Management of Pests, including Alien Invasive Species, in Fruit Growing Regions of the Great Lakes and Pacific Northwest America and Canada

Main findings of a study tour part funded by
The Horticultural Development Company

Produced by
Jerry Cross
East Malling Research

Disclaimer

The results and conclusions in this report are based on an investigation conducted over a one year period. The conditions under which the experiments were carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

Contents

Introduction

In the late summer of 2012, HDC part funded Professor Jerry Cross of East Malling Research to conduct a study tour of fruit growing regions around the Great Lakes and Pacific North West of USA and Canada. The purpose of the tour was to meet fruit growers and scientists working in the fruit industry to learn more about a range of pest species and in particular gather research information about alien invasive pests which may pose a threat to production in the UK. This report provides an account of the information gathered on the Spotted Wing Drosophila and the Brown Marmorated Stink Bug.

Report summary

A five week study tour of pest management, including of alien invasive species, in fruit growing in the Great Lakes and Pacific Northwest of America and Canada was undertaken by Jerry Cross of EMR between 31 July and 8 September 2012. Fifteen research laboratories/sites and several experimental and commercial fruit farms and packhouses were visited in Michigan, Oregon, Washington, USA, and British Columbia, Canada (see Appendix). Discussions were held with over 90 researchers and advisors (see Appendix) on a very wide range of topics encompassing the full range from grower practice to latest research. This summary provides the main findings on the two most important alien invasive pests which threaten UK fruit growing, the Spotted Wing Drosophila (SWD) and the Brown Marmorated Stink Bug (BMSB).

During the course of the study tour, as more information was gained about SWD, the importance of monitoring for the presence of the pest became increasingly obvious to Jerry Cross, which prompted him to contact the EMR entomology team and request them to deploy monitoring traps in fruit crops at the East Malling Research Station. As a result, SWD was first found at EMR a few days later on 29 August 2012.

SWD is a highly damaging pest of a wide range of soft and stone fruit crops which spreads and can very rapidly build up in number. Females have a serrated ovipositor enabling them to lay eggs in fruit as it starts to ripen, unlike our native Drosophila species that can only lay eggs in overripe fruit. Larvae feed inside the fruit causing a rapid degradation in fruit quality, leaving infested fruit being unmarketable. Research and experience in the USA and Canada indicates that temperature and humidity conditions in UK soft fruit tunnels are probably ideal

for SWD. The fruit growing regions visited on the study tour have been badly affected and experience indicates that monitoring for adults and for larval infestation in fruit through the season in all susceptible crops is vital. Control is achieved in these areas of USA and Canada through programmes of sprays of organophosphate, synthetic pyrethroid and spinosyn insecticides, targeted against adults. Once egg laying females have been recorded, a 7 day programme of sprays of suitable insecticides is applied, starting from when the fruit starts to colour until the end of harvest, rotating insecticide groups to reduce the risk of resistance. If the right measures are universally implemented in the UK, then the pest will be controlled and not cause serious difficulties.

BMSB is also a very serious alien invasive pest of a wide range of fruit, vegetable and ornamental crops. In contrast to SWD, it spreads only slowly, having only one generation per season in the more northerly areas of the North American continent. Though it first arrived in the USA in the 1990s, it did not build up to become a really serious pest until 2010, when it caused serious losses in apple orchards in the mid-Atlantic States for the first time. It is gradually spreading north and westwards and has recently arrived in Oregon though it is not yet known to be present in the main apple and pear growing areas of the USA in Washington.

BMSB has a very wide host range. The adult and all nymph life stages cause damage by inserting their proboscis into plant tissues to feed. Damage does not immediately become visible. A very wide range of crops are damaged, apple and pear being highly vulnerable. It is also a serious public nuisance pest because it forms large overwintering aggregations in homes. Control of the pest is through full programmes of sprays of broad spectrum insecticides including organophosphates, carbamates, synthetic pyrethroids and neonicotinoids. Ten or more sprays including five or more active substances are commonly used in the mid-Atlantic States. Despite such programmes, 10% crop damage is frequently suffered. Intensive spraying with broad-spectrum insecticides is very damaging to natural enemies and serious difficulties with resistant secondary pests such as spider mites and pear sucker are provoked. BMSB is a much more serious pest than SWD as it is so difficult to control. Worryingly, BMSB was found in Switzerland in 2007 and it is probable that it will now gradually spread throughout continental Europe. Though it is not known how well it will thrive in continental Europe or the UK, it clearly poses a very serious potential threat.

Spotted Wing Drosophila (*Drosophila suzukii*) (SWD)

SWD is a recently-arrived, damaging alien invasive pest of soft fruit, stone fruit and grapes on the North American continent. Because of its importance to USA and Canadian fruit industries, it was the central focus of attention of growers, advisors and many of the applied entomologists in all the research labs visited. A large, and impressively well-resourced and co-ordinated research effort on SWD was on-going. The development of the pest had been a strong learning experience for all concerned in the places visited on the study. The main information gained from discussions with all concerned about the pest is summarised below.

Arrival and spread

A native of East Asia (Japan), SWD first arrived on the North American continent in 2008 in California (note it had been present in Hawai since 1980) almost certainly as larvae or pupae in infested fruit, though the exact origin and mode of entry is unknown. By 2009, its distribution had extended over all the Pacific Ocean bordering states of the USA and probably into British Columbia, Canada and into Florida. In 2010 and 2011, the known distribution extended to most states of the USA and Canada where susceptible fruit crops are grown. The rate of spread of SWD was thus exceptionally rapid. Whilst it is known that SWD adults can actively disperse over 4 km per day by flight, passive spread in fruit traded from California and possibly hitch-hiking by adults in vehicles played a major role in its very rapid spread.

The same rapid spread has occurred in continental Europe and the UK. SWD was first found in Spain in 2008 extending to southern France and Italy in 2009. In 2010 it was found over most of central and southern continental Europe though it was not found in more northern European countries (N France, Germany) until 2012. It is not known for certain when it first arrived in the UK (possibly in 2011) because no monitoring programme for it had been instigated. The vital importance of a monitoring programme was highlighted by the USA and Canadian experiences and in the third week of the study tour an urgent email was sent to the entomological team at EMR requesting SWD monitoring traps to be deployed in susceptible crops on the research station. This was done and a few days later on 29 August 2012, Adrian Harris recorded the first catch of SWD in the UK.

Crops attacked and wild hosts

Blackberry, blackcurrant, blueberry, cherry, plum, raspberry, redcurrant, strawberry and table grapes are all very vulnerable to SWD. Skin thickness/toughness is an important factor in susceptibility, soft fruits with thin skins being most vulnerable. Apricot, elderberry, gooseberry and peach with intact skins can be susceptible but for other crops with thicker tough skins (apple, pear, tomato, wine grapes) attacks only occur to fruit with split skins or where fruits are overripe.

SWD has many wild host plants and these are a primary refuge of the pest and source of infestation for crops. Wild blackberry was considered to be a most important wild host but a systematic search for wild hosts showed that SWD larvae can be found in the berries of a very wide range of wild and garden plants including wild cherry, dogwood, elderberry, honeysuckle, Mahonia, mountain ash, mulberry, nightshade, wild raspberry, rose and snowberry. In a systematic search for wild hosts in British Columbia in 2010 and 2011, SWD had not been found in asparagus (16 samples), Berberis (26 samples), Cotoneaster (16 samples), hawthorn (23 samples), privet (10 samples), rose (66 samples) or saskatoon (*Amelanchier alnifolia*) (41 samples). However, this clearly does not mean they are definitely not hosts plants. It is possible that some hosts are only attacked when the berries are very ripe and relatively soft.

Apart from wild berries, adult SWD feed on a wide range of sugar sources and these are vital for survival early in the season before berries become available. SWD had been found in abundance on flowering English holly early in the season on the campus at Corvallis (OR) and adults had also been found high in forest trees feeding on aphid and scale insect honeydew in Washington.

Crop damage

The presence of eggs, larvae or pupae in fruits or damage caused by these, was severely undesirable, even in a small proportion of fruits, and was not tolerated in the market. The filaments of eggs can be visible on the surface of some fruits (blueberry, cherry). Oviposition, spotting and scarring also occurs on the fruit surface, which collapses at the scarring site after 2-3 days. Larvae feeding under the skin cause softening and bruising. Infested fruit liquefy and small white larvae are found inside.

Identification

Sound identification of SWD posed problems to growers who therefore relied on local entomological services, at least for confirmation. Many small flying insects have wing spots (including tephritid fruit flies that are important pests of many soft fruit in North America and continental Europe). It is important to ensure that specimens are in the genus *Drosophila* (small flies, typically pale yellow - reddish brown - black, with red eyes and with a plumose arista - diagnostic character a small, branched modified sub-apical bristle arising from the 3rd antennal segment). Wing venation and the presence of wing spot (males only) are also important characteristics, as well as the particular form of two black groups of setae (sex combs) on the tarsi of males. The presence of these in their characteristic pattern together with the wing spots and venation are diagnostic for males. For females, wing venation and the large sickle shaped, serrated ovipositor are diagnostic but note that other *Drosophila* sp. common in the UK also have partially toothed, sickle shaped ovipositors. Useful keys for entomologists for identifying SWD and distinguishing it from other similar flies were obtained.

In the entomology labs visited, at least one assistant entomologist was dedicated to identifying SWD. Such individuals were proficient due to the high exposure and handling of material. The dedication to the job is important for efficient working.

Drosophila larvae can be distinguished by several morphological characters, the most important of which is the presence of 3 pairs of fleshy protuberances on their terminal segment. Larvae of SWD cannot be distinguished from larvae of other *Drosophila* sp. and have to be reared to adult for identification. However, it should be noted that there is a high probability that *Drosophila* larvae in fruits collected from the plant and not from in contact with the ground will be SWD. Fruits collected in contact with the ground can be infested with SWD but are often infested by other *Drosophila* sp. which are more competitive in fruits in contact with the soil. The *Drosophila* sp. most likely to occur in UK fruit crops, in probable order of abundance are *D. melanogaster, D. immigrans, D. hydei, D. subobscura* and *D. obscura.*

SWD eggs have a characteristic long pair of breathing tubes on one end that protrude from the fruits and the form of these is diagnostic. Pupae are also distinctive with two large prominent anterior breathing tubes with a distinctive whorl of hairs round the rim of each.

Life cycle and effects of temperature and humidity on development and oviposition

SWD has the typical classical development cycle of a fly with adult, egg, 3 larval instar and pupal stages. The sex ratio is 1:1 but the longevity of males is shorter than females which skews the sex ratio to female in the field. Males sit on ripe fruit waiting for females to arrive. Mating occurs after a short courtship dance. Males flash their wings and hoot at females. Multiple matings occur. In summer, adults have a longevity of 20-30 days each, laying up to 350 eggs on average, with 1-3 eggs per oviposition site. Eggs hatch after 12-72 hours, depending on temperature and the three larval instars are completed in 5-7 days. Pupation takes 4-15 days again depending on temperature. The whole development from egg to adult takes 8-14 days per generation at optimum temperatures, though development can be protracted at low temperatures. Thus SWD can have numerous (>10) generations per annum in temperate climates if temperature conditions are ideal. The high reproductive rate would lead to an enormous rate of population increase if food sources and climatic conditions were unlimited.

As with all insects, the rate of development of SWD is greatly affected by temperature. The relationship between rate of development of SWD on artificial diet had been determined by Oregon State University (OSU). The relationship showed a strong curvilinear pattern with no development below 10 °C or above 30 °C and a maximum rate at 27.5 °C. The OSU data was broadly similar, though not identical, to that determined in Japan (Kanzawa, 1953). Very useful data on development times (in days) of SWD from egg to adult on cherry and blueberry fruit was obtained from Corvallis, OSU (S Tochen and V. Walton in prep.) is summarised as follows:

Temperature (°C)	Days on cherry	Days on blueberry
10	79± 7.1	78±5.6
14	29 ± 2.2	28±2.5
18	18 ± 1.5	20±1.3
22	14± 0.9	14±1
26	11 ± 1	11±1
28	10 ± 1	10±1
30	12 ± 1	11±1

Excellent data on the relationship between oviposition rate and temperature on cherry and blueberry has also been obtained from OSU, Corvallis. On cherries, a strong peak in the rate of oviposition was found at 18 °C with no oviposition at 10 °C and 30 °C. On blueberries, the trends and limits were the same but the peak rate was at 22 °C but rates varied less with temperature and were similar at 18 °C. In any event, the peak temperature for oviposition was found to be 6-8 °C lower than the temperature for the peak rate for development. Note that despite development at 10 and 30 °C no oviposition occurs at these temperatures.

Humidity also appears to have important influences on SWD, especially at higher temperatures. SWD appears to thrive better at higher humidities in arid climates. The effects of humidity on survival and longevity does not appear to have been quantified, though doing so would probably constitute an important advance in understanding SWD population dynamics.

In short, the data on the effects of temperature on SWD development indicate that the UK climate is ideal for SWD population development throughout much of the year. Conditions in tunnels are likely to be especially favourable, and will provide conditions where SWD can breed and thrive throughout the spring, summer and autumn. SWD development and population increase is only likely to cease, in winter, in the UK.

Overwintering and seasonal dynamics

In temperate regions, SWD overwinters in the adult stage, predominantly as females though some males overwinter. It is not known whether the overwintering adults are quiescent or in diapause. Some other *Drosophila* sp. overwinter as adults in diapause. It is not known whether SWD can overwinter in other life stages, e.g. in the pupal stage. Attempts in Summerland, BC, to capture adults emerging from the soil from under fruit crops using emergence cages which had been heavily infested the previous year had been unsuccessful. However, even very large cages would not prove conclusively that SWD does not emerge form soil in spring, it being impossible to prove a negative. The place(s) of overwintering are unknown but could include buildings in urban areas and/or natural shelter e.g. in forests. Comprehensive laboratory studies by Dalton et al. (2011) exploring the effects of prolonged cold temperatures on SWD survival and oviposition indicate that in constant temperature conditions in the laboratory, SWD cannot survive beyond 85 days at 10 °C, with progressively shorter durations of survival at lower temperatures, such that at 1 °C none survive beyond 18 days. On this basis, SWD would not be able to survive in northern temperate regions as temperatures are well below 10 °C for much greater than 85 days in the winter. However, the fact that SWD thrives in the northern part of the North American continent (e.g. British Columbia) where prolonged periods of cold occur in winter indicates that SWD overwinter in places where they can escape the cold. It is likely that they are able to find shelter in either urban or natural environments. An excellent experiment illustrating the way SWD can survive the winter in various urban domestic environments examined the survival of SWD adults held in cages in an attic in a domestic house, versus in a greenhouse, a garden shed or kitchen in the Willamette valley, Oregon. Adults in the loft survived up to 158 days (Tochen et al., in press). OSU Corvallis also derived an overwintering chilling mortality model which predicts the effects of chilling on mortality when SWD has no chilling refuges. A threshold temperature of 11.7 °C gave the best fit for chilling day –degrees below the threshold. The model predicts 20%, 50%, 90% and 99% mort after 31, 61, 151 and 359 day degrees below 11.7 °C (Walton et al., in prep.).

In any event, very high winter mortality occurs: populations that reach high levels in late summer and autumn are reduced to very low levels during winter. Monitoring through the winter in Hood River, Oregon, showed that adults fly in mild periods during the winter and are captured in monitoring traps (P Shearer, pers. comm.). It is probable that the pattern of alternating periods of cold and milder winter weather determine the degree of winter mortality. It seems improbable that SWD adults that emerge in mild periods in January for example, can re-find protected overwintering sites to survive subsequent below zero cold periods in February and March, though a small proportion of them may. It seems likely that only a proportion of overwintering adults actually emerge during mild winter periods.

In any event, the degree of winter survival affects the time by which populations have increased to sufficient levels to be detected in monitoring traps in spring, and thus the time when control measures have to be started.

SWD is quiescent or in reproductive diapause during the winter. Females predominate but do not contain viable eggs over the winter period (November – March/April). Beverly Gerdeman, Entomologist, Mount Vernon, WA, has closely studied ovarian development and had developed excellent skills for dissecting SWD adults and determining their reproductive state. She had distinguished five ovarian development stages: 1) no distinguishable ovrarioles; 2) with distinguishable ovrarioles; 3) with ovrarioles, eggs large proximally but with no filaments; 4) ovaries mature, eggs with filaments; 5) ovaries with few mature eggs, without developing eggs (note that mature eggs are often wrinkled). An ‘ovrariole’ is one of the tubes from which ovaries are composed. The reproductive state of flies was monitored through the season, and the information was used to refine advice given on timing of spraying.

The timing of detection and when control measures have to be started clearly vary considerably from season to season and between locations. In four fruit producing regions in the interior valleys of British Columbia (North Okanagen, South Okanagen, Similkameen, Creston) first trap catches occurred in early July in 2010 and reached a mean peak of 10 adults per trap per week. In 2011, the first catches were in mid-August and only reached a mean peak of <5 per trap per week. Spraying to protect against SWD needed to be started some 5 weeks later in 2011 than in 2010.

Monitoring adults and larvae

Experience from the USA and Canada indicates that monitoring for the adults and larvae on soft and stone fruit farms is vital. For adults, the time and severity of attack varies greatly from year to year and regionally and locally, and the time of appearance of first adults indicates when programmes of preventive treatments must be started. Both males and females need to be monitored because females often appear first and it is also necessary to check samples of females to determine whether they contain eggs, especially early in the season. Monitoring for larvae, eggs and damage is also vital to ensure infested fruit is not sent to market.

The commonly used adult monitoring trap consists of a 950 ml clear plastic Delhi cup with ten 5 mm holes in an equi-spaced ring round the circumference about 3 cm from the rim. The cup contains 2-3 cm of real apple cider vinegar (changed weekly) plus a drop of unscented washing up detergent to break the surface tension so that adults are not able to settle on the surface without sinking. The advantages of this design are low cost, ease of use, simplicity and ready availability of materials. The disadvantages are low sensitivity and the requirement of adults to be removed from the cider vinegar for identification.

An excellent collaborative programme of testing of trap designs and baits in Michigan, North Carolina and Oregon in 2012 showed that fermenting/fermented baker's yeast + sugar is far more attractive than apple cider vinegar, that inclusion of a yellow sticky card marginally improves catches and possibly makes trap monitoring easier, that minimising distance between liquid surface and holes and improving the entry area greatly increases catches and sensitivity. Dangers are that larger holes increase non-target bicatch and that yellow sticky card damages specimens and makes storage of samples more difficult. Traps are not selective for SWD. Only <30% of *Drosophila* adults captured in the traps were SWD.

Based on this work, the entomology team at East Malling Research have proposed a new standard adult monitoring trap for use in the UK. It consists of a bait cup containing 2-3 cm of fermenting yeast/sugar water (changed weekly) below a trap chamber with fifty 5 mm diameter holes in the side to allow entry of adults and fifty 1 mm diameter holes in the base from which the volatiles from the bait enter the chamber which contains a 10 x 8 cm double sided yellow dry sticky card (1/6 of a 20 x 24 cm card from Agralan). The body of the trap is made from parts of two 2 l plastic drinks bottles. The main important and unique feature of this design is the separation of the bait cup from the trap chamber so that flies do not fall into the bait and so that the card does not get contaminated by the bait. The bait recipe is 60 ml (20.5 g; 4 tbs) dry baker's yeast (*Saccharomyces cerevisiae*) + 240 ml (214 g; 16 tbs) white sugar + 1420 ml (2.5 pts) water. If drowning of the SWD adults in the bait is desired, 1.5 ml (3 drops) of unscented dishwashing detergent should be added. The bait should be changed weekly. Salt can be added in winter to prevent freezing.

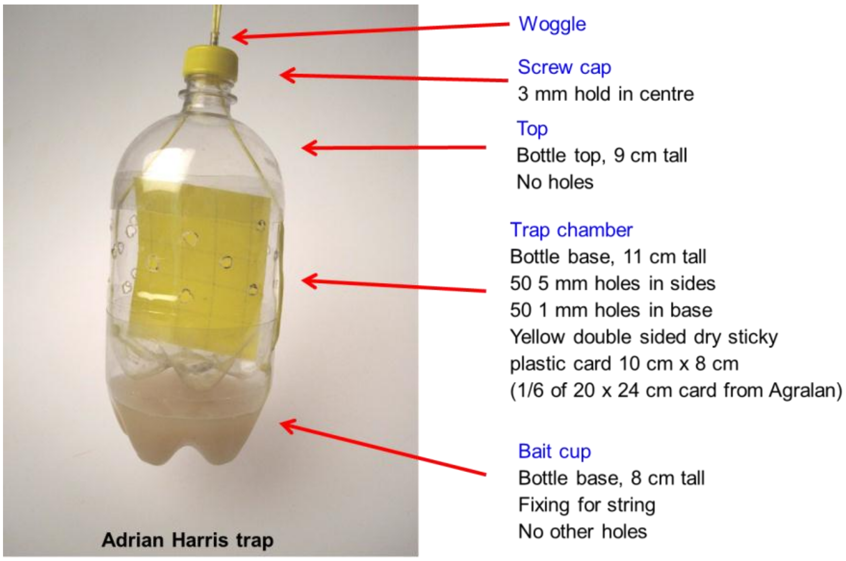

Figure. Adult SWD monitoring trap designed by Adrian Harris, East Malling Research. The trap's unique and important design feature is the separate trap chamber where the sticky card is held. This design prevents adults from entering the liquid bait and also ensures that the card does not become contaminated with bait.

Sampling and examination of fruit for signs of damage and for infestation by SWD is vital to ensure that damaged or infested fruit is not sent to market. Sending infested fruit to market could have serious financial and reputational consequences for the grower or packhouse concerned, and the whole industry.

An understanding of the relationship between sample size and the likelihood that an infested fruit will be detected with varying degrees of confidence and how that is affected by the efficacy of the sampler, is important for determining the appropriate sample size and guiding the process of sampling. The importance of the efficacy of detection of the sampler is illustrated.

The statistics of sampling are well known. When the lot size is sufficiently large (there are usually very large numbers of berries in a plantation) and mixed, the likelihood of finding an infested unit is approximated by simple binomial statistics. The hypergeometric distribution is appropriate for small lots. Sample sizes for 95% and 99% confidence at varying levels of detection and efficacies of detection (lot size large and mixed, binomial distribution) are given in the table below

% efficacy of sampler	P = 95% (confidence level) % level of detection					P = 99% (confidence level) % level of detection				
	5	2	1	0.5	0.1	5	2	1	0.5	0.1
100	59	149	299	598	2995	90	228	459	919	4603
99	60	150	302	604	3025	91	231	463	929	4650
95	62	157	314	630	3152	95	241	483	968	4846
90	66	165	332	665	3328	101	254	510	1022	5115
85	69	175	351	704	3523	107	269	540	1082	5416
80	74	186	373	748	3744	113	286	574	1149	5755
75	79	199	398	798	3993	121	305	612	1226	6138
50	119	299	598	1197	5990	182	459	919	1840	9209
25	239	598	1197	2396	11982	367	919	1840	3682	18419
10	598	1497	2995	5990	29956	919	2301	4603	9209	46050

A sample of 600 fruits is needed to ensure <1% of fruits are infested with 95% confidence if the efficacy of detection is 50% (see underlined values in the table). This would seem a reasonable standard for the UK industry to adopt.

Pre-picking crop sampling did not appear to be done in any of the areas visited on the study tour. However, for high value UK soft fruit crops, it would be good practice if samples were taken weekly from all plantations at risk. At least 100 of the most mature ripe fruits should be selected from a transect across the crop, covering the edges of plantations (near wild hosts/infested crops). Fruits should be selected from the lower centres of the plant where the chance of infestation occurring is greatest. Sampling fruit in contact with the ground should be avoided if possible, as there is a higher chance that these will be infested with other *Drosophila* sp.

Post picking sampling of fruit to monitor for SWD damage or infestation (outside the packhouse but with further monitoring inside in some instances) was standard practice and part of routine quality control procedures in the fruit growing regions visited. The sample size was somewhat haphazard in some instances, e.g. comprising a jug of berries scooped from the tops of a few trays or bins. Ideally, at least 600 fruits would be sampled from top of multiple trays, before the fruit enters the packhouse. In the USA/Canada, consignments were either rejected or consigned for juice if significant damage or SWD larvae were found.

Samples were closely examined for damage or infestation with eggs, larvae or pupae. Fruit was transferred to shallow trays and larvae extracted by immersion in sugar water in which they exit the fruit and float to the surface. Salt was used in some labs but this affected the survival of larvae if they had to be reared to adult for confirmation of identity. The concentration used was at least 170 g sugar per litre water (15 °Brix). If foaming occurred, the surface was hand squirted (sprayed) with a spray tank defoamer. The fruit was added to the sugar water, stirred, left to settle for 10 minutes, stirred again, the surface spritzed with defoamer, and the larvae counted 10 minutes later.

The consensus amongst the US and Canadian scientists was that pre-extraction crushing of fruit improved the efficacy of SWD extraction by flotation. No systematic data comparing the efficacy of extraction with versus without pre-crushing was obtained and whether or not crushing was done in commercial practice was variable. Pre-extraction crushing of cherries was standard practice in Oregon, a powerful electric motor driven crusher with a hopper being used as standard practice. This practice had been instigated prior to the advent of SWD, for detection of cherry fruit fly larvae, a quarantine pest in several countries to which cherries were exported. In Michigan, a large blueberry grading and packhouse was visited where the blueberries were forced through a coarse sieve prior to flotation extraction but in the Fraser valley BC, extraction from blueberries was done without pre-crushing. In the Michigan State University lab, pre-crushing of raspberries was standard practice and found to be effective. Research is needed to investigate the methods and efficacy of pre-extraction crushing for different susceptible fruits so that standard practices appropriate for the UK can be determined. In the meanwhile, crushing should be done where practical, by coarse sieving or gentle mashing, taking care to minimise the risk of killing larvae.

Natural enemies

Parasitoids appear to be the most important natural enemies of SWD. The larval parasitoids *Ganaspis xanthopoda* (Figitidae) and *Ascobara japonica* (Braconidae) cause significant mortality in Asia. These parasitoids do not occur in North America or Europe. The pest has arrived without its key natural enemies, which has significantly worsened its impact. The obvious answer might be to import these two species from Japan to regulate SWD populations, but this would require licenses, which would require extensive data on the host range and impact of the species on other *Drosophila* and possible hosts. Such studies would be costly and difficult to conduct and licences very difficult to obtain. Parasitoids are very well studied in *D. melanogaster* and other native *Drosophila* sp. The two most common native larval parasitoids of native *Drosophila* sp. are *Asobara tabida* (Braconidae) and *Leptopilina heterotoma* (Figitidae) but studies at CNRS, France indicate these species do not attack SWD.

The pupal parasitoid, *Pachycrepoideus vindemmiae* (Pteromalidae) was first reared from SWD at Agriculture and Agri-Food Canada, Summerland in 2010. It is being studied as a possible biocontrol agent for SWD at several of the labs visited in USA and Canada. The parasitoid is easy to rear on SWD and several labs had good cultures. In lab cultures, *P. vindemmiae* can give very high levels of parasitism of SWD, but in the field natural levels of parasitism are much lower. Eggs are laid on the outside of pupae (ectoparasioid). Its generation time in the lab is about a month so it can have multiple generations per year if suitable hosts are available. The longevity of adults is about 6 weeks, egg laying commencing about 1 week after emergence. It has a broad host range on Diptera including on common flies like *Musca domestica*. Its efficacy as a parasitoid of SWD may be limited by poor host availability early in the season when SWD populations are generally very low. Ways of overcoming this problem (e.g. by providing alternative hosts) were being investigated. Sentinel traps baited with SWD infested fruits were being used to explore natural parasitism rates and to seek other parasitoid species.

SWD are known to be predated by *Orius* sp. and by *Atheta* ground beetles though the impact of these on SWD populations was considered to probably be small.

Hygiene and sanitation

Hygiene and sanitation are clearly important for minimising attacks from SWD. If waste fruit is not removed from the plantation or is disposed of carelessly, if could be a source of large numbers of SWD. Ideally all overripe, damaged, infested or dropped fruit would be meticulously removed from plantations and eliminated as a source of infestation.

In the fruit growing regions visited on the study tour, advice and advisory literature advised against open disposal or open composting of fruit as this would potentially be a serious source of infestation. SWD can easily multiply in and emerge from fruit that is below critical temperatures in compost piles, so open composting was not advised. The fact that SWD development may be accelerated in warm areas of the pile was recognised.

It was recommended that waste fruit should be disposed of in a way that will keep SWD from feeding on it or from hatching from it. SWD will continue multiplying in cull fruit, so it was recommended that it should be removed from the field and destroyed. Burying to a minimum depth of two feet (> 0.6 m) deep is recommended, as shallow burial has been shown to be unsatisfactory. Crushing the fruit does not hamper SWD emergence from it. Research in Oregon has found that sealing fruit in plastic bags or on the ground with plastic and then solarising it by exposing it to full sun for at least a week kills all eggs and larvae.

However, there was little evidence of these stringent hygiene and sanitation measures being implemented in practice on farms visited in the USA or BC during the study tour. The high costs of meticulous removal of all fruit from plantations (e.g. of blueberries or raspberries that had fallen to the ground during mechanical harvesting) meant that these practices could not be implemented. In Oregon, harvesting of fruit from a partially picked cherry orchard was terminated because of SWD infestation. The crop was abandoned on the tree and not harvested, so becoming very heavily infested with SWD and a source of the pest for other crops.

Effective disposal methods include freezing (Individually Quick Frozen), cooking, juicing, drying and anaerobic digestion, but these would be difficult to implement on a large scale on most farms as equipment and facilities for doing so are not available.

Mass trapping

Unlike in southern Europe, mass trapping was not practiced in the areas of the USA or Canada visited on the study tour and no work investigating it directly was mentioned. Work to develop synthetic lures for SWD was on-going in several labs with some progress being made. An excellent programme of work investigating trap design for monitoring was in progress.

Control with insecticides

SWD is principally controlled with insecticides in fruit crops in the USA and Canada. Insecticide sprays were applied to prevent egg laying in fruit because once eggs and larvae are in fruit, there is little chance of control. This highlights the need for adulticides with residual activity on the surfaces of fruit to kill or repel SWD adults that alight on the fruit. The main insecticides used were OPs (azinphos-methyl, chlorpyrifos, diazinon, dimethoate, malathion, phosmet), some carbamates (methomyl, carbaryl, not pirimicarb), synthetic pyrethroids (cypermethrin, deltamethrin, lambda-cyhalothrin) and spinosyns (spinosad, spinetoram). These materials gave 5-7 days protection so programmes of multiple applications are needed from the time the SWD attack starts to the end of harvesting. Neonicotinoid insecticides (acetamiprid, imidacloprid, thiacloprid, thiamethoxam) were considered to have limited adulticide activity but may control larvae. Excellent field-lab insecticide efficacy bioassays were being used to quantify the efficacy and persistence of insecticides on different field crops. Insecticides were applied in the field to the target crop and samples of shoots bearing fruits were brought into the lab at various intervals after treatment where they were held in individual beakers and exposed to ovipositing females. The effects of in-field plant growth and weathering on the efficacy of the residual deposit were therefore determined over time.

Pyrethrins and spinosad were the only insecticides that could be used for SWD control in organic crops. Pyrethrins had no residual activity. Growing soft fruit crops organically had been made much more challenging by SWD and advisors considered the future of the organic soft fruit industry to be bleak.

Pesticide application for SWD

Most insecticide sprays for SWD were applied with the growers' normal air-assisted fruit sprayers. However, non-air-assisted boom sprayers were also commonly used in blueberry and strawberry crops because application could be made very rapidly. No scientific work comparing the efficacy of air-assisted versus non-air assisted applications for SWD was mentioned.

An impressive co-ordinated programme of research to investigate application of pesticides by chemigation was on-going in the USA including on soft fruit (raspberries and blueberries) at Mount Vernon, Washington, and on tree fruits at Sunrise Orchard, Wenatchee and at the Trevor Nicholls Research Centre, Fennville, Michigan. Chemigation is normally defined as the application of water soluble agrochemicals through an 'irrigation' system. Pesticides and system maintenance compounds are applied through a fixed grid of pipework, through nozzles or drippers.

The research mainly focussed on the application through a spray nozzle system, above and/or in the crops. One of the big difficulties of chemigation systems is the high volumes of spray liquid that remains in the pipes after the applications are made. An important innovation was the use of a pressure valve in the pipeline just before each nozzle which only allowed spray to be emitted from the nozzle when the pressure was above a certain threshold (e.g. 10 bar). Sprays were applied at high pressure (e.g. 30 bar) and air was used at low pressure (< 10 bar) to purge the spray in the pipework system and recover unused spray after spraying. An acre could easily be sprayed in 10 minutes. At Sunrise Orchard, a system was being tested on cherry for SWD control. Medium to coarse impact nozzles were deployed at two heights in the crop, at the top and at middle height. At Mount Vernon, an experimental raspberry polytunnel had been furnished with very fine mist nozzles, two from each hoop of the tunnel. Obtaining adequate uniformity of spray deposit distribution is the main challenge for application by chemigation and the systems seen would not give good cover on the undersides of leaves or on fruits sheltered under leaves. The dual pressure system allowing air purging avoids waste in pipes and appeared rapid and easy to use. Dosing precision was claimed to be good. Chemigation could be good for application of pesticides for SWD control in tunnels. It would be an attractive proposition for tunnels in fixed positions (e.g. table tops). In the USA, pesticide approval for a different method of application is needed and few pesticides had such approval. It is suspected that this could also be a requirement for pesticides in the UK and could be a significant barrier to this method of application.

Research was also ongoing at Mount Vernon in the use of low level irrigation dripper systems to apply pesticides to the soil in blueberries. Neonicotinoids (thiamethoxam, imidacloprid) were being investigated for control of SWD. The big challenge is lateral uniformity of soil distribution. This approach would only be suitable for highly systemic soil applied insecticides and few if any of these are available. The precision of dosing is low, purging not possible and there is high waste in pipes. Approval for this method of application for pesticides is unlikely in UK, but it could be useful for nematodes for control of soil pests, e.g. vine weevil.

Disruption of Integrated Pest Management (IPM)

Many of the broad spectrum pesticides that will have to be applied for SWD control in the UK (chlorpyrifos, deltamethrin, lambda-cyhalothrin) are persistently harmful to the phytoseiid predatory mites *Amblyseius (=Neoseiulus) cucumeris* and *Phytoseiulus persimilis* that are routinely used for two spotted spider mite (TSSM), tarsonemid mite and western flower thrips (WFT) control in UK fruit crops. IPM will be seriously disrupted and major problems with TSSM, tarsonemid, WFT will be provoked. Early season control of these with Biological Control Agents before SWD spray programmes have to start is vital.

Insecticide resistance

Long experience with *Drosophila melanogaster* indicates even occasional exposure of lab colonies to insecticides induces resistance. Every spray application in the field is a massive selection event. Only three chemical groups (OPs, SPs, spinosyns) are available for SWD control and there is a high chance that insecticide resistance will develop. To date none has been reported from the areas visited during the study tour but exposure has only been for two seasons.

The existence of large susceptible populations in wild refuges (blackberry) helps to mitigate risk, presenting the dilemma of whether such refuges close to commercial crops should be tolerated or not. To minimise the risk of resistance developing, the use of non-pesticidal methods should be maximised and use of the different insecticide groups rotated. Establishment of baseline susceptibilities, monitoring of susceptibility and genetic studies are needed. Four labs in the USA were working to develop base-line response parameters including lethal concentrations and potency. Female flies were exposed under a Potter tower. LD50 values for spinetoram varied between 12 and 25 ppm for 3 populations collected from different locations (Shearer and Brown, OSU).

Being prepared for SWD

An Early Detection – Rapid Response strategy was advised to growers for commercial management of SWD. Co-ordinated monitoring programmes were in place in all fruit growing regions with growers being notified of risks and attacks by web site and electronic alerts.

Brown Marmorated Stink Bug

Brown Marmorated Stink Bug (BMSB) (*Halyomorpha halys* (Stål) (Hemiptera - Pentatomidae)) is a very serious alien invasive pest of a wide range of crops including tree and soft fruits in the USA.

Arrival and spread

A native of SE Asia (China, Korea, Taiwan), BMSB is estimated to have been inadvertently introduced into USA in 1996 though it was first properly identified in Allentown, Pennsylvania in 2001. Though it is a strong flier it is a pest that spreads relatively slowly with only 1-2 generations per year, depending on latitude. The number of generations is much lower and the rate of spread is much slower than that of SWD. Passive spread by hitch hiking is considered to be a major route of spread in the USA, first findings in new localities often being close to public transport hubs. By 2004 it was confirmed in the mid-Atlantic states of New Jersey, Maryland, West Virginia, Virginia and in 2008 the first serious damage was noticed in orchards. Serious losses occurred in orchards in 2010 and by 2011 it was present in 35 states. At the time of the study tour, it had recently arrived in Oregon, but had not been recorded in Washington (either Wenatchee or Yakima), Michigan or British Columbia.

Worryingly, BMSB was found in Switzerland in 2007 and it is probable that it will now gradually spread throughout continental Europe.

Crops attacked and host range

All crops and numerous wild hosts are susceptible to BMSB. It is highly damaging to a wide range of fruit, vegetable and ornamental crops including apples, cherry, green beans, soybeans, peaches, pears and raspberries. Particularly favoured hosts include the Tree of Heaven (*Ailanthus altissima*) and the Princess Tree (*Paulownia tomentosa*). *A. altissima* was a common and abundant weed species in Oregon. A group of trees near the railway station in Hood River, Oregon, were heavily infested with all life stages being present. The bugs were particularly abundant amongst the flowers/seed clusters.

Pest status and damage

BMSB is a large sucking insect, a true bug that uses its proboscis to pierce its host plant in order to feed. This feeding results in the formation of dimpled or necrotic areas on the outer surface of fruits, leaf stippling, seed loss, and possible transmission of plant pathogens. Brown necrotic patches develop inside fruit. The damage is not immediately apparent, developing over a period after the feeding occurs. In 2010 it is estimated to have caused $35 million in losses in orchards, despite heavy programmes of sprays of broad-spectrum insecticides.

Though it is not known how well BMSB will thrive in continental Europe or the UK, it clearly poses a very serious threat.

BMSB becomes a nuisance pest both indoors and out when it is attracted to the outside of houses on warm autumn days in search of protected, overwintering sites. Aggregation of many thousands of individuals can occur. BMSB occasionally reappears during warmer sunny periods throughout the winter, and again as it emerges in the spring. The bug survives the winter as an adult by entering houses and structures when autumn evenings become colder. Adults can live from several months to a year. They will enter under eves, into soffits, around window and door frames, or any space which has openings big enough to fit through. Once inside the house, they will go into a state of hibernation. They wait for winter to pass, but often the warmth inside the house causes them to become active, and they may fly clumsily around light fixtures.

Life cycle and biology

BMSB probably has a single generation per year in the more northern states of the USA, feeding starting in May or June, depending on temperatures. Warm spring and summer conditions could permit the development of two generations. However, in parts of sub-tropical China, records indicate from four to possibly six generations per year. Adults will emerge sometime in the spring of the year (late April to mid-May), and mate and deposit eggs from May through until August. The eggs hatch into small black and red nymphs that go through five moults. Adults begin to search for overwintering sites starting in September through to the first half of October.

BMSB can emit a pungent odour through pores in its abdomen, a defence mechanism to prevent it from being eaten by predators such as birds and lizards. However, simply handling the bug, injuring it, or attempting to move it can trigger it to release the odour. The odour from the stink bug is due to the volatile compounds trans-2-decenal and trans-2-Octenal. The smell has been characterized as a pungent odour that smells like cilantro.

Control with insecticides

BMSB is much more difficult to control with insecticides than SWD. In the mid-Atlantic states where BMSB is well established, full programmes of sprays of broad-spectrum OPs (azinphos-methyl), carbamates (methomyl), synthetic pyrethroids (bifenthrin, cypremethrin, fenpropathrin) and certain neonicotinoids (clothianidin, thiamethoxam), comprising 10-15 insecticide sprays are typically applied per season, and damage still sometimes exceeds 10%. More selective insecticides (e.g. chlorantraniliprole, indoxacarb) and spinosyns are ineffective.

Disruption of IPM

The heavy programmes of sprays of broad spectrum insecticides are completely deleterious to natural enemies and biocontrol agents and serious difficulties with resistant secondary pests such as spider mites and pear sucker are provoked. It poses a very serious threat to the pome fruit growing industry in Washington state.

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Appendix

Summary of Itinerary	
Day/Date	**Activities**
Tuesday Jul 31	Fly Heathrow to Lansing Michigan US via Chicago
Wednesday Aug 1	Host Rufus Isaacs, MSU. Travel west with Rufus Isaacs to MI fruit growing areas. Visit True Blue blueberry grading and packing facility (Shelly Hartman) and Trevor Nichols Research Centre, Fenville. Discussions with John Wise, Director. Toured research plots. Return to Lansing. Discussions with Annemiek Schilder and Mark Whalon (Pesticides Alternatives lab)
Thursday Aug 2	Visit blueberry farms and processing facilities. Discussions with David Trinka, Blueberry marketing Group. Visited research trials.
Friday Aug 3	Visited MSU campus labs including Doug Landis lab, Larry Gut Lab, Rufus Isaacs lab, Mark Whalon Lab. Gave seminar. Discussions with Ben Worley, Christie Bali, Meghan Waltz, Brett Blaauw, Juan Huang, George Sudin and Ernest Delfosee (MSU Principal)
Saturday 4 Aug	Fly Lansing MI to Portland OR via Chicago Pick up hire car 1 and drive to Hood River, OR.
Monday 6 Aug	Visit Mid-Columbia Agricultural Research and Extension Centre, Oregon State University, Hood River, OR. Hosts Peter Shearer and Steve Castagnoli. Discussions with Kaushi Sekare, Preston Brown
Tuesday 7 Aug	Visit Oregon State University and USDA, Corvallis. Hosted by Vaughn Walton. Visited Louis Brown Farm (nut germplasm repository). Visited 'Nut House'. Discussions with David Smith and Becky Mclusky.
Wednesday 8 Aug	Visits to Vaughn Walton lab. Discussions with Sam Tochen, Nick Mills, Jimmy Click, Dani Lightte, Jana Lee, Nick Wyman, Jeff Miller
Thursday 9 Aug Friday 10 Aug	Discussions with Ramesh (beekeeping). Depart Corvallis and drive to Washington State University, Mount Vernon Research & Extension Centre, Mount Vernon, WA. Host Lynell Tanigoshi. Discussions and training session with Beverley Gerdeman. Visit research plots and chemigation trials.

Saturday 11 Aug	Depart Mt Vernon and drive to Leavenworth
Sunday 12 Aug	Drive to Wenatchee
Monday 13 Aug	Visit Washington State University, Tree Fruit Research and Extension Centre, Wenatchee. Hosts Betsy Beers and Kate Evans. Discussions with Jay Brunner. Visit Stemilt grading line (Jim Nelson) with Betsy Beers and Eugene Kupferman. Visited pome fruit farms (growers Dennis Smithson & Matt McDevitt, fieldsman Bob Gix)
Tuesday 14 Aug 2012	Visit Washington State University, Tree Fruit Research and Extension Centre, Wenatchee Attended fieldsmen (breakfast) debriefing meeting of Northwest Wholesale Agchem merchants (about 10 advisors present). Visited Sunrise orchard (sub-station of Wenatchee). Discussions with Betsy Beers, Vince Jones and Rebecca Schmidt
Wednesday 15 Aug 12	Discussions with Jim McFerson and Tory Schmidt, Washington State Horticultural Association. Drive to Yakima, WA
Thursday 16 Aug 12	Visit Yakima Agricultural Research Laboratory (USDA), Wapato, Washington. Gave seminar. Discussions Wee Yee, Alan Knight, Mike Bush, Tom Unruh, Rodney Cooper
Friday 17 Aug 12	Visit to Yakima continued Meetings with Steve Garczynski, Godfrey Miles, Dave Horton, Pete Landolt, Anne Kenny Chapman (Lisa Neven group)
Saturday 18 Aug Sunday 19 Aug	Drive to Portland, OR. Return hire car 1. Fly Portland to Vancouver BC, Canada
Monday 20 Aug	Rest day
Tuesday 21 Aug Wednesday 22 Aug	Visit British Columbia Ministry of Agriculture. Abbotsford Agriculture Centre, Abbotsford, BC. Hosts Tracy Hueppelsheuser and Mark Sweeney. Visited lab, gave seminar. Visited several growers in Fraser valley including Berry haven Farm Ltd (growers Henry & David Mutz). Visited Clearbrook sub-station of Agassiz. Discussions with Michael Dossett (breeder) Visited Krause Berry farms. Visited Kwantlen Polytechnic University (impressive biopesticide development lab) and lab and research coordinator Lisa Wegener and Michelle Franklin. Visited Berryhill (Steve Glove) and South Alder farms (Harvey and son Jordan)

Thursday 23 Aug	Visit Pacific Agri-Food Research Centre, Agassiz, British Columbia Hosts David Gillespie and Sheila Fitzpatrick
Friday 24 Aug	Visit Simon Fraser University Burnaby, nr Vancouver, BC Visit Gerhard and Regina Gries.
Saturday 25 Aug	Drive to Summerland, BC arriving late pm
Sunday 26 Aug	Rest day
Monday 27 Aug	Visit Pacific Agri-Food Research Centre, Summerland Discussions with Kenna Mackenzie, Brigitte Rozema. Tour station, field plots and spray facility. Meet Dave Nield, Karen Bedford. Brent Tiffin
Tuesday 28 Aug	Visit Pacific Agri-Food Research Centre, Summerland. Discussions with Gary Judd, Joan Cossentine. Visit cherry orchards and packing facility Keith and Janine Carlson
Wednesday 29 Aug	Fruit production area tour with Gerry Neilsen, Alan Hallsworth Penticton - Naramata area
Thursday 30 Aug	BCMAL office, Kelowna Meet Susanna Acheampong, British Columbia Ministry of Agriculture. Then visit packhouse Okanagan Tree Fruit Company, Kelowna. Discussions with Gayle Krahn, Central Okanagen Regional District, Kelowna: Then meet Hugh Philip, consulting entomologist, former BCMAL extension and Cara McCurrah, general manager of SIR programme
Friday 31 Aug	Pacific Agri-Food Research Centre, Summerland. Discussions with Tom Lowry. Visit Charlotte Leaming, OKTF Packhouse, Oliver, and visit orchards. Then visit SIR programme facility at Osoyoos. Discussions with Scott Arthur and tour of facility. Visit Vollo Orchards, apple and cider grower. Discussions with Ron Vollo
Saturday 1 Sep	Depart Summerland
Friday 7 Sep	Depart from Vancouver
Saturday 8 Sep	Arrive Heathrow