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Codling Moth Areawide Integrated Pest Management

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Introduction

Codling moth (CM) is an insidious pest, tunnelling to the core of valuable commodities that are typically marketed with exceptional quality standards for appearance, firmness and sweetness. While there is no mention in the Bible of whether the apple that Eve gave to Adam graded 'Extra fancy', it is likely that if this fruit had been infested with CM, the human race would not be as anxious about returning to a pest-ridden garden of paradise. Nevertheless, since Noah allowed two adult CM to disembark from his boat, the distribution of this pest has closely followed man's cultivation of its hosts around the world (Shel'deshova, 1967). Historically, commercial plantings of both apple (*Malus domestica* Borkhausen) and pear (*Pyrus communis* L.) have been heavily sprayed with seasonal programmes of broad-spectrum insecticides as part of the management of CM (Barnes, 1959; Madsen and Morgan, 1970). These intensive and indiscriminate management practices have not only defined the efficacy of control for this key pest, but also the population dynamics of a suite of secondary pests and their associated natural enemies, and the occurrence of several negative spill-over effects related to the environment and human safety (Prokopy and Croft, 1994).

Growers in the USA were offered in the early 1990s a new integrated pest management programme (IPM) for their orchards that hinged on the adoption of sex pheromones for mating disruption (MD) of CM, an intensive monitoring programme and the judicious use of more selective pesticides (Barnes *et al.*, 1992). Initial testing of this integrated approach, when applied to individual small orchards with low CM pressure, was mostly successful (Howell and Britt, 1994; Knight, 1995a; Gut and Brunner, 1998). Yet, some growers experienced higher levels of CM damage. The cost of the new IPM programme was higher than most growers' current management programmes because many growers applied only a few seasonal sprays for CM, and subsequent reductions in the use of pesticides to manage secondary pests were minimal (Knight, 1995a; Williamson *et al.*, 1996). Secondly, new pest problems

developed in many orchards that required the application of additional sprays, further disrupting the implementation of IPM and raising the new programme's overall cost (Knight, 1995a; Gut and Brunner, 1998). Thirdly, the performance of the early dispensers was poor as the sex pheromones were not well protected and their emission rates were not adequate late in the season (Brown *et al.*, 1992; Knight *et al.*, 1995). Perhaps not surprisingly, a significant proportion of growers initially adopting the use of MD dropped out of the IPM programme prior to 1995 (Howell and Britt, 1994).

An areawide pest management (AWPM) approach was proposed as a potentially more effective strategy that could improve both the performance of sex pheromones and biological control (BC) (Kogan, 1995). AWPM accepts that pests and their natural enemies do not recognize individual orchards' boundaries and that effective management requires a coordinated, regionally focused project (Knipling, 1979). Essentially, the programme was conceived as a 'pyramid scheme', where more and more small growers situated in the centre of an ever-expanding project would benefit as all potential sources of CM impacting their orchards would be treated with MD and intensively monitored, and that the expanding area coming under a more selective management programme would harbour a significant increase in populations of natural enemies and their contribution to BC would also increase.

Demonstration of this concept was initiated in 1995 in a multi-institutional programme created by a close collaboration of university and governmental researchers in Washington, Oregon and California, with primary funding provided by the US Department of Agriculture's (USDA) Agricultural Research Service (ARS) (Kogan, 1994). The 5-year CAMP (CM Areawide Management Program) was the first of the areawide programmes initiated by USDA. The goal of this programme was to implement, assess, research and educate the industry about promising new IPM technologies. CAMP was highly successful in fuelling the rapid adoption of a new paradigm in orchard pest management that resulted in significant reductions in fruit injury using nearly 80% less broad-spectrum insecticides.

Constraints in Developing Areawide CM Management

Management of CM is difficult due to a number of operational, biological and ecological factors. CM is well adapted to the temperate climate zones, can have one to four generations per year and overwinters as a mature larva hibernating in protected bark crevices (Riedl and Croft, 1978). Both sexes are winged and they can disperse widely between managed and unmanaged hosts (White *et al.*, 1973; Knight *et al.*, 1995). Unmanaged sites can include backyard fruit trees, municipal plantings of crab apples, trees surviving at old homesteads and along pasture fencerows and in poorly managed orchards.

Female moths emerge with mature oocytes and have to mate only once to lay a full complement of fertile eggs (Howell, 1991). Females can deposit 50–100 eggs that are laid individually on or adjacent (< 15 cm) to fruits (Jackson, 1979). This oviposition strategy minimizes predation and larval competition for fruits, while maximizing the proportion of fruits that are attacked. Levels of fruit injury can rise

rapidly between generations, and unmanaged orchards can experience over 80% fruit injury (Myburgh, 1980). Neonate larvae do not generally feed before entering the fruit, which significantly reduces the effectiveness of many of the selective insecticides that require ingestion (Croft and Riedl, 1991). Larvae tunnel through the flesh of the fruits to feed on the seeds, rendering fruit infested by even a single larva worthless.

Natural control of CM due to predation or parasitism of eggs and larvae is low in unmanaged sites (Falcon and Huber, 1991) or in orchards under MD (Knight *et al.*, 1997), and natural regulation of CM populations is more strongly influenced by density-dependent factors, such as crop load and available overwintering sites (Ferro *et al.*, 1974).

Effective control of CM requires the repeated applications of cover sprays to maintain an effective toxic residue during the season (Barnes, 1959). Unfortunately, CM has evolved resistance to every class of insecticides applied by growers, from the early use of lead arsenate (Hough, 1928) and DDT (Cutwright, 1954) to the more recently developed insect growth regulators (Sauphanor and Bouvier, 1995) and granulosis virus (Fritsch *et al.*, 2005). The organophosphate (OP) insecticide, azinphosmethyl, has been the primary insecticide used in the USA for CM since the mid-1960s and, surprisingly, resistance was not detected until 1989 (Varela *et al.*, 1993). Resistance mechanisms in CM have included a number of physiological pathways, including altered target sites and amplified detoxification enzymes (Reyes *et al.*, 2007). Cross-resistance among classes of insecticide has apparently reduced the effectiveness of new classes of insecticide, even before they had become widely adopted (Sauphanor and Bouvier, 1995; Dunley and Welter, 2000).

Codling moth pressures in Washington State orchards by the early 1990s had increased significantly, with seasonal moth catches nearly tripling and spray applications doubling from the mid-1980s for many growers (Howell and Britt, 1994). In addition, in response to elevated levels of resistance, many growers increased their application rate of azinphosmethyl and tightened spray intervals. The use of both methyl parathion and chlorpyrifos for CM increased precipitously during this period, causing serious impacts on both pollinators and BC of secondary pests (Gut *et al.*, 1992). Coincidentally, the Alar 'scare' (plant growth hormone) in 1989, the cancellation of phosphamidon (aphicide) in 1990 and the withdrawal of cyhexatin (miticide) in 1992 were harbingers for the eventual loss of even more pesticides registered for use in pome fruits. In particular, the future of the nine OP insecticides registered for tree fruit in 1995 seemed dim.

In 1996 the Food Quality Protection Act was passed, and the Environmental Protection Agency (EPA) was ordered to undertake a reassessment of all pesticide tolerances using a new risk standard of 'a reasonable certainty of no harm'. A new quantitative approach was adopted that considered both the aggregate exposure (all exposure pathways) and the cumulative exposure (all chemicals with the same modes of action considered together), adding up to a tenfold safety factor to protect children. Use restrictions of certain insecticides were tightened by extending worker re-entry periods and preharvest spray intervals and by reducing the total amount of material that could be used per year. By 2006 EPA had reviewed all 9600 pesticide tolerances and revoked 3200, modified 1200 and left 5237 unchanged (Willett, 2006). Currently, there are only four OP insecticides registered in tree fruits in the USA, and a complete phase-out for azinphosmethyl is now scheduled for 2012.

Quarantine security and phytosanitary requirements have serious impacts on the international marketing of apples and pears (Hansen and Johnson, 2007). For example, Japan requires a postharvest quarantine treatment (probit-9 efficacy) of US cherries with methyl bromide to disinfest fruit for codling moth (MAFF-Japan, 1950). Other countries have strict tolerances for the incidence of pests such as CM, which can lead to rejection of shipments and the eventual shutdown in the market. Postharvest treatments are a significant cost added to the marketing of these fruits, and can have serious impacts on the quality of the treated commodity and risks to human health and environmental degradation (Hansen and Johnson, 2007). These strict international tolerances for CM force growers to integrate a system of various biological and operational production and postharvest factors that can provide near-quarantine security levels of pest-free produce prior to shipment (Jang and Moffitt, 1994).

Disruption of the natural control of secondary pests in pome fruits by the sprays applied for CM can contribute to the use of additional sprays and subsequent development of resistance in species, such as aphids, leafhoppers and mites (Croft and Bode, 1983). Most noteworthy has been the history of repeated development of resistance to new classes of pesticides by pear psylla, *Cacopsylla pyricola* (Van de Baan and Croft, 1991) and the tetranychid mites, *Tetranychus urticae* and *Panonychus ulmi* (Croft, 1979). The application of additional sprays to manage these OP-resistant pests can cause secondary outbreaks of pests. For example, the western tentiform leaf miner (WTLM), *Phyllonorycter elmaella*, developed resistance to azinphosmethyl in the early 1980s, and BC of this pest by the eulophid, *Pnigalio flavipes*, is disrupted by summer use of chlorpyrifos and methyl parathion (Barrett, 1988). The subsequent use of the carbamate, oxamyl, to control leaf miners disrupts integrated mite control, forcing growers to apply costly miticides (Hoyt, 1983).

Conversely, reductions in the use of broad-spectrum sprays can release populations of other pests from chemical control. When broad-spectrum sprays were reduced in MD orchards, minor problems with sporadic pests, such as true bugs, increased (Gut and Brunner, 1998). Of greater concern, however, were the outbreaks of the tortricid leafrollers, *Pandemis pyrusana* and *Choristoneura rosaceana*, which caused significant levels of fruit injury (Knight, 1995a; Gut and Brunner, 1998). Infestations of orchards by leafrollers can occur from importation of infested nursery stock and the immigration of adult moths from unsprayed, non-bearing blocks of apple, and from cherry orchards after mid-summer harvest (Knight, 2001). While a number of parasitoids can attack these leafroller species, parasitism levels are typically low in conventional orchards (Brunner and Beers, 1990). The use of OP insecticides in the spring and summer for these pests further destabilizes secondary pest populations (Beers *et al.*, 1998) and has selected for resistance in some populations (Smirle *et al.*, 1998). Selective control of leafrollers is possible with *Bacillus thuringiensis* (Bt) but the level of control is variable (Brunner, 1994). MD for leafrollers is an added expense, and preliminary trials were only marginally effective due to the relatively high population density of these polyphagous pests and their dispersal capabilities (Gut *et al.*, 1992).

Studies prior to CAMP had demonstrated that BC of secondary pests was not significantly improved when growers reduced their use of broad-spectrum sprays for CM (Howell and Britt, 1994; Knight, 1995a; Gut and Brunner, 1998). For example, the population densities of generalist aphid predators and an egg parasitoid of white

apple leafhopper (WALH), *Typhlocyba pomaria*, were higher, but pest levels were unaffected in sex pheromone-treated orchards (Knight, 1995a; Gut and Brunner, 1998). However, the full potential of BC was difficult to assess in these studies as growers only marginally reduced their use of pesticides for secondary pests (Knight, 1995a). The often marginal effectiveness of the available selective insecticides (*Bt* for leafrollers, soaps for aphids and oil for CM eggs) was a significant constraint in 1995.

Organic tree fruit production increased dramatically, from 1988 when the certification programme began in Washington State with 11 growers farming 40 ha, to 1990 with 100 growers farming 800 ha. A small survey of organic apple-growing practices in 1990 found that orchards were treated, on average, with 14 botanical and microbial sprays per season for CM, yet many orchards still suffered high levels of fruit injury (Knight, 1994). A high proportion of organic growers adopted MD after 1991, but this approach was often ineffective when used as the sole tactic to manage high population densities of CM (Trimble, 1995).

One major constraint common in implementation of IPM technologies has been the establishment of effective systems of information delivery to participants (Travis and Rajotte, 1995). Traditionally, growers obtain information from a large variety of sources, including university extension activities (meetings, publications and field demonstrations), fieldmen, consultants, agricultural supply companies, packing houses and cooperatives. However, acquiring real-time information concerning pest populations in surrounding orchards is more difficult. While some growers may know something about the pest pressures in the adjacent surrounding orchards, they are unlikely to be able to assess pest pressures impacting them from more distant sources.

A number of farm operational factors have negative impact on the management of CM. Many orchards (60% in the Yakima Valley; Howell and Maitlen, 1987) are irrigated with overhead sprinklers. Overhead irrigation can wash off spray residues, forcing growers to apply higher rates of insecticides and to spray more frequently (Howell and Maitlan, 1987). Similarly, the use of evaporative cooling to reduce sunburn can remove residues and require similar increased spray use in orchards (Williams, 1993). Storage and transport of bins can introduce CM infestations into clean orchards (Newcomber, 1936; Proverbs and Newton, 1975).

Asynchronous emergence of adult moths from bin piles can create unexpected periods of CM activity (Higbee *et al.*, 2001). This problem is heightened because bins are introduced into orchards at variable time periods during the season, and the strong temperature gradient that exists from the inside to the outside of large bin piles can extend the moth's emergence period (Higbee *et al.*, 2001). Finally, attaining complete coverage and fruit protection in large, three-dimensional tree canopies is difficult (Byers *et al.*, 1984). The deposition patterns achieved by growers vary widely, and tractor speed, nozzle type, water volume and air velocity all have a significant impact on these (Howell and Maitlen, 1987).

Codling moth has always been a greater problem on orchard borders rather than in the interior (Madsen and Vakenti, 1973; Gut and Brunner, 1998). Moths, both immigrating into and emigrating out of orchards, pool along the borders resulting in higher densities of injured fruits (Knight, 2007). In addition, spray coverage can be poor along the edges of orchards. The distribution of sex pheromone along borders is also reduced by higher wind speed and turbulence (Milli *et al.*, 1997).

Monitoring CM with sex pheromone-baited traps is widely practised by growers (Riedl *et al.*, 1986). A number of factors influence moth catches, including a rapid degradation of the sex pheromone within lures (Knight and Christianson, 1999). Thresholds of moth catches have been used as recommendation for the application of insecticides, but the frequent occurrence of ‘false negatives’, where traps fail to detect local infestations, is a particular problem for MD orchards (Knight and Light, 2005). Recommendations for monitoring CM in MD orchards have suggested that growers should use a higher density of traps and replace lures more frequently, practices that increase monitoring costs (Gut and Brunner, 1996).

Mating disruption prior to CAMP was used on 3800 ha in Washington State in 1994 (see Fig. 9.1). The original Isomate-C dispenser was a clear polyethylene tube characterized by a rapid reduction in its emission rate and increased degradation of the pheromone when placed in full sunlight (Brown *et al.*, 1992). A number of factors were known to influence the performance of MD for codling moth, such as dispenser characteristics, pest population density and an orchard’s isolation and topography (Charmillot, 1990). For example, MD failed in only one site, Y6, in the 3-year Yakima Valley study (Knight, 1995b). This orchard had a number of poor characteristics that lessened the likely success of MD: a high initial population of CM, a 6% slope, a high proportion of missing trees and an uneven orchard canopy (tree heights ranged from 2 to 5 m). Specific studies addressing the optimal use of the Isomate-C dispenser for CM MD – such as characterizing the seasonal dispenser emission rate, the influence of dispenser density and positioning within the canopy and the role of sex pheromone blend – were not sufficiently characterized until 1995 (Knight, 1995b; Knight *et al.*, 1995; Weissling and Knight, 1995).

The cost of Isomate-C dispensers in 1991 started at US\$326/ha and application costs, depending on the method used by growers, varied from US\$27 to 69/ha (Knight, 1995a). This initial cost of MD was equivalent to four applications of azinphosmethyl, but most growers in Washington State were applying more than

Fig. 9.1. The acreage of total apple and pear production (◇) and acreage treated with sex pheromones (vertical bars) for codling moth in Washington State, 1990–2006. The acreage treated during the 5-year codling moth areawide management programme (CAMP) is shown by solid bars.

three sprays per season (Knight, 1995a). An economic break-even analysis found that the cost of MD would have to decline by 30–73% to be equivalent to the growers' then current spray programmes (Williamson *et al.*, 1996). Furthermore, this analysis did not include the grower's increased cost of monitoring of MD orchards. Perhaps, in response to both its higher cost and variable effectiveness, over one-third of growers surveyed from 1991 to 1994 had stopped using this new technology (Howell and Britt, 1994).

Factors Available for Successful AWPM Implementation

There are many constraints that impact the management of CM and the various secondary pests in tree fruits. However, there are also a number of very important factors that were in place in the early 1990s that facilitated the development of effective AWPM programmes. CM has a narrow host range, and in the major tree fruit growing regions in the western USA there are not a large number of unmanaged orchards or large sources of CM outside of commercial orchards (Barnes, 1991). In general, CM populations are maintained at very low levels in commercial orchards and most growers in Washington State prior to 1995 applied no more than two sprays per season (see Table 9.1). Pest boards are funded in nearly every county to deal with the presence of pest problems emanating from unmanaged sites, and are usually mandated either to spray orchards or to remove trees at the owner's expense.

Table 9.1. Survey of insecticide usage for management of codling moth and leafrollers in Washington State, USA, apple from summaries of agricultural chemical usage in 1991, 1995, 1999 and 2005 (from NASS reports).

Insecticide	Mean no. of sprays (percentage of area treated)			
	1991	1995	1999	2005
Azinphosmethyl	2.8 (90)	3.3 (94)	2.3 (78)	1.8 (72)
Chlorpyrifos ^a	1.4 (65)	1.3 (80)	1.3 (65)	1.1 (58)
Phosmet	2.1 (9)	2.4 (2)	2.0 (7)	1.4 (15)
Ethyl parathion	1.0 (32)	— ^c	— ^c	— ^c
Methyl parathion ^a	1.5 (28)	1.2 (19)	1.1 (5)	— ^c
<i>Bacillus thuringiensis</i> ^b	NA	2.2 (21)	2.0 (19)	1.3 (18)
Spinosad ^b	NA	NA	1.4 (39)	1.3 (62)
Acetamiprid	NA	NA	NA	1.2 (41)
Thiacloprid	NA	NA	NA	1.1 (2)
Novaluron	NA	NA	NA	1.2 (12)
Lambda-cyhalothrin	NA	NA	NR	1.7 (3)
Granulosis virus	NA	NR	NR	1.5 (9)

NA, not available; NR, no records.

^aThese insecticides are applied for control of either codling moth or leafrollers.

^bThese insecticides are applied for control of leafrollers.

^cNo longer registered for use in apple.

Experience developed for the use of CM MD during the 3-year transition programmes conducted in the Yakima and Wenatchee Valleys in Washington State (Brunner *et al.*, 1992), the first coordinated areawide programme developed by five pear growers in Randall Island, California, in response to OP resistance (Varela *et al.*, 1993) and the use of MD on a large, contiguous apple block (400 ha) by a single grower in north-central Washington (Knight, 1992) were key events that provided the industry with an important early assessment of the potential outcome of adopting MD. Risk assessment indices were developed to assess the probable success of MD based on orchards' previous and current levels of fruit injury and moth catches in sex pheromone-baited traps (Gut and Brunner, 1996). Four risk categories (very low, low, moderate and high) were created, each with associated guidelines for the supplemental use of insecticides and suggested dispenser application rates (Gut and Brunner, 1996). Recommendations for the monitoring and managing of secondary pests in MD orchards were also outlined (Gut *et al.*, 1995).

Despite the detection of incipient levels of resistance to azinphosmethyl in some orchards, the majority of CM populations monitored remained susceptible (Varela *et al.*, 1993; Knight *et al.*, 1994). The availability of both methyl parathion and chlorpyrifos, which exhibited negative cross-resistances with azinphosmethyl (Dunley and Welter, 2000), allowed growers to use other effective materials if needed. The existing integrated mite management programme present in most orchards was largely created by the development of resistance by the phytoseiid mites to azinphosmethyl (Hoyt, 1969). This was also true for the effective BC of the western tentiform leaf miner by *P. flavipes* (Beers *et al.*, 1993).

Several new selective approaches were developed to manage leafrollers in the early 1990s. *Bt* sprays could be optimized if the first spray was applied at the maximum rate, delayed until petal fall and applied only with a forecast of extended warm weather (Knight, 1997). Studies found that significant BC of leafrollers could develop in orchards with selective programmes (Brunner, 1992). Demonstrations that a generic, partial sex pheromone blend could be effective for several of the suite of leafroller species attacking a number of horticultural crops in western USA increased the likelihood of commercial development (Knight, 1996; Knight *et al.*, 1998; Knight and Turner, 1999). The first testing of MD in the USA for leafrollers in larger (16 ha) replicated orchard blocks demonstrated the effectiveness of this selective approach (Knight *et al.*, 1998).

Several improvements were made with sex pheromone-based products early in the 1990s. A new Isomate-C Plus dispenser was developed that significantly reduced the degradation of the pheromone and had an improved seasonal emission profile (Gut *et al.*, 1995). Competition among several small companies registering MD dispensers for CM caused significant reductions in the retail price of dispensers. The application cost of MD declined as growers developed more efficient methods of applying dispensers. For example, the total cost of Isomate-C dispensers and their application dropped US\$100/ha from 1991 to 1993 (Knight, 1995a). In particular, the cost of MD dropped most dramatically for growers who cut their application rate of dispensers. Advantages – such as no re-entry waiting periods, compatibility with overhead irrigation, lowered risk of incidence of insecticide resistance, improved worker safety and no container disposal – all combined to generate growing interest in this technology (Brunner *et al.*, 1992).

A few studies demonstrated that CM could be managed in organic orchards successfully using MD. Successful organic production was demonstrated in Canada by removal of injured fruits during the season, banding of trees to remove overwintering larvae and the use of sex pheromones (Judd *et al.*, 1997). Gut and Brunner (1998) were able to clean up an infested organic orchard using two applications of MD dispensers and 16 supplemental sprays of ryania and *Bt*. In subsequent years, CM was effectively managed using only MD in this orchard.

Management of the problematic orchard borders was achieved with a number of approaches. Typically, growers sprayed borders of MD orchards with insecticide sprays (Knight, 1995a; Gut and Brunner, 1998). A few growers applied additional dispensers on borders or extended the pheromone-treated area to include adjoining blocks of hosts or non-hosts, windbreaks or fencerows (Gut and Brunner, 1998). Treating larger, contiguous areas reduced the relative size of orchards' borders relative to the total area, and subsequently the importance of these areas.

Several institutional factors were present prior to CAMP that strongly benefited the development of AWPM. Thresholds and sampling plans were developed for nearly all secondary pests (Beers *et al.*, 1993). A predictive phenology model to time the first cover spray to coincide with the start of CM egg hatch had been validated and was widely used (Brunner *et al.*, 1982). Weather monitoring networks, such as Washington State's Public Agricultural Weather System (PAWS), were established and provided input for a number of insect, disease and plant models that growers could readily access. The various land grant university extension services were relatively well-funded, gathering and disseminating information for growers through publications, workshops, field days and via telephone, fax, mail and the fledgling Internet. In addition, private consultants and fieldmen representing chemical supply companies, cooperatives and packing houses provided monitoring services and made informed management recommendations for growers.

The tree fruit industry in the western USA has a history of providing generous support for pest management-related research (Ing, 1999). The first research project funded by the Washington Tree Fruit Research Commission (WTFRC) for CM MD (US\$6000) was granted in 1991, along with a budget of US\$100,000 for entomological research (Ing, 1992). Levels of funding by WTFRC for entomological research increased by US\$100,000 each year prior to CAMP, with over US\$200,000 granted for CM and leafroller MD research alone in 1994 (Ing, 1995).

The Structure of CAMP

The AWPM programme was developed as a partnership of federal agencies, university researchers and extension personnel, state departments of agriculture and the private sector, including growers, commodity groups and other stakeholders (Calkins and Faust, 2003). CAMP was constructed as a coordinated programme requiring active grower involvement to apply environmentally sound, effective and economical approaches over large, contiguous areas of tree fruit production (Calkins, 1998). The objectives of the programme focused primarily on entomology and did not incorporate new approaches for either horticultural or postharvest control.

The specific objectives were to:

- Reduce the use of neurotoxic insecticides by 80%.
- Demonstrate that MD worked better when applied over large areas, partially through the need for less pheromone and lower costs.
- Develop companion technologies to supplement MD that have a lower cost.
- Increase the role of BC in managing pest populations.
- Develop an effective areawide monitoring programme and establish the use of thresholds.
- Improve worker safety.
- Improve public perception that fruit production is safe for consumers (Calkins *et al.*, 2000).

The expected benefits of this programme were that the AWPM programme would be as effective as, or better than, conventional programmes for CM, reduce the need for sprays for other pests and reduce the use of broad-spectrum insecticides. These benefits would be reached through coordination and optimization of growers' actions, including expanded monitoring, adoption of action thresholds and the use of selective and efficacious tactics (Calkins *et al.*, 2000). A transition to this new programme for growers was eased by providing a direct subsidy to growers within the pilot projects for 3 years (US\$125/ha), as well as providing funding for each project to hire a manager and supplies. The intention of the project was that government involvement would end after 5 years and AWPM would be maintained through a sustainable framework created by farmers, consultants and local organizations (Calkins and Faust, 2003).

Five pilot projects were established in the western USA, with one project in California and Oregon and three in Washington State. These five sites were selected to encompass a broad geographical area and included a range of climatic conditions, fruit varieties and cultural practices, as well as differences in pest management practices. A few basic criteria were established to identify the suitability of each site: (i) a typical fruit production area in the region with consistent pest pressure from CM and other pests; (ii) producers within the project would be willing to cooperate and share costs; and (iii) each group would have the ability to construct a local organizational structure to support and continue the use of AWPM (Calkins and Faust, 2003).

Similar management tactics were applied to orchards in all projects (Calkins, 1999). Orchards were treated with the full rate of sex pheromone dispensers (Isomate-C+ was the sole product used in all but one project), and growers were encouraged to apply one spray of azinphosmethyl to lower the initial population density of CM. All orchards were monitored with a high density of traps (one per ha) baited with high-load sex pheromone lures, and placed in the upper third of the canopy. Moth catch thresholds were established to recommend the use of supplemental sprays during the second moth generation. Secondary pests and natural enemies were closely monitored in a proportion of blocks, and the supplemental use of insecticides for secondary pests was based on the use of accepted thresholds (Calkins, 2003). Comparison orchards outside of the projects were selected based on their similarity in cultivars and horticultural practices, but these conventionally managed orchards were not treated with MD.

The organization of CAMP was structured into four subsections: administration, implementation, research and education. Dr Calkins, the research leader at the

ARS laboratory in Wapato, Washington, was the project's overall administrative leader and controlled the funding provided to the various pilot projects, research projects and education and extension outreach efforts. An Areawide CM Industry Advisory Committee comprised of a cross-section of industry leaders met with the administrators, project coordinators and researchers to review progress at each project site and discuss the related ongoing research concerning control of CM and other orchard pests. This group then reported their findings to other committees, such as the Washington State Horticultural Association Agriculture Chemical Committee, within the industry of each state. ARS administrators from the beginning emphasized the importance of bringing growers into the process early.

Implementation efforts in each of the five original CAMP sites were managed by scientists at the universities and at ARS. Funding provided to each of the pilot projects ranged from US\$50,000 to 185,000 per year depending on the size and specific needs of the project. The first year of the projects was the most difficult due to some concern by growers that they were being forced, even if by peer pressure, to join a government-mandated programme. Before becoming active participants, growers had to be assured that they had control of the project. The use of the 3-year subsidy appeared to have been a very effective enticement for growers to join the programme.

CAMP projects

Howard Flat, Washington, was characterized as an isolated, typical tree fruit production area (90% apple) in north-central Washington, with flat topography. A preliminary coordinated study began in 1994 using MD on 125 ha. The funding provided by CAMP increased the size of the project to 486 ha, with 176 blocks farmed by 34 growers. The Howard Flat Management Board was formed with five fruit industry fieldmen (individuals who worked for local packing houses and agricultural chemical distribution companies) and three local growers. A Technical Advisory Committee was created with a group of applied entomologists (university and government researchers), and weekly breakfast meetings were held from the start to the end of each growing season. A project coordinator was hired to handle the daily activities, such as orchard monitoring and data summation. Monitoring information from all blocks was disseminated through weekly meetings, postings at a centrally located kiosk within the project, an electronic bulletin board and a monthly newsletter.

Parker Heights was considered to be a challenging area (190 ha), characterized by mixed-crop production (80:20 apple and pear) and situated across a hilly terrain. Pome fruit orchards were interspersed among 60 ha of stone fruit (cherry and peach), creating an extensive array of MD-treated borders in the project. An ARS employee served as the site coordinator and managed the project, along with a steering committee of two growers and three fruit industry fieldmen.

Oroville was a unique site consisting of 154 ha situated on the Canadian border on either side of Lake Osoyoos. Thirteen growers farmed 65 orchard blocks with 90% apple production. All orchards received weekly releases of sterilized CM adults provided by the Canadian Sterile Insect Release Program in Osoyoos, British Columbia (Bloem and Bloem, 2000). ARS hired a project coordinator, released the

moths, monitored the orchards and maintained an office on site where growers could access project information and discuss issues with the coordinator's staff.

Medford, situated in southern Oregon, was characterized by a flat topography and 90% of its 121 ha were planted in 13 cultivars of pear and farmed by seven growers. The project was organized by Oregon State University personnel and began in 1994 on 30 ha, using a selective programme based on MD and repeated applications of horticultural oil for CM. The project had the same coordinator for all 5 years, and bi-weekly meetings were held with all participants during each growing season.

Randall Island was the first coordinated areawide project for CM and was started by five Bartlett pear growers on 308 ha in 1993, with support from the University of California in Berkeley, California. The project focused on the use of MD to combat the development of high levels of OP resistance (five- to eightfold) in local CM populations. Initially, growers used two dispenser applications and evaluated the use of rotations of methyl parathion and azinphosmethyl in combination with MD to manage CM and OP resistance.

CAMP funded 17 one-year sites from 1997 to 1999 (see Table 9.2). Each project received US\$40,000 to hire a project manager and purchase basic supplies, such as traps and lures. The criteria used to select these new sites were that they be comprised of > 160 ha of contiguous orchards, used MD and be farmed by at least five growers. Selection preference was given to sites that: (i) had some prior experience with MD; (ii) were farmed mostly by small growers; (iii) had a unique feature that would help extend the fruit industry's knowledge and adoption of the areawide control approach – such as pest complex, pest pressure or the site's topography or location; and (iv) could demonstrate a strong likelihood of continuing the project after the 1-year support ended (Calkins, 1999).

Support provided for research

CAMP provided nearly US\$1 million to support various research projects that:

- Addressed improved monitoring of CM and leafrollers.
- Quantified the atmospheric sex pheromone concentration within orchards and the release rates of lures and dispensers.
- Improved monitoring for stink bugs.
- Enhanced BC of CM, leafrollers and the tarnished plant bug, *Lygus lineolaris*, through classical and augmentative releases of parasitoids.
- Assessed the importance of biodiversity and the population dynamics of selected BC predator species in orchards.
- Characterized the impact of seasonal spray programmes of horticultural oil and kaolin particle films on pest management and plant growth.
- Tested new technologies for MD of CM and leafrollers.

Proposed projects were submitted on a yearly basis to CAMP and evaluated by a panel of ARS scientists, with recommendations provided by representatives of WTFRC and the California Pear Advisory Board. The goals of this collaborative project were to avoid duplicative funding by WTFRC and/or the Pear Pest Management

Table 9.2. General characteristics of the project sites established during the CAMP programme.

Year (s)	Location	Crop mix ^a	Hectares	No. of growers
1995–1999	Randall Island, CA	0:100	308	5
1995–1999	Medford, OR	20:80	121–202 ^b	5–7 ^b
1995–1999	Parker, WA	80:20	190–224 ^b	7–11 ^b
1995–1999	Howard's Flat, WA	90:10	486–688 ^b	36–57 ^b
1995–1999	Oroville, WA	95:5	154–526 ^b	66–09 ^b
1997	Progressive Flat, WA	100:0	243	25
1997	Brewster, WA	96:4	1902	41
1997	Manson, WA	98:2	410	68
1997	Wapato, WA	90:10	364	18
1997	Mendocino, CA	0:100	223	10
1998	Chelan, WA	100:0	263	11
1998	E. Wenatchee, WA	95:5	202	12
1998	Quincy, WA	100:0	283	7
1998	Bench Road, WA	95:5	506	9
1998	Moxee, WA	100:0	271	6
1998	Lower Roza, WA	90:10	688	23
1998	Rogers Mesa, CO	100:0	243	17
1999	Milton Freewater, OR	100:0	422	20
1999	Entiat Valley, WA	50:50	565	32
1999	Highland, WA	95:5	690	24
1999	West Valley, WA	92:8	338	12
1999	Lake County, CA	0:100	202	9
1995–1999	Total (1999)		9763	533

^aRatio of apple to pear within the project.^bFigures increased between 1995 and 1999.

Research Fund in California and to maximize the overall impact of the dollars spent in supporting research. The impact of the CAMP programme was clearly expanded by the acquisition of additional funding to support both research and implementation by the various participants in the project.

Centralized project coordination

One necessary structural component envisioned to develop an AWPM programme was the establishment of a central authority to run the project (Kogan, 1995). However, due to the large geographical size and number of participants, a centralized authority for CAMP proved to be cumbersome and largely unnecessary to coordinate the activities at each site. Several useful tools were developed at Oregon State University that aided the project, including: (i) a generalized bibliographic database

for CM; (ii) an online weather data and degree-day web site supporting 102 sites from Oregon, Washington and Idaho, with 20 insect and disease models and crop models; (iii) GIS tools to develop maps of each of the sites and to summarize moth catches and levels of fruit injury among orchards; and (iv) grower satisfaction surveys in 1995 and 1996.

Orchard monitoring

One major impetus for growers to adopt MD for CM was the belief that achieving significant reductions in the use of broad-spectrum insecticides for this key pest would allow them also to reduce their use of sprays for secondary pests. Thus, CAMP spent nearly US\$200,000 each year monitoring pests and natural enemies in comparison blocks under areawide MD versus conventional OP-based programmes (Beers *et al.*, 1998). Researchers at Washington State University developed the standardized protocols for monitoring, including sampling plans and data sheets for both apple and pear. Data were collected from a subsample of orchards (4 ha blocks) in each of the five original pilot project sites from 1996 to 1999 (see Table 9.3). In addition, data were collected from apple plots within four large, contiguous orchard sites in Washington State managed by individual growers (GRABS – Growers Resource Acquisition Baseline Study). Unfortunately, an additional objective of this project to ‘assess the effect of MD versus conventional management on spray practices for secondary pests and its economic significance’ was not completed.

Twelve different types of samples were collected in apple and pear during the project (Beers *et al.*, 1998). The eight samples collected from apple included: (i) the

Table 9.3. Summary of secondary pest sampling conducted in selected orchards (4 ha plots) treated with sex pheromone within areawide projects and compared with similar (tree age, cultivar and training system) conventional orchards.

Site/state	Crop	Contiguous hectares of MD	No. of blocks sampled (no. of comparison blocks)			
			1996	1997	1998	1999
Oroville/WA	Apple	526	12(6)	5(5)	5(5)	5(5)
Howard Flat/WA	Apple	344	12(8)	12(8)	12(8)	12(8)
Parker/WA	Apple	179	14–16(8)	15–17(8)	15–25(8)	13–28(8)
Parker/WA	Pear	45	9–20(4–8)	9–10(5–9)	9–14(4–6)	15–21(6–9)
Medford/OR	Pear	202	3(3)	4(4)	4(4)	4(4)
Randall Island/CA	Pear	308	9–11(2)	8(8)	8(8)	8 (8–11)
Vantage/WA ^a	Apple	202	4(4)	4(4)	4(4)	4(4)
Brewster/WA ^a	Apple	486	4(4)	4(4)	4(4)	4(4)
Bridgeport/WA ^a	Apple	202	4(4)	4(4)	4(4)	4(4)
Pateros/WA ^a	Apple	233	4(4)	4(4)	4(4)	4(4)

^aGRABS (Grower Resource Acquisition Baseline Study) sites were large, contiguous areas of apple owned by a single grower under MD.

density of overwintering eggs and levels of parasitism for WALH; (ii) WALH nymphal densities during the first and second generations; (iii) aphid population (*Aphis* spp.) and natural enemy counts at five time periods during the season; (iv) leaf samples of WTLM mines and parasitism rates during the second and third generations; (v) *Campylomma* nymph counts during petal fall; (vi) leafroller larval counts for the overwintering and summer generations; (vii) mite binomial and leaf brushing samples; and (viii) fruit damage samples at mid-season and preharvest. The four types of pear samples collected were: (i) pre-bloom cluster samples for mites and psylla; (ii) post-bloom leaf brushing for mites and psylla; (iii) limb taps for psylla and generalist predators; and (iv) fruit damage counts at mid-season and preharvest.

Extension and education activities

CAMP was extremely active in the collection and distribution of information concerning the various aspects of pest management under the new AWPM programme. An Extension Program Coordinator was hired in 1996 and stationed with Washington State University Extension in Wenatchee, Washington. A similar 2-year extension position was funded in Yakima, Washington, during the last 2 years of the project. Extension personnel were also active in promoting MD for CM in both Oregon and California, though no new positions were created.

The Program Coordinator published 31 issues of the *Areawide IPM Update Newsletter* from 1996 to 1998. This newsletter provided a comprehensive review of research findings and information concerning each of the CAMP sites. Summer IPM tours and winter workshops were held to present the latest findings on the use of MD and the progress of the areawide programmes. The Coordinator produced an informational booklet on using MD and guidelines to establish new areawide projects (Alway, 1998a). Guides were also produced specifically for pear pest identification and monitoring (VanBuskirk *et al.*, 1998; Bush *et al.*, 1999).

Outcome of the CM AWPM Programme

CAMP was considered a great success by the industry because most growers were able to reduce their use of OP insecticides and their levels of CM injury without a noticeable increase in production costs (Calkins, 1999). This generalized result was sufficient to create a 'buzz' and promote a more rapid rate of adoption of MD, starting in 1998 (see Fig. 9.1). However, the specific components of pest management used in each project varied and a clear interpretation of the project's overall results is more nuanced. A number of additional factors affecting the economics of tree fruit production probably impacted the increased rate of adoption of MD that occurred after the conclusion of the project. Of particular importance was the development of OP resistance and the anticipation of use restrictions implemented by EPA for certain OP insecticides (Willett, 2006).

Levels of CM injury were generally higher in orchards during 1994 prior to the start of CAMP, and declined strongly during the 5-year project (see Fig. 9.2a).

Fig. 9.2. Summary of the extent of (a) codling moth fruit injury; (b) leafroller fruit injury; and (c) organophosphate spraying applied per season for codling moth in the five original CAMP sites prior to the start of the project (1994) and during the 5-year project (1995–1999).

Injury levels in the first year of CAMP declined in all sites except Randall Island, where 1995 was actually the third year of the project. The ability of growers to reduce their use of supplemental OP sprays at this site during the project's first 3 years (1993–1995) was limited by a continued high pest pressure and elevated levels of OP resistance. CM populations in the later years of the project were significantly reduced by the rotation of methyl parathion and azinphosmethyl during the season and the occasional postharvest use of chlorpyrifos.

The significant increase in CM injury in the last year of the Parker project was also noteworthy (see Fig. 9.2a). The project coordinator hypothesized that this spike was the result of growers sharply reducing their dispenser density from 1998 after the cost subsidy was dropped by ARS (Higbee and Calkins, 2000). An apparent poor correlation of moth counts in traps with pest pressure 'false negatives' in some orchards in this hilly terrain allowed growers to forego sprays, and high levels of fruit injury occurred in 1999.

Levels of fruit injury by leafrollers were generally higher than CM injury in all of the pilot projects (see Figs 9.2a, b). Interestingly, growers in the Oroville site were not aware of leafrollers being present in their orchards prior to 1994. Levels of leafroller injury increased in all projects in the first year of CAMP (Fig. 9.2b). Injury levels were variable between years in each of the sites, with populations gradually increasing in Oroville, declining in Howard Flat, variable in Parker and declining in the last 2 years of the projects in Medford and Randall Island (see Fig. 9.2b).

The use of OP sprays targeted specifically for CM declined by nearly 75% in orchards within the five projects compared with either the levels used prior to the project in 1994 or the comparison blocks surveyed during the project (see Fig. 9.2c). The use of sprays declined most precipitously in Oroville, probably due to the supplemental control provided by the SIT programme. Use of OP sprays also declined sharply in Howard Flat and Parker; however, as previously mentioned, the sharp reduction in sprays applied in Parker was correlated with an equally sharp increase in CM injury (see Fig. 9.2a). The use of one seasonal OP application remained consistent in both the Randall Island and Medford pear sites.

In the first year of the project some growers did not spray for leafrollers because of the high cost of MD for CM (Beers *et al.*, 1998). However, in general, leafrollers were a problem in most orchards inside and outside the projects and all growers increased their use of both chlorpyrifos against delayed dormant and methyl parathion during the summer, as well as the use of *Bt* for spring and summer leafroller control (see Table 9.1). Unfortunately, the spray records for materials applied for other secondary pests such as aphids were not summarized from each site.

Sampling of secondary pest and natural enemy populations found a few significant differences between apple and pear blocks in the CAMP versus conventional blocks (see Table 9.4). WALH population densities were lower in CAMP than in conventional blocks only in 1997 (early-summer nymphs) and 1999 (overwintering eggs); however, parasitism levels of the overwintering eggs by the mymarid, *Anagrus epos*, were higher in all years. No significant differences were found in either the densities of green aphids or their assemblage of generalist predators (coccinellids, syrphids, lacewings, mirids and cecidomyiids) during the study. The density of WTLM was lower and parasitism levels by *P. flavipes* were higher in some samples in 1998 and 1999. The density of phytophagous mites was lower in CAMP only in 1998, but the

density of predator mites was higher during the last 3 years of the project. In pear, phytophagous mite densities were lower in CAMP only in 1996 and predatory mites were higher only in 1998. The mid-summer density of pear psylla was lower in CAMP from 1996 to 1998 (see Table 9.4).

The assessment of fruit injury from 1996 to 1999 found that CM injury was lower in apple CAMP blocks from 1996 to 1998 (see Table 9.5). Similarly, fruit injury by leafrollers was also lower from 1996 to 1998. Levels of fruit injury by the western flower thrips, *Frankliniella occidentalis*, were higher in CAMP in 1997 than in conventional blocks, but *Campylomma* injury levels were lower in CAMP in 1996. Tarnished plant bug injury was higher in CAMP than in conventional blocks in 1997 but lower in 1999. No significant differences in injury were found between treatments due to the cutworm, *Lacanobia subjuncta*, the stink bug, *Euschistus conspersus* or green aphids (see Table 9.5). Overall, levels of fruit injury were lower in CAMP than in conventional apple orchards in both 1998 and 1999. Total pear injury was lower in CAMP in both 1997 and 1998, primarily due to lower levels of injury from tarnish plant bug and, in particular, pear psylla in these years (see Table 9.6). No difference was found for levels of injury in pear due to CM, leafroller, *L. subjuncta*, the grape mealybug, *Pseudococcus maritimus*, or the stink bug, *E. conspersus*.

Table 9.4. Summary of secondary pest and natural enemy sampling in apple and pear blocks where significant differences were found in the areawide sex pheromone-treated blocks versus those in the comparison conventional blocks, 1996–1999.

Crop/sample timing	Sample	Significant difference in arthropod population densities in areawide MD versus the comparison conventional orchards			
		1996	1997	1998	1999
Apple/overwintering	Leafhopper eggs				Lower
Apple/early summer	Leafhopper nymphs		Lower		
Apple/mid-summer	Leafroller larvae		Lower	Lower	
Apple/mid-summer	Mines per leaf			Lower	Lower
Apple/late summer	Mines per leaf				Lower
Apple/mid-summer	Mites per leaf			Lower	
Apple/late summer	Mites per leaf			Lower	
Pear/pre-bloom	Pear psylla eggs per cluster			Lower	
Pear/mid-summer	Mites per leaf	Lower			
Pear/mid-summer	Pear psylla per leaf	Lower	Lower	Lower	
Apple/overwintering	Parasitized leafhopper eggs	Higher	Higher	Higher	Higher
Apple/mid-summer	Parasitism of leaf miners			Higher	Higher
Apple/late summer	Parasitism of leaf miners				Higher
Apple/mid-summer	Predatory mites per leaf		Higher	Higher	Higher
Pear/mid-summer	Predatory mites per leaf			Higher	

Table 9.5. Summary of percentage fruit injury in the apple blocks treated with sex pheromone (MD) within areawide projects versus conventional blocks (Conv) outwith the Oroville, Howard Flat, Parker, Vantage, Brewster, Pateros and Chelan areawide codling moth (CM) projects.

Treatment	Year	CM	Leafroller	Cutworm	Thrips	<i>Campylomma</i>	<i>Lygus</i>	Stink bug	Aphids	Total
MD	1996	0.17 ^a	0.15 ^a	—	0.08 ^a	0.01 ^a	0.14 ^a	—	0.17 ^a	0.72 ^a
Conv	1996	0.34 ^b	0.25 ^b	—	0.03 ^a	0.05 ^b	0.09 ^a	—	0.09 ^a	0.85 ^a
MD	1997	0.05 ^a	0.05 ^a	—	0.11 ^b	0.07 ^a	0.15 ^b	—	0.01 ^a	0.44 ^a
Conv	1997	0.15 ^b	0.18 ^b	—	0.02 ^a	0.07 ^a	0.03 ^a	—	0.02 ^a	0.47 ^a
MD	1998	0.09 ^a	0.10 ^a	0.10 ^a	0.24 ^a	0.05 ^a	0.06 ^a	0.06 ^a	0.02 ^a	0.72 ^a
Conv	1998	0.60 ^b	0.29 ^b	0.10 ^a	0.01 ^a	0.06 ^a	0.06 ^a	0.08 ^a	0.04 ^a	1.24 ^b
MD	1999	0.32 ^a	0.47 ^a	0.20 ^a	0.20 ^a	0.11 ^a	0.13 ^a	0.20 ^a	0.02 ^a	1.65 ^a
Conv	1999	0.59 ^a	0.92 ^a	0.23 ^a	0.19 ^a	0.22 ^a	0.39 ^b	0.36 ^a	0.05 ^a	2.95 ^b

Means within year followed by a different superscript letter were significantly different, $P < 0.05$.

Table 9.6. Summary of fruit injury in the pear blocks treated with sex pheromone (MD) within areawide projects versus conventional blocks (Conv) outwith the Parker, Medford and Randall Island areawide codling moth (CM) projects.

Treatment	Year	CM	Leafroller	Cutworm	Psylla	Mealybug	<i>Lygus</i>	Stink bug	Total
MD	1996 ^c	0.19 ^a	0.26 ^a	—	0.02 ^a	0.0 ^a	0.26 ^a	— ^d	0.73 ^a
Conv	1996 ^c	0.02 ^a	0.14 ^a	—	0.09 ^a	0.0 ^a	0.62 ^a	— ^d	0.87 ^a
MD	1997	0.08 ^a	0.31 ^a	—	0.52 ^a	0.03 ^a	0.48 ^a	0.03 ^a	1.45 ^a
Conv	1997	0.05 ^a	0.03 ^a	—	1.38 ^b	0.02 ^a	0.64 ^a	0.02 ^a	2.14 ^b
MD	1998	0.32 ^a	0.12 ^a	0.02 ^a	1.42 ^a	0.00 ^a	0.15 ^b	0.01 ^a	2.04 ^a
Conv	1998	0.05 ^a	0.02 ^a	0.02 ^a	4.94 ^b	0.00 ^a	0.05 ^a	0.01 ^a	5.09 ^b
MD	1999	0.08 ^a	0.13 ^a	0.02 ^a	0.56 ^a	0.05 ^a	0.12 ^a	0.00 ^a	0.96 ^a
Conv	1999	0.09 ^a	0.11 ^a	0.04 ^a	0.53 ^a	0.01 ^a	0.10 ^a	0.02 ^a	0.90 ^a

Means within year followed by a different superscript letter (a, b) were significantly different, $P < 0.05$.

^cInjury by pear psylla, mealybug and sucking bugs was collected only in Medford in 1996.

^dAll sucking bug fruit injury was grouped together as *Lygus* injury in 1986.

Evaluations of the 17 one-year areawide projects found that all growers considered the project to be a success (Coop *et al.*, 1999). In general, growers in these projects used reduced rates of dispensers, except along orchard borders or in problem hot spots. Low-pressure sites were able to use none to one cover sprays, while mid- and high-pressure orchards used one to two sprays for the first generation and a reduced number of sprays in the second generation, mostly along borders and in hot spots. These spray programmes contrasted with the previous use of the three to five cover sprays that many growers had applied prior to the projects. In general, no CM injury was reported in these sites or, in some cases, injury was confined to a few small areas within each project, usually known hot spots.

The major secondary pest problems experienced in these projects were either from true bugs, such as the western boxelder bug, *Leptocoris rubrolineatus*, or stink bugs and the noctuid, *Lacanobia subjuncta*. Leafrollers were a concern for growers in a number of projects, as moth counts in traps were generally very high during the season. Injury levels from leafrollers, however, were low to moderate in only a few orchards. The large (1902 ha) Brewster project included a 200 ha contiguous area that was treated with MD for both CM and leafrollers (Dual MD) for 3 years (Knight *et al.*, 2001). Leafroller injury in the Dual MD project was reduced by 41%, and growers used approximately one fewer *Bt* spray compared with the orchards in the regular MD programme for CM. Despite these promising results leafroller injury was considered too high, and growers dropped the use of MD and switched to newly registered insecticides, i.e. spinosad (see Table 9.1).

Economic Evaluation of the CM AWPM Programme

Growers have consistently cited the high cost of adopting MD for CM as the major disincentive for them in adopting this new technology (Coop *et al.*, 1999). Prior to CAMP, an analysis found that costs had increased by US\$740/ha for pear growers in Sacramento County, California who made two dispenser applications per season (Weddle, 1994). Similarly, Williamson *et al.* (1996) found MD was US\$188/ha more expensive than conventional management in Washington State apple orchards. Other economic impacts that influenced grower adoption of MD included the effectiveness of MD, the difficulty in applying dispensers, the uncertainty associated with monitoring CM, the need for increased attention in orchards (US\$80–120/ha to hire a consultant or for scouting) and the increased risk of secondary pest problems (Weddle, 1993).

Proponents have hypothesized from the earliest adoption of MD that growers would experience reduced injury levels in treated orchards, partially because the evolution of OP resistance was curtailing the effectiveness of the current programme in conventionally managed sites (Weddle, 1994); and that enhanced BC would allow growers to reduce their spray bill in the second and subsequent years (Connor and Higbee, 1999). Williamson *et al.* (1996) suggested that the benefits of this programme would outweigh its costs when dispensers cost less, growers could further reduce their spray use and the proportion of fruit packed could increase in MD orchards. This optimistic analysis, however, suggested that the benefits of adopting MD would be

reduced by the continued need for growers to spray orchards with other pesticides or crop amendments, such as calcium chloride.

The economic analysis following the 5-year CAMP was similar (Connor and Higbee, 1999). MD could only be cost-effective in a straight benefit–cost analysis if growers reduced their dispenser densities by half in the second and subsequent years and could maintain a reduced spray programme. Unfortunately, this analysis did not include the costs of two ‘down side’ outcomes: the higher cost of monitoring and the higher risk of new pest problems developing in MD orchards. Again, the potential impact of MD on BC was mentioned but not included in the analysis (Connor and Higbee, 1999).

The limited value of these analyses was highlighted by: (i) their failure to include the benefits accrued to growers using MD who developed experience with an alternative technology prior to the loss of OP insecticides; (ii) growers’ greater ability to schedule workers to re-enter unsprayed orchards and complete other essential operations, i.e. thinning, irrigation, etc.; and (iii) growers’ reduced liability when the potential for worker exposure to OP residues was eliminated.

Interestingly, two analyses found that the cost of implementing a MD-based programme in pear was less expensive than the then-current conventional programmes. Growers in the Medford project reduced their pesticide use by US\$520/ha as compared with conventional growers (VanBuskirk *et al.*, 1999). Total operating costs of production for pear orchards using the MD aerosol ‘puffer’ for Lake County, California were marginally higher in the first year of the project, but 3% lower in the later years (Elkins *et al.*, 2005).

Growers’ Responses to the CM AWPM Programme

Twenty-two areawide projects, including 533 growers farming 9763 ha, were organized within CAMP (see Table 9.2). Nearly all growers responding to a survey were very pleased with the results obtained with AWPM and the organizational structure of the CAMP projects (Coop *et al.*, 1999). This enthusiasm was reflected in the growth in both the size and number of participants in four of the five original sites that occurred during the 5-year period (see Table 9.2). In addition, new groups of growers were eager to join the 17 one-year projects (Calkins, 1999).

The structure of these projects varied in terms of both the information provided to the growers and the actions requested by the participants. Generally, all projects created a structure that allowed groups of growers to meet and discuss mutual problems and interests. Usually, there were highly knowledgeable advisors associated with the projects to help solve problems and answer bug-related questions. Projects implemented intensive monitoring programmes for CM and often a select group of secondary pests, and these data were summarized and shared among members. The projects allowed growers to manage their pests effectively through scouting, use of action thresholds and reliance on selective integrated tactics. The outcome of nearly all of these projects was to corral a group of growers together and transform them all into practitioners of IPM through greater knowledge and the use of

research-based programmes. The successes of the projects were in direct proportion to the intensity of the grower involvement in the group (Knight, 1999).

The number one factor indicating the potential for success has been the group's efforts to clean up the problem orchards in their area. Every successful project included the previously non-participating (NP) grower. For example, the successful grassroots movement at Howard Flat eventually convinced 34 of the 36 growers to join the project. In Oroville, all but one grower joined. NP growers had a number of reasons for not joining the projects: some were against government programmes of any kind; others did not want to work closely with their neighbours either because of past grievances or due to a fear that they would be criticized or lose their management independence. Many growers were initially sceptical of the efficacy of the programme or felt that it was too expensive. And, perhaps the number one reason why pockets of CM existed initially in each of the projects, was because some farmers did not farm full-time and because events in their personal life prevented them from effectively focusing their management skills (Knight, 1999). Areawide problems with CM were dramatically reduced once these growers joined with their neighbours.

Conversely, the major reasons why growers joined the project were because they saw that it was not a top-down government programme; growers in the projects actively reached out to educate and persuade others to join; and, after the first year, the programme was demonstrated to be working and other growers realized they could save money and avoid some of the pesticide-related headaches by joining the project.

Unexpected Outcomes of the CM AWPM Programme

Immediately following the first registration of CM MD in the USA, growers expressed their concern that MD was too expensive (Knight, 1995a). The initial implementation of CAMP required that growers receive a subsidy of US\$125/ha (Kogan, 1995). From the beginning, growers adopting MD seemed to push the limits of this technology by stretching the established orchard risk categories to allow them to reduce their dispenser density (Gut and Brunner, 1996). For example, by 1997 only 55% of Washington State growers were using the full rate of pheromone (Alway, 1997), and this had declined further to 27% by 1998 (Alway, 1998b). The potential negative impact of reducing dispenser density on CM management could be observed in the Parker CAMP site (see Fig. 9.2a). While growers reduced their use of MD, they also continued to apply broad-spectrum insecticides for CM on more than 80% of orchards (Alway, 1998b). This grower-developed programme did not allow CAMP to quite achieve its goal of reducing OP use by 80% (see Fig. 9.2c).

The relative importance of BC in the CAMP projects was similar to the earlier results found in the 3-year transition studies conducted in individual orchards (Knight, 1995a; Gut and Brunner, 1998). In both studies, growers saw an increase in BC but few significant reductions in most secondary pest populations (Beers *et al.*, 1998). The one exception was the significant reductions that occurred in pear psylla populations in the Parker and Medford pear projects (see Table 9.6). Also, similar to findings from earlier studies, certain pests became more important in MD orchards

(Brunner, 1999). For example, the grape mealybug increased gradually in the Parker site in both apple and pear (Higbee and Calkins, 2000). Leafrollers became a much more important problem requiring specific sprays in all sites.

Sucking bugs, such as stink bugs and tarnish plant bug, were major problems in some orchards, particularly along their borders. The noctuid, *L. subjuncta*, was a new pest for growers that caused serious problems in some blocks (Landolt, 1998). Nevertheless, other potential pests – such as the lesser appleworm, *Grapholitha prunivora*, which had become a pest in commercial apple orchards in the eastern USA (Krawczyk and Johnson, 1996) and is known to be present in wild hosts such as hawthorn and native plum in the Pacific north-west (Brown, 1953) – did not become a problem.

Apple and pear production is ultimately not driven by CM management success but by the economics of farm management. By 1999 the economics of tree fruit production were very poor for growers, and this led to both an overall reduction in the area under production and a noticeable slowing in the adoption rate of MD (see Fig. 9.1). In particular, some growers with older varieties such as Red Delicious went out of business, as did many smaller operations. Other orchards were replanted with wine grapes, cherry or stone fruit. The continued sprawl of towns and cities has forced the conversion of many orchards into rural housing developments. Orchards owned by absentee investment groups and speculators were managed with a thin array of low-cost inputs. These financial conditions led to neglect of some orchards, and CM population levels skyrocketed in some districts. Pest control boards became largely ineffective due to the abundance of problem sites. In many former CAMP sites it took about 3 years for pest problems to build to the levels existing prior to the project.

The ARS-funded project effectively brought together personnel from government, industry and several universities. Tremendous successes were reached in the implementation of AWPM projects, in new research discoveries and in outreach efforts to educate the industry. Not unexpectedly, a few problems occurred with the functioning of such an independent group of experts. The group did not easily adopt the AWPM tenet of having a centralized structure for programme coordination and data collection and dissemination (Kogan, 1995), as some project leaders were hesitant to share information. Control of research funding by ARS created some dissension among researchers when their projects were not fully funded. The unity of the group appeared to break apart by the end of the project, and a summary report was never completed.

Future Prospects for the CM AWPM Programme

CAMP was an extremely well-funded project, well received by growers and the industry and was clearly influential in the shift that has occurred in tree fruit pest management away from OP-based programmes. CAMP demonstrated that MD could substitute for some use of insecticides, but also emphasized that insecticides are still needed to maintain pest populations at low levels. The use of MD for CM has continued to grow since CAMP ended, and comprises nearly 75% of the production

area in Washington State (see Fig. 9.1). Today, with such a large proportion of orchards under MD, there are many contiguous areas treated with MD but, in general, these growers do not work together.

Developing and maintaining a coordinated approach is more difficult than having all growers in a region adopt a similar technology. For example, pear growers in Lake County adopted the use of an areawide grid of aerosol puffers for MD (Shorey and Gerber, 1996). The University of California Extension, with some support from CAMP, ran a demonstration programme for 3 years in this area, and this has been smoothly adopted by the local private consultants (PCAs). Today, these pear growers are on autopilot for control of CM, while the management of secondary pests varies widely among orchards (Elkins, 2002).

Few coordinated AWPM programmes exist today. Government support was necessary in organizing the 22 CAMP projects and it appears that in most regions there is not sufficient organizational structure for growers to maintain their own projects without government funding. Various factors caused projects to dissolve following the CAMP programme. Many projects were fragile, consisting of growers expressing a stereotypical American Wild-West 'go-it-alone' mentality. Projects such as Rogers Mesa in western Colorado were abandoned as growers switched production from apple to stone fruits. Howard Flat lost a large proportion of its tree fruit production due to poor economics and the steady usurpation of orchards by rural real estate development. Some projects were able to function for more than one year with CAMP funding or by obtaining additional government funding or working within funded research projects. Having a few large, contiguous blocks of orchards monitored by one PCA has allowed several large areas to continue under a centralized stewardship.

Other projects, where growers worked with multiple PCAs or sent their fruit to several cooperatives or packing houses, have tended to dissolve. Some such as Brewster were able to exist for a few years due to a combination of factors, such as stretching their use of CAMP funds, obtaining additional government funding, working with a government-funded research project and by forming a non-profit organization that could allocate participants a fee to fund a centralized monitoring and data dissemination programme. However, this project ended after 5 years due to poor farm economics and a lack of a strong and unified grower commitment to the project.

Today, only two of the original 22 CAMP projects remain: Ukiah Valley in California and Milton Freewater in Oregon. Ukiah Valley started in 1996 with a grant from EPA and then extended the 1-year CAMP funding in 1997 to fund a 3-year project headed by University of California Extension personnel. Pear growers farming 536 ha formed the non-profit Ukiah Pear Grower Association and continue to allocate growers a fee to hire a trap checker who monitors orchards and distributes information to all participants. Unfortunately, the cohesiveness of the project is threatened by both the reduced problems in managing CM and the emergence of new pests. The Milton Freewater growers organized themselves through the Blue Mountain Horticultural Society in 1998, and have maintained a coordinated project on nearly 1000 ha in north-eastern Oregon. Interestingly, not all growers use MD in the project. Growers are assessed at US\$45/ha to fund a monitoring programme. Data are e-mailed to all growers and the various warehouses in the district and are

posted on several bulletin boards within the project site. General information is exchanged, and the group's cohesion is maintained at weekly meetings held at the local extension office.

In summary, 7 years after the end of CAMP there remains a general lack of local coordination between growers' pest management activities, but there has been an exponential increase in the knowledge of how to implement MD (Brunner *et al.*, 2007). CAMP was followed by other, well-funded USDA projects, which achieved further improvements in MD and tested alternative, selective tactics to replace the use of OPs (Initiative for Future Agricultural and Food Systems, Risk Avoidance and Mitigation for Major Food Crops Systems, American Farmland Trust and Sustainable Agriculture Research and Education). Unfortunately, CM remains the number one pest problem for most growers and management programmes have become more expensive as they shifted from OPs to MD supported by a diversity of supplemental spray programmes using several new insecticides (see Table 9.1). The evolution of resistance to these new insecticides and their negative impacts on BC continue to be key concerns in implementing sustainable IPM programmes (Brunner *et al.*, 2005).

Epilogue

Several factors have contributed to the success of the CAMP programme (Coop *et al.*, 1999). These can be grouped into two categories: (i) operational – the availability of several effective and selective tactics for both the key and secondary pests backed by technical support; and (ii) organizational – well-funded, coordinated programmes directly involving growers, researchers, industry leaders and governmental administrators. The lesson learned from the CAMP programme is that pest management is similar to rocket science and requires attention, experience and skill to be effective (Knight, 1999). Dissemination of knowledge and coordination of actions by individual growers have been shown to improve pest management, and offer tremendous benefits to society. Future efforts should focus on how similar, grower-based organizations can be developed and sustained.

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