Management and Control: Queensland fruit fly (*Bactrocera tryoni*)

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1.0 EARLY DETECTION

Early detection of an outbreak of any invasive species is very important, as it increases the odds of a successful eradication, before the pest becomes established. In South Australia there is an ‘early warning system’ of traps to detect outbreaks of adult Q-flies. “A grid of more than 3800 fruit fly trapping sites in metropolitan Adelaide, Northern Adelaide Plains, Adelaide Hills, Riverland and a number of country towns are checked regularly by PIRSA officers” (Heaven, 2007). There is also a ‘Fruit Fly Hotline’ for the public to report possible discoveries of Q-fly.

In New Zealand, an annual fruit fly surveillance trapping program is undertaken by MAF Biosecurity New Zealand (MAFBNZ) to detect any incursions of fruit flies, including the Q- (MAFBNZ, 2008b). There are over 7500 traps used nationwide in this surveillance, and they are “concentrated in populated areas serving as centers for tourism and/or trade, areas of significant horticultural activity and areas specified as being climatically conducive to the establishment of fruit fly” http://www.biosecurity.govt.nz/pests/queensland-fruit-fly (MAFBNZ, 2008a).

2.0 COMBINED MANAGEMENT

As with the control of many pest species, a single control method by itself is often not sufficient to eradicate (or even effectively control) the Queensland fruit fly (Q-fly) from an area. The best results are gained from a combination of the methods found in the section below. For example, bait spraying, male annihilation and good hygiene have been used in combination in attempts to eradicate Q-fly in New South Wales, Australia (Gilchrist, pers. Comm. 2008).

3.0 CHEMICAL

3.1 GROUND SPRAYING

Ground spraying is applied under host trees which are known to be infested with Q-flies. A spray of insecticide (eg. Chlorpyrifos) is applied to the ground under infested trees. The ground area which is sprayed includes the area from the trunk to the outer perimeter of the foliage. All compost heaps in the vicinity are also sprayed. No more than two ground sprays are usually necessary under one tree. This method targets larvae and emerging adults in the soil (Dominiak, 2007b).

3.2 BAIT SPRAYING

This method of Q-fly control involves the spot spraying of a combination of a dilute protein mixture and an insecticide (eg. Maldison). The protein serves as an attractant, and when the Q-fly feed on the protein mixture the insecticide component causes death: this method targets both the male and female Q-fly. A recommended bait spraying regime is 100 ml doses, targeting the shady spots which Q-flies like to occupy. A density of 100 spot sprays per hectare (around 6 to 8 per residential property) is used in the Fruit Fly Exclusion Zone (FFEZ) of Eastern Australia. This amount of spraying is thought to be effective due to a bait spot being within the “daily wandering range of each fly within the treatment area (Dominiak, 2007b).

The effectiveness of this control method can be reduced by rain washing off bait spots and the pesticide degrading over time (Gilchrist, pers. Comm.. 2008). Maldison is used as an insecticide in bait spraying within the FFEZ, as it has a short residual life and low mammalian toxicity. “Bait spraying alone will not be enough to control high populations of
QFF” – it should be used in combination with other control techniques (Dominiak, 2007b). Bait sprays generally use much smaller quantities of chemical than cover sprays. Bait sprays are generally applied to foliage and not to the fruit (Dominiak, 2007c).

3.3 COVER SPRAYING
Cover sprays are applied to the whole tree, and target Q-flies sheltering in the tree canopy and maggots located within host fruit. Insecticide sprays used include dimethoate, fenthion and trichlorfon, depending on the tree being sprayed (Dominiak, 2007c). After cover spraying, there is a period of time for which fruit should not be picked or eaten. The length of this withholding period depends on which insecticide was used (Dominiak, 2007b). As mentioned above, cover spraying is often used in combination with bait spraying to achieve suppression of high populations of Q-fly.

3.4 MALE ANNIHILATION
This control option uses traps or pieces of board or fibre which have had a male-specific lure (such as Cue-lure or raseberry ketone) and an insecticide applied to them, and are usually hung in trees. As male annihilation only reduces the size of males within a population, females can still cause damage by attacking fruit. Male annihilation is not effective in the situation where there is even modest immigration from nearby populations. This control option is best suited to isolated environments such as islands (Gilchrist, pers. Comm., 2008). Male annihilation traps cannot be used within the Fruit Fly Exclusion Zone in Australia (Dominiak, 2007c).

4.0 PHYSICAL & CULTURAL

4.1 TRAPPING
Traps are used as a monitoring device rather as well as a control method. Generally, traps use synthetic attractants (sometimes sex-specific) to attract fruit flies to them (DPI, 2008). Brightly coloured traps emulating colours of host fruit (eg. orange, yellow, and green) have been found to be most attractive to Australian fruit flies including the Q-fly (Hill & Hooper, 1984).

4.2 FRUIT TYPE SELECTION
The worst attacks of fruit flies, including the Q-fly, often occur in late summer and autumn. Fruit losses can be minimised if fruit growers chose to grow varieties of fruit which mature before or after this period of maximum impact (Dominiak, 2007a). Removing less valuable host plants will reduce the amount of control needed, and reduce the likelihood of Q-fly escaping control actions. (Gilchrist, pers. Comm. 2008).

4.3 TREE PRUNING
Trees which are well pruned, and not too tall, are much easier to adequately spray with insecticides. It is also easier to make sure that all ripe fruit is picked, if trees are kept at a manageable height (Dominiak, 2007c).

4.4 PICKING FRUIT
Fruit should be picked off trees as it ripens. This stops Q-flies from laying eggs inside it, and prevents any larvae surviving. This fruit should either be eaten immediately, or put in the refrigerator. It is recommended that “all mature fruit should be stripped from trees by April 30 to prevent fruit flies overwintering” (Dominiak, 2007c).
4.5 PICKING UP FALLEN FRUIT
Fallen fruit should be removed, to stop larvae from getting into the soil and continuing their life cycle (pupating) (Dominiak, 2007c).

4.6 DISPOSAL
Suitable disposal of infested fruit is required to prevent outbreaks of Q-fly. A recommended (Dominiak, 2007c) way of safely disposing of unwanted fruit is:
1. Place any unwanted fruit in a plastic bag.
2. Tie the top of the bag shut.
3. Leave the bag in a sunny position for three (so heat from the sun can kill the fruit fly maggots and adults).
4. Dispose of the bag through the garbage system (do not bury the bag in soil).

5.0 BIOLOGICAL CONTROL

5.1 CLASSICAL BIOLOGICAL CONTROL
Although the classical biological control program in French Polynesia, in which Fopius arisanus (a wasp which parasitises tephritid fruit flies) was released to control fruit flies, was originally aimed at suppressing the Oriental fruit fly (Bactrocera dorsalis), fruit collections showed that the release of this biological control agent caused a decline in the numbers of the Queensland fruit fly emerging from fruit. Compared to before release of F. Arisanus, a decrease of 79.3% in the number of emerging fruit flies was recorded in guava. Similar rates of decrease were found in other host fruits (Vargas et al. 2007). F. arisanus has been reared on the Queensland fruit fly in the lab on a number of occasions (eg. Quimio & Walter, 2001 in Vargas et al. 2007).

5.2 STERILE INSECT TECHNIQUE (SIT)
A technique called the sterile insect technique (SIT) is used to contain and exclude populations of Queensland fruit fly. The goal of SIT is to release a large amount of sterile males to mate with any introduced wild females, resulting in the production of infertile eggs (Knipling, 1959). The potential of SIT for controlling pests has been around since the 1960s, when SIT trials first caused large declines in the size of Q-fly populations (Monro, 1966). Compared to insecticidal control methods, SIT has some advantages including increased specificity and can be targeted to affected regions (Knipling, 1959). SIT programs in the past have failed due to continual immigration into the areas being targeted (Meats et al. 2003).

The most common method used to make fruit flies sterile for SIT programs is to irradiate them. The most effective time of the life cycle for irradiation to occur is when pupation is approximately 70% complete. (Gilchrist & Crisafulli, 2005). The most effective irradiation dose rate for SIT programs should be at a level which makes individuals sterile without reducing its reproductive competitiveness. Studies have found that dose rate does not affect sterility induction, but higher does rates can cause stress mortality. The “lowest practical” dose rate should be used when irradiating for SIT control programs (Collins et al. 2008). Irradiated males are not reproductively disadvantaged against normal males in terms of female remating – levels of female remating have been found to be similar for irradiated and normal males (Harmer et al. 2006).

Although irradiation of male Q-flies causes changes in the temporal patterns of calling and courtship sounds, which could potentially affect mating competitiveness, there is no difference between the proportions of irradiated and untreated males which copulate
successfully (Mankin et al. 2008). This is confirmed by Weldon (2005) who found that “despite differences in behaviour, frequency of successful copulations and mating success were similar among wild, mass-reared and sterile males.”

**5.3 DISTINGUISHING SIT FLIES**

Sterile male flies which are released into the wild should be marked, so if they are detected in a trap they can be distinguished from a wild infestation. One such way of marking flies is with fluorescent dust as they emerge from the pupae (Gilchrist et al. 2004). When this happens, the ptilinum (a sac on the top of the head) is temporarily everted to break through the puparium, so the adult fly can emerge. Fluorescent dust adheres to the ptilinum while it is still everted, and after it retracts back into the head “some fluorescent particles are, in effect, embedded in the head, resulting in relatively permanent marking” (Gilchrist & Crisafulli, 2005). This method of marking SIT flies, however, fails to mark a small number of sterile Q-flies. Strict international quarantine protocols to prevent the export of Q-fly to importing countries means that the detection of a very small number of flies that appear to be wild (not SIT released) could suspend international trade and have severe economic consequences to the agricultural sector of Australia. It is currently a very high priority to develop methods to unambiguously identify any captured Q-flies as wild or sterile (Gilchrist & Crisafulli, 2005).

It should be noted that the cost of misclassifying sterile flies is very different to the cost of misclassifying wild flies. The only consequence of misclassifying a sterile Q-fly as a wild Q-fly is that one more fly needs to be examined using another method. “However, if a wild fly is misclassified (as a sterile), then a wild population may remain undetected, with the possibility of larger subsequent outbreaks” (Gilchrist & Crisafulli, 2005).

One method to unambiguously identify captured Q-flies as wild or sterile that is currently in development is using geometric morphometrics to analyse the subtle variation in wing shape between sterile and wild populations. Studies have shown that the results of this shape analysis can be used as the basis of a test to distinguish wild and sterile Q-flies. This method has a number of advantages over the fluorescent dust technique (Gilchrist & Crisafulli, 2005):

- it is very easy to perform
- a lot faster to complete than other methods (several 100 wings/day)
- uses mainly non-living tissue (the wing) so both live and long-dead specimens can be examined
- collecting data for wing shape analysis is relatively cheap, with the only requirements being a microscope-mounted video camera.

Other methods which have been trialled include tests examining the difference in testes morphology (unreliable because some Q-fly bodies deteriorate while in traps for up to 2 weeks) and using DNA microsatellite markers to distinguish populations of wild and sterile Q-flies, which is very expensive and takes 5 – 10 days to complete (Gilchrist & Crisafulli, 2005).

**5.4 QUEENSLAND FRUIT FLY VIRUS**

A picornavirus known as Queensland Fruit Fly Virus (QFFV) has been isolated in laboratory stocks of the Queensland fruit fly. Within these laboratory populations QFFV virus propagated easily among individuals, probably via feeding contact between adults (Moussa, 1978). QFFV was found to be highly pathogenic, resulting in the mortality of up to 50% by the 3rd week after adults emerged. Adults that survive may have reduced fecundity for a few days (Bashruddin et al. 1988).
The United States Department of Agriculture manual on ‘Natural Enemies of True Fruit Flies (Tephritidae)’ (Stibick, 2004) lists QFFV as a possible agent for the biological control of Queensland fruit fly, as it is both effective at control and relatively host-specific (Stibick, 2004). Although not a large amount of research appears to have been focussed on the use of QFFV as a biological control agent, it has the potential to be an effective control method in the future.

6.0 GENETIC

6.1 GENETIC ANALYSES TO AID MANAGEMENT

The relatedness of Q-flies captured in traps can be examined through the analysis of microsatellite markers. This technique can be used to find out if invasions occurring in different places and at different times involve individuals which are from the same source population and that are related to each other, or if they represent distinct invasions independent of each other. In Adelaide, Australia at least six Q-flies which were full siblings of each other were caught in traps in the same month, by Gilchrist et al. (2004). These six flies were trapped at a number of sites separated by “distances greater than the unaided dispersal distance of Q-fly,” which provides evidence for human-aided dispersal of Q-flies in Adelaide. Previously, many outbreaks occurring at the same time in places separated by large distances were thought to be separate outbreaks, but this research showed that this situation could be a single outbreak, spread around by humans (Gilchrist et al. 2004).

6.2 TRANSGENIC CONTROL STRATEGIES

Recent developments have led to the possibility of genetically engineering “factory strains of pest insects which produce male-only broods.” When released into the wild in large numbers, these flies would mate with female flies, but all of the next generation of flies would be male. This would improve the sterile insect technique (SIT) currently used to control Queensland fruit fly (Q-fly) populations. A 100% male population cannot reproduce, and so the fly species population would collapse.

This control strategy has become near-possible due to the development of transformation vectors for insects other than drosophilid flies. There are 5 transformation vectors developed which have the potential to be used in the Q-fly. The process by which this method works is very complex, but involves ‘RNA interference’ (RNAi) targeting genes critical to early development. The sex ratio of a population could be altered by placing this RNAi under the control of a sex-limited gene promoter. This would mean that no young which were either male or female would develop properly (Raphael et al. 2004).

7.0 DISINFESTATION

Disinfestation is a process which removes all life stages of Q-fly from fruit, prior to export, to prevent the spread of this pest around the world. The most common, approved methods of pre-export disinfestations are mainly chemical treatments such as methyl bromide fumigation, or the application of insecticides. These chemical are becoming “increasingly unacceptable” to people at all stages of the export process, from the technicians performing the treatments to the end consumer (Jessup et al. 1998a). In recent years there has been an increasing emphasis on finding more consumer-accepted methods of disinfesting fruit prior to export.

Studies have shown that a keeping fruit at a temperature of 3°C or lower for 16 days is sufficient to cause complete mortality in >30 000 Queensland fruit flies on citrus fruit. This
provides a less-intensive alternative to fumigation while still satisfying quarantine treatments (De Lima et al. 2007). Storage of blueberries at 1°C for 12 days is sufficient to achieve 100% mortality of all life stages of Q-fly (Jessup et al. 1998b). Cold storage has some disadvantages including cold damage to fruit, the cost of the power and cold-room space required, and the duration of the treatment (Jessup et al. 1998a).

Jessup et al. (1998) have shown that sealing fruit in polyethylene bags and storing them at 38°C for 3 days caused 100% mortality of Q-fly eggs and larvae in a number of fruit. The treatment components, polythene wrap and mild heat, are relatively inexpensive when compared to both cold-storage and chemical disinfestation methods. The 3 day duration of heat treatment is substantially less than the 12 – 16 days needed to achieve 100% mortality in cold treatment programs. The heat treatment process did not promote mould or shrivelling, or negatively affect the colour evenness or taste of the fruit. Some judges used in this experiment “preferred the flavour of sealed, heat-treated tomatoes and apples over that of non-treated fruit” (Jessup et al. 1998a).

8.0 CASE STUDY: AUSTRALIAN FRUIT FLY MANAGEMENT ZONES

8.1 FRUIT FLY EXCLUSION ZONE (FFEZ)
The key fruit production areas in New South Wales, Victoria and South Australia are located within an area known as the Fruit Fly Exclusion Zone (FFEZ). The aim is to allow exports of horticultural produce from the area to be accepted into fruit fly sensitive markets within Australia and overseas (DPI, 2008). Fruit exports from this area rely upon the fact that it can be demonstrated that the area is completely free of fruit flies (Dominiak et al. 2003b).

8.2 PREVENTION AND DETECTION
The movement of fruit into South Australia is restricted to commercial shipments of fruit which are certified free of fruit fly. Checkpoints at airports and roadblocks are manned by quarantine officers from Primary Industries and Resources South Australia (PIRSA), preventing travellers bringing fruit of any type into the state (Heaven, 2007). Signs on major roads indicate when the FFEZ is being entered, and that any fruit must be destroyed (DPI, 2008). Roadside quarantine bins are provided for the disposal of fruit. People who break the law by bringing fruit or vegetables of any kind into South Australia face fines of up to $20 000 (Heaven, 2007). Vehicles entering the FFEZ are often inspected, to ensure no fruit is being intentionally or unintentionally brought in to the FFEZ (Dominiak et al. 2003a).

8.3 RISK REDUCTION ZONE (RRZ)
The area surrounding the FFEZ is known as the Risk Reduction Zone (RRZ), and in this area there is constant suppression of fruit fly populations. Eradication is not feasible in this RRZ due to high and continuous incursion pressure from the surrounding areas in which Q-fly is established (Dominiak et al. 2003a).

8.4 PERMANENT FRUIT FLY ZONE (PFFZ)
The Permanent Fruit Fly Zone (PFFZ) is a large part of eastern Victoria in which the Queensland fruit fly is endemic. The PPFZ is declared as a Restricted Area under section 20 of the Plant Health and Plant Products Act 1995. The PPFZ includes Wodonga, a small city in Victoria, near the border with New South Wales. Fruit which is a possible host of the Queensland fruit fly cannot be moved out of the PPFZ. No eradication programs currently operate within the PPFZ (DPI, 2008).
8.5 OUTBREAK RESPONSE
Currently, the capture of 5 male Q-flies in adjacent traps within a 2 week period inside the FFEZ ‘triggers’ the declaration of an outbreak. This lead to the establishment of a 15km radius quarantine area, within which no fruit transport is allowed. An intensive chemical eradication program is also undertaken, to eradicate the invasion before it can establish. Studies agree that it is “highly unlikely a male QFF would fly 15km” (Dominiak et al. 2003b), and the 80km quarantine radius required by some export countries if the 5-fly trigger is set off is greatly excessive. A reduction in quarantine area radius could both save money, with chemical eradication and quarantine efforts having a smaller area to cover, and reduce the time taken to effectively deal with an outbreak, as effort can be focussed on the areas in which Q-flies are most likely to be found.

Most researchers agree that my fruit fly outbreaks in South Australia are the result of repeated introductions, rather that the presence of a population permanently but at levels low enough to avoid detection. The increased effectiveness and lowering costs of genetic methods are the only way to confirm this hypothesis for sure (Maelzer et al. 2004).

8.6 CLIMATE CHANGE & FRUIT FLIES
Climate change is predicted to increase the climatic suitability of the Fruit Fly Exclusion Zone (FFEZ) for the Queensland fruit fly (Q-fly). This means that it is more likely that the Q-fly will invade the FFEZ and become established, threatening the export of any fruit produced in this area. As well as large hugely increasing management costs, the viability of the whole industry could be jeopardised (Sutherst et al. 2000). It has been predicted that a raise in temperature of just 0.5°C will cost apple, orange, and pear growers in Australia an estimated $3.1 million. A 2°C temperature rise would see the costs rising to $12.0 million. This does not include costs associated with the potential failure to maintain the FFEZ free of fruit flies (Sutherst et al. 2000).