 1992a, 1992b; Boller & Aluja 1992).

Examples of current research programs

Foraging behavior of *Rhagoletis cerasi* influenced by HMP

Field-cage experiments carried out between 1985 and 1990 in Switzerland involving single cherry trees and entire cherry orchards showed interesting behavioral patterns:

Flies landing on cherries with complete HMP treatment of foliage and fruit exhibited a significantly reduced residence time on the tree compared to the time for flies landing on untreated trees or trees where only the cherries had been treated. However, those flies landing on trees with full HMP treatment could no longer discriminate HMP treated fruit due to constant exposure of their tarsal sensillae to the HMP on the leaf surface. Hence it was concluded that optimal HMP application should aim at treating only the fruits and if necessary only the underside of the leaves. Foliage should be left untreated whenever feasible in order to allow the HMP sensilla to recover quickly after HMP contact (Aluja & Boller 1992a, 1992b).

Experiments were conducted to explore the feasibility of applying HMP only to one-half of the tree crown whereby the trees were divided either vertically or horizontally.

In the former case, only the south and east quadrants of the trees were sprayed with HMP, whereas in the latter case only the lower part of the tree crown was treated. The results were surprising.

In the case of vertical division the treated quadrants could be protected against oviposition with an effectiveness of 95 percent but the infestation rate of cherries in the untreated parts was only one-third of the expected value. This strongly suggests that flies landing on HMP treated trees do not move horizontally within the tree in search for untreated resources. Where only the lower part was treated, the infestation rate of cherries in the untreated upper part was as high as in untreated check trees, whereas the treated lower part could be protected against oviposition. This is suggestive that flies landing on HMP

treated trees start an upward movement in search of

M : MP (Male : Male pheromone) tree resources (Aluja & Boller 1992a).

The most recent experiments carried out between 1990 and 1994 investigated the effect of optimal HMP allocation on cherry fruit fly infestation patterns and control efficiency in commercial cherry orchards in Switzerland. In one case during 1990, 24 cherry trees (4 rows of 6 trees) were included in the experiment and sprayed with 5 liters of a 10ppm HMP solution per tree. The second tree in each row remained untreated (= 4 check trees). It was speculated that the infestation rate would build up with increasing distance from the untreated trees due to frequent encounters with HMP treated resources and increasing ovarian pressure.

The opposite was true. Highest infestation levels were, of course, observed on the untreated check trees (17 percent) and between 2.3 percent and 5.7 percent of infestation was observed in the trees in their immediate neighborhood. The infestation rates at distant corners of the orchard were very low (<1 percent).

These results suggest that flies in constant contact with HMP-treated resources can refrain from oviposition and move around within a patch of host trees in search for suitable oviposition sites much longer than anticipated. In our experiments they did locate the few untreated trees, concentrated on their fruits until fly density and/or natural HMP intensity exceeded a critical threshold. Then they moved to adjacent HMP treated trees accepting the treated cherries reluctantly as second choice. These experiments indicate that HMP application should be combined with efficient trapping on and around untreated catch-trees.

Further field experiments conducted in 1991 and 1992 utilized this approach, and cherries could be protected with an efficiency of >90 percent even under adverse meteorological conditions. Based on these field data the synthetic pheromone was submitted to the Swiss registration authorities in 1993 for official registration.

Permission was received for 1994 to conduct large field experiments and two different application procedures were tested. Both applications by knapsack sprayer and by gun produced excellent protection of 98 percent with two treatments. However, the application by gun required double the amount of HMP (i.e., 13 liters per tree) than the knapsack-sprayer, but only one-fourth of the time to apply spray.

It can be concluded that the HMP is ready for practical application against the European cherry fruit fly as soon as the product can be synthesised in larger quantities at moderate costs and sold through commercial channels. It has to be applied twice in a weekly interval.

Response of *Ceratitidis capitata* of different geographic regions to a standard HMP solution.

The response of the medfly to its HMP has been investigated on and off by various scientists in Europe and the United States of America after the existence of the HMP had been reported for this species by Prokopy *et al.* (1978). In Europe preliminary laboratory and field experiments were conducted from 1983-86 in Switzerland, Italy (Sardinia), and Greece in the framework of an International Organization for Biological Control of Noxious Animals and Plants (IOBC) co-ordinated research project. The results obtained both in field and laboratory experiments were highly inconsistent, unpredictable, and not reproducible at other locations indicating various interfering factors such as inadequate laboratory bioassays, influence of host fruit characteristics, and possible influence of geographic origin of the given medfly strains. Best results were achieved in the Swiss laboratory with medfly material from Kenya, whereas flies from Sardinia seemed to exhibit a different behavioral pattern (Boller, unpublished IOBC report).

When the Global IOBC fruit fly working group was established in Rome (1987), it was decided to start a new co-ordinated research project addressing the question of variability in HMP perception by medfly strains of different geographic origins. Seven collaborating fruit fly laboratories (Argentina, Brazil, Greece, Reunion Islands/France, Mexico, Switzerland, and the United States of America) utilized an improved standard laboratory bioassay (Boller & Aluja 1992) and a standardized HMP stock solution provided by the Swiss laboratory. The results of this joint project became available in 1992 and have been published (Boller *et al.* 1994).

It can be concluded that all geographic populations react the same way to a standard HMP solution prepared from medflies of Mediterranean origin.

Comparative results of three medfly strains with different rearing histories (Kenya F50, Sardinia F38, and Seibersdorf F500) show that the Kenya strain had fully retained its HMP discrimination abilities (discrimination coefficient DC =76.8 percent) and host marking behavior. The performance of the two other strains was reduced (Sardinia DC 47.7 percent; Seibersdorf DC 43.5%) and their dragging lasted only a few seconds. However, it is remarkable that even the medfly strain with the longest rearing history in the world (Seibersdorf) has still retained a residual capability to discriminate HMP marked fruits. These results indicate a genetic plasticity and robustness of the medfly, confirming earlier observations in the field of quality control (Boller & Calkins 1984).

Recent investigations of Papaj *et al.* (1989a, 1989b, 1990 & 1992) show that the medfly can not only be deterred from oviposition by HMP marked oviposition sites, but can also be stimulated by HMP to lay eggs into existing oviposition punctures. However, the

authors conclude that HMP still remains an interesting potential tool in the management of medfly population if the proper concentrations are applied .

Taking note of these advances in HMP biology, the Global IOBC fruit fly group has decided to continue laboratory and field investigation to further explore this potential. The current project is co-ordinated by F. Diaz-Fleischer of the Moscamed Program at Tapachula, Mexico, and is assisted in Europe by the Swiss laboratory at Wädenswil. The main objective is to conduct simple experiments both in field-cages and in the field with natural populations, and with crude HMP extracts provided to the participants.

Prospects

Research on the chemistry and deployment strategies of HMP in *Rhagoletis* spp. is likely to continue and to produce new insight into the practical potentials of HMP application in IPM programs. HMPs of *Rhagoletis* might therefore become the pacemakers of a future HMP technology.

It is anticipated that the co-ordinated IOBC activities in progress on *Certitis capitata* in the laboratory and under field conditions will produce important base-line data in the near future that might help to clarify certain contradicting phenomena in the relationship of the medfly and its host marking pheromone. One of the interesting questions that remains to be clarified is the knowledge of the conditions that are inducing oviposition-detering HMP to change into a signal acting as oviposition stimulant. A prerequisite for a chemical identification of the ODP is the development of a reliable electrophysiological technique for *Certitis capitata* that so far has encountered many problems (Cmjar & Städler, personal communication). But in consideration of the cosmopolitan nature and economic importance of the medfly, such investigations might be justified.

Investigations on HMP of *Anastrepha* spp. are in progress in various Latin American countries. Here we can expect interesting new insight into the HMP-fruit fly interactions that might stimulate the interest of chemists to take a closer look at the chemistry in this important fruit fly complex. This could potentially lead to novel strategies of biotechnical fruit fly control.

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Behavioral Approaches to Cherry Fly Management

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In this contribution on the behavioral ecology of cherry flies, numerous examples were put forward of potentially effective ingredients for behavioral control derived from knowledge of fly behavioral ecology. No method of control can ignore the behavior of targeted flies. But some methods of potential control that directly involve manipulating fly behavior are emphasized in this paper. The aspects of fly behavior associated with the sterile insect release technique or the spraying of synthetic host marking pheromone are not discussed. These behavior-based approaches to fly management are discussed in depth in other papers. This paper concentrates on three other behavior-based approaches: application of bait sprays; design and efficacy of traps; and establishing fly-free areas.

Bait sprays

Bait sprays comprised of a combination of an attractive feeding stimulant (such as one or another form of protein hydrolysate) plus an insecticide have been, and continue to be, widely used to control Mediterranean fruit flies (reviewed in Prokopy *et al.* 1992). Recent strong objections of homeowners to the drift of aerially applied bait spray droplets onto their properties have prompted concerned entomologists to search for alternatives to malathion as a toxicant for use in bait sprays against medflies.

To date, the most promising alternative to malathion in a bait spray appears to be photo-activated dyes, such as halogenated flouricine red dyes (Krasnoff *et al.* 1994). Such dyes are essentially harmless to humans and in fact are already present in consumed products such as

Peptobismol. Their toxic effects upon insects, particularly dipteran insects (flies), have been known for more than 20 years. They become active only after ingestion and only when the ingesting insect exposes itself to sufficient light to cause a photon-activated change in the molecular structure of the dye, leading to toxicity. Usually there exists a sufficient amount of skylight, even within a tree canopy under cloudy conditions, to result in toxicity, provided the amount of dye ingested is sufficiently great. Prospects appear excellent that such dyes will soon receive EPA approval for application to a variety of orchard crops. Aerially applied on a weekly basis, photo-activated dyes could effectively replace malathion in bait sprays. The major challenge for cherry fly control would lie in inducing cherry flies to feed on bait spray droplets.

In the only published study of which I am aware that involves comparison of bait spray application against cherry flies with application of pesticide alone, Reissig (1977) found that ground sprays of azinphosmethyl alone provided better control of *Rhagoletis fausta* flies than ground sprays of azinphosmethyl combined with any of several sorts of protein hydrolysate materials as bait.

Why was the bait spray no more effective than application of azinphosmethyl alone?

One can't be certain of the reasons, but suggestive leads come from recent studies on effects of bait sprays on medflies and apple maggot flies (Prokopy *et al.* 1992, 1993). These studies showed that hungry flies of these two species were much more responsive to a single fresh bird dropping than to an equivalent amount of protein hydrolysate bait droplets (in this case droplets of Nulure, the bait most commonly used when spraying medflies). Moreover, even the slight attractiveness of the fresh Nulure droplets to the flies essentially disappeared after the droplets had dried on foliage a day after application.

These findings strongly suggest that presence of natural food (such as bird droppings or aphid honeydew) in an orchard environment might outcompete bait spray droplets in attractiveness to cherry flies. Because cherry flies might be unresponsive to most of the sources of proteinaceous food for several days after ingesting a protein meal, any program aimed at using photo-activated dyes in combination with proteinaceous food for bait spray application against *R. indifferens* ought to be preceded by extensive study of the potential attractiveness of bait spray droplets to the flies under field conditions. Conceivably, one or

another attractive chemical component of bird droppings (or the associated bacteria) could be combined with existing protein hydrolysates to render bait spray droplets more attractive than they appear to be in present form.

Design and efficacy of traps

The visual equivalents of a mass of super-bright foliage (yellow rectangles) attractive to food- and foliage-seeking flies, and of a super-size fruit (a medium or large sphere) attractive to fruit-seeking flies offer the greatest potential among visual stimuli for trapping cherry flies.

In studies of *R. pomonella*, *R. fausta*, and *R. cingulata* alightings on yellow rectangles hung in various positions with respect to orientation of the yellow surface of the rectangle, Prokopy (1975) and Reissig (1976) found that more *R. fausta* and *R. cingulata* flies alighted on a V-shaped rectangle having the yellow surface oriented downward than on vertically oriented or upward or downward horizontally oriented yellow surfaces. This was not so for *R. pomonella* flies, which alighted in greatest numbers on vertically oriented yellow rectangles. The principal reason for the greater response of cherry flies to V-shaped rectangles possibly lies in the tendency of *R. fausta* and *R. cingulata* to make numerous short upward flights from leaf to leaf when foraging for food, thereby affording enhanced opportunity to see a V-shaped yellow surface. Another major advantage of a V-shaped orientation of yellow is that few unwanted insects alight on rectangles so oriented. Thus, for *R. fausta* and *R. cingulata* flies, a V-shaped yellow rectangle is both more attractive and more selective against other insects than a vertical yellow rectangle. This can be a major advantage when using a sticky yellow rectangle in detecting flies or monitoring fly abundance. Capture of unwanted insects might obscure visibility of captured cherry flies or otherwise make it difficult to see cherry flies within a mass of other sorts of insects.

Cherry fly attractiveness to yellow rectangles can be increased by addition of ammonium salts or some other substance that releases ammonia (Frick *et al.* 1954, Banham 1973). For example, captures of *R. cingulata* flies were two to five times greater on yellow rectangle baited with ammonium acetate than on unbaited yellow rectangles (Prokopy 1975, Reissig 1976). In a study by AliNiazee (1978), captures of *R. indifferens* flies proved 50 percent greater on ammonium-baited yellow rectangles than unbaited yellow rectangles during mid- and late-season, but were no greater early in the fly season. As said earlier ammonia is a principal compound produced by bacteria associated with attractive bird droppings. Other bacterial-produced compounds from bird droppings show promise of being equally or more attractive than ammonia (MacCollom *et al.* 1994) and could substantially enhance attractive-

ness of yellow rectangles if these compounds could be identified.

In regard to fruit-mimicking spheres, Prokopy (1969) found that *R. cerasi* flies were more attracted to cherry-size red or black spheres than to cherry-size spheres of other colors or to similar-size red or black objects of other shapes. When red spheres of various sizes were evaluated, more *R. fausta* and *R. cingulata* alighted on 8 cm red spheres than on 3, 4, or 23 cm red spheres (Prokopy 1977). But Reissig (1976) found that 8 cm red spheres were less attractive to *R. cingulata* than were 13 cm red spheres. As sphere size is increased from cherry-size to apple-size or larger, *R. cerasi*, *R. fausta* and *R. cingulata* become increasingly more attracted to yellow spheres compared with red spheres (Prokopy 1969, Reissig 1976). Such change undoubtedly reflects increased response to increasing size of yellow spheres as representing not only the cherry fruit but also a mass of super-bright foliage, whereas with red spheres, a size is eventually reached which no longer represents a super-large fruit to the flies.

If cherry flies were to be shown attracted to the odor of host fruit and if the attractive volatiles were to be identified, then synthetic host fruit volatiles might enhance attractiveness of fruit-mimicking spheres to cherry flies in the same manner they do with apple maggot flies (Reissig *et al.* 1982).

Are cherry flies more attracted to foliage-mimicking yellow rectangles or to fruit-mimicking spheres?

To date, direct comparisons have been few. But the scant published findings suggest that unbaited yellow rectangles are equal or superior to unbaited 5 or 8 cm red or yellow-spheres (Prokopy 1975, Reissig 1976, AliNiazee 1978).

Fly-free areas

A fly-free area is an area with no detectable populations of a fruit fly species (Malavasi *et al.* 1994). These authors put forward two models of fly-free areas:

- (1) a fly-free zone, where an entire geographical or political entity is recognized to be free from target flies, and
- (2) fly-free production fields, where flies are managed in a way that ensures absence of flies from specific production areas but not necessarily from large geographic or political entities. Several factors come into play in characterizing and establishing a fly-free area, including physical, ecological, biological, political, economic, and social factors (Malavasi *et al.* 1994).

Three aspects associated with cherry fruit fly behavior and ecology come into play if effective fly-free areas are to be established.

First, one needs substantial knowledge of distance moved by individual flies under varying ecological and environmental conditions. To date, there is very little published information on this aspect of cherry fly behavior, although Pugsley (Chapter 3) has detected marked *R. indifferens* females moving at least 12 kilometers from one host patch to another on hot windy days. The author's observations of *R. cerasi* behavior would confirm Pugsley's findings in that on hot, dry, and windy days, *R. cerasi* are strongly inclined to leave host trees and move into ground cover or other vegetation for protection. During such movement, he has observed flies involuntarily carried aloft by wind, possibly to distant places.

Second, all unmanaged host trees within a certain distance of designated fly-free orchards must be removed or otherwise managed by treating with pesticide or some other method of ensuring complete control of flies. The distance in question must correspond to the maximum distance over which flies are capable of moving.

Third, there must exist a truly effective methodology for detecting the presence of flies in designated fly-free orchards to ensure that such orchards are in fact free of flies. If these behavior-associated requirements can be met, then there exists a good foundation for eventual establishment of fly-free areas.

Conclusions

There are several approaches to manipulating cherry fly behavior that could conceivably provide very effective fly control. The focus here has been upon bait sprays, design and efficacy of traps, and establishment of fly-free areas. Some behavior-based methods might provide maximum control if they were to be used in combination with one another. For example, application of synthetic host marking pheromone could be used to "push" cherry flies away from treated trees in an orchard. These flies could then be "pulled" toward attractive traps and eliminated. Such a push/pull system of behavioral control might work better than either push or pull alone.

All of the behavioral control approaches discussed here are constructed largely from research information published on *R. cerasi*, *R. fausta*, and *R. cingulata* flies. Information on *R. indifferens* is scant. Hence, until more is known about *R. indifferens* response to baits as components of bait sprays, to stimuli used in traps, and distances moved on hot, windy days, it will be difficult to recommend with confidence a prudent approach to behavioral control.

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Mass Trapping: Apple Maggot Flies as an Example

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Among North American *Rhagoletis* flies, the use of traps to achieve control has to date been explored and practiced more extensively with apple maggot flies than any other species. In several respects, current approaches to mass trapping apple maggot flies could have direct application to potential future approaches to mass trapping of *Rhagoletis indifferens*. In this paper a synopsis of past, present, and planned future tactics for mass trapping of apple maggot flies are provided.

Sticky red spheres

In commercial orchards in eastern North America, apple maggot flies are more attracted to 8 cm red spheres than to any other visual stimulus. The first published reports on use of sticky red 8 cm spheres for apple maggot control involved hanging several unbaited spheres on each tree in small orchards or plots. If the tree canopies were somewhat large (for example, semi-dwarf trees), usually about six spheres per tree were used. If the canopies were smaller (for example, dwarf-trees), usually only one or two spheres per tree were used. Results generally showed 2 percent or less damaged fruits on trapped trees compared to 90 percent or greater damage on unmanaged trees, or 1 percent or less injury on insecticide sprayed trees (Prokopy 1975, 1985; Reissig *et al.* 1984). While hanging several traps on every tree could

be considered an economically feasible approach to controlling apple maggot in small orchards of an acre or less, it is an extremely expensive approach for use in larger orchards.

From 1991-1994, an evaluation was made for an alternative approach to deploying traps in larger orchards. It involved hanging sticky red spheres (baited with synthetic food odor and synthetic fruit odor) about 5 yards apart on perimeter apple trees, thereby creating a ring of traps around the perimeter of a block. For 10-acre blocks of M-7 trees, this reduced the number of traps needed per acre from about 600 (when hanging unbaited traps in every tree) to about 16. The goal was to intercept immigrating flies before they could invade the block. Results in six commercial orchard blocks of 6-10 acres each were encouraging. Fruit injury by apple maggot averaged 1.1 percent in trapped blocks compared with 0.7 percent in nearby blocks that received about three insecticide sprays (Prokopy *et al.* in press).

Even though the perimeter-trapping approach afforded very good apple maggot control using rather few traps, two shortcomings became apparent that would inevitably constrain use of this practice by the great majority of commercial growers:

First- the sticky traps proved very messy to handle on a large-scale basis.

Second- unless the traps were cleaned of all insects and stickyum was reapplied every two weeks, the traps soon became incapable of capturing the frequently very large numbers of maggot flies that alighted upon them (Duan & Prokopy 1995). Cleaning and re-coating traps every alternate week from July to September is very labor-intensive and thereby effectively precludes use of perimeter sticky spheres for maggot fly control in most commercial orchards.

Pesticide-treated spheres

Recently, investigations were initiated to find alternatives to sticky material as the agent for killing apple maggot flies that alight on red spheres. Initially it was thought that by simply replacing the sticky material with a coating of insecticide on the sphere surface, the flies alighting on the sphere would die within few minutes after landing. In the first test, all the principal types of insecticides currently labeled for use in apple orchards were evaluated. Cygon™ (dimethoate) was found to be the most toxic insecticide. When the spheres were treated with a solution of 2 percent Cygon (which is 1 percent dimethoate and equivalent to about 16 times the diluted orchard labeled rate), alighting flies stayed only for a short time (usually less than a minute) on the spheres. Less than a third of these died within a day. Perhaps more would have died if the dose of Cygon had been greater. But we reckoned that the dose required to kill the desired percentage of 90 percent or more of alighting flies through body contact alone would have to be so great that such percent spheres were un-

likely to receive serious consideration for approval by the EPA.

It was then thought that combining a feeding stimulant with Cygon might encourage ingestion of Cygon by flies, which would increase fly mortality at a comparatively low dose. So, numerous types of potential fly feeding stimulants (various carbohydrates and amino acids) were evaluated, sucrose (table sugar) and fructose (corn syrup) were found to be by far the best.

It was therefore decided to coat red spheres with a mixture of 2 percent Cygon, 58 percent corn syrup and 40 percent water. About 90 percent of alighting flies fed on these spheres and died within an hour. The results were quite encouraging. However, when the spheres were hung outdoors, nearly all the Cygon and corn syrup was washed away with the first rainfall, which drastically reduced the killing power of the spheres. It was then deemed necessary to find an effective way of protecting both the Cygon and the feeding stimulant from the degrading effects of rainfall.

First of all, dipping spherical red sponges in the mixture of Cygon, corn syrup, and water was tried, anticipating that the sponge would absorb sufficient mixture to permit gradual metering of Cygon and corn syrup to the sponge surface over an extended period. Inversely, the sponges proved ineffective by leaking mixture excessively or by drying out prematurely. Then, diaper lining and other absorbent materials were used to form spheres and covered with red cloth. These metered out a desired level of mixture better than sponges did. But, no matter what kind of cloth material was used, alighting flies were inclined to remain on the sphere only for a short time. This period was too short to pick up a toxic dose of Cygon. The feet of the flies seemed to get entangled in the mesh of the cloth in a way that was irritating, causing them to fly off. In contrast, flies seemed very comfortable on the surface of a painted smooth sphere.

Later, it was concluded that, an insecticide/feeding stimulant mixture would indeed be most effective when applied to smooth surface spheres, as it was done in the initial tests. In the first attempt to protect the treated smooth-surface spheres against degrading effects of rainfall, a variety of protective covers above the spheres were tried. But in every case, the covers reduced numbers of flies alighting on the spheres by 70 percent or more. To get protection from rainfall by the sphere shell itself, hollow red plastic spheres were used, whose interior surface was coated with sucrose, insecticide, attractive food, and fruit odor. Numerous holes of different sizes were drilled through the sphere surface to allow entry of alighting flies into the interior. But, very few alighting flies were observed entering the spheres.

Thus, it was concluded that the most feasible approach to protect the residual activity of feeding stimulant and toxicant was through application of a residual toxicity

extending substance to the sphere surface. Several candidate substances were evaluated and to date only latex paint was found to be the most effective agent for extending the insecticidal effect. Even after 3 months of exposure to summer rainfall in apple trees, spheres coated with a mixture of red latex paint and dimethoate are capable of killing 70 percent of alighting flies provided there is sufficient feeding stimulant present on the sphere surface. However, latex paint has failed to protect feeding stimulant against rainfall. Thus, it has proved necessary to dip pesticide-treated spheres in sugar-water solution after every rainfall to restore effectiveness. So far, none of the candidate substances tested has proved really effective in extending the effect of sucrose.

Currently, therefore, the most effective pesticide-treated sphere against apple maggot is a smooth red wooden or plastic sphere painted with a mixture of 2 percent Cygon 4E (which contains 50 percent dimethoate as active ingredient), 43 percent corn syrup, 40 percent red latex paint and 15 percent water. After painting, the spheres are allowed to dry completely (2-3 days) before use in orchards. Such spheres have proven just as effective as clean sticky-coated spheres in controlling apple maggot, provided the spheres are dipped in a solution of 20 percent sucrose, 80 percent water after every rainfall (Duan & Prokopy 1995).

Future prospects

Two distinct pathways are envisaged as future prospects for the continued development and eventual EPA registration of pesticide-treated spheres to control apple maggot.

The first pathway may offer the most immediate hope for an effective, EPA-approved sphere. It would involve finding an effective substance for ensuring the residual activity of feeding stimulant over the needed 3-month period of sphere lethality in orchards. Once found, this substance would be combined with dimethoate, sucrose, or fructose, and red latex paint into a mixture that could be painted by growers onto wooden or plastic spheres. The spheres could remain permanently in place on the trees and simply receive a new coating of mixture each June. Only the synthetic attractive odor would need annual replacement. This pathway could be inexpensive and simple to employ. The principal uncertainty could be unwillingness on the part of industry to spend the necessary funds for EPA registration, and then enter into production of a mixture whose ingredients could be so inexpensive that there would be little prospect of recovering return on investment. Conceivably, an organization of fruit growers could substitute for private industry in this process.

The second pathway may offer a better hope in the long run. It would involve substituting dimethoate with a toxicant that is similarly highly lethal to the flies, but is much safer for handling by humans. Currently, a phototoxic dye and a species of bacteria are being explored

for this purpose. Such a safe toxicant might then be incorporated together with sucrose or fructose into a polymeric matrix (possibly some sort of plastic), shaped in the form of a sphere, that would degrade during winter months, after the fly season is over. Annually, growers would hang such spheres at the start of the fly season, together with synthetic, attractive odor. This pathway would have high EPA-appeal as well as high appeal to private industry, who could profit from sales of new spheres to commercial growers and homeowners in each growing season. If the cost of these spheres were competitive with the cost of pesticide application or the cost of using sticky spheres, considerable use and sales might follow.

Conclusions

The synopsis presented here on past, present, and future prospects for using odor-baited 8-cm red spheres in mass trapping of apple maggot flies in commercial orchards could have strong relevance to control of *R. indifferens* provided that the following four conditions could be met:

- 1 A truly effective odor/visual trap would have to be developed for *R. indifferens*.
- 2 Feasible and effective approaches to trap deployment would need to be determined. For example, should one trap be on every tree, or on every 10th tree or only on perimeter trees?
- 3 A mixture of pesticide, fly feeding stimulant, and residual toxicity-extending agent appropriate to achieve maximum kill of *R. indifferens* flies alighting on treated traps would have to be established.
- 4 Sufficient and affordable labor would have to be available for hanging traps. If these challenges could be met, then the door could be open to effective mass trapping of *R. indifferens*.

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Chemical and Non-chemical Alternatives for Control of the Western Cherry Fruit Fly

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Introduction

Chemical insecticides have formed the backbone of cherry fruit fly control for many decades throughout the world (AliNiazee 1986). Growers preferred using chemicals due to the efficacy, convenience, and easy availability. Some chemicals were so effective that the growers had the option of applying them a few days before harvest and getting perfect control. Other growers preferred applying only one spray of a systemic insecticide and receiving season long protection. Others enjoyed the luxury of letting an aerial applicator apply the pesticide and provide effective suppression of the pest without much worry. In short, the convenience of control made the chemicals the most important and sole component of cherry fruit fly control in North America.

Nearly all commercial orchards of the Pacific Northwest are sprayed with 1-5 sprays of chemical insecticides per year. Nearly one half of these sprays are perhaps unnecessary (AliNiazee 1978) because no flies are present in these orchards. Most sprays are applied either because of habit or to meet the requirements of the cherry processors. Little attention is given to the population of the flies or their biology. A large reduction in pesticide usage is possible, as documented by AliNiazee (1981).

On the other hand, if left untreated, nearly one hundred percent fruit damage can

occur (AliNiazee 1978). In orchards with a high level of beneficial insect activity, extremely high levels of pest infestation are common. Export to the Far East countries are an important source of income to North American cherry growers. Nothing more than zero percent infestation is tolerated in this market. Therefore, chemical control becomes an essential component of any integrated pest management (IPM) program.

Why chemical control?

As mentioned earlier, the western cherry fruit fly (*Rhagoletis indifferens*) tolerance levels are near zero and all commercial growers have to use pesticides to adequately protect their crop. Control measures currently used include application of ultra low volume (ULV) malathion on a weekly basis or ground application of one of a number registered compounds such as dimethoate, azinphosmethyl, diazinon, Asana, Lorsban, and carbaryl (Table 1). Most of the organophosphate (OP) compounds have 14-21 day pre-harvest restrictions, while carbaryl and malathion ULV can be used very close to harvest (1-2 days). Botanical insecticides such as pyrethrum and rotenone can be used in dilute application form and they apparently provide fairly good control. Chemicals like dimethoate which have systemic activity kill both adults and newly hatching larvae (AliNiazee 1974, Zwick *et al.* 1975), while

Table 1. Insecticides used against the cherry fruit fly in Oregon and Washington for the past seventy years and the current status (AliNiazee 1986).

Chemicals used	Mode of application	Aproximate time first recommended for use	Current use status
Lead arsenate	Dust, bait spray	1920	Discontinued
Cryolite	Dust	1930	Discontinued
Rotenone	Dust, spray	1934	Not used
DDT	Dust	1947	Discontinued
methoxychlor	Dust, spray	1950	Rarely used
parathion	Spray	1955	Discontinued
TEPP	Spray	1958	Not used
diazinon	Spray	1959	Moderately used
perthane	Spray	1961	Discontinued
carbaryl	Dust, spray	1961	Moderately used
azinphosmethyl	Spray	1965	Moderately used
malathion	Dust, spray	1965	Rarely used
malathion	ULV	1970	Widely used
dimethoate	Spray	1980	Moderately used
Asana XL	Spray	1986	Used
Lorsban	Spray	1989	Less used
Penncap-M	Spray	1989-90	Less used

ULV malathion and carbaryl are primarily adulticidal in their activity.

The western cherry fruit fly (WCFF) has long been controlled by using chemical pesticides (AliNiazee 1986). Starting from the lead arsenate use in the 1920s, to the current use of OP and pyrethroids (Table 1), single dimensional control using pesticides has caused relatively few problems in the Willamette Valley. However, some mite and scale problems have been noticed in other areas such as the Dalles and Yakima Valley. Since this use of pesticide is primarily for the insurance purposes, as most commercial orchards have virtually a zero fly population (AliNiazee 1981), the primary reason for extensive use of pesticides in cherry orchard relates more to a sense of economic security than to actual biological justification.

Alternative methods

Attempts have been made to search for alternative approaches to control WCFF for the past 30 years in Oregon. Although dependence on any one of the following techniques for season-long commercial control is not possible, most of the methods described below can be used as components of an integrated pest management (IPM) program.

a) Sterile Insect Technique (SIT):

As discussed in Chapter 13, the SIT appears to have good potential for management of the WCFF, either as a part of an IPM program to provide effective control at low population level or as an eradication technique in isolated areas with good natural barriers. Elimination of fertile fly immigration by reducing the sources of uncared for and or backyard cherry trees will be an essential requirement of this program if it is to be efficacious. Similarly, good management practices, including removal of unpicked fruits after mechanical harvesting, and an effective monitoring of the fly population is also required.

The eradication program will require an adequate knowledge of fly population density at a given time to arrive at required ratios of release for sterile males. A localized eradication program is possible and can be pursued, however, an area-wide eradication from the entire valleys such as the Willamette Valley or the Yakima Valley might be very difficult.

b) Pheromonal Control:

The western cherry fruit fly uses a number of chemical scents or pheromones to communicate with the individuals of the same species. Although there appears to be no true sex pheromone, an oviposition-detering pheromone (ODP) and a male-arresting pheromone have been recorded from this species (Brown 1978, Mumtaz & AliNiazee 1983). The

oviposition deterring pheromone(s) are deposited by female flies immediately after oviposition in the fruit by dragging their ovipositors around the site of oviposition. As other flies come in and land on the fruit, they detect the presence of the pheromone and leave without ovipositing in the same fruit (Mumtaz 1976). This type of behavior has also been recorded from other tephritid fruit flies (see Chapter 9).

Mumtaz (1976) attempted to utilize the aqueous and methanol washings from the cherries with oviposition deterring pheromone and sprayed fresh cherries in the field to see whether or not the treated cherries will be receptive for oviposition. A 73 percent reduction in oviposition was achieved when flies were released on cherries treated with water or methanol washings of ODP. There was no difference between water and methanol washings. Although these studies were not followed by large scale field testing of the ODP, the preliminary data suggest that under suitable conditions, the preparations of ODP are capable of reducing fruit infestation.

Similarly, Katsoyannos and Boller (1976) had found a 76 percent reduction in fruit infestation caused by *R. cerasi* when trees were treated with ODP mixed with a wetting agent. Later studies (Aluja & Boller 1992a, 1992b) showed a synthetic version of ODP was capable of reducing nearly 90 percent fruit infestation in small field studies. As our understanding of the role of ODP and other host marking pheromone increases, we might be in a better position to determine when and how to use pheromones in fruit fly management.

c) Attractant Trap-based Control:

Mass trapping as a control measure for cherry fruit flies has proven to be effective on a limited basis, particularly under back-yard or small plot situations. However, the number of traps required and servicing costs might be prohibitive for a large scale use of this method. Using trap as indicator of the presence or absence of flies is possible and has been extensively used for almost all cherry fruit flies (AliNiazee 1978, Chapter 10). Drastic reduction in the amount of pesticides used against WCFE was achieved by the utilization of a management program based on using chemical insecticides only after certain threshold levels, determined by aerial traps, had been reached (AliNiazee 1981). Although this program was not extensively followed by the growers in Oregon, it did show the efficacy of these traps.

Two factors determine the acceptance of the trap based management program by the growers: (1) the availability of pesticides and requirements of the packing houses. The easy availability of chemicals and the stringent requirements in term of fly control generally placed by the processors or control districts, may make such a program unacceptable to many growers.

(2) most growers would like to have a high degree of security and assurance that the program will work even under very low fly population conditions.

At present, the program is less desirable on both counts, therefore, not very appealing to the growers.

d) Soft Pesticides:

Although relatively few data exist on the effect of insect growth regulators (IGRs) including the chitin synthesis inhibitors and growth retardants on cherry fruit flies, it is conceivable that products such as neem, abamectin, Dimilin, and fenoxycarb may play an important role in management of this pest in the future. Also, insect repellents and botanical compounds need further investigations.

The use of bait sprays have been shown to be effective against a closely related species, the apple maggot (Mohammed & AliNiazee 1989). Whether or not such a program will work against the cherry fruit flies is unknown. If it does work, it might reduce the use of broad- spectrum insecticides.

e) Pest Evasion:

The cherry fruit flies are oligophagous species and require the availability of the ripening host fruit for oviposition. The western cherry fruit fly in particular, has made the host shift from native *Prunus emarginata* to the cultivated cherries. Phenologically speaking, the CFF has lost the ability to revert back to the native host, particularly early in the season. If the fruit is harvested before the majority of the flies emerge, it is possible to avoid the cherry fruit fly problem. Earlier work (AliNiazee, unpublished) does demonstrate that most cherry producing areas of California (particularly in the Sacramento Valley) are capable of avoiding the cherry fruit fly infestation by using early maturing varieties. If fruit is picked by the first week of June, the chances of fly infestation are reduced by 95 percent (AliNiazee, unpublished). A similar program might also be possible in some areas of Oregon.

f) Biological Control:

Research on biological control of cherry fruit flies has been neglected for years. Although some effective parasitoids have been recorded, no systematic work on seasonal dynamics and efficacy of these parasitoids has been conducted. Also, relatively few attempts have been made to explore the natural enemies in foreign lands and import suitable biological control agents against the cherry fruit flies.

AliNiazee (1975) found *Coptera occidentalis*, *Phygadeuon wiesmanni* and a number of

species of predaceous carabids to be important natural enemies of the cherry fruit fly in an abandoned orchard near Albany, Oregon. The parasitoids were able to reduce the larval-pupal population nearly 70 percent. However, the remaining 30 percent of the fly population was large enough to cause economic loss. These parasitoids were also highly susceptible to pesticides. Consequently, they were rarely found in the commercial orchards. The role of generalist predators in suppression of the cherry fruit flies is not clearly understood. Undoubtedly, they are important, but under what conditions they are capable of controlling fly population is unknown. In general however, the biological control alone may be insufficient to provide adequate control of the cherry fruit flies.

g) Integrated Control:

The most appropriate approach for management of the cherry fruit flies appears to be combination of a number of tactics discussed above in an integrated program. Fly monitoring using traps (both for detection and determination of appropriate timing) and phenological models (AliNiazee 1976), utilization of pest evasion wherever possible, and judicious and timely use of narrow spectrum pesticides might provide the needed combination. Utilization of SIT, either as a sole technique in isolated areas for eradication purposes or as a part of an IPM program needs further investigation.

In summary, it is clear that chemical control using synthetic organic insecticide is still the most effective method for controlling the cherry fruit flies, although substantial progress has been made in developing alternatives to chemical control. The integrated approach as discussed above appears to be most viable alternative to the use of chemicals.

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Sterile Insect Technique Against the European Cherry Fruit Fly in Northwest Switzerland

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The European cherry fruit fly (ECFF), *Rhagoletis cerasi*, is the key pest of sweet cherries throughout Europe.

In Switzerland chemical control of the pest is achieved by a single application of dimethoate (0.05 percent) 3 weeks before harvest. The timing of the spray is based on a temperature driven prediction model that allows relatively precise forecasts and recommendations by the national ECFF warning service located at Wädenswil, Switzerland. Research carried out at the Swiss Federal Research Station for Fruit Growing, Viticulture and Horticulture at Wädenswil focuses, however, on the development of ecologically safer control methods. Besides visual traps and oviposition deterring pheromone, we developed the Sterile Insect Technique (SIT) as a potential substitute for the pesticide approach.

SIT program 1976-1979

After 5 years of development and successful small scale field experiments, a larger SIT program involving some 140 cherry trees was initiated in 1976 to demonstrate the feasibility

of the SIT approach and to calculate the costs of a potential large scale program in North-west Switzerland (Boller *et al.* 1980).

An area of 2.5 square kilometers was located in the community of Bubendorf (20 km SE of Basel) and was divided into three subareas with distinctly different characteristics. Subarea 1 is a state farm and subarea 2 a private farm, both with a history of excellent cherry fruit fly control and hence with very low population densities of the fruit fly. Subarea 3 is community land with more than 40 different cherry producers.

Table 1. Summary of SIT operations against ECFF in Bubendorf, Switzerland.

	1976	1977	1978	1979	1980
Sterile flies released (mio)	0.15	0.39	1.1	1.1	-
Infestation rate of cherries					
Subarea I (184 trees)	0.06%	1.06%	0.00%	0.00%	0.00%
Subarea II (330 trees)	0.00%	1.50%	0.00%	0.00%	0.00%
Subarea III (875 trees)	(0.24)*	3.33%	0.10%	0.09%	1.00%

*) Suppression program by mass trapping (REBELL traps)

The infestation rate of cherries by the fruit fly varied greatly according to the control practice of the individual owners and called for a suppression program prior to the release of sterile flies. The required reduction of the ECFF population was achieved in 1976 by means of a mass-trapping program carried out with 3,500 yellow sticky traps (REBELL) while sterile fly releases were initiated in subareas 1 and 2. The entire SIT area was situated on top of a mountain range, surrounded by forest, but eye-level with other cherry orchards on neighboring hilltops located at a distance of 3-5 km.

The number of sterile flies released between 1976 and 1979 as well the infestation rates observed in the three SIT subareas between 1976 and 1980 are given in table 1.

Successful release of sterile flies

In all four years of the SIT program all cherries could be marketed as table grade cherries without application of insecticides.

A total of 2.8 million sterile flies was released. An elimination (eradication) of the pest was achieved in 1978 (3rd year) in subareas 1 and 2 which lasted up to 1981. Two years after termination of the SIT program, the effect of the operation started to deteriorate

probably due to incomplete isolation.

Costs not prohibitive

Cost calculations made in 1980 showed surprising results. When the costs of a conventional chemical control strategy, a biotechnical strategy with mass-application of REBELL traps, and a SIT program were calculated for a period of 12 years and 10,000 trees, it was evident that a single and well-timed application of dimethoate provided an extremely cheap ECFE control for Sfr. 2.- (US \$ 1.50) per tree per season. Area-wide application of traps (4 traps per tree) would cost 4.6 times as much, whereas control and protection by SIT could be obtained by 2.1 times the cost of chemical control, i.e., Sfr. 4.15 (US \$ 3.20) per tree.

A re-calculation of the costs today would possibly double the absolute figures, but probably confirm the cost relationship between the different control strategies. Certain cost factors might be different in other countries (such as the portion of free services rendered by the governmental agencies).

The feasibility of SIT

The SIT approach for the control of the European cherry fruit fly, *Rhagoletis cerasi*, is ready for application in large areas that can be protected by buffer-zones (of at least 3 km) shielding SIT treated areas from nearby areas of cherry production. The techniques and logistics have been developed to the point that would allow an efficient implementation of SIT programs where a thorough analysis of the situation indicates that SIT might be the proper strategy. Thus the conclusions published in the early 80s are still valid (Boller & Remund 1983).

Why has SIT not been implemented in large scale programs in Switzerland?

There seem to be several reasons that might, however, be less important in other countries:

1. The SIT arrived too early. In 1980 Swiss cherry producers and marketing organizations were not interested in opening a new market segment for organically grown fruit.
2. Unlike chemical control, SIT has to be applied on an area-wide basis. This requires a straight forward collaboration between individual growers, between individual cherry production centers of the Northwest and between politically independent communities as well as between cantons (states). This collaboration is certainly easier to obtain under increased public pressure (e.g., preference for organic fruit; severe quarantine regulations

of importing countries). This pressure was not strong enough in 1980 but is now increasing.

- SIT requires adequate scientific support and technical infrastructures (Fig. 1). Both were and still are available in Switzerland, but might be a major stumbling block in other countries. Unlike chemical control SIT does require substantial financial investments at the very beginning of the program.

SIT: a realistic option for cherry fruit fly control in the Pacific Northwest of the United States ?

The situations observed in the European cherry fruit fly and the western cherry fruit fly, *Rhagoletis indifferens*, show many similarities that can be summarized as follows:

Infrastructures needed

Figure 1 shows a schematic presentation of the necessary infrastructures needed for SIT operations. Two of the major differences in SIT programs developed for subtropical fruit fly species (such as the medfly) and the temperate *Rhagoletis* are:

- the way flies are produced in sufficiently large quantities, and
- the sterilization procedure.

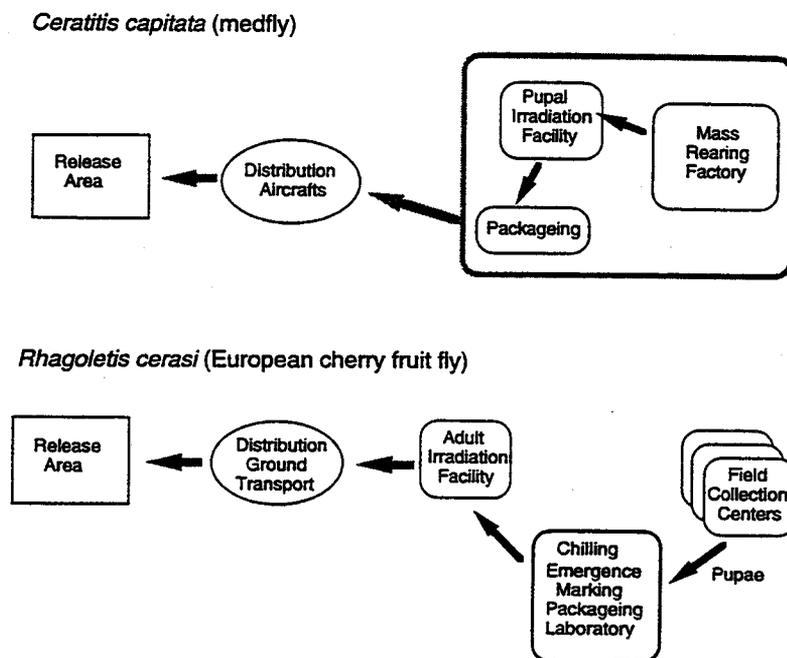


Figure 1. Infrastructures needed for SIT operations.

Production of sterile flies

Rhagoletis flies are much more difficult to rear on artificial diet in the laboratory than the subtropical Mediterranean fruit flies that can be easily mass reared in rearing factories (Boller 1989). It has proved to be easier and cheaper to produce the required number of CFF on suitable host plants in nature.

Infested cherries used for distillation (in Europe) are a potential source of field collected CFF material. This approach was used until 1977, but later could not provide the required one million sterile flies per year. Heavily infested honey suckle berries (*Lonicera xylosteum*) growing on the side lanes of super-highways were not only known hosts of *Rhagoletis cerasi*, but at the same time available in large quantities free of charge.

The honey-suckle material harvested in late July was spread on wire-screens under superhighway bridges and the pupae collected by late August.

The western cherry fruit Fly, *Rhagoletis indifferens*, attacks sweet and sour cherries as well as a number of wild host plants. It is conceivable that a similar mass-rearing operation could be established based on heavily infested wild hosts planted with adequate distances from potential SIT treated areas.

Sterilization of pupae and adults

The current procedures of sterilization utilize gamma-irradiation. Polyvoltine insect pests such as the subtropical fruit flies can be reared in such a way that the pupae of a given rearing batch show an almost identical physiological age. Their irradiation by most of the available irradiation equipment can be timed with high precision to occur for example, 24 hours before emergence of the adults.

Hence large quantities of pupae can be manipulated with ease and without complicated infrastructures required for the handling of mobile adult insects.

Temperate fruit flies with obligatory diapause must be chilled in the pupal stage before they develop into adult flies. Their developmental pattern during the pupal stage and the pattern of emergence of the adult flies depends largely on the host plant where they grew up as larvae.

ECFF reared in sweet cherries emerge as adults within a time span of ca. 7 days but those reared from honey-suckle extend their emergence period for more than 3 weeks (Boller & Bush 1974; Fig. 2). For this reason pupae cannot be irradiated without major somatic damage (causing a severe drop in behavioral quality) to that part of the pupal population that has not yet reached the optimal age for pupal irradiation.

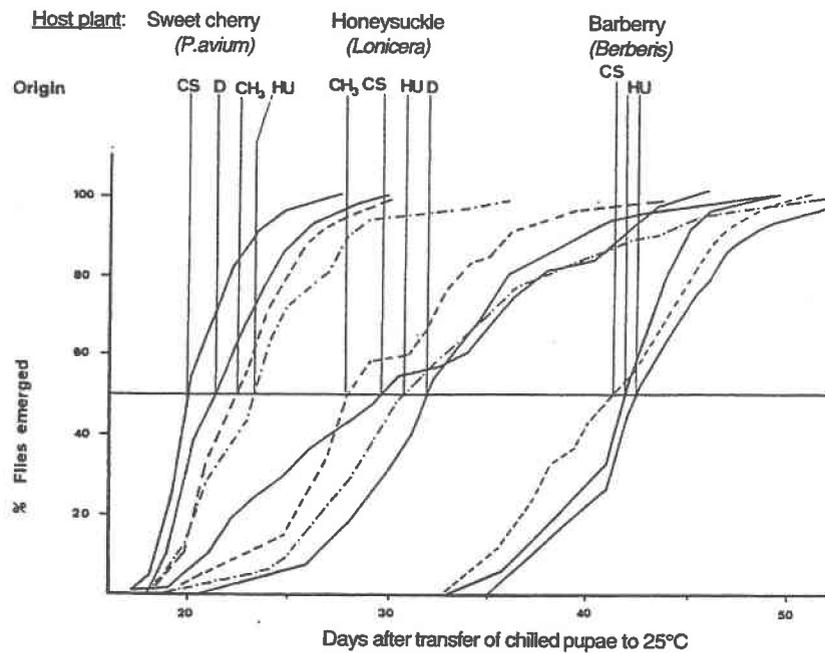


Figure 2. Emergence patterns of cherry fruit fly adults reared on sweet cherries (*Prunus avium*) and on honey-suckle (*Lonicera xylosteum*).

A similar situation might occur in the North American cherry fruit fly species being mass-reared on wild hosts. The solution to that problem is the irradiation of adult flies held for 1 week in appropriate containers that require special irradiation facilities. Figure 3 shows a SULZER pool type irradiation facility used at the Wädenswil research station in Switzerland. The sterilizing dose applied was 10 krad.

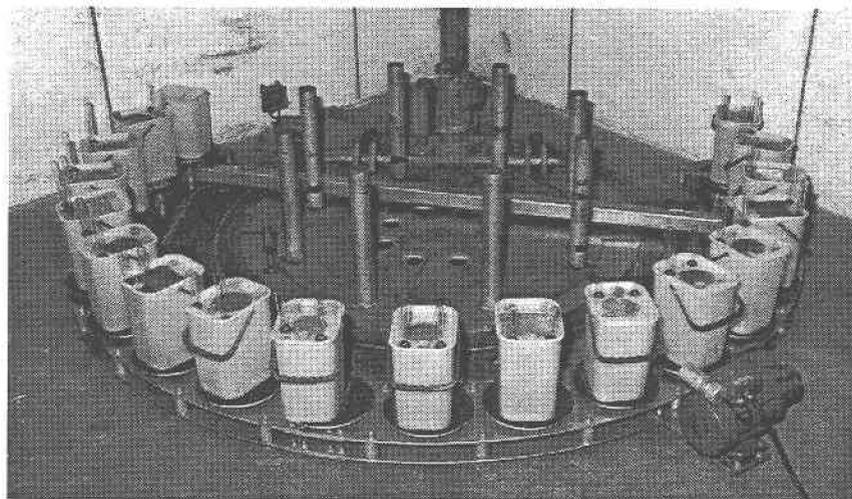


Figure 3. A pool-type Cobalt-60 irradiation facility and 18 modified milk-containers (with 200 flies each) arranged on turn-tables around the 8 radioactive bars in circular configuration.

Flight range

The flight range of the CFF is another important aspect for the establishment of adequate buffer zones around a SIT-treated area. Since all 2 million sterile flies released in Switzerland were marked with a fluorescent spray, we could determine the maximum flight range during the SIT operation with a large network of traps installed around the SIT-treated area. The results (Fig. 4) confirmed that the vast majority of flies are rather stationary and remain in the neighborhood, but also showed that some 0.1 percent of the fly population was capable of flying to cherry orchards across a valley located visibly at eye-level at 3 km distance. These long distance flights were greatly reduced by forests. This phenomenon would need verification in the western cherry fruit fly.

The establishment of density maps of the CFF in and around potential SIT areas as well as the constant monitoring of the ratio between the wild CFF population and the released sterile flies (1: 20-50) during the conduct of the SIT program would make use of similar trapping systems feasible in Europe and North America.

The success of a SIT operation could be evaluated by checking adequate fruit samples at frequent intervals.

If all relevant biological, ecological and economic information is available, one might have to consider a time-lapse of about 3 years between the decision to start a SIT program and the actual release of the first sterile cherry fruit flies.

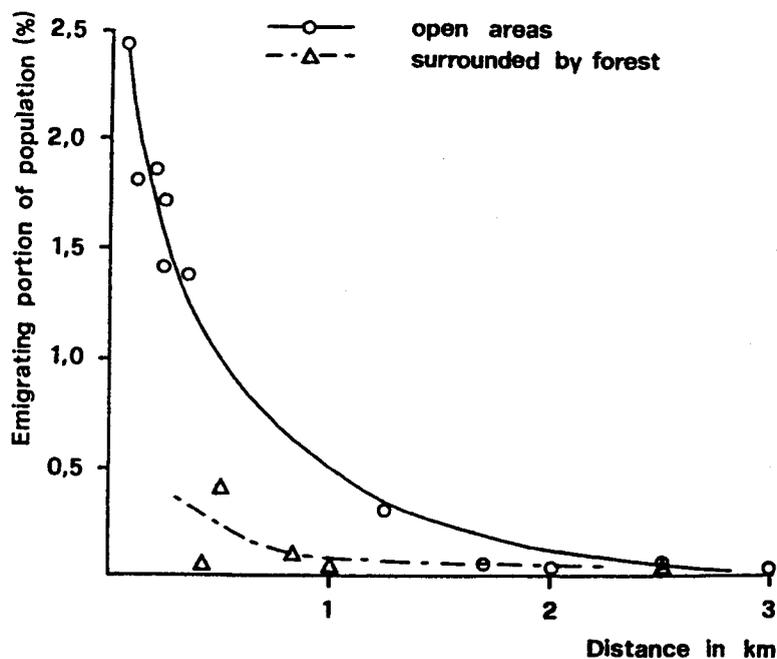


Figure 4. Flight range of sterilized and marked ECFF in 1978 expressed as percentage of population in the SIT area and being intercepted by a trap network operated outside the SIT area.

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Sterile Insect Release Method for Controlling *Rhagoletis indifferens* in the Pacific Northwest

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Introduction

Sterile Insect Release Method (SIRM) which also has been referred to as SIT (Sterile Insect Technique) or Sterile Male Technique (SMT) in the literature, is a widely accepted approach to eradicating and suppressing harmful insect populations. Since the general acceptance of its original concept (proposed by Knipling 1955), a number of field studies have successfully demonstrated the feasibility of this approach. Although not applicable to all injurious pests (Knipling 1979), it is highly effective in controlling harmful fruit flies and some species of Lepidoptera. The method had been particularly successful against the screw-worm fly, *Cochliomyia hominivorax*, and many species of tephritid flies.

Rhagoletis indifferens, the western cherry fruit fly (WCFF), is a pest of major concern throughout the cherry growing areas of the western United States and Canada (see Chapter 5). Chemicals are the major defense against this pest (see Chapter 10), although in recent years, attempts have been made to incorporate some alternative approaches to the calendar based use of pesticides (AliNiazee 1986). Also, initial studies assessing the feasibility of a SIRM approach were conducted during the late 1970s. The salient features of this program are discussed in this paper.

Mass rearing

One of the basic requirements of a SIRM program is the availability of an adequate rearing method for producing a large number of competitive insects. Without this, no SIRM program can be initiated.

AliNiazee and Brown (1977) developed a successful laboratory rearing method for the WCFF using artificial diets. However, the yield and cost of production were prohibitive for procurement of a large number of individuals that might be required for a SIRM program. Alternatively, a field rearing method was developed, involving selecting and infesting isolated sweet cherry trees with laboratory produced flies during early June, and harvesting infested fruit during early July. The fruit was then brought to the laboratory for extracting pupae. Infested cherries were placed on top of the screen cages containing 2 to 3 inches of a mixture of fine vermiculite and soil. Approximately four weeks were allowed for larval development and exit from cherries and to pupate in the soil mixture. At the end of this period, the soil plus vermiculite mixture was sifted using a fine mesh screen and pupae collected, counted and stored at $3 \pm 1^\circ\text{C}$ temperature for 2 to 5 months to satisfy chilling requirements. The chilled pupae were brought out of the cold room and placed at $22 \pm 1^\circ\text{C}$ for adult emergence, as needed. This type of stock piling allowed for collection of a large number of pupae. Although the method is perhaps not as efficient as the laboratory mass rearing used for the tropical fruit flies, it nevertheless provides an adequate supply of pupae for a small scale SIRM program. The cost of production is also reasonable.

Sterilization of flies

Initial laboratory work conducted during 1977 showed that radiation sterilization of adults was possible using Cobalt-60 source. A radiation dosage that induced a high degree of sterility while maintaining acceptable levels of competitiveness was determined (Brown & AliNiazee 1978). Nearly 99 percent sterility was recorded when males were irradiated with 8 Krad as 1-2 day old adults, and mated with fertile females. Adult females were slightly more sensitive to radiation than males, they became infecund at 5 Krad. Although irradiation of mature pupae (2-4 days before adult emergence) also caused a very high level of sterility (Brown 1978), the competitiveness of emerging adults was adversely affected. On the other hand, males irradiated as adults were highly competitive. The females irradiated as adults showed relatively little impact on longevity but males had some deleterious effects. Adult females did not lay eggs after irradiation with a dose of 5 Krad or higher, and pupae irradiated at 8 Krad did not make ovipunctures during the first month (Brown 1978).

Table 1. Status of feasibility studies regarding application of SIRM against the western cherry fruit fly

Steps	Results and/or status	References
Mass rearing	A laboratory and field rearing method established	AliNiazee & Brown (1977)
Sterilization	A radiation procedure causing >99% sterility established	Brown & AliNiazee (1978)
Competitiveness	Competitiveness studies completed	Brown & AliNiazee (1978)
Laboratory and cage study	Small scale laboratory and field cage study conducted	Brown & AliNiazee (1978)
Ecological studies	Relatively large data base exists on pest biology and ecology	Brown (1978), AliNiazee (unpublished)
Field tests	Required	
Organizational setup	Required	
Pilot program	Required	
Evaluation of biological effectiveness	Required	
Economics - cost/benefit analysis	Required	

Release ratios and effect on infestation rates

Small field cage studies conducted earlier (Brown & AliNiazee 1978) suggest that males irradiated at 8 Krad and released with normal males at ratios of 4:1 and 8:1 (sterile : normal) mated about the same number of times as the normal males alone, and caused substantial reduction in cherry infestation rates and subsequent progeny production. A ratio of 20:1 (irradiated : normal) reduced the infestation rates approximately 96 percent. Substantial reduction in infestation was also noticed in the 8:1 ratio. Although the studies were limited in scope, they clearly demonstrate the efficacy of this technique under field conditions.

Suitability of SIRM for *R. indifferens*

It is obvious from the earlier studies (Brown 1978, Brown & AliNiazee 1978) that *R. indifferens* is indeed a suitable candidate for SIRM. The relatively long preoviposition period and the possibility of mass rearing under field conditions make this fly an ideal prospect. Both males and females are easily made infertile by irradiation, and both sexes could possibly be used in a release program. Donnelly (1965) noted that if females are released with males, it may lessen dispersal. Thus releasing of both sexes might be preferable in *R. indifferens*, as the irradiated females not only lay fewer eggs, but also make fewer oviposition punctures.

One of the major problems faced by cherry growers in the Pacific Northwest is the

immigration of fertile flies from the infested backyard and abandoned trees to commercial orchards. If these sources are far enough away, then SIRM might provide effective control. The release of sterile flies into backyard trees might also be an effective and safer way of suppressing overall fly population in a given area. Moreover, the chemical control appears to face some very difficult prospects in the future. The availability of new pesticides is dwindling rapidly and concerns for drift of ultra-low volume (ULV) malathion treatments is increasing in general public. As urbanization increases around the orchards, ULV malathion treatments might become completely unacceptable.

An integrated control program utilizing SIRM component rather than a complete reliance on the use of pesticides would be an improvement in management of this pest. Since cherry harvest invariably fails to remove all the fruit from the trees, a reservoir of breeding population is always present in the orchards. Release of sterile males after the fruit harvest would therefore be an effective option in combating this insect at low density populations.

The feasibility of a SIRM program is generally evaluated at first in extremely isolated areas or islands. Within the distribution range of WCFF no such areas exist. However, cherry growing areas of the Pacific Northwest are divided into a number of moderately isolated areas such as The Dalles, Yakima Valley of Washington, and the Willamette Valley of Oregon. The later is a large area with the availability of an ample amount of wild hosts. The southern cherry growing areas of Lane county, however, are not contiguous with the larger cherry growing areas in the northern part of the valley. These types of semi-isolated areas can be utilized in developing and testing pilot programs to evaluate the field efficacy of this method. Moreover, the WCFF is a relatively less mobile insect in the presence of host fruit, thus there is a limited amount of dispersion. Also, distinct phenological differences occur between the WCFF populations from the commercial orchards and the native hosts (AliNiazee, unpublished). This eliminates the fear of frequent immigration of fertile flies from the wild hosts.

In the final analysis, it appears that the WCFF is a suitable candidate for SIRM. Either as a part of an IPM program or as an eradication method, this technique is indeed applicable in the Pacific Northwest. Additional work on acceptable ratios of sterile and fertile individuals, large scale field testing, and development of required infrastructure is essential if this approach is to be followed.

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Section IV
Experience With Other Pests

Experience with Apple Maggot in the Western United States

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Distribution

The apple maggot (AM), *Rhagoletis pomonella* (Walsh), is a native North American insect, and fruit of hawthorn (*Crataegus* spp.) is considered its original host (Bush 1969). The first published report of the AM as a pest of apple occurred in 1866 (Ward 1866). The insect is the key pest of commercial apples throughout eastern Canada and the northeastern United States.

The first confirmed apple maggot infestations in the Pacific Northwest were in Oregon in 1979 (AliNiazee & Penrose 1981). Since then, trapping programs have located maggots in western Washington and western Oregon, on both sides of the Columbia River Gorge, and in Spokane in eastern Washington (Brunner 1982, AliNiazee & Westcott 1986). AM has also been reported from Idaho, Utah, Colorado, and California (Fig. 1). The pest apparently can survive in a wide range of conditions, from the cool, coastal climate of western Oregon and Washington, to the hot, dry climate of The Dalles, Oregon, or the mountain conditions of Utah.

Successful establishment of the AM in major apple production areas of Washington would create a loss to the state's economy estimated to be between 71 and 93 million dollars

annually (Schotzko 1984). About half of this loss would be in grower receipts and the remainder would be from a reduction in income throughout the rest of the state.

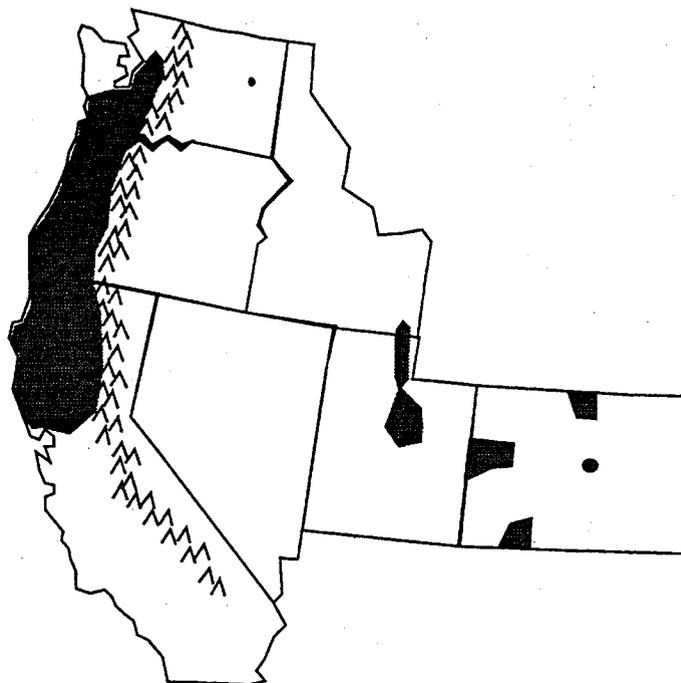


Figure 1. Distribution of the apple maggot in the western United States.

Host plants

The AM is one member of what Bush (1966) referred to as the “*pomonella* group.” In addition to AM, this group includes the blueberry maggot, *Rhagoletis mendax* Curran; the dogwood maggot, *Rhagoletis cornivora* Bush; and the snowberry maggot (SBM), *Rhagoletis zephyria* Snow. With the exception of AM, the other *Rhagoletis* species in the *pomonella* group infest only one or two plant genera, each in different families (Bush 1969). AM seems to be the most adaptable, infesting at least 16 plant species in five genera of the family *Rosaceae* (see Table 1, Chapter 5). In Utah, AM seems to prefer cherry as a host over apple. In addition to apple and cherry, it can infest crab apple, hawthorn, plum, apricot, pear, wild rose, *Cotoneaster* sp., and *Pyracantha* sp. However, in Washington it has been found only on apple, crab apple, and hawthorn. It is most often found in highest numbers infesting early maturing, sweet varieties of apples.

Life stages

The AM fly is about the size of a common housefly. Its body is black, eyes are dark

red, and the thorax and abdomen have distinctive white or cream bands. The male has a blunt abdomen with three white lines, while the female's more pointed abdomen has four white stripes. A distinct banding pattern on its wings distinguishes it from most other *Rhagoletis* species except the snowberry maggot, which is found throughout the western United States (see Fig. 2, Chapter 5). The egg is whitish, small, smooth, elongated, and slightly curved. Because eggs are laid beneath skin of the host fruit, they are rarely seen.

The AM larva is a typical fly maggot. It is cylindrical, tapering from a blunt posterior to a pointed head, and has no legs. The mature larva is creamy-white except for two dark mouth hooks and is 1/4 to 3/8 inch (6 to 9 mm) long. The larva tunnels through apple flesh and can be distinguished from other insect larvae found in apples by its lack of a distinct head capsule. The pupa looks like a large, dark brown grain of wheat. It is usually found in the top 2 inches (5 cm) of soil under infested trees.

Life history

AM spends the winter in the soil as a pupa. In late June or early July, adults begin emerging. Flies continue to emerge from the soil throughout the summer and are active up to October. Figure 2 shows the pattern of AM catch on traps typical of western WA. While AM activity periods on different hosts overlap, peak activity occurs at different times of the year. The maturity of fruit on the host tree appears to be a major factor in determining the sequence of peak activity (Tracewski *et al.* 1987). AM activity peaks earliest on apple varieties maturing in mid-summer, followed by native hawthorn and apple varieties maturing in early fall, and then on imported hawthorn and apple varieties maturing in late fall (Fig. 2).

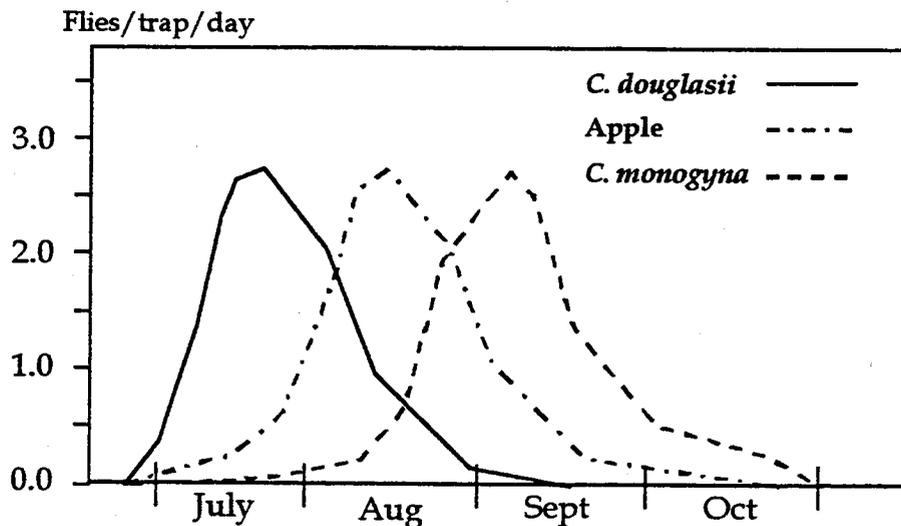


Figure 2. Activity pattern of adult apple maggot on apple and two hawthorn species in western Washington.

After emergence, the adult AM feeds for a period of 7 to 10 days before becoming sexually mature. The principal food source taken during this period is probably insect honeydew, although liquid from plant glands, wounds and oviposition stings, bacteria, yeast and fungal spores represent other possible food sources (Boller & Prokopy 1976). Mating occurs on the host plant (Prokopy *et al.* 1971, Smith & Prokopy 1980). Oviposition begins soon after mating. Eggs are inserted in host fruit just beneath the skin and hatch in 3 to 7 days.

The time required for larval development varies from 13 to 50+ days and depends primarily on fruit hardness (Dean & Chapman 1973). When fully grown, larvae leave the fruit (usually after it has dropped to the ground) and enter the soil to pupate. Most AM remain in the soil for one winter, but a small proportion may remain there for two or more years. A few AM may complete pupal development in the same year and emerge as a partial second generation (Dean and Chapman 1973). Under Pacific Northwest conditions, this emergence is considered suicidal since it is doubtful there would be sufficient time to complete larval development prior to the onset of winter. The ability of AM to remain in the soil more than one year complicates control, containment, and eradication efforts by requiring infested sites to be treated with insecticide or monitored for at least three successive years to ensure elimination of any residual AM population remaining in the soil.

Monitoring and management

Research conducted in the eastern United States found that the most attractive lure for AM was various forms of ammonia and protein extracts (Hudson 1943, Neilson 1960, Prokopy 1968b, Reissig 1974). Trap types most attractive to AM have been yellow panels, dark red spheres, or combinations of these colors and shapes (Prokopy 1968a, 1972, 1975; Kring 1970, Reissig 1974, 1975; Swift 1982,). The yellow panel is thought to be attractive to AM because it mimics an area of bright foliage. The red sphere is thought to be attractive because it mimics the shape of a host fruit. In the eastern United States, yellow traps combined with an ammonium lure or red spheres combined with an apple volatile lure (Fein *et al.* 1982) are most commonly used to monitor AM in commercial orchards (Trottier *et al.* 1975, Neilson *et al.* 1976, Reissig & Tette 1979, Leeper 1980, Reissig *et al.* 1982).

Response of the AM to traps placed in native or urban habitats in the western United States has been different than that reported from orchard habitats in the eastern United States. The yellow sticky trap baited with ammonium carbonate has been more attractive to AM than red spheres baited with or without apple volatiles (Jones & Davis 1989, Brunner unpublished). In Washington, the Pherocon AM trap caught as many AM on apple or hawthorn hosts as any other trap tested and, in addition, caught flies in more

situations where AM densities were low (Brunner unpublished). The red sphere was found to be more selective than other traps, catching fewer miscellaneous flies and fewer SBM, and did not have to be changed as often as the yellow sticky trap (Brunner 1987).

The management guidelines for AM in Washington relate only to orchards in areas where it occurs, the Columbia River Gorge, Spokane, and western Washington. The need to apply controls depends on how close the orchard is to an AM detection. If an AM is detected in or near a commercial orchard, fruit must be inspected by the Washington State Department of Agriculture to certify that it is free of AM infestation or the fruit must be placed in cold storage for at least 40 days before shipping out of the area. Recommendations on how to manage AM in Washington are outlined in Beers *et al.* (1993).

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Biology and Management of Walnut Husk Fly

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Introduction

The walnut husk fly (WHF), *Rhagoletis completa* Cresson was first described by Cresson from adults emerging from larvae mining the exocarp of persian walnut in Carr Canyon, Huachuca Mountains, Arizona (Boyce 1929). This native of the southern and midwestern United States was probably accidentally introduced into southern California in the early 1920s (Boyce 1934), and has since spread throughout the Pacific coastal states. It was first discovered in 1926 near Chino, San Bernardino Co., California, in groves of persian walnut. It was later found in orchards of Sonoma Co., in 1954. Infestations were noticed in Oregon and Washington during 1973 suggesting earlier establishment in these areas (AliNiazee & Fisher 1985). Currently, *R. completa* is quite prevalent in California, Oregon, and Washington (Boyce 1934, Bush 1966, Retan 1980, AliNiazee & Fisher 1985) and other western states including Arizona, Idaho, and Utah. Some recent studies suggest that it has also been established in parts of Italy (Duso 1991).

The genus *Juglans*, to which walnuts belong, is a host for more than 300 insect species. Approximately 25 or so arthropod species cause injury to walnuts in the western United States (Riedl *et al.* 1979). The husk fly is among the key pests of walnuts and is an occasional pest of peaches and nectarines. It attacks maturing fruits and the degree of damage

depends upon walnut husk hardness and the variety. The infestation may reach upto 100 percent in untreated orchards (Riedl & Hoying 1980).

Biology

The biology of WHF is similar to that of other *Rhagoletis* fruit flies. It overwinters in the pupal stage in soil at a depth of 1-4 inches (Kasana & AliNiazee 1996). The adults emerge in early summer, the emergence varies from season to season and locality to locality. In general, it corresponds with the maturing of the nut husk. In most areas of its distribution range the adult flies emerge between July and October (Gibson & Kearby 1978, Riedl & Hoying 1980, Kasana & AliNiazee 1996). Mating occurs within 7-10 days after emergence and mature females penetrate the husk of the nut with their sharp ovipositors and deposit eggs in batches. Eggs hatch in 7-20 days depending upon the temperature and husk maturity, and the larvae tunnel through the husk as they feed. The feeding and general metabolic activity soon turn the green husk into a black, slimy mass. The larvae undergo two molts. At the end of the third instar, they leave the blackened husk to enter the soil, where the larval cuticle is shed and hardens to form a puparium, within which pupation takes place. A majority of the adults emerge the following summer, however, some continue to stay in this diapausing stage for two or more years. This insect is generally univoltine, however, a second generation in the southern ranges of its distribution, and only during certain years, might be possible. Based on its diapause termination requirements, it is conceivable that such occurrences may happen repeatedly and can easily pass unnoticed (AliNiazee 1988).

Pest monitoring

The success of all pest management programs depends on the development and implementation of efficient pest and natural enemy monitoring techniques. With WHF effective monitoring to determine the emergence and oviposition dates is essential. The earliest methods of monitoring for this fly were liquid bait traps consisting of glycine, sodium hydroxide, and water (Boyce 1934) or glycine and lye (Barnes & Ortega 1958). Although these traps were useful, they were highly cumbersome, and thus never became popular with growers. Also the alkaline nature of the solutions made them difficult to maintain in the field.

Husk flies are strongly attracted to the odor of ammonia. Barnes and Osborn (1958) evaluated sticky traps baited with powdered ammonium carbonate as an attractant and compared it with a standard glycine-sodium hydroxide bait solution. The ammonium carbonate traps were effective in determining emergence dates and population levels. Sticky

food-carton traps baited with dry ammonium carbonate (Barnes & Osborn 1958) therefore, were widely used for survey work in the 1950s, and later on they were also used for the timing of malathion bait spray. The first spray was recommended about 10 days after the first sharp increase in fly catches. Barnes and Ortega (1959) reported slightly better results with a liquid corn protein hydrolysate (Staley's Protein Insecticide Bait No.7) bait.

Fluorescent yellow sticky rectangles, originally developed for the apple maggot, were found to be effective in trapping husk flies; these rectangles were also easier to handle in the field (Riedl and Hoying 1980). Commercial traps consisting of ammonium acetate and protein hydrolysate baits on yellow rectangles marketed by Zoëcon Corp. (now Téréc Corp.) thus became very popular for monitoring these flies although no consistent relationship between adult catches and the onset of oviposition was established. Riedl and Hoying (1981) found that an ammonium carbonate baited fluorescent yellow Pherocon AM rectangle was approximately 10 times more attractive to adult flies than the standard Pherocon AM trap. Both types of traps (the standard Trécé trap and one with an additional charge of dry ammonium carbonate) are used in current pest management programs.

Biological control

Boyce (1934) reported that the walnut husk fly was remarkably free from natural enemies in California. However, a few generalist predators, such as, spiders, anthocorids, chrysopids, and ants were occasionally found preying upon different life stages. Although several parasitoids have been reared from the WHF pupae, none appears to be effective enough to provide economical control of this pest. A list of the most commonly found parasitoids is given below.

Parasitoid name	Reported from	Reference
<i>Splangia rugosicollis</i> Ashm. (= <i>S. nigra</i> Latneille)	Oregon	Kasana, unpublished
<i>Coptera occidentalis</i> Mues.	California	Hagen <i>et al.</i> (1995)
<i>Coptera</i> sp.	Oregon	AliNiazee, unpublished
<i>Biosteres sublaevis</i> Wharton	Texas	Legner & Goeden 1987
<i>Trybliographa</i> sp.	Texas	Legner & Goeden 1987

The opiine larval-pupal parasitoids *Opius humilis* and *Biosteres tryoni* were introduced into California from Hawaii. Some establishment was noticed in central California. *Biosteres tryoni* was released in an untreated commercial walnut orchard in Solano Co., California from Hawaii in the fall of 1984 and the parasitoid was recovered the same year, but unfortunately no further efforts were made. *B. juglandis* and *Pseudeucila* sp. were released in San Bento Co., California in untreated walnut orchards and backyard black walnut trees heavily infested with WHF from 1967 to 1970. No recoveries were made from the release sites.

Since 1977, hundreds of both *C. occidentalis* and *C. evansi* were released in California. *C. occidentalis* became established against WHF and the western cherry fruit fly, *R. indifferens*. *B. sublaevis* was also released at different places in California in 1979, 1980-81, 1983-86 (Hagen *et al.* 1995). It was recovered from some locations. The overall impact of these and other parasitoids in suppression of WHF populations is unknown, although they appear to be a major mortality factor in untreated orchards.

Chemical control

The management of WHF in commercial orchards is primarily based on the use of insecticides. The organophosphates are the most widely used compounds, and most of them are applied to suppress adult population before oviposition. Use of feeding attractants and stimulants such as protein hydrolysates (like the Staley's Bait) mixed with organophosphates, such as malathion, has improved the performance of insecticides (Barnes & Ortega 1959). Spraying the ground surface underneath infested trees has also helped in reduction of WHF infestation in some earlier trials.

Some systemic organophosphates such as dimethoate and phosphamidon were effective against the newly hatched larvae if properly timed (Nickel & Wong 1966). These insecticides prevented shell staining when applied as sprays to infested nuts containing eggs or newly hatched larvae.

Barnes *et al.* (1978) reported that where WHF population is high, at least one application of organophosphate insecticide was required. Timing of treatments by trapping adults or careful observation of the appearance of "stung" nuts was essential. Choice of materials was determined by the status of infestation and by occurrence of other pests in the orchard. In order to avoid irrigation schedule interference, a bait spray using a hydrolysate corn protein plus malathion was recommended as an aerial spray. Hislop *et al.* (1981) found pyrethroids, fenvalerate and permethrin, to be effective against adults when applied in a protein hydrolysate bait, while efficacy dropped dramatically when these compounds were used without baits.

Proper timing of application of insecticides is very critical in suppression of husk fly populations, and utilization of only trap catch data may be unreliable because their relationship to onset of oviposition is too variable. However, routine inspection of nuts for oviposition along with a consistent monitoring of fly catches may provide a better indication of fly activity for treatment needs. In summary, it appears that application of chemical insecticides is still the most common and preferred method of controlling husk fly. Better monitoring and proper timing can improve the effectiveness of the insecticides used and reduce the quantities of toxic materials in the environment.

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Control and Eradication of the Mediterranean Fruit Fly by the Sterile Insect Technique

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The Mediterranean fruit fly, *Ceratitidis capitata* (Wiedemann), also referred to as the medfly, is a tropical multivoltine species with a wide host range that probably originated in Africa (Back & Pemberton 1918). It has since spread to South and Central America, southern Europe, North Africa and the Middle East, Australia, and to Hawaii. It has invaded Florida and California on numerous occasions but has always been eradicated. There is an infestation of medflies presently in the Los Angeles Basin of California that is in the process of being eradicated. If the medfly becomes established in California the annual cost of living with the pest would range from an estimate of \$1.057 to \$1.440 billion (Siebert 1994).

Life cycle

The life cycle of the medfly is quite rapid but temperature and host dependent. It overwinters as pupae in the more temperate parts of its range, although Cirio *et al.* (1972) found it to overwinter as larvae in citrus in Procida, Italy. Adult survival in the field lasts two to three months.

Each female lays 1-14 eggs per fruit depending on the size of the fruit (McDonald & McInnis 1985) and can produce 300-1,000 eggs throughout its life span. Adult size varies depending on the density of larvae in the fruit and on the type of fruit. Egg production is

directly related to size of the female (Inglesfield 1981).

Larvae feed within host fruit for 8 to 35 days depending on temperature and host fruit ripeness. The host range is known to comprise some 250 species of fruits, nuts, and vegetables, mostly of tropical or subtropical origin. They will infest some major temperate species important to the Pacific Northwest such as apple, apricot, cherry, peach, pear, and plum (Metcalf 1994). Larvae leave the fruit when mature and enter the soil to pupate. Pupal duration is also temperature dependent and takes 10 to 40 days. Under tropical or temperate summer conditions, the pupation period is usually 10-12 days. Adults, after emergence, take 8-10 days to reach sexual maturity. Mating takes place on the underside of leaves on host and non-host trees. The medfly uses a lek mating system where males aggregate and defend individual leaves where females come to mate. Male leks provide for female mate choice where unfit males may be rejected (Prokopy & Hendrichs 1979).

Adults have been recorded to disperse for more than 20 miles over water between islands in the Hawaiian Island chain. These flights were undoubtedly wind aided (Wong *et al.* 1982). Dispersal internationally is by infested fruit moved between countries.

The sterile insect technique

The medfly has several traits that make it very difficult to control. Among these are a multivoltine life cycle with explosive reproductive capacity, a capacity to exploit a large number of host plants, a pronounced ability to disperse, and the ability to survive inclement weather. Not only do they cause great losses in fruit and vegetable production, but they seriously interfere with international trade in affected commodities. Thus, they are a major impediment to economic development. Control is usually not enough to allow shipment of commodities as being free of the pest. In most cases, eradication is the only option available (Klassen *et al.* 1994).

The concept of the sterile insect technique (SIT) originated with Dr. E. F. Knipling (Knipling 1955). The idea, in theory, was that if a sterile male insect mated with a fertile female of the same species, all of the eggs would be sterile. If a large enough population of sterile males were released in an area where an indigenous population occurred, the percentage of fertile females mating with sterile males would be great enough that the wild population would decrease in size. If the program continued, the decrease in the wild population would accelerate from generation to generation until eradication occurred. This theory was proven in Dr. Knipling's efforts to eradicate the screwworm fly, *Cochliomyia hominivorax* (Coquerel), from the United States. By using gamma radiation to sterilize flies in the pupal stage, and then releasing the sterile adults throughout the control areas, the USDA was able

to eradicate screwworm populations first from Florida and finally from the Southwestern United States. The program is continuing and has now eradicated the screwworm fly from Mexico, Guatemala, and Honduras.

The first attempt to use this technique against the medfly was in 1959 in Hawaii. Large programs were subsequently conducted in Argentina, Italy, Chile, Spain, Costa Rica, Nicaragua, Peru, Tunisia, Israel, Mexico, Guatemala, Australia, Hawaii, Florida, and California with varying degrees of success (Klassen *et al.* 1994). The main impediments to these programs were reinfestation by dispersal and/or by movement of infested fruit, or by the release of flies having poor quality parameters such as flight ability or fitness. Quality control programs for evaluating and controlling the effectiveness of mass reared medflies are now a part of all mass rearing and sterile release programs (Boller *et al.* 1981, Calkins *et al.* 1982, Calkins 1984, 1989 & 1991, Chambers *et al.* 1983, Boller & Calkins 1984, Burk & Calkins 1983, Moore *et al.* 1985, Brazzel *et al.* 1986).

In large programs, sterile flies are released by air. In smaller programs, releases are made from the ground. The recommended release rate is at 1 million sterile flies per square mile. If the population density of wild flies is known, an overflooding ratio of at least 100 sterile males for every wild male is targeted when the program begins. With each successive generation, the overflooding ratio should increase until the wild population disappears. For example, if a theoretical population is initially overflooded with a ratio of 100 effective flies per wild fly, the overflooding ratio would be 842 to 1 during the second generation, if the same number of sterile flies were released per unit. During the third generation, the overflooding ratio would be 59,102 to 1 and the wild population would disappear (Calkins & Ashley 1989).

A recently published book, "Fruit Flies and the Sterile Insect Technique", (Calkins *et al.* 1994) describes most aspects of fruit fly eradication programs throughout the world.

Mass rearing

An eradication program employing the sterile insect technique requires that a large supply of insects of the proper stage for sterilization be available on a continuous basis. The only way to ensure this is by instituting a mass rearing program at a production level sufficient to meet the needs of the release program.

Large scale tephritid fruit fly mass rearing was first developed by Maeda *et al.* (1953) and Finney (1956). A large medfly eradication program was begun in Mexico in 1977 that required a mass rearing system capable of producing 500 million flies per week (Schwarz *et al.* 1985). The system was developed by David Nadel (1970) in Austria utilizing several

components invented earlier by several rearing specialists including Nadel. This system was transferred to Metapa, Mexico where it was improved and expanded (Hendrichs *et al.* 1982). Most other medfly rearing factories in the world are patterned after this system.

A large mass rearing factory for medflies requires a well managed system under one roof with adequate air handling and security. The program must have an organized flow of activities from diet mixing to shipment. The system consists of diet storage and a mixing center external to the insect rearing rooms. The mixed diet is augured through the wall into the tray filling area.

The egg collecting system consists of large cages measuring 280 x 200 x 20 cm made up of a framework of aluminum, screened on the wide sides with nylon cloth of an open weave. Each cage is loaded with 750,000 mature pupae. Females oviposit their eggs through the cloth where the eggs drop into water below. Eggs are collected every 12 hours and placed into 5 liter plastic bottles with water. Air is bubbled through the mixture to ensure oxygenation while the eggs are maturing. When the egg-hatch within the bottles reaches 5-25 percent, the eggs and young larvae are pipetted directly onto the diet in large pans.

The diet consists of a mixture of soy flour (14.2 percent), wheat bran (14.2 percent), granulated sugar (17.3 percent), torula yeast (Type B) (6.7 percent), methyl parahydroxybenzoate (0.6 percent) and tap water (57 percent). The pans of diet are transferred to incubation rooms held at 29 °C and 88 percent RH where the 1st instar larvae complete development in 48 hours. They are then moved into a cooler room (28 °C and 83 percent RH) to dissipate the metabolic heat generated by the developing larvae. The larval stage lasts about 6 days after which the larvae leave the diet by popping or jumping (Schwarz *et al.* 1985).

Larvae are stimulated to leave the diet by adding dry wheat bran and placing the mixture into large larval separators. The separator is a large drum perforated with holes that slowly rotates. The inside of the drum contains a nylon net liner that retains the diet within but allows the larvae to escape. The larvae are collected on canvas and put into screened trays to a depth of about 1 cm. A more recently developed method is to let the larvae exit the diet on their own and drop into water. Larvae are collected from the water every 6 to 12 hours and placed in pupation trays. Because the larvae are not forced from the diet prematurely, they tend to be a bit larger. Pupation trays are placed on racks and wheeled into a dark room held at 22 °C and 70 percent RH. The darkness and drier air stimulate the larvae to pupate. Pupation lasts about 10-12 days. After 9 days the pupae are removed and placed in 30 liter bottles where they are mixed with a pink day-glo powder and capped to produce a state of hypoxia. It is in this state that the pupae are irradiated with 14,500 rads of gamma radiation.

This results in 99 percent male and 99.9 percent female sterility (Schwarz *et al.* 1985). The day-glo powder adheres to the pupal cases but the newly emerging adults pick up the powder on their cuticle, and most importantly, on the ptilinum (a bulbous inflatable sac) that is withdrawn into the head. The powder that stays on the ptilinum marks the fly permanently.

The Metapa, Mexico medfly factory produced an average of 510 million flies per week during a 5-year period (1980-1985). The estimated cost of production was \$95/million flies in 1985, of which 44 percent was for diet ingredients, 38 percent for salaries, and 18 percent for materials, operations, and other expenses (Schwarz *et al.* 1985).

Detection and monitoring

Detection and monitoring is necessary to delineate medfly populations and to determine the effect that the eradication program is having on the target population. Food attractants have been used to trap both males and females. The most common bait in use is protein hydrolysate or torula yeast in a McPhail trap containing about one liter of water. The McPhail trap is an invaginated glass trap that allows access of the flies through the bottom. As the flies seek the food, they fall into the liquid and drown.

The most efficient lure is trimedlure, a parapheromone that attracts primarily male medflies. The most common trap in use with trimedlure is referred to as a Jackson or delta trap, made of cardboard with a sticky insert in the floor of the triangular shaped container, which is open at both ends. These traps are used for detection of new populations or for newly emerging flies.

Another trap design used for trapping flies during sterile releases is a plain plastic cylinder about 6in long and 3in in diameter having a single 1in hole on each end. It is hung horizontally. A small Vapona strip or a dog flea and tick collar is suspended inside the cylinder to quickly kill any flies that enter. This trap is referred to as a Steiner trap (Steiner 1957). The advantage of this trap is that flies trapped remain dry and free of sticky material. This allows them to be easily examined for the day-glo powder that is found on sterile released flies.

Trapping during sterile fly release allows personnel to determine the ratio of wild flies to sterile flies. For eradication of a fly population in three generations the overflooding ratio should be around 100 sterile males for every fertile male in the first generation of the sterile release program (Calkins & Ashley 1989).

SIT Programs in the United States

The SIT programs for medfly that have received the most publicity in recent years

are those that occurred in the contiguous United States. In probably all cases, fly infestations were a result of larvae being brought in with contraband fruit. The present inspection and quarantine treatments of commercial fruit shipments now preclude this route as a pathway for the fly's entrance into this country.

The medfly was introduced accidentally into the United States several times. In Florida, it was controlled by SIT after introduction into the Miami area in 1985. The sterile insect technique was used after four aerial sprays of a combination of malathion and Staley's sauce bait (A. E. Staley Manufacturing Company, Atlanta, GA) to ensure eradication of the pest. Approximately 5 million sterile flies were reared in Hawaii and shipped on each day for four days to Miami for release. A total of 200 million flies were released over an 83 square mile area from May 5 to July 16, 1985. The fly was eradicated successfully at a cost of \$1.1 million using this technique (Calkins *et al.* 1988).

The programs in California from 1986 to 1992 were somewhat different. The original protocol called for an eradication program to be initiated when two male flies or one mated female or a larva were found. When fly was found, the area was saturated with Jackson traps for a 200 yard radius around the point of discovery. In addition, fruit from all trees within this area were stripped, and a bait spray was applied from the ground to all tree foliage. Also, a Diazinon drench was applied to the ground under all of the fruit trees in the area. Trap concentration was increased to 100 in the surrounding square mile. For a distance of 0.5 to 1.5 miles from the center of infestation, traps were placed at the rate of 50/ sq. mile, followed by a density of 25/ sq. mile at 1.5 and 2.5 miles, and then 25/sq. mile at the 2.5 and 3.5 mile distance, and finally at the rate of 20/sq. mile at the 3.5 and 4.5 mile interval. This 81 square mile area also comprised the quarantine area from which fruit grown inside the area could not be transported. This trapping scheme allowed the program to delineate the range of the introduced population.

Approximately two weeks after the trap grid was in place, sterile insects were released at a rate of about one million flies per square mile each week in the 81 square mile area for the calculated time, that takes three generations to develop. During this time the Jackson detection traps were removed and Steiner traps were installed at a density of five per square mile. Additional ground releases of sterile males were made around the discovery site.

Medflies have been found in Los Angeles every year since 1986. Eradication programs there were generally successful except in 1989. So many outbreaks occurred that there were not enough sterile flies to treat all of the infested areas. Due to this shortage of sterile flies, control was maintained by malathion bait sprays aerially applied in most areas except those around Whittier where the release of sterile flies was continued. In 1993 it appeared

that the same widespread problem was emerging. The California Department of Food and Agriculture (CDFA) and USDA-APHIS decided to release 250 million flies per square mile over the entire Los Angeles Basin (1,464 sq. mi.) for a period of two years. There were 1,531 square miles in quarantine (Los Angeles Area Cooperative Medfly Project Report, April 1995). By that time there were four medfly factories operating from which sterile flies could be obtained; two in Hawaii, one in Guatemala, and one in Metapa, Mexico. After the two year period that should end in June 1995, an intensive monitoring program will commence for four months. The cost of the eradication program for medfly in California in 1994 alone was \$34 million.

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Codling Moth Eradication Program in British Columbia: A Review and Update

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The codling moth, *Cydia pomonella*, is considered the key pest of apples and pears in the fruit growing regions of south-central British Columbia (BC). This region includes about 7,500 ha of commercial apple and pear production, as well as several urban centers with abundant backyard fruit-trees and ornamental crabapple trees. Now, after 30 years of research and planning, an eradication program using Sterile Insect Release (SIR) technology has been implemented against this pest (Dyck *et al.* 1993). The SIR Program officially began operating in January 1992; construction of the mass-rearing facility was completed in March 1993, and sterile moths were released into area orchards for the first time in the spring of 1994. This article briefly reviews how the program's implementation plan was developed, examines some of the basic assumptions of the implementation plan, and then discusses how well reality has met expectations in key program areas.

History

Pilot program

Control of the codling moth by sterile insect release (SIR) was assessed in approximately 500 ha of apples and pears in the Similkameen Valley of BC from 1976-1978 (Prov-

erbs *et al.* 1982). Sterile (treated with 35 Krad Gamma irradiation) male and female moths were released into area orchards two to three times a week from May to September. Despite moth production problems, the ratio of sterile to wild males was always well above the planned minimum of 40:1. Although complete eradication was not achieved, damaged fruit was found only in 15 of 116 orchards inspected in 1978, and did not exceed the economic threshold (0.5 percent) in any of the 157 orchards treated. Follow-up studies indicated that when wild codling moth populations were brought very close to extinction, all control measures could be omitted for 2 or more years. A comparison of the cost of controlling codling moth with SIR versus a conventional spray program showed that SIR was about 2.4 times more expensive.

Economic studies

Although SIR had been determined to be significantly more expensive than conventional control programs, the thought of not having to deal with codling moth on a yearly basis had obvious appeal to growers. In addition, increasing concern was being expressed about codling moth developing resistance to azinphosmethyl (Guthion), the most effective and commonly used insecticide for its control, as well as the negative impact of insecticide sprays in general on the environment. Therefore, the costs/benefits of a SIR program were re-examined several times over the next 10 years to determine if cost savings could be introduced and if such a program could be justified (Holm *et al.* 1985, 1986; Hansen & Jeck 1987). These studies concluded that a SIR program could be economically feasible in the long term if changes in strategy and operations were made.

The principal assumptions that were changed from the initial cost/benefit analysis were:

1. Eradication of the codling moth and maintenance of a pest-free status were assumed possible. The original concept (Proverbs *et al.* 1982) was to cycle between 3 years of release and 3 years of monitoring.
2. Only the minimum number of moths required to eradicate the area would be produced and released, thus keeping both facility construction and rearing costs down. This minimum number was based on Proverbs' calculation that if codling moth damage was first reduced to 0.05 percent at harvest, a release rate of 2,000 moths per hectare per week should be enough to achieve the minimum desired overflooding ratio of 40 sterile:1 wild moth and accomplish eradication in 3 years.
3. The benefits of a SIR program were calculated over the long term in which the continuing costs of a conventional spray program were compared to the cost of eradication

followed by many years of minimal or no control costs for codling moth. It should be noted that none of the economic studies quantified the potential environmental, health, tourism, and marketing benefits emerging from the expected reduction in pesticide application.

Implementation plan

Before launching directly into an eradication program, the British Columbia Fruit Growers' Association obtained funds to develop a detailed implementation plan (DeBiasio 1988) that included recommendations for a legal, political, and administrative framework, an organizational structure, a logistical plan with timelines for different activities such as pre-release sanitation, rearing and releasing, long term monitoring and regulation of bin movement, staffing needs (including job descriptions and salaries), descriptions of general rearing and release procedures, yearly cost estimates, a revenue raising process, and a summary of program benefits and risks.

The Current Program - 1992 to 1995

Construction of the rearing facility

Capital funds in the amount of \$7.7 million Canadian were approved by the Federal and Provincial Governments for construction of the codling moth mass-rearing facility and the purchase of operating equipment. Ground breaking began in January 1992 and construction was substantially completed in March 1993. The project finished \$300,000 under budget.

Although the reproductive colony was established and a small number of release trials were conducted during the summer of 1993, budget constraints did not permit full-scale operation of either the rearing facility or the release equipment until the first actual field season began in 1994. Unfortunately, when the program went into full production, equipment failures began to appear that soon became a chronic problem and threatened the delivery of the program. Some of the problems encountered included undersized gear boxes for the diet pumps, microswitches on the diet lines that were not water/dust proof, insufficient cooling capacity to maintain proper rearing room temperatures during the summer, humidity control problems, and an unreliable electrical system on the moth release devices.

Start-up problems such as these are not uncommon for a program and facility of this type. The Waimanalo mass-rearing facility for Mediterranean fruit fly in Hawaii had significant production problems for over a year after construction was finalized. The new pink bollworm mass-rearing facility in Phoenix, Arizona is currently struggling with diet dispens-

ing equipment, a moth scale collection system, and egg collection procedures. The Agriculture Canada Research Station in Summerland, BC has had chronic problems with their controlled environment rooms since the building was completed in 1986. Given the fact that operational and equipment problems should be expected during the start-up phase of a mass-rearing facility, it is critical to allow time for sufficient testing of all systems under actual operating conditions while they are under warranty and before program demands for rearing and releasing become critical. This is particularly true when new and/or 'improved' technologies are being introduced.

Separate from start-up problems associated with new equipment are problems associated with facility design. Providing the proper conditions for good insect rearing must be kept as the first priority. This means insuring that requirements for both high production and high quality are met. It is critical, therefore, that the engineering firm in charge of construction be flexible and willing to work with scientists, so that new technologies are introduced and adapted to provide a better rearing environment rather than allowing rearing procedures to be adapted to fit an engineer's idea of 'improvements' in the new facility.

Wild population and overflooding ratios

SIT programs for pest eradication are typically won by excesses. There are often excesses in money as the costs are up front and the benefits are long term, and there are definitely excesses in effort requiring continued vigilance and persistence, and by design, excesses in the numbers of sterile insects released. Although this last point may seem obvious, it cannot be overstated. Overflooding ratios for a given species are generally calculated based on many years of field experience, combined with computer prediction models for population rates of increase/decrease. Influencing factors include the starting size of the wild population, the reproductive potential of the female, weather conditions in a given year, the quality and competitiveness of the sterile insects, and the desired length of time in which eradication is to be achieved. Most of these factors are very difficult to measure with a great degree of accuracy.

Overflooding ratios, therefore, are good, ballpark estimates at best and should be used cautiously, i.e., calculations of production needs should be on the high side rather than the low side, and calculations of production capabilities should be conservative and low rather than optimistically high. Miscalculations resulting in over-production may increase costs but should bring about eradication more quickly (or production can be scaled back), whereas miscalculations on the low side may jeopardize success altogether. Once a facility has been built and production capabilities established, the only recourse for dealing with poor

overflooding ratios is to decrease the size of the treatment area or to combine releases with other measures to lower the wild population.

Unfortunately, the codling moth eradication program in British Columbia, for purposes of the cost/benefit analyses, used minimum number calculations for

- (1) the overflooding ratio (40 sterile : 1 wild),
- (2) the size of the wild population (one that would produce 0.05 percent or less damage at harvest in the year prior to releases), and
- (3) its production requirements (5.25 million moths/week for orchard releases, urban releases and colony maintenance, with a release rate of 1,000 moths/ha/week in commercial orchards).

These minimum number calculations are not holding true and the program is now struggling with a high wild population, poor overflooding ratios, less than adequate control, and potential cost and timeline overruns. Because of these concerns the program, with funding assistance from the provincial government, is offering a one-time SIR grower compliance grant of \$65/acre to growers who achieve good codling moth control in 1995.

Insect quality

Producing quality insects is one of the most important yet easily forgotten components of a SIR program. Rearing staff are continually pressured by program managers to reduce rearing costs, improve rearing efficiency, and increase production numbers. Numbers, after all, are what drive SIR programs. Overflooding ratios have to be 'good' in order to gain the upper hand on the wild population and, invariably, the size of the wild population and treatment area are larger than originally expected. However, the requirement for success is not only large numbers of sterile insects, but large numbers of sterile insects that can mate competitively with the wild population. Unfortunately, many steps in the rearing and release process can have a negative impact on field performance and mating competitiveness (quality) of the mass-reared insects.

As was mentioned under 'Facility Construction', insect quality issues can and should be addressed whenever possible during the facility design phase. For example, the rearing facility in BC has a unique adult collection system in which codling moths emerge directly into rearing rooms and are attracted by UV-lights attached to vacuum hoods mounted in the ceiling. This system only collects moths that are capable of flying to the hoods and thus helps insure that good flight ability is selected for and maintained in the reproductive colony.

Two quality issues that the program has had to deal with are the adverse effects of handling the moths prior to release, and poor moth activity (relative to that of wild moths)

during cool weather. With respect to handling, it has been discovered that it is important to minimize the length of time the moths are kept in cold storage. In 1994 the turnaround time between collection and field release was 36-48 hours. In 1995 a third shift was implemented at the rearing facility to irradiate the moths at night. As a consequence, moths are now no more than 12 hours old when released and field quality has significantly improved. It has also been determined that the jostling of the insects inside the coolers has a serious negative effect on moth quality. The release drivers have now been instructed to carry no more than half of their day's supply of moths at any one time. With respect to poor competitiveness in cool weather, fluctuating the rearing temperatures has been shown to help increase adult flight activity. All of the moths released in May and June of 1995 were reared under a daily temperature regime that fluctuated between 18-34 °C. Preliminary results also seem to suggest that moths that are reared and induced into diapause in the laboratory and later released in the field perform better in cool weather than do moths reared under constant temperatures. The possibility of stockpiling diapausing larvae for spring releases is currently being investigated.

Bylaw enforcement and urban areas

In any eradication program it will be necessary to make inspections of properties to determine infestation levels and enforce appropriate control actions if infestations are found. The Okanagan-Kootenay Sterile Insect Release Board was established under special legislation through an amendment to the BC Municipalities Enabling and Validating Act. The authority of the board was to fall within the political and administrative framework of the Regional Districts (units of local municipal government covering both rural and urban areas) in the eradication zone. Part of the authority granted to the board under this legislation was the authority to enter properties to effect the release of sterile insects and enforce compliance requirements for clearing a property of an infestation or preventing an infestation from developing. The cost of enforcement was to be borne by the person at whose expense the work was done and could be added to the taxes payable on the property as taxes in arrears.

Because of their high initial capital costs, the eradication programs using SIR are only cost effective on a relatively large scale. However, as size increases the number of properties in non-compliance category will also increase. Bylaw enforcement, therefore, becomes both a critical and a major time component of the field program. Enforcement policies must be clear, legally well thought-out, firmly and uniformly applied, and strict enough to allow them to be effective given the relatively narrow time window in which control actions need to be carried out. It is also necessary to have a readily available labor pool to carry out en-

forcement actions. It can potentially do more harm than good to talk tough and issue a control order and then not have a stripping crew or contract sprayer available to get the job done if the order is ignored.

Although the success of a program such as the codling moth eradication program in BC will largely be based on how well it controls infestations in commercial orchards, in the long term (from an eradication standpoint), bylaw enforcement and elimination of urban infestations will most likely be more important and difficult to achieve. Unfortunately, nearly all of the research and development for codling moth SIR has been done in commercial production areas. Urban areas, where there are relatively few host trees that are widely spaced and may show infestation levels of 50-100 percent, present a much different scenario. Under such conditions it is difficult to imagine that the uniform distribution of sterile moths throughout a city at standard orchard release rates will result in sufficiently high numbers of moths arriving at the problem trees to bring about any meaningful level of control. Unfortunately, release results in urban centers such as Penticton, BC during 1994 seemed to bear this out.

In 1995, as an alternative to urban releases of sterile moths, the SIR Program adopted a policy of 'zero tolerance' for infested fruit in all urban and non-commercial orchard properties. The preferred method of achieving zero tolerance is for property owners to either remove all apples, pears, and crabapples from their trees before the end of the spring generation (during eradication years) or to remove their trees entirely. Incentive programs have been developed where those who choose fruit removal receive a discount on replacement apples at local packinghouses, and those who remove their trees receive a discount on replacement non-host trees at local nurseries and garden centers. Other methods, such as the removal of only infested fruit and/or the use of pesticide sprays are acceptable, but only if the same level of zero tolerance is maintained throughout the season. As soon as a property is found to have any level of codling moth damage it is immediately posted with a control order for complete fruit removal. The SIR Program currently employs eight urban monitors to make door to door inspections and enforce the zero tolerance policy on roughly 3,200 properties.

Publicity

Insect eradication programs cannot be conducted in an information vacuum. They are not 'service for hire' ventures, but require the active support and participation of various levels of government, the grower community, and the general urban public if they are to be successful. To effectively solicit and maintain this support requires an aggressive, ongoing communications campaign. The information provided needs to be useful in terms of clearly

stating what is expected of everyone involved, and objective in presenting the benefits as well as the problems involved in such a program.

Probably the biggest failing of the SIR Program in 1994 (the first year of release) was insufficient communications with orchardists and homeowners as to what was happening in the field, what the program wanted them to do, and when it wanted them to do it. Pre-release publicity, what little there was of it, left people with high expectations for quick results and with little understanding of how a SIR program works. As a result, many people stopped all control measures for codling moth, did not realize they had wild infestation levels that were much too high for SIR to control, and sustained damage well above the economic injury level of 0.5 percent at harvest. At the end of the season newspaper headlines talked of growers complaining about still having to spray for control of codling moth, and pay for SIR, and accused officials of using tax dollars to run a poorly planned experiment.

In order to improve public awareness and perception of the program, Greenaway Communications was hired for 1995 with a budget of just over \$100,000 Canadian. Their strategy called for informing the public of the importance of SIR and appealing to their sense of responsibility - not unlike campaigns for community recycling programs. Commercial growers were primarily dealt with through a direct mailout. In addition, they were reminded of compliance information and spray requirements through regular news releases, radio announcements, the BC Ministry of Agriculture's information network, and weekly SIR Program updates that were faxed to packinghouses and local fieldmen. The urban and non-commercial property owners were dealt with through a separate, direct mail campaign stressing the 'zero tolerance' policy, as well as extensive radio and newspaper advertising, frequent presentations about SIR to schools and community groups, and information booths at shopping malls and garden centers.

Budget

As was previously mentioned, capital funds in the amount of \$7.4 million Canadian for equipment and construction of the rearing facility were provided jointly by the Federal Government through Western Economic Diversification and the Provincial Government through the Okanagan Valley Tree Fruit Authority. Operationally, however, the SIR Program is funded 100 percent by growers and property owners in the five Regional Districts encompassing the treatment area. Growers pay a parcel tax based on the number of acres planted to apples and pears. In 1988 it was proposed that growers receiving sterile moths would pay \$40 Canadian per acre (roughly the yearly cost of codling moth control for an average grower based on 2.5 applications of Guthion at 1.4 kg/ha). Due to inflation and

previously unidentified program costs, growers actually paid \$70 Canadian per acre in 1994, and \$72.10 Canadian in 1995. Property owners pay a SIR program tax based on the assessed value of their land not including improvements. The rate varies from year to year depending on the need for revenue, but is generally quite low. In 1995 the cost per \$1,000 Canadian of property value was \$0.16 Canadian.

Although the revenue process is relatively straight forward, i.e., the SIR Board approves the budget for a given year and then sets the acreage and property taxes to collect that amount of money, increases in both the budget and SIR Program timeline have called the process into question. The SIR Board is currently updating the implementation plan and long range financial model to deal with the following concerns:

1. It was always stated that growers would pay by far the largest portion (over 85 percent) of the SIR Program's operating costs. However, this was calculated over the long term life of the program. Growers were to begin paying when they started receiving sterile moths and continue paying indefinitely, even after eradication had been achieved, to maintain the area pest free. Property owners, on the other hand, only had to pay the SIR property tax during the eradication phase. Regional Districts now realize that while eradication is on-going, they actually pay almost 70 percent of the yearly operating budget.
2. Oversights and errors in the 1988 implementation plan have resulted in the yearly operating budget increasing from an estimated \$1.5 million Canadian to approximately \$2 million Canadian. Some of the miscalculations included the cost for publicity, facility and equipment maintenance, diet ingredients, urban bylaw enforcement, and accounting and legal advice.
3. In order to deal with high wild populations and large numbers of wild trees, abandoned orchards, and backyard sites in the northern half of the eradication area, it has been proposed to divide Zone 2 into up to four smaller zones. This would obviously extend the length of the program (eradication phase) and the number of years that Regional Districts would need to pay into the program. It would also mean that some growers would not receive the benefits of the program for many years.
4. Under the validating legislation the SIR Board is composed of five voting Directors, one from each of the five Regional District Boards in the eradication area, each with one vote. However, the urban tax bases of the Regional Districts are not of equal size. For example, Kelowna, in the Central Okanagan Regional District, pays over 53 percent of the property tax revenue, while Creston, in the Central Kootenay Regional District, pays less than 2 percent.
5. Although the growers currently pay about one-third of the operating budget they do not

have a vote on the SIR Board on matters relating to Program delivery (e.g., acreage tax rate or decision to divide Zone 2 into smaller zones).

6. Early cost/benefit studies and the implementation plan identified the treatment of urban and non-commercial properties as a concern, but no budget or program structure was ever developed. The Regional Districts now differ in their opinions on whether it is the responsibility of the SIR Program or the individual Regional Districts to clean up these areas.

Summary

The SIR Program for codling moth eradication in British Columbia was used to point out the wide range of potential problems that can develop when trying to conduct an area-wide pest control/eradication program. However, despite such problems we feel that SIR has found an important place in dealing with a number of major pests worldwide, including codling moth. As conventional pest control methods become more costly and less effective, SIR will likely provide an increasingly better solution for an expanding range of important pest problems in a uniquely effective, economical, and ecologically sound manner.

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