Pest Risk Analysis (PRA) for apple maggot (*Rhagoletis pomonella*) moving on municipal green waste into the Pest-Free Area (PFA) of the state of Washington, USA

For:

The Washington State Department of Agriculture

Authors:

Dr Claire E Sansford, Independent Plant Health Consultant, York, UK
Mr Victor Mastro, Consultant, Cotuit, Massachusetts, USA
Mr James R Reynolds, Consultant, Fort Collins, Colorado, USA

Date: April 30th 2016
Version: 2.0

Pest Risk Analysis (PRA) for apple maggot (*Rhagoletis pomonella*) moving on municipal green waste (MGW) into the Pest-Free Area of the state of Washington, USA

Index

Preamble

This Pest Risk Analysis (PRA) has been written using the EPPO Standard PM 5/3(5) Guidelines on Pest Risk Analysis, Decision-support scheme for quarantine pests, 11- 17053 PM 5/3 (5) (EPPO, 2011) and the EPPO CAPRA (Computer Aided Pest Risk Analysis) computer programme http://capra.eppo.org/

The latest version of the EPPO scheme was approved in September 2011. It is based upon the FAO International Standard for Phytosanitary Measures, no. 11, '*Pest Risk Analysis for Quarantine Pests including analysis of environmental risks and living modified organisms'*. (FAO, 2004). The EPPO CAPRA programme aims to assist pest risk analysts in running the EPPO scheme. More information is available at:
https://www.eppo.int/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm

Notes to the reader

- A PRA conducted using the EPPO scheme can either be initiated as the result of an identification of a single pest that may pose a threat, or the pest itself can be evaluated in the framework of a pathway analysis (or there may be another reason)

- This PRA has been conducted as a pest-specific PRA since the CAPRA programme is best-adjusted to this type of analysis

- The CAPRA programme only selects those questions in the scheme relevant to this type of analysis and in relation to the responses given. Thus, the numbering of the questions in this document is not always continuous

- To the best of our knowledge, assessment of municipal green waste for composting has not been assessed as a pathway for a pest using the EPPO scheme previously. The responses to the questions or statements in the scheme have been adapted accordingly.

- Both imperial and metric units have been used in this document; in particular for weights, municipal green waste is presented in imperial tons and apples in metric tonnes

Review of first draft prior to external peer review

The risk of entry and risk management sections were reviewed by Dr Jaak Ryckeboer, Ensus Consulting BVBA, Belgium, on contract to the WSDA. Dr Ryckeboer is an expert in the hygienic safety of organic waste processing via composting and anaerobic digestion. Dr Ryckeboer also holds also a position at the University of Leuven, Belgium.
http://www.kuleuven.be/wieiswie/en/person/00019203

External peer review

External peer review of version 1.0 of this PRA was facilitated by the WSDA, co-ordinated by Deanna Painter (WSDA) and undertaken by the following individuals:

Gary Bahr, WSDA
Mark Calkins, ATG (Office of the Attorney General, state of Washington)
Robert Griffin, USDA
Mary Harrington, ECY (Department of Ecology, state of Washington)
Mike Klaus, WSDA
Jim Marra, WSDA
Brad White, WSDA
Wee Yee, USDA

Executive summary

Rhagoletis pomonella (Walsh) (apple maggot) is an insect pest of quarantine concern which is subject to regulation in areas where it occurs including in the state of Washington, USA. It is also listed as a quarantine pest by a number of National and Regional Plant Protection Organisations.

R. pomonella has a recorded host range of 55 plant species in ten genera in the family Rosaceae. It is widespread in the USA and has a restricted distribution in Canada and Mexico. It is endemic in the east of the USA and is considered to have been introduced to the Pacific Northwest including the state of Washington, most likely as result of the movement of infested apple fruit. In the state of Washington there are records of the pest on 17 plant species in six genera including apples and 4 species of hawthorns (its native host). *R. pomonella* lays its eggs in host fruit within which the larvae develop. This results in direct yield and quality losses in areas where the pest is established if it is not controlled, and increased control costs at affected commercial premises. In the Washington State Department of Agriculture (WSDA) annual surveys for the pest, it has been recorded on traps in the Pest-Free Area (PFA) of the state outside of commercial orchards, but it has not been found in commercial apple fruit harvested in the area.

Municipal green waste (MGW) containing host fruit (and possibly soil infested with pupae) originating in quarantine areas for *R. pomonella* has been shipped to the PFA of the state of Washington for a number of years where it is subject to composting at four facilities (one of the facilities only started operating in 2015). Currently three of the facilities have been prohibited from processing MGW from the quarantine area pending the decision of the WSDA.

Using the European and Mediterranean Plant Protection Organisation's (EPPO) '*Guidelines on Pest Risk Analysis (PRA) Decision Support Scheme' (*11- 17053 PM 5/3 (5)) (EPPO, 2011), a PRA has been produced which assesses the risk of entry of *R. pomonella* to the PFA (referred to hereafter mainly as the '*PRA area*') on MGW using each facility as a separate pathway[1], determines the risk of establishment and spread of the pest in the PRA area and the likely economic impact (including social and environmental impacts). Options for managing the identified risks have been developed based upon on the '*EPPO Guidelines for the management of plant health risks of biowaste[2] of plant origin'* (Phytosanitary Procedure PM 3/66 (2)), EPPO (2008), supported by the results of recent experimental work conducted in the quarantine area on composting yard waste containing pupae of the pest, and temperatures known to be lethal to the pest.

The overall risk of entry of *R. pomonella* on MGW from the quarantine area to the PRA area is assessed as *likely* to occur with *low uncertainty*. Two of the facilities were rated as *very likely*, one

---

[1] A pathway is defined as '*Any means that allows the entry or spread of a pest'*. The entry of a pest is defined as: '*Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled*'. (FAO, 2015).

[2] EPPO (2008) defines '*biowaste*' as '*Any plant or animal waste destined for 'end-use' (as defined below) that can be degraded by micro-organisms, soil organisms or enzymes. The EPPO (2008) standard is concerned only with biowaste of plant origin which may be derived from the following sources: kitchen (household or catering) waste, forest or wood-processing waste (e.g. bark, wood, sawdust), garden and park waste, waste from markets, waste from agricultural processes (e.g. husk and cereal dust, potato peelings and washings), waste feeding-stuffs, human food stored beyond its safety period, waste from industrial food processes (e.g. fruit pulp, spent hops, sludges). The European Waste Catalogue (EU, 2001) lists and indexes types of wastes. Plant residues generated on land used for agricultural, horticultural or silvicultural purposes, and remaining on that land, are not included in this standard but may be regulated by other national or international standards'.* In this PRA the term biowaste refers to municipal green waste.

as *likely*, and one as *moderately likely;* all with *low uncertainty*. The reasons for the differences between the facilities varies but in part they are related to the prevalence of *R. pomonella* in the area of origin of the waste (the western side of the state of Washington and Oregon having higher pest prevalence than the east), volumes of waste received, storage times of MGW onsite and the composting methodology deployed at each facility. Because *R. pomonella* is a flying insect, for all of the facilities there is a period of time from arrival of the MGW on site when transfer of *R. pomonella* to the PRA area may occur from flies eclosing from pupae in the waste during the flight period of the pest (when favourable temperatures occur during June to October). The duration of this period depends upon when/if all of the MGW reaches temperatures that are likely to be lethal to the pupal stage; around 50°C. The composting methodologies at each facility vary significantly but the one thing that all facilities have in common is that surface temperatures on windrows or static piles will not become lethal to the pest immediately. This may be protracted if the waste is never turned, as is the case with static piles.

If *R. pomonella* enters the PRA area on these pathways it has a *medium* probability of establishment in the areas where hosts occur in commercial apple orchards, commercial nurseries with hosts bearing fruit (not common in commercial premises supplying growers), backyards and the wider environment with *low uncertainty*. The pest has a maximum reported flying distance (from flight mill studies) of 3 miles with a maximum published flight distance in the field of *ca*. 1 mile. Although distances obtained from flight mill studies cannot be directly related to field dispersal distances they can indicate the potential of the insect. All but one of the composting facilities has a commercial apple orchard within a 3 mile radius. All of the facilities have non-commercial hosts growing in very close proximity. The climate in the PRA area is not completely favourable to population growth (with hot dry summers) and current pest management practices in apple orchards will limit infestation until early season codling moth (*Cydia pomonella*) treatments cease to be effective. Nevertheless, establishment could occur.

Eradication or containment of *R. pomonella* is known to be difficult because a) the pest is a flying insect with a potential to fly up to 3 miles (from flight mill studies) in a single flight and *ca*. 1 mile from field studies making delimitation of an outbreak difficult b) traps to detect populations are only effective in close proximity to the pest, and c) the pupal stage resides in the soil (sometimes in dropped fruit); in soil it can survive for at least 2 years if not longer. Historically, parts of the PRA area have become quarantined as a result of finding reproducing populations of *R. pomonella* outside of apple orchards, with the most recent proposal for a move to quarantine status arising from finds in the WSDA survey for the pest in Lincoln County in 2015. This is in spite of the efforts of the County Pest Boards taking action in response to detections made by the WSDA.

Spread by natural means in the PRA area is likely to be *moderate* with *low uncertainty* but spread with human assistance (infested fruit or soil) is likely to be *high* with *medium uncertainty* until the regulatory authorities take control of an outbreak. The rate of spread in the PRA area outside of apple orchards is not known since studies have not been undertaken in the area or similar areas and host distribution is discontinuous.

Introduction (entry and establishment) of *R. pomonella* to the PRA area is likely to result in *major* economic impacts (with *low uncertainty*) resulting largely from the increased cost of control in commercial premises, particularly apple orchards, costs and losses related to the effects on export markets, as well as environmental impacts arising from increased pesticide use. Potential impacts to other commercially-produced fruit have not been assessed but it is assumed that those host species which are currently known to be attacked by *R. pomonella* in the state of Washington (plums – various species; common and Asian pear and apricot) are at risk. Sweet cherry is the other commercial fruit host attacked outside of the state of Washington and this may be at risk in the PRA area if the biology of the pest changes within the state. There is potential for impacts arising from the pest attacking ecologically-important plant species in the PRA area (such as native hawthorns) but this requires investigation.

The risk posed by *R. pomonella* moving on MGW from the quarantine area to the PRA area is assessed as unacceptable.

Around 2 million metric tonnes of apple fruit, representing 30% of the crop produced in the PRA area is exported annually to a wide range of destinations around the world; this is facilitated by the pest-free status of the area where the majority of the state's orchards are located. To help maintain the PFA, regulations are in place which includes the regulation of fruit of a range of hosts (including apple, crab apple (*Malus* spp.) and hawthorn (*Crataegus* spp.)) originating in quarantine areas. These '*regulated articles'* cannot be moved into the PFA of the state without meeting certain requirements including cold treatment(s) to ensure that *R. pomonella* is not introduced to the area. Since MGW from the quarantine area is likely to contain host fruit and possibly infested soil, it seems appropriate to consider options for regulation of the MGW which would mitigate the risk and potentially facilitate the safe movement of MGW to the PFA (the PRA area).

Two main options have been proposed for consideration to mitigate the risk. These are based around the EPPO Phytosanitary Procedure (EPPO, 2008). One is that the MGW is subject to composting in the quarantine area, at least to the point that all of the waste is exposed to temperatures lethal to pupae of the pest. This could be achieved 1 to 2 weeks after the MGW has reached lethal temperatures depending upon the process. The second is that the MGW could be subject to direct heat treatment to lethal temperatures, also in the quarantine area. The details of these options are outlined in the risk management section of this PRA. They require validation in the quarantine area. If these prove to be successful in eradicating pupae of *R. pomonella* at the industrial-scale, and are considered feasible, then it should be possible to safely move the treated MGW to the PRA area to continue the composting and curing process. It is recommended that consideration be given to investigating the potential for treatment of the MGW in the quarantine area under the supervision of the WSDA.

There may be other treatment options available and these are listed in the PRA, but they have not been tested against pupae of *R. pomonella* in MGW. They may warrant investigation.

This PRA has identified a number of areas of uncertainty which can be addressed through research and surveillance if this is deemed necessary. Recommendations for actions to address these are given. This PRA can be reviewed and revised in the light of any new findings that arise.

Disclaimer

Our examination of the steps and processes of the composting operations of the four facilities and resulting scientific evaluations in this PRA, only evaluated the potential survivability and transfer of R. pomonella *to the PFA (the PRA area) at various stages of the process. This PRA does not evaluate or make any statements concerning composting operations or the finished compost products for any other reason.*

Stage 1: Initiation

1.01 - Give the reason for performing the PRA

This PRA was initiated by the Washington State Department of Agriculture (WSDA), USA, in response to concerns arising from the potential movement of the quarantine pest, *Rhagoletis pomonella* (apple maggot) on municipal green waste being transported from areas of the state of Washington where the pest is established (the quarantine area), to four composting facilities in the pest-free area of the state where commercial apple orchards, certified as free from the pest, are situated.

1.02a - Name of the pest

Rhagoletis pomonella (Walsh).

1.02b - Indicate the type of the pest

Arthropod.

<u>Note on the biology of the pest</u>

The basic biology of the pest is presented here based upon Brunner (1987), Dean and Chapman (1973) and Marra (*undated*). Further detail on specific aspects is given where necessary in later sections of this PRA.

R. pomonella (apple maggot) is a fly, approximately 5mm long, which overwinters as pupae in the top 2 inches of soil beneath host trees (mainly *Malus* spp.: apples, crab apples; and *Crataegus* spp.: hawthorns), but also sometimes on the soil surface, and occasionally in fallen fruit. Most of the pupae (ca. 5 mm long and 2.3 mm wide; many are smaller) remain in a state of diapause in the soil for one winter but some can remain there for ≥2 years. A few pupae may complete development in the same year without undergoing diapause and can emerge as a partial second generation before or at the onset of winter. Thus in addition to a single annual generation, there is the possibility of 1 generation every 2 or more years, and, a second generation in the same year. Adult flies can emerge from pupae from early June through to September and they can live for up to 40 days. When the flies emerge they feed for 7 to 10 days before reaching sexual maturity and they continue to feed thereafter. Food sources vary, surmised mainly to be plant leachates, insect honeydew, as well as liquid from plant glands, wounds and oviposition stings; also possibly bacteria, yeasts and fungal spores.

Adult flies mate on the host plant (normally on the fruit) and the female lays a single fertilised egg beneath the skin of the fruit. This and the following information pertains to apples; development times may differ on other hosts. A single female can lay > 200 eggs deposited singly under the skin of the fruit and egg-laying will occur in more than one fruit. Eggs measure 0.9mm long and 0.23mm wide. Eggs hatch within 3 to 7 days and the emerging larvae take 13 to 50 days to develop within the fruit depending upon the hardness of the fruit (soft-fleshed fruit speeds development) and temperature. They tunnel through the flesh of the fruit while feeding resulting in discolouration and deterioration of the fruit. Mature larvae (measuring 6.5 - 8 mm long and 1.5 - 2 mm wide) drop to the ground, or they leave the fruit after it has dropped to the ground. The larvae burrow into the soil but may remain on the soil surface or sometimes in infested fruit. The prepupal period is between 2 and 18hrs with the majority in this phase for 6 to 11hrs. Pupation is normally completed by the end of October but may extend to later in the year depending in part on temperatures; however, some larvae have been detected in apple fruit in December (based on one study in New York – in Dean and Chapman, 1973).
A lifecycle diagram modified from blueberry maggot (*Rhagoletis mendax*) provided by Yee (USDA,

ARS, USA, *personal communication*, April 2016) is presented below (Figure 1). This is a generalised lifecycle and does not account for all possible development times observed in the field.

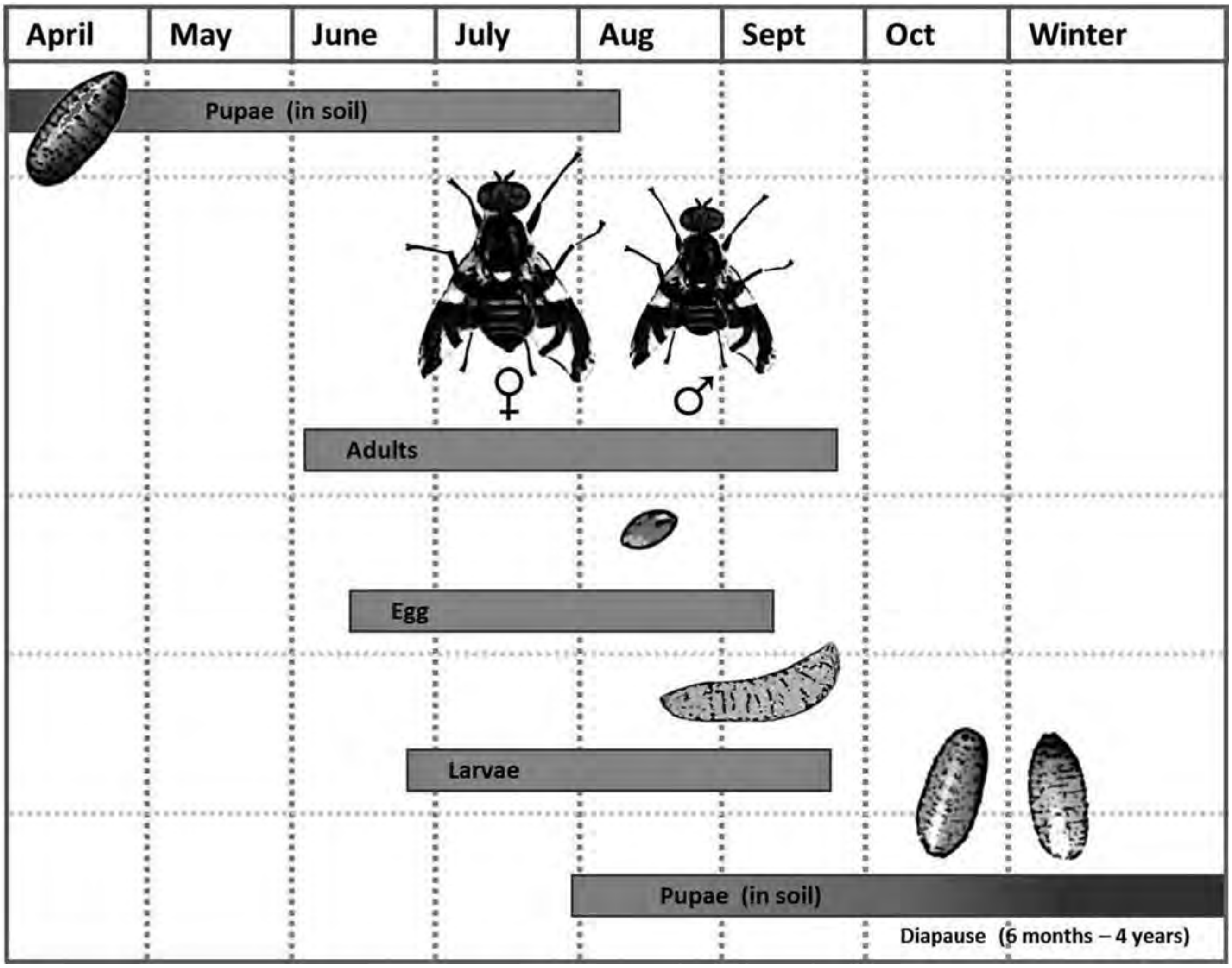


Figure 1. Generalised lifecycle of *Rhagoletis pomonella*. (Yee, USDA, ARS, USA, *personal communication*, April 2016). Specific details of timings for *R. pomonella* differ slightly and are provided in the text of this PRA.

1.02d - Indicate the taxonomic position

The classification of the pest, *Rhagoletis pomonella* (Walsh) is given below:
Phylum: Arthropoda
Class: Insecta
Order: Diptera
Family: Tephritidae
Genus: *Rhagoletis*
Species: *pomonella*

Common names of the pest include:

Apple maggot, apple fruit fly, apple maggot fly, railroad worm (EPPO, 2015; accessed 12 November 2015).
Rhagoletis pomonella was first described as *Trypeta pomonella* by Walsh (1867) (in Bush, 1993) a

year after apples (named then as *Malus pumila*) in the Hudson River area of New York were reported as being infested with the maggots of an unknown fly. Walsh based his description on flies reared from infested apples in the east of the USA and from fruits of hawthorn (*Crataegus* spp.) from Illinois (noting the fly did not attack apples in that area) (Bush, 1993). The fly was later described as *R. pomonella* by Snow (1894) (in Bush, 1993).

The pest is one of 4 in the genus *Rhagoletis* which fall into the *'Pomonella* species group', comprising *R. pomonella*, *R. mendax*, *R. zephyria*, and *R. cornivora*. This group of flies has close morphological similarities but distinct host requirements. They were originally considered, by some, to be races or subspecies of the single species *R. pomonella*. (Bush, 1966).

While *R. pomonella* is still recognised as a single species it can be differentiated into races according to the preferred host plant(s), and this preference differs according to location. Bush (1969) describing the formation of host races citing Mayr (1963), stating: '*For the purpose of this paper I restrict the term* 'host race' *to a population of a species living on and showing a preference for a host which is different from the host or hosts of other populations of the same species. Host races represent a continuum between forms which freely interbreed to those that rarely exchange genes. The latter may approach the status of a species generally regarded as an interbreeding population reproductively isolated from all other such populations'*. In this respect, when Walsh (1867; in Bush, 1993) first described *T. pomonella*, he suggested that the flies that were found to be infesting apples in New York were a newly-established host race which were biologically-distinct from those associated with hawthorn.

In the east of North America there is the hawthorn (*Crataegus* spp.) race (a race which attacks the ancestral host, hawthorn, in the native range of the pest) and the relatively more recently-emerged apple race (Feder *et al*. 1988; in Yee *et al*., 2014). These differ in their preference for their hosts based upon olfactory cues (Linn *et al*., 2003; in Yee *et al*., 2014). However, the hawthorn race can also infest apples (Reissig and Smith, 1978; in Yee *et al*., 2014). There is also behavioural evidence of different races in the west of the United States where the pest is non-native/introduced (Linn *et al*. 2012; in Yee *et al*., 2014). In field studies, Mattson *et al.* (2015) showed that '*host associated fly populations were 24.4 % to 92.6% offset in their seasonal distribution*' and this implies that *R. pomonella* has the capacity to rapidly shift its diapause to match the phenology of host plants. Yee thought that populations in the state of Washington on hawthorn (*Crataegus* spp.) had the potential to attack apples (*Malus* spp.), hypothesising that this might be with a reduced probability compared to apple populations. This mainly appears to depend upon when the flies emerge since, according to Yee (USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016), generally speaking, populations on black hawthorn (*Crataegus douglasii*) (and early apple varieties), in the state of Washington, emerge before most apple varieties are susceptible, whereas the populations on ornamental hawthorn emerge after most apples are susceptible. This is complicated though because black hawthorn can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October). Populations in Mexico also exhibit genetic and morphological differences (Feder *et al*., 2003; Foote *et al*., 1993; in Yee *et al*., 2014). Rull *et al*. (2006) (in Yee *et al*., 2014) thought that these may represent host races, subspecies or even undescribed species.

Irrespective of the existence of races, for the purposes of this PRA, *R. pomonella* is considered to be a single species since it is this, rather than the races, which is the subject of phytosanitary regulation. More detail on host preference and geographical differences is given in later sections of the PRA.

1.03 - Clearly define the PRA area

The PRA area (the area at risk) is defined as the parts of the state of Washington, USA, which are currently defined as the pest-free area (PFA) for the pest *R. pomonella*.

A PFA is defined as: *'An area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained'* (FAO, 2015).

The PFA is the counties and parts of counties shown in green and grey to the eastern side of the state, in Figure 1a, below:

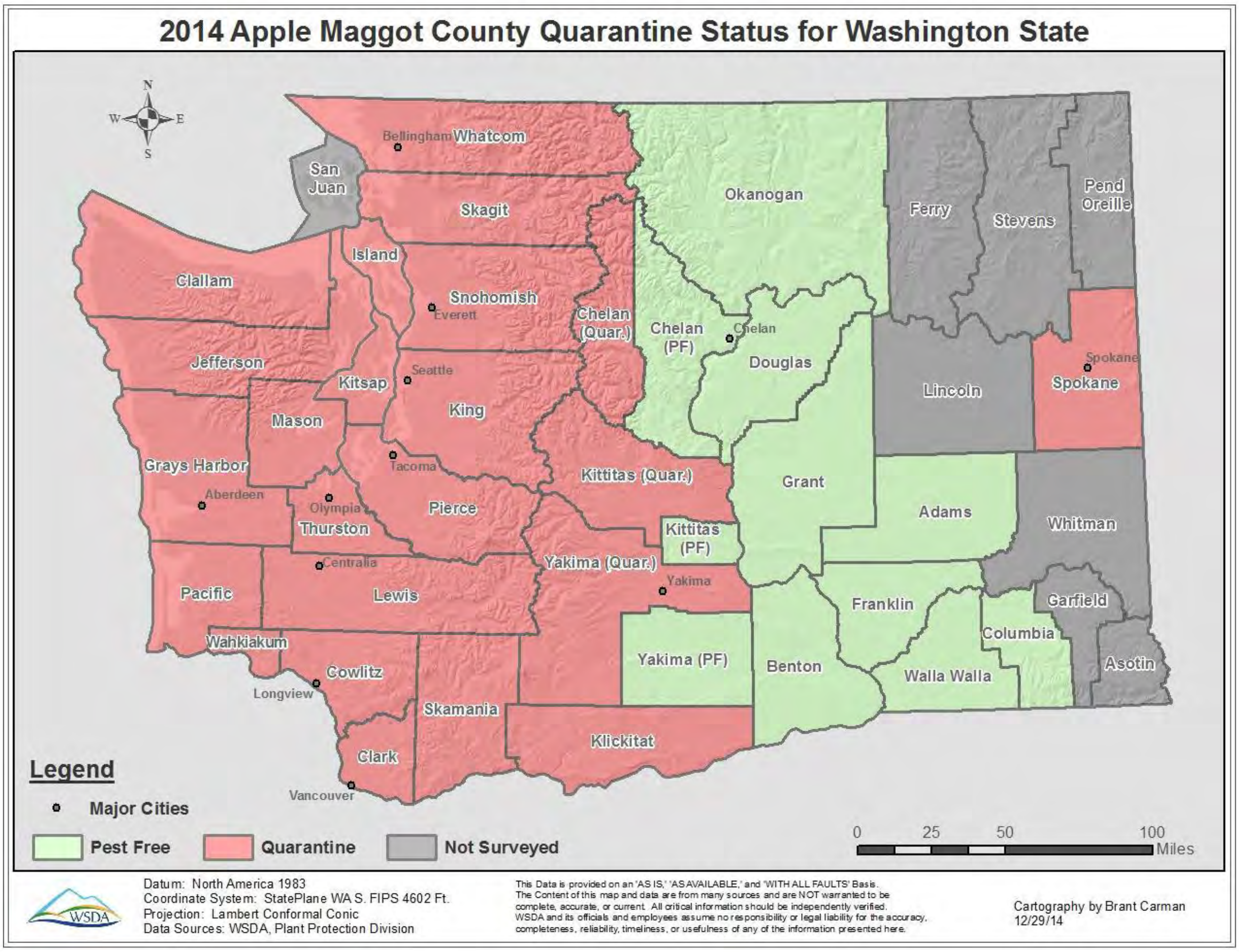


Figure 1a. Map of the pest-free area (*'non-quarantine'*) and quarantine area for *R. pomonella* in the state of Washington, USA. Source: Klaus (2014). Areas not surveyed in the east of the state are part of the pest-free area.

The list of counties or parts of counties which are currently in the PFA of Washington, and therefore form the PRA area is as follows:

Adams, Asotin, Benton, Chelan (part), Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas (part), Lincoln, Okanogan, Pend Oreille, Stevens, Walla Walla, Whitman, and Yakima (part).

See: http://apps.leg.wa.gov/WAC/default.aspx?cite=16-470-105

The detail of the distribution of the pest, the status of the pest in the PFA (the PRA area) and in the '*quarantine area*' is discussed in section 1.07 (and later sections) of this PRA.

Figure 2 shows the main apple-growing areas of the state.

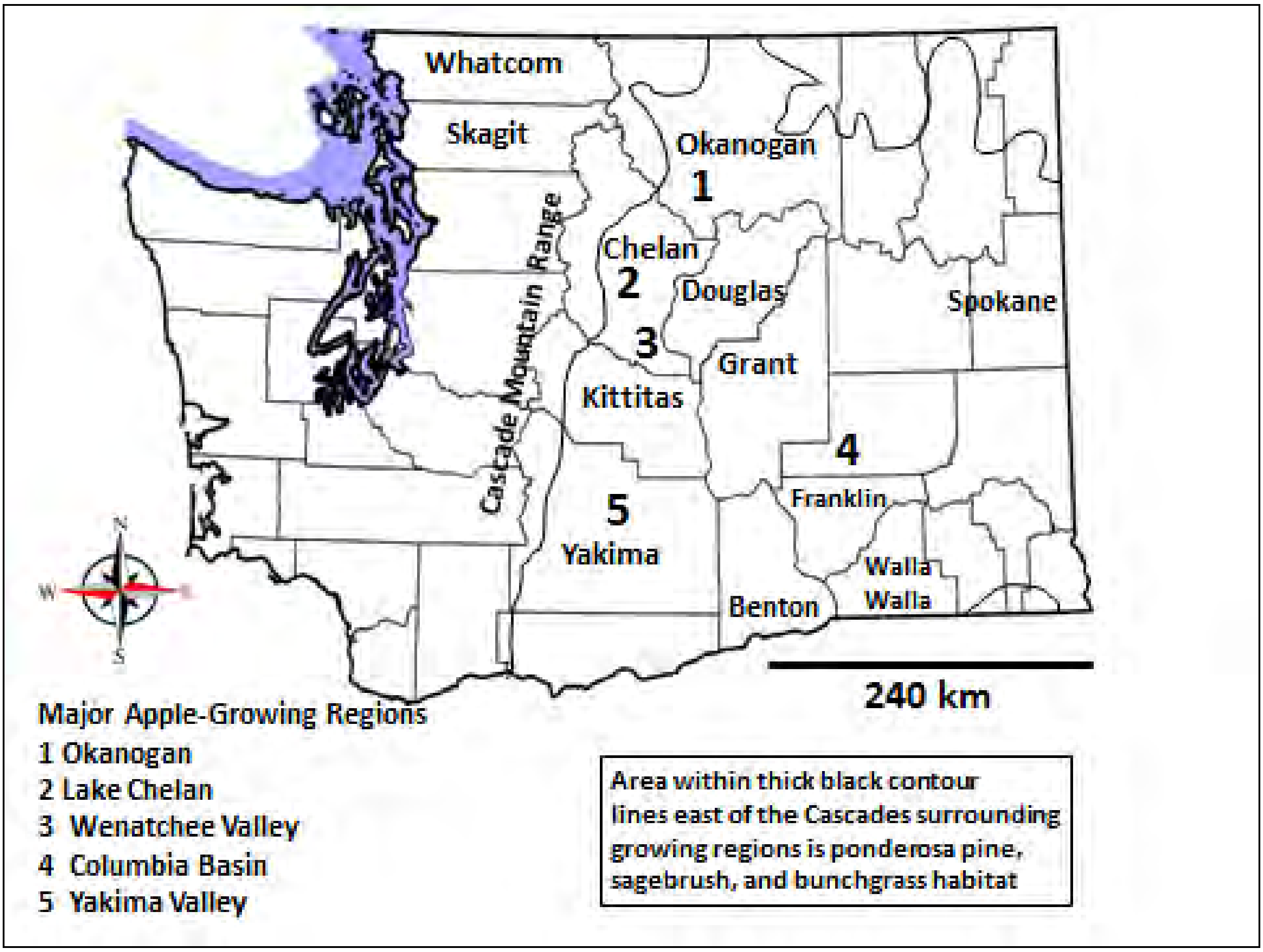


Figure 2. Map of the main apple-growing areas in the state of Washington. Yee (2015).

1.04 - Does a relevant earlier PRA exist?
No.

Although *R. pomonella* is regulated by various National Plant Protection Organisations (NPPOs) and listed as a quarantine pest by various Regional Plant Protection Organisations (RPPOs) around the world (EPPO, 2015), there is no evidence of the existence of a PRA. EPPO has produced a datasheet which is similar to a PRA (EPPO, 2006) and CABI have also attempted to assess the risk posed by *R. pomonella* in their datasheet (CABI, 2015). There are also some papers examining economic impact as well as the costs of risk management or mitigation and these are discussed in the relevant sections of the PRA.

1.06 - Specify all host plant species (for pests directly affecting plants) or suitable habitats (for non-parasitic plants). Indicate the ones which are present in the PRA area.
The most recently-published list of hosts of *R. pomonella* (Yee *et al.,* 2014) which was based upon the available literature is presented in Table 1 and discussed below.

Table 1. Natural host range of *Rhagoletis pomonella* based on available literature (from Yee *et al*., 2014[3])

Hosts			Published records: country or state of USA	Importance as a fly host
Common name	Genus	Species/hybrids		
Apples and crab apples	*Malus* spp.	***M. domestica*** (Borkh.) Borkh., *M. pumila* Mill.	Canada USA (many eastern and western states **including WA**) Mexico	**High**
		M. baccata (L.) Borkh. and hybrid crab apples	USA: NH, MI, UT Canada	Low
Hawthorn	*Crataegus*	*C. aestivalis* (Walter) Torr. & A. Gray	USA: GA	High?
		C. brainerdii Sarg.	USA: NY	Medium?
		C. brachyacantha Sarg. & Engelm.	USA: AK, TX	High?
		C. crus-galli L.	USA: NY, TX	High?
		C. cuprina J. B. Phipps	Mexico	Medium?
		***C. douglasii* Lindl.**	USA: CA, CO, ID, OR, UT, **WA**	**High**
		C. erythropoda Ashe	USA: CO	Medium?
		C. flabellata (Bosc ex Spach) K. Koch.	USA: SC, TN	High?
		C. flava Ait.	USA: AL, GA, SC	High?
		C. gracilior J. B. Phipps	Mexico	High?
		C. greggiana Eggl.	USA: TX, Mexico	High
		C. holmesiana Ashe	USA: NY	High
		***C. laevigata* (Poir.) DC.**	**USA: WA**	**Medium**
		C. invisa Sarg. (unresolved name) = *C. mollis* Scheele	USA:TX	Medium?
		C. macracantha Lodd ex London	USA: CO, ID	Medium?
		C. macrosperma Ashe	USA:NY	High?
		C. marshallii Eggl.	USA:TX	Medium?
		C. mexicana Moc & Sessé ex DC.	Mexico	High
		C. mollis Scheele	USA: CO, IL, KY, MD, MI, NY, TX	High
		***C. monogyna* Jacq.**	**USA:** NY, OR, UT, **WA**	**High**
		C. opaca Hook. & Arn.	USA:TX	High?
		C. pedicellata Sarg.	USA: NY	Medium?
		C. pruinosa (Wendl.f.) K. Koch.	USA: NY, MD, PA, VA	High?
		C. punctata Jacq.	USA: NY	High?
		C. rivularis Nutt. Ex Torr & A. Gray[a]	U.S: CO, UT	High
		C. rosei Eggl.	Mexico	High
		***C. suksdorfii* (Sarg.) Kruschke**	**USA: WA**	**Medium**
		C. viridis L.	USA: GA, LA, MS, TX	High
Serviceberries	*Amelanchier*	*A. bartramiana* (Tausch) M. Roem	USA:ME	Low

[3] One subsequent record on *C. douglasii* was made in Montana – Yee *et al.* (2015)

Chokeberries	*Aronia* (accepted name of *Photinia* spp.)	*Photinia pyrifolia* (Lam.) K. R. Robertson & Phipps (*A. arbutifolia*)	USA: FL	Low
		Photinia melanocarpa (Michx.) K. R. Robertson & Phipps (*A. melanocarpa*)	USA: ME	Low
Firethorns	*Pyracantha*	*P. angustifolia* (Franch.) C. K. Schneid.	USA: TX	Low
		P. coccinea M. Roem.	USA: UT	Low
Cotoneasters	*Cotoneaster*	***C. apiculatus* Rehd. & E. H. Wilson**	**USA: WA**	**Low**
		***C. integerrimus* Medik.**	**USA: WA**	**Low**
		***C. lacteus* W. W. Smith**	**USA:WA**	**Low**
Mountain ash	*Sorbus*	***S. aucuparia* L.**	**USA: WA**	**Low**
		***S. scopulina* Greene**	**USA: WA**	**Low**
Cherries	*Prunus*	*P. avium* (L.) L.	USA: UT	Low
		P. cerasus L.	USA: UT, WI	Low
		***P. emarginata* (Douglas ex Hook.) D. Dietr.**	**USA: WA**	**Low**
		P. mahaleb L.	USA: UT	Low
		P. virginiana L.	USA:UT	Low
Plums	*Prunus*	*P. angustifolia* Marsh.	USA: FL	Low
		***P. armeniaca* L.**	**USA:** NY, UT, **WA**	**Low**
		***P. cerasifera* Ehrh.**	**USA.:** UT, **WA**	**Low**
		***P. domestica* L.**	**USA:** NY, **WA**	**Low**
		***P. salicina* Lindl.**	**USA:WA**	**Low**
		P. umbellata Elliot	USA:FL	Low
Pears	*Pyrus*	***P. communis* L.**	**USA:WA,** WI	**Low**
		***P. pyrifolia* (Burm. F.) Nakai *(P. serotina* Rehder)**	**USA:WA**	**Medium**
Roses	*Rosa*	*Rosa rugosa* Thunb.	USA: MA, RI	Low
		Rosa virginiana Mill.	USA: MA	Low

Footnotes:
Hosts in red recorded in Washington
Authors of plant species based mostly on:
USDA Natural Resources Conservation Service Plants Database (http://plants.usda.gov/java/profile?symbol=CRBR);
and The Plant List (http://www.theplantlist.org/tpl/record/tro-50249452).
Records may not include all US states
Most records based on rearing to adult stage; for crab apples and *Photinia melanacarpa*, larval stage: questionable but within the *R. pomonella* species group, *R. pomonella* is the most likely species; excludes trap records
[a]Treated as a valid species, sometimes referred to as a subspecies of *C. douglasii*

Up until 2014, *R. pomonella* had been recorded on 55 hosts (54 if *C. invisa* is synonymous with *C. mollis*) in ten genera, all in the family Rosaceae. There are far fewer hosts (17, in 6 genera) recorded in the state of Washington (Yee *et al*., 2014) where the pest is considered to be an introduced species. The first record of the pest in the state was in 1980 when adult flies were detected in two traps (Rebhan, 1980; in Brunner, 1987).

The native host of *R. pomonella* is hawthorn (*Crataegus* spp.) of which there are 28 recorded host species (27 if *C. invisa* is synonymous with *C. mollis*), four of which are recorded as hosts in the state of Washington. No clarification is possible on the host species affected in the PRA area.

The other main hosts are apples (*Malus* spp.). *M. domestica* has been recorded as a host in the state of Washington (Yee *et al*., 2008) but not as a host in commercial apples in the PRA area (M. Klaus, WSDA, USA, *personal communication*, December 2015). Yee *et al*. (2014) considered that *Malus domestica* and a number of hosts in the genus *Crataegus* are of high importance for the pest. Hosts in other genera were rated as being of low importance with the exception of *Pyrus pyrifolia* (Asian pear) which is of medium importance.

Of the crab apples, Yee *et al*. (2014) list *M. baccata* – an Asian species, and hybrid crab apples as hosts but did not cite any records in the state (albeit the manuscript states that the records may not include all US states). They consider crab apples as being of low importance for *R. pomonella*. Neilson (1967) found that eggs of *R. pomonella* laid in Siberian crab apple (*M. baccata* Borkh.) hatched but the larvae did not develop past the first instar and feeding on the fruit was minimal. They found similar incidents occurred with some but not all of a range of varieties of the crab apple *M. toringoides* infested in the laboratory. The cause of mortality was not known. Bush (1969), citing others (including Bush, 1966) stated that native crab apples (species not specified) are not hosts of *R. pomonella* possibly because they mature too late in the season and lack suitable nutritive qualities. Earlier, Bush (1966) said that introduced species and hybrids of crab apple are hosts possibly because the fruit of most North American crab apple species ripens too late for the pest to complete its development before winter (O'Kane, 1914; in Bush, 1966). Reissig *et al*. (1990) showed that crab apples varied in their susceptibility to infestation, with eggs being laid in a range of varieties and species in the laboratory (more so than in the field) but larval development being hindered in some.

As discussed under 1.02d, both hawthorn (*Crataegus* spp.) and apple (*Malus* spp.) races of *R. pomonella* exist based largely on host preference; but the distribution of these races in North America is not uniform. The apple race emerged from the hawthorn race in the east of North America over 150 years ago. The races emerge from their pupae when their respective hosts are in a suitable condition for oviposition by the adult female flies (Bush, 1969; referring to Pickett and Neary, 1940). Thus, Bush (1969) found that in eastern North America the apple race emerges and commences oviposition *ca*. 4-5 weeks before the hawthorn race.

Adult flies were first found in central Washington (Yakima County), the major apple-growing area of the USA, in 1995 (Klaus, 1996 in Yee *et al*., 2014). Yee (2008) investigated host plant use by the pest in south central Washington from 2004 to 2006. *R. pomonella* was found to infest 0 to 1.6% of non-commercial apple trees (*M. domestica*), and 0 to 22.5% of wild black hawthorn (*C. douglasii*). These were the first data to demonstrate that the pest had established in this part of the state.

The situation with races in the state of Washington is discussed under section 1.02d.

The potential for populations on hawthorn in the state to attack apples depends mainly on when the flies emerge since generally speaking, populations on black hawthorn (*C. douglasii*) emerge when early apple varieties are susceptible but before most apple varieties are susceptible, whereas the populations on ornamental hawthorn emerge after most apples are susceptible. As noted previously this is not so simple since black hawthorn ripening is variable and some can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October).

While *R. pomonella* has a wide-range of recorded hosts, the potential host-range in the PRA area (the PFA) is likely to be smaller because of the behaviour (emergence times and host preference) of the populations of the pest in the state.

With respect to which host species or habitats are present in the PRA area, the WSDA places traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in the area when fruit is on the tree. Of primary importance is the presence of commercial apple orchards that are potentially at risk from infestation by the pest. Wild apples, and crab apples (albeit considered to be of low importance for the pest by Yee *et al*., 2014) of many varieties can be found anywhere in the PRA area where there is sufficient water – streams, high elevations, towns, cities, homesteads etc. There are no maps available of their distribution. Ornamental hawthorns are found in most urban areas. They are very common in the wild in western Washington where rainfall is sufficient as they are spread by birds and other animals. (M. Klaus, WSDA, USA, *personal communication*, December 2015). The distribution of native hawthorn (*C. douglasii*) is discontinuous http://www.plantmaps.com/nrm/crataegus-douglasii-black-hawthorn-native-range-map.php. in the PRA area. (Hood *et al*., 2013).

Maps of the hosts that have been trapped around the four main composting facilities and the proximity of commercial apple orchards to these facilities are presented and discussed under the risk of entry section (2.0) of this PRA; their relevance in relation to the risk of establishment is discussed in the risk of establishment section (3.0) along with maps of hosts that are trapped across the state by the WSDA.

1.07 - Specify the pest distribution for a pest initiated PRA, or the distribution of the pests identified in 2b for pathway initiated PRA

The global distribution of *R. pomonella* is restricted to Canada, Mexico and the USA (Yee *et al*., 2014). Table 2 gives details of the official pest distribution status (FAO, 2011) as determined by the North American Plant Protection Organisation (NAPPO) and presented by EPPO (2015). In addition to these records the pest has also been found in Montana infesting black hawthorn (*C. douglasii*) (Yee *et al*., 2015).

Table 2. Distribution of *R. pomonella* (EPPO, 2015, Version 5.3.5, accessed 18 September 2015)

Country/state	**Official distribution (FAO, 2011)**
Canada	***Present, restricted distribution***
British Columbia	Present, few occurrences
Manitoba	Present, no details
New Brunswick	Present, no details
Nova Scotia	Present, no details
Ontario	Present, no details
Prince Edward Island	Present, no details
Québec	Present, no details
Saskatchewan	Present, no details
Mexico	***Present, restricted distribution***
USA	***Present, widespread***
Arkansas	Present, no details
California	Present, widespread
Colorado	Present, widespread
Connecticut	Present, widespread
Delaware	Present, no details

Florida	Present, restricted distribution
Georgia	Present, no details
Idaho	Present, no details
Illinois	Present, widespread
Indiana	Present, widespread
Iowa	Present, no details
Kansas	Present, no details
Maine	Present, no details
Maryland	Present, no details
Massachusetts	Present, widespread
Michigan	Present, widespread
Minnesota	Present, no details
Mississippi	Present, no details
Missouri	Present, no details
Nebraska	Present, no details
New Hampshire	Present, widespread
New Jersey	Present, widespread
New York	Present, widespread
North Carolina	Present, widespread
North Dakota	Present, no details
Ohio	Present, no details
Oregon	Present, widespread
Pennsylvania	Present, no details
Rhode Island	Present, no details
South Carolina	Present, no details
South Dakota	Present, no details
Texas	Present, widespread
Utah	Present, widespread
Vermont	Present, widespread
Virginia	Present, no details
Washington	Present, no details
West Virginia	Present, no details
Wisconsin	Present, widespread
Wyoming	Present, no details

The pest is present with restricted distribution in Canada and Mexico but it is more widespread in the USA. It is endemic in the east of the USA where it shifted from its native hawthorn (*Crataegus*) (thought to be *C. mollis*; Hood *et al*., 2013) to apple (*Malus*) around 150 years ago. Its presence in the Pacific Northwest (not a strictly-defined area), including the state of Washington was recently-reviewed and it is considered to be an introduced species as a result of the movement of infested apple fruit (Hood *et al*., 2013).

The first detection of *R. pomonella* in the west of the USA was made in Oregon in 1979 (AliNiazee and Penrose, 1981; in Brunner, 1987) and then in Washington in 1980 (Rebhan, 1980; in Brunner 1987).

Distribution of *R. pomonella* in the state of Washington, USA
The distribution of the pest in the state of Washington has been defined by official surveillance led by the WSDA, since *R. pomonella* is regulated within the state of Washington.

The rationale for this is described at: http://agr.wa.gov/plantsinsects/insectpests/applemaggot/

The purpose of regulation is: '*to facilitate the movement of commercial fruit to domestic and international markets by providing shippers with one of two types of WSDA documents certifying their fruit is apple-maggot free*'

In order to achieve this, the state is divided into the quarantine area and the pest-free area (PFA) for the pest. See Figure 1a.

The use of the term *'pest-free area'* was first formally implemented in 1995 when the International Standard for Phytosanitary Measures (ISPM) number 4, '*Requirements for the establishment of pest-free areas'* was published (FAO, 1995).

Correspondence with the WSDA (M. Klaus, WSDA, USA, *personal communication*, December 2015) showed that official surveillance for *R. pomonella* has been ongoing since 1980, the term *'pest-free area'* was adopted in 2000.

The term *'quarantine area'* is defined as '*an area in which a quarantine pest is present and is being officially controlled'* (this term is pending revision) (FAO, 2015). In the state of Washington the '*quarantine area*' for *R. pomonella* is those parts of the state where the pest is considered to be established. While *R. pomonella* is not subject to eradication in those locations, measures are in place aimed at preventing spread. This area falls outside of the PRA area and is not subject to much general surveillance by the WSDA.

The PFA (the PRA area) is subject to revision each year by the WSDA following review of the preceding year's survey data and other information by the WSDA-led Apple Maggot Working Group (AMWG) and public consultation on their recommendations. The final decision on which parts of the state are in the PFA and which are in the quarantine area is taken by the Director of the WSDA. M. Klaus, WSDA, USA, *personal communication*, December 2015.

As stated in Klaus (2014), within the state of Washington, annual surveys for *R. pomonella* are undertaken to:

- Determine which areas meet the PFA status (FAO, 2015)
- Conduct certification monitoring (in) or around commercial orchards to determine which growers meet the phytosanitary requirements to allow them to ship fresh apples
- Implement an *'Apple Maggot Detection Response Plan'* - aimed at preventing the establishment of the pest in the PFAs of the state

Further detail on the survey methodology is presented in the standard operating procedure (SOP) (Klaus, 2007) with some detail given below.

Traps for apple maggot are deployed in the PFA as well as around orchards in the quarantine areas if an orchard owner wishes to have their premises certified to move into the PFA. Traps are placed in trees bearing fruit of all species of apple, crab apples, ornamental and native hawthorn.

For commercial orchards, the WSDA does not trap inside or on the borders of commercial orchards for certification. Orchards are not trapped because current Integrated Pest Management (IPM) practices (sprays, sanitation etc.) are believed to keep the risk from the pest extremely low (this is further assessed in this PRA). If the pest is detected within ½ mile of the orchard (where all hosts are trapped) then '*high density trapping'* (and appropriate follow-up action- the *'Apple Maggot Detection Response Plan'* - as detailed in Klaus (2007)) will be deployed (M. Klaus, WSDA, USA, *personal communication*, December 2015).

Additional intensive trapping, whereby all known hosts located within a 5 mile radius of the four composting facilities in the PFA are trapped, commenced in 2015.

In general there are 3 types of trapping methodology used (as cited from Klaus, 2014):

- High density – placed in all accessible host trees 0.5 to 1 mile around sites positive for the pest; used to delimit the scope of newly-detected pest infestations
- Certification – placed in the 0.5 mile buffer zone around orchards; required for exportation of fruit from quarantined areas and may be needed for exports from the PFA
- General survey – placed on host trees at *ca.* 1/square mile where no pest has been previously been detected in the PFA; rotated annually for optimal sampling within the square mile

In recent years in the main apple maggot survey the WSDA has placed traps and monitored for the pest from 20 June to 30 September in selected counties using standard yellow panel sticky traps baited with ammonium carbonate lures. Wherever practical, traps were placed under canopies on the south facing side of host trees. Traps were checked every two to four weeks and changed at least every four weeks. Trap deployment focused on non-commercial, residential host trees in populated areas, abandoned apple orchards, and feral, roadside host trees. Klaus (2013, 2014, 2016).

Detections of the pest between 2003 and 2015 in relation to the four composting facilities in the PFA are presented in Figure 3.

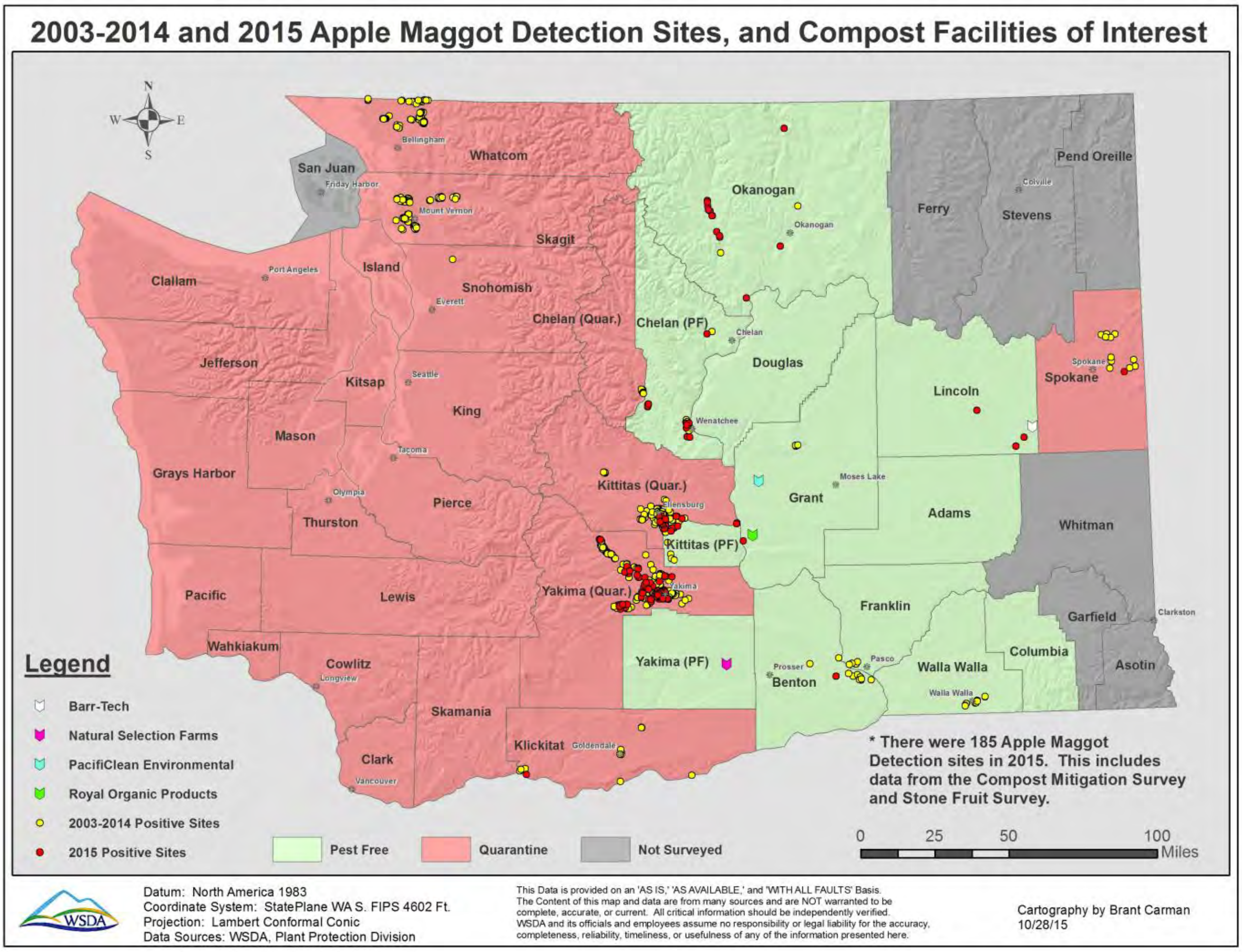


Figure 3. Trapping sites found positive for *R. pomonella* between 2003 and 2015. WSDA, 28 October 2015.

Detections of the pest in 2015 alone up to 31 August in relation to the four composting facilities in the PFA are presented in Figure 4.

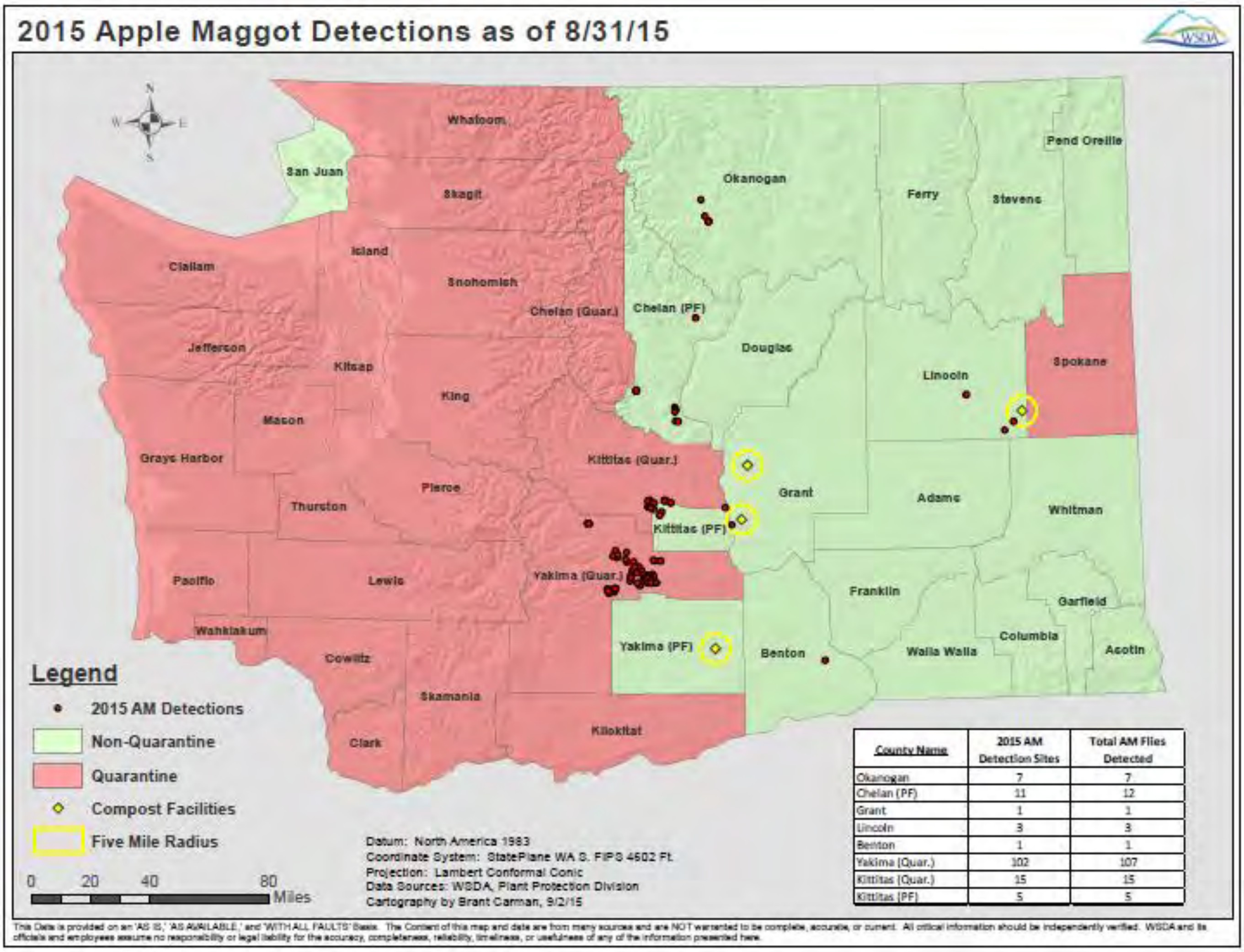


Figure 4. Trapping sites found positive for *R. pomonella* in 2015. WSDA, 28 October 2015.

Findings in 2014 in relation to previous years are presented in Figure 5 and the trap sites and types of traps deployed in 2014 are presented in Figure 6.

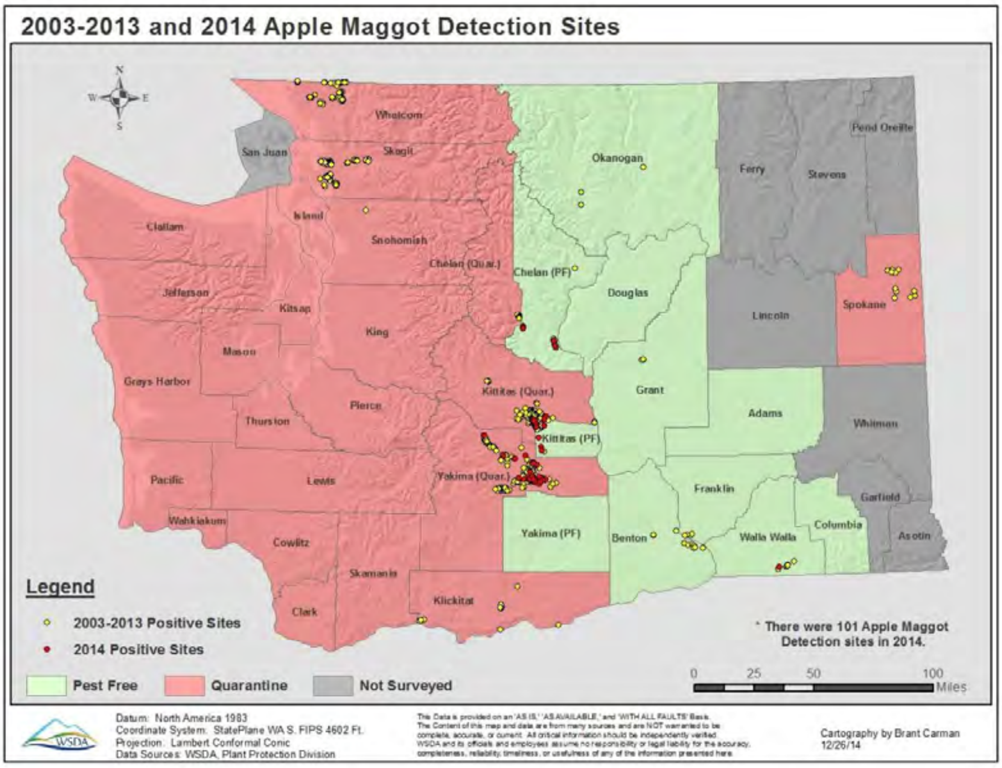


Figure 5. Trapping sites found positive for *R. pomonella* between 2003 and 2014. Klaus (2014).

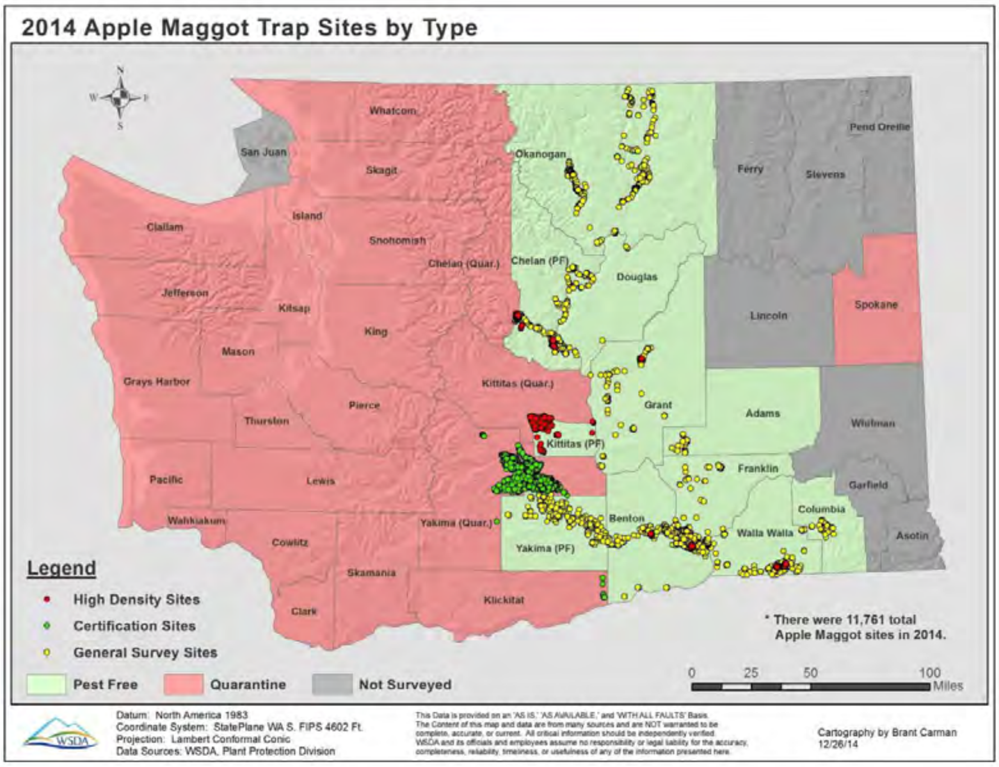


Figure 6. Trapping sites and types of trapping deployed by the WSDA in 2014. Klaus (2014).

Findings in 2013 in relation to previous years are presented in Figure 7 and the trap sites and types of traps deployed in 2013 are presented in Figure 8.

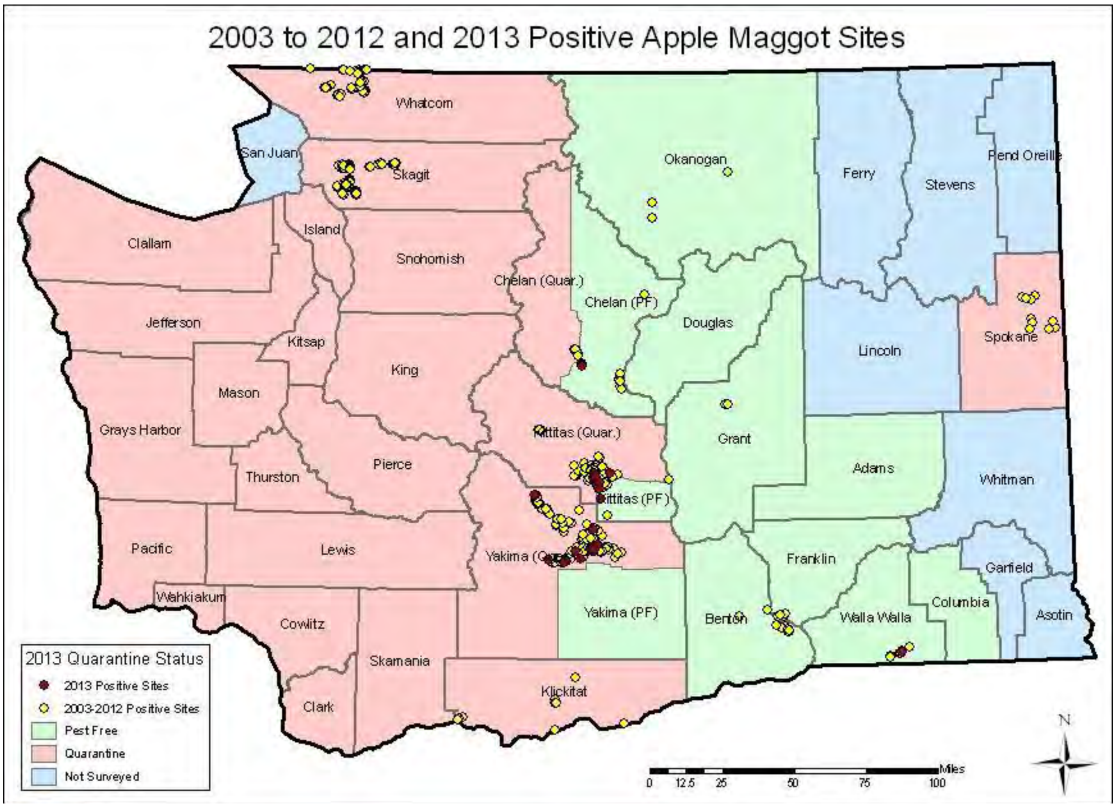


Figure 7. Trapping sites found positive for *R. pomonella* between 2003 and 2013. Klaus (2013).

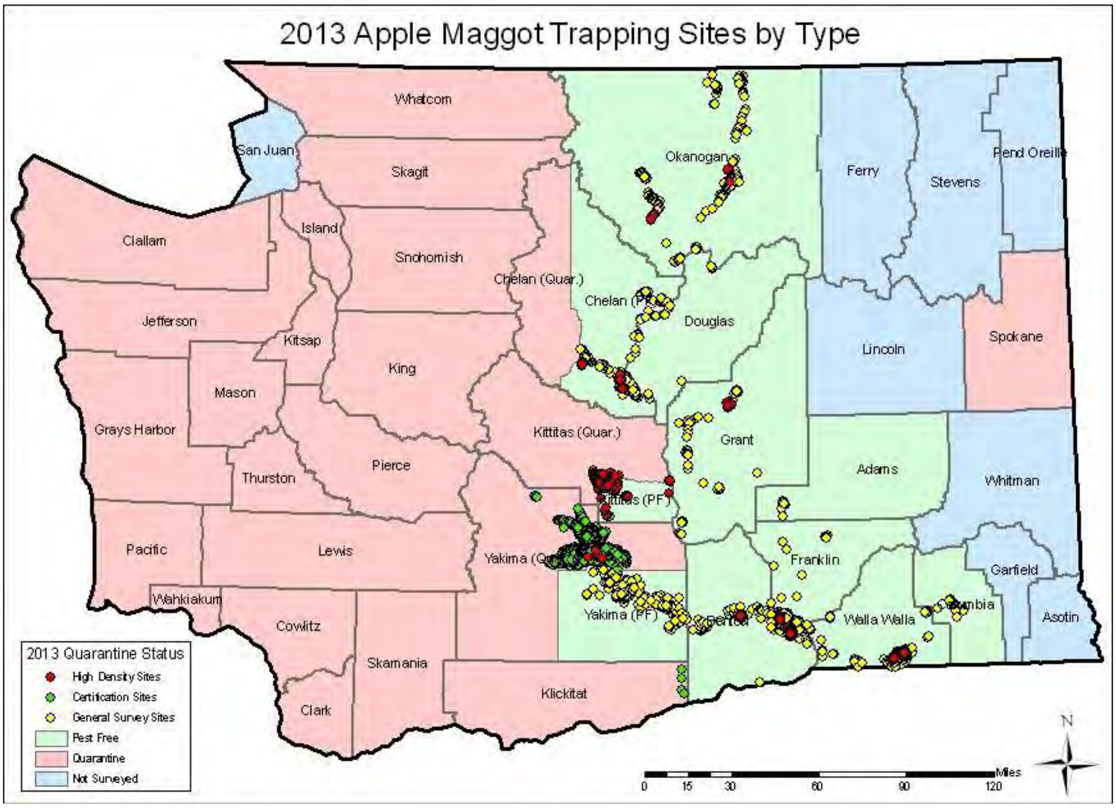


Figure 8. Trapping sites and types of trapping deployed by the WSDA in 2013. Klaus (2013).

The ongoing surveillance and trapping undertaken by the WSDA has led to the detection of low numbers of adult flies of *R. pomonella* on traps in host trees located outside of commercial apple orchards in the current PFA (the PRA area). Fruit harvested from these trees has been incubated. In some years juvenile forms of *R. pomonella* have developed and some parts of the PFA have been added to the quarantine area, most recently in 2011. However, there has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). The pest has not been detected in commercial apple fruit harvested in this area of the state. (Klaus *et al*., 2016).

Although there have been detections of *R. pomonella* in the current PFA, the pest is not considered to be established there. All such findings are subject to the *'Apple Maggot Detection Response Plan'* (Klaus *et al*., 2007). In such circumstances the WSDA Plant Protection Division notifies the local county pest board, members of the Apple Maggot Working Group and the WSDA Commodity Inspection Division. The response depends upon the location of the detection but the aim is to invoke any necessary control measures, inspect fruit from threatened orchards and to determine whether the pest has become established at the affected site.

The pest is considered to be established in the quarantine area of the state and trapping is rarely undertaken there, thus, the levels of infestation in those areas are not easily described. The most recent surveillance results for counties in the quarantine area where municipal green waste is sourced for processing in the PFA along with the maps of trapping for *R. pomonella* around the four composting facilities in the PFA in 2015 are presented and discussed in the risk of entry section (section 2.0).

<u>Detection efficiency for *R. pomonella* in the state of Washington</u>

As stated above, the traps for *R. pomonella* that have been used in recent years are yellow panel sticky traps baited with ammonium carbonate lures. There are alternative traps (red spheres, etc.) and lures (fruit volatiles). These are discussed in the risk management section of the PRA.

The efficacy of the trapping methodology depends on a number of factors including the density of the pest in the area being trapped (low density means lower probability of detection), the type of host being trapped, the abundance of hosts etc. Fruit fly traps generally detect low percentages of local populations of flies. As *R. pomonella* is not a long-distance flier this means that the traps have to be placed in areas where the pest would establish and might be most easily detected. In the PRA area (the PFA) fly densities are very low or non-existent which reduces the likelihood of detection. Further discussion on trapping methodology and efficacy is given in the risk management section of this PRA (section 7.0).

Over the last ten years the programme has trapped approximately 7,400 to 10,300 sites (Table 3) in the state of Washington. A very low percentage of the sites resulted in positive detections. Positive sites range from a minimum of 0.51% to a maximum 4.29%. Of these positive sites (1368 sites 2005 - 2014) only two have resulted in the discovery of populations that resulted in a change in the PRA area, most recently in 2011. (Klaus *et al*., 2016).

Table 3. WSDA trapping sites and positive finds of *R. pomonella* across the state of Washington, 2005-2015 (Klaus *et al.*, 2016)

Year	**Trap sites across the state of Washington**		
	Total number	Total number that were positive for *R. pomonella*	% sites that were positive
2005	8,265	355	4.30
2006	10,332	183	1.77
2007	8,523	205	2.41
2008	9,118	144	1.58
2009	9,422	124	1.32
2010	7,427	84	1.13
2011	7,543	64	0.85
2012	8,223	67	0.81
2013	7,889	41	0.52
2014	8,164	101	1.24
2015	9,832	185	1.88

However, there has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016).

Pest categorisation

Identity of the pest (or potential pest)

1.08 - Does the name you have given for the organism correspond to a single taxonomic entity which can be adequately distinguished from other entities of the same rank?

Yes.

R. pomonella is a single taxonomic entity within the *'Pomonella species group'* (*R. pomonella*, *R. mendax*, *R. zephyria*, and *R. cornivora*). The strongest feature that distinguishes *R. pomonella* from the other 3 species is its wide host range. (Bush, 1966).

Host-range aside, there may be difficulties in differentiating the species both morphologically and based on molecular analysis of DNA, as summarised by CABI (2015):

Adult flies of *R. pomonella* cannot be easily distinguished from other species in the same group based upon morphology alone (Berlocher, 2000). *R. pomonella* may be distinguished from *R. zephyria*, in most, but not all cases, based upon genital morphology (Westcott, 1982); morphometric analyses may be of use in distinguishing *R. pomonella* from other species (Bi *et al*., 2007). Even detailed genetic studies have not revealed any consistent differences between *R. pomonella* and *R. mendax*, and *R. zephyria,* making the use of conventional barcoding *'improbable'* (Xie *et al*., 2008). An alternative which may have potential is the use of multilocus genotypes to assign single individual specimens of unknown taxonomy to one of the species (Schwarz *et al*., 2005; Michel *et al*., 2007).

Yee and Klaus (2015) described the difficulties involved in separating *R. pomonella* from *R. zephyria* during the WSDA surveys for the pest since both species are caught on the yellow sticky traps that are used to detect the adult flies. Females can *normally* be separated since *R. pomonella* usually has a longer aculeus (ovipositor) but there can be some that are intermediate between the two species and may be misidentified or not identified. Female flies are assigned to *R. pomonella* if their aculeus length is $\geq$ 0.98mm; they are assigned to *R. zephyria* if the measurement falls below that. According to Westcott (1982) (in Yee and Klaus, 2015) those falling between 0.88 and 0.98mm are a *'problem area'*. Males are separated using the orientation and shape of the surstyli (paired appendages on the 9th abdominal tergum – the dorsal surface of the 9th segment). (Bush, 1966; Westcott, 1982; Yee *et al*., 2011; in Yee and Klaus, 2015). Yee and Klaus (2015) found that for surveys conducted between 2005 and 2013, based upon aculeus length alone, >94% of flies were identified with a mean of 3.6% falling in the intermediate range (0.6 to 5.8% of captures).

Yee (USDA, ARS, USA, *personal communication*, April 2015) advised that with the state of Washington, most adult flies of *R. pomonella* and *R. zephyria* are easy to distinguish using ovipositor (aculeus) length, wing shape, and male genitalia citing Yee *et al*. (2013) and Yee *et al*. (2009); however, he acknowledged that accurate identification is necessary for a quarantine pest.

In addition to the difficulties in separating the species, some populations of *R. pomonella* may be classified as belonging to a particular race (primarily apple or hawthorn) based upon host preferences, as well as time of adult emergence which is genetically-based (Yee, *personal communication*, April 2016). See section 1.02d for further details.

1.10 - Is the organism in its area of current distribution a known pest (or vector of a pest) of plants or plant products?
Yes. *R. pomonella* is a very damaging pest of the fruit of apples (*Malus* spp.), hawthorns (*Crataegus* spp.), and other hosts in areas where it occurs in Canada, Mexico and the USA (Yee *et al*., 2014).

Direct damage is caused when the adult female fly deposits her fertilised eggs beneath the surface of a host fruit causing a puncture wound. The flesh around the puncture wound often fails to grow leading to a sunken spot on the surface of the fruit. Larvae that develop from the eggs feed on the flesh of the fruit and move through the fruit leaving a brown trail in their wake. Damaged fruit usually drops prematurely and rots on the ground. Direct losses arise from the negative effect the pest has on fruit quality and the overall yield of an orchard. Indirect losses may arise from the potential loss of export markets due the phytosanitary requirements imposed by countries importing fruit from countries or areas where *R. pomonella* is known to occur. Control costs are significant where the pest is established. Zhao (2007). Detail on the economic impact caused by *R. pomonella* is described in section 6.0 of this PRA.

1.12 - Does the pest occur in the PRA area?
Yes. Adult flies of *R. pomonella* have been detected in the PRA area (the PFA of the state of Washington), albeit at relatively low numbers. However, the pest is not considered to be established here. The primary criterion for determining if the pest is established is the discovery of multiple life stages (Marra, WSDA, USA, *personal communication*, April 2016). It is subject to official control in this area of the state (Klaus *et al*., 2007). See sections 1.03 and 1.07 for further detail.

1.13 - Is the pest widely distributed in the PRA area?
The pest is not widely-distributed in the PRA area (see sections 1.03 and 1.07 for further details).

1.14 - Does at least one host-plant species (for pests directly affecting plants) or one suitable habitat (for non-parasitic plants) occur in the PRA area (outdoors, in protected cultivation or both)?
Yes. Hosts in the main genera *Malus* and *Crataegus* as well as other genera occur in the PRA area. This is where most of the commercial apple orchards of the state are situated. Details of the hosts are given in section 1.06 and later sections of this PRA. *Malus* spp. (apple and crab apple); *Crataegus* spp. (native and ornamental hawthorn) are used to place traps for the pest by the WSDA in their annual surveys (Klaus *et al*., 2007) and maps of the hosts which have been used to bear traps are given in section B, potential for establishment.

1.15a - Is transmission by a vector the only means by which the pest can spread naturally?
No. *R. pomonella* is a free-living organism. The adult insects are flies which spread naturally without the need for a vector.

1.16 - Does the known area of current distribution of the pest include ecoclimatic conditions comparable with those of the PRA area or sufficiently similar for the pest to survive and thrive (consider also protected conditions)?
Yes in part. *R. pomonella* is established in a range of ecoclimatic conditions in the USA, Canada and Mexico. It is considered to be an introduced species in the western side of the USA, including the state of Washington. It is not established in the PRA area (the PFA) but adult flies have been detected here; its prevalence is considered to be low relative to the quarantine area of the state. This is partly-explained by a difference in climate (see 3.03) between the quarantine area and the

PFA. Parts of the area are similar; principally those where there are riparian habitats and cooler temperatures. See 3.03 for further details.

1.17 - With specific reference to the plant(s) or habitats which occur(s) in the PRA area, and the damage or loss caused by the pest in its area of current distribution, could the pest by itself, or acting as a vector, cause significant damage or loss to plants or other negative economic impacts (on the environment, on society, on export markets) through the effect on plant health in the PRA area?

Yes. Host plants are present in the PRA area including commercially-grown apples, native and ornamental hawthorn, feral and backyard apples, and crab apples.

Across its area of distribution outside of the PFA of the state of Washington, in the absence of control *R. pomonella* can cause direct damage to fruit leading to quality and yield losses in commercial apple orchards (amongst other commercial hosts). It already attacks non-commercial hosts in the PRA area (including hawthorns and apples outside of commercial orchards). It has the potential to infest commercially-grown fruit, principally apples in this area.

In addition to the potential for loss of quality and yield, because of its status as a quarantine pest, if it established in commercial orchards in the PRA area it would result in costs and losses related to control, as well as export markets for fruit of hosts grown here, principally apples (but possibly also plums, pear, apricots and possibly sweet cherry).

This pest could present a phytosanitary risk to the PRA area.

1.18 - Summarise the main elements leading to this conclusion.
R. pomonella is already known to be a highly-damaging pest of a range of hosts in its current area of distribution. It is also subject to phytosanitary regulation both in the PRA area and around the world.

Host plants are present in the PRA area including in commercial apple orchards and non-commercial hosts outside of orchards such as native hawthorn (*C. douglasii*) and feral or untended apple trees.

Although the ecoclimatic conditions that favour the pest (moderate temperatures, high precipitation) are limiting in the PRA area, where summer rainfall is low and temperatures are high, low numbers of adult flies have been trapped here during the WSDA surveys. Over the years as a result of finds of juvenile forms of the pest in the WSDA survey, parts of the PFA have been recommended for a change in status to becoming part of the quarantine area. Most recently part of Lincoln County has been proposed for this change resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). This suggests that *R. pomonella* has the potential to establish in parts of the PRA area (the PFA of the state of Washington).

R. pomonella poses a potential phytosanitary risk to the PRA area.

Probability of entry of a pest

Preamble

The apple maggot (*R. pomonella*) is a successful invader of the western states of the USA including the state of Washington. The natural movement of *R. pomonella* from the western side of the state to the PRA area (the PFA) is restrained by mountain passes that are absent of hosts except for black hawthorn (*C. douglasii*) and feral apple and crabapple trees (*Malus* spp.) along stream courses.

The most likely risk of movement to the PRA area is believed to be mainly by the transport of infested fresh fruit by individuals (Brunner 1987; Dowell, 1990 (in Dowell and Wilson, editors, 1990); Hood *et al*., 2013) but there is also the potential for the pest to move with soil (or growing media) associated with infested host trees (CABI, 2015; EPPO 2006, 2015, 2016).

In fruit of apples, hawthorns or other host trees it is likely that all immature life stages will be present. This would include mature larvae ready to drop from the fruit prior to pupation, and possibly pupae that are contained in the fruit. Adults may be ready to emerge from pupae or the pupae may be ready to undergo diapause or are in diapause. Soil (or growing media) associated with infested host trees would contain only pupae in diapause or which are in post diapause development and may be ready to develop into adults.

A pathway is defined as '*Any means that allows the entry or spread of a pest*'. The entry of a pest is defined as: '*Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled*'. (FAO, 2015).

Recently a new pathway for the potential entry of *R. pomonella* to the PRA area was recognised. Although at least three composting facilities have been moving municipal green waste from parts of the quarantine area of the state of Washington[4] into the PRA area for a number of years, the recent construction and startup of a new fourth large operation in Grant County (in the PRA area) brought to light this pathway and its potential for the risk of entry of the pest to the area. In general terms, the route that the waste takes is that it is first gathered at transfer stations where it may or may not be mechanically processed (ground or shredded) before it is moved to the facilities. Some waste is also moved directly to the facilities from within the PRA area.

Factors that influence the risk of entry of the pest to the PRA area on this pathway are considered at the end of this preamble for each of the four composting facilities in turn (as four separate pathways). No other pathways have been assessed.

[4] One of the composters, Royal Organic Products has also received waste from Oregon

These factors are:

- The association of the pest at the point of origin
- The impact of current management practices on the pest
- The volume and frequency of movement of the commodity on the pathway
- The likelihood of the pest surviving and multiplying on the pathway
- The likelihood of the pest being detected on the pathway

And

- The risk of transfer of the pest at the end of the pathway to a suitable host or habitat.

Background information relevant to assessing the risk of entry of *R. pomonella* to the PRA area on this new pathway is provided below.

Waste stream
The municipal green waste stream includes grass clippings, fruit from private yards, municipal spaces and discarded from fruit collection programmes, shrub and tree trimmings, whole plants with roots and associated soil (observed at two transfer stations in the autumn of 2015 by Mastro and Reynolds), and agricultural waste and fruit from commercial premises. Other materials in this waste stream (metals, plastics, glass etc.) do not provide a direct pathway for the movement of *R. pomonella*, but will affect how and where the green waste is handled, processed and composted and thus may influence the risk of movement of the pest. This is not discussed further in this PRA.

Pest biology, geographic incidence, and potential numbers of life stages in municipal green waste
The biology of *R. pomonella* is relevant to the likelihood of entry of the pest to the PRA area. It is described under section 1.02b and summarised here. Adult females are attracted to ripening fruit where they can each lay more than 200 eggs just under the skin of the fruit. Eggs normally hatch within 3 to 7 days. The larvae develop within the fruit for an additional 13 to 50 days depending on temperature and the host fruit type. Late third instars normally drop from the fruit, burrow into the soil, and moult to a fourth instar and then quickly to the pupal stage. After diapausing over the winter, adult flies emerge beginning in June in the following year (Mattsson *et al*., 2015). Some pupate in the duff layer, and occasionally directly in the fruit. Some flies may emerge from non-diapausing pupae in the same year (a second brood); while others may delay emergence for two or three years. This means that in one area, there is the possibility of one or two generations per year as well as one generation every two or three years. Normally it is believed that emergence in the same year without diapausing is suicidal as the second brood does not have time to complete a life cycle (i.e., produce offspring that pupate before the onset of winter). Completion of a second generation was thought possible in the southern part of the eastern range of apple maggot where host maturation is spread over a longer period and where freezing occurs infrequently. However,

in that area there was no evidence of a second brood of flies (Bush, 1966). More recently however Meck *et al*. (2008) showed strong evidence for a second brood in North and South Carolina at lower elevations. This was based on bimodal trap capture data and development times from Boulanger *et al*. (1969) with a degree day (DD) estimate of 1,047 DD for *R. pomonella* to go from egg to adult.

According to Brunner (Washington State University, *personal communication* to Mastro, USA, October 2015) the temperatures during the 2015 apple growing season would have provided a good opportunity to complete a second generation in the state of Washington. In this instance the life cycle would be that after the first generation has pupated they emerge in the same year, mate, lay eggs, complete larval development, pupate, and overwinter in diapause. Neven (USDA, ARS, *personal communication* to Mastro, USA, October 2015) stated '*Non-diapausing AM pupating in late June or early July could easily complete a 2nd generation in one year. My data show that the non-diapausing pupae take about 4 to 6 weeks to emerge as adults. If these flies emerge early in the season, there would be enough time for them to produce a 2nd generation, especially on the west side of WA or in areas where the temperatures are milder and host fruits are available*'. Thus, two generations per year could increase the number of life stages of *R. pomonella* in the municipal green waste stream.

With the exception of adult flies, potentially all life stages of *R. pomonella* could be transported in municipal green waste from the quarantine areas of the state where the waste is collected to the PRA area.

The risk of association of *R. pomonella* with municipal green waste is related to a number of factors which are discussed below and then again for each pathway based upon the origin of the waste that each of the facilities processes. Thus:

In terms of the period of time when fruit is likely to become infested, Yee and Goughnour (2008) found that apple maggot had suitable hosts available for infesting for at least 3 months in two areas of western Washington. In their study, the major hosts, apples and hawthorns, were ripe and thus susceptible to infestation from early August to mid-October. The aim of the study was not to describe the seasonality of fruit becoming infested so earlier collections were not made. Fruit that ripens as early as June can also be infested. Given larval development times of 13 to 50 days, depending upon the temperature and the variety of apple infested (Brunner, 1987) apples infested even as late as early October (or later) could contain larvae in November. Dean and Chapman (1973) reported that larvae were found in apple in December based upon one study in New York. Mattsson *et al*. (2015) found that flight activity for adult flies of *R. pomonella* began about June 1 on black hawthorns and a few days later on early apples in Vancouver in the western side of the state of Washington. He also determined that the date when rapidly growing or softening of host fruit (making the fruit more suitable for oviposition) began on black hawthorns and early apples was about June 9 and June 12, respectively (based on Figures 5 and 6 of their paper).

Although municipal green waste is collected both in the east and the west side of the state, it is the west (the main quarantine area for *R. pomonella*) which is more heavily infested. Yee and

Goughnour (2008) found high levels of fruit infestation in their sampling of four sites in western Washington. Over two years at two sites (2005 and 2006) and three years (2004 to 2006) at one of these sites they found 100% of the apple trees sampled were infested. Other hosts (crabapple, hawthorn, common and Asian pear etc.) showed various high levels of infestation with Asian pear (named then as *P. serotina*) and English hawthorn (*C. monogyna*) exceeding 80% of the sampled plants infested. Hood *et al.* (2013) found fruit infestation rates (several hosts) on the west side of the Cascade mountain range to be over 400 times greater than on the east side. By some estimates over eighty percent of the untended apples in western Washington are infested with the pest (Yee and Goughnour, 2008).

Spokane County is in the eastern side of the state of Washington and is also part of the quarantine area where municipal green waste is gathered. The most recent levels of infestation were determined in 2015 by the WSDA using a low level of trapping compared to other counties. Four sites were trapped; one of these yielded 22 flies. Personal communications support the view that Spokane County has a lower level of infestation than parts of the western side of the state such as Seattle. It is thought that if 100 traps were randomly placed in host trees in these areas, 80% would be positive in the Seattle area compared to 20% in Spokane county (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015).

Yakima County is in central Washington and part of it is in the quarantine area where municipal green waste is gathered. The most recent levels of infestation in the quarantine area were determined in 2015 when 4870 certification traps yielded 153 flies at 109 sites (Klaus, 2016). It is thought that if 100 traps were randomly placed in host trees in this area only 1% would be positive (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015).

Shipment of municipal green waste – unprocessed or processed

When municipal green waste is shipped in an unprocessed form (not reduced in size by grinding, shredding, or chipping) it may undergo some compaction, mechanical damage, and heating when it is collected at the points of origin and consolidated at transfer stations. The effects these factors would have are variable and it is not known what the impact would be on the survival of the various life stages of *R. pomonella*. Although these are not mitigation measures they may reduce the survival and thus the numbers of life stages of the pest arriving at the composting facilities in the PFA.

In other cases the waste is reduced in volume by mechanical means (grinding, or shredding, but not chipping, dependent on the operator) before shipment to the PFA. This may affect the various life stages mechanically, or by heating associated with the beginning of the decomposition process where or when this commences prior to arrival at the composting facilities. The effect of the mechanical reduction processes on the life stages of *R. pomonella* has not been studied but the potential impact is discussed below.

Effect of storage of waste and transportation
The effects of the conditions and length of storage of unprocessed or processed waste before and after transportation, and possibly the mode of transportation on any of the life stages of *R. pomonella* would vary in an unknown way.

Regardless of whether the waste was transported as unprocessed, or ground or shredded (or chipped) prior to transport, the incidence of survival prior to arrival at the composting facilities would largely be related to the amount of heating (temperature and duration) that occurred prior to or during transport.

Given the same length of time until transportation of the waste and other variables being equal until arrival at the composting facilities in the PRA area, mechanically processed waste would rise to a higher temperature more uniformly throughout a pile or load compared to the waste that is not processed prior to arrival at these facilities. There is currently no uniform requirement or standard for either processing by mechanical means; or heating, either through pre-composting or by any other artificial means prior to transport to the PRA area or in the transportation phase. In other words initial collection, processing, and transport are not standardised and so cannot be evaluated.

Mechanical processing and composting of municipal green waste
Municipal green waste collected in the state of Washington is being processed mechanically at various points along the pathways of movement, dependent upon the composting facility, with composting (in windrows or aerated/passively-aerated static piles) being the final step in the process. There are no published studies of the impact that the mechanical processes and the range of equipment that is used has on any of the life stages of *R. pomonella*. Nor are there any published studies on the impact that the various types of composting have on the pest.

Yee and Chapman (USDA ARS, USA) have recently conducted a study to investigate the survival of pupae of *R. pomonella* buried at different depths in ground yard waste in outdoor piles in the state under different conditions including the use of tarpaulins and insulation. Their study does not attempt to evaluate the effect of grinding itself. Yee also conducted a short heat-kill study for pupae. These studies are discussed later in this section.

It is logical to assume that some mortality occurs in the mechanical processing of the waste and this is demonstrated in the few published studies (summarised below) that provide some information on insects other than *R. pomonella*. Similarly, heating, whether it is achieved via composting or any other process, if maintained at a lethal temperature for a sufficient length of time will also reduce the pest's viability. If during composting, all of the life stages are exposed to lethal temperatures the risk posed by *R. pomonella* would be nullified. However, the likelihood of this happening depends on how strictly-managed the processes are. Incomplete composting, which can arise from a number of factors, could result in viable pupae surviving the initial composting process and being transferred to the curing windrows. This increases the possibility of emergence and escape of adult flies. We have no data to suggest that this happens in practice, nor have we found any data that would indicate how the curing process may affect the viability of juvenile stages of *R. pomonella.* This is discussed later in this section.

Mechanical processing of municipal green waste
There are two main types of equipment that can be used for processing green waste, chippers, and grinders.

Chippers are mainly used for processing woody material and would not perform well on grass clippings and similar soft material. Mastro and Reynolds visited the facilities involved in handling and composting the waste in the autumn of 2015 and found that chippers were not being used at the transfer stations where the waste is collected or at the composting facilities. However they are discussed here as they were tested in some of the studies that have been reviewed in this section.

Grinders handle a wider variety material than chippers and can handle greater volumes.

In a questionnaire used to produce this PRA, all of the composting facilities responded that they were using various types of grinders for mechanical processing of the waste at different points on the pathway. However, Mastro and Reynolds believe that the Natural Selection Farms facility also uses a shredder (a type of chipper), (which they did not see), but which the composter indicated was only being used for municipal green waste generated in the PFA (the PRA area) rather than in the quarantine area.

Of the grinders that are available there are two main types: '*horizontal*' and '*tub*'. They both work by pushing the waste against screens (grates) until the waste material goes through. The forces generated include compression (smashing), shearing and torsion (and probably others). The size of the material produced is controlled by the grate/screen size that is used to configure the machine. If it is a 2.5 cm (1 inch) grate then the maximum dimension in two planes of the particle should be no greater than 2.5 cm, however, in the third dimension, the pieces can be quite long, particularly for fibrous material. The size of the material generated by mechanical processing of the waste before it is composted at each of the facilities varies and this is indicated in the assessment of each of the four facilities in the main pathway section of this PRA.

Chippers are machines that use a sharp edge(s) to reduce the material. Most machines have a large heavy disc or drum that is fitted with knives in one or more openings. The material is forced against these knives and sheared into small pieces (chips). Another type of chipper is one which is equipped with two counter-rotating shafts that are fitted with knives or rippers that reduce the material. Shearing forces play a major part in the reduction process but compression and torsion forces are also applied.

Shredders are not discussed since none of the waste originating in the quarantine area is processed using this type of machinery. However there is some indication that some of the waste received by Royal Organic Products at the end of 2013 from Oregon was either not ground or it was coarsely shredded.

Review of studies on the effect of chipping and grinding host material on insect pests: Wood-boring beetles
In the studies that have been reviewed below, some of the insects are wood borers and have

fundamental differences from *R. pomonella* which must be borne in mind when making comparisons. The main difference is that *R. pomonella* is not protected by wood at any stage in the lifecycle but the pupae are capable of survival outside of host material (fruit) in soil or in duff. However, very dry soil conditions may kill the pupae (Yee, USDA, ARS, USA, *personal communication*, April 2016). The eggs and larvae of *R. pomonella* are afforded some level of protection when they are inside of host fruit. If wood is left intact then the life stages of the beetles that reside within the wood remain viable; disruption by mechanical processing leads to some or all of them being destroyed, as described below.

The Asian long horned beetle (*Anoplophora glabripennis*) is one of the wood-boring pests. It is much larger than *R. pomonella* and because its early instars depend on intact phloem for development, and it normally has a long, one or two-year life cycle; disrupting the wood that it lives in can cause mortality. The stages that offer the greatest regulatory risk are the callow adults, which have not emerged, pupae, and the late stage larvae. It should be noted that this insect can complete development in cut bolts of wood even when they are in the early larval stages. This is dependent on the size of the wood pieces and the conditions they are held under. Larvae, which are soft bodied, range in size from 5 to 60 mm long and up to 11mm wide (Wang *et al*., 2000). The first 2 or 3 instars feed on the vascular cambium and phloem of the host wood. The later larger instars seem to be able to survive largely on xylem tissue (including heart wood and sap wood). (Mastro, USA, *unpublished data*). The pupa (30 – 37 mm long) which is normally in a chamber cut in the xylem is so fragile that even careful handling in rearing operations can inflict damage. These life stages and the callow adults are all inside of the tree in the larval tunnels or the pupal chambers and are well protected from most physical damage (Wang *et al*., 2000). The adult does not emerge until it has hardened and can chew out through the wood and the bark. Even after emergence, the adults require some hours to become completely mobile. (Mastro, USA, *unpublished data*).

A study designed to answer regulatory questions about moving wood chips from trees infested with *A. glabripennis* used surrogates to evaluate the damage caused by mechanical processing (Wang *et al*., 2000). Other species and life stages of insects (described as being of a similar size and '*possibly*' body hardness to *A. glabripennis*) as well as plastic worms, were used as surrogates for *A. glabripennis* because of a lack of life stages. This study showed that it was the smallest of the plastic worms tested (10, 25 and 40 mm length tested in 1997; 10 and 40mm tested in 1998) which sustained the least damage. In fact in 1997 the 40mm length plastic worm was 14.3 times more likely to sustain damage than the 10mm length worm. In the 1998 trial 96% of the 40 mm worms were damaged and only 74% of the 10mm worms. One hundred percent of all three species of live surrogate insects used in the 1998 study were killed. All three species tested were soft-bodied immature insects and were not generally distinguishable after chipping. This study, although done with a chipper, illustrates that in the case of the plastic worms, the smaller the surrogate the more likely it is to <u>not</u> sustain damage.

Similar to the Asian long horned beetle, the emerald ash borer (*Agrilus planipennis*) begins feeding in the phloem of host trees but it completes its larval development there and does not feed on the xylem. It is also soft-bodied, and prone in the late larval and pre-pupal and pupal stages to be easily damaged. The larvae can be compromised if they have lost their food source or physical protection. This pest usually spends 10.5 to 11 months inside of host ash trees (*Fraxinus* spp.) developing to the adult stage. In colder climates they can require 2 years to complete a life cycle. Late instars are 26 to 32 mm long and the pre-pupal stage is ½ to 2/3 that length. The pre-pupal stage is the overwintering stage and it is located approximately 1 cm under the bark surface of its host.

In a series of trials (2002 to 2005) both a chipper and a grinder were evaluated for their effect on (mostly) the pre-pupal stage of *A. planipennis* (McCullough *et al*., 2007). The chipper was tested in only one configuration while the horizontal grinder was tested with four grate/screen sizes (2.5, 5, 10 and 12.7cm) over two series of tests. The chipper produced more uniform chips; 84% were in a 2.5 cm sieve size class and there were no survivors out of the 1,565 life stages contained in the logs that were chipped. However, there was some survival in all material that had been ground with the exception of the machine configuration which included the 2.5 cm grate.

In the 2002 test, 18% of the pre-pupae recovered in chips created using the 10cm grate with the grinder were still alive. In the later 2005 test pre-pupal survival was 0.19, 0.57, and 0.57% with respectively 5, 10, or 12.7 cm grates, with an overall survival rate of 0.45%. In a related experiment when chips containing pre-pupae were buried in chip piles, 85% of them perished during the winter and none emerged as adults the following spring. In separate samples with pre-pupae held in plastic tubs there was no adult emergence. The larval, pre-pupal and pupal stages of *A. planipennis* are normally all completed under the intact bark of living ash trees. In the phloem area, where they develop, conditions are favorable for them and they are protected from physical injury from most causes (the exception being wood peckers or parasites). In a chip pile they are subjected to desiccation, changes in temperature and pathogens, and probably in small piles also predators. Because the larvae and pre-pupae have a limited ability to move once separated from their galleries they are therefore unlikely to be able to move to more favorable conditions. It should be noted that this pest does survive in small logs cut from infested trees and held outside during the winter months. The authors of this manuscript note that even though the survival rates of the pre-pupae in grinding chips is low, when large volumes of waste created in grinding infested ash, potentially containing this pest, the number of pre-pupae in a large volume increases the numbers of survivors and therefore the risk of their movement to a new area.

Of note is that during these trials the researchers found that some chips larger than the grate size were being produced. When this was investigated it was found that the operator had modified the rails that held the screens which produced a large gap above them. The point to be made is that this occurred, even though the machine was being used for research and there were numerous supervisory people on site. The operator's error would probably have not been detected for some time if the chip stream was not being sampled. To our knowledge there is currently no monitoring of the size of particles produced by any of the machinery used in the processing of the municipal green waste streams which Mastro and Reynolds observed in the autumn of 2015.

R. pomonella

Like the two wood-boring beetles, *R. pomonella* is also soft-bodied in the larval stage in its host fruit and it must remain in contact with the fruit until it is ready for pupation. However, its larval period is much shorter than either of the beetles, spanning 13 to 50+ days depending upon the host fruit and the temperature (Dean and Chapman, 1973). If the pest is removed from its food source before it develops into a mature larvae or pre-pupa it will perish from a lack of nutrition, desiccation, or from being preyed upon. Immature larvae have very limited mobility since they are legless; thus their ability to find and colonise another food source would be very limited (Dean and Chapman 1973; Snodgrass, 1924).

R. pomonella is relatively small compared to *A. glabripennis* and *A. planipennis*. The adult fly is approximately 5mm long. Eggs measure 0.9mm long and 0.23mm wide. Late third instars measure 6.5 - 8 mm long x 1.5 - 2 mm wide. Pupae are even smaller at 5mm long x 2.3mm wide; recent measurements from two locations in the state of Washington gave more specific mean values of *ca*. 4.5mm long x 2.1 mm wide (central Washington); and 4.3 x 2.1mm wide; males are smaller; some are only 3.8 mm long and 1.7 mm wide) (western Washington) (Yee, USDA ARS, USA, *personal communication* to Mastro, USA, December 2015).

Although the pupa is susceptible to desiccation (Illingworth, 1912) it is also described as tough and heat resistant (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) as shown in oven-heating studies by Yee and Chapman (*manuscript in preparation*). In addition the pre-diapausing larvae have the ability to move to a favourable habitat to pupate. Once formed into a pupa the insect is contained in a tough double envelope which protects it from organisms in the soil where it normally pupates (Snodgrass, 1924; Dean and Chapman 1973) although under very dry conditions it may be vulnerable to desiccation.

Because of the small size of the juvenile life stages of *R. pomonella* that will be present in infested fruit or soil in the waste stream, there is a high probability that they will escape the grinding process used to process the municipal green waste from the quarantine area of the state of Washington.

Review of studies on the effect of chipping and grinding host material ***followed*** *by heating, on insect pests: Beetles*

Other studies that we have reviewed include investigating the effect of composting or heating following a chipping/grinding step. Jones and Paine (2015) demonstrated that chipping followed by solarisation could significantly reduce populations of the polyphagous shot hole borer (*Euwallacea* sp). Beetle activity was reduced by 98% in material reduced to greater to or equal to 5cm and 99.9% for chips smaller than 5cm. This beetle is very small, with adult females ranging between 1.8 and 2.5mm and males ranging 1.5 to 1.67mm, so chipping must have some direct physical impact on the adults to kill them. They are usually in the galleries where the female and the larvae mature. The symbiotic fungi (which the female uses to inoculate the galleries) are probably adversely affected, very soon after the chipping process. Chipping not only upsets the environmental conditions favorable to the symbiotic fungus but could introduce and promote the growth of saprophytic fungi. In this study the authors observed the growth of other fungi but did not identify the species or monitor the activity of the symbiotic fungi. Solarisation of infested wood logs during the summer months resulted in the greatest reduction in beetle activity in the first few weeks after the logs were covered but after 4 weeks there was no difference in beetle activity between the control logs and the solarised wet or dry logs covered in either black or clear plastic.

In a similar study Spence *et al*. (2013) investigated the effect of chipping on the Redbay ambrosia beetle (*Xyleborus glabratus*); another small (2mm long) beetle which kills by infesting trees in the genera *Persea* and *Sassafras* with a symbiotic fungus *Raffaelea lauricola.* Chipping significantly reduced the percentage of beetles emerging from chips compared to control bolts of wood (which were left intact), by greater than 95% over the two weeks post chipping. Also the symbiotic fungus could not be detected in chips after two days. This study used a chipper and although they did not report the size of the chips produced by the machine, more than likely they were smaller and more uniform in size than those produced by a grinder with any of the larger size grates. In this study chips were either held in the sun or shade and in two different types of configurations (1m^3 bins, or piles of chips on tarpaulins). Temperatures in bins reached 63°C and 60°C respectively for sun and shade placement and for small piles (4.5 x 4.5 x1.8 dm high) on tarpaulins, 48°C and 40°C.

Review of studies on the effect of composting alone: Fruit flies including R. pomonella *and a leafhopper*

In a study by Kendra *et al*. (2007), the survival of the Caribbean fruit fly (*Anastrepha suspensa*) was investigated in infested grapefruit placed in backyard compost piles. The piles were constructed out of chipped wood and grass clippings (1:1) and turned until the infested fruit was added. The fruit was either placed on top of the pile or 4 to 5 cm deep within the pile. Although the infested fruit did not go through a chipping or grinding process, this situation may be more analogous to apple maggot-infested apples or smaller infested hawthorn fruit or crab apple going through a grinding process with no or little damage and ending up on or near the surface of a compost pile or windrow. This study was replicated at four different times during the year (early fall, late fall, summer and spring). Adults emerged from grapefruit in piles constructed during all four time frames. Overall, compared to the control grapefruits, emergence was 10.8% (9.4 and 12.0% respectively for males and females). The authors concluded that the overall risk of a potentially mated female emerging from composted fruit was approximately 10%. According to Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016), backyard composting such as this differs from industrial composting since it is '*typically characterised with lower temperature profiles that also do not have a long life span*'. He noted that '*in the past we have studied the hygienic potential of backyard composting and you can even get eradication of thermophilic organisms even if lethal temperatures are not reached'* (Ryckeboer *et al*., 2002). He described the paper by Kendra *et al*. (2007) as '*a study of edge effects during composting (on top of the pile or 4 to 5 cm deep in the pile*)'. He advised that '*if only 10% survived the upper edge (with expected temperatures comparable with ambient temperatures) you can assume that the kill rate in the composting pile will be a multiple factor higher…so after a minimal number of turnings an eradication of the insect could be expected, of course sufficient turnings are needed (to be done) and all materials should be exposed to lethal temperatures before the insect can complete its life cycle*'. Relating this to *R. pomonella*, for infested material which is at the surface or in the outer edge of a windrow that has not yet been turned or turned sufficiently, or, in a static pile that is never turned, a lack of exposure to lethal temperatures for the necessary period of time presents a risk of survival and dispersal. This is because it is possible that a late instar could emerge from a host fruit and pupate; or the more immediate risk is that of an adult emerging from pupae contained in soil – most likely to occur in spring or summer; or possibly from a non-diapausing pupae in fruit; both present a risk of dispersal from the facility. Pupae that arrive at a facility when in diapause or quiescent can survive if they are not exposed to lethal temperatures and do not dessicate.

Larvae of *R. pomonella* can pupate as deep as 12 inches (30.48cm) in soil (Dean and Chapman, 1973) but whether adult flies can emerge from this depth was not stated. Yee (USDA, ARS, USA, *personal communication* to Mastro, USA, March 2016) advised that '*In one study of the related cherry fruit fly, about 85% of adults made it to the surface when the pupae were 12 inches below the surface in tubes filled with sandy loam'.* Emergence of flies of *R. pomonella* from pupae in the outer layer of a pile of waste being composted could be possible if lethal temperatures had not been reached and the flies were ready to eclose.

Crohn *et al*. (2008) investigated the probabilities of two insects, *Homolodisca coagulata* (glassy winged sharpshooter) and *Bactrocera oleae* (olive fruit fly) surviving in compost piles. *B. oleae* is in some respects similar to *R. pomonella*. Piles were constructed from yard waste using a horizontal grinder, similar to those used by at least 3 of the composters in the state of Washington. As in the previous study the insects used in the study were **not** subjected to a chipping or grinding process. The survival of the two species was completely dependent on the composting process. When temperatures were measured at depths of 15 cm or greater they reached 55°C within two days. Surface temperatures however remained mostly in the 25 to 30°C range. Neither pest survived at any depth in the pile greater than 14 days. The authors constructed a mathematical model and calculated that to have a 95% probability that no fruit flies would survive, 14.3 temperature adjusted days (TAD) must elapse; and, for a 99% probability 16.5 TAD must elapse. The model predicted that for conditions similar to this study, there was 99% confidence that all eggs of *H. coagulata* would be eliminated from 1000 infected leaves in 6.1 days at 15 cm depth and in 4.8 days at 30 cm or below. Larvae of *B. oleae* at these depths would require 4.8 and 4.1 days, respectively for 1000 infested olive fruits. Projected elimination times at the surface were longer, 6.5 days for *H. coagulata* eggs and 14.3 days for larvae of *B. oleae*. This study illustrates that the risk of survival of juvenile life stages of insect pests is longer the closer they are to the surface of a windrow or static pile; the same effect is likely to occur for *R. pomonella*. The authors note that the olives placed at the greater depths became softened by the heat and were covered with fungi. Similar effects could be expected for soft fruits that are infested with *R. pomonella* but this has not been investigated.

Yee and Chapman (*manuscript in preparation*) investigated the mortality of free-living pupae of *R. pomonella* in piles of ground yard waste between October and December 2015 at the Terrace Heights transfer station in the quarantine area of Yakima in the state of Washington. Because this work was conducted during the cooler months of the year, temperatures in the waste piles would not be expected to rise as quickly as in warmer months and thus challenged the system's ability to kill the pupae. This work was presented by Yee (USDA, ARS, USA) in January 2016 at the Washington Tree Fruit Research Commission (WTFRC) meeting in Wenatchee, Washington and some of the draft manuscript and the slides were used in this PRA to review the results. Although the researchers measured temperatures in centigrade, the temperatures in the slides presented at the meeting were in farenheit so they have been converted back to centigrade for the PRA. The aim of the work was to try to identify a cost effective method to kill pupae of *R. pomonella* in yard waste piles at transfer stations. In preparation for the work, the mortality of pupae was investigated under 3 heating regimes in a laboratory oven held at 100% RH. In the first test pupae were held at 80°F (27°C) for 1 day, then 100°F (38°C) for 1 day, and finally 132 - 137°F (56 - 58°C) for 3 days. Control pupae were held at 80°F (27°C). Mortality reached 100% for the heated pupae compared to 5.3% for the control pupae. In the second and third test, pupae were held at 80°F (27°C) for 1 day then 122.9°F (50.5°C) for 3 or 7 days respectively. Control pupae were also held at 80°F (27°C). After 3 days of heating at 122.9°F (50.5°C), mortality was 100% compared to 9% of the controls; at 7 days mortality was 100% for the heated pupae and 0% for the controls. Following-on from this, but as part of the same study, various field tests were undertaken whereby pupae were buried in bags at 0cm, 5cm or 45cm in piles of ground residential yard waste (ground waste dimensions less than 5cm). Piles were approximately 30yd^3 with 60-65% moisture. Control pupae were held in cups of ground waste at 50°F (10°C) and 70% RH in a refrigerator. The piles were left uncovered or covered with different types of tarpaulin. Mean temperatures at 0cm, 5cm and 46cm were recorded; temperatures were always highest at the 46cm depth. In an uncovered pile in late October 2015, 100% mortality was reached at 4 days at 46cm depth with a mean temperature of 137.5°F (59°C); at 5cm mortality reached 37% at 4 days and 66% at 7 days (temperatures 110 and 109°F (*ca*. 43°C) respectively; controls 8.5% mortality at 4 days and 31% at 7 days). Using tarpaulins in early November mortality was less than 30% after 3 days at 5 or 46 cm (temperatures 104 and 116°F/40 and 47°C respectively) but 100% mortality was achieved after 7 days at both depths (100 and 125°F/38 and 52°C respectively; controls 17% mortality at 3 days and 22% at 7 days). In mid-November pupae were held for 7 days in a tarped pile and mortality only reached 11% on the surface compared to 100% at 46cm (temperatures 70 and 128°F/21 and 53°C respectively; controls 8% mortality). In mid-December piles were covered with two tarpaulins between which reflective insulation was placed. Mortality at 9 days was 100% at 0cm, 5cm and 46cm (temperatures reached 102, 111 and 137°F/39, 44 and 58°C respectively; control mortality was 2.5%). The field tests showed that it is possible to kill free pupae of *R. pomonella* in ground waste piles once they have been exposed to sufficient heat and that the use of tarpaulins as well as added insulation could aid the killing of pupae in waste during the colder months of the year.

Heat treatments for fruit infested with fruit flies

There is a wealth of data on the effects of heat treatments for killing fruit fly larvae inside fruit. Using hot water immersion or hot air treatments, 100% of larvae of a range of pests in various fruit were killed at 45–50°C when exposed for various time periods (e.g., Gould 1994, Shellie and Mangan 2000, Neven and Rehfield-Ray 2006, Armstrong and Follett 2007, Velazquez *et al*, 2010, Self *et al*. 2012).

The USDA treatment manual (USDA, 2015) gives a range of treatment options for fruit flies depending upon the pest and the commodity, including hot water dips and high temperature forced air. Heat treatments for infested fruit can be for several hours' exposure in the upper 40's centigrade range to ensure mortality of the pest within the fruit.

The research data and the USDA treatment options do not relate directly to the effects experienced when life stages of fruit flies are exposed to heat within a pile of green waste that is being composted since there are likely to be other factors in the composting process that may influence viability. However, they do give an indication of the temperature and time durations that are lethal to fruit fly pests like *R. pomonella*.

Effect of heat on eggs larvae and pupae of R. pomonella
Hallman (*undated*) investigated the effect of heat in controlled atmospheres (CA) on eggs of *R. pomonella* in apples as part of a study to find alternative treatments for disinfesting fruit destined for export from the state of Washington. The work was based on previous work in CA (unspecified regime) which showed that compared to larvae the eggs were more heat tolerant. The earlier work showed that the time (hours) taken to kill 100% of eggs, early instar and late instar at 44°C was *ca*. 4, 3 and <3.5hrs respectively; at 46°C it was *ca*. 3, <3 and < 3hrs respectively. In the current study, when working with eggs laid in apples held under 1.5% oxygen and 5% carbon dioxide CA, it took 4.5 and 4 hours at 44 and 46°C respectively to kill the eggs. It is assumed pupae were not tested as these are less commonly found in fruit.

There are no <u>published</u> studies on the temperature x time duration needed to kill pupae of *R. pomonella*. Although larvae do not survive rearing at 40°C (Lopez-Martinez and Denlinger 2008) it is not known whether this would be lethal to pupae. However, a personal communication from Neven (USDA, ARS, USA) to Mastro (USA, October 2015) stated that: '*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stage. This stage is still metabolizing at 50°C and the normal metabolizing only begins to breakdown at 55°C. To determine this you were using a fairly aggressive heating protocol of 0.4 degrees/minute. The diapausing pupae is also cold tolerant to temperatures of -23 to -25°* [°C]'.

A subsequent discussion (Neven, USDA, ARS, USA; with Mastro USA, January 2016) confirmed that the most heat-resistant stage of *R. pomonella* is the diapausing pupa. This life stage is in deep diapause until 5 days before emergence. A 30 minute exposure to 45°C does not kill pupae. At 50°C it takes 20 minutes for death to occur.

These results were obtained when testing pupae in Petri dishes that were free from host material (%RH unknown).

The preliminary work undertaken by Yee and Chapman (*manuscript in preparation*) prior to investigating the effect of composting pupae in piles of ground waste in late 2015 was aimed at increasing the temperature experienced by pupae over a number of days, as would happen in a pile of waste being composted. In the first test pupae were held at 80°F (27°C) for 1 day, then 100°F (38°C) for 1 day, and finally 132 - 137°F (56 - 58°C) for 3 days. Control pupae were held at 80°F (27°C). All pupae were held at 100% RH. Mortality reached 100% for the heated pupae compared to 5.3% for the control pupae. In a later test, after 3 days of heating at 122.9°F (50.5°C) and at 100% RH, mortality was 100% compared to 9% of the controls which had been held at 80°F (27°C). These laboratory tests showed that slowly increasing the temperature over a few days can ultimately lead to mortality of pupae.

More recent work by Yee (USDA, ARS, USA, *personal communication*, March 2016) investigated the effect of heat on pupae of *R. pomonella* at lower temperatures in the laboratory. Pupae were held at 100% RH at a mean temperature of 46.3°C for 3 days, or 45.3°C for 1 day, with control pupae being held at mean temperatures of 22.8°C and 23°C respectively. Mortality was 100%

after 3 days at 46.3°C compared to 15.4% for the control; and 6.7% at 45.3°C compared to 0% for the control. Compared to Neven's results (no %RH provided), this indicates that a much longer period is required at lower temperatures for lethal effects to occur for pupae of the pest, with 1 day at 45.3°C being insufficient to kill all pupae but 3 days at 46.3°C leading to complete mortality. These results do not account for any other factors that may influence mortality during the composting process. These are described below.

Composting
Composting is an aerobic and exothermic process in which the temperature of the material being composted should rise above 50°C (and sometimes above 70°C) for several weeks or months, before dropping back again below 40°C as the decomposition process slows (EPPO, 2008).

The composting process is described in more detail at:
http://compost.css.cornell.edu/microorg.html accessed 16 March 2016 and quoted below:

In the process of composting, microorganisms break down organic matter and produce carbon dioxide, water, heat, and humus, the relatively stable organic end product. Under optimal conditions, composting proceeds through three phases: 1) the mesophilic, or moderate-temperature phase, which lasts for a couple of days, 2) the thermophilic, or high-temperature phase, which can last from a few days to several months, and finally, 3) a several-month cooling and maturation phase.

Different communities of microorganisms predominate during the various composting phases. Initial decomposition is carried out by mesophilic microorganisms, which rapidly break down the soluble, readily degradable compounds. The heat they produce causes the compost temperature to rapidly rise.

As the temperature rises above about 40°C, the mesophilic microorganisms become less competitive and are replaced by others that are thermophilic, or heat-loving. At temperatures of 55°C and above, many microorganisms that are human or plant pathogens are destroyed. Because temperatures over about 65°C kill many forms of microbes and limit the rate of decomposition, compost managers use aeration and mixing to keep the temperature below this point.

During the thermophilic phase, high temperatures accelerate the breakdown of proteins, fats, and complex carboydrates [sic] *like cellulose and hemicellulose, the major structural molecules in plants. As the supply of these high-energy compounds becomes exhausted, the compost temperature gradually decreases and mesophilic microorganisms once again take over for the final phase of "curing" or maturation of the remaining organic matter'*

.
Material being composted may be periodically turned before curing to ensure even decomposition, although systems without turning but with forced aeration also exist ('*aerated static pile*'). In industrial situations, composting of waste is most commonly performed in long heaps known as '*windrows*' which are turned mechanically. The windrows may be maintained outdoors, or kept indoors in vessels or halls. Other systems of composting have been developed. (EPPO, 2008).

With respect to systems where waste is not turned, aerated static piles are normally actively aerated either through suction or blowing of air through the piles. Passively-aerated windrows or piles have air supplied to material being composted via open-ended perforated pipes that are embedded in the waste. See (e.g.): http://www.fao.org/docrep/007/y5104e/y5104e07.htm accessed February 12th 2015.

The EPPO (2008) phytosanitary procedure for managing the risks posed by plant pests and pathogens in '*biowaste*' (in this PRA this refers to municipal green waste) advises that:

'*The processes at composting facilities should be managed in such a way as to guarantee a thermophilic temperature range and a high level of biological activity over a period of several weeks. This should be achieved under appropriate conditions of humidity and nutrients, as well as by optimum structure and optimum air conduction. In general, the water content should be at least 40%. In the course of the composting process, the entire quantity of materials being treated should be exposed either to a temperature of at least 55°C for a continuous period of two weeks, or to a temperature of at least 65°C over a continuous period of one week (or, in the case of enclosed composting facilities, at least 60°C). A minimum number of turnings may be required to ensure that the whole mass is exposed to this temperature'*.

EPPO (2008) gave further advice on additional heat treatments to manage the risks posed by quarantine pests and this is discussed in the risk management section of this PRA.

Although in principle the highest temperatures reached in composting should destroy plant pathogens and pests as well as weed seeds, there is evidence (e.g. Sansford, 2003; Noble and Roberts, 2004) that certain organisms may survive some of these processes. Those that have been reviewed as fitting this category include fungi with hardy resting spores and certain heat-resistant viruses along with various plant parasitic nematodes. In some cases survival of these organisms resulted from failures in the process. (EPPO, 2008).

There are various mechanisms by which composting inactivates plant pathogens and pests:

- by heat generated during the thermophilic phase
- by microbial antagonism, and;
- from the toxicity of products generated by composting

However, most of the published literature relates to the effect of these factors on plant pathogens rather than invertebrate pests (Sansford, 2003).

Ryckeboer (Ensus Consulting BVBA, Belgium; *personal communication*, March 2016) further advised that these three factors as well as the lytic activity of enzymes produced by bacteria and fungi and competition for nutrients in the outer low temperature zones of compost piles or during curing influenced the likelihood or eradication of pathogens (citing Bollen, 1993a; Hoitink and Fahy, 1986; Golueke, 1982; Bollen and Volker, 1996; Ryckeboer, 2001). He stated that '*of course not all these factors have an impact on all life stages of insects*'. He also advised that '*heat is certainly the primary factor affecting the mortality of insects, but when temperatures are lower or* *drop, then the other factors may also become important. How this affects the various life stages of* R. pomonella *requires further investigation'*.

We are not aware of any studies on the effect of these factors on the mortality of insects. However, variation in the feedstock materials and the composting process means that this would be highly complex to study.

Although temperature is considered to be the easiest and most reliable parameter to relate to the inactivation of plant pathogens or pests, laboratory studies on thermal inactivation may not necessarily be a valid guide to the effect of the equivalent temperatures in a composting process. Also, clumping of solids, incomplete mixing, and differences in moisture content within the material being composted leads to irregular distribution of temperatures (Hay, 1996; in Sansford, 2003).

Ryckeboer (Ensus Consulting BVBA, Belgium; *personal communication*, March 2016) advised that '*if you monitor a composting pile, with a scale typically found in industrial composting plants, you will see that when a pile is built with respect to the basics of composting, it achieves thermophilic temperature profiles, with variation, but mostly within acceptable ranges. The most common exceptions are edge effects, and the latter can only be solved by turnings, or by composting in (insulated) tunnels where the edge effects are lessened. Dry spots which fail to heat up can also be an exception to this but these are not expected if composting is 'properly managed'. If they exist they are mostly blended-out when materials with sufficient moisture or water are added during turning'.*

He described *'Properly managed'* as meaning '*sufficient time/temperature profiles, sufficient turnings, sufficient facility hygiene management, etc.'*

He also advised that because static piles are not turned they are expected to have cooler edges which can include the edge which is contact with the surface on which the pile is built. These edges are likely not to heat up as a result of the microbial activity which normally occurs within the pile. Microbial activity is hampered at the bottom of the pile as a result of limited aeration. Ryckeboer advised that in general, edge effects are observed down to about 25cm but this will vary with the climate, season, and type of waste feedstocks, etc. Edge effects in the outer-most compost layers would pose a risk of escape for a flying insect such as *R. pomonella* since it appears they have potential to be able to emerge from a depth of up to *ca.* 30 cm. This assumes a pupa is ready to produce an adult shortly after arrival at the compost facility. For pupae that are in diapause or quiescent, if they are not exposed to lethal temperatures this poses a risk of survival of the pest. Temperatures within the waste may rise to lethal levels below the surface at the height of the summer but the time for this to occur is not known. In windrows which are turned, the risk of escape from pupae that contain adults that are ready to emerge is related to how long it is until the material at all of the edges is turned inwards and reaches lethal temperatures.

To illustrate this, Teutli *et al*. (2010) modelled heat flux in a 3m x 4m composting pile and showed that cooler temperatures experience at the edge of the pile were still in existence after 60 days. See Figure 9 below.

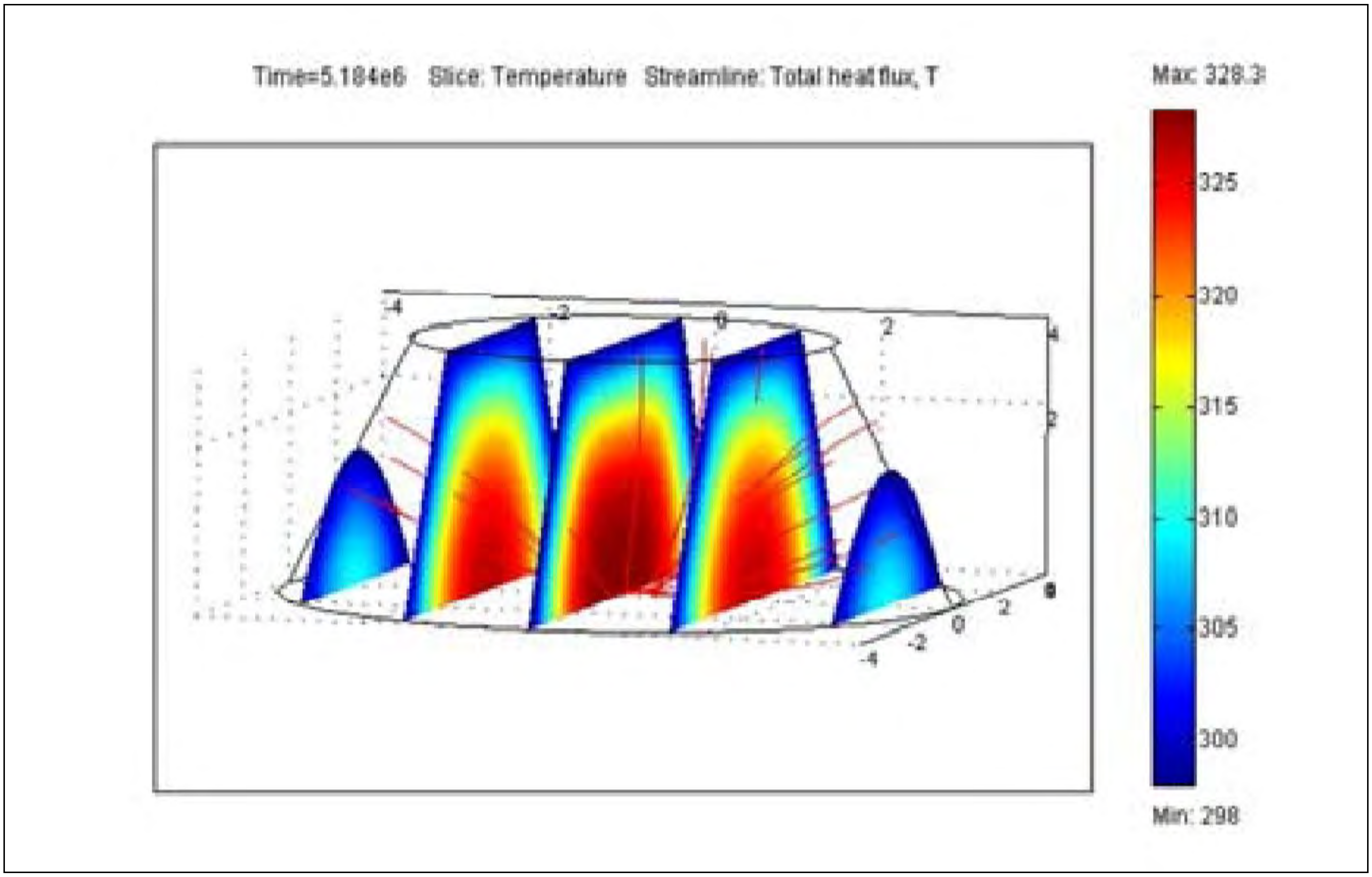


Figure 9. Temperature and heat flux predictions for a 60 day period of a composting process (reproduction of Figure 4 of Teutli *et al*., 2010). Y-axis = degrees Kelvin. Note that [°C] = [K] − 273.15.

Ryckeboer advised (illustrated with an image from Vanacker *et al*., 1996) that for an aerated static piles, the edge effect (expressed as a percentage of the volume) of a large static pile is much less that in a smaller windrow but there are still edges, and thus there will also be edge effects.

Yuen and Raabe (1984) investigated the effect of small-scale backyard composting of yard waste or dried spice plant residues in bins on the survival of sclerotia of three fungal plant pathogens in infested plant material, and sclerotia of one pathogen retained in glass vials or mesh bags (which was tested only in dried spice plant residues). All four were inactivated after 21 days when incorporated in the compost and moved through the bin by turning. When kept in the corners of the bin all of them remained viable except for sclerotia of *Sclerotium rolfsii* held in mesh bags which lost their viability. The authors concluded that corner temperatures (which were cooler than the centre of the bins throughout the experiment) were not lethal to these fungi and that the death of sclerotia of *S. rolfsii*, when held in mesh bags in the corners, was attributable to other factors such as toxic products produced during microbial decomposition and microbial antagonism. This also illustrates the '*edge effect*' albeit it is not a study of industrial composting.

With respect to the effect of turning during the composting process, Larney *et al*. (2006) compared active (turning) and passive (not turned) aeration of beef cattle feedlot manure being composted in windrows. Temperatures were monitored over the first 90 days of composting. In the turned windrow, mean daily temperature was warmest at the bottom (53.6°C) and coolest at the top (46.4°C). However, in the passively-aerated (not turned) windrow, it was warmest at the top (44.1°C) and coolest at the bottom (33.9°C). After the thermophilic phase, the authors described the passively-aerated unturned windrow as '*only partially-composted'*. They felt that the lower windrow temperatures experienced in the passively-aerated (not turned) system might fail to eliminate pathogens.

For windrow composting of yard waste Evanylo *et al*. (2009) advise that: '*the size of the windrow has a direct effect on the amount of oxygen reaching the pile interior. This affects the temperature and the microbial activity inside the piles. The windrows should be large enough to conserve heat and moisture and to effectively utilize available composting space, but not so large as to promote anaerobic conditions'*

Also that:

'*With the proper moisture level and oxygen concentration, the windrows will begin to heat up very quickly and will need to be turned every 24 to 48 hours. Thorough mixing while turning will promote shredding and expose more particle surface area. It also allows exterior material to be moved to the interior where the temperature will be higher'*.

'*To effectively control the composting process with this* [windrow] *method, thermometers should be placed in the windrows approximately every 50 feet and the temperatures recorded daily. Windrows should be turned and thoroughly mixed when the temperature reaches 140°F (60°C). Composting to this temperature is optimum for destroying most pathogens and weed seeds, while allowing for maximum growth and reproduction of thermophilic bacteria'.*

Temperature monitoring is vital to determine when to turn waste during the composting process.

The USDA advise: '*use a minimum of 2 probes per windrow based on observed data variability. Initial measurements should be taken at fairly close increments to provide an initial idea of variability. If the observed temperatures are reasonably consistent (less than 10°F difference between comparable locations), greater distances between monitoring locations would be justified. Occasional rechecks at the reduced spacing may be taken to verify that temperature variability has not changed greatly. Ideally probes should be placed at the outside edges of the pile and inside the center of the pile, every 10 to 20 feet along the length of the pile'*. https://aglearn.usda.gov/customcontent/APHIS/APHIS-CarcassDisposal-OutdoorComposting-01/scopage_dir/intro/main.html accessed 4 April 2016.

Temperature monitoring can be used to help ensure that any system of composting municipal green waste that may contain the juvenile stages of *R. pomonella* achieves adequate exposure of all of the waste material to conditions that are likely to ensure mortality. Turning of the waste seems to be key to achieving this.

Particle size and composting

Mechanical reduction of the waste to smaller sized particles prior to composting will facilitate more even and rapid heating. The principles of reducing particle size before composting are that: '*The more 'surface area' available, the easier it is for microorganisms to work, because activity occurs at the interface of particle surfaces and air. Microorganisms are able to digest more, generate more heat, and multiply faster with smaller pieces of material'*; but also 'don't *'powder' materials, because they will compact and impede air movement in the pile'*
http://web.extension.illinois.edu/homecompost/science.cfm accessed 29 March 2016.

Another source advised that '*The best sized particles for composting are less than 2 inches in the largest dimension, but larger particles can be composted satisfactorily'*.
http://whatcom.wsu.edu/ag/compost/fundamentals/needs_particle_size.htm accessed 29 March 2016.

If the particle size is too small it leads to compaction which can restrict oxygen flow and can lead to anaerobic conditions if aeration is insufficient (DEP, *undated*). Bary (*undated)* suggested that 1/8 to 1/2 inch (3.2mm to 12.7mm) is a *'reasonable range*' for particle size when composting and that a preferred range '*varies*'. However, Sherman (*undated*) suggested that 1/8 - 2 inch (3.2mm to 50mm) diameter was a '*reasonable range*' and that the preferred range also '*varies'* and '*depends on raw materials, pile size, and/or weather conditions*'.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016), advised '1*/8 to 1/2 inch as the maximum size is too strict, as such small sizes are not so supportive for aeration of the composting pile. From the perspective of 'damaging the host materials of apple maggot' a small particle size might be seen as positive, but this is not supportive of composting'.*

Thus the particle size(s) of material being composted should be within a range that allows sufficient aeration and enables uniform heating in the waste.

Conclusion on the effects of mechanical processing and composting of municipal green waste on R. pomonella

This review suggests that with the exception of all but the largest and most fragile of insects, chipping (not used by the facilities being assessed in this PRA) and or grinding is unlikely to reduce the viability of juvenile forms of *R. pomonella* to an acceptable level for a quarantine pest (most likely zero tolerance). This is because the pupae in particular are very small and tough and therefore they are likely to escape the effect of mechanical reduction of the green waste material. The larger the size of particle achieved by the process, the more likely it is that such small life stages will survive. However, particle sizes of mechanically-reduced waste being composted should not be so small as to impede aeration. The size of the particles produced by each of the facilities is reviewed for each composter.

There are few studies on the effect of composting on insect pests and only one (as yet unpublished) study by Yee and Chapman looking specifically at *R. pomonella*. However, it is surmised that if high enough temperatures are achieved for a sufficient length of time, it is likely to be this process rather than mechanical processing that would reduce the viability of the pest. There may be other factors in the composting or curing process that influence viability but from our limited investigation we are not aware that these have been studied. Currently the time x temperature requirement to kill free-living pupae of *R. pomonella* in the laboratory has rarely been studied; however, Neven has indicated this could be around 50°C for 20 minutes but the % RH during the exposure in this study is not known. In trying to replicate the heating that might occur in a composting situation, Yee and Chapman subjected pupae to a 5 day period of increasing temperatures at 100% RH in laboratory ovens (27°C for 1 day, 38°C for 1 day and finally 56 - 58°C for 3 days). At the end of the 5 day period none of the pupae were viable. In another laboratory experiment, subjecting pupae to 27°C for 1 day followed by 50.5°C for 3 days also led to 100% mortality. More recently, Yee (USDA, ARS, USA, *personal communication*, March 2016) showed that at 100% RH, lower temperatures are less effective at killing pupae of *R. pomonella* with 1 day at 45.3°C only leading to 6.7% mortality compared to 3 days at 46.3°C resulting in 100% mortality. In the composting process the material takes time to heat up and the period needed for all the waste to heat to lethal temperatures will vary. This partly depends upon ambient temperatures so will vary with the time of year. Waste will need to be turned to ensure that all material reaches this point but during the turning the temperature will drop. Until pupae are exposed to lethal temperatures there is a risk that flies that are ready to eclose may emerge and disperse.

If pupae of *R. pomonella* are present in whole apples in waste being composted then the time x temperature requirement for mortality of the pupae is likely to be greater than it would be for those that are free of host material. Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016) advised that whole fruit containing the pest should be damaged by grinding and this will help with the composting process since the material is wet and rich with nutrients which will encourage microbial activity. Yee (USDA, ARS, *personal communication*, April 2016) advised that a grinder tested at the Terrace Heights transfer station, Yakima in the autumn of 2015 ground all of the apples that were put through it. However, at the industrial scale, there may be some infested material that remains intact or partially-intact, including parts of infested apples and smaller infested fruit such as hawthorn. If this is within the windrow or pile, the weight of the material will also help break this down along with friction from woody materials. If it is on the edge of the windrow or pile it will take longer to heat up. Clods of soil containing pupae that survive the effects of grinding will also take time to heat up. This is because there will be no composting activity in the clod and so heating of the clod is dependent upon the heat from the surrounding compost environment. The effect of the surrounding environment will be limited for larger clods and/or those clods that remain on the edge of the windrow or pile.

Thus, uniform heating <u>throughout</u> the mass of waste at the requisite time x temperature would be required to achieve 100% mortality of the pest. Whether the pest is free or within mechanically-reduced waste, in whole apples, or in soil, the longevity of the pest will depend upon where it is situated in the pile of waste that is being composted, since this will influence the starting point and the length of time for which it is exposed to lethal temperatures.

Risk of transfer of R. pomonella *from infested fruit in municipal green waste*
Infested fruit, particularly (but not exclusively) apples, is thought to be the most likely route of entry of the pest to the PFA (Hood *et al*., 2013). However, infested fruit of hawthorn and crabapple (being smaller than apples) may survive mechanical processing better than apples.

The survival of eggs or immature larvae, pupae and potentially emerging adults in unprocessed fruit from quarantine areas to composting facilities in the PRA area depends mainly on the effect of processing at the transfer station, if used, and at the receiving facility, and as stated above, storage and shipment times and conditions. Although we do not have any direct measurement of the effect of the processes to render all fruit in the waste stream unsuitable for development of *R. pomonella*, WSDA inspectors have found whole apples '*laying out of tarp in the windrow'* in one of the composting facilities receiving unprocessed waste and whole apples in mechanically treated waste (processed using a horizontal grinder) at a transfer station. Information supplied by the WSDA showed that between July 1st and August 19th 2015, a total of 222 apples and 1 Asian pear were found at various locations at 3 of the compost facilities. Viable larvae and pupae of *R. pomonella* were detected in infested fruit at two of the facilities in spillage areas. These pose a risk of transfer of the pest into the PRA area.

Risk of transfer of R. pomonella *from infested soil in municipal green waste*
Amongst the RPPOs that currently recommend that *R. pomonella* should be regulated, EPPO (for example) state that '*Plants of host species transported with roots from countries where* R. pomonella *occurs should be free from soil, or the soil should be treated against puparia, and should not carry fruits. Such plants may indeed be prohibited importation'* (EPPO, 2006). CABI (2015) consider that pupae in soil in the nursery trade is a likely pathway of introduction.

Pupae potentially inhabiting potting mixtures or soil in waste from discarded host plants within pots or as balled and burlapped nursery stock pose a possible risk of transferring *R. pomonella* to the PRA area over a longer period of time than any of the life stages associated with fruit. We do not have any information on the movement of discarded host plants but note this possibility so that further work can be done to determine to what extent the movement of this material may occur and the likelihood of it being infested. However small shrubs and trees are often removed from landscaped or construction sites by pulling them out with the roots and soil attached. Members of this PRA team (Reynolds and Mastro) saw evidence of this at two transfer facilities. If this material enters the waste stream it offers a commodity in the pathway that extends the risk of movement of the pest throughout the year. *R. pomonella* adults can take more than 2 years to emerge from pupae and the pupae could be in the soil in the waste stream throughout the year.

The window of time from November until the initiation of emergence in June should have the greatest soil load of pupae. It is during this time frame that the movement of soil associated with host plants would be of the greatest risk. Yee has advised that recent experience in searching for pupae over the winter months showed that the pupae are difficult to find in the soil in western Washington (Yee, USDA, ARS, *personal communication*, April 2016). Very little is known about the overwintering survival of the pest under the range of soil types and environmental conditions that it may occupy. However the pest pupates in the soil so pupae must be present to maintain populations of *R. pomonella* in the quarantine area.

Pupae contained in the soil would be largely unharmed by any mechanical preprocessing at transfer stations and also at the destination composting facilities. If not adequately broken-down then clods of soil containing pupae will take longer to heat up than those situated in pure green waste. This is because inorganic matter does not heat itself; heating depends on the surrounding heat generated by microbial activity during the composting of organic matter. Inadequate or inconsistent heating may allow the insects to survive and emerge as adults in the early summer or in a small percentage of cases (where they do not diapause) at any time that temperatures permit it.

Life stages of R. pomonella *that pose the greatest risk of transfer to the PRA area*
Although the eggs of *R. pomonella* are more heat resistant than larvae in apple fruit, it is the late instars or pupae in the waste stream which probably offer the greatest potential for successful movement and establishment of *R. pomonella* in the PRA area. Fruit collected in private yards has usually fallen from fruit trees. If infested with the pest the insects are probably close to pupation. Late instars and pupae would not be badly damaged by the collection and transportation processes unless lethal temperatures are reached. Because of their relative small size a high percentage of both life stages would most likely survive a grinding or shredding process. Pupae (*ca.* 5mm long) and fully mature 3rd instar larvae have no need to feed. Pupae are relatively tough, and would not be greatly affected by grinding, shredding, or any other common mechanical waste reduction methods. When these are transported in the waste or develop from larvae pupating during the preprocessing or transportation process or at the composting facility, they may survive at least prior to waste entering the composting process and up to the point that they experience lethal time x temperatures. To support this perspective, Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) stated '*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stages. This stage is still metabolising at 50°C and the normal metabolising only begins to breakdown at 55°C. To determine this, they or we depending on the person you want to be speaking in were using a fairly aggressive heating protocol of 0.4 degrees/minute. The diapausing pupae is also cold tolerant to temperatures of -23 to -25° C*.' She also advised that mortality of pupae was achieved after 50°C at 20 minutes in the laboratory.

Yee and Chapman (*manuscript in preparation*) have shown that 100% mortality of pupae can be achieved in small-scale composting of yard waste provided lethal temperatures are experienced. The time taken for this to occur during the composting of municipal green waste will be longer than required for pupae tested in a laboratory setting while waiting for microbial activity to increase the temperature of the waste. Prior to their field tests, 100% mortality of pupae was achieved in the laboratory by ramping-up temperatures (as would be expected at the start of the composting process) from 27°C for 1 day, then 38°C for 1 day followed by 3 days at 56 to 58°C; or by 27°C for 1 day, then 3 or 7 days at 50.5°C. Subsequent field tests of pupae held in bags in yard waste subject to composting resulted in 100% mortality in an uncovered pile in October 2015 for pupae held at 46cm depth with a mean temperature of 59°C for 4 days; in a tarped pile in November 2015 at 5cm depth and 38°C or 46cm depth and 52°C for 7 days; and in December 2015 in a pile covered with two tarpaulins with reflective insulation sandwiched in-between for pupae held at 0cm and 39°C, 5cm and 44°C and 46cm and 58°C for 9 days respectively. Temperatures were always highest at the 46cm depth. More recent work by Yee (USDA, ARS, USA, *personal* *communication*, March 2016) showed that pupae of *R. pomonella* held at lower temperatures in the labororatory needed longer exposure to heat to achieve mortality compared to Neven's unpublished work. Yee showed that 1 day at 45.3°C was insufficient to kill all pupae but 3 days at 46.3°C led to eradication at 100% RH; Neven showed that 20 minutes at 50°C led to 100% pupal mortality (%RH unknown). These results do not account for any other factors that may influence mortality during the composting process.

For larvae that survive in fruit and which emerge from the fruit they would need to find a suitable place to pupate. Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) has evidence of pupation in a plastic box in laboratory conditions. She concurred with Mastro that the pest will pupate on any hard surface, concrete asphalt etc. and added that in laboratory rearing, the mature larvae typically exit fruit through a hardware cloth and fall into plastic tubs for pupation. This is a standard incubation or rearing technique used by a number of apple maggot workers (Yee, USDA, ARS, USA; Klaus, WSDA, USA; *personal communications* to Mastro, USA, October,2015) See Figure 10 below.

Figure 10. Apple maggot pupae (light brown shapes) in a plastic container (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015).

It is assumed that larvae must enter the soil and pupate to survive the winter and would perish from desiccation if they remained on a hard surface such as those found in some parts of the composting facilities (Yee, USDA ARS, USA, *personal communication* to Mastro, USA, October 2015).

Of course, larvae that are ready to pupate could do so in the windrows or aerated static piles since the moist material would be a suitable alternative to burrowing into soil, and they would remain viable until such times as lethal temperatures are experienced for a sufficient length of time.

Risk of transfer of R. pomonella *to host fruit on trees in the PFA*
The first scenario that poses a risk of transfer of *R. pomonella* to the apple orchards in the PRA area is that the pest completes its life cycle on fruit that survive the transfer to and processing at the composting facilities and adult flies emerge as a second brood in the same year. Because the pest could arrive at the composting facilities at any developmental stage this is possible prior to lethal time x temperatures are experienced. Pupae that survive in infested soil may also emerge as adults. Adults emerging in the same year, if abundant enough, could mate and infest fruit on trees near the facility and go on to complete a life cycle in the PRA area. Even at low densities, adult flies are apparently capable of finding mates and maintaining populations. Alternatively if arriving in the spring as overwintering pupae in soil in the waste they could emerge prior to the thermophilic phase of the composting processes commences and before lethal time x temperatures are experienced, disperse, mate, and begin the first brood generation for the year.

2.01a - Describe the relevant pathways and make a note of any obvious pathways that are impossible and record the reasons. Explain your judgement

There is 1 main pathway of concern (municipal green waste) but for ease of assessment it is represented as 4 pathways relating to the four facilities that compost waste in the PRA area. There are other potential pathways of entry of the pest to the PRA area (infested fruit, plants for planting with associated infested soil or growing media, and possibly infested soil or growing media) but these have not been assessed in this PRA.

The four pathways which have been assessed are the movement of *R. pomonella* on municipal green waste to four composting facilities situated in the PFA of the state of Washington (the PRA area).

Each of the facilities is assessed as a separate pathway. Responses are based in part on the answers to questionnaires provided by the PRA team to each of the facilities in the autumn of 2015. The respondents for each of the facilities are named for each pathway.

All facilities receive waste from the quarantine area and some also receive waste from the PFA of the state. The waste originating in the quarantine area is of concern. Waste originating in the PFA has not been assessed as it is assumed to pose a lower risk due to the status of the pest in the PFA.

In general, municipal green waste is collected from residential curb side containers by urban trash collection services and it is compacted in the back of the trucks. It is then unloaded at transfer stations where it may or may not be mechanically-processed; then it is loaded into the back of transfer trailers for onward movement to the composting facilities where it is processed. Waste is also received at each composting facility from landscapers, home owners and other businesses that unload individual trailers and truck loads of waste at the transfer stations.

An overview of the pathways is presented in Figure 10a below and is discussed in detail for each of the four pathways.

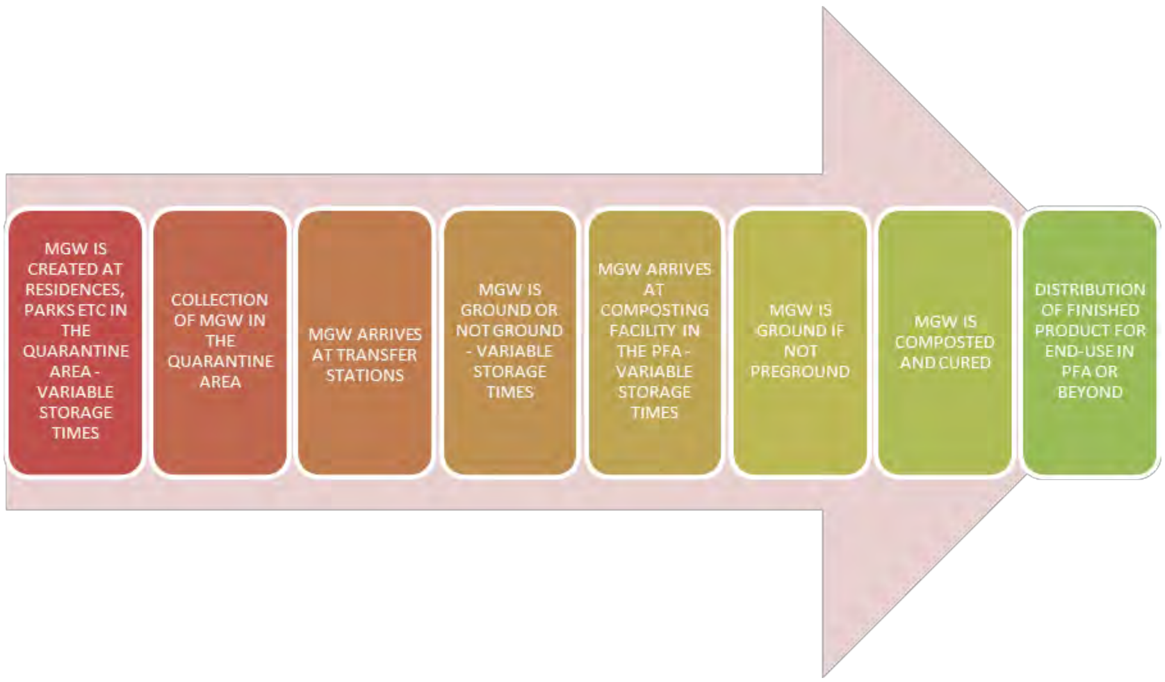


Figure 10a. General overview of movement of municipal green waste (MGW) from the quarantine area of the state of Washington (and Oregon) to the PFA of the state of Washington, subsequent processing and end-use

The waste stream and the key factors that will influence the entry of *R. pomonella* to the PRA area is described above.

2.01b - List the relevant pathways that will be considered for entry and/or management. Some pathways may not be considered in detail in the entry section due to lack of data but will be considered in the management part.

1. Municipal green waste moving to Barr-Tech LLC, Lincoln County from the quarantine area of the state of Washington
2. Municipal green waste moving to Natural Selection Farms, Yakima County from the quarantine area of the state of Washington
3. Municipal green waste moving to Pacificlean Environmental, Grant County from the quarantine area of the state of Washington
4. Municipal green waste moving to Royal Organic Products, Grant County from the quarantine area of the state of Washington

Pathway 1. Risk of entry of *R. pomonella* on municipal green waste moving to Barr-Tech LLC, Lincoln County

The questionnaire from the PRA team used in this section was completed by Mr Scott Deatherage, Operations Manager.

2.03 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account the <u>biology</u> of the pest?

Likely

Level of uncertainty: *Low*

Barr-Tech LLC receives municipal green waste all year round, mainly from Spokane County in the <u>east</u> side of the state of Washington which is in the quarantine area for the pest. The waste is yard debris and mixed food/yard debris. It is likely to contain whole apples and may contain fruit from other hosts. It may also contain soil (or growing media) associated with any of the hosts that are collected in the waste stream.

R. pomonella is associated with the fruit of a range of hosts and also with soil associated with host plants.

The biology of the pest is described in section 1.02b and summarised below.

Adult flies emerge from pupae from June through to September and they can live for up to 40 days. Once mature (within 7 to 10 days) the flies are attracted to host fruit attached to host trees, they mate and the female can lay more than 200 eggs beneath the skin of the fruit, singly and in more than one fruit. The eggs hatch in the fruit within 3 to 7 days. The emerging larvae feed and develop within the fruit and when they reach maturity at the 3rd instar stage they drop to the ground, moult to the fourth instar and pupate in the top 2 inches of the soil, or in the duff layer. Occasionally the larvae pupate within the fruit. Pupation is normally completed by the end of October but it can be as late as December (based on one study in New York; Dean and Chapman, 1973) when the pupae enter diapause, overwintering till the following summer. Studies investigating when fruit is infested with larvae rarely sample as late as December; for example Mattson *et al.* (2015) found infested fruit until the last week in September and Yee and Goughnour (2008) found infested fruit in October; neither study sampled after those times. Non-diapausing pupae may emerge as a second brood in the same year as they are formed, and could in favourable conditions mate and lead to further infestation of fruit on host trees.

The life stages associated with infested fruit are eggs, larvae and occasionally pupae. Fruit begins to be infested in June in the state of Washington. The numbers of each life stage associated with the fruit will vary with the variety and size of fruit. Studies undertaken in the state of Washington (Tracewski *et al*., 1985) found that a single hawthorn (species not specified) can yield 65,000 to 112,000 fruits (1984); it was estimated that with an average rate of 5% of fruit infested (assuming one larva per fruit) there could be 3000 to 6000 flies produced per tree. Incubation of several hundred infested apple fruit (1982 to 1983) mostly yielded 1 or 2 larvae per fruit; however, one fruit yielded 6 pupae. These figures were obtained early in the history of *R. pomonella* in the west of the USA and current infestation rates, at least in the west of the state of Washington are much higher than they were then. If a higher percentage of fruit is infested per tree there will be a greater number of larvae and pupae resulting from an attack by *R. pomonella*.

Despite the high numbers of flies presumed to be produced from a single infested hawthorn, Tracewski *et al.* (1985) did not record the actual number of flies produced. Dean and Chapman (1973) state there is some natural mortality at all stages of the life cycle but that it is highest in the larval and pupal stage and lowest at the egg stage. They cited studies suggesting pupal mortality could be between 47 and 96% influenced by parasitism, predation and ambient conditions. Larval mortality was particularly influenced by the variety of apple since hard-fleshed fruits can lead to 100% mortality. Nonetheless sufficient life stages persist to maintain populations of *R. pomonella* in the quarantine area.

Pupae (and late third instar – albeit this is a transient stage of a few hours) are the life stages associated with soil. According to Dean and Chapman (1973) the pre-pupal lasts from 2 to 18 hours with the majority taking 6 to 11 hours) .

The periods of time over which eggs, larvae and pupae are likely to be found in fruit in municipal green waste from the quarantine area of the state of Washington depends upon whether it originates in the east (in the case of Barr-Tech LLC) or the west of the state. See Table 4. This geographic split will influence the prevalence of the pest both in fruit, and as pupae in soil associated with the waste stream, due to the lower levels of infestation in the east side of the state. This is discussed for each of the four pathways and is dependent upon the origin of the waste that is being processed at each facility.

Table 4. Periods when eggs, larvae, and pupae can be in municipal green waste originating in the quarantine areas of the state of Washington.

Life stage	**Eastern Washington**		**Western Washington**	
	Start date	End date	Start date	End date
Eggs (in fruit)	Mid to late June	Late September to October* depending on date of first hard freezing temperatures	Early to mid-June	Late October depending on date of first hard freezing temperatures
Larvae (in fruit)	Mid to late June	Early November depending on date of first hard freezing temperatures	Early to mid-June	End of November into early December depending on date of first hard freezing temperatures
Pupae	In fruit, soil, growing media, or in the sod or duff at any time of the year[5]			

*Because the populations are so sparse or nonexistent in areas in central Washington (Yee *et al*., 2012) the seasonality or even the entire host range of the apple maggot is uncertain on the eastern side of the Cascade mountain range. The timing provided in the table is based on what is known and assumes that the same host range exists on the eastern side as on the western side of the state.

In **eastern Washington**, where the waste being processed by Barr-Tech LLC originates, black hawthorn (*C. douglasii*) and early varieties of apples ripen in early to late June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). Emerging adult flies of *R. pomonella* aligned with these major hosts could begin laying eggs by mid-June. Larvae could be present in the fruit of apples or black hawthorn within 5 to 7 days of oviposition (Dean and Chapman 1973). In an apple maggot survey for Spokane County in 1985 the first recorded fly capture was on June 26th (Klaus, 1985). The end date is based on the presence of ornamental

[5] Only soil is mentioned in the main text for the assessment but the other substrates are relevant

hawthorns (*C. monogyna* or *C. laevigata*) which consistently bear ripened fruit in late October. (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). However, because populations on the east side of the Cascade mountain range are sparse or nonexistent they are difficult to characterise. We assume here, that if established they will utilise the same hosts as they utilise on the west side including ornamental hawthorns.

In **western Washington**, all fruiting starts earlier than in eastern Washington because of the warmer temperatures. Fly trapping data show adults were captured in the first week of June (unspecified year) by a hobbyist organisation in Puyallup (Pierce County) (Klaus, WSDA, USA, *personal communication* to Mastro, USA, January 2016). Mattsson (2015) also reported apple maggot adults emerging in early June. Based on the presence of active adults in the first week of June, mature females could be laying eggs by the second or third week of June and larvae would be present in fruit within 5 to 7 days. Although there are no trapping data from research or programme activities from early June it is believed that some flies can be active in early June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). In one year adults were trapped in late May in Vancouver, Washington (Yee, *personal communication*, April 2016) but this is an exception. The end date is based on data from Mattsson (2015) indicating that maximum flight activities for adult flies on ornamental hawthorn in Vancouver (Clark County) was determined to be in mid-September. Depending on the impact of lower degree days at this time of the year, the life cycle of *R. pomonella* could extend into November or December.

Infested fruit, particularly (but not exclusively) apples, is thought to be the most likely route of entry of the pest to the PFA (Hood *et al*., 2013). This could enter the waste stream at any time of year if it is stored or retained by homeowners in green waste in their yards but the most likely period for this to occur is from June to November. This is based upon when fruit on trees is likely to be infested and may be culled from the tree, or collected from the ground, or harvested and rejected, and so may enter the waste stream. During the winter and early spring months dropped fruit should rot *in situ*.

Adults are only in the vicinity of fruit when they are mature and ready to mate or lay eggs (Porter 1928; in Dean and Chapman 1973). This period spans June to October. Adults are unlikely to move with green waste unless they emerge from pupae in soil or fruit during transport.

Life stages associated with soil in waste from discarded host plants are late third instar, and pupae. The window of time from November until the initiation of emergence in June should have the greatest soil load of pupae (the most resilient stage of the pest). It is during this time frame that the movement of soil associated with host plants would be of the greatest risk. However, because pupae can survive in soil for more than 2 years (in Brunner 1987, in Dean and Chapman 1973), they could be in the soil in the waste stream throughout the year.

The main hosts in the state of Washington are apples (*Malus* spp.) and several species of hawthorn including black hawthorn (*C. douglasii*). However, there have also been records on various species of cotoneaster (*Cotoneaster* spp.), mountain ash (*Sorbus* spp.), apricots, various plums and cherries (*Prunus* spp.), as well as common and Asian pear (*Pyrus* spp.).

Of these, apples, black hawthorn and oneseed hawthorn (*C. monogyna*) are considered to be of high importance for the pest and several species are of medium importance including smooth hawthorn (*C. laevigata*), Suksdorf's hawthorn (*C. suksforfii*), and Asian pear (*P. pyrifolia*). See section 1.06 and Yee *et al*. (2014).

In the case of Barr-Tech LLC, the prevalence of these hosts in the waste stream originating in Spokane, either as fruit, or as host plants with associated soil, or just soil that has been associated with these hosts is unknown.

However, whole apples were found at the Barr-Tech LLC facility in July and August 2015 and one larva (dead) was found in a cut fruit and two pupae respectively (WSDA, USA, *personal communication*) so it is likely that infested material will be present in the waste stream. Small fruit such as hawthorn, if detached from the host, may be difficult to detect on inspection of waste

The most recent levels of infestation with *R. pomonella* for Spokane County were determined by the WSDA in 2015 with a low level of trapping. Four traps yielded 22 adult flies at 1 site (Klaus, 2016). Personal communications support the view that Spokane county has a lower level of infestation than parts of the western side of the state such as Seattle. It is thought that if 100 traps were randomly placed in host trees in these areas 80% would be positive in the Seattle area compared to 20% in Spokane county (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015).

Nevertheless, because of the detection of the pest at the facility in the summer of 2015 and the fact that municipal green waste enters this facility from a quarantined county it is considered that it is *likely* with *low uncertainty* that *R. pomonella* will be associated with this pathway taking account of the biology of the pest.

2.04 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account <u>current management</u> conditions?

Very likely

Level of uncertainty: *Low*

The municipal green waste arriving at the Barr-Tech LLC facility originates in the eastern side of the quarantine area for *R. pomonella* in Spokane County and the pest is considered to be established here. Management of the pest in quarantine areas is likely to be less intensive than in the PFA, and, in homeowner's yards, it may not be very effective even if it is deployed. However, advice is available through Washington State University's extension service:
http://ext100.wsu.edu/skagit/agriculture/apple-maggot/ and via amateur fruit-growing societies. The success of control will vary with the homeowner. At the point of collection it is considered that there is no management of the municipal green waste with respect to the pest.

Thus, accounting for current management conditions any viable life stages of *R. pomonella* which are present are *very likely* to be associated with the waste at the point(s) of origin with *low uncertainty.*

2.05 - Consider the <u>volume</u> of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

Very likely

Level of uncertainty: *Low*

The amount of municipal green waste that was received (99% from Spokane County in the east of the quarantine area) in the last 4 years is presented in Table 5 below.

Table 5. *Tons of municipal green waste received by Barr-Tech LLC, Lincoln County

Month	2012	2013	2014	2015
January	308	288	468	492
February	642	434	211	899
March	1810	2520	2086	3854
April	5285	4906	5367	5398
May	7487	6803	7364	6351
June	6291	6278	6210	6053
July	4796	4852	5553	4371
August	4578	4755	6218	4924
September	3677	4798	4824	4759
October	5404	5202	5199	4035
November	7706	7454	5891	7091
December	1655	1431	2656	5406
TOTALS	**49640**	**49723**	**52045**	**41136**

*Figures rounded from 2 decimal places

High amounts of municipal green waste are received each year at this facility; and also each month, with only January and February having relatively low amounts, though even this is not insignificant.

On the assumption that infested material is present in the municipal green waste, since the amount of waste arriving at this facility is high, it is considered *very likely* with *low uncertainty* that this volume of waste will support the entry of the pest to the PRA area.

2.06 - Consider the <u>frequency</u> of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

Very likely

Level of uncertainty: *Low*

See Table 5 in section 2.05.

Historically, municipal green waste has been received all year round at the Barr-Tech LLC facility.

During normal operations around 50 truckloads of waste arrive each week with an average of 25 tons per load.

Waste host fruit arriving at the facility may be infested with *R. pomonella* from mid to late June when early varieties of apple start to ripen through to at least late October when all fruit should have fallen, but depending upon when the first freezing temperatures occur. Black hawthorn (*C. douglasii*) can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October). As hawthorn fruit are small they may be present in waste from June to October.

Up unto 2014, municipal green waste was received in all of these months. No data were obtained for November and December 2015 as the response to the questionnaire supplied by the PRA team had been received before this was available.

When soil is in the waste stream that has been gathered with host plants that have fruited and are infested, pupae of *R. pomonella* are likely to be associated with the soil. This is possible all year round with peak numbers of pupae being present from November to June, months when a high amount of waste is received.

Thus, due to the fact that municipal green waste from the quarantine area arrives at this facility every month, if not every week, the frequency of movement is *very likely* to support entry of *R. pomonella* to the PRA area, with *low uncertainty*.

2.07 - How likely is the pest to survive during transport or storage?

Very likely

Level of uncertainty: *Low*

The likelihood of survival of *R. pomonella* prior to arrival in municipal green waste arriving at the Barr-Tech LLC facility is largely related to the amount of heating (temperature and duration) that occurs prior to or during transport.

It is assumed that as the waste that is received by Barr-Tech LLC is unprocessed it is less likely to heat up *en route* compared to waste that is mechanically processed prior to transportation.

With respect to the transfer stations for Barr-Tech LLC, the response to the PRA team's questionnaire showed that there are 3: North County, Valley Transfer and Waste to Energy Recycling Center, all of which are located in Spokane County. The length of time that waste is stored at these stations is no more than 24 hours.

Subsequent to receipt of the questionnaire it was learned that there are another 3 transfer stations in Spokane County from which Barr-Tech LLC received municipal green waste:

Barr-Tech LLC contracts with Action Materials to receive and transfer green waste from the City of Spokane kerbside collection vehicles; they also collect and transfer from the city of Medical Lake and receive material from Sunshine Disposal who collect and transfer from the city of Spokane Valley. (Deatherage, Barr-Tech LLC, USA, *personal communication* to Reynolds, USA, January 2016).

From the time of departure from the transfer facilities, the routes taken to the Barr-Tech LLC facility are less than 1 hour's driving time (see Figure 11 below).

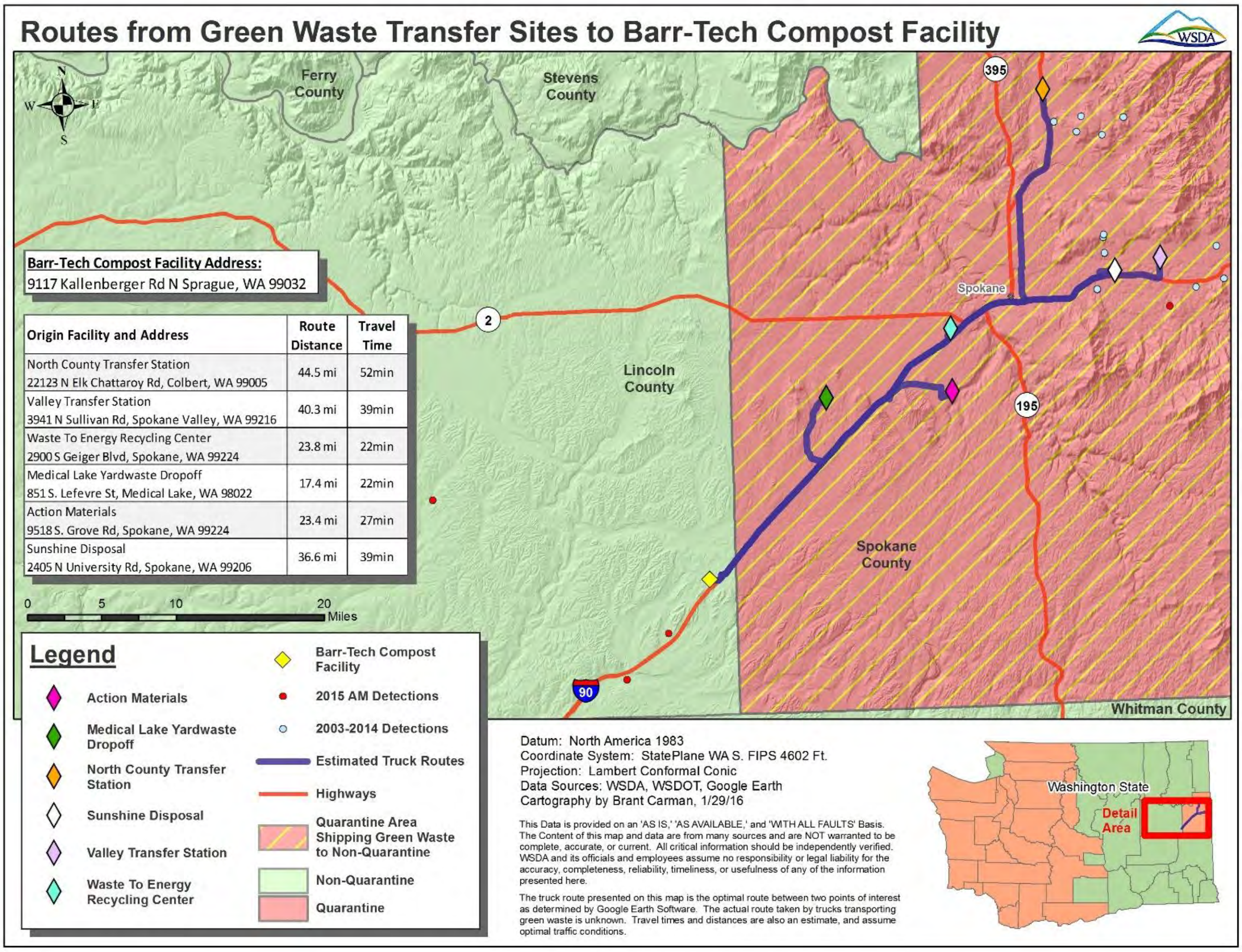


Figure 11: Distance and travel time from three transfer stations in Spokane County to Barr-Tech LLC (source WSDA)

Waste is transported from the transfer stations in trailers that are 48 to 53ft long and which are covered with a solid water-tight tarpaulin. The trailers themselves are not water-tight. On arrival at the Barr-Tech LLC facility the waste is dumped onto an asphalt pad and then it is pushed into a pile on an asphalt pad where it may be stored for up to 1 week without being covered.

Although there will be some heating of the waste material within the pile due to natural microbial activity the waste on the surface of the pile will not be affected by this. Also, as the waste has not yet been subjected to any mechanical processing, heating within the pile would be less even than if it had been ground. Any infested intact or partial fruit, as well as pupae present in soil will be *very likely* to survive transport and storage with *low uncertainty*.

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

Unlikely

Level of uncertainty: *Low*

R. pomonella reproduces by laying eggs within host fruit while it is still hanging on the tree. Dean and Chapman (1973) cite Porter (1928) stating *'Fruit in shaded locations are preferred to those in sunny spots and neither ripe fruit nor drops are attractive to ovipositing flies'*. Thus there should be no oviposition occurring during transport to or storage of host fruit in municipal green waste for any facility.

However, during the period of transportation of the municipal green waste to the transfer stations and onwards to the Barr-Tech LLC facility, as well as for the period of storage at the facility before it is processed, which may be up to a week, the pest will continue its life cycle. This may extend into the period of processing.

Late instars present in fruit may emerge from the fruit and start to pupate. Pupation takes place within 24hrs of emergence from fruit. Partial fruits (cut or partially-eaten) yield pupae from larvae (3rd instars) which can continue to develop and pupate (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Occasionally larvae may pupate within fruit (Illingworth 1912; in Dean and Chapman, 1973).

Although pupation can take place on any hard surface it is thought that survival of pupae would be much lower in situations where the larvae cannot burrow into the soil, however it is possible that adults would emerge (Brunner, *personal communication* to Mastro, USA, October 2015). Dean and Chapman (1973) citing others state that some moisture is required in the pupal environment with 80 and 100% RH resulting in 81% and 70% emergence (and 2% and 2.5% mortality respectively). Note these are not measures of soil moisture. Survival would be increased if the pupae were in an atmosphere of high humidity such as might occur if they were covered with a small amount of waste material, e.g. as sweepings or spillage at the edge of the main pile of waste. Under such circumstances, pupae that are on hard surfaces at the composting facility could yield flies when they are ready to eclose and these could disperse in favourable temperatures during the normal period of flight activity (when temperatures are favourable between June and October). Pupation could occur in the moist waste once it is being composted before the material reached lethal time x temperatures.

The surface on which the windrows are built is asphalt. As this is not part of the transport or storage of the waste (it is the start of the composting process) it is discussed in 2.10.

Emergence of flies from pupae in the waste that have either:

- Overwintered as diapausing pupae
- Have remained in diapause for more than 2 years
- Were produced in the same season and which have not undergone diapause will lead to an increase in the prevalence of adult flies in the PRA area.

This is not an increase in the prevalence of the pest *per se*. It is a continuation of the life cycle with a potential increase in the numbers of adults that could reproduce.

Thus it is *unlikely* with *low* uncertainty that there would be an increase in the prevalence of the pest up to at least the period when the waste becomes subject to processing or maybe beyond at the Barr-Tech LLC facility. The processing of the waste and the potential risk that the adult flies pose to hosts in the PRA area is discussed under section 2.10.

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Very likely

Level of uncertainty: *Low*

Currently the municipal green waste stream is not subject to official inspection procedures at the point of origin.

However, inspection of all of the composting facilities was undertaken by the WSDA in July and August 2015 (looking for apples, crab apples and hawthorn); intact apples and some larvae and pupae of *R. pomonella* were found, including at the Barr-Tech LLC facility. Given the size of hawthorn fruit as well as parts of apples and crab apples these are unlikely to be found.

Detection also depends upon the intensity of the surveillance in relation to the volume of material; with waste this would be a difficult process.

In the absence of regular official inspection at the point of origin it is *very likely* with *low* uncertainty that *R. pomonella* will enter the PRA area undetected until such times as it is trapped during the WSDA annual survey for the pest.

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat ?

Very likely

Level of uncertainty: *Low*

During the period that the municipal green waste is stored at the Barr-Tech LLC facility pending processing (up to 1 week) and even at the beginning of the processing period there is a risk that adult flies of *R. pomonella* emerging from pupae could transfer to hosts in the PRA area during the normal period of adult activity (June to October). They can also transfer to non-host trees, where they can probably sustain themselves by feeding on leachates and other substances on leaf surfaces (Hendrichs and Prokopy, 1990) or possibly on substrates on other surfaces (although this has not been documented). The likelihood of this occurring is dependent upon the dispersal distances of the flies, the proximity and availability of hosts and non-hosts, and the impact of the processes that the waste is subjected to at the facility has on the pest.

<u>Dispersal distances</u>
Adult flies of *R. pomonella* normally travel relatively short distances when host plants are abundant and their fruit are ripening and are therefore susceptible to infestation. However, they may travel longer distances where this is not the case. All of the dispersal studies that have been done in the field were conducted in the east of the USA where hosts were abundant.

Maxwell (1968) released flies within an apple orchard in fruit and found they dispersed up to 250ft (0.05 miles) from the point of release and Neilson (1971) found similar results (up to 300ft = 0.06 miles).

Bourne *et al*. (1934) released flies in an area where the nearest abundant apple trees in fruit were 600 to 700 yards away from the release site. The furthest distance that a marked fly was trapped was 728 yards away (0.41 miles).

Maxwell and Parsons (1968) released flies in an area away from but within the vicinity of susceptible apple orchards in fruit and found that the majority were trapped within about 560 yards (0.32 miles) but the furthest distance flies were trapped was 1719 yards (0.97 miles).

Sharp (1978) investigated potential flight distances of *R. pomonella* in the laboratory using tethered flies on flight mills. It was found that tethered females flew up to 4.5km (2.8 miles) in 3hrs even when though they were deprived of food and water. The author felt that they had the potential to fly greater distances in the field when not constrained by tethering. However, Yee (USDA, ARS, USA, *personal communication* April 2016) commented that '*free flight is always less than tethered flight*'. He also stated that '*It is possible, though, that under sustained windy conditions, flies in the absence of a nearby host could take off and then be assisted by wind and use less energy. This could allow them to travel farther than 'normal'. But this is speculation'.*

Brunner (Washington State University, USA, *personal communication* to Mastro, USA; October 2015) (interpretation of a discussion between Brunner and Mastro, October 27th, 2015):

'He believes that if a fly emerges it will go ½ mile or further to find a host. They have not done mark recapture studies in the absence of host in central or eastern Washington because of quarantine restrictions. No one has attempted using sterile flies because of the difficulty of rearing large numbers'. Yee (USDA, ARS, USA, *personal communication* April 2016) commented that '*mark-release-recaptures studies are risky and many times yield little information despite great effort'*.

Brunner believed that an adult fly had the potential to move 3km (1.86 miles) in one generation.

In summary the maximum published flight distance for *R. pomonella* in the field is *ca.* 1 mile with a single laboratory study indicating potential for greater than *ca*. 3 miles in a single flight. Given the longevity of the adults (up to 40 days) a single fly could cover a large distance during this stage of the life cycle depending upon its behavioural preferences, need to travel and availability of hosts.

<u>Proximity and availability of hosts</u>
Yee (USDA ARS, USA, *personal communication* to Marra and Klaus, WSDA, USA, April 2015) discussed the possibility of categorising the four composting facilities in the PFA (the PRA area) into high and low risk depending upon the proximity of the nearest hosts. He felt that where host prevalence was high then flies will disperse faster and over longer distances.

He stated that: '*In* [the] *barren landscape in central/eastern WA: Low risk compost facility: greater than 1 mile from host trees. So if the facility is 3, 10, or 20 miles away from hosts, it would be a low risk*'. And: '*High risk facility would be one <1 mile from host trees*'.

This is assumed to mean that when hosts are abundant, the flies have more opportunity to reproduce since flies will normally travel <u>shorter</u> distances when host abundance is high as their need to reproduce is more easily satisfied. Adult flies can feed on leaf surfaces of non-host trees and potentially on other surfaces, so in areas of low host prevalence they can still feed, and will travel further to reproduce.

Prevalence of apple orchards

The nearest apple orchard is thought to be 16 miles away, just north of Cheney in the quarantine area of Spokane County. The nearest orchard in the PFA is roughly 26 miles away, 7 miles north of the town of Reardan in Lincoln County. However, it appears to be abandoned. Thereafter the next closest would be in Stevens County, just west of the town of Enterprise, about 48 miles away. Source: Carman, WSDA, USA, *personal communication*, January 2016. See Figure 12.

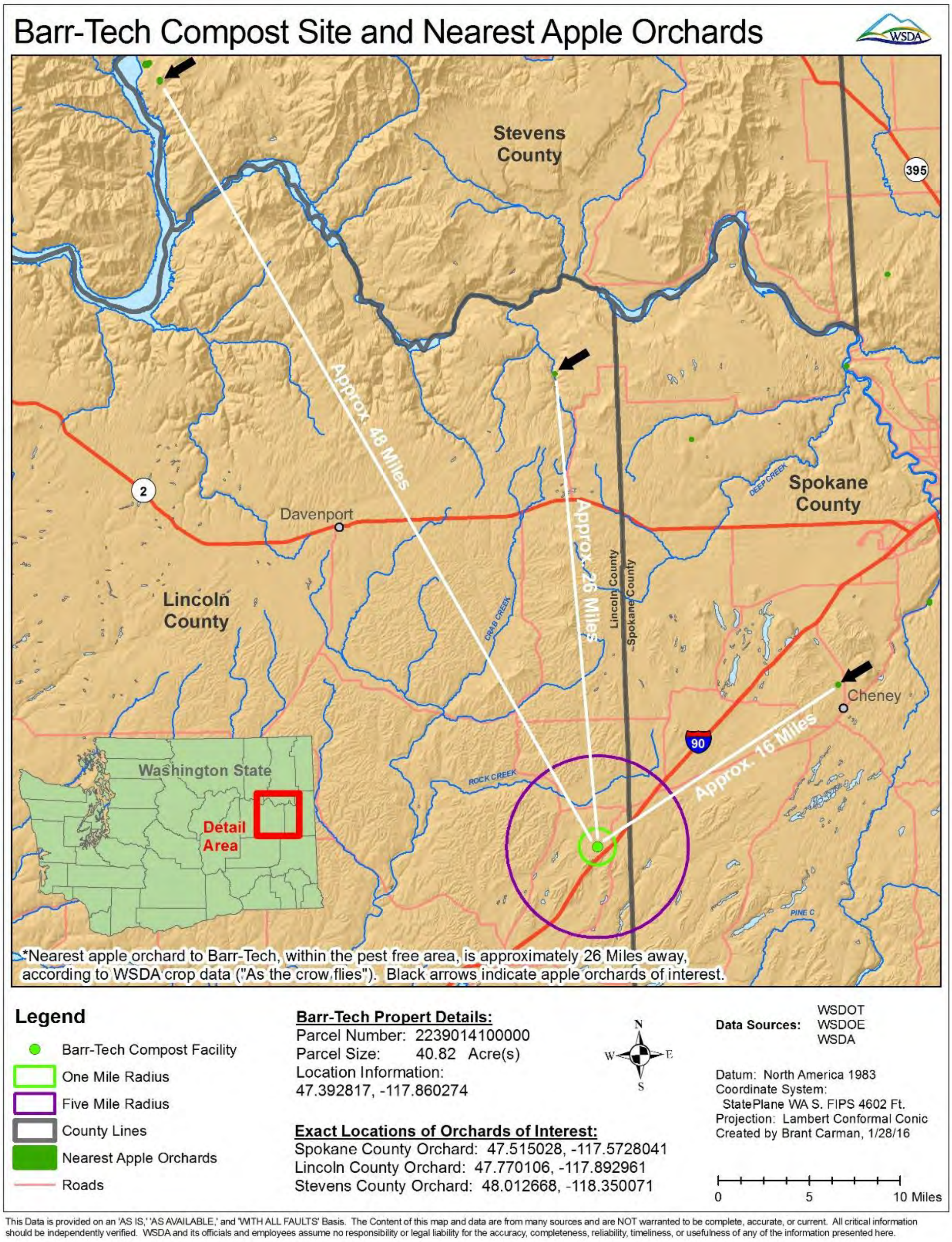


Figure 12. Nearest orchards to Barr-Tech LLC (source WSDA).

Prevalence of other hosts

Host distribution in the PRA area is discussed under section 1.06. Outside of the orchards in the east of the state host distribution is discontinuous since it is reliant upon the presence of waterways and wet areas, and this part of the state is relatively dry. The WSDA hangs traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in the area when fruit is on the tree. The only maps of host distribution in the vicinity of the composting facilities are those showing which hosts are used for trapping. However, this map is not meant to be a complete inventory of host plants within the 5-mile radius largely due to logistical constraints in surveying the area. In 2015 the WSDA aimed to place traps in all of the main hosts within a 5-mile radius of each composting facility. Figure 13 shows the host trees where traps were placed around the Barr-Tech LLC facility indicating the presence of a number of hosts, especially native hawthorn, within 0.5, 1 and 5 miles of the site. The nearest host, native hawthorn, is estimated from the GIS to be 475ft (0.09 miles) away (Carman, WSDA, USA, *personal communication*, March 2016). Within 1 mile of the facility the WSDA trapped a reasonable number of native hawthorns. Within the 5 mile radius there were still a number of hosts that were trapped. This offers an opportunity for adult flies of *R. pomonella* to transfer to non-commercial hosts.

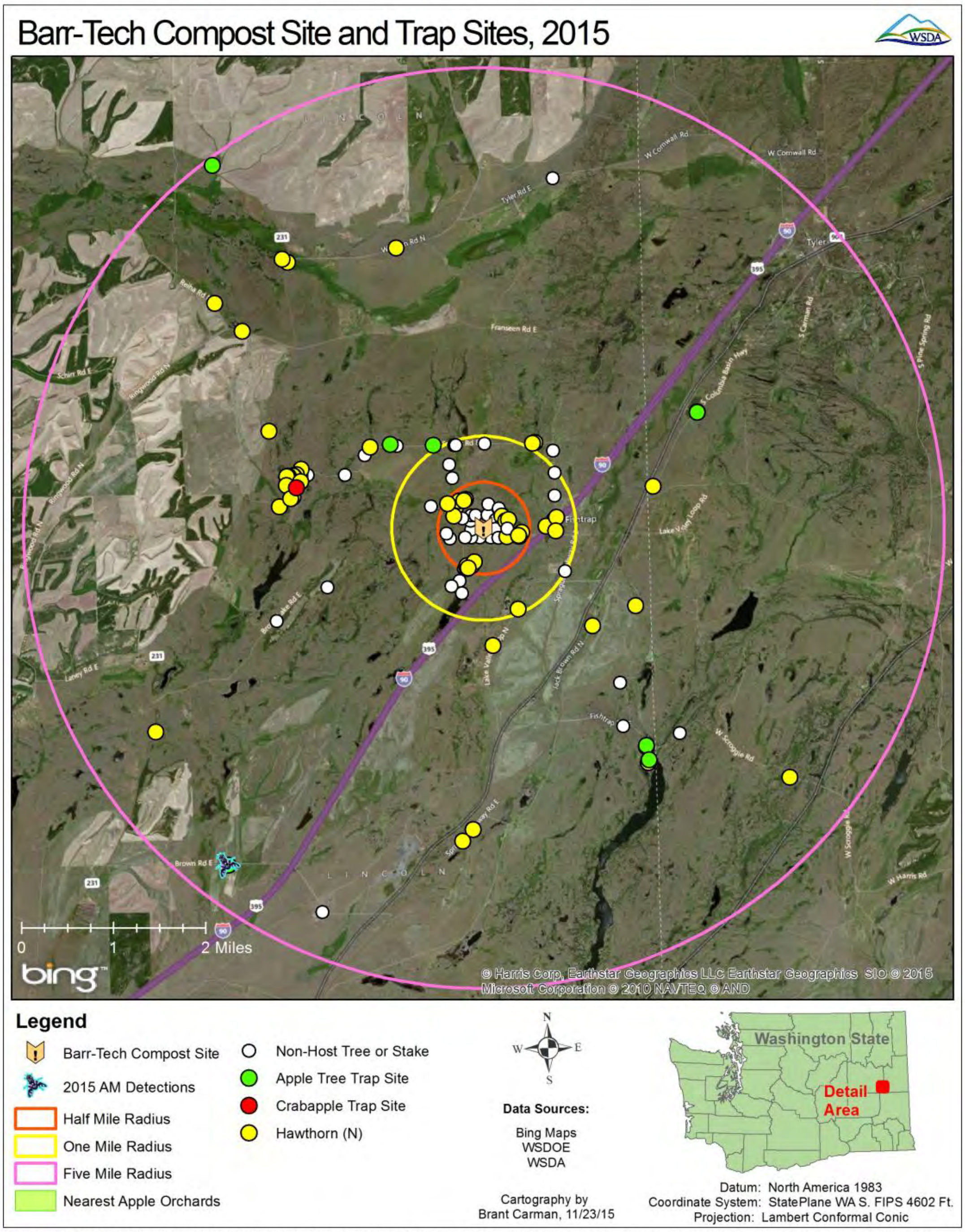


Figure 13. Host trees trapped by the WSDA around the Barr-Tech LLC facility in 2015 (source WSDA)

Results of trapping

Trapping undertaken in 2015 shows that a single trap was positive for *R. pomonella* at a distance of 4.6 miles from the Barr-Tech LLC facility. The source of this find is unknown. See Figure 14 below.

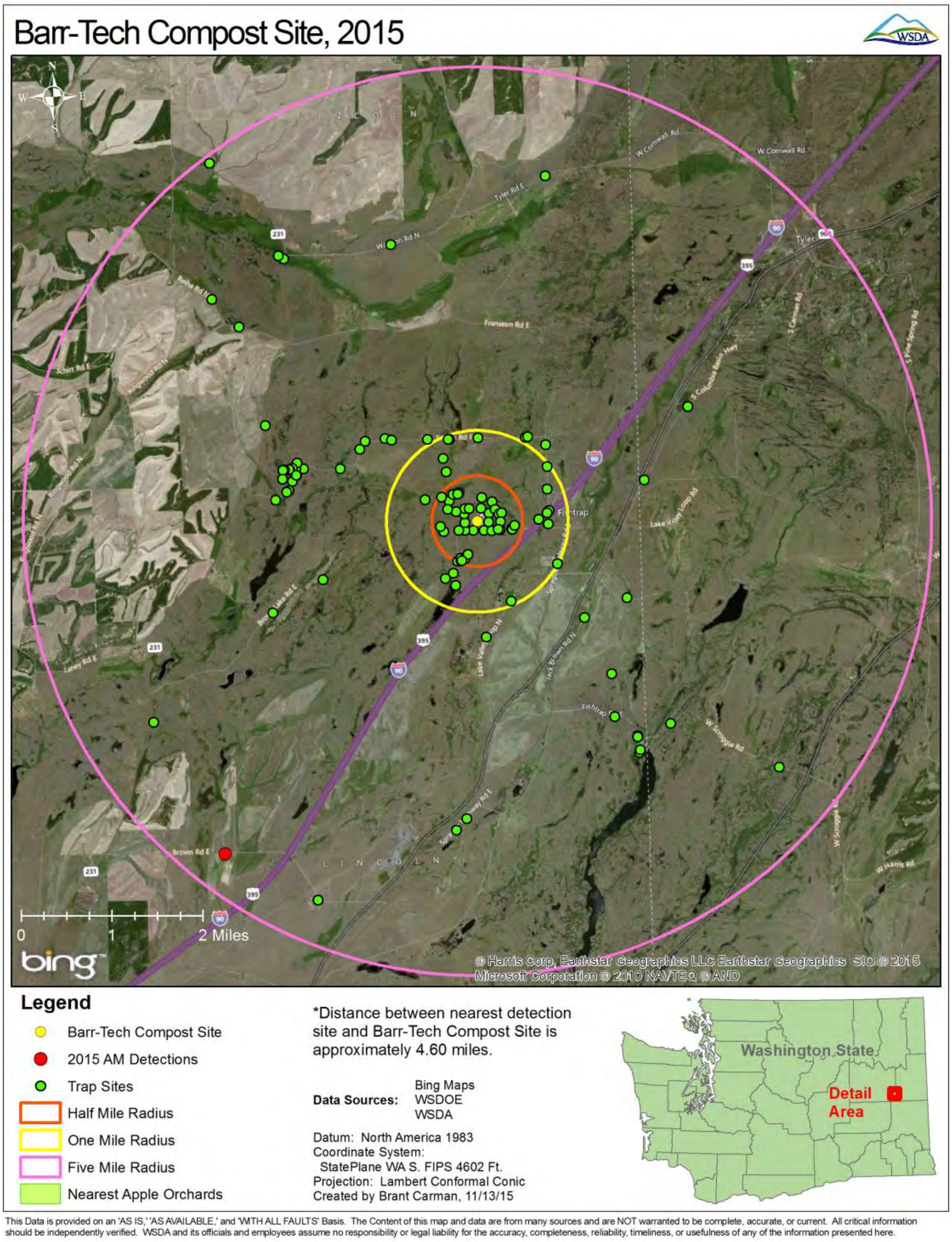


Figure 14. Host trees trapped by the WSDA around the Barr-Tech LLC facility in 2015 showing one positive trap site (source WSDA)

Processing of municipal green waste at the Barr-Tech LLC facility

Grinding

Following transport and storage, the first stage in the processing of the municipal green waste is when it is ground. Barr-Tech LLC uses a tub grinder. A description of the grinding process was provided by the facility:

'The tub grinder is a large 700 hp. machine that has a rotating tub hopper over a hammer mill with 26, 100 pound fixed hammers turning at 2000 rpm. As the material is fed into the tub it rotates over the mill and the yard debris is immiserated. You can find an occasional stick the size of your index finger, however anything soft like fruit is completely pulverized. There is no identifiable fruit or even parts of fruit in the material discharged from the tub grinder'

The dimensions of the ground material were described thus:

'We produce material with a min. 1/8", mean 1", max. 3"; I haven't tested the ground material but I would guess 95% would pass a 1" sieve'.

Composting
Once ground, the material is then composted, first in a static pile and then in an aerated static pile. All piles are located on 6.5 acres of *'paved asphalt compost pad'*. The process is described thus:

'The static pile composting process starts immediately once the material is ground and water is added. The processed green waste is placed on the asphalt composting pad in <u>uncovered</u>, unmonitored thermophilic (temperatures in excess of 110°F) [43°C] *static piles. <u>Internal pile</u> temperatures will reach 131°F* [55°C] *<u>within 48 hours of grinding</u>. It remains in the initial high temperature static pile for 15 to 30 days (depending on the time of year) prior to being remixed and placed into a 45 day negatively aerated static pile process. One of the primary goals of the aeration process is to keep the temperatures in the piles below 160°F* [71°C]. *In order to keep the material aerobic and under 160°F* [71°C]. *the material is remixed and moved twice more every 15 days, then placed into a final 15 day curing phase before the material is removed from the composting pad'.*

'In general, negative aeration consists of drawing fresh air through the compost pile (i.e., from outside to inside), collecting the off-gases from the core of the aerated static pile, and treating these off-gases through an organic-media biofilter specifically designed for this purpose'.

'The material is not covered in the initial static pile, only after it is in the aerated phase of the process are the piles covered with a vented compost cover (tarp) that is designed to provide uniform air flow throughout the pile. In the initial aeration phase it is covered with 1 ft. of finished compost then covered with the vented compost cover (tarp)'.

Process monitoring
The automated part of the process and monitoring starts when the waste is moved into the negatively aerated static pile. At this point Barr-Tech LLC state that:

'Temperature probes are inserted that control the airflow in order to maintain pile temperatures below 165°F (74°C) and above 131°F (55°C for at least 3 days). Here the temperatures are monitored for approximately 28 days'.

The number and depth that the probes are inserted to within the waste was not specified.

A brief description of the aeration/temperature monitoring system provided by Engineered Compost Systems (ECS) was provided:

'The ASP system utilized at the Barr-Tech facility is operated and monitored using a proprietary control technology provided by Engineered Compost Systems, Inc. (ECS) of Seattle, Washington. Individual piles are negatively aerated to maintain aerobic conditions throughout the pile, in an effort to: 1) mitigate potential off-site impacts from odor; 2) retain moisture in the compost piles, 3) expedite the composting process by maintaining proper temperatures; and 4) produce a high quality finished compost product.

With the ECS management system, each compost pile is constructed over a pipe-less aeration floor and then covered with a durable, impermeable cover, with distributed ports that allow for even airflow across the outer surface of the pile. Temperature probes are inserted to continuously monitor pile temperatures. Oxygen levels and pile temperatures are managed by varying the volume of airflow over time.

The AC Composter™ is a covered Aerated Static Pile (ASP) designed to provide the operator with a cost-effective tool for controlling air emissions and maintaining optimal pile conditions during composting. It combines an innovative fabric cover with the long proven ECS control and aeration technologies. The AC Composter™ is appropriate for a wide range of facility sizes and feedstocks.

The AC Composter includes ECS's time tested composting aeration and automated control technologies. The process is controlled and data is logged by the CompTroller™. Batches of compost are easily tracked through the facility from start to finish; and a time/temperature compliance record is automatically created. The negative airflow through the piles is automatically controlled per operator chosen set-points. The exhaust air is scrubbed in a small organic media biofilter. The aeration rates can be set very low to conserve moisture and fan power, without releasing odors. Prior to removing the cover and turning, the aeration is typically increased to lower temperatures and raise Oxygen levels; this greatly diminishes odor releases and can quickly dry the material if required.'

<u>Assessment of processing at the Barr-Tech LLC facility</u>
Before the municipal green waste is processed it is stored for up to 1 week in an uncovered pile; the risk from this stage has already been assessed.

When it is ground, Barr-Tech LLC advised that any fruit that is present should be pulverised, but the size of the ground waste is described as a minimum of 1/8" (3.2mm), mean 1" (25.4mm), and a maximum of 3" (76.2mm) with an estimate (not based on measurements) that the 95% of the ground material would pass through a 1" (25.4mm) sieve. It is possible that small fruit of hawthorn may survive the process. Although some infested apple fruit was observed by the WSDA at the Barr-Tech LLC facility in June 2015 this was in waste that had not been ground.

Eggs of *R. pomonella* measure 0.9mm long and 0.23mm wide.
Late third instars measure 6.5 - 8 mm long x 1.5 - 2 mm wide.
Pupae measure 5mm long x 2.3mm wide; or from two locations in the state of Washington more recent specific values of *ca*. 4.5mm long x 2.1 mm wide and 4.3 x 2.1mm wide have been provided (with males being smaller; some are only 3.8 mm long and 1.7 mm wide).

Because of their small size all life stages have potential to be present in some of the ground waste but the pupae are the most resilient and are most likely to survive the grinding process.

When the ground waste is moved to the unmonitored thermophilic static piles for between 15 and 30 days it is not covered. It is feasible that during this period any adults inside the puparia that are ready to eclose and which are near to the surface of the pile, where they do not reach lethal temperatures because of the edge effect (which can be experienced down to *ca*. 25cm), could lead to their emergence from the pile. These may transfer to any host trees that are within a dispersal distance of up to at least 1 mile of the site. Based upon Figure 13 this is most likely to be native hawthorn. They can also disperse to non-host trees where they can feed on their leaf surfaces; and possibly on other surfaces. Any late 3rd instars could pupate within 2 to 18hrs and if they do not enter diapause they can take 4 to 6 weeks to emerge as adults (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Yee (USDA, ARS, USA, *personal communication*, April 2016) advised that under laboratory conditions up to 50% of pupae in the state of Washington do not require a chilling period (i.e. if kept at room temperature) to lead to emergence of adults. This may increase the risk of dispersal of flies from non-diapausing pupae at composting facilities. In this instance this is unlikely to add to the population of adult flies since the maximum 30 day period for waste to remain in these uncovered piles is likely to be in the colder months and thus not likely to coincide with this stage in the life cycle of *R. pomonella.*

The temperature of the static piles is described as around 43°C but reaching 55°C within 48 hours of grinding. (Also described by Barr-Tech LLC as '*often within 24 hours after grinding'*).

Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) stated that: '*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stages. This stage is still metabolizing at 50°C and the normal metabolizing only begins to breakdown at 55°C. To determine this you were using a fairly aggressive heating protocol of 0.4 degrees/minute'.* She also advised that this life stage is in deep diapause until 5 days before emergence. A 30 minute exposure to 45°C does not kill pupae. At 50°C it takes 20 minutes for thermal death. Yee (USDA, ARS, *personal communication*, March 2016) showed that holding pupae at 100% RH at 45.3°C for 1 day only led to 6.7% mortality whereas holding them at 46.3°C for 3 days resulted in 100% mortality. In a separate experiment, exposure of pupae to 50.5°C for 3 days or 38°C for 1 day followed by 56-58°C for 3 days at 100% RH led to 100% mortality (Yee and Chapman; *manuscript in preparation*).

Although the minimum time and temperature combination that is needed to kill pupae of *R. pomonella* is thought to be around 50°C for 20 minutes (based upon Neven's unpublished work) it seems that at least <u>within</u> the static piles the pupae could survive for up to 48hrs but those on the surface of the pile will escape this exposure since the material is not remixed during the 15 to 30 day period it is in the first static pile. Again, those flies that are ready to eclose and can escape the pile prior to heating could disperse to host or non-host plants within flying distance of the facility during the normal period of flight activity (when temperatures are suitable between June and October).

When the period in the first static pile is completed (after 15 to 30 days), the material is mixed and moved to the negatively aerated static pile for 45 days and it is at this stage when it is covered with 1ft of finished compost and then with the vented compost cover (tarp). Mixing of the material will help move waste from the edge of the first static pile towards the centre which will also help to expose any remaining pupae to heat as the pile warms up. The material is then remixed every 15 days which will also enable material on the outside to be moved to the centre. Temperatures in the aerated static pile have to reach more than 55°C for at least 3 days based on temperature probes used to monitor the pile for 28 days. The number and position of the probes is unknown. If all of the material is exposed to this time x temperature this would be sufficient to destroy any remaining pupae. However, it is not known whether this time x temperature would occur for all of the waste material. If there are any cold spots or areas where larger pieces of infested material are located, these could pose a risk of survival of pupae of *R. pomonella*.

Because the surface upon which the piles are constructed is asphalt any late third instars which tumble from the piles could not burrow into the soil but they can still pupate. They may crawl into a crack or crevice or pupate on a flat surface. Any pupae that tumble from the piles during any of the processes have the potential to develop into adults that disperse since this is not a closed system. If this occurs during the period when adults can take flight (June to October) the pest could transfer to foliage of host or non-host trees from any spillages that may occur.

Although any of the life stages of *R. pomonella* which are present in municipal green waste that are exposed to sufficient heat for sufficient time are likely to be killed, there seem to be some opportunities for the adult flies to transfer from the facility to hosts within *ca*. 1 mile, most likely native hawthorn as well as to non-hosts or other surfaces for feeding. It seems less likely that pupae would survive through to the end of the process unless there were free pupae or infested material that escaped <u>full</u> exposure to lethal temperatures for the requisite amount of time required to kill them. Based on Neven's unpublished laboratory work this could be 50°C for *ca*. 30 minutes. Yee and Chapman (*manuscript in preparation*) sampled later than this and showed 100% mortality after exposure to 50.5°C for 3 days. It is not known whether this time x temperature would occur for all of the pupae in the waste material.

During the final 15 day curing stage, temperatures will be lower than during the composting stage. Cornell advises that: '*After the thermophilic phase, the compost temperature drops and is not restored by turning or mixing. At this point, decomposition is taken over by mesophilic microbes through a long process of "curing" or maturation. Although the compost temperature is close to ambient during the curing phase, chemical reactions continue to occur that make the remaining organic matter more stable and suitable for use with plants'*.
http://compost.css.cornell.edu/physics.html accessed 17 March 2016.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016) advised that during this phase there is an increase in microbial diversity with the production of lytic enzymes etc. These and other factors during maturation of the compost could have an impact on the viability of *R. pomonella*, especially on pupae that may not have been exposed to lethal temperatures prior to curing. However, this has not been studied and remains an uncertainty.

<u>Intended use of the compost</u>
Barr-Tech LLC has advised that *ca*. 30,000 tons of finished compost is produced per year. Approximately 70% is sold as an agricultural soil amendment and 30% is sold into the local urban landscape market (including State Highway road and bridge projects); less than 1% is sold more than 100 miles from the facility. They advised that for the agricultural market they do not and have not sold finished compost to orchards and nurseries producing host plants and that no orchards or nurseries produce host plants in their (unspecified) area.

The impact of the curing phase on pupae of *R. pomonella* has not been investigated and we have no data to suggest that viable pupae might end-up in the finished compost. This would only occur if procedures are not executed and monitored carefully. An investigation of the effect of curing on pupae of *R. pomonella* would be beneficial.

Taking into account dispersal distances of the adult flies in relation to the proximity of at least some hosts of *R. pomonella*, the processing that takes place at the Barr-Tech LLC facility it seems *very likely* with *low uncertainty* that the pest could transfer from the pathway to a suitable host or habitat. This risk is primarily from the point of arrival of the waste at the facility for up to 1 week while it may be stored without covers before grinding. After that, transfer could potentially occur from the outside of the uncovered static pile for between 15 to 30 days if the edges of the pile do not reach lethal temperatures and this coincides with the normal period flight activity when favourable temperatures occur between June and October. Once the waste is moved into the aerated static pile for 45 days the risk is significantly reduced by the turning process leading to exposure of the waste to lethal temperatures and the fact that the pile is covered with finished compost <u>and</u> a vented tarpaulin (albeit this is not 100% insect-proof). However, the risk of transfer to commercial orchards in the same year is low since the nearest apple orchard is thought to be 16 miles away (in the quarantine area). Orchards in the PFA are further afield (nearest abandoned orchard is 26 miles away and the nearest operational orchard is 48 miles away. The abandoned orchard could act as a refuge for *R. pomonella* if there are fruiting apple trees *in situ*. The time taken to transfer to these locations given sufficient hosts between the facility and these orchards is likely to be several years when conditions are favourable for the pest. Although the area around the Barr-Tech LLC facility was surveyed in 2015 the area is not surveyed annually normally due to the lack of commercial orchards. If the area around the facility is not surveyed in future, the status of the pest will be unknown.

2.11 - The probability of entry for the pathway should be described
It is *likely* with *low* uncertainty that *R. pomonella* could enter the PRA area (the PFA) on municipal green waste originating in Spokane County and being processed at the Barr-Tech LLC facility in Lincoln County.

Although there are no recent survey data for Spokane it is considered to have a lower level of infestation with *R. pomonella* than western Washington State. The waste received by Barr-Tech LLC is not pre-ground. It is stored, uncovered onsite at the composting facility for up to 1 week before it is ground. It is then composted in an unmonitored static pile for 15 to 30 days. This is also not covered and not turned. It is then mixed and moved to the aerated static pile for 45 days which is covered with finished compost and a vented tarpaulin, and it is turned. Up to the time that the waste is put into the aerated static pile there is a risk that any pupae that may be near the surface of the stored waste or in the unmonitored static pile could produce adults which may transfer to hosts that are in the vicinity of the facility. Once the waste is turned and covered the risk is much reduced.

The finished compost is sold to various businesses including landscapers.

The most likely waste material to pose a risk is infested host fruit and soil associated with infested hosts at the origin of the material being collected.

The main areas of uncertainty are:

- The amount and type of infested host material in the waste stream at different times of year
- The amount of infested soil in the waste stream at different times of year

- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The proportion and size of soil clods which may escape the grinding process
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit or soil clods that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The impact of the curing phase on pupae of *R. pomonella*
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- The current level of infestation in Spokane County where the waste originates
- Whether adults of *R. pomonella* will feed on leachates from compost piles

The risk of transfer in the same year as adults emerge from the facility is likely to be to non-commercial hosts within the vicinity of the facility that could maintain populations of the pest, rather than to commercial apple orchards. Depending upon the distribution of non-commercial hosts between the Barr-Tech LLC facility and the nearest operational commercial orchard in the PFA and the ability of *R. pomonella* to establish populations in this area, there may be a risk that the pest could eventually reach the orchard over a period of more than one year. The nearest commercial orchard in the PFA is 48 miles away but there is an abandoned orchard in the PFA 26 miles away.

Pathway 2. Risk of entry of *R. pomonella* on municipal green waste moving to Natural Selection Farms, Yakima County

The questionnaire from the PRA team used in this section was completed by Ted Durfey, Chelsea Durfey and Nehemias Chalma.

2.03 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account the biology of the pest?

Moderately likely

Level of uncertainty: *Low*

Natural Selection Farms (NSF) receives municipal green waste, normally all year round, from Yakima County in central Washington (considered to be in the east of the state for the purposes of answering this question).

Yakima County is split between the quarantine area and the PFA. The facility receives waste from both areas (but only received waste from the PFA in 2015).

NSF also receives waste from within the PFA of Benton County.

All of the waste received by NSF from the quarantine area of Yakima County is yard debris which has been pre-ground at a transfer station known as Terrace Heights (see Figure 15). At the point of origin (before arrival at the transfer station) it is likely to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream.

R. pomonella is associated with the fruit of a range of hosts and also with soil associated with host plants.

The biology of the pest is described in section 1.02b and was summarised under question 2.03 for Pathway 1 so it has not been repeated here.

The life stages associated with infested fruit are eggs, larvae and occasionally pupae. Fruit begins to be infested in June in the state of Washington. The numbers of each life stage associated with the fruit will vary with the variety and size of fruit. Studies undertaken in the state of Washington (Tracewski *et al*., 1985) found that a single hawthorn (species not specified) can yield 65,000 to 112,000 fruits (1984); it was estimated that with an average rate of 5% of fruit infested (assuming one larva per fruit) there could be 3000 to 6000 flies produced per tree. Incubation of several hundred infested apple fruit (1982 to 1983) mostly yielded 1 or 2 larvae per fruit; however, one fruit yielded 6 pupae. These figures were obtained early in the history of *R. pomonella* in the west of the USA and current infestation rates, at least in the west of the state of Washington are much higher than they were then. If a higher percentage of fruit is infested per tree there will be a greater number of larvae and pupae resulting from an attack by *R. pomonella*.

Despite the high numbers of flies presumed to be produced from a single infested hawthorn, Tracewski *et al.* (1985) did not record the actual number of flies produced. Dean and Chapman (1973) state there is some natural mortality at all stages of the life cycle but that it is highest in the larval and pupal stage and lowest at the egg stage. They cited studies suggesting pupal mortality could be between 47 and 96% influenced by parasitism, predation and ambient conditions. Larval mortality was particularly influenced by the variety of apple since hard-fleshed fruits can lead to 100% mortality. Nonetheless sufficient life stages persist to maintain populations of *R. pomonella* in the quarantine area.

Pupae (and late third instar – albeit this is a transient stage of a few hours) are the life stages associated with soil. According to Dean and Chapman (1073) the pre-pupal stage of *R. pomonella* lasts from 2 to 18 hours with the majority taking 6 to 11 hours to form pupae.

The periods of time over which eggs, larvae and pupae are likely to be found in fruit in municipal green waste from the quarantine area of the state of Washington depends upon whether it originates in the east (in the case of NSF) or the west of the state. See Table 6. This geographic split will influence the prevalence of the pest both in fruit, and as pupae in soil associated with the waste stream, due to the lower levels of infestation in the east side of the state.

Table 6. Periods when eggs, larvae, and pupae can be in municipal green waste originating in the quarantine areas of the state of Washington.

Life stage	**Eastern Washington**		**Western Washington**	
	Start date	End date	Start date	End date
Eggs (in fruit)	Mid to late June	Late September to October* depending on date of first hard freezing temperatures	Early to mid-June	Late October depending on date of first hard freezing temperatures
Larvae (in fruit)	Mid to late June	Early November depending on date of first hard freezing temperatures	Early to mid-June	End of November into early December depending on date of first hard freezing temperatures
Pupae	In fruit, soil , growing media, or in the sod or duff at any time of the year[6]			

*Because the populations are so sparse or nonexistent in areas in central Washington (Yee *et al*., 2012) the seasonality or even the entire host range of the apple maggot is uncertain on the eastern side of the Cascade mountain range. The timing provided in the table is based on what is known and assumes that the same host range exists on the eastern side as on the western side of the state.

In **eastern Washington** where the waste being processed by NSF originates, black hawthorn (*C. douglasii*) and early varieties of apples ripen in early to late June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). Emerging adult flies of *R. pomonella* aligned with these major hosts could begin laying eggs by mid-June. Larvae could be present in the fruit of apples or black hawthorn within 5 to 7 days of oviposition (Dean and Chapman 1973).

[6] Only soil is mentioned in the main text for the assessment but the other substrates are relevant

In an apple maggot survey for Spokane County in 1985 the first recorded fly capture was on June 26th (Klaus, 1985). The end date is based on the presence of ornamental hawthorns (*C. monogyna* or *C. laevigata*) which consistently bear ripened fruit in late October. (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). However because populations on the east side of the Cascade mountain range are sparse or nonexistent they are difficult to characterise. We assume here, that if established they will utilise the same hosts as they utilise on the west side including ornamental hawthorns.

In **western Washington**, all fruiting starts earlier than in eastern Washington because of the warmer temperatures. Fly trapping data show adults were captured in the first week of June (unspecified year) by a hobbyist organisation in Puyallup (Pierce County) (Klaus, WSDA, USA, *personal communication* to Mastro, USA, January 2016). Mattsson (2015) also reported apple maggot adults emerging in early June. Based on the presence of active adults in the first week of June, mature females could be laying eggs by the second or third week of June and larvae would be present in fruit within 5 to 7 days. Although there are no trapping data from research or programme activities from early June it is believed that some flies can be active in early June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). In one year adults were trapped in late May in Vancouver, Washington (Yee, *personal communication*, April 2016) but this is an exception. The end date is based on data from Mattsson (2015) indicating that maximum flight activities for adult flies on ornamental hawthorn in Vancouver (Clark County) was determined to be in mid-September. Depending on the impact of lower degree days at this time of the year, the life cycle of *R. pomonella* would extend into November or December.

Infested fruit, particularly (but not exclusively) apples, is thought to be the most likely route of entry of the pest to the PFA (Hood *et al*., 2013). This could enter the waste stream at any time of year if it is stored or retained by homeowners in green waste in their yards but the most likely period for this to occur is from June to November. This is based upon when fruit on trees is likely to be infested and may be culled from the tree, or collected from the ground, or harvested and rejected and so may enter the waste stream. During the winter and early spring months dropped fruit should rot *in situ*.

Adults are only in the vicinity of fruit when they are mature and ready to mate or lay eggs (Porter 1928; in Dean and Chapman 1973). This period spans June to October. Adults are unlikely to move with green waste unless they emerge from pupae in soil or fruit during transport.

Life stages associated with soil in waste from discarded host plants are late third instar, and pupae. The window of time from November until the initiation of emergence in June should have the greatest soil load of pupae (the most resilient stage of the pest). It is during this time frame that the movement of soil associated with host plants would be of the greatest risk. However, because pupae can survive in soil for more than 2 years (in Brunner 1987, in Dean and Chapman 1973), they could be in the soil in the waste stream throughout the year.

The main hosts in the state of Washington are apples (*Malus* spp.) and several species of hawthorn including black hawthorn (*C. douglasii*) and Asian pear (*P. pyrifolia*). However, there have also been records on various species of cotoneaster (*Cotoneaster* spp.), mountain ash

(*Sorbus* spp.), apricots, various plums and cherries (*Prunus* spp.), as well as common and Asian pear (*Pyrus* spp.).

Of these, apples, black hawthorn and oneseed hawthorn (*C. monogyna*) are considered to be of high importance for the pest and several species are of medium importance including smooth hawthorn (*C. laevigata*), Suksdorf's hawthorn (*C. suksforfii*), and Asian pear (*P. pyrifolia*). See section 1.06 and Yee *et al*. (2014).

The prevalence of the hosts in the waste stream originating in the quarantine area of Yakima County, either as fruit, or as host plants with associated soil, or just soil that has been associated with these hosts is unknown.

The WSDA visited the NSF composting facilities in the summer of 2015 and provided data on the presence of fruit (apple, crab apple and hawthorn) and the pest to the PRA team. For NSF, inspections were done but nothing was found. However, hawthorn fruit are very small and parts of larger fruit that may be present in pre-ground waste are likely to be difficult to find.

The WSDA survey report for 2015 (Klaus, 2016) showed that 4870 active traps were used for certification in the quarantine area (to determine which apple growers met the regulations for shipping fresh fruit out of the quarantine area), and 283 in the PFA as part of the WSDA General Survey. No flies were caught in the PFA. In the quarantine area 153 flies were caught at 109 sites but no pupae were reared from fruit from the trapped trees.

Personal communications support the view that the quarantined area of Yakima County has a much lower level of infestation than areas such as Spokane (see Pathway 1), and parts of the western side of the state such as the quarantined area of Seattle. It is thought that if 100 traps were randomly placed in host trees in the Seattle area, 80% would be positive, compared to 1% in Yakima County (and 20% in Spokane County) (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015).

The level of infestation in the quarantine area of Yakima County where the municipal green waste processed by NSF originates is very low relative to Spokane and the Seattle area and so based on the biology of the pest it is considered that it is *moderately likely* with *low uncertainty* that *R. pomonella* will be associated with this pathway.

2.04 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account <u>current management</u> conditions?

Likely
Level of uncertainty: *Low*

The municipal green waste arriving at the NSF facility that is being assessed originates in the quarantine area for *R. pomonella* in Yakima County where the pest is established but in low numbers. Management of the pest in this part of the quarantine area will vary since there are commercial orchards located here which are certified by the WSDA through their surveillance programme (e.g. Klaus, 2014). Pest management in these orchards is likely to be intensive. However, the waste that is being processed by NSF originates from homeowner's yards and this is where pest management by the homeowner may not be very effective even if it is deployed. However, advice is available through Washington State University's extension service: http://ext100.wsu.edu/skagit/agriculture/apple-maggot/ and via amateur fruit-growing societies. The success of control will vary with the homeowner.

Yakima County Pest Board does take action against the pest in the quarantine area when it is detected during the WSDA survey (this is certification trapping). In 2015, treatments were applied in late June and early July; most were within the city of Yakima. The number of treatments was up substantially from previous years. Treatment is performed for three seasons. Removal (of host trees) off season is the aim where the pest has been detected to stop reinfestation. There were 62 new locations with detections in 2015 in addition to the previous two season's locations. (Anon., 2016).

At the point of origin it is considered there is no management of the municipal green waste with respect to the pest by the homeowner; however, management by the County Pest Board will have some impact on the association of the pest at the point of origin. The apparent increase in the number of treatments referred to above suggests that management is proving to be challenging, especially in 2015.

Accounting for current management conditions, any viable life stages of *R. pomonella* which are present are *likely* to be associated with the waste at the point(s) of origin with *low uncertainty.*

2.05 - Consider the volume of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

Likely

Level of uncertainty: *Low*

The amount of pre-ground municipal green waste that was received by NSF from the quarantine area of Yakima County in the last 5 years is presented in Table 7 below.

Table 7. *Tons of pre-ground municipal green waste received by NSF, Yakima County (quarantine area)

Month	2011	2012	2013	2014	2015
January	-	153	128	350	669
February	-	95	328	65	418
March	-	867	988	806	1033
April	-	1066	1018	1034	1018
May	-	1288	1462	1103	1313
June	-	1098	1176	1365	857
July	-	1010	779	805	1011
August	-	915	1026	1092	967
September	-	1034	379	896	None
October	565	833	-	1097	None
November	985	1399	816	839	None
December	652	766	292	301	None
TOTALS	**2201**	**10524**	**8392**	**9753**	**7286**

*Figures rounded from two decimal places

The total amount of waste received each year at this facility from the quarantine area of Yakima County is moderate compared to Pathway 1; but it is not insignificant.

On the assumption that infested material is present in the municipal green waste, based on this information it is considered *likely* with *low uncertainty* that this volume of movement will support the entry of the pest to the PRA area.

2.06 - Consider the <u>frequency</u> of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

Very likely

Level of uncertainty: *Low*

See Table 7 in section 2.05.

Historically (back to 2012), pre-ground municipal green waste has been received all year round at the NSF facility (operations ceased in September 2015).

During normal operations around six truckloads of pre-ground waste arrive at the facility each week from the quarantine area with an average of 26 to 28 tons per load.

If there is any waste host fruit arriving at the facility in the pre-ground waste (see 2.10 for the impact of grinding on waste material) this may be infested with *R. pomonella* from mid to late June when early varieties of apple start to ripen, through to at least late October when all fruit should have fallen, but depending upon when the first freezing temperatures occur. Black hawthorn (*C. douglasii*) can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October). As hawthorn fruit are small they may be present in the pre-ground waste from June to October.

From 2012 to 2014, pre-ground municipal green waste was received in all of these months (except October 2013).

When soil is in the waste stream that has been gathered with host plants that have fruited and are infested, pupae of *R. pomonella* are likely to be associated with the soil. This is possible all year round with peak numbers of pupae being present from November to June, months when a moderate amount of waste is received.

Thus, due to the fact that municipal green waste from the quarantine area normally arrives at this facility every month, if not every week, the frequency of movement is *very likely* to support entry of *R. pomonella* to the PRA area, with *low uncertainty*.

2.07 - How likely is the pest to survive during transport or storage?

Likely

Level of uncertainty: *Low*

The likelihood of survival of *R. pomonella* prior to arrival in the pre-ground municipal green waste arriving at the NSF facility is largely related to the amount of heating (temperature and duration) that occurs prior to or during transport.

It is assumed that as the waste that is received by NSF is ground prior to transportation it is more likely to heat up *en route* compared to waste that is not mechanically processed prior to transportation.

With respect to the transfer stations for NSF there is just one: Terrace Heights, which is situated in the quarantine area of Yakima County. The amount of time for which the unground waste is stored at Terrace Heights before grinding is 1 to 4 days.

The waste is ground (grinding is discussed in 2.10) at Terrace Heights and the operator contacts NSF once this process is completed to go to collect it; this is presumed to be on the same day. From the time of departure from Terrace Heights, the route taken to the NSF facility is less than 1 hour's driving time (see Figure 15 below).

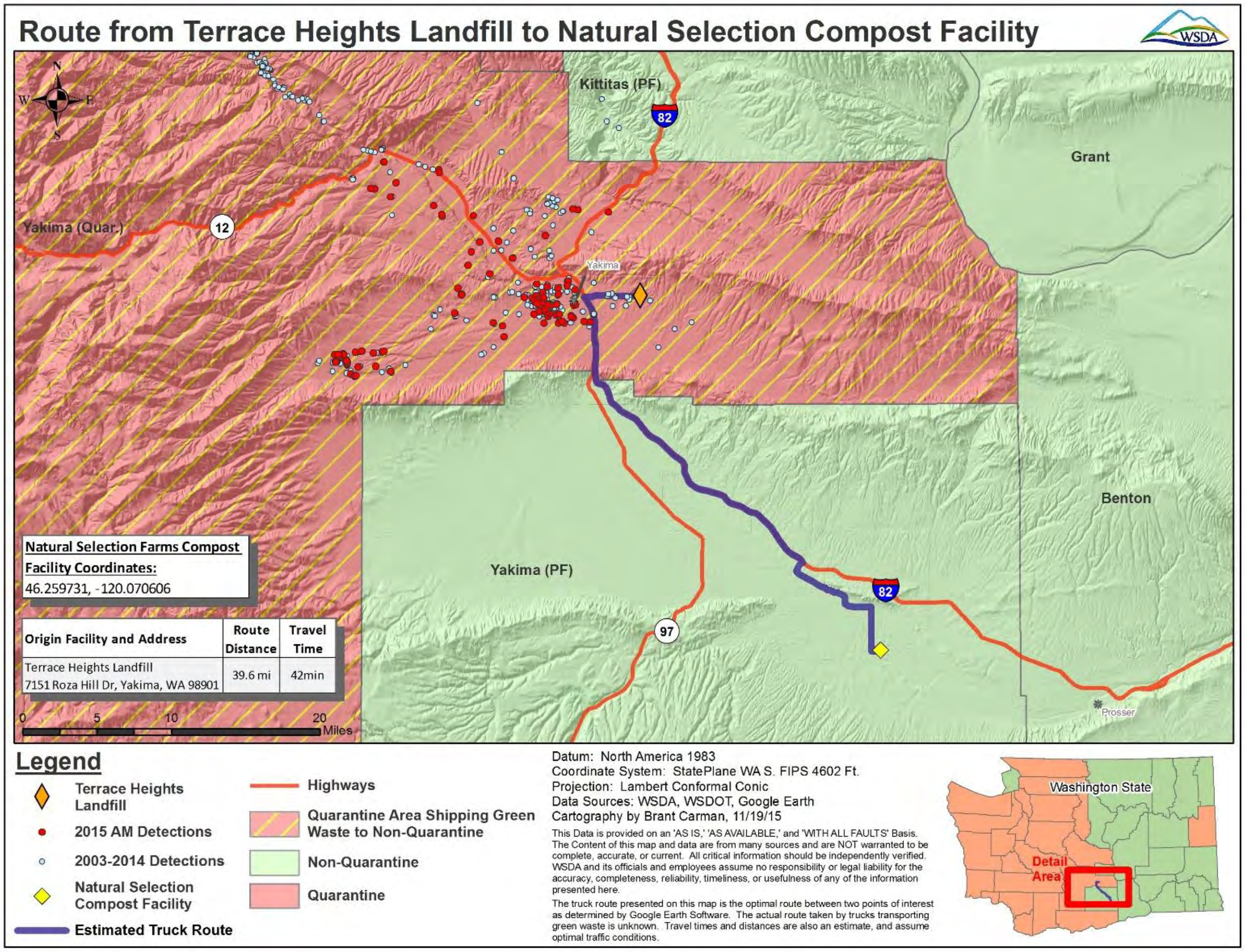


Figure 15. Distance and travel time from Terrace Heights transfer station in Yakima County to NSF (source WSDA)

Ground waste is transported from Terrace Heights in a trailer which is 53ft long and not water tight but is covered with tarpaulins.

On arrival at the NSF facility, the ground waste is dumped onto a soil cement pad and built into an open windrow (not covered) for immediate composting.

There will be some heating of the waste material when it is at the transfer station for up to 4 days prior to grinding due to natural microbial activity, but the waste on the surface of the pile will not be affected by this. Once the waste is ground it will start to heat up but the period of time from grinding to the time it is transferred to NSF and starts to be built into a windrow is assumed to be less than a day and so this is not likely to reach lethal temperatures for the pest.

NSF responded:

'*We receive the call from Terrace Heights Landfill, pick up the ground yard waste in covered trucks, arrive at NSF Compost Facility, unload directly into the windrow lines, and then add additional composting ingredients to the row'.*

'As the green waste arrives it is built into windrows. As other feedstocks arrive (daily), they are layered on top. The green waste provides a sponge-like base to absorb the moisture of the wetter feedstocks. It takes approximately 21 hours of active work time to build a row, and 2 hours to complete the first turn/mix'.

The period of time taken to build a windrow is not clear but during this time any life stages in infested intact or partial fruit which have survived the grinding process, as well as pupae present in soil will be *likely* to survive transport and storage with *low uncertainty* because the time for heating is relatively short.

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

Unlikely

Level of uncertainty: *Low*

R. pomonella reproduces by laying eggs within host fruit while it is still hanging on the tree. Dean and Chapman (1973) cite Porter (1928) stating *'Fruit in shaded locations are preferred to those in sunny spots and neither ripe fruit nor drops are attractive to ovipositing flies'*. Thus there should be no oviposition occurring during transport to or storage of host fruit in municipal green waste for any facility.

However, during the period of transportation of the municipal green waste to the Terrace Height transfer station for the period it is stored at Terrace Heights as unground waste (1 to 4 days) the pest will continue its life cycle. On arrival at the NSF facility the ground waste is built into windrows and new material is added as it arrives. This may extend the period into which the life cycle could continue.

If there are any small fruit or partial fruit that have survived the grinding process at Terrace Heights then any late instars present in the fruit may emerge and start to pupate. Pupation takes place within 24hrs of emergence from fruit. Partial fruits (cut or partially-eaten) yield pupae from larvae (3rd instars) which can continue to develop and pupate (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Occasionally larvae may pupate within fruit (Illingworth1912; in Dean and Chapman, 1973).

Although pupation can take place on any hard surface it is thought that survival of pupae would be much lower in situations where the larvae cannot burrow into the soil, however it is possible that adults would emerge (Brunner, *personal communication* to Mastro, USA, October 2015). Dean and Chapman (1973) citing others state that some moisture is required in the pupal environment with 80 and 100% RH resulting in 81% and 70% emergence (and 2% and 2.5% mortality respectively). Note these are not measures of soil moisture. Survival would be increased if the pupae were in an atmosphere of high humidity such as might occur if they were covered with a small amount of waste material, e.g. as sweepings or spillage at the edge of the main pile of waste. Under such circumstances, pupae that are on hard surfaces at the composting facility could yield flies when they are ready to eclose and these could disperse in favourable temperatures during the normal period of flight activity (when temperatures are favourable between June and October). Pupation could occur in the moist waste once it is being composted before the material reached lethal time x temperatures.

The surface on which the windrows are built is a soil cement pad. As this is not part of the transport or storage of the waste (it is the start of the composting process) it is discussed in 2.10.

Emergence of flies from pupae in the waste that have either:

- Overwintered as diapausing pupae
- Have remained in diapause for more than 2 years
- Were produced in the same season and which have not undergone diapause would lead to an increase in the prevalence of adult flies in the PRA area.

This is not an increase in the prevalence of the pest *per se*. It is a continuation of the life cycle with a potential increase in the numbers of adults that could reproduce

Thus it is *unlikely* with *low* uncertainty that during transport and storage there would be an increase in the prevalence of the pest up to at least the period when the waste becomes subject to processing or maybe beyond at the NSF facility. The processing of the waste and the potential risk of transfer of the adult flies to hosts in the PRA area is discussed under section 2.10.

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Very likely

Level of uncertainty: *Low*

Currently the municipal green waste stream is not subject to official inspection procedures at the point of origin.

The WSDA inspected the NSF facility in the summer of 2015 for fruit of apples, crab apples and hawthorn but did not find any. However, given the size of hawthorn fruit as well as parts of apples and crab apples these are likely to be difficult to find in piles of pre-ground waste. Detection also depends upon the intensity of the surveillance in relation to the volume of material; with piles of waste this would be a difficult process.

In the absence of regular official inspection at the point of origin it is *very likely* with *low* *uncertainty* that *R. pomonella* will enter the PRA area undetected until such times as it is trapped during the WSDA annual survey for the pest.

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat ?

Moderately likely

Level of uncertainty: *Low*

Once the pre-ground waste arrives at the NSF facility it is unloaded directly into the windrow lines and then additional ingredients are added. Feedstocks that arrive daily are layered on top. Over an unspecified period of time it takes 21 hours of active work to build a row and 2 hours to complete the first turn/mix of the row. The windrows are not covered but they are turned. At the beginning of the process there is a risk that adult flies of *R. pomonella* emerging from pupae could transfer to hosts in the PRA area during the normal period of adult activity (June to October). The likelihood of this occurring is dependent upon the dispersal distances of the flies, the proximity and availability of the hosts, and the impact of the processes that the waste is subjected to at the facility has on the pest.

<u>Dispersal distances</u>

Adult flies of *R. pomonella* normally travel relatively short distances when host plants are abundant and their fruit are ripening and are therefore susceptible to infestation. However, they may travel longer distances where this is not the case. All of the dispersal studies that have been done in the field were conducted in the east of the USA where hosts were abundant

Dispersal distances are discussed in detail based upon available research in 2.10 for Pathway 1 so they are not presented here.

The maximum published flight distance for *R. pomonella* in the field is *ca.* 1 mile with a single laboratory study indicating potential for greater than *ca.* 3 miles. Given the longevity of the adults (up to 40 days) a single fly could cover a large distance during this stage of the life cycle depending upon its behavioural preferences, need to travel and availability of hosts.

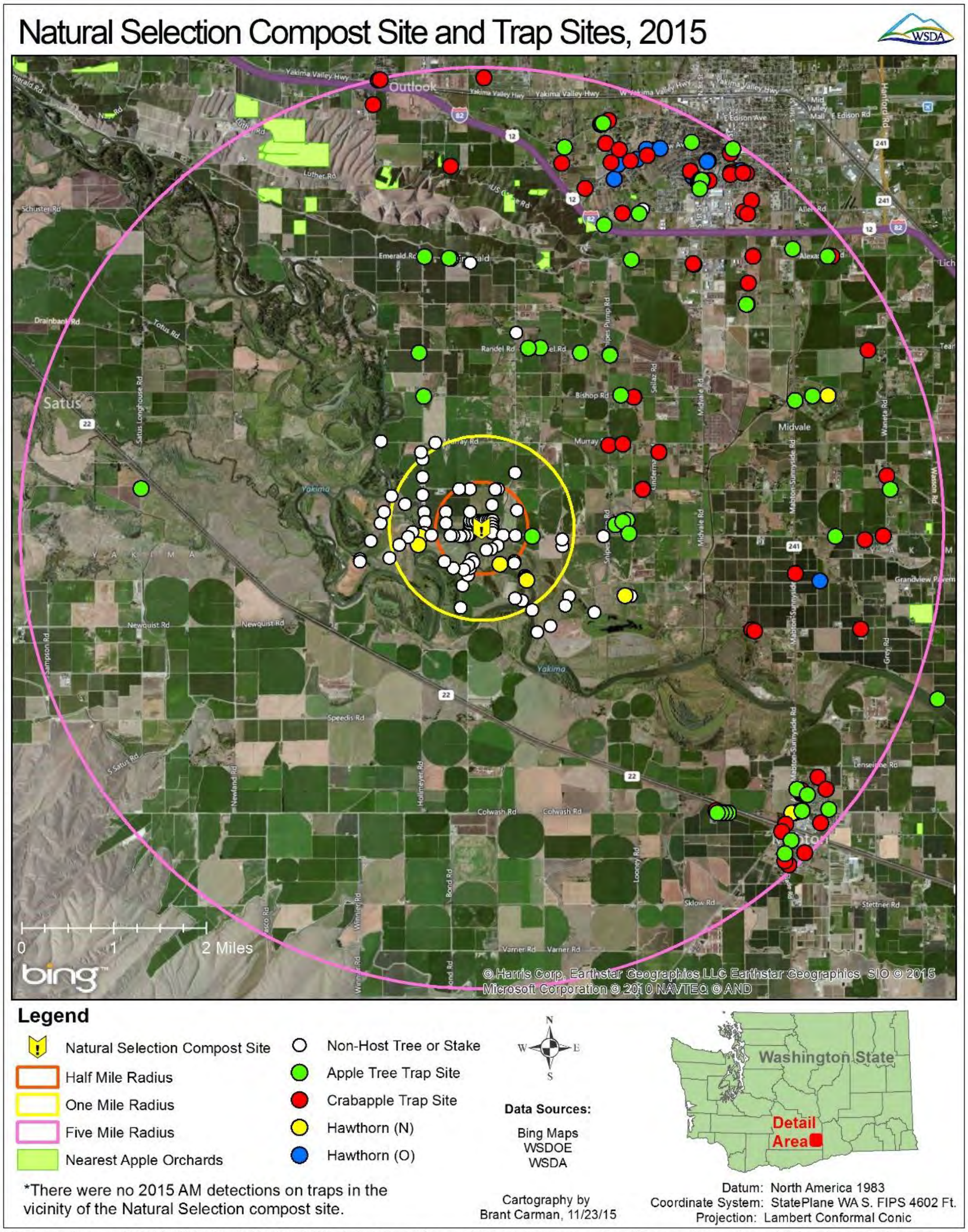
<u>Proximity and availability of hosts</u>
Yee (USDA ARS, USA, *personal communication* to Marra and Klaus, WSDA, USA, April 2015) discussed the possibility of categorising the four composting facilities in the PFA (the PRA area) into high and low risk depending upon the proximity of the nearest hosts. He felt that where host prevalence was high then flies will disperse faster and over longer distances.

He stated that: '*In* [the] *barren landscape in central/eastern WA: Low risk compost facility: greater than 1 mile from host trees. So if the facility is 3, 10, or 20 miles away from hosts, it would be a low risk*'. And: '*High risk facility would be one <1 mile from host trees*'.

This is assumed to mean that when hosts are abundant, the flies have more opportunity to reproduce since flies will normally travel shorter distances when host abundance is high as their need to reproduce is more easily satisfied. Adult flies can feed on non-host trees where they can probably sustain themselves by feeding on leachates on leaf surfaces and other substances as well as possibly on other surfaces and so in areas of low host prevalence they can still feed, but will travel further to reproduce.

Prevalence of apple orchards
There are apple orchards within a 5 mile radius of the NSF facility (see Figure 16 below). The nearest orchard is estimated to be 3 miles away (Carman, WSDA, USA, *personal communication*, March 2016).

Prevalence of other hosts
Host distribution in the PRA area is discussed under section 1.06. Outside of the orchards in the east of the state host distribution is discontinuous since it is reliant upon the presence of waterways and wet areas, and this part of the state is relatively dry. The WSDA hangs traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in the area when fruit is on the tree. The only maps of host distribution in the vicinity of the composting facilities are those showing which hosts are used for trapping. However, this map is not meant to be a complete inventory of host plants within the 5-mile radius largely due to logistical constraints in surveying the area. In 2015 the WSDA aimed to place traps in all of the main hosts within a 5-mile radius of each composting facility. Figure 16 shows the host trees where traps were placed around the NSF facility indicating the presence of a number of hosts, especially apples, and crab apples (albeit crab apples were rated as relatively low risk according to Yee *et al*., 2014 and have been shown to vary in their susceptibility to infestation depending upon species and variety by Reissig *et al*., 1990), within 5 miles of the site. Within 1 mile the WSDA trapped three native hawthorns and one apple tree. However within the 5 mile radius the prevalence of hosts that were trapped is greater. The nearest host is native hawthorn, estimated from the GIS to be 1700ft (0.32 miles) away (Carman, WSDA, USA, *personal communication*, March 2016). This offers an opportunity for adult flies of *R. pomonella* to transfer to non-commercial hosts and could lead to spread to the nearest commercial orchard, the closest of which is estimated to be 3 miles away from the NSF facility.



This Data is provided on an 'AS IS,' 'AS AVAILABLE,' and 'WITH ALL FAULTS' Basis. The Content of this map and data are from many sources and are NOT warranted to be complete, accurate, or current. All critical information should be independently verified. WSDA and its officials and employees assume no responsibility or legal liability for the accuracy, completeness, reliability, timeliness, or usefulness of any of the information presented here.

Figure 16. Host trees trapped by the WSDA around the Natural Selection Farms facility in 2015 and the nearest commercial apple orchards (source WSDA)

Results of trapping

Trapping undertaken in 2015 shows that none of the traps within a 5 mile radius of the NSF facility were positive for *R. pomonella*. See Figure 17 below.

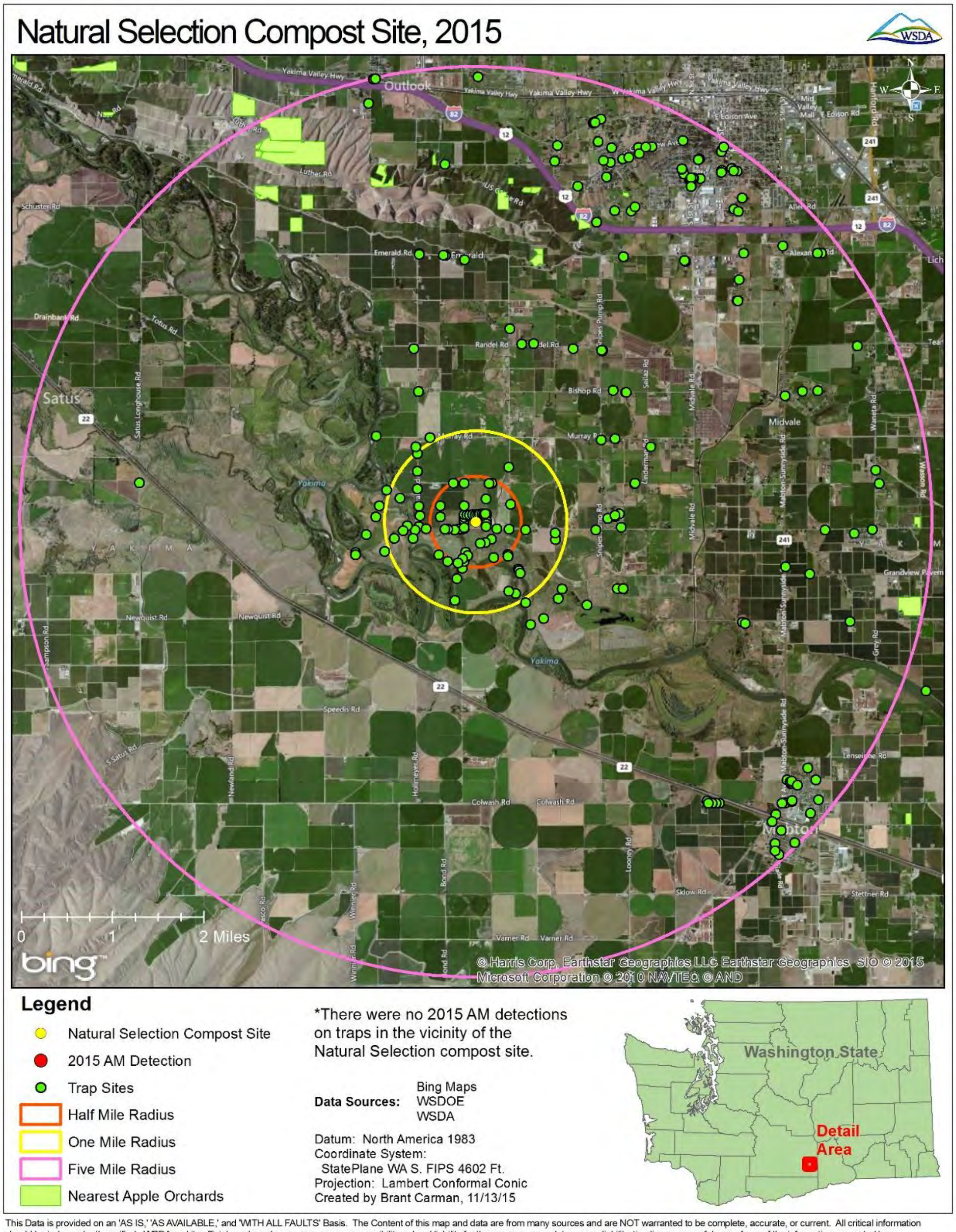


Figure 17. Host trees trapped by the WSDA around the Natural Selection Farms facility in 2015 showing no positive trap sites (source WSDA)

Processing of municipal green waste at the transfer station and at the NSF facility

Grinding
The municipal green waste is pre-ground at the Terrace Heights transfer facility before being transferred to the NSF facility. NSF has advised the following:

'*The green waste is received from the public in the public drop area* [at Terrace Heights]. *The public drop area has an asphalt surface. It is then processed through a Morbark grinder with a 2" screen. Finally, the ground product is loaded into NSF's trucks and covered with vinyl tarps prior to transport to the NSF compost facility'*.

'Yakima County Public Services-Solid Waste Division currently owns and operates a Morbark 6600 Horizontal Grinder for processing yard waste. The Solid Waste Division will be purchasing a 2016 Morbark 6600 Horizontal Grinder in Spring 2016 as replacement to the current grinder. Attached you will find the specifications for the proposed new grinder'.

'Yard debris is placed into the Morbark Horizontal Grinder infeed system by the loader. The infeed system is a variable speed system which has a live floor equipped with five strands of WDH-120 chain in a staggered configuration that carries the yard debris to the hammermill system and grates. The 42" x 67" hammermill is equipped with heavy duty 28" diameter rotors that are laser cut for more precise tolerances. 30 fixed hammers pulverize the yard debris into pieces that pass through a 2" grate. The material is then discharged to the conveyor system for stockpiling'.

The dimensions of the ground waste were assessed by NSF as:

Length: < 1/64"- 5.0" (0.4 to 127mm) in length. Most common by volume, length is 0.5" – 3.0" (12.7 to 76.2mm)

Width: Length: less than 1/64" to < 2" (0.2 to 50.8mm) diameter in thickness. Most common by volume 1/32-1/4" (0.8 to 6.4mm)

Height/thickness: Length: < 1/64" < 2" (0.2 to 50.8mm) diameter in thickness. Most common by volume 1/32-1/4" (0.8 to 6.4mm)

Eggs of *R. pomonella* measure 0.9mm long and 0.23mm wide.
Late third instars measure 6.5 - 8 mm long x 1.5 - 2 mm wide.
Pupae measure 5mm long x 2.3mm wide; or from two locations in the state of Washington more recent specific values of *ca*. 4.5mm long x 2.1 mm wide and 4.3 x 2.1mm wide have been provided (with males being smaller; some are only 3.8 mm long and 1.7 mm wide).

Because of their small size all life stages have potential to be present in some of the pre-ground waste arriving at the NSF facility but the pupae are the most resilient and are most likely to survive the grinding process.

Infested hawthorn fruit are small, may survive the grinding process, and along with pieces of larger fruit such as apples, could also slip through the 2-inch (5cm) grate in the grinder used at Terrace Heights.

Composting
The composting process used by NSF is a turned windrow. As described under 2.07, the pre-ground waste is built into windrows on a soil cement pad on arrival at the NSF facility. There is a period at the beginning of the process when more feedstocks are added to each new windrow as the ground waste arrives at the site. The time period is unknown but it takes 21 hours of active work to build a row (and 2 hours to complete the first turn). No covers are placed on the windrows.

NSF has advised that:

'Once all the ingredients have been added and mixed and the compost process has been initiated, it takes between 24-48 hours for the entire row to meet temperatures of 131 degrees Fahrenheit [55°C]*'*.

NSF described a process known as '*Process to Further Reduce Pathogens (PFRP), Vector Attraction Reduction (VAR), and prevention of Agricultural Pest Migration'* thus:

'During PFRP, pile temperatures of 55°C (131° F) or higher are maintained for at least 15 days with a minimum of 5 turnings of the windrow. NSF's ideal temperature range for PFRP is 131-150° F. Subsequent to turning a windrow, the temperature may briefly fall below 55° C (131° F). In the event that a row does not achieve PFRP, appropriate adjustments will be made to the row. After the first PFRP turning, the windrows are no longer irrigated with leachate. NSF may choose an alternative method of composting, so long as it demonstrates equivalent pathogen reduction. NSF utilizes proper pile and process management, and the time and temperature of PFRP to control vectors and mitigate agricultural pests. Maintaining aerobic composting conditions minimizes odor and vector potential'.*

*In response to a question regarding whether there was a Standard Operating Procedure to *'mitigate agricultural pests'*, NSF responded:

'As agricultural pests can range in size from bacteria to deer, the SOP for mitigating agricultural pests is a function of a large spectrum of processes and steps such as:

Facility design features

- *Isolated location surrounded by an arbores barrier*
- *Soil cement pad which is continually inspected and maintained.*
- *Pad graded to direct storm water and leachate into the leachate collection pond. By preventing standing water we reduce odor potential and attraction of agricultural pests.*

Proper pile and process management, including but not limited to:

- *Receiving and mixing based upon odoriferous potential*
- *Feedstock screening to insure that only compostable products enter our feedstock stream*
- *Proper mix ratios and parameters (bulk density, C:N, free airspace, initial moisture, porosity)*
- *Continued temperature monitoring*
- *Continued turning: each turn circulates the material from the outside of the pile to the inside to ensure circulation and even distribution of heat-treated feedstocks*
- *Continued moisture analysis*
- *Sufficient time to ensure thorough composting*

***PFRP - Process to Further Reduce Pathogens** – This is the heat kill step*
VAR - Vector Attraction Reduction
***Sampling and analysis of product:** Including maturity, stability, pH, and nutrients. Sampling assures that proper composting has been achieved.*
***Proper personnel training** to recognize potential vectors that will attract agricultural pests*
***Facility maintenance and upkeep** to reduce potential for agricultural pests by mitigating pest vectors.*
***Dust abatement measures** to reduce potential for agricultural pests by mitigating pest vectors.*
***Facility Inspections and maintenance by NSF Personnel**: Includes assessment and removal of vectors*
***Facility Inspections by Yakima Health District:** Includes assessment of vectors. If vectors are found, YHD asserts regulatory pressure until NSF has managed the vector*
***Equipment: Inspections and Maintenance:** Properly maintaining equipment ensures that equipment is clean and does not attract vectors, and that it is ready to respond to any urgent situations'*

Images of the soil-cement pad on which the windrows are built were provided by NSF along with other documents related to its composition, construction and testing. NSF stated:

'NSF continually visually inspects the pad and thickens it as needed by compacting the lime-soil mixture (4-7% lime) into the worn places and compacting with a roller compactor or equivalent. Following the removal of a windrow, NSF personnel visually inspect the area of the old windrow and repairs any compromises prior to building another windrow in that location. Pad inspections are documented in the monthly safety walk-around checklist (or equivalent)'.

This base is essentially a pad made of soil mixed with lime and compacted to provide a surface to minimise the ingress of leachate from the windrows into groundwater while facilitating the movement of vehicles across its surface.

Process monitoring

NSF advised that:

*'Each temperature sample is taken at depths of 1' and 2'. There are seven sample points per windrow.** Initial temperatures are taken after feedstocks are mixed. Row temperatures are monitored weekly before and after PFRP. During PFRP temperatures are monitored prior to windrows being turned, and on the day following the turning ensure the temperatures return to appropriate PFRP levels. Final temperatures are taken prior to screening. Achievement and maintenance of temperatures begins and is controlled by the properties of the initial mix. To reduce temperatures once the composting process has been initiated, the row is turned and or water is added as necessary. If the initial mix does not generate sufficient heat, a nitrogen-rich feedstock can be added'.*

*Note that the windrows are 750ft long (observed by Reynolds when visiting NSF in October 2015).

'Temperatures are input directly into a handheld device, then uploaded to MyCompostWatch.Com, where they are stored in the Cloud. MyCompostWatch is a compost temperature data program by ReoTemp Instrument Corporation. This program allows us to view temperature by row, and at a glance using adjusted colors to indicate variations in temperatures. MyCompostWatch.Com documents the PFRP for each row, as well as initial mix ingredients and proportions'.

<u>Assessment of the composting process at the NSF facility</u>
Because of their small size, all life stages have the potential to be present in some of the ground waste arriving at the facility but the pupae are the most resilient and are most likely to survive the grinding process. Infested small fruit such as hawthorn have the potential to slip through the 2" (5cm) grate in the grinder along with pieces of larger fruit such as apples that have survived the grinding process, and so could also be present in the waste. On arrival at the NSF facility the pre-ground waste is built into windrows on a soil cement pad. For each new windrow as waste arrives daily it is added to the windrow. The windrows are not covered.

During the period of building the windrow (21 hours over an unspecified period of time) before it is turned there is a risk that during the normal period of flight activity when favourable temperatures occur between June and October, adult flies may emerge from pupae if they are present in the pre-ground waste near to the surface of the windrow. This process could also continue at the edges of the windrow after the first turn while the waste is heating-up and before it is turned again due to the lack of covers.

Any emerging flies may transfer to non-host trees or other surfaces for feeding and any host trees that are within a dispersal distance of up to at least 1 mile of the site. Based upon Figure 16 the host trees are most likely to be native hawthorn although there is one apple tree that was trapped by the WSDA. Also any late 3rd instars could pupate within 2 to 18hrs and if they do not enter diapause they can take 4 to 6 weeks to emerge as adults (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Yee (USDA, ARS, USA, *personal communication*, April 2016) advised that under laboratory conditions up to 50% of pupae in the state of Washington do not require a chilling period (i.e. if kept at room temperature) to lead to emergence of adults. This may increase the risk of dispersal of flies from non-diapausing pupae at composting facilities. In this instance, provided any pupae that are on the surface are mixed thoroughly into the windrow during the turning process this should not add significantly to the population of adult flies unless they are returned to the surface during subsequent turns and have survived the heating process.

The temperature of the windrows is said to reach 55°C within 48hrs of all the ingredients being added to the mix and they are maintained at this temperature for 15 days with at least 5 turnings of the windrow. These temperatures are measured at 1 and 2ft depths in the windrow at seven sampling points along a 750ft length; if heating is not uniform then there may be some ground waste that does not reach this temperature. Material on the surface is presumed not to heat up to this level until it has been turned into the windrow and held for a period of time.

Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) stated that: '*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stages. This stage is still metabolizing at 50°C and the normal metabolizing only begins to breakdown at 55°C. To determine this you were using a fairly aggressive heating protocol of 0.4 degrees/minute'.* She also advised that this life stage is in deep diapause until 5 days before emergence. A 30 minute exposure to 45°C does not kill pupae. At 50°C it takes 20 minutes for thermal death. Yee (USDA, ARS, *personal communication*, March 2016) showed that holding pupae at 100% RH at 45.3°C for 1 day only led to 6.7% mortality whereas holding them at 46.3°C for 3 days resulted in 100% mortality. Exposure to 50.5°C for 3 days or 38°C for 1 day followed by 56-58°C for 3 days at 100%RH led to 100% mortality (Yee and Chapman; *manuscript in preparation*).

Although the minimum time and temperature combination that is needed to kill pupae of *R. pomonella* is thought to be around 50°C for 20 minutes (based upon Neven's unpublished work) it seems that at least <u>within</u> the windrow once it is built, pupae could survive for up to 48hrs from the start of the composting process while the pile heats up, but those on surface of the pile will escape this exposure until the row is turned again. Any cold spots or areas within the windrow where larger pieces of infested material are located could pose a risk of survival of pupae of *R. pomonella*. Again, those pupae that contain flies which are ready to eclose and can escape the pile prior to heating could disperse to host or non-host plants within flying distance of the facility when favourable temperatures occur during the normal period of flight activity (June to October).

During the PFRP when temperatures reach 55°C for 15 days if all of the material is exposed to this time x temperature this would be sufficient to destroy any remaining pupae. However, it is not known whether this time x temperature would occur for all of the waste material.

Because the surface upon which the windrows are constructed is compacted soil cement any late third instars which tumble from the piles are assumed not to be able to burrow into the soil but they can still pupate on the hard surface, or they may crawl into a crack or crevice and pupate there. Any pupae that tumble from the piles during any of the processes have the potential to produce adults that disperse since this is not a closed system. If this occurs during the period when adults can take flight (when favourable temperatures occur between June and October) the pest could transfer to foliage of host or non-host trees from any spillages that may occur.

Although any of the life stages of *R. pomonella* that are present in the pre-ground municipal green waste that is exposed to sufficient heat for sufficient time are likely to be killed there seem to be some opportunities for the adult flies to transfer from the facility to hosts within *ca*. 1 mile, most likely native hawthorn as well as to non-hosts or other surfaces for feeding. It seems less likely that pupae would survive through to the very end of the process unless there were free pupae or infested material that escaped <u>full</u> exposure to lethal temperatures for the requisite amount of time required to kill them. Based on Neven's unpublished laboratory work this could be 50°C for *ca*. 30 minutes. Yee and Chapman (*manuscript in preparation*) sampled later than this and showed 100% mortality after exposure to 50.5°C for 3 days. It is not known whether this time x temperature would occur for all of the pupae in the waste material.

During the final curing stage which is a minimum of 30 days, temperatures will be lower than during the composting stage. Cornell advises that: '*After the thermophilic phase, the compost temperature drops and is not restored by turning or mixing. At this point, decomposition is taken over by mesophilic microbes through a long process of "curing" or maturation. Although the compost temperature is close to ambient during the curing phase, chemical reactions continue to occur that make the remaining organic matter more stable and suitable for use with plants*'. http://compost.css.cornell.edu/physics.html accessed 17 March 2016.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016 advised that during this phase there is an increase in microbial diversity with the production of lytic enzymes etc. These and other factors during maturation of the compost could have an impact on the viability of *R. pomonella*, especially on pupae that may not have been exposed to lethal temperatures prior to curing. However, this has not been studied and remains an uncertainty.

<u>Intended use of the compost</u>
NSF has advised that they produce *ca*. 5000 tons of finished compost from the pre-ground waste that is received from the quarantine area of Yakima County.

In terms of end use NSF advised: '*The highest of percentage of our compost is utilized by tree fruit growers, grape, hop, blueberry and watermelon producers, with lesser volumes going to other crops. Our garden blend is purchased by commercial and home gardeners. Our turf blend is a top dressing used for lawns. Natural Selection Farms sells compost to customers located more than 100 miles from our facility. Very few of our customers are located outside of the 100 mile radius*'.

The impact of the curing phase on pupae of *R. pomonella* has not been investigated and we have no data to suggest that viable pupae might end-up in the finished compost. This would only occur if procedures are not executed and monitored carefully. An investigation of the effect of curing on pupae of *R. pomonella* would be beneficial.

In this system, the main risk of transfer of adult flies of *R. pomonella* to a suitable host or habitat during the normal period of flight activity when favourable temperatures occur between June and

October, arises while the windrow is being built and before it is turned; also at the beginning of the composting process before the windrow receives a second turn. The windrows are not covered and may contain pupae in soil or in small fruit such as hawthorns or pieces of larger fruit such as apples, or clods of soil that have escaped the pre-grinding process. Any flies which are ready to eclose could escape if they are near the surface of the waste before they are exposed to lethal temperatures. There may also be opportunities for flies to escape if infested material present in the windows does not reach lethal temperatures for a sufficient period of time. The dispersal distances of the adult flies in relation to the proximity of at least some hosts of *R. pomonella* means there is potential for transfer in this way (and adults can disperse to non-host trees or other surfaces for feeding).

Taking account of all these factors it seems *moderately likely* with *low uncertainty* that the pest could transfer from this pathway to a suitable host or habitat. The risk of transfer to commercial orchards in the same year may be feasible as the nearest commercial orchard in the PFA is estimated to be 3 miles from the facility.

2.11 - The probability of entry for the pathway should be described
It is *moderately likely* with *low* uncertainty that *R. pomonella* could enter the PRA area (the PFA) from municipal green waste originating in the quarantine area of Yakima County. This an area of relatively low infestation with *R. pomonella*, where the waste is pre-ground, and then transferred to the NSF for composting in open uncovered windrows which take a total of 21 hours to build spread over an unspecified period of time. The windrows are subject to turning, with the finished compost being sold to various businesses including tree fruit growers.

The finished product is sold to various businesses including tree fruit growers.

The most likely material to pose a risk is infested host fruit, and soil associated with infested hosts at the origin of the material being collected.

The main areas of uncertainty are:

- The amount and type of infested host material in the waste stream at different times of year
- The amount of infested soil in the waste stream at different times of year
- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The proportion and size of soil clods which may escape the grinding process
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit or soil clods that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The impact of the curing phase on pupae of *R. pomonella*
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- Whether adults of *R. pomonella* will feed on leachates from compost piles

The risk of transfer in the same year as adults emerge from the facility is likely to be to non-commercial hosts within the vicinity of the facility that could maintain populations of the pest, and possibly to the nearest commercial apple orchard(s), the closest of which is estimated to be 3 miles away from the NSF facility, depending upon the favourability of the environment in that year.

Pathway 3. Risk of entry of *R. pomonella* on municipal green waste moving to Pacificlean Environmental, Grant County

The questionnaire[7] from the PRA team used in this section was completed by Ryan Leong and Travis Maynard. The assessment of this pathway was based upon the receipt of pre-ground and unground waste during 2015. However, it is understood that the plan is to only receive unground waste for future operations at this site. The facility funded the design of a building intended to receive waste on site with a view to reducing the potential risk of escape of *R. pomonella* to the PFA. The building was not constructed in 2015 and so it has not been assessed.

2.03 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account the biology of the pest?

Very likely

Level of uncertainty: *Low*

Pacificlean Environmental first began receiving municipal green waste from the city of Seattle in King County in western Washington in February 2015. King County is in the quarantine area of the state of Washington.

All of the waste received by Pacificlean Environmental from this source in 2015 was described as '*green waste*' with '*a growing portion…comprised of food waste since the City of Seattle's organics ban took effect on January 1, 2015*'.

The operations plan (see footnote) referred to this as '*Municipal Source-separated Organic Wastes*' and defined it as '*curbside collected municipal source-separated yard waste comingled with foodwaste*' as well as '*commercial food waste (restaurants, cafeterias, schools, etc.)*'

The waste that was received in 2015 was both ground and unground. Grinding took place at the South Seattle transfer station (see Figure 18).

At the point of origin (before arrival at the transfer station) the waste is likely to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream.

R. pomonella is associated with the fruit of a range of hosts and also with soil associated with host plants. More detail on the prevalence of host material is given later in this section.

The biology of the pest is described in section 1.02b and was summarised under question 2.03 for

[7] Pacificlean Environmental provided several other pieces of information including a 53-page document entitled: '*Ovenell Land LLC Compost Facility Operations Plan*' as well as an Addendum. The assessment of this pathway is based mainly on the responses to the questionnaire (as has been done with the other 3 pathways). Selected text from the Operations Plan/Addendum has been used where it was referred to by Pacificlean Environmental in their response to the questionnaire and where it has been necessary to elaborate on the processes.

Pathway 1 so it has not been repeated here.

The life stages associated with infested fruit are eggs, larvae and occasionally pupae. Fruit begins to be infested in June in the state of Washington. The numbers of each life stage associated with the fruit will vary with the variety and size of fruit. Studies undertaken in the state of Washington (Tracewski *et al*., 1985) found that a single hawthorn (species not specified) can yield 65,000 to 112,000 fruits (1984); it was estimated that with an average rate of 5% of fruit infested (assuming one larva per fruit) there could be 3000 to 6000 flies produced per tree. Incubation of several hundred infested apple fruit (1982 to 1983) mostly yielded 1 or 2 larvae per fruit; however, one fruit yielded 6 pupae. These figures were obtained early in the history of *R. pomonella* in the west of the USA and current infestation rates, at least in the west of the state of Washington are much higher than they were then. If a higher percentage of fruit is infested per tree there will be a greater number of larvae and pupae resulting from an attack by *R. pomonella*.

Despite the high numbers of flies presumed to be produced from a single infested hawthorn, Tracewski *et al.* (1985) did not record the actual number of flies produced. Dean and Chapman (1973) state there is some natural mortality at all stages of the life cycle but that it is highest in the larval and pupal stage and lowest at the egg stage. They cited studies suggesting pupal mortality could be between 47 and 96% influenced by parasitism, predation and ambient conditions. Larval mortality was particularly influenced by the variety of apple since hard-fleshed fruits can lead to 100% mortality. Nonetheless sufficient life stages persist to maintain populations of *R. pomonella* in the quarantine area.

Pupae (and late third instar – albeit this is a transient stage of a few hours) are the life stages associated with soil. According to Dean and Chapman (1973) the pre-pupal stage of *R. pomonella* lasts from 2 to 18 hours with the majority taking 6 to 11 hours to form pupae.

The periods of time over which eggs, larvae and pupae are likely to be found in fruit in municipal green waste from the quarantine area of the state of Washington depends upon whether it originates in the east or the west (in the case of Pacificlean Environmental) of the state. See Table 8. This geographic split will influence the prevalence of the pest both in fruit, and as pupae in soil associated with the waste stream, due to the higher levels of infestation in the west side of the state.

Table 8. Periods when eggs, larvae, and pupae can be in municipal green waste originating in the quarantine areas of the state of Washington.

Life stage	**Eastern Washington**		**Western Washington**	
	Start date	End date	Start date	End date
Eggs (in fruit)	Mid to late June	Late September to October* depending on date of first hard freezing temperatures	Early to mid-June	Late October depending on date of first hard freezing temperatures
Larvae (in fruit)	Mid to late June	Early November depending on date of first hard freezing temperatures	Early to mid-June	End of November into early December depending on date of first hard freezing temperatures
Pupae	In fruit, soil , growing media, or in the sod or duff at any time of the year[8]			

*Because the populations are so sparse or nonexistent in areas in central Washington (Yee *et al*., 2012) the seasonality or even the entire host range of the apple maggot is uncertain on the eastern side of the Cascade mountain range. The timing provided in the table is based on what is known and assumes that the same host range exists on the eastern side as on the western side of the state.

In **eastern Washington**, black hawthorn (*C. douglasii*) and early varieties of apples ripen in early to late June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). Emerging adult flies of *R. pomonella* aligned with these major hosts could begin laying eggs by mid-June. Larvae could be present in the fruit of apples or black hawthorn within 5 to 7 days of oviposition (Dean and Chapman 1973). In an apple maggot survey for Spokane County in 1985 the first recorded fly capture was on June 26th (Klaus, 1985). The end date is based on the presence of ornamental hawthorns (*C. monogyna* or *C. laevigata*) which consistently bear ripened fruit in late October. (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). However because populations on the east side of the Cascade mountain range are sparse or nonexistent they are difficult to characterise. We assume here, that if established they will utilise the same hosts as they utilise on the west side including ornamental hawthorns.

In **western Washington**, where the waste being processed by Pacificlean Environmental originates, all fruiting starts earlier than in eastern Washington because of the warmer temperatures. Fly trapping data show adults were captured in the first week of June (unspecified year) by a hobbyist organisation in Puyallup (Pierce County) (Klaus, WSDA, USA, *personal communication* to Mastro, USA, January 2016). Mattsson (2015) also reported apple maggot adults emerging in early June. Based on the presence of active adults in the first week of June, mature females could be laying eggs by the second or third week of June and larvae would be present in fruit within 5 to 7 days. Although there are no trapping data from research or programme activities from early June it is believed that some flies can be active in early June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). In one year adults were trapped in late May in Vancouver, Washington (Yee, *personal communication*, April 2016) but this is an exception. The end date is based on data from Mattsson (2015) indicating that maximum flight activities for adult flies on ornamental hawthorn in Vancouver (Clark County) was

[8] Only soil is mentioned in the main text for the assessment but the other substrates are relevant

determined to be in mid-September. Depending on the impact of lower degree days at this time of the year, the life cycle of *R. pomonella* would extend into November or December.

Infested fruit, particularly (but not exclusively) apples, is thought to be the most likely route of entry of the pest to the PFA (Hood *et al*., 2013). This could enter the waste stream at any time of year if it is stored or retained by homeowners in green waste in their yards but the most likely period for this to occur is from June to November or early December. This is based upon when fruit on trees is likely to be infested and may be culled from the tree, or collected from the ground, or harvested and rejected and so may enter the waste stream. During the winter and early spring months dropped fruit should rot *in situ*.

Adults are only in the vicinity of fruit when they are mature and ready to mate or lay eggs (Porter 1928; in Dean and Chapman 1973). This period spans June to October. Adults are unlikely to move with green waste unless they emerge from pupae in soil or fruit during transport.

Life stages associated with soil in waste from discarded host plants are late third instar, and pupae. The window of time from November until the initiation of emergence in June should have the greatest soil load of pupae (the most resilient stage of the pest). It is during this time frame that the movement of soil associated with host plants would be of the greatest risk. However, because pupae can survive in soil for more than 2 years (in Brunner 1987, in Dean and Chapman 1973), they could be in the soil in the waste stream throughout the year.

The main hosts in the state of Washington are apples (*Malus* spp.) and several species of hawthorn including black hawthorn (*C. douglasii*). However, there have also been records on various species of cotoneaster (*Cotoneaster* spp.), mountain ash (*Sorbus* spp.), apricots, various plums and cherries (*Prunus* spp.), as well as common and Asian pear (*Pyrus* spp.).

Of these, apples, black hawthorn and oneseed hawthorn (*C. monogyna*) are considered to be of high importance for the pest and several species are of medium importance including smooth hawthorn (*C. laevigata*), Suksdorf's hawthorn (*C. suksforfii*), and Asian pear (*P. pyrifolia*). See section 1.06 and Yee *et al*. (2014).

The prevalence of the hosts in the waste stream originating in the city of Seattle is not known with any certainty, either as fruit, or as host plants with associated soil, or just soil that has been associated with these hosts.

However, the PRA team found 3 sources of information which have helped give some clarification on this matter:

- The Seattle Department of Transportation (DOT) – street trees maintained by the DOT http://www.seattle.gov/transportation/treeinventory.htm
- The Seattle Parks Department – trees in the parks http://www.seattle.gov/parks/
- City Fruit - private landowners https://www.cityfruit.org/#/

The only data that were available on host tree numbers came via an organisation known as

Seattle Audubon http://www.seattleaudubon.org/sas/

They advised that they own the Seattle Tree Map website: http://web6.seattle.gov/SDOT/StreetTrees/ which is part of the DOT site; this accounts for the numbers of street trees in Seattle.

In the dataset which informs the map there are 7863 records of *Crataegus* (hawthorns) and 6233 records of *Malus* (presumed to be crab apples). (Humphrey, volunteer with Seattle Audabon; *personal communication* to Mastro, USA, January 2016). There is no indication of when this database was last updated.

The Seattle DOT website (accessed 29 January 2016) showed that in 2011, *Crataegus* (hawthorns) and *Malus* (crab apples) represented 6% and 5% respectively of the genera in the street tree database (being the 3rd and 4th most common genera of street trees in Seattle) http://www.seattle.gov/transportation/treeinventory.htm

Hawthorns (and apples) are major hosts for *R. pomonella* and while crab apples are hosts they are considered to be of low importance for the pest <u>relative</u> to the major hosts (Yee *et al*., 2014).

The Seattle Parks Department website gave no indication of the tree species that are in the city parks or what happens to green waste generated there (i.e. whether the park waste is recycled *in situ* or sent for recycling along with the residential municipal green waste). They manage >6200 acres of natural area and park landscapes within the urban area; 2,300 acres of this is developed parkland.

However, City Fruit's website (accessed 29 January 2016) states: *'More than 30 Seattle parks have fruit trees — many of them are the remnants of heritage orchards. Parks like Carkeek, Meridian, and Amy Yee Tennis Center have extensive orchards with good varieties. Many other parks, such as Linden Orchard Park and Bradner Gardens, have planted mini-orchards as part of a community garden'*. https://www.cityfruit.org/public-orchards

The City Fruit organisation harvests fruit, including apples, from residential properties and public parks and donates the fruit into Seattle's emergency food system to provide food for vulnerable people. City Fruit have observed apple maggot damage in the apple trees from which they collect the fruit. To try to reduce damage from insect pests including *R. pomonella* and codling moth (*Cydia pomonella*) they deploy a variety of physical control measures in orchards (but not in residences) (see 2.04). They stated that for 2015, '*in orchards this year we avoided apple maggot* [and codling moth*] *damage in 60% of our trees*'. In 2015, 13554 pounds of apples were harvested and donated through this scheme and 5516 pounds were sent to food waste. Codling moth and apple maggot are prevalent in the apples in the area where City Fruit collect their fruit. (Burrill, City Fruit, Seattle, USA; *personal communications* to Mastro and Reynolds, December 2015 and follow-up* in February 2016 with Reynolds). The percentage of the discarded fruit which was infested with apple maggot is unknown since this is not recorded. However, it is known that food waste forms part of the green waste received by the Pacificlean Environmental facility. It is likely that fruit infested with *R. pomonella* will be rejected and if it is recycled (sent for composting) as in the case of City Fruit, it will end up in the waste stream.

Inspection of the South Seattle transfer station by the WSDA in July 2015 (the transfer station from which Pacificlean Environmental receives waste from the Seattle area) revealed the presence of backyard apples in the waste stream (Taylor, WSDA, USA *personal communication* to Reynolds, USA, January 2016).

The WSDA also visited the Pacificlean Environmental composting facilities in July 2015 and they found a number of apples and 1 Asian pear in a range of locations at the facility; this included apples in the windrows. Evidence of apple fruit infested with *R. pomonella* was also obtained, with pupae and larvae of *R. pomonella* being found or reared from fruit.

From these sources it is clear that at the very least, *Crataegus* (hawthorn) and *Malus* (apples and crab apples) fruit and possibly trees have potential to be in the waste stream and there will be some level of infested fruit present.

The most recent level of infestation with *R. pomonella* for King County from surveillance undertaken by the WSDA is unknown as the county has been in the quarantine area for many years and has not been surveyed.

However, it is thought that if 100 traps were randomly placed in host trees in the Seattle area, 80% would be positive, (compared to 1% in the quarantined area of Yakima County and 20% in Spokane County) (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015).

Thus, the level of infestation in the Seattle area of King County where the municipal green waste processed by Pacificlean Environmental originates is considered to be very high relative to the quarantined area of Yakima County, and Spokane County.

Based on the biology of the pest it is considered that it is *very likely* with *low uncertainty* that *R. pomonella* will be associated with this pathway.

2.04 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account <u>current management</u> conditions?

Very likely

Level of uncertainty: *Low*

The municipal green waste arriving at the Pacificlean Environmental facility originates in the Seattle area of King County, part of the quarantine area for *R. pomonella*, where the level of infestation is thought to be high and where the pest is considered to be established.

Management of the pest in this part of the quarantine area will be undertaken in commercial orchards that grow apples; the Washington State University Small Farms Team list 7 farms in

King County which do this http://smallfarms.wsu.edu/farms/locate_search.asp (accessed 31 January 2016) but their proximity to the Seattle area has not been investigated. It is assumed that there are no commercial orchards located in King County which are certified as pest-free by the WSDA through their surveillance programme (no surveillance has been undertaken for many years). Such orchards would require intensive pest management practices in this infested area to qualify for pest-free status for *R. pomonella*. Nonetheless, the waste that is being processed by Pacificlean Environmental does not originate from commercial fruit orchards, rather it originates from homeowner's yards (and maybe from parks).

In the case of homeowner's yards this is where pest management may not be very effective even if it is deployed. However, advice is available through Washington State University's extension service:
http://ext100.wsu.edu/skagit/agriculture/apple-maggot/ and via amateur fruit-growing societies. The success of control will vary with the homeowner.

The Seattle Parks Department website refers to integrated pest management but there is no specific mention of *R. pomonella*. However, it is known that waste fruit from organisations such as City Fruit ends up in the waste stream and this is collected from a variety of sources including parks (where there are orchards) as well as from homeowner's trees. City Fruit stated that:

'City Fruit's goal is to produce as much organically grown bug-free fruit as possible, and donate it to food banks and feeding programs, so for now we just try to cover as many apples as we can with either paper bags (each apple covered individually) or poly hail nets (entire tree covered), which we tried for the first time this year, and which were extremely effective'.
City Fruit continued:

- *Cover individual apples with lightly waxed paper bags*
- *Covering the entire tree with a poly hail net*
- *in both cases protected fruit from apple maggot damage*
- *apple maggot fly easier to deter than codling moth*
- *any sort of covering on an apple will keep the apple maggot fly from landing ----- codling moths are much more persistent and insistent on chewing through*
- *In orchards this year we avoided apple maggot damage in 60% of our trees*
- *Next year we will do better as we net more trees completely*
- *Pest-damaged apples were collected by cider makers*
- *HUGE decrease in apple maggot-infested apples ending up in the green waste stream*[9]

Source: Burrill, City Fruit, Seattle, USA; *personal communication* to Mastro and Reynolds, December 2015.

Management of *R. pomonella* in this way means that while there is no potential for pesticide residues in the fruit (which would conflict with their aim of organic production), this approach

[9] It is not known how this was measured

would allow some life stages of the pest to be present in any fruit which may be discarded and could enter the municipal green waste stream.

Since, at the point of origin, the waste stream is from non-commercial orchard sources and locations such as homeowner's yards, the management of the pest in the Seattle area would not be sufficient to eliminate *R. pomonella* in the waste.

Thus, accounting for current management conditions, *R. pomonella* is *very likely* to be associated with the waste at the point(s) of origin with *low uncertainty.*

2.05 - Consider the volume of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

Very likely

Level of uncertainty: *Low*

In 2015, Pacificlean Environmental received *ca*. 24,000 tons of municipal green waste from the city of Seattle which was shipped via the South Seattle transfer station.

They also have a contract to receive 20,000 tons of municipal green waste from a transfer station known as Cedar Grove (which in fact has two locations: Maple Valley and Everett). Cedar Grove has contracts with King County '*and other western Washington municipalities'* (Leong, Pacificlean Environmental, USA; *personal communication* to Reynolds, USA, November 2015). However, no waste was received from Cedar Grove in 2015.

The amount of municipal green waste that was forecast to be received in 2016 was 65,000 tons.

This is a high volume of waste. On the assumption that infested material is present in the municipal green waste it is considered *very likely* with *low uncertainty* that this volume of movement will support the entry of the pest to the PRA area.

2.06 - Consider the frequency of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

Very likely

Level of uncertainty: *Low*

Table 9 shows the amount of municipal green waste that was received by Pacificlean in 2015 and the projected amount that was planned to be received in 2016 by month.

Table 9. Tons of municipal green waste received by Pacificlean Environmental, King County in 2015 and forecast for 2016

Month	2015	2016*
January	0	2496
February	565	2598
March	3489	4136
April	5423	8710
May	6027	9393
June	5109	9393
July	1641	8125
August	1940	3900
September	0	3900
October	0	3900
November	0	6500
December	0	1950
TOTALS	**24194**	**65000**

*Forecast but not received

Although receipt of municipal green waste by Pacificlean Environmental from the quarantine area of King County only commenced in 2015 and ceased in September 2015 it was planned to be received all year round.

In 2015 the average amount received was 34 loads/week or 5-6 loads per day Monday to Saturday.

Waste fruit that was infested is known to have arrived at this facility

Any waste host fruit arriving at the facility in unground or pre-ground waste (see 2.10 for the impact of grinding on waste material) may be infested with *R. pomonella* from early to mid-June when early varieties of apple are ripening, through to at least the end of November and maybe early December when all fruit should have fallen and has been gathered, but depending upon when the first freezing temperatures occur. Black hawthorn (*C. douglasii*) can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October). As hawthorn fruit are small they may be present in the pre-ground waste from June to October.

In 2015 ground and pre-ground municipal green waste was received in June, July and August and ceased due to detection of the pest at the facility (larvae and pupae). In 2016, if Pacificlean Environmental was operational, waste would be received in all of the months when the pest could be associated with host fruit in the waste.

When soil is in the waste stream that has been gathered with host plants that have fruited and are infested, pupae of *R. pomonella* are likely to be associated with the soil. This is possible all year round with peak numbers of pupae being present from November to June, months when a moderate amount of waste is received.

Thus, due to the fact that municipal green waste from the quarantine area would normally arrive at this facility every month, if not every week, the frequency of movement is *very likely* to support entry of *R. pomonella* to the PRA area, with *low uncertainty*.

2.07 - How likely is the pest to survive during transport or storage?

Very likely

Level of uncertainty: *Low*

The likelihood of survival of *R. pomonella* prior to arrival at the Pacificlean Environmental facility is largely related to the amount of heating (temperature and duration) that occurs prior to or during transport.

Pacificlean Environmental advised that:

'*The green waste is picked up curbside by the municipality or its contractor and compacted in the back of the garbage trucks. It is then unloaded at the transfer station where it is loaded into the back of transfer trailers. During a trial period, the green waste was ground at the transfer station prior to loading into the transfer trailers. The grinding took place in a covered building using 2" screens.'*

It is assumed the pre-ground waste that was received in 2015 (but is not planned to be received in 2016) is more likely to heat up *en route* compared to the waste that was not mechanically processed prior to transportation.

With respect to the transfer stations for Pacificlean Environmental there are two: South Seattle and Cedar Grove, which has two locations – Maple Valley and Everett; all situated in King County, part of the quarantine area of the state of Washington. In 2015 only the South Seattle transfer station despatched waste to the facility.

The raw material is picked up and delivered to the transfer station on the same day; it leaves the transfer station within 24hrs. (Hildreth, South Seattle Transfer station, USA, *personal communication* to Reynolds, USA, November 2015).

Thus, the amount of time for which the <u>unground</u> waste was stored at the South Seattle transfer station before grinding is no more than 24hrs.

For the ground waste (grinding is discussed in 2.10); it is assumed it was despatched to Pacificlean Environmental within 24 hrs of grinding.

From the time of departure from South Seattle or Cedar Grove (Maple Valley site), the route taken to the Pacificlean Environmental facility is no more than 2.5 hour's driving time (see Figure 18 below).

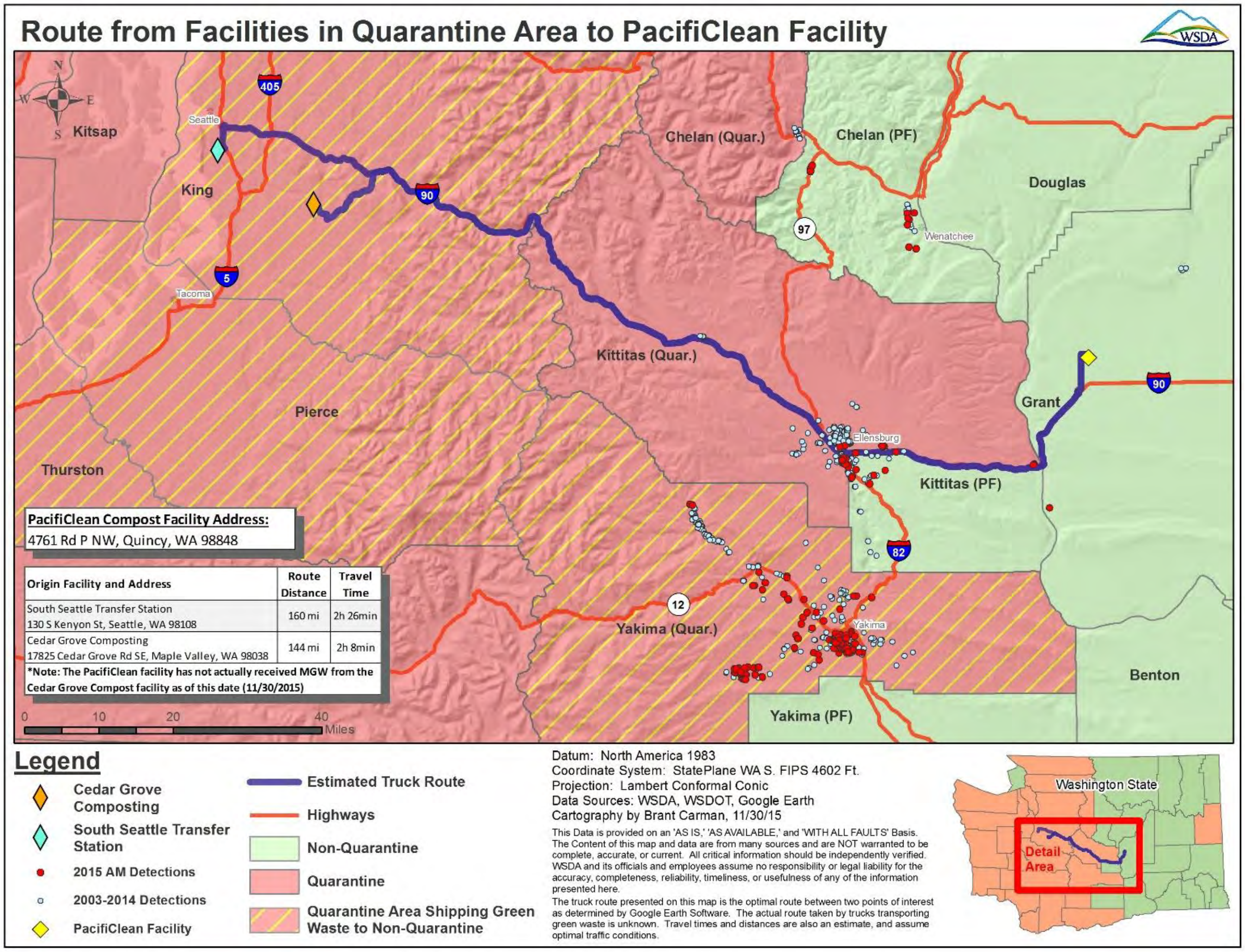


Figure 18. Distance and travel time from South Seattle and Cedar Grove (Maple Valley site) transfer stations in King County to Pacificlean Environmental, Grant County (source WSDA).

The trailers used to transport the waste from South Seattle transfer station to Pacificlean Environmental are 48ft long and not water tight. The trailers are covered in a 1.49mm mesh.

Two Nuvan® pesticide strips are used in the trailers (containing dichlorvos = 2, 2-dichlorovinyl dimethyl phosphate at 18.6%). The Nuvan® label states these are for use in enclosed spaces which unfortunately would not be the case with a trailer covered by a mesh. One unit treats from 100 to 200 cubic feet; the trailer volume is estimated to 3000 cubic feet. This control strategy is unlikely to have an influence on the prevalence of *R. pomonella* in the waste.

On arrival at the Pacificlean Environmental facility, the ground waste was unloaded directly into windrows. Unground material is ground on site with 2 truckloads per hour being processed (60 tons/hour). This is then moved to windrows within 30 minutes.

There will be some heating of the waste material when it is at the transfer station prior to grinding due to natural microbial activity, but the waste on the surface of the pile will not be affected by this. Waste ground prior to arrival at Pacificlean Environmental (in 2015 only) would start to heat up but the period of time from grinding to the time it was transferred to the facility and was put into a windrow is assumed to be less than a day so this is not likely to reach lethal temperatures for the pest.

The operations plan refers to contingencies where waste received on site may be stored in piles no taller than 14ft for up to 3 days before being moved to a windrow. It is assumed this refers to either pre-ground material (received in 2015) or material that has been ground on site, thus:

'Manure and agricultural based feedstocks consist of locally generated manures, various waste bedding materials, and locally generated agricultural waste materials. The municipal organic waste feedstocks will be ground and may be utilized to bulk and otherwise augment the manure based compost windrows or vice versa.. Within 36-hours of putrescible materials being received, the prepared feedstock mix will be placed in the active windrows. ***If not prepared and placed in windrows by the end of the day they are accepted, the materials will be covered with a minimum thickness of 12-inches of biofilter materials'.***

And:

'As a contingency, these feedstock materials may be shaped into 'pre-compost' piles not to exceed 14-feet high and approximately 200-cubic yards total volume each. By the end of the day constructed, a minimum 12-inch thick layer of biofilter material will be placed over this pile. This volume of material will form approximately 100-linear feet of windrow and make possible more efficient operations. The pile will be placed in the windrows within 3-days regardless of volume accumulated. By the end of any day in which new materials were added to the pile, the new materials will be covered ***with a biofilter of at least 12-inches of woody materials, overs, or finished compost*** *to minimize generation of odor'.*

Again there will be some heating of the material but it is not likely to affect the viability of the pest on the surface of the storage piles.

The time taken for transport and storage of unground waste and waste that was pre-ground (in 2015 only) and the conditions in which it is transported and held is unlikely to be lethal to the pest. Evidence of live larvae and pupae at the Pacificlean Environmental facility in 2015 indicates that any life stages in infested intact or partial fruit which have survived the grinding process, as well as pupae which are present in soil will be *very likely* to survive transport and storage with *low uncertainty* because the time for heating is relatively short.

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

Unlikely

Level of uncertainty: *Low*
R. pomonella reproduces by laying eggs within host fruit while it is still hanging on the tree. Dean

and Chapman (1973) cite Porter (1928) stating *'Fruit in shaded locations are preferred to those in sunny spots and neither ripe fruit nor drops are attractive to ovipositing flies'*. Thus there should be no oviposition occurring during transport to or storage of host fruit in municipal green waste for any facility.

However, for the period it is stored at the South Seattle transfer station as unground waste the pest will continue its life cycle. For waste that was pre-ground (in 2015 only) it was transported over a short period of time to the facility and built into windrows. Unground waste transported to the facility is ground and put into windrows very quickly (although there was some indication from the response to the questionnaire and the operational plan that there may occasions where it could be stored, for up to 3 days, if necessary). During this period, while lethal temperatures are not experienced for a sufficient length of time the pest can continue its life cycle.

If there are any fruit or partial fruit that have survived the grinding process either at the transfer station (in 2015) or at the facility then any late instars present in the fruit may emerge and start to pupate. Pupation takes place within 24hrs of emergence from fruit. Partial fruits (cut or partially-eaten) yield pupae from larvae (3rd instars) which can continue to develop and pupate (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Occasionally larvae may pupate within fruit (Illingworth 1912; in Dean and Chapman, 1973). The WSDA found whole apples in the windrows and they also found apples and one Asian pear in various places at the facility. Infested apples were also found.

Although pupation can take place on any hard surface it is thought that survival of pupae would be much lower in situations where the larvae cannot burrow into the soil, however it is possible that adults would emerge (Brunner, *personal communication* to Mastro, USA, October 2015). Dean and Chapman (1973) citing others state that some moisture is required in the pupal environment with 80 and 100% RH resulting in 81% and 70% emergence (and 2% and 2.5% mortality respectively). Note these are not measures of soil moisture. Survival would be increased if the pupae were in an atmosphere of high humidity such as might occur if they were covered with a small amount of waste material, e.g. as sweepings or spillage at the edge of the main pile of waste. Under such circumstances, pupae that are on hard surfaces at the composting facility could yield flies when they are ready to eclose and these could disperse in favourable temperatures during the normal period of flight activity (when temperatures are favourable between June and October). Pupation could occur in the moist waste once it is being composted before the material reached lethal time x temperatures.

The surface on which the windrows are built is heavily compacted clay and caliche. As this is not part of the transport or storage of the waste (it is the start of the composting process) it is discussed in 2.10.

Emergence of flies from pupae in the waste that have either:

- Overwintered as diapausing pupae
- Have remained in diapause for more than 2 years
- Were produced in the same season and which have not undergone diapause would lead to an

increase in the prevalence of adult flies in the PRA area.

This is not an increase in the prevalence of the pest *per se*. It is a continuation of the life cycle with a potential increase in the numbers of adults that could reproduce

Although the time periods involved from collection to being built into windrows is relatively short, it is considered to be *unlikely* with *low* uncertainty that during transport and storage there would be an increase in the prevalence of the pest up to at least the period when the waste becomes subject to the composting process or maybe beyond at the Pacificlean Environmental facility. The processing of the waste and the potential risk of transfer of the adult flies to hosts in the PRA area is discussed under section 2.10.

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Very likely

Level of uncertainty: *Low*

Currently the municipal green waste stream is not subject to official inspection procedures at the point of origin.

The WSDA inspected the Pacificlean Environmental facility in the summer of 2015 for fruit of apples, crab apples and hawthorn. They found a number of apples and 1 Asian pear in a range of locations at the facility; this included apples in the windrows. Evidence of apple fruit infested with *R. pomonella* was also obtained with pupae and larvae of *R. pomonella* being found or reared from fruit.

In the absence of regular official inspection at the point of origin it is *very likely* with *low uncertainty* that *R. pomonella* will enter the PRA area undetected on this pathway until such times as it is trapped during the WSDA annual survey for the pest.

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat ?

Very likely

Level of uncertainty: *Low*

Once the pre-ground waste arrived at the Pacificlean Environmental facility in 2015 it was unloaded directly into windrows. Waste that was ground at the facility was also put into windrows on the same day. However there is information in the operational plan that for contingencies, waste (assumed to be ground waste) may be stored in piles up to 14 ft. tall for up to 3 days covered with 12 inches of woody material. The windrows were covered in July and August 2015 as part of the requirements of the permit issued by the WSDA that allowed the facility to process municipal green waste from the quarantine area. However, when the WSDA visited in July 2015 they found one apple had escaped from a covered windrow and they also found apples in a number of locations at the site. In addition pupae and larvae of *R. pomonella* were found or reared from fruit.

On arrival at the site and during any period of storage before lethal time x temperatures are experienced, there is a risk that adult flies of *R. pomonella* emerging from pupae in municipal green waste could transfer to suitable hosts in the PRA area during the normal period of adult activity when favourable temperatures occur between June and to October. The likelihood of this occurring is dependent upon the dispersal distances of the flies, the proximity and availability of the hosts, and the impact of the processes that the waste is subjected to at the facility has on the pest.

<u>Dispersal distances</u>
Adult flies of *R. pomonella* normally travel relatively short distances when host plants are abundant and their fruit are ripening and are therefore susceptible to infestation. However, they may travel longer distances where this is not the case. All of the dispersal studies that have been done in the field were conducted in the east of the USA where hosts were abundant. Dispersal distances are discussed in detail based upon available research in 2.10 for Pathway 1 so they are not presented here.

The maximum published flight distance for *R. pomonella* in the field is *ca.* 1 mile with a single laboratory study indicating potential for greater than *ca.* 3 miles. Given the longevity of the adults (up to 40 days) a single fly could cover a large distance during this stage of the life cycle depending upon its behavioural preferences, need to travel and availability of hosts.

<u>Proximity and availability of hosts</u>
Yee (USDA ARS, USA, *personal communication* to Marra and Klaus, WSDA, USA, April 2015) discussed the possibility of categorising the four composting facilities in the PFA (the PRA area) into high and low risk depending upon the proximity of the nearest hosts. He felt that where host prevalence was high then flies will disperse faster and over longer distances.

He stated that: '*In* [the] *barren landscape in central/eastern WA: Low risk compost facility: greater than 1 mile from host trees. So if the facility is 3, 10, or 20 miles away from hosts, it would be a low risk*'. And: '*High risk facility would be one <1 mile from host trees*'.

This is assumed to mean that when hosts are abundant, the flies have more opportunity to reproduce since flies will normally travel <u>shorter</u> distances when host abundance is high as their need to reproduce is more easily satisfied. Adult flies can feed on non-host trees and on other surfaces and so in areas of low host prevalence they can still feed, and will travel further to reproduce.

Prevalence of apple orchards

There are a number of apple orchards within a 5 mile radius of the Pacificlean Environmental facility (see Figure 19 below). The nearest orchard is estimated as being 50ft (0.009 miles) away (Carman, WSDA, USA, *personal communication*, March 2016).

Prevalence of other hosts
Host distribution in the PRA area is discussed under section 1.06. Outside of the orchards in the east of the state host distribution is discontinuous since it is reliant upon the presence of waterways and wet areas, and this part of the state is relatively dry. The WSDA hangs traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in the area when fruit is on the tree. The only maps of host distribution in the vicinity of the composting facilities are those showing which hosts are used for trapping. However, this map is not meant to be a complete inventory of host plants within the 5-mile radius largely due to logistical constraints in surveying the area. In 2015 the WSDA aimed to place traps in all of the main hosts within a 5-mile radius of each composting facility. Figure 19 shows the host trees where traps were placed around the Pacificlean Environmental facility indicating the presence of a number of hosts, especially apples, and crab apples (albeit crab apples were rated as relatively low risk according to Yee *et al*., 2014 and have been shown to vary in their susceptibility to infestation depending upon species and variety by Reissig *et al*., 1990), within 5 miles of the site. Within 0.5 mile the WSDA trapped six apple trees the nearest of which is estimated (from the GIS) to be on-site (Carman, WSDA, USA, *personal communication*, March 2016). However within the 5 mile radius the prevalence of hosts that were trapped is greater. This offers an opportunity for adult flies of *R. pomonella* to transfer to non-commercial hosts and to reproduce, and could lead to spread to the nearest commercial orchards, the closest of which is estimated to be 50ft (0.009 miles away) from the Pacificlean Environmental facility.

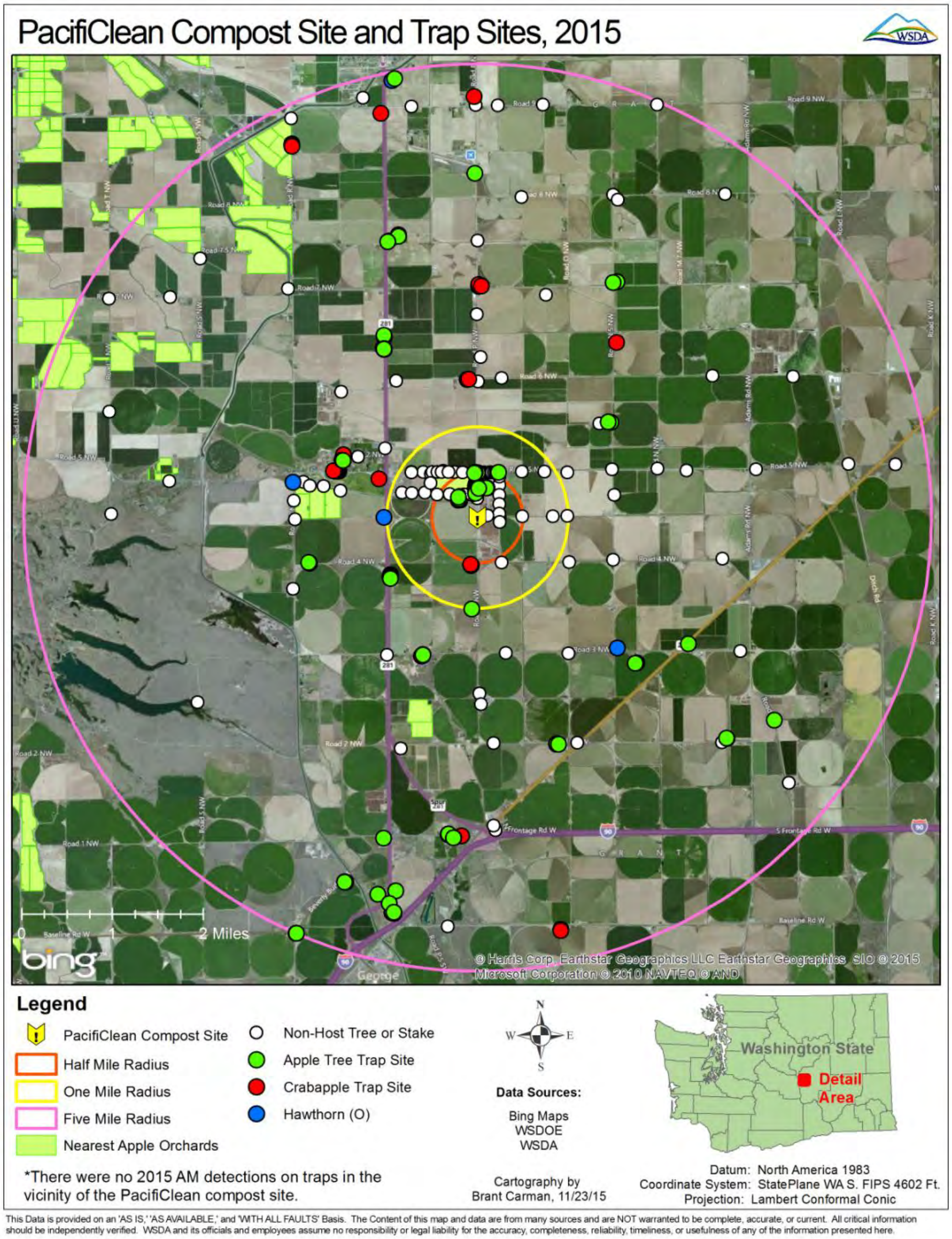


Figure 19. Host trees trapped by the WSDA around the Pacificlean Environmental facility in 2015 and the nearest commercial apple orchards (source WSDA)

Results of trapping

Trapping undertaken in 2015 shows that none of the traps within a 5 mile radius of the Pacificlean Environmental facility were positive for *R. pomonella*. See Figure 20 below.

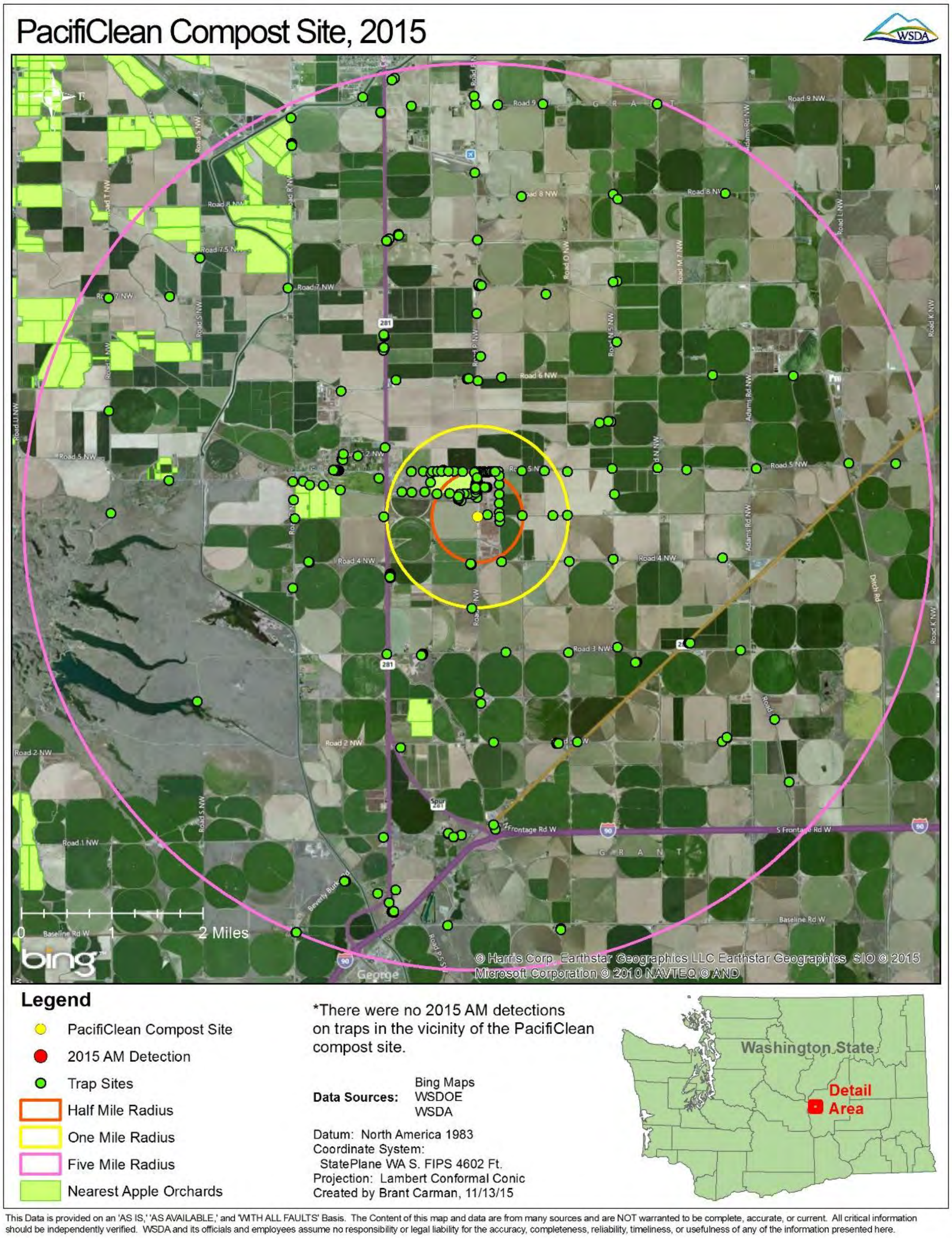


Figure 20. Host trees trapped by the WSDA around the Pacificlean Environmental facility in 2015 showing no positive trap sites (source WSDA)

Processing of municipal green waste at the transfer station and at the Pacificlean Environmental Facility

Municipal green waste received at the Pacificlean Environmental facility in 2015 was pre-ground for a trial period at the South Seattle transfer station prior to loading into the transfer trailers. Pacificlean Environmental advised that:

'The grinding took place in a covered building. The grinder was a Peterson 2710 horizontal high speed grinder with 100% of the material being ground and ran through it utilizing 2" grates'.

Waste that was ground at the facility itself was ground using the same type of machine. The facility advised that:

'Municipal organic wastes are tipped onto the Wobble sorter and conveyed through the following contaminant removal process: Loading onto a Wobbler feeder which separates/pulls the material apart and is conveyed to a pick line, where six to eight employees hand pick contaminants from the feedstock, then the material is ground via a high speed horizontal grinder which can accommodate grates of 2" size or larger'.

For pre-ground waste the dimensions of the resulting material were described as:
'During the trial grinding period, the ground/processed material was ground to 2" or less. We don't have data on the dimensions of the materials, but when the 2" screens were used no apples (even apples 1" or less) were making it through the grinder whole'

For waste ground at the facility they advised that:
'We never were given a chance to run 2" grates at our composting site grinder but identical results would have been achieved'.

The facility advised that with respect to there being any variation in the dimensions of the ground material:
'We don't have enough history receiving and/or grinding material to comment'.

It is assumed therefore that waste ground using this type of grinder with a 2-inch grate will be 2-inches (5cm) or less in two dimensions but may be longer in the third dimension.

Eggs of *R. pomonella* measure 0.9mm long and 0.23mm wide.
Late third instars measure 6.5 - 8 mm long x 1.5 - 2 mm wide.
Pupae measure 5mm long x 2.3mm wide; or from two locations in the state of Washington more recent specific values of *ca*. 4.5mm long x 2.1 mm wide and 4.3 x 2.1mm wide have been provided (with males being smaller; some are only 3.8 mm long and 1.7 mm wide).

Because of their small size all life stages have potential to be present in the waste after it is ground using this type of grinder. The pupae are the most resilient and are most likely to survive the grinding process.

Infested hawthorn fruit are small, may survive the grinding process, and along with larger pieces of fruit such as apples, could also slip through the 2-inch (5cm) grate.

Composting
The composting process used by Pacificlean Environmental is a turned windrow.

The facility advised that:
'*Covering windrow composting piles is counter-productive to bringing the heat up to 131 degrees* [55°C] *because it suffocates the piles when they require oxygen.* ***The WSDA special permit required us to cover but we found it was taking on average 16 days to get to 131 degrees* [55°C] *as compared to 2-3 days uncovered*.** *We followed the WSDA's rules in the Special Permit and covered the windrows until they reached 131 degrees* [55°C] *for 12 hours. After this temp and time was achieved we uncovered and turned the windrow. This activity occurred during the months of July and August 2015'.*

Also that:

'The facility processing area is concrete and the windrow surface is heavily compacted clay and caliche. The climate at the composting facility is very hot and dry so leachate evaporates without special handling. Also the surface has been deemed impervious per WA State Dept. of Ecology regulations; therefore, leachate does not contaminate the sub service and no containment pond is required'.

In their response to the PRA team's questionnaire, Pacificlean Environmental did not give any further details on the composting process. However, a brief review of their operations plan and the addendum (which were provided separately) showed:

Reconfiguration of the site reoriented the planned direction of the windrows such that for a trial period they would be 20-27ft wide and 640ft long (from the addendum).

Also that:

'*After construction of a given length of windrow, the windrow turner is driven over the layered materials to aerate and mix the materials together'*.

'Windrows are….turned a minimum of five times within the minimum of 15 days at which the temperature is greater than 131°F. This requirement is based on the EPA section 503 regulations for a "Process to Further Reduce Pathogens" (PFRP). After that minimum 15-day time and temperature process has been achieved, turning occurs on an as needed basis as determined by the operator to encourage optimum breakdown of the material. Depending upon the specific feedstocks and the ability to maintain optimum conditions for the microbial breakdown of the feedstocks, Ovenell Land's finished compost may begin to cool down after about 4 weeks or about 10- to 16-turns'.

Process monitoring

Pacificlean Environmental advised that:

'The temperatures are monitored with a wireless probe system that records time and temperature data. Please see attached operations plan for full details'.

The operations plan stated that temperatures were monitored thus:
On windrows: Daily through PFRP (min 15 days with 5 turns), then weekly through screening.
On curing piles: Weekly on piles larger than 500 cubic yards – or as needed

There is no indication of the number/frequency of probes or depth at which temperatures are measured.

Assessment of the composting process at the Pacificlean Environmental facility

Because of their small size, all life stages have the potential to be present in some of the ground waste which arrived at the facility in 2015, but the pupae are the most resilient and are most likely to survive the grinding process. Infested small fruit such as hawthorn and larger pieces of fruit such as apples that have survived the grinding process have the potential to slip through the 2-inch (5cm) grate in the grinder and so could also be present in the waste. Unground waste is ground the same day on site using the same type of grinder so the risk is the same.

Ground waste is built into windrows on a heavily compacted clay and caliche pad. The windrows were covered in 2015 as required by the WSDA but this is not an insect-proof seal and inspection by the WSDA showed an apple had escaped not only from the grinder but also from the tarpaulin covering the windrow. The facility has suggested that they did not have time to test the 2-inch grate in their onsite grinder so this may explain the presence of intact fruit in the windrow. However, clearly the tarpaulins will not totally prevent escape of any flies that may emerge from pupae. Also any waste (assumed to be ground waste) that is stored on site in a contingency situation (up to 3 days) is covered with 12 inches of woody material which would not prevent escape of flies of *R. pomonella.* Once the windrows are constructed they are turned and the facility advised that it took up to 16 days to reach 55°C when covered (compared to 2 to 3 days uncovered). (NB: This seems at odds with Yee and Chapman's unpublished findings that covering piles of ground waste speeded-up the time for ground waste to reach temperatures lethal to pupae of *R. pomonella*). They are maintained at this temperature for 15 days with at least 5 turnings of the windrow. This is the PFRP stage. It is not known at what depth the temperature probes are located or how many sampling points there are on the windrows which are 640ft long. If heating is not uniform then there may be some ground waste that does not reach this temperature. Material on the surface is presumed not to heat up to this level until it has been turned into the windrow and held for a sufficient period of time.

This is a relatively long period of time during which any flies that are ready to eclose may transfer to non-host trees or other surfaces for feeding as well as to any host trees that are within a dispersal distance of up to at least 1 mile of the site during the normal period of flight activity when favourable temperatures occur between June and October. Based upon Figure 19 the host trees are most likely to be apples, although there is one crab apple and one ornamental hawthorn that are trapped by the WSDA.

Any late 3rd instars could pupate within 2 to 18hrs and if they do not enter diapause they can take 4 to 6 weeks to emerge as adults (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Yee (USDA, ARS, USA, *personal communication*, April 2016) advised that under laboratory conditions up to 50% of pupae in the state of Washington do not require a chilling period (i.e. if kept at room temperature) to lead to emergence of adults. This may increase the risk of dispersal of flies from non-diapausing pupae at composting facilities. In this instance, provided any newly-formed pupae that are on the surface are mixed thoroughly into the windrow during the turning process this should not add significantly to the population of adult flies unless they are returned to the surface during subsequent turns and have survived the heating process.

Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) stated that: '*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stages. This stage is still metabolizing at 50°C and the normal metabolizing only begins to breakdown at 55°C. To determine this you were using a fairly aggressive heating protocol of 0.4 degrees/minute'.* She also advised that this life stage is in deep diapause until 5 days before emergence. A 30 minute exposure to 45°C does not kill pupae. At 50°C it takes 20 minutes for thermal death. Yee (USDA, ARS, *personal communication*, March 2016) showed that holding pupae at 100% RH at 45.3°C for 1 day only led to 6.7% mortality whereas holding them at 46.3°C for 3 days resulted in 100% mortality. Exposure to 50.5°C for 3 days or 38°C for 1 day followed by 56-58°C for 3 days at 100%RH led to 100% mortality (Yee and Chapman; *manuscript in preparation*).

Although the minimum time and temperature combination that is needed to kill pupae of *R. pomonella* is thought to be around 50°C for 20 minutes (based upon Neven's unpublished work) it seems that at least <u>within</u> the windrow pupae could survive for up to 16 days from the start of the composting process while the pile heats up (at least based upon the maximum length of time that Pacificlean Environmental advised it took to reach this temperature when windrows are covered), but those on surface of the pile will probably escape this exposure until the windrow is turned. Any cold spots or areas within the windrow where larger pieces of infested material are located (intact fruit were found in the windrows by the WSDA in July 2015) could pose a risk of survival of pupae of *R. pomonella*.

Because the surface upon which the windrows are constructed is compacted clay and caliche any late third instars which tumble from the piles are assumed not to be able to burrow into the soil but they can still pupate on the hard surface. They may crawl into a crack or crevice and pupate there. Any pupae that tumble from the piles during any of the processes have the potential for adults to emerge and disperse since this is not a closed system. If this occurs during the period when adults can take flight (when favourable temperatures occur between June and October), the pest could transfer to foliage of host or non-host trees from any spillages that may occur.

Although any of the life stages of *R. pomonella* that are present in the municipal green waste once it is ground and that are exposed to sufficient heat for sufficient time are likely to be killed, there seem to be ample opportunities for the adult flies to transfer from the facility to hosts within *ca*. 1 mile, most likely apples, as well as to non-hosts or other surfaces for feeding. It seems less likely that pupae would survive through to the very end of the process unless there were free pupae or infested material that escaped full exposure to lethal temperatures for the requisite amount of time required to kill them. Based on Neven's unpublished laboratory work this could be 50°C for *ca*. 30 minutes. Yee and Chapman (*manuscript in preparation*) sampled later than this and showed 100% mortality after exposure to 50.5°C for 3 days. It is not known whether this time x temperature would occur for all of the pupae in the waste material.

During the final (unspecified period) curing stage, temperatures will be lower than during the composting stage. Cornell advises that: '*After the thermophilic phase, the compost temperature drops and is not restored by turning or mixing. At this point, decomposition is taken over by mesophilic microbes through a long process of "curing" or maturation. Although the compost temperature is close to ambient during the curing phase, chemical reactions continue to occur that make the remaining organic matter more stable and suitable for use with plants'*.
http://compost.css.cornell.edu/physics.html accessed 17 March 2016.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016 advised that during this phase there is an increase in microbial diversity with the production of lytic enzymes etc. These and other factors during maturation of the compost could have an impact on the viability of *R. pomonella*, especially on pupae that may not have been exposed to lethal temperatures prior to curing. However, this has not been studied and remains an uncertainty.

Intended use of the compost
Pacificlean Environmental advised that in a normal operating year they would anticipate producing 39,000 tons of finished compost from the waste that is received from the Seattle area of King County.

In terms of end use they advised:
'*100% of our compost is sold wholesale to a compost/manure applicator company that applies it all locally on farmland within 100 miles of the facility'.*

Also that:
'All of our compost, 100% of it goes back to farms and all within 100 miles of the facility. We are a new company but so far all customers are in the PFA. These farmers grow everything from apples, potatoes, corn, grains, peas, grapes, etc. The farmers change the crops through the year based on prices, timing, and weather'.

The impact of the curing phase on pupae of *R. pomonella* has not been investigated and we have no data to suggest that viable pupae might end-up in the finished compost. This would only occur if procedures are not executed and monitored carefully. An investigation of the effect of curing on pupae of *R. pomonella* would be beneficial.

In this system, the main risk of transfer of *R. pomonella* to a suitable host or habitat arises from the potential risk of transfer at the beginning of the composting process up to at least 16 days into the process from covered ground waste that may contain pupae in soil or in apples or small fruit such as hawthorns or larger pieces of fruit that have escaped the pre-grinding process. The cover is not an insect-tight seal. There may also be opportunities for flies to escape from storage piles which are held for up to 3 days before being moved into windrows. If infested material present in the windows does not reach lethal temperatures for a sufficient period of time then transfer of adult flies is possible during the normal flight period of the pest when favourable temperatures occur between June and October. The dispersal distances of the adult flies in relation to the proximity of at least some hosts of *R. pomonella* means there is potential for transfer in this way (and adults can transfer to non-host trees or possibly to other surfaces for feeding).

Taking account of all these factors it seems *very likely* with *low uncertainty* that the pest could transfer from this pathway to a suitable host or habitat. The risk of transfer to commercial apple orchards in the same year may be feasible as the nearest in the PFA is estimated to be 50 ft. from the facility.

2.11 - The probability of entry for the pathway should be described
It is *very likely* with *low* uncertainty that *R. pomonella* could enter the PRA area (the PFA) from municipal green waste originating in the Seattle area of King County.

This an area which is considered to have a high level of infestation with *R. pomonella*, where the waste has either been pre-ground (in 2015) or unground, and then transferred to the Pacificlean Environmental facility for composting in windrows which while subject to covering with tarpaulins and turned, take up to 16 days to reach 55°C (as advised by the facility) and in which whole apples have been found in and adjacent to windrows. The finished compost is sold to one business which spreads it on farm land including that where apples are grown commercially in the PFA.

The most likely material to pose a risk is infested host fruit, and soil associated with infested hosts at the origin of the material being collected.

The main areas of uncertainty are:

- The amount and type of infested host material in the waste stream at different times of year
- The amount of infested soil in the waste stream at different times of year
- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The proportion and size of soil clods which may escape the grinding process
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit or soil clods that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The impact of the curing phase on pupae of *R. pomonella*
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- Whether adults of *R. pomonella* will feed on leachates from compost piles

As referred to at the start of this pathway, Pacificlean Environmental funded the design of a building intended to receive waste on site with a view to reducing the potential risk of escape of *R. pomonella* to the PFA. The building was not constructed in 2015 and so it has not been assessed, the impact it might have on the risk of transfer of the pest to the PRA area remains uncertain.

Meanwhile, the risk of transfer in the same year as adults emerge from the facility is likely to be to non-commercial hosts within the vicinity of the facility that could maintain populations of the pest, and possibly to the nearest commercial apple orchard(s), the closest of which is estimated to be 50ft (0.009 miles) away from the Pacificlean Environmental facility, depending upon the favourability of the environment in that year.

Pathway 4. Risk of entry of *R. pomonella* on municipal green waste moving to Royal Organic Products, Grant County

The questionnaire from the PRA team used in this section was completed by Thad Schutt

2.03 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account the biology of the pest?

Very likely

Level of uncertainty: *Low*

Royal Organic Products (ROP) first started receiving municipal green waste from the quarantine area of the state of Washington in 2006; this originated in Spokane, in the east of the state. They have not received municipal green waste containing yard debris from Spokane County since 2012. ROP ceased receiving waste from the quarantine areas after September 2015.

Data provided by ROP in their reports to the Department of Ecology, Washington State, from 2009 to 2014 show that the facility has received a variety of municipal green waste (categorised up to 2013 as '*yard debris'*, '*mixed food and yard debris (residential)'*, *'food waste (pre-consumer vegetative)'*, '*crop residues'* and '*wood waste'*; from the quarantine and PFA of the state, as well as from one county in the state of Oregon in the quarantine area for *R. pomonella*. Categories changed in 2014 and '*mixed food and yard debris (residential)*' was assigned to '*yard debris/food scraps (mixed)*', '*food waste (pre-consumer) vegetative*' was assigned to '*food waste, pre-consumer*' and '*crop residues*' was assigned to '*agricultural organics (vegetative) includes crop residue etc.'*. For the purposes of assessing ROP the original categories are used.

In terms of municipal green waste originating in the quarantine area of the state of Washington, from 2012, ROP has also received relatively small amounts of unground food waste (pre-consumer vegetative) from grocery stores in Spokane County; as well as either yard debris, mixed food and yard debris (residential), or both, from King County, Pierce County and Thurston County in the west side of the state. Both types of waste were received from Multnomah County in the state of Oregon.

All of the waste originating in the west side of the state of Washington and Oregon is pre-ground[10] at 3 transfer stations in western Washington and one transfer station in Oregon (see Figure 22).

At the point of origin (before arrival at the transfer stations), and, accounting for all sources, the waste is likely to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream.

R. pomonella is associated with the fruit of a range of hosts and also with soil associated with host plants. More detail on the prevalence of host material is given later in this section.

[10] The last shipment from Oregon in 2013 was either not ground or coarsely-shredded (*personal communication* from Bruce Philbrook, manager of Metro Waste in Portland, Oregon to Reynolds, USA)

The biology of the pest is described in section 1.02b and was summarised under question 2.03 for Pathway 1 so it has not been repeated here.

The life stages associated with infested fruit are eggs, larvae and occasionally pupae. Fruit begins to be infested in June in the state of Washington. The numbers of each life stage associated with the fruit will vary with the variety and size of fruit. Studies undertaken in the state of Washington (Tracewski *et al*., 1985) found that a single hawthorn (species not specified) can yield 65,000 to 112,000 fruits (1984); it was estimated that with an average rate of 5% of fruit infested (assuming one larva per fruit) there could be 3000 to 6000 flies produced per tree. Incubation of several hundred infested apple fruit (1982 to 1983) mostly yielded 1 or 2 larvae per fruit; however, one fruit yielded 6 pupae. These figures were obtained early in the history of *R. pomonella* in the west of the USA and current infestation rates, at least in the west of the state of Washington are much higher than they were then. If a higher percentage of fruit is infested per tree there will be a greater number of larvae and pupae resulting from an attack by *R. pomonella*.

Despite the high numbers of flies presumed to be produced from a single infested hawthorn, Tracewski *et al.* (1985) did not record the actual number of flies produced. Dean and Chapman (1973) state there is some natural mortality at all stages of the life cycle but that it is highest in the larval and pupal stage and lowest at the egg stage. They cited studies suggesting pupal mortality could be between 47 and 96% influenced by parasitism, predation and ambient conditions. Larval mortality was particularly influenced by the variety of apple since hard-fleshed fruits can lead to 100% mortality. Nonetheless sufficient life stages persist to maintain populations of *R. pomonella* in the quarantine area.

Pupae (and late third instar – albeit this is a transient stage of a few hours) are the life stages associated with soil. According to Dean and Chapman (1973) the pre-pupal stage of *R. pomonella* lasts from 2 to 18 hours with the majority taking 6 to 11 hours to form pupae.

The periods of time over which eggs, larvae and pupae are likely to be found in fruit in municipal green waste from the quarantine area of the state of Washington depends upon whether it originates in the east or the west of the state. See Table 10. This geographic split will influence the prevalence of the pest both in fruit, and as pupae in soil associated with the waste stream, due to the higher levels of infestation in the west side of the state.

Table 10. Periods when eggs, larvae, and pupae can be in municipal green waste originating in the quarantine areas of the state of Washington.

Life stage	**Eastern Washington**		**Western Washington**	
	Start date	End date	Start date	End date
Eggs (in fruit)	Mid to late June	Late September to October* depending on date of first hard freezing temperatures	Early to mid-June	Late October depending on date of first hard freezing temperatures
Larvae (in fruit)	Mid to late June	Early November depending on date of first hard freezing temperatures	Early to mid-June	End of November into early December depending on date of first hard freezing temperatures
Pupae	In fruit, soil , growing media, or in the sod or duff at any time of the year[11]			

*Because the populations are so sparse or nonexistent in areas in central Washington (Yee *et al*., 2012) the seasonality or even the entire host range of the apple maggot is uncertain on the eastern side of the Cascade mountain range. The timing provided in the table is based on what is known and assumes that the same host range exists on the eastern side as on the western side of the state.

In **eastern Washington**, where the vegetative food waste from Spokane being processed by ROP originates (*see later notes on this material as it is difficult if not impossible to assess*), black hawthorn (*C. douglasii*) and early varieties of apples ripen in early to late June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). Emerging adult flies of *R. pomonella* aligned with these major hosts could begin laying eggs by mid-June. Larvae could be present in the fruit of apples or black hawthorn within 5 to 7 days of oviposition (Dean and Chapman 1973). In an apple maggot survey for Spokane County in 1985 the first recorded fly capture was on June 26th (Klaus, 1985). The end date is based on the presence of ornamental hawthorns (*C. monogyna* or *C. laevigata*) which consistently bear ripened fruit in late October. (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). However because populations on the east side of the Cascade mountain range are sparse or nonexistent they are difficult to characterise. We assume here, that if established they will utilise the same hosts as they utilise on the west side including ornamental hawthorns.

In **western Washington**, where most of the municipal green waste being processed by ROP originates, all fruiting starts earlier than in eastern Washington because of the warmer temperatures. Fly trapping data show adults were captured in the first week of June (unspecified year) by a hobbyist organisation in Puyallup (Pierce County) (Klaus, WSDA, USA, *personal communication* to Mastro, USA, January 2016). Mattson (2015) also reported apple maggot adults emerging in early June. Based on the presence of active adults in the first week of June, mature females could be laying eggs by the second or third week of June and larvae would be present in fruit within 5 to 7 days. Although there are no trapping data from research or programme activities from early June it is believed that some flies can be active in early June (Yee, USDA, ARS, USA, *personal communication* to Mastro, USA, January 2016). In one year adults were trapped in late May in Vancouver, Washington (Yee, *personal communication*, April

[11] Only soil is mentioned in the main text for the assessment but the other substrates are relevant

2016) but this is an exception. The end date is based on data from Mattsson (2015) indicating that maximum flight activities for adult flies on ornamental hawthorn in Vancouver (Clark County) was determined to be in mid-September. Depending on the impact of lower degree days at this time of the year, the life cycle of *R. pomonella* would extend into November or December.

In **Oregon** where the pest is established in some counties and where the waste received by ROP originates from a county quarantined for *R. pomonella*, the biology of the pest is thought to be the same as in western Washington.

Infested fruit, particularly (but not exclusively) apples, is thought to be the most likely route of entry of the pest to the PFA (Hood *et al*., 2013). This could enter the municipal green waste stream at any time of year if it is stored or retained by homeowners in green waste in their yards but the most likely period for this to occur in waste from the west side of the state of Washington or from Oregon is from June to November or early December. This is based upon when fruit on trees in these areas is likely to be infested and may be culled from the tree, or collected from the ground, or harvested and rejected and so may enter the waste stream. If the vegetative food waste originating in grocery stores in Spokane in the east of the state of Washington contains infested host fruit the likelihood of association of the pest depends upon where the fruit was sourced. Given the life cycle of the pest it has potential to be in this waste at any time from June to early December if it is sourced from infested areas in Spokane. However, this is highly uncertain. During the winter and early spring months dropped fruit should rot *in situ*.

Adults are only in the vicinity of fruit when they are mature and ready to mate or lay eggs (Porter 1928; in Dean and Chapman 1973). This period spans June to October. Adults are unlikely to move with green waste unless they emerge from pupae in soil or fruit during transport.

Life stages associated with soil in waste from discarded host plants are late third instar, and pupae. The window of time from November until the initiation of emergence in June should have the greatest soil load of pupae (the most resilient stage of the pest). It is during this time frame that the movement of soil associated with host plants would be of the greatest risk. However, because pupae can survive in soil for more than 2 years (in Brunner 1987, in Dean and Chapman 1973), they could be in the soil in the waste stream throughout the year.

The main hosts in the state of Washington are apples (*Malus* spp.) and several species of hawthorn including black hawthorn (*C. douglasii*). However, there have also been records on various species of cotoneaster (*Cotoneaster* spp.), mountain ash (*Sorbus* spp.), apricots, various plums and cherries (*Prunus* spp.), as well as common and Asian pear (*Pyrus* spp.).

Of these, apples, black hawthorn and oneseed hawthorn (*C. monogyna*) are considered to be of high importance for the pest and several species are of medium importance including smooth hawthorn (*C. laevigata*), Suksdorf's hawthorn (*C. suksforfii*), and Asian pear (*P. pyrifolia*). See section 1.06 and Yee *et al*. (2014).

The prevalence of the hosts in the waste stream originating in the areas where the waste is gathered from is not known. If any of the waste from King County originates in or around the city of Seattle then the review of information sources for Pathway 3 (Pacificlean Environmental) shows that there are abundant apples, crab apples and hawthorn in the area and that there is potential for apples, if not other host fruit and plants to be in the waste stream.

The WSDA visited the ROP composting facilities once in August 2015 and they found some apple fruit but these were reported to be in a '*non-quarantine waste pile'*. This originated in the PFA. No infested fruit were found.

Host fruit and possibly trees have potential to be in the waste stream and given the origin of most of the waste there is likely to be some level of infested fruit present.

In terms of the levels of infestation with *R. pomonella*, this will vary with the origin of the waste but with the exception of waste originating in the east of the state of Washington (Spokane) and that from Thurston County in the west of the state, both of which are likely to be vegetative food waste with an unknown origin, it is likely to be high. These counties are included in the review of pest prevalence for completeness:

King County, Washington State
The most recent level of infestation with *R. pomonella* for King County from surveillance undertaken by the WSDA is unknown as the county has been in the quarantine area for many years and has not been surveyed.

However, it is thought that if 100 traps were randomly placed in host trees in the Seattle area of King County, 80% would be positive (Klaus, WSDA, USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015). Infestation levels of host fruit and soil associated with host material are likely to be high.

Pierce County, Washington State
The most recent level of infestation with *R. pomonella* for Pierce County from surveillance undertaken by the WSDA is unknown as the county has been in the quarantine area for many years and has not been surveyed. Infestation levels of host fruit and soil associated with host material are likely to be high.

Thurston County, Washington State
The most recent level of infestation with *R. pomonella* for Thurston County from surveillance undertaken by the WSDA is unknown as the county has been in the quarantine area for many years and has not been surveyed. Infestation levels of host fruit and soil associated with host material sourced from this county are likely to be high.

Spokane County, Washington State
The most recent levels of infestation with *R. pomonella* for Spokane County were determined by the WSDA with a low level of trapping. Four traps yielded 22 adult flies at 1 site. Personal communications support the view that Spokane county has a lower level of infestation than parts of the western side of the state such as Seattle as referred to above. It is thought that if 100 traps were randomly placed in host trees in Spokane County, 20% would be positive (Klaus, WSDA,

USA; concurred by Yee, USDA, ARS, USA; *personal communications* to Mastro, USA, December 2015). Infestation levels of host fruit and soil associated with host material sourced from this county are likely to be moderate.

Multnomah County, Oregon State
The official distribution of *R. pomonella* in the state of Oregon is described as '*present, widespread*' (EPPO, 2015). The pest was first reported here in 1979 in backyard apples in Portland (Multnomah County); the first surveys for *R. pomonella* by the Oregon State Department of Agriculture in 1980 showed the Portland area to be '*generally infested'* (Dowell, 1990). Multnomah County is one of a number of counties in the state that are subject to quarantine regulations by the Oregon State Department of Agriculture (website accessed 5 February 2016): http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_603/603_052.html

No survey data were found for this Oregon county but given its long history of infestation and its quarantine status, it is assumed that the level of infestation of host fruit and soil associated with host material is likely to be high. Mattsson *et al.* (2015) found that in studies in Vancouver, Washington (which is adjacent to Portland, Oregon), larval infestation rates (larvae per fruit) were: 0.045 to 0.112 for black hawthorn; 5.400 to 8.794 for early apples; 2.384 to 2.973 for late apples; and 0.108 to 0.385 for ornamental hawthorn. Yee (USDA, ARS, US, *personal communication* April 2016) also found that the Vancouver area is heavily infested from his research trapping data.

Based on the biology of the pest, it is considered that overall, it is *very likely* with *low uncertainty* that *R. pomonella* will be associated with this pathway on waste originating in the west side of the state of Washington and from Oregon. It is considered that it is *moderately likely* with *high uncertainty* that *R. pomonella* will be associated with waste from Spokane since it is not known if the vegetative food waste from grocery stores contains host fruit sourced from areas where the pest is present.

2.04 - How likely is the pest to be associated with the pathway at the point(s) of origin taking into account current management conditions?

Very likely

Level of uncertainty: *Low*

Municipal green waste arriving at the ROP facility between 2012 and 2014 originated in King County, Pierce County, and Thurston County in the quarantine area of western Washington and the Portland area of Oregon in Multnomah County (2012) and Multnomah County (2013) (no area specified), Oregon where *R. pomonella* is subject to quarantine regulation; areas where the level of infestation with *R. pomonella* is thought to be high.

Waste from Thurston County was classified as mixed food and yard debris in the ROP reports to the Department of Ecology, Washington State but recent information from Thurston County transfer station suggests that this is food waste from places such as schools, restaurants and grocery stores; Cox, Thurston County transfer station, Washington State, USA, *personal* *communication* to Reynolds, USA, February 2016. It is not known if this contains host fruit that is sourced locally or elsewhere and so the management of the orchards from which it was harvested cannot be assessed.

Vegetative grocery store waste from Spokane also cannot be easily assessed. If it contains host fruit then the origin of the fruit is unknown and so the management of the orchards from which it was harvested cannot be assessed.

With respect to the remaining counties in the west side of the state of Washington (King and Pierce) and Oregon (Multnomah), management of the pest will be undertaken in commercial orchards that grow apples. However, it is assumed that there are no commercial orchards located in the quarantined counties of western Washington which are certified as pest-free by the WSDA through their surveillance programme, since no surveillance has been undertaken in these counties for many years. Such orchards would require intensive pest management practices in this infested area to qualify for pest-free status for *R. pomonella*. In Multnomah County, Oregon it is assumed the situation is the same. Nonetheless, the waste from these counties that is being processed by ROP does not originate from commercial fruit orchards; rather much of it originates from homeowner's yards (and maybe from parks and other municipal areas).

In the case of homeowner's yards this is where pest management may not be very effective even if it is deployed. However, advice is available through Washington State University's extension service:
http://ext100.wsu.edu/skagit/agriculture/apple-maggot/ and via amateur fruit-growing societies. The success of control will vary with the homeowner.

For King County, the Seattle Parks Department website refers to integrated pest management but there is no specific mention of *R. pomonella*. However, it is known that waste fruit from organisations in Seattle (King County) such as City Fruit ends up in the waste stream and this is collected from a variety of sources including parks (where there are orchards) as well as from homeowner's trees. City Fruit stated that:

'City Fruit's goal is to produce as much organically grown bug-free fruit as possible, and donate it to food banks and feeding programs, so for now we just try to cover as many apples as we can with either paper bags (each apple covered individually) or poly hail nets (entire tree covered), which we tried for the first time this year, and which were extremely effective'.

City Fruit continued:

- *Cover individual apples with lightly waxed paper bags*
- *Covering the entire tree with a poly hail net*
- *in both cases protected fruit from apple maggot damage*
- *apple maggot fly easier to deter than codling moth*
- *any sort of covering on an apple will keep the apple maggot fly from landing ----- codling moths are much more persistent and insistent on chewing through*
- *In orchards this year we avoided apple maggot damage in 60% of our trees*

- *Next year we will do better as we net more trees completely*
- *Pest-damaged apples were collected by cider makers*
- *HUGE decrease in apple maggot-infested apples ending up in the green waste stream*[12]

Source: Burrill, City Fruit, Seattle, USA; *personal communication* to Mastro and Reynolds, December 2015.

Management of *R. pomonella* in this way means that while there is no potential for pesticide residues in the fruit (which would conflict with their aim of organic production), this approach would allow some life stages of the pest to be present in any fruit which may be discarded and could enter the municipal green waste stream.

Since, at the point of origin, the waste stream is from non-commercial orchard sources and locations such as homeowner's yards, the management of the pest in the west side of the state of Washington and from Multnomah County, Oregon would not be sufficient to eliminate *R. pomonella* in the waste.

Disregarding the vegetative grocery store waste from Spokane County and that from Thurston County which is difficult to assess, accounting for current management conditions for all of the remaining material that contains yard debris, *R. pomonella* is *very likely* to be associated with the waste at the point(s) of origin with *low uncertainty.*

2.05 - Consider the <u>volume</u> of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

Very likely

Level of uncertainty: *Low*

Table 11 summarises the data on municipal green waste received from the quarantine areas for *R. pomonella* supplied by ROP in their annual reports to the Department of Ecology for the state of Washington.

[12] It is not known how this was measured

Table 11. Municipal green waste (tons) received between 2012 and 2014 by ROP

Year	Yard debris	Mixed food and yard debris (residential)	Food waste (pre-consumer – vegetative)	County of origin	State of origin
2012	0	1429	0	Spokane	Washington
	4712	0	0	Multnomah (Portland area)	Oregon
	25215	0	0	Pierce	Washington
TOTALS	**29927**	**1429**	**0**		
2013	0	0	966	Spokane	Washington
	0	213	0	Thurston	Washington
	0	7479	0	Multnomah	Oregon
	1287	0	0	King	Washington
TOTALS	**1287**	**7692**	**966**		
2014	0	0	**159	Spokane	Washington
	31870	0	0	King	Washington
	110	0	0	Adams	Washington
	0	***1794	0	Thurston	Washington
TOTALS	**31980**	**1794**	**159**		

Categories of waste are those assigned in the ROP reports to the Department of Ecology, Washington State
In 2014, waste categories were changed by the Department of Ecology:
**Mixed food and yard debris (residential) was reassigned to 'Yard debris/food scraps (mixed)' – for ROP it is pre-ground
*** Food waste (pre-consumer – vegetative) was reassigned to 'Food waste, pre-consumer', for ROP it is from grocery stores and is not pre-ground

Note that since these data were supplied, correspondence with the transfer stations showed that the pre-ground '*mixed food and yard debris'* received by ROP from Thurston County is in fact commercial food waste from places such as schools, restaurants and grocery stores (Cox, Thurston County transfer station, Washington State, USA, *personal communication* to Reynolds, USA, February 2016).

Between 2012 and 2014, the amount of municipal green waste received by ROP from the five counties of origin varied by type and by year. Yard debris was the main category of waste in 2012 and 2014 with *ca.* 30,000 and 32,000 tons being received respectively. In 2013 much less yard debris was received (*ca*. 1300 tons). Mixed food and yard debris also varied; although Spokane despatched *ca*. 1400 tons in 2012 this is no longer a source of this type of material and in 2013 and 2014 all waste of this type came from western Washington; *ca*. 7700 (213 tons from Thurston County) and 1800 tons – all from Thurston County, respectively. Relatively low amounts of vegetative waste from grocery stores from Spokane was received in 2013 and 2014; *ca*. 970 and 160 tons respectively.

Although the amount and type of municipal green waste has varied, the amount of yard debris received from western Washington in 2012 and 2014 was high.

In one spreadsheet supplied by ROP to the PRA team the facility advised that for 2012, 2013, 2014 and 2015 the total amount of green waste received from west of the Cascade mountains (not broken-down by category or county) amounted to *ca*. 30,000, 9000, 33,700 and 4500 tons respectively (to October 2015). This shows the variability in the volume of green waste in the waste stream.

On the assumption that infested material is present in the municipal green waste, although the amount of waste varies between years, because of the origin of most of the waste, it is considered *very likely* with *low uncertainty* that this volume of movement will support the entry of the pest to the PRA area.

2.06 - Consider the <u>frequency</u> of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

Very likely

Level of uncertainty: *Low*

In one of the spreadsheets supplied by ROP there is a breakdown of waste received each month presented in a series of charts for 2012 to 2015 (see Figure 21). Although these charts do not indicate the origin of the waste (it is assumed they include waste from quarantine areas as well as from the PFA of Washington State) they give a good indication of when yard waste was received at this facility.

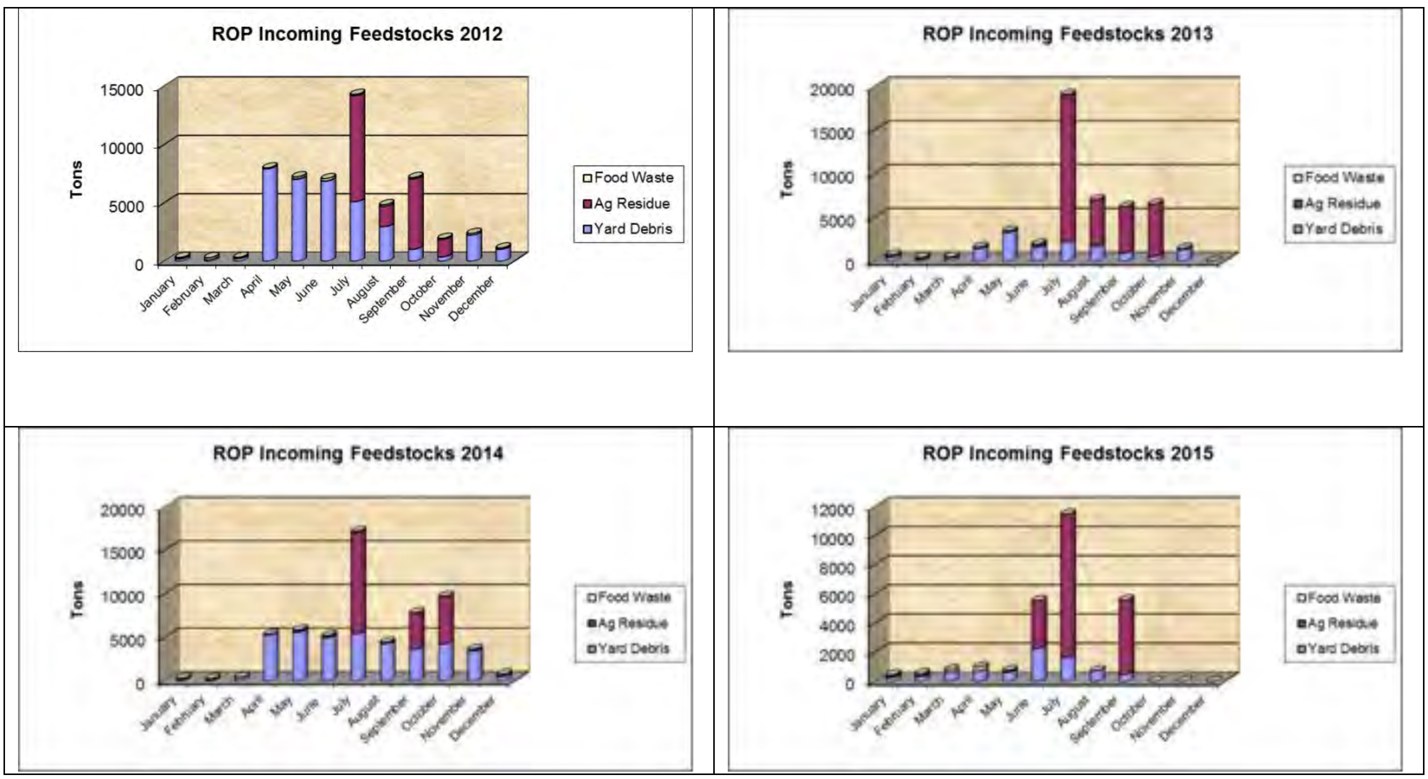


Figure 21. Monthly tonnage of waste received at Royal Organic Products: 2012-2015
[Includes all sources (all counties including PFA counties and all types of waste). Processing stopped in September 2015]

Yard debris was received in all months of the year but the highest amounts were mainly received between April and November. No comment can be made on origin from these charts. However, monthly data for pre-ground municipal green waste originating in the west side of the quarantine area and vegetative grocery waste (unground) were supplied by ROP for 2014. See Table 12.

Table 12. Tons of municipal green waste received per month from quarantined counties in Washington State, 2014

Month	**County of origin**		
	King*	Thurston**	Spokane***
January	0	70	0
February	0	69	0
March	0	104	0
April	4713	131	0
May	4800	134	53
June	4330	132	51
July	4771	159	27
August	3579	170	0
September	3061	139	0
October	3673	134	0
November	2909	236	0
December	35	316	28
Totals	**31870**	**1794**	**159**

*Yard debris
**Mixed food and yard debris (now understood to be food waste from schools, restaurants and grocery stores)
***Vegetative grocery waste

These data show that municipal green waste was received in each month of 2014 from Thurston County (now thought to be food waste) with most of the yard waste coming from King County between April and November. Vegetative grocery waste (unknown origin and type) came from Spokane County in May, June, July and December 2014.

The number of truckloads of municipal green waste per week from quarantine areas was described by ROP as varying widely. Pre-ground waste from these areas amounts to 32.5 tons per load. Unground loads (e.g. vegetative grocery waste from Spokane) average about 25.8 tons per load.

Any waste host fruit arriving at the facility in pre-ground waste from the quarantine areas of western Washington state or Oregon (see 2.10 for the impact of grinding on waste material) may be infested with *R. pomonella* from early to mid-June when early varieties of apple are ripening, through to at least the end of November and maybe early December when all fruit should have fallen and has been gathered, but depending upon when the first freezing temperatures occur. Black hawthorn (*C. douglasii*) can ripen early (June to July) but also late (late August to early September). Ornamental hawthorns (*C. monogyna* and *C. laevigata*) tend to ripen late (October). As hawthorn fruit are small they may be present in the pre-ground waste from June to October. The months when pre-ground yard waste arrived from King County in 2014 tie in with this (and in other years from all sources), therefore the frequency of movement of the waste means the pest has the potential to be associated with it.

No comment can be made on the waste originating in Spokane County as although it is unground vegetative grocery waste it is not known if it contains host fruit from areas quarantined for *R. pomonella.* The same applies to waste originating in Thurston County. No data on frequency of movement were available for Pierce County in 2012 (the other major source of yard debris to King County).

When soil is in the waste stream that has been gathered with host plants that have fruited and are infested, pupae of *R. pomonella* are likely to be associated with the soil. This is possible all year round with peak numbers of pupae being present from November to June, months when a variable amount of waste has been received from all areas but in most of the last 4 years some waste has been received in each month from all areas (combined quarantine area and PFA); and in 2014 from the quarantine area (King County; November, December, April, May and June).

As pre-ground yard debris from the quarantine area arrived at this facility from April to December in 2014 and yard debris from all sources (this includes waste from the PFA of Washington State) has arrived virtually every month between 2012 and until operations ceased in 2015, assuming some of this is from the quarantine area, the frequency of movement is *very likely* to support entry of *R. pomonella* to the PRA area, with *low uncertainty*.

2.07 - How likely is the pest to survive during transport or storage?

Very likely

Level of uncertainty: *Low*

The likelihood of survival of *R. pomonella* prior to arrival at the ROP facility is largely related to the amount of heating (temperature and duration) that occurs prior to or during transport.

There are four transfer stations where municipal green waste is ground prior to transport to the RO facility (see Figure 22):

- Waste from King County is ground at Cedar Grove (Maple Valley site) transfer station
- Waste from Pierce County is ground at Hidden Valley transfer station
- Waste from Thurston County is ground at Thurston County transfer station
- Waste from Multnomah County is ground at Portland Metro Central transfer station

Waste from Thurston County has not been assessed further as it is food waste from sources such as schools, restaurants and grocery stores which is ground on site (using a tub grinder) before being sent to ROP. The time the waste is stored before it is received by Thurston County is unknown. Source: Cox, Thurston County transfer station, Washington State, USA, *personal communication* to Reynolds, USA, February 2016.

Vegetative grocery waste from Spokane County has not been assessed further. For background a company known as Sunshine Disposal (Spokane County) supply containers to grocery stores and collect food waste from them according to their contracted arrangements which vary according to the customer. Source: Sunshine Disposal, *personal communication* to Reynolds, USA, February 2016. The waste is not ground and is delivered directly to ROP where it is ground (horizontal grounder) and composted on site.

The length of time that unground waste is stored at each of the other transfer stations before it is ground and moved to the ROP facility is:

- Waste from King County - Cedar Grove (Maple Valley site) transfer station is processed using a horizontal grinder and normally removed within 24hrs for transport to ROP
- Waste from Pierce County - Hidden Valley transfer station is processed using a tub grinder and removed within 1 to 3 days

For waste from Multnomah County the time from arrival at Portland Metro Central transfer station to departure as ground waste is 4 to 7 days.

There will be some heating of the waste material when it is at the transfer stations prior to grinding due to natural microbial activity, but the waste on the surface of the pile will not be affected by this.

It is assumed that pre-ground waste is more likely to heat up before transport to ROP compared to waste that is not mechanically processed prior to transportation. The period of time from grinding to the time transfer commences is not likely to allow the waste to reach lethal temperatures for the pest.

From the time of departure from the four transfer stations (includes Thurston County) that move the ground waste, the route taken to the ROP facility is no more than 4 hour's driving time (see Figure 22 below).

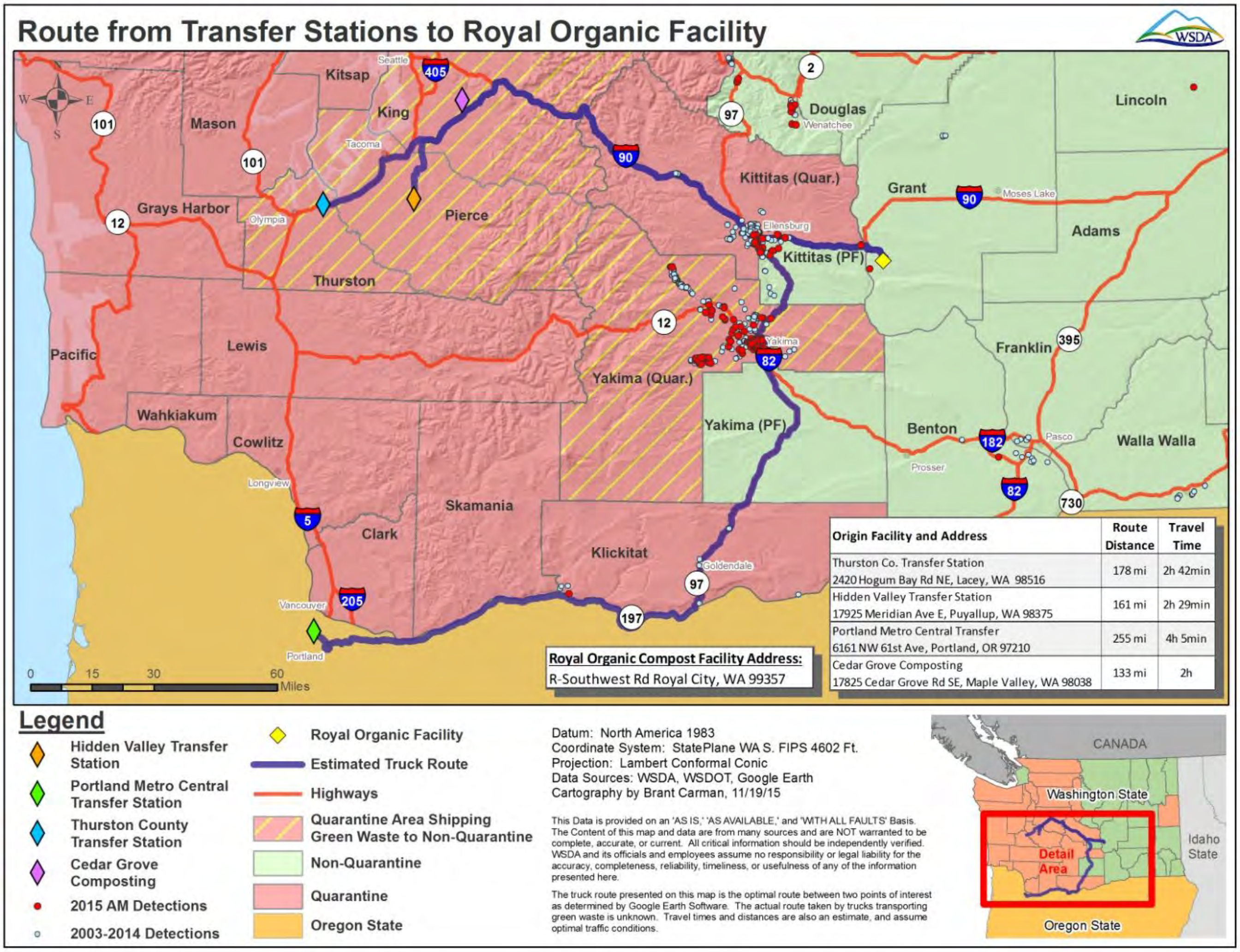


Figure 22. Distance and travel time from four transfer stations to Royal Organic Products, Grant County (source WSDA)

The trailers used to transport the pre-ground waste to the ROP facility are 53ft long and water tight. The trailers are covered in a tarpaulin and have a sealed door.

On arrival at the ROP facility, there is no further storage as the ground waste is unloaded directly into a passively-aerated[13] static pile for composting. ROP advised in their response to the PRA team's questionnaire that the pile is covered with a 1ft thick blanket of '*finished compost'* or *'overs'*. See 2.10 for further details.

[13] The responses to the questionnaire posed by the PRA team indicated this was an aerated static pile but during the week commencing 8 February we learned this is in fact a passively-aerated pile

Overall, the time taken for transport and storage of pre-ground waste and the conditions in which it is transported and held is unlikely to result in temperatures that are lethal to the pest.

Any life stages in infested intact or partial fruit which have survived the grinding process, as well as pupae which are present in soil will be *very likely* to survive transport and storage with *low uncertainty* because the time for heating is relatively short.

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

Likely

Level of uncertainty: *Low*

R. pomonella reproduces by laying eggs within host fruit while it is still hanging on the tree. Dean and Chapman (1973) cite Porter (1928) stating *'Fruit in shaded locations are preferred to those in sunny spots and neither ripe fruit nor drops are attractive to ovipositing flies'*. Thus there should be no oviposition occurring during transport to or storage of host fruit in municipal green waste for any facility.

Disregarding the waste from Spokane and Thurston, for the period material is stored at each of the transfer stations as unground waste the pest will continue its life cycle. Once ground, waste is transported over a short period of time to the ROP facility and put directly into a passively-aerated static pile.

Up to this point, while lethal temperatures are not experienced for a sufficient length of time the pest can continue its life cycle.

If there are any fruit or partial fruit that have survived the grinding process at the transfer stations then any late instars present in the fruit may emerge and start to pupate. Pupation takes place within 24hrs of emergence from fruit. Partial fruits (cut or partially-eaten) yield pupae from larvae (3^{rd} instars) which can continue to develop and pupate (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Occasionally larvae may pupate within fruit (Illingworth, 1912; in Dean and Chapman, 1973). The WSDA found whole apples in a '*non-quarantine storage pile'* when they visited the facility on one occasion in August 2015. This waste originated in the PFA.

Although pupation can take place on any hard surface it is thought that survival of pupae would be much lower in situations where the larvae cannot burrow into the soil, however it is possible that adults would emerge (Brunner, *personal communication* to Mastro, USA, October 2015). Dean and Chapman (1973) citing others state that some moisture is required in the pupal environment with 80 and 100% RH resulting in 81% and 70% emergence (and 2% and 2.5% mortality respectively). Note these are not measures of soil moisture. Survival would be increased if the pupae were in an atmosphere of high humidity such as might occur if they were covered with a small amount of waste material, e.g. as sweepings or spillage at the edge of the main pile of waste. Under such circumstances, pupae that are on hard surfaces at the composting facility could yield flies when they are ready to eclose and these could disperse in favourable temperatures during the normal period of flight activity (when temperatures are favourable between June and October). Pupation could occur in the moist waste once it is being composted before the material reached lethal time x temperatures.

The surface on which the passively-aerated static pile is situated was described as highway grade asphalt on 6 inches of compacted gravel. As this is not part of the transport or storage of the waste (it is the start of the composting process) it is discussed in 2.10.

Emergence of flies from pupae in the waste that have either:

- Overwintered as diapausing pupae
- Have remained in diapause for more than 2 years
- Were produced in the same season and which have not undergone diapause would lead to an increase in the prevalence of adult flies in the PRA area.

This is not an increase in the prevalence of the pest *per se*. It is a continuation of the life cycle with a potential increase in the numbers of adults that could reproduce

Although the time periods involved from collection to being built into the passively-aerated static pile is relatively short, it is considered to be *unlikely* with *low* uncertainty that during transport and storage there would be an increase in the prevalence of the pest up to at least the period when the waste becomes subject to composting or maybe beyond at the ROP facility. The processing of the waste and the potential risk of transfer of the adult flies to hosts in the PRA area is discussed under section 2.10.

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Very likely

Level of uncertainty: *Low*

Currently the municipal green waste stream is not subject to official inspection procedures at the point of origin.

The WSDA inspected the ROP facility in the summer of 2015 for fruit of apples, crab apples and hawthorn. They found apples on site albeit they were not infested and they were in a '*non-quarantine area waste pile*'. This waste originated in the PFA.

As much of the waste originates in areas of high pest prevalence, in the absence of regular official inspection at the point of origin it is *very likely* with *low uncertainty* that *R. pomonella* will enter the PRA area undetected on this pathway until such times as it is trapped during the WSDA annual survey for the pest.

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat ?

Very likely

Level of uncertainty: *Low*

Disregarding unground food waste from Spokane County (which is ground on site) and pre-ground food waste from Thurston County, waste from King County, Pierce County and Multnomah County is placed into '*cells*' or *'walls'* for composting in one main passively-aerated static pile.

According to the response to the PRA team's questionnaire in the autumn of 2015 this is covered with 1ft of '*finished compost*' also described as '*overs*'. This is done by the end of the working day on which the waste arrives. '*Overs*' are large particles screened from finished compost prior to sale of the finished product. This material appeared coarse when observed by Reynolds and Mastro in their visit to the facility in the autumn of 2015. As a covering, this could allow the escape of any emerging adult flies. There is also some indication[14] that this covering is not consistently at this depth and may be shallower, which would also favour escape.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016) stated that '*A 1ft thick cover with finished, sieved compost is a good method for preventing apple maggot moving in or out the pile, but it is less supportive for the aeration of the pile, especially as the pile has no forced aeration. The reason is that the density of this finished compost is much higher and the pore sizes are much smaller*'. However, referring to coarse overs he stated that '*aeration is less affected, and there is certainly an added value in preventing apple maggot to move out the pile, but this is not fully guaranteed'.* Subsequently he advised that '*if the covering is questionable*[15] *than the time to reach lethal temperature especially on the edges is critical. And the edges will be there as they do not turn*'. He also suggested that there needs to be evidence that this way of covering guarantees no escape of the adult flies, implying that an alternative cover could be considered, or that turning of the edges into the pile may be needed to try to reduce the risk.

If finished sieved compost was used this would help to raise the temperature of the surface of the pile to lethal levels; however, before this occurs, because flies normally emerge from soil it is unlikely to present a physical barrier to emergence of flies of *R. pomonella*.

Larvae of *R. pomonella* can pupate as deep as 12 inches (30.48cm) in soil (Dean and Chapman, 1973) but whether adult flies can emerge from this depth was not stated. Yee (USDA, ARS, USA,

---

[14] Source: Letter dated July* 30th 2014 from Tamara Thomas, Terre-Source LLC responding to an inspection letter of September 11th 2014 from Amy Holler, Grant County Health District - inspection undertaken September 10th 2014 (*July date seems incorrect)

[15] Source: Letter dated July* 30th 2014 from Tamara Thomas, Terre-Source LLC responding to an inspection letter of September 11th 2014 from Amy Holler, Grant County Health District - inspection undertaken September 10th 2014 (*July date seems incorrect)

personal communication to Mastro, USA, March 2016) advised that '*assuming the temperatures within the overs are insufficient to kill the pupae, the adults produced should be able to make their way up. In one study of the related cherry fruit fly, about 85% of adults made it to the surface when the pupae were 12 inches below the surface in tubes filled with sandy loam'*.

Emergence of flies which are ready to eclose from pupae in the outer layer of a pile of waste being composted could be possible..

ROP advised that:

'The "cell", or "wall", in our case refers to the wall created by the reach of the radial stacker as it places new feedstocks against the main pile. It [the cell] *is approximately 150 ft. long, 20-25 ft. wide at the base, and about 18 ft. tall. It is capped with a 1 ft. thick layer of finished compost at the end of the day or completion of the wall'.*

Figure 23 illustrates the construction of a passively-aerated static pile. It can take several weeks to build the pile.[16] The size of the completed pile is not known.

[16] Source: Letter dated July* 30th 2014 from Tamara Thomas, Terre-Source LLC responding to an inspection letter of September 11th 2014 from Amy Holler, Grant County Health District - inspection undertaken September 10th 2014 (*July date seems incorrect)

Figure 23. Construction of a static pile at ROP with conveyor *in situ*
Source: Vic Mastro, USA, autumn 2015

Thus, on arrival at the site and during the construction of the cells over several weeks into one large passively-aerated static pile, in the period before lethal time x temperatures are experienced within the pile, there is a risk that adult flies of *R. pomonella* emerging from pupae in the municipal green waste near the surface could transfer to suitable hosts in the PRA area during the normal period of adult activity (when temperatures are favourable between June and October). With such a large pile and given the type of covering material it is also not known whether this will provide adequate insulation to ensure that the surface layers reach adequate temperatures to be lethal to pupae of *R. pomonella*. The likelihood of successful transfer to suitable hosts in the PRA area is also dependent upon the dispersal distances of the flies, the proximity and availability of the hosts, and the impact of the processes that the waste is subjected to at the facility has on the pest.

<u>Dispersal distances</u>

Adult flies of *R. pomonella* normally travel relatively short distances when host plants are abundant and their fruit are ripening and therefore susceptible to infestation. However, they may travel longer distances where this is not the case. All of the dispersal studies that have been done in the field were conducted in the east of the USA where hosts were abundant. Dispersal distances are discussed in detail based upon available research in 2.10 for Pathway 1 so they are not presented here.

The maximum published flight distance for *R. pomonella* in the field is *ca.* 1 mile with a single laboratory study indicating potential for greater than *ca.* 3 miles. Given the longevity of the adults (up to 40 days) a single fly could cover a large distance during this stage of the life cycle depending upon its behavioural preferences, need to travel and availability of hosts.

<u>Proximity and availability of hosts</u>
Yee (USDA ARS, USA, *personal communication* to Marra and Klaus, WSDA, USA, April 2015) discussed the possibility of categorising the four composting facilities in the PFA (the PRA area) into high and low risk depending upon the proximity of the nearest hosts. He felt that where host prevalence was high then flies will disperse faster and over longer distances.

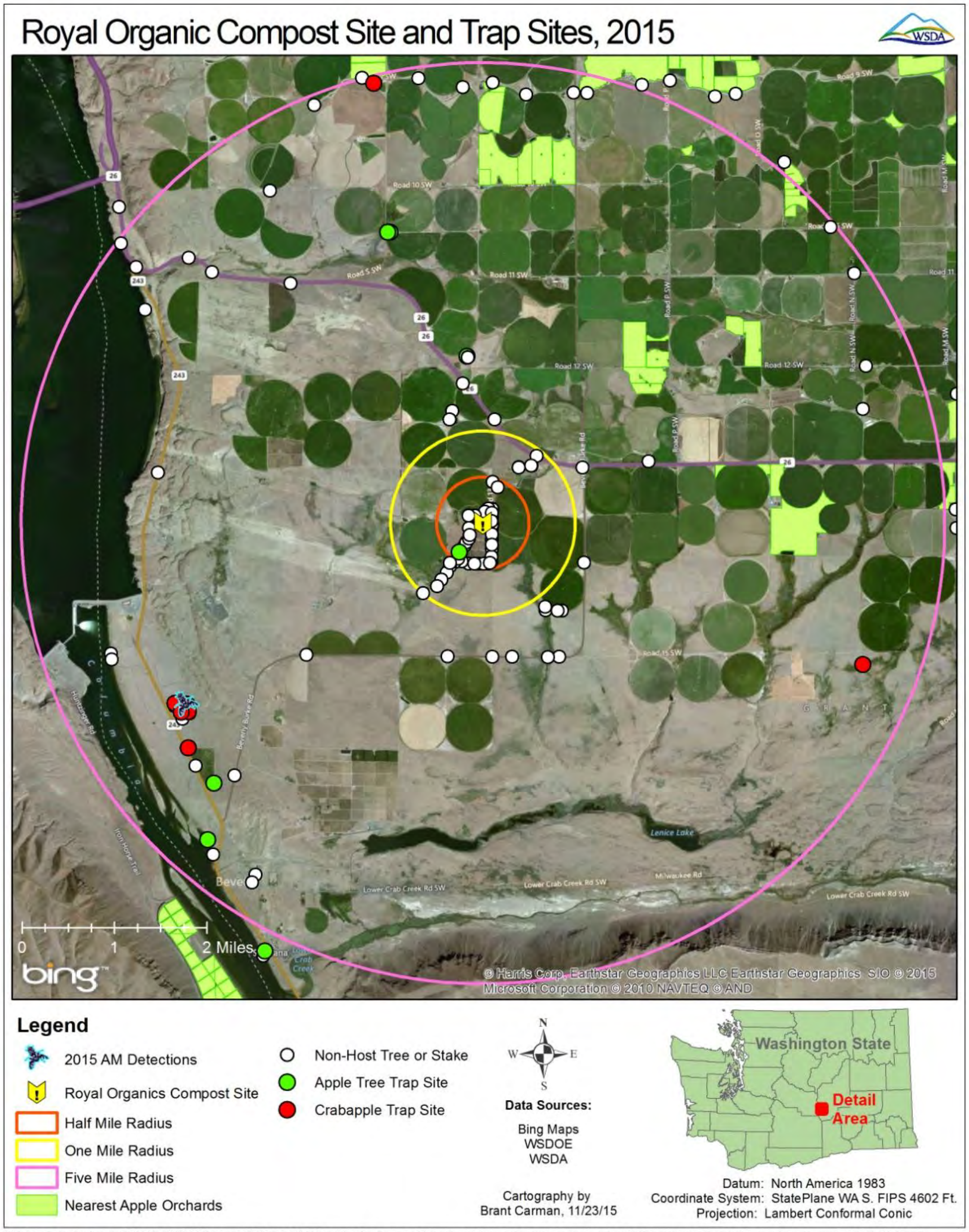
He stated that: '*In* [the] *barren landscape in central/eastern WA: Low risk compost facility: greater than 1 mile from host trees. So if the facility is 3, 10, or 20 miles away from hosts, it would be a low risk*'. And: '*High risk facility would be one <1 mile from host trees*'.

This is assumed to mean that when hosts are abundant, the flies have more opportunity to reproduce since flies will normally travel <u>shorter</u> distances when host abundance is high as their need to reproduce is more easily satisfied. Adult flies can feed on non-host trees or on other surfaces and so in areas of low host prevalence they can still feed, and will travel further to reproduce.

Prevalence of apple orchards
There are a number of apple orchards within a 5 mile radius of the ROP facility (see Figure 24 below). The nearest orchard is estimated to be 2 miles away (Carman, WSDA, USA, *personal communication*, March 2016).

Prevalence of other hosts
Host distribution in the PRA area is discussed under section 1.06. Outside of the orchards in the east of the state host distribution is discontinuous since it is reliant upon the presence of waterways and wet areas, and this part of the state is relatively dry. The WSDA hangs traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in the area when fruit is on the tree. The only maps of host distribution in the vicinity of the composting facilities are those showing which hosts are used for trapping. In 2015 the WSDA aimed to place traps in all of the main hosts within a 5-mile radius of each composting facility. However, this map is not meant to be a complete inventory of host plants within the 5-mile radius largely due to logistical constraints in surveying the area. Figure 24 shows the hosts where traps were placed around the ROP facility indicating the presence of several apples, and crab apples (albeit crab apples were rated as relatively low risk according to Yee *et al*., 2014 and have been shown to vary in their susceptibility to infestation depending upon species and variety by Reissig *et al*., 1990), within 5 miles of the site. Within 0.5 mile the WSDA trapped one apple tree. This is the nearest host and

it is estimated (from the GIS) to be 175ft (0.03 miles) away (Carman, WSDA, USA, *personal communication*, March 2016). Although within the 5 mile radius the prevalence of non-commercial hosts that were trapped is not high they are present. This offers an opportunity for adult flies of *R. pomonella* to transfer to non-commercial hosts and to reproduce, and could lead to spread to the nearest commercial orchards, the closest of which is estimated to be 2 miles away from the ROP facility.



This Data is provided on an 'AS IS,' 'AS AVAILABLE,' and 'WITH ALL FAULTS' Basis. The Content of this map and data are from many sources and are NOT warranted to be complete, accurate, or current. All critical information should be independently verified. WSDA and its officials and employees assume no responsibility or legal liability for the accuracy, completeness, reliability, timeliness, or usefulness of any of the information presented here.

Figure 24. Host trees trapped by the WSDA around the Royal Organic Products facility in 2015 and the nearest commercial apple orchards (source WSDA).

Results of trapping

Trapping undertaken in 2015 shows that one of the traps within a 5 mile radius of the ROP facility was positive for *R. pomonella*. See Figure 25 below.

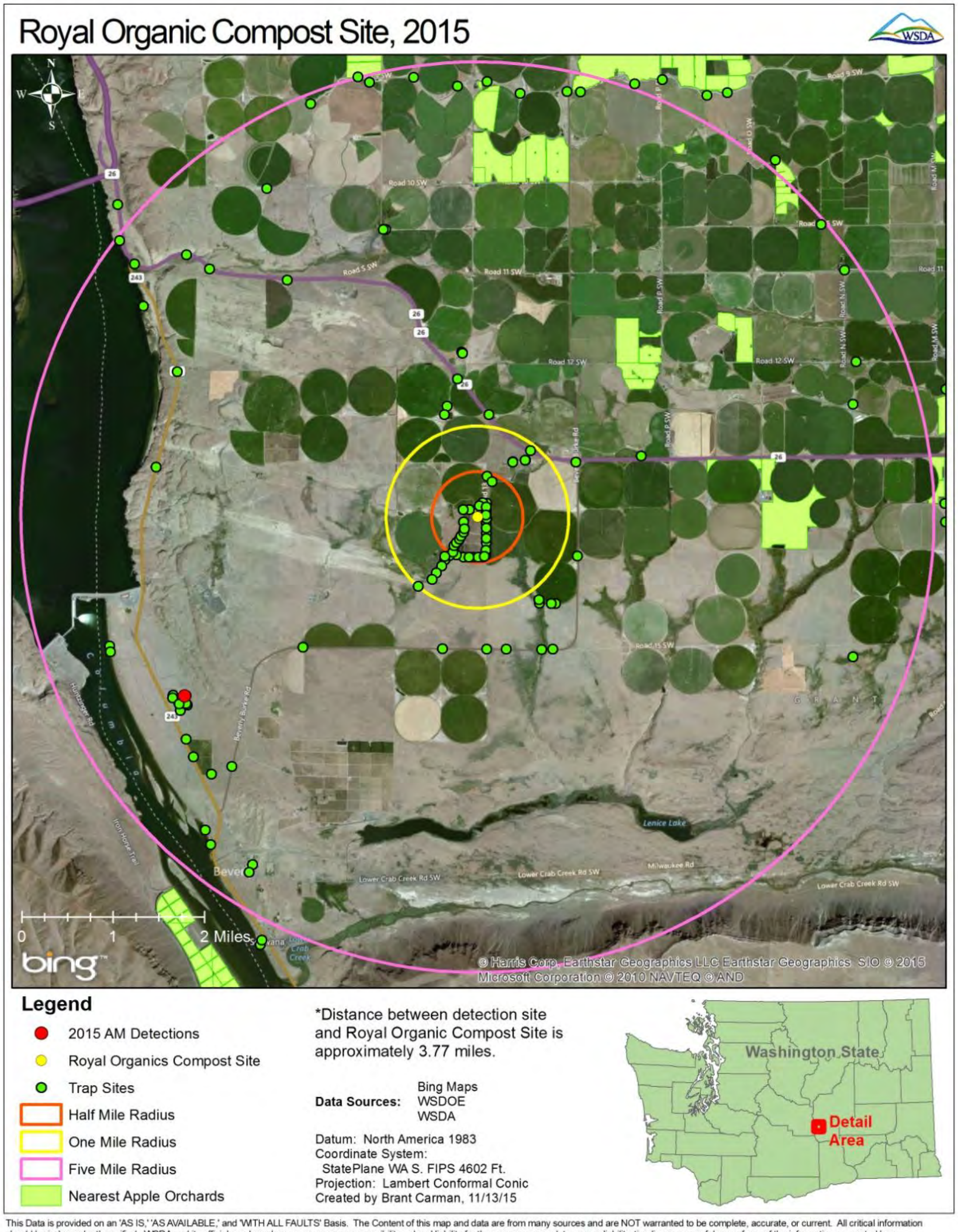


Figure 25. Host trees trapped by the WSDA around the ROP facility in 2015 showing one positive trap site (source WSDA)

<u>Processing of municipal green waste at the transfer stations and at the Royal Organic Products facility</u>

Disregarding unground <u>food</u> waste from Spokane County (which is ground on site at ROP) and pre-ground <u>food</u> waste from Thurston County; as mentioned previously, waste from King County, Pierce County and Multnomah County is pre-ground before transportation to the ROP facility. No details of the grinders used at the transfer stations were obtained.

The pre-ground waste is placed into '*cells*' or *'walls'* for composting at the ROP facility in one main passively-aerated static pile which is covered with overs screened from finished compost to a depth of 1ft (this is the target depth) by the end of the working day on which the waste arrives. Waste is added to the piles as it arrives each day and this covering is then added on top. It can take several weeks to build a pile.[17]

ROP advised that pre-ground material is ground to '*a maximum of 4 inches long and less than 2 inches wide'* (102mm x 51mm); the minimum size was described as '*microscopic'.* They have not observed much variability in the size of the waste other than that arriving from Portland which first arrived with some pieces of wood longer than 6 inches but they changed the screen size to address this.

Eggs of *R. pomonella* measure 0.9mm long and 0.23mm wide.
Late third instars measure 6.5 - 8 mm long x 1.5 - 2 mm wide.
Pupae measure 5mm long x 2.3mm wide; or from two locations in the state of Washington more recent specific values of *ca*. 4.5mm long x 2.1 mm wide and 4.3 x 2.1mm wide have been provided (with males being smaller; some are only 3.8 mm long and 1.7 mm wide).

Because of their small size all life stages have potential to be present in the waste after it is ground prior to arrival at ROP. The pupae are the most resilient and are most likely to survive the grinding process.

Infested hawthorn fruit are small and may survive the grinding process, along with larger pieces of fruit such as apples.

Composting
Composting takes place on a surface of highway grade asphalt on 6 inches of compacted gravel.

The composting process used by ROP was described as a passively-aerated static pile held for '*3 months*+' after which the material is moved to windrows to mature. The aeration is created within the pile by pipes placed vertically within the static pile, covered mostly by overs screened from finished compost but the pipes stick out in a few places, we assume as intake air sources. The pipes are perforated. No description of the aeration process was supplied in the response to the

[17] Source: Letter dated July* 30th 2014 from Tamara Thomas, Terre-Source LLC responding to an inspection letter of September 11th 2014 from Amy Holler, Grant County Health District - inspection undertaken September 10th 2014 (*July date seems incorrect)

PRA team's questionnaire. See Figure 26.

Figure 26. Passively-aerated static pile at ROP showing the aeration pipes emerging from the pile
Source: Jim Reynolds, USA, autumn 2015

In response to a question on what the average time is from starting a pile until it reaches 131°F/55°C, ROP advised that it takes:

'About 5 days to reach temperature throughout the pile at the scale we are working. Portions of the pile may reach 131 earlier, as seen on the previously provided temperature log, but it takes time to get the entire pile up to required PFRP (Process to Further Reduce Pathogens) levels, in part because of the size and also because we add a large amount of moisture at the beginning of the process'.

Process monitoring
ROP advised that:

'We begin taking temperatures on new cells after three days of being formed to give it a chance to come up to heat. Temperatures are taken on a daily basis from then through 30 days as we monitor the heat and able to adjust moisture if needed. The procedure includes using a long probe to measure to 3 feet into the pile. Temperatures are recorded near the barrier zone of the blanket and to 3 feet into the pile, and this is duplicated at high, middle, and low locations across the cell. Temperature logs are recorded and maintained according to our operations plan and WAC 173-350'.

Questions posed to clarify this response elicited this reply (partly presented here):

'The "cell", or "wall", in our case refers to the wall created by the reach of the radial stacker as it places new feedstocks against the main pile. It is approximately 150 ft. long, 20-25 ft. wide at the base, and about 18 ft. tall. It is capped with a 1 ft. thick layer of finished compost at the end of the day or completion of the wall. The "barrier zone" term was used for a lack of a better word. I was referring to the interface between the new feedstocks, where temperatures must rise above 130°F and the finished compost blanket that acts as an insulator as well as a barrier for vectors and odors'. The "operations plan" is just that, our operations plan. According to WAC 173-350-220 all permitted compost facilities must create, publish, and have an operations approved by the jurisdictional health district with guidance from the Department of Ecology'.

'We begin recording when we think it is nearing required temperatures (+130° F). Each specific cell is probed in multiple locations (as indicated in the log) and the clock doesn't start until each location has reached temperature. Once all locations reach the required temperature regulations state that those temperatures must be maintained for a minimum of 3 days to reach PFRP (Process to Further Reduce Pathogens), however we continue monitor and maintain temperatures for 30 days'.

The number/frequency of probes was not apparent from the questionnaire response. However, ROP supplied an operations plan[18] which states:

'*On the piles temperatures will be recorded, at a minimum, at 3 locations on each exposed side of the pile. The probe will be inserted approximately horizontally into the upper 1/3 of the pile face, into the middle 1/3 of the pile face, and into the lower 1/3 of the pile face'.*

As the size of the cells that comprise the pile are large and the probes can only reach 3ft into the pile it must be difficult to get representative measurements across the pile and to all depths. In a sufficiently-aerated pile any cold spots are not expected to occur deeper than 3ft. However, as the pile is not turned the edges are expected not to heat up as much as the inside of the pile. An example temperature record provided by ROP does not indicate the depth at which the

[18] Royal Organic Products WAC 173-350 Solid Waste Handling Standards. 2014 Operations Plan Revision. Last revised 5 September 2014. 89pp.

measurements were taken.

Assessment of the composting process at the Royal Organic Products facility

Because of their small size, all life stages have the potential to be present in some of the ground waste arriving at the ROP facility but the pupae are the most resilient and are most likely to survive the grinding process. Infested small fruit such as hawthorn and larger pieces of fruit such as apples that have survived the grinding process have the potential to be present in the waste. Unground waste from Spokane is ground on site but the material is food waste of unknown origin and has not been assessed.

Ground waste is built into one large passively-aerated static pile (composed of '*cells*') on highway grade asphalt on 6 inches of compacted gravel which remains *in situ* for 3 months. The pile is added to each day when new ground waste arrives at the site (these are new cells). At the end of each working day, the material is covered with screenings from finished compost (overs) (up to) 12 inches thick (the specification is 12 inches). Observations by Mastro and Reynolds in the autumn of 2015 suggest these overs are coarse material. Given the height and steep sides of the pile the uniformness of this covering is unknown.

Each cell takes up to 5 days to reach 55°C. The cell is maintained at this temperature for 30 days during which time the waste is not turned. This is the PFRP stage. Each cell is large (150ft long, 20-25ft wide at the base, and about 18ft tall) and the temperature probes only measure down to 3ft into the ground waste. It is not known how many cells comprise a pile and from the operations plan there appears to be just 3 sampling points across a pile. If heating is not uniform then there may be some ground waste that does not reach this temperature. Material on the surface is presumed to take longer to heat up to 55°C than material within the pile and in fact it is not known whether it actually does achieve this temperature. The covering used by ROP appears to be coarse material which may not always be uniform in depth. This is unlikely to prevent escape of any adult flies because they are small and likely to be able to crawl up to the surface.

During the period it takes for the waste to heat up to lethal time x temperatures for *R. pomonella*, any flies that are ready to eclose could emerge from pupae and may transfer to non-host trees or other surfaces for feeding as well as to any host trees that are within a dispersal distance of up to at least 1 mile of the site. Based upon Figure 24 the host trees are most likely to be apples and crab apples.

Any late 3rd instars could pupate within 2 to 18hrs and if they do not enter diapause they can take 4 to 6 weeks to emerge as adults (Neven, USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015). Yee (USDA, ARS, USA, *personal communication*, April 2016) advised that under laboratory conditions up to 50% of pupae in the state of Washington do not require a chilling period (i.e. if kept at room temperature) to lead to emergence of adults. This may increase the risk of dispersal of flies from non-diapausing pupae at composting facilities. In this instance, it is only if any newly-formed pupae that are on the surface of the static pile reach lethal time x temperatures that the risk of escape is nullified since the waste is never turned.

Neven (USDA, ARS, USA, *personal communication* to Mastro, USA, October 2015) stated that:

'*The apple maggot is a very temperature tolerant insect. The diapausing pupae are the most heat and cold tolerant stages. This stage is still metabolizing at 50°C and the normal metabolizing only begins to breakdown at 55°C. To determine this you were using a fairly aggressive heating protocol of 0.4 degrees/minute'.* She also advised that this life stage is in deep diapause until 5 days before emergence. A 30 minute exposure to 45°C does not kill pupae. At 50°C it takes 20 minutes for thermal death. Yee (USDA, ARS, *personal communication*, March 2016) showed that holding pupae at 100% RH at 45.3°C for 1 day only led to 6.7% mortality whereas holding them at 46.3°C for 3 days resulted in 100% mortality. Exposure to 50.5°C for 3 days or 38°C for 1 day followed by 56-58°C for 3 days at 100%RH led to 100% mortality (Yee and Chapman; *manuscript in preparation*).

Although the minimum time and temperature combination that is needed to kill pupae of *R. pomonella* is thought to be around 50°C for 20 minutes (based upon Neven's unpublished work) it seems that at least <u>within</u> the cell/pile pupae could survive for up to 5 days from the start of the composting process while the material heats up to lethal temperatures, but those on the surface may escape this exposure for longer despite being covered with the coarse overs because of the edge effect which can be experienced down to *ca.* 25cm. Any cold spots or areas within the cell/pile where larger pieces of infested material are located could pose a risk of survival of pupae of *R. pomonella*. The pile is *in situ* for 3 months.

Because the surface upon which the pile is constructed is highway grade asphalt on 6 inches of compacted gravel any late third instars which tumble from the pile will not burrow into the surface but they can still pupate on it. They may crawl into a crack or crevice and pupate there. Any pupae that tumble from the pile during any of the processes have the potential for flies to emerge and disperse since this is not a closed system. If this occurs during the period when temperatures are favourable for adult flight (June to October), the pest could transfer to foliage of host or non-host trees from any spillages that may occur.

Although any of the life stages of *R. pomonella* that are present in the municipal green waste once it is ground and that are exposed to sufficient heat for sufficient time are likely to be killed there seem to be ample opportunities for the adult flies to transfer from the facility to hosts within *ca*. 1 mile, most likely apples, as well as to non-hosts or other surfaces for feeding. It seems less likely that pupae would survive through to the very end of the process unless there were free pupae or infested material that escaped <u>full</u> exposure to lethal temperatures for the requisite amount of time required to kill them. Based on Neven's unpublished laboratory work this could be 50°C for *ca*. 30 minutes. Yee and Chapman (*manuscript in preparation*) sampled later than this and showed 100% mortality after exposure to 50.5°C for 3 days. It is not known whether this time x temperature would occur for all of the pupae in the waste material. This is dependent upon the position of the pupae in the pile and the effect of the covering.

At the end of the composting phase, the static pile is taken apart and formed into windrows for curing. Mixing of the waste will occur at this point and material that had been at the edge of the pile should get incorporated into the interior of the windrows. During the final (unspecified period) curing stage temperatures will be lower than during the composting stage. Cornell advises that: '*After the thermophilic phase, the compost temperature drops and is not restored by turning or*

mixing. At this point, decomposition is taken over by mesophilic microbes through a long process of "curing" or maturation. Although the compost temperature is close to ambient during the curing phase, chemical reactions continue to occur that make the remaining organic matter more stable and suitable for use with plants'.
http://compost.css.cornell.edu/physics.html accessed 17 March 2016.

Ryckeboer (Ensus Consulting BVBA, Belgium, *personal communication*, March 2016 advised that during this phase there is an increase in microbial diversity with the production of lytic enzymes etc. These and other factors during maturation of the compost could have an impact on the viability of *R. pomonella*, especially on pupae that may not have been exposed to lethal temperatures prior to curing. However, this has not been studied and remains an uncertainty.

Intended use of the compost
ROP produce two products, Royal Classic and Soil Supplimint (made from mint hay). Royal Classic is compost made from all other feedstocks that are processed at their facility. In terms of the amount of compost produced from waste from the quarantine area ROP advised that the '*rule of thumb'* was that *'50% of the mass of incoming feedstocks is lost during the composting process'.* On that basis approximately 15,000, 600 and 16,000 tons of compost was produced from yard waste alone from quarantine areas in 2012, 2013 and 2014 respectively.

ROP advised that:

'Agriculture is our primary market with about 70% of product sales. We also provide compost for the erosion control markets, landscaping projects, turf markets, and to home garden/retail. Bulk compost is shipped within about a 150 mile radius. Our pelletized compost has been shipped as far away as Colorado and Utah'.

And that:

'Currently the majority of the compost in the agriculture market is applied to orchards, with nearly all of that in pest-free areas'

The impact of the curing phase on pupae of *R. pomonella* has not been investigated and we have no data to suggest that viable pupae might end-up in the finished compost. This would only occur if procedures are not executed and monitored carefully. An investigation of the effect of curing on pupae of *R. pomonella* would be beneficial.

In this system, the main risk of transfer of *R. pomonella* to a suitable host or habitat arises from the potential risk of transfer during the time that a pile is constructed which can be several weeks, and then at the beginning of the composting process for up to at least 5 days (time taken to reach 55°C) once the pre-ground waste is in the passively-aerated static pile. If there are pupae in soil or in apples or small fruit such as hawthorns or larger pieces of fruit that have escaped the pre-grinding process there is potential for flies to emerge. The mantle of overs screened from finished compost placed on the static pile is coarse and although the depth is intended to be 12 inches there has been some discussion over whether this is consistent across the pile. This means that material on the surface of the pile may remain exposed throughout the 3 month period that the waste is *in situ* before being moved to windrows for curing since the waste is not turned. If infested material present in the pile, especially near the edges, does not reach lethal temperatures for a sufficient period of time then transfer of adult flies during the flight period of adult activity (June to October) when temperatures are favourable is possible. Although not investigated, 12 inches of overs is not likely to prove a barrier to emergence of flies. Whether the insulation provided by the overs is sufficient to increase the heat at the edge of the waste material in the pile is uncertain. The dispersal distances of the adult flies in relation to the proximity of at least some hosts of *R. pomonella* means there is potential for transfer in this way (and adults can transfer to non-host trees or possibly other surfaces for feeding). This facility sells its compost to range of outlets, mainly to orchards but also to (e.g.) landscapers.

Taking account of all these factors it seems *very likely* with *low uncertainty* that the pest could transfer from this pathway to a suitable host or habitat. The risk of transfer to commercial orchards in the same year may be feasible as the nearest commercial orchard in the PFA is estimated to be 2 miles from the facility.

2.11 - The probability of entry for the pathway should be described

Waste from Spokane County and Thurston County has not been included in this assessment of the risk of entry as it is thought to be vegetative food waste from grocery stores and the origin of the waste is not known.

It is considered to be *very likely* with *low* uncertainty that *R. pomonella* could enter the PRA area (the PFA) from municipal green waste originating in the quarantine area to the west of the Cascade mountain range including King County and Pierce County in the state of Washington and Multnomah County in the state of Oregon.

These counties, while not having recent survey data, are considered to have a high level of infestation with *R. pomonella*. The waste from these counties is normally pre-ground and then transferred to the ROP facility for composting in one large passively-aerated static pile composed of cells, which while subject to covering with overs screened from finished compost take up to 5 days to reach 55°C. The covering used is coarse and the depth of the covering may be inconsistent meaning that the pre-ground waste may not be sufficiently covered. The waste is not turned during the 3 months it remains in the pile thus any pupae that have not been subject to lethal temperatures for a sufficient period of time could remain viable. This is especially a risk near the surface of the pile which may not reach lethal temperatures. Transfer of flies that are ready to eclose from such pupae could occur directly at the site to hosts in the PRA area including commercial orchards, the nearest of which is estimated to be 2 miles away from the ROP facility.

The finished compost made from waste from the quarantine areas is sold to a range of businesses including orchards in the PFA and potentially to landscaping projects.

The most likely waste material to pose a risk is infested host fruit, and soil associated with infested hosts at the origin of the material being collected.

The main areas of uncertainty are:

- The amount and type of infested host material in the waste stream at different times of year
- The amount of infested soil in the waste stream at different times of year
- The effect of the covering of overs that is placed on the top of the pile
- The temperatures on the surface of the pile underneath the overs
- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The proportion and size of soil clods which may escape the grinding process
- The impact of grinding on pupae of *R. pomonella* (not previously tested)
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit or soil clods that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The impact of the curing phase on pupae of *R. pomonella*
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- Whether adults of *R. pomonella* will feed on leachates from compost piles

The risk of transfer in the same year as adults emerge from the facility is likely to be to non-commercial hosts within the vicinity of the facility that could maintain populations of the pest, and possibly to the nearest commercial apple orchard(s), the nearest of which is estimated to be 2 miles from the facility, depending upon the favourability of the environment in that year.

2.13b - Describe the overall probability of entry taking into account the risk presented by different pathways and estimate the overall likelihood of entry into the PRA area for this pest (comment on the key issues that lead to this conclusion).

*Pathway 1: **Municipal green waste moving to Barr-Tech LLC, Lincoln County***

Barr-Tech LLC receives unground municipal green waste all year round, mainly from Spokane County in the east side of the state of Washington which is in the quarantine area; an area of infestation that is considered to be lower than the west side of the state (moderate infestation levels relative to other counties of origin). The waste is yard debris and mixed food/yard debris. It is likely to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream. Figure 27 illustrates the likelihood of association, transportation, arrival and transfer of *R. pomonella* on this pathway into the PRA area from the responses to questions 2.03 to 2.10 for this pathway. The level of uncertainty was *low* for all responses.

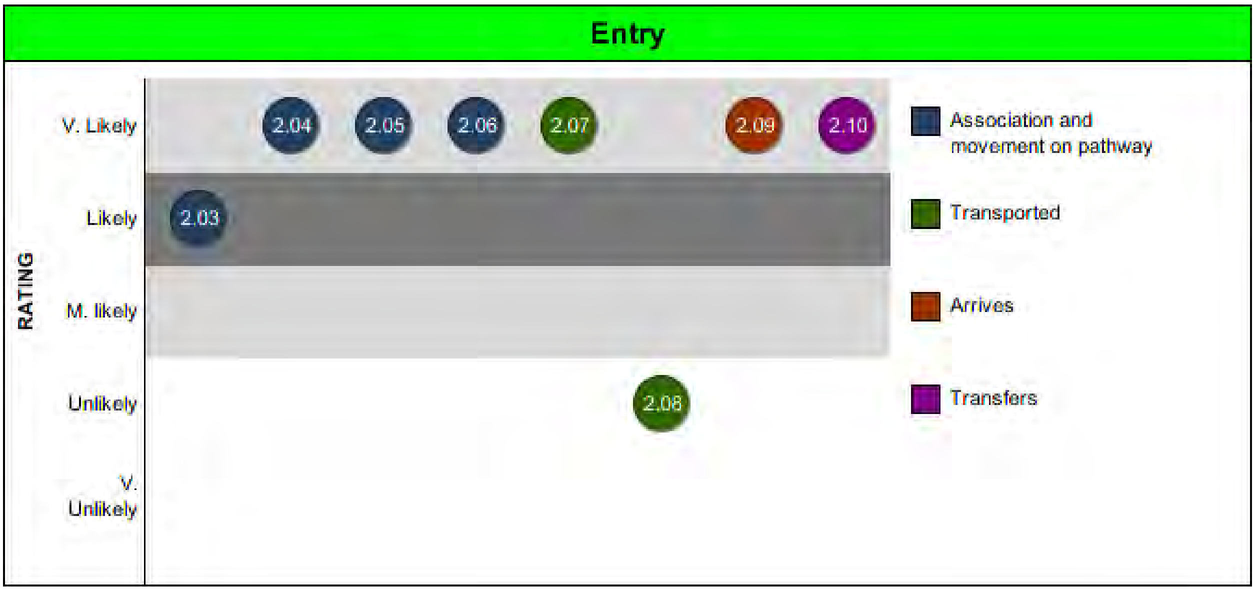


Figure 27. Illustration of the responses to questions 2.03 to 2.10 for Pathway 1 – BarrTech LLC

If adults of *R. pomonella* emerge from the facility the risk of transfer in the same year is likely to be to non-commercial hosts within the vicinity of the facility that could maintain populations of the pest, rather than to commercial apple orchards which are some distance away.

Urban landscaping is one market to which this facility sells its product.

The overall probability of entry of *R. pomonella* to the PRA area (the PFA of the state of Washington) on this pathway is considered to be *likely* with *low uncertainty*.

Overall risk of entry of *R. pomonella* on municipal green waste moving from the quarantine area for *R. pomonella* to the PFA of the state of Washington.

*Pathway 2: **Municipal green waste moving to Natural Selection Farms, Yakima County***

Natural Selection Farms receives pre-ground municipal green waste all year round, mainly from the quarantine area of Yakima County in central Washington, an area of infestation that is considered to be lower than the west side of the state (low infestation levels relative to other counties of origin). The waste is yard debris. It has potential to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream. Figure 28 illustrates the likelihood of association, transportation, arrival and transfer of *R. pomonella* on this pathway into the PRA area from the responses to questions 2.03 to 2.10 for this pathway. The level of uncertainty was *low* for all responses

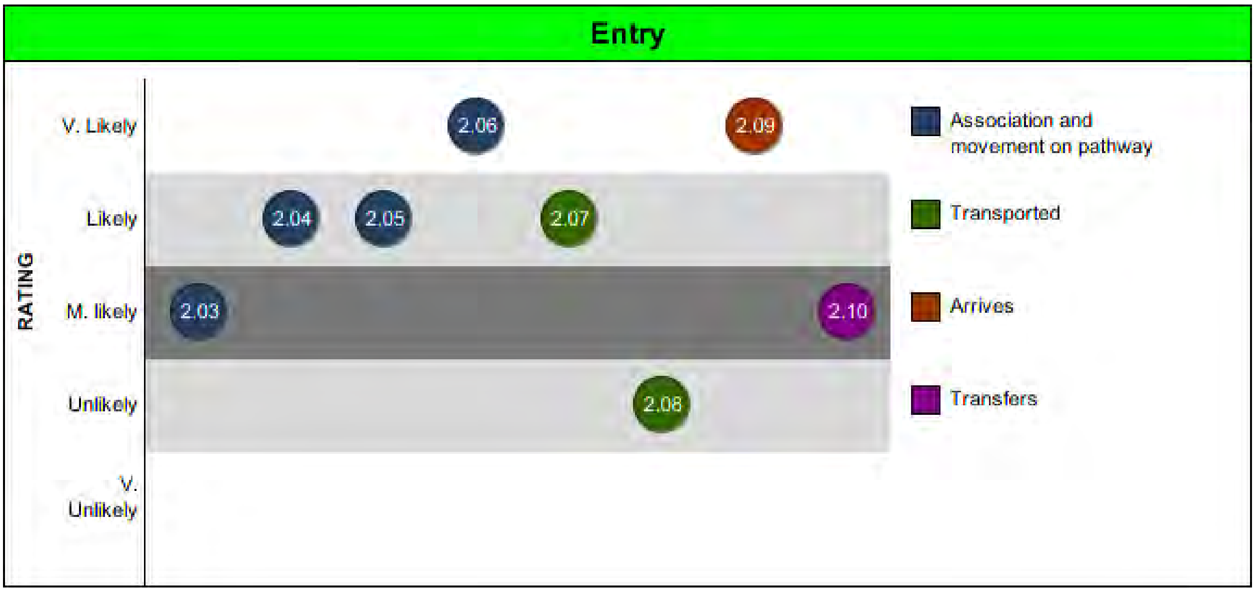


Figure 28. Illustration of the responses to questions 2.03 to 2.10 for Pathway 2 - NSF

If adults of *R. pomonella* emerge from the facility there is a risk of transfer in the same year to commercial orchards as the nearest in the PFA (the PRA area) is estimated to be 3 miles away from the NSF facility and there are some non-commercial hosts in between.

One of the markets to which this facility sells its product is to tree fruit growers.

The overall probability of entry of *R. pomonella* to the PRA area (the PFA of the state of Washington) on this pathway is considered to be *moderately likely* with *low uncertainty.*

*Pathway 3: **Municipal green waste moving to Pacificlean Environmental, Grant County***

Pacificlean Environmental only started operating in 2015. It received pre-ground and unground waste in that year but the plan is only to receive unground waste in the future. All of the waste is yard waste mixed with food waste and all of it originates in/around the city of Seattle, King County in western Washington; an area where the level of infestation with *R. pomonella* is considered to be high. The waste has potential to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream. Figure 29 illustrates the likelihood of association, transportation, arrival and transfer of *R. pomonella* on this pathway into the PRA area from the responses to questions 2.03 to 2.10 for this pathway. The level of uncertainty was *low* for all responses.

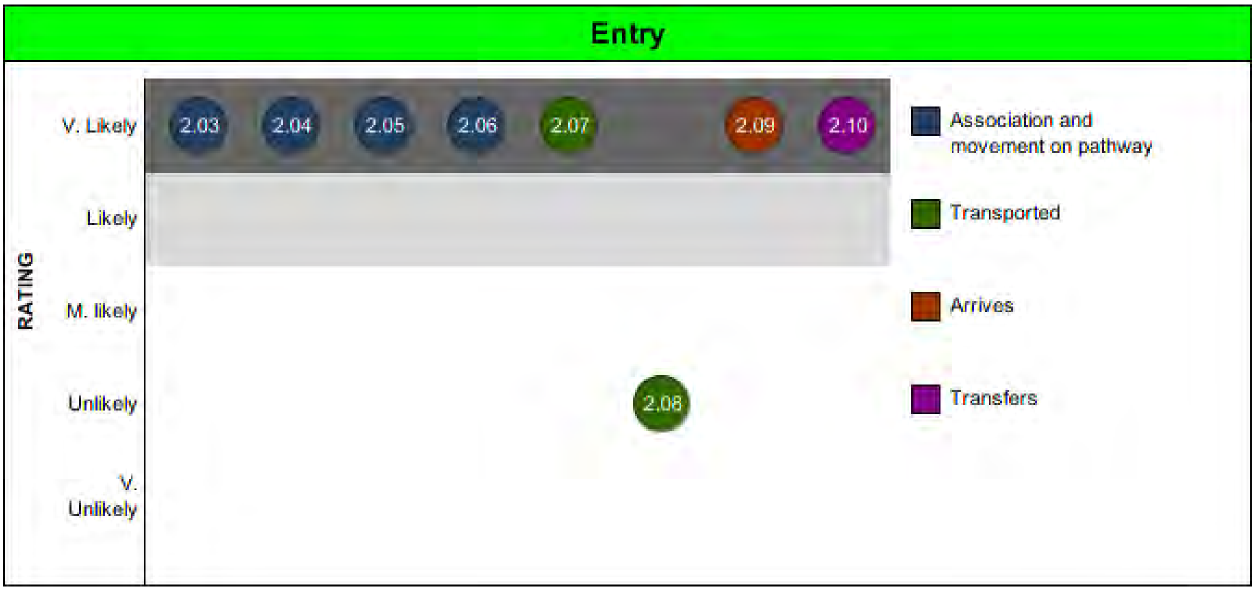


Figure 29. Illustration of the responses to questions 2.03 to 2.10 for Pathway 3 – Pacificlean Environmental

If adults of *R. pomonella* emerge from the facility there is a risk of transfer in the same year to commercial orchards as the nearest in the PRA area (the PFA of the state of Washington) is estimated to be 50ft. (0.009 miles) away from the facility and there are some non-commercial hosts in between.

In 2015 this facility sold its entire product to farms within 100 miles of the facility some of whom grow apples.

The overall probability of entry of *R. pomonella* to the PRA area (the PFA of the state of Washington) on this pathway is considered to be *very likely* with *low uncertainty*

Pathway 4: ***Municipal green waste moving to Royal Organic Products, Grant County***

Royal Organic Products has received a variety of municipal green waste all year round from both the west side of the state of Washington and from Spokane County in the east of the state. The last load of yard waste from Spokane County was in 2012 and since that time only unground food waste from grocery stores of unknown origin has been received from that area. Pre-ground food waste from commercial premises in Thurston County in the west of the state of Washington has also been received. The commercial food waste cannot be assessed since its origins are unknown. Pre-ground yard debris and pre-ground mixed food and yard debris are the main categories of waste received from the west of the state of Washington (King County and Pierce County) but this has also come from Multnomah County in Oregon. These three counties are considered to have a high level of infestation with *R. pomonella*. The waste has potential to contain whole apples and may contain fruit from other hosts. It may also contain soil associated with any of the hosts that are collected in the waste stream. Figure 30 illustrates the likelihood of association, transportation, arrival and transfer of *R. pomonella* on this pathway into the PRA area from the responses to questions 2.03 to 2.10 for this pathway. The level of uncertainty was *low* for all responses.

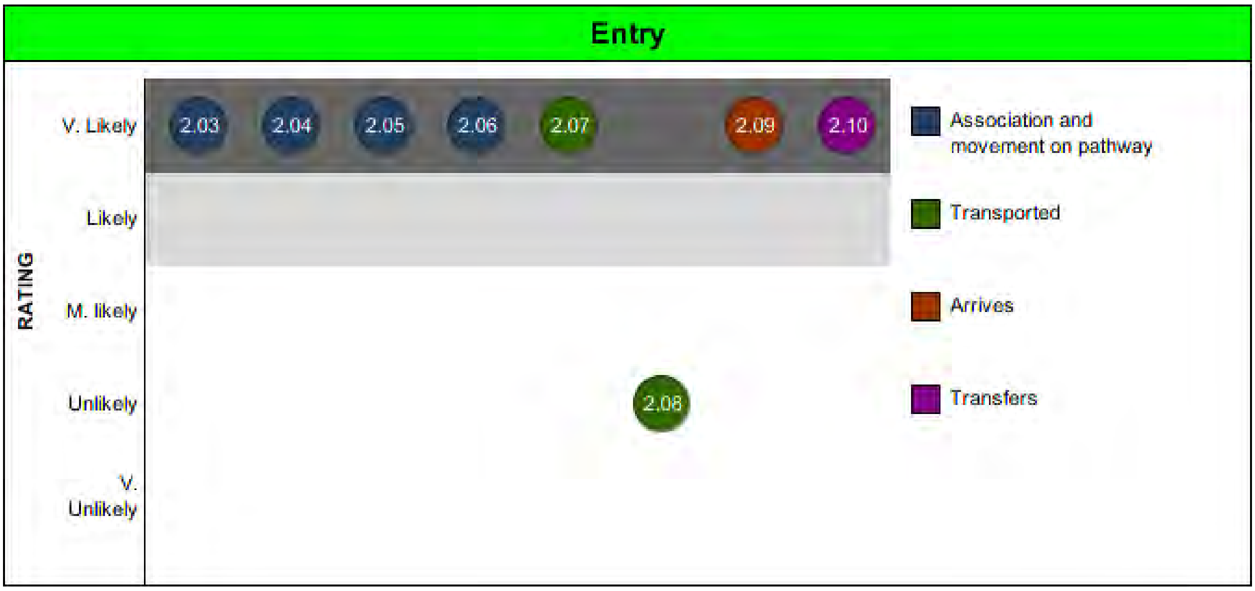


Figure 30. Illustration of the responses to questions 2.03 to 2.10 for Pathway 4 - ROP

If adults of *R. pomonella* emerge from the facility there is a risk of transfer in the same year to commercial orchards as the nearest in the PFA (the PRA area) is estimated to be 2 miles away from the ROP facility and there are some non-commercial hosts in between.

This facility has a range of outlets for its compost including orchards and landscapers.

The overall probability of entry of *R. pomonella* to the PRA area (the PFA of the state of Washington) on this pathway is considered to be *very likely* with *low uncertainty*.

Overall risk of entry of *R. pomonella* on municipal green waste moving from the quarantine area for *R. pomonella* to the PFA of the state of Washington.

For all four pathways, the period of time from the point that waste arrives on site to the time that the waste is put into the windrows or static piles for composting and reaches temperatures lethal to the pest poses the primary risk of transfer of *R. pomonella* to the PRA area (the PFA of the state of Washington). It is during this period that any pupae that contain flies that are ready to eclose could lead to the escape of flies from each facility. The duration of this period varies with each of the facilities. Although there is some uncertainty as to whether all of the waste is exposed to lethal temperatures, where waste is turned during the thermophilic phase this helps reduce the risk of transfer as it aids with heat-exposure of waste that was on the surface.

No discussion has taken place about the risks of transporting municipal green waste that may contain a quarantine pest but in the event of an accident en route to the facilities, there is potential for spillage of material. If this is swept to the side of the road and it contains late instar larvae or pupae there is a risk of transfer of *R. pomonella* to the PRA area.

Although the level of uncertainty associated with the responses to each of the questions was low there are a number of areas of uncertainty that are common to all four pathways. These are:

- The amount and type of infested host material in the waste stream at different time of year
- The amount of infested soil in the waste stream at different times of year
- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The proportion and size of soil clods which may escape the grinding process
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit or soil clods that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The impact of the curing phase on pupae of *R. pomonella*
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- Whether adults of *R. pomonella* will feed on leachates from compost piles

For Pathway 4 there are two additional areas of uncertainty:

- The effect of the overs/finished compost that is placed on the top of the pile
- The temperatures on the surface of the pile underneath the overs

The level of infestation in the western side of the state of Washington (Pathways 3 and 4) has not been assessed for many years but this is the area where *R. pomonella* was first introduced and it is recognised as an area of high infestation.

The overall probability of entry of *R. pomonella* to the PRA area on municipal green waste originating in the quarantine area of the state of Washington (and Oregon) is considered to be *likely* with *low uncertainty*.

Probability of establishment

In a first step, assessors should select the ecological factors that influence the potential for establishment.

Seven factors may influence the limits to the area of potential establishment and the suitability for establishment within this area:

- *1 - Host plants and suitable habitats*
- *2 - Alternate hosts and other essential species*
- *3 - Climatic suitability*
- *4 - Other abiotic factors*
- *5 - Competition and natural enemies*
- *6 - The managed environment*
- *7 - Protected cultivation*

No.	Factor	Is the factor likely to have an influence on the limits to the area of potential establishment?	Is the factor likely to have an influence on the suitability of the area of potential establishment?	Justification for 'no' answers
1	Host plants and suitable habitats (see note for Q3.01)	Yes (see 3.01)	Yes (see 3.09)	
2	Alternate hosts and other essential species	No (see 3.02)	No (see 3.10)	*R. pomonella* does not require alternate hosts to complete its lifecycle
3	Climatic suitability	Yes (see 3.03)	Yes (see 3.11)	
4	Other abiotic factors	No (see 3.04)	No (see 3.12)	Although not thought to be limiting to the establishment of *R. pomonella*, soil type can influence timing of emergence of adult flies from pupae in the soil and the types of predators that are present which could cause a decline in pupal numbers. Soil type is thought to influence the depth at which larvae can burrow but results vary. Dry surface crusts may prevent fly emergence.
5	Competition and natural enemies	No (see 3.05)	No (see 3.13)	*R. pomonella* has competitors and natural enemies but these are not likely to limit establishment in the PRA area.
6	The managed environment	Yes (see 3.06)	Yes (see 3.14 / 3.15)	
7	Protected cultivation	No (see 3.07)	No (see 3.16)	*R. pomonella* is not a pest of protected cultivation (grown under glass or polythene). It is a pest of outdoor plants (including trees) located in orchards, nurseries, backyards, landscaped areas and in the wider environment.

Questions 3.01 to 3.09 delimit the area (within the PRA area) where there is potential for establishment.

Questions 3.10 to 3.16 determine the suitability of the delimited area for establishment.

Delimitation of the area within the PRA area where there is potential for establishment

Host plants and suitable habitats

3.01 - Identify and describe the area where the host plants or suitable habitats are present in the PRA area outside protected cultivation.

The PRA area is the PFA of the state of Washington (see Figure 1a). Within this area, host plants or suitable habitats (outside of protected cultivation) are: in commercial apple orchards, at commercial nurseries producing planting material of apples and other hosts including ornamentals if they bear fruit, in backyards especially where irrigation is applied. In addition, natural habitats in the wider environment including those where hosts occur in riparian areas (along creeks and ditches etc.); also in low lying areas where there is agricultural run-off. (Yee, USDA, ARS, *personal communication*, April 2016).

Alternate hosts and other essential species

3.02 - Does all the area identified in 3.01 have alternate hosts or other essential species if these are required to complete the pest's life cycle?

R. pomonella does not require alternate hosts or other essential species to be able to complete its lifecycle. It has a relatively wide range of hosts for a *Rhagoletis* fly, all within family Rosaceae, albeit apples (*Malus* spp.) and hawthorns (*Crataegus* spp.) are its preferred or major hosts. See 3.09.

Climatic suitability

3.03 - Does all the area identified as being suitable for establishment in previous question(s) have a suitable climate for establishment?

Based on the area assessed as being suitable for establishment in previous questions, identify and describe the area where the climate is similar to that in the pest's current area of distribution. Describe how this affects the area identified where hosts, suitable habitats and other essential species are present.

No. Not all of the area identified as being suitable for establishment has a climate which is completely suitable for establishment. From previous questions, the area identified as being suitable is the part of the PFA of the state of Washington where hosts are present (see 3.09).

Generally-speaking, in the PRA area (the PFA of the state of Washington), summers are warmer, winters are colder and precipitation is less than in western Washington (Anon., *undated*) where the pest is established. Within the area, locations at lower elevations are hotter and drier than those at higher elevations; one example of a cooler wetter area is Spokane, a county to the east of the PRA area which is a quarantine area where *R. pomonella* is established (Anon., 2015).

The main production areas for apples in the eastern side (PFA) of the state are located in what is described as a *'moderate marine-influenced, desert climate'*, where little rainfall occurs over the winter. The growing season is dry and sunny and the apple trees require irrigation. This averages

3.5 *'acre feet'* (see footnote[19]) of water per season, most of which is applied mid-summer when melting snow on the mountains supplies water to the streams in the area. (Smith, 2001). Thus, although the climate in the eastern side of the state is considered to be desert-like, irrigation allows commercial apple orchards to thrive in the area.

Irrigation in the PRA area outside of orchards also allows host feral/backyard apples, crab apples (*Malus* spp.); and ornamental hawthorns (*C. monogyna* and *C. laevigata*) to grow; native black hawthorn (principally *C. douglasii*) can be found in wild riparian and wet areas (Yee and Klaus, 2015).

Yee *et al*. (2012) discussed the low abundance of *R. pomonella* in central Washington and investigated the abundance of larvae in native hawthorns (*C. douglasii* and *C. suksdorfii*) in 2008 and 2010; finding it to be low relative to one site in the quarantine area in western Washington. The exception was in a remote forested area, away from commercial orchards, where moisture levels were presumably higher. They reviewed the WSDA survey data over a 30-yr period (1981-2010) and found that less than 5% of WSDA's traps were positive for *R. pomonella* in Kittitas and Yakima counties, parts of which are in the PRA area. They hypothesised that this may be related to the hot dry summer climate in this part of the state and felt that the pest was unlikely to develop high populations rapidly near to commercial apple orchards in central Washington.

A review of the results of the WSDA surveys for *R. pomonella* between 2005 and 2013 across 12 counties, 9 of which are in the current PFA (3 only partially) and 3 in the quarantine area of the state, showed that where temperatures were moderate and precipitation high, these conditions favoured abundance of flies. There was a strong positive correlation between the number of detections of flies of *R. pomonella* and mean annual precipitation. The correlation between mean maximum monthly temperature and numbers of detections was lower and negative, and, there was no correlation between mean minimum monthly temperature and fly abundance in traps. (Yee and Klaus, 2015).

Overall, the climate in the part of the PRA area where *R. pomonella* might establish (because of the availability of hosts) is not totally favourable for the pest, albeit it has been trapped in low numbers by the WSDA in host trees outside of commercial orchards on a yearly basis in a number of counties. Yee and Klaus (2015) commented that high temperatures, low precipitation and *'other factors'* (rather than host plant availability) may explain the low abundance of the pest in the central and eastern parts of the state. Referring to earlier work they commented that '*even where black hawthorn trees are abundant in riparian zones at low altitudes in central Washington, larval infestations in its fruit are low (Yee 2008, Yee* et al*,. 2012, Hood* et al*., 2013), perhaps because intense summer heat causes fruit to desiccate too quickly before flies oviposit or larvae can develop. At higher altitudes in central Washington where temperatures are cooler,* R. pomonella *abundance in black hawthorn fruit is greater (Yee 2008)*'. Additional influencing factors which they referred to relate to host fruit availability on hawthorns and chemistry of host fruit. These factors are not discussed further here.

Nonetheless, according to CABI (2015), *R. pomonella* can tolerate a broad range of air temperatures and rainfall, and prefers or can tolerate a range of climate classifications. See Tables 13 and 14 below. No indication of the source of this information was given.

[19] An acre foot is the volume of one acre of surface area to a depth of one foot

Table 13. Temperature and rainfall tolerances for *R. pomonella* (CABI, 2015).

Parameter	Lower limit	Upper limit
Absolute minimum temperature (°C)	-40	0
Mean annual temperature (°C)	0	21
Mean maximum temperature of hottest month (°C)	21	37
Mean minimum temperature of coldest month (°C)	-20	15
Mean annual rainfall	380	3000

Table 14. Preferred and tolerated climates for *R. pomonella* (CABI, 2015).

Climate*	Status	Description
C - Temperate/Mesothermal climate	Preferred	Average temp. of coldest month > 0°C and < 18°C, mean warmest month > 10°C
Cf - Warm temperate climate, wet all year	Preferred	Warm average temp. > 10°C, Cold average temp. > 0°C, wet all year
Cs - Warm temperate climate with dry summer	Tolerated	Warm average temp. > 10°C, Cold average temp. > 0°C, dry summers
Cw - Warm temperate climate with dry winter	Preferred	Warm temperate climate with dry winter (Warm average temp. > 10°C, Cold average temp. > 0°C, dry winters)
D - Continental/Microthermal climate	Preferred	Continental/Microthermal climate (Average temp. of coldest month < 0°C, mean warmest month > 10°C)
Df - Continental climate, wet all year	Preferred	Continental climate, wet all year (Warm average temp. > 10°C, coldest month < 0°C, wet all year)
Ds - Continental climate with dry summer	Tolerated	Continental climate with dry summer (Warm average temp. > 10°C, coldest month < 0°C, dry summers)
Dw - Continental climate with dry winter	Preferred	Continental climate with dry winter (Warm average temp. > 10°C, coldest month < 0°C, dry winters)

*The source of the climate classifications was not described

Geng *et al*. (2011) gave more detailed parameters which they used for predicting the potential distribution of *R. pomonella* in China using CLIMEX 3.0 based upon the present distribution in North America. These values (Table 1 of their paper) have not been repeated here as the list is too long and requires detailed explanation. However their Figure 1 (reproduced here as Figure 31) gives some indication of the current distribution of the pest with and without irrigation. This factor was included because *R. pomonella* occurs in otherwise dry areas of North America aided by irrigation.

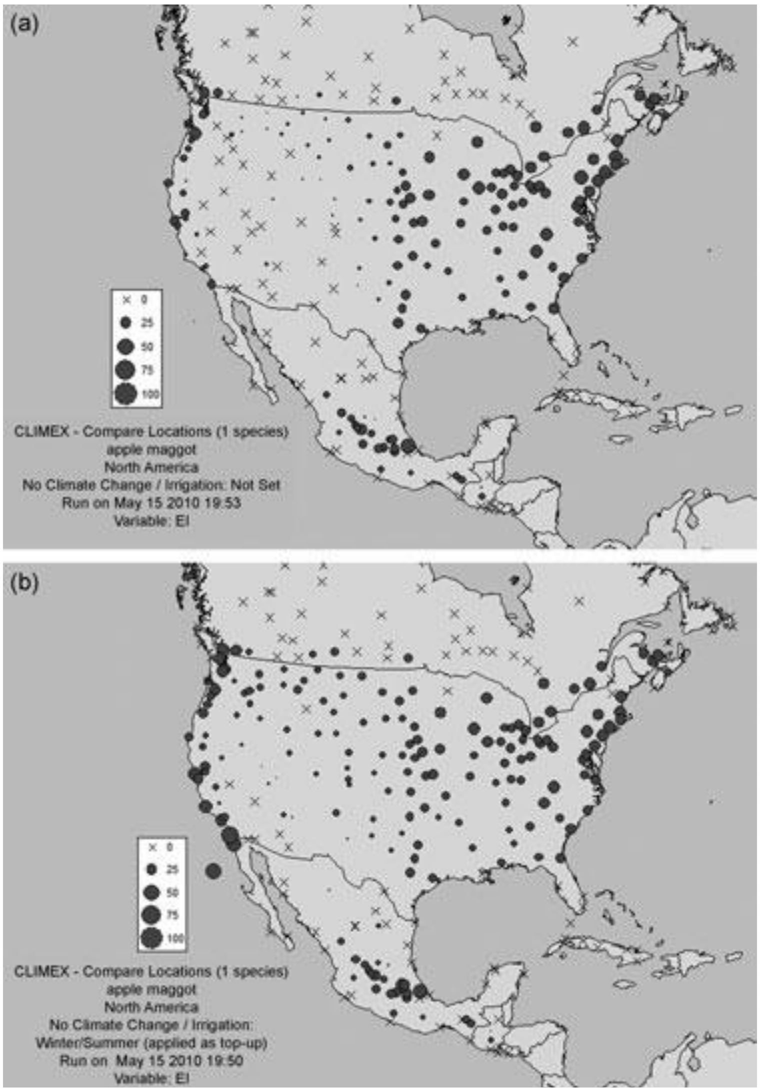


Figure 31. The predicted geographical distribution of *R. pomonella* in North America. (a) Predicted distribution estimated by CLIMEX based on parameters shown in Table 1 of Geng *et al*. (2011). (b) Predicted distribution estimated by CLIMEX with 2.5 mm of irrigation per day included. Reproduced from Geng *et al*. (2011)

Geng *et al*. (2011) suggested that there were some discrepancies between the predicted and known distribution of *R. pomonella* in North America. This is not surprising as they explained their use of CLIMEX for North America did not account for factors other than climate (e.g. host plant distribution). However, the predicted distribution considering the effects of irrigation was closer to the observed distribution of *R. pomonella* in the USA than when it was excluded.

Geng *et al*. (2011) suggested that the environmental conditions affecting the pupae are the most important factor for predicting the potential geographical distribution of *R. pomonella*. Pest prevalence is lower in summers which are hot and dry rather than cool and wet. This is thought to be because the emerging adults cannot tunnel out through soils with a hard surface crust resulting from dry conditions (Neilson 1964a in Geng *et al*., 2011). By contrast, the eggs and larvae are normally protected from environmental fluctuations because they are laid in and develop in host fruit so the effect of moisture is thought to be less important. However, note that Yee and Klaus (2015) consider that some fruit may desiccate in hot dry summers and this may affect the potential for oviposition or larval development. Yee (USDA, ARS, USA, *personal communication*, April 2016) suggested this may be one of several reasons why black hawthorn (*C. douglasii*) is a '*marginal host*' for *R. pomonella* in central Washington State.

Recent work on ecoclimatic mapping has been undertaken for *R. pomonella* by Kumar *et al.* (2016). Their work suggests that the top predictors for predicting climatic suitability for *R. pomonella* within the state of Washington with their relative percentage contribution are:

- Degree days at 6.7°C (degdays6.7) 65.1%
- Elevation (m) 14.8%
- Temperature seasonality (bio4) 8.2%
- Apple climatic suitability (ApplSuit) 5.2%
- Annual precipitation (bio12; mm) 5.2%
- Mean diurnal range in temp. (bio2; °C) 0.9%
- Latitude (absolute) 0.5%

Figure 32 overlays finds of the pest from WSDA survey data for 2003 to 2014 onto the predicted potential distribution for the pest. It appears to show that there may be parts of the PRA area that are favourable for establishment of the pest (host prevalence permitting).

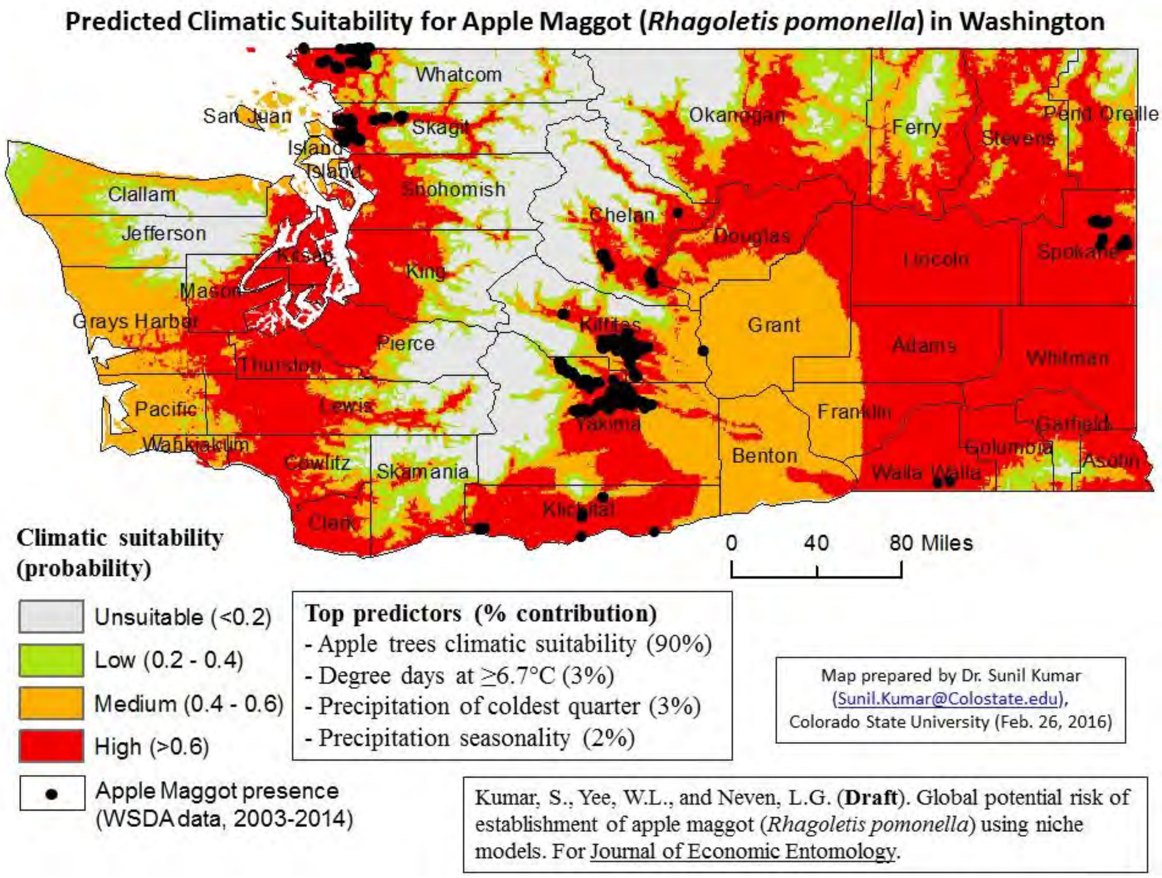


Figure 32. Probability of *R. pomonella* presence in the state of Washington and WSDA survey finds (2003 to 2014)[20] (Kumar *et al*., 2016).

[20] Figure title as presented by Kumar (Colorado State University, USA, *personal communication*, February 26th 2016).

Figure 33 shows the same map, including the sites of the four compost facilities but without the WSDA survey data.

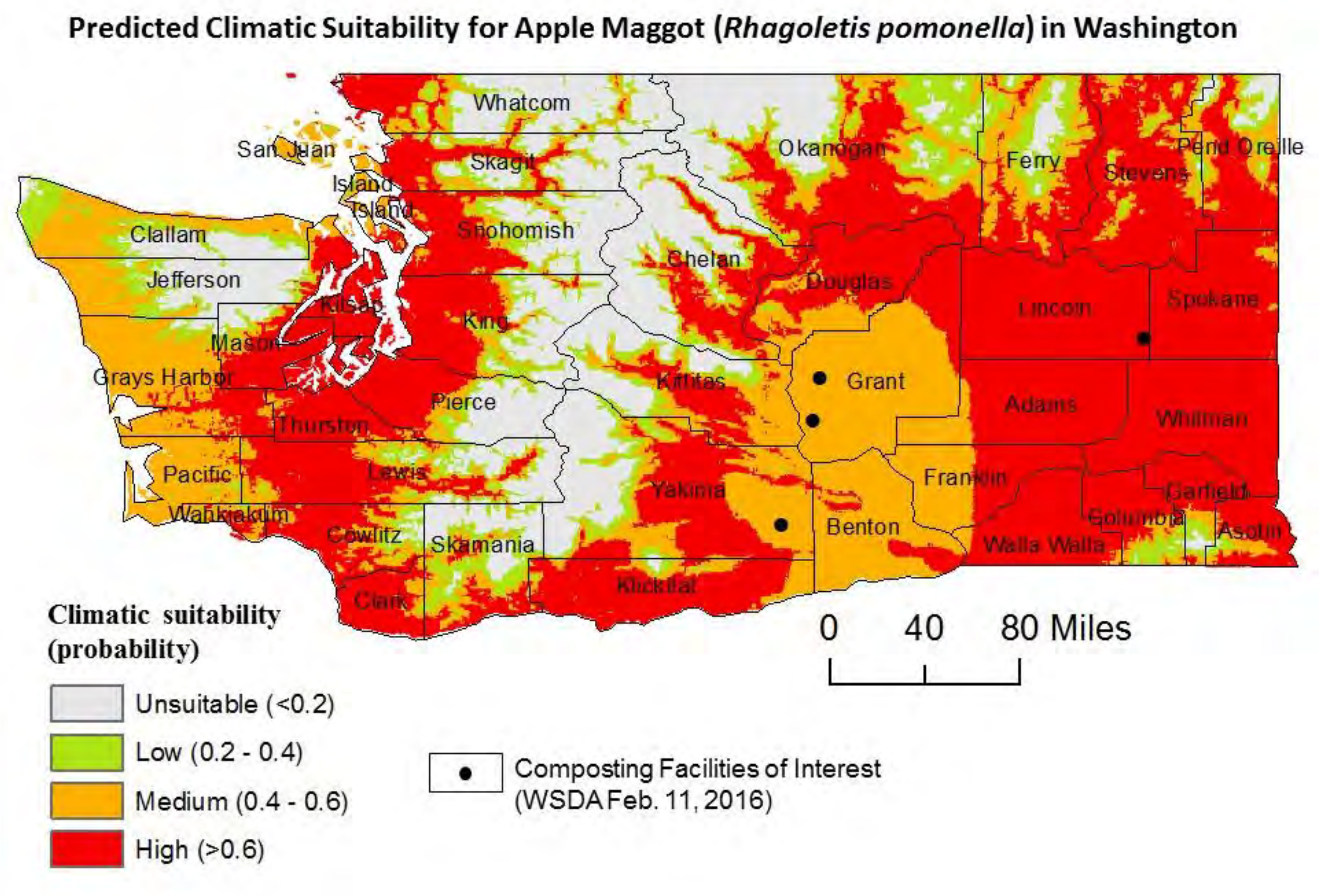


Figure 33. Relative climatic suitability in the state of Washington for establishment of *R. pomonella* (Kumar, Colorado State University, USA, February 26th 2016).

Counties or parts of counties that are in the PFA are: Adams, Asotin, Benton, Chelan (part), Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas (part), Lincoln, Okanogan, Pend Oreille, Stevens, Walla Walla, Whitman, and Yakima (part). See Figure 1a.

Based on Figure 33, many of these counties seems to have a high probability of the climate being suitable for establishment of *R. pomonella* with 3 of the 4 composting facilities located in areas of counties which have a medium probability of being climatically favourable and one (Barr-Tech LLC) located in an area with a high probability of being climatically favourable.

There are four main apple-growing areas in the counties of Okanogan, Chelan (Lake Chelan and Wenatchee Valley), and Yakima (Yakima Valley) as well as the Columbia Basin to the east of the PFA. See Figure 2, Figure 39 and the Washington Apple Commission's (WAC) website: http://bestapples.com/washington-orchards/regions/

Based upon Figure 33, these areas appear to have a medium to high probability of being climatically favourable for establishment of *R. pomonella*.

The descriptions of the apple-growing regions in the state of Washington from the WAC website (accessed 18 February 2016) are quoted below, primarily to illustrate the prevailing growing conditions:

Okanogan
From the terraced riverside orchards of the scenic Okanogan comes much of Washington's late-season fruit. Located to the north, it consists of the narrow Methow Valley, its lush orchards hugging the Methow River, and the wider, steep-walled Okanogan Valley. The region's shorter growing days and cool temperatures produce excellent apples of all varieties.

Lake Chelan
Orchards lining the shores of Lake Chelan are steeped in a unique, temperate microclimate. This deep lake cools the hot summer days and warms the air temperature in winter.

Columbia Basin
Between the Columbia and Snake Rivers lies the broad Columbia Basin. Its rich volcanic soil, fed by the cool waters of the Columbia, nurtures vast acres of apples. Blessed by a long growing season, the basin is noted for producing larger apples and later-maturing varieties.

Yakima Valley
Surrounded by gently rolling mountains, the wide Yakima Valley employs irrigation to create an oasis for apple cultivation. Stretching from the Naches to the Tri-Cities, it is the largest apple producing region in Washington. Noted for its earlier, as well as longer, growing season, the Yakima region produces high quality apples of every variety.

For all hosts, the presence of waterways, irrigation, and in cooler summer temperatures which may occur in some of the orchard locations for example, will favour establishment of *R. pomonella*.

Overall there are ecoclimatic conditions favourable to *R. pomonella* in the parts of the PRA area where the pest might establish (i.e. where hosts are present) but climatic conditions in the summer may limit population growth.

Other abiotic factors

3.04 - Does all the area identified as being suitable for establishment in previous questions have other suitable abiotic factors for establishment?

Yes.

The main abiotic factor that might be thought to influence the biology of *R. pomonella* in the area where hosts and climate(s) suitable for establishment occur is soil type, since the larvae burrow into the soil for pupation. Soil type may influence the timing of emergence of adult flies from pupae in the soil as stated at: http://www.pestid.msu.edu/insects-and-arthropods/apple-maggot/ (accessed 15 February 2016):

*'Emergence patterns vary considerably among different geographic locations and even within a specific area, depending on the host and environmental parameters, particularly temperature, **soil type**, and rainfall'*.

Dean and Chapman (1973) noted that sandy soils should be the most easily penetrated by *R.*

pomonella but that the deepest that pupae were found in a sandy soil was 5 inches (12.7cm) and the deepest in a heavy clay soil was 12 inches (30.5cm). They noted that almost all pupae are found within 2 inches (5cm) of the surface and some will pupate within a sod or duff layer. In one study a contributing factor to mortality of pupae was a hard soil crust that prevented emergence of flies or entry of the larvae into the soil to pupate. This was also noted by Geng *et al*., 2011 citing Neilson *et al*., 1964. However, there is no indication that soil type favours or is detrimental to pupation.

Soil type may also influence the species of predators that are present which can consume pupae of insects such as fruit flies. Hodgson *et al*. (1998) showed that pupae of fruit flies in the genus *Anastrepha* disappeared from soil with dry loose soil at a higher rate than pupae in damp clay soils with fine particle sizes and small interparticle spaces. This may be related to differences in the species of predators in the different soil types. However, although predators of *R. pomonella* are likely to be present in the soils in the PRA area, this is unlikely to influence the suitability of soils within the part of the PRA area where hosts of *R. pomonella* occur and where climate is favourable for establishment.

In conclusion, soil types will vary within the suitable area but this should not affect the risk of establishment. Yee (USDA, ARS, USA, *personal communication*, April 2016) has studies of the effect of soil moisture in different soil types on pupal mortality underway.

Competition and natural enemies

3.05 - Is all the area identified as being suitable for establishment in previous questions likely to remain unchanged despite the presence of competitors and natural enemies?

Yes.

CABI (2015) lists 17 species/genera of predators and parasites of *R. pomonella*.

They stated that*: 'Up to 90% of larvae may be parasitised in* Crataegus *fruits (Gut and Brunner, 1994) in Washington State, USA. However, in a comparative study of parasitism levels in* Crataegus *and apple in Michigan, USA, Feder (1995) found only 46% and 13% parasitism, respectively. Allen and Hagley (1989[21]) reviewed predators found in an orchard in Ontario, Canada, but indicated that the impact was probably very low'*.

Yee (USDA, ARS, USA, *personal communication*, April 2016) advised that (with respect to apples) '*parasitoids cannot access the larvae using their ovipositors in the large fruit as they can in the smaller hawthorns'.*

The areas suitable for establishment may vary in the types and abundance of competitors and natural enemies but these are not considered to be limiting factors to the area which is favourable to establishment of *R. pomonella.*

[21] Should be 1990

The managed environment

3.06 - Is all the area identified as being suitable for establishment in previous questions likely to remain unchanged despite the management of the environment?

No. (*Identify and describe any locations where the area suitable for establishment based on previous questions is likely to be altered due to the management of the environment. Provide justification).*

Within the PRA area the only control work being undertaken specifically against *R. pomonella* is done by the County Pest Boards responding to detections made in the trapping and certification programme. Quoting from Klaus *et al*. (2007):

Eradication and County Pest Boards

County Horticultural Pest and Disease Boards conduct apple maggot control measures in cooperation with the apple maggot survey. These measures include tree and fruit removal, pesticide applications or other control treatments approved by Washington State University and the Washington State Department of Agriculture.

Several counties conduct apple maggot pest prevention and control activities under interagency agreements with the Washington State Department of Agriculture and in accordance with state regulations as defined by RCW 15.09. Pest Board efforts focus on containing existing populations identified by the state survey program, preventing establishment and spread to adjacent areas, and eradicating new infestations where possible.

The Washington State Department of Agriculture provides notification of all new positive sites to the County Horticultural Pest and Disease Board Control Coordinator (hereafter known as the control coordinator). Specifically, counties contract for the services of a control coordinator. The control coordinator conducts initial and follow-up contacts with affected landowners and provides oversight for direct apple maggot control of all types (i.e. insecticide application, fruit removal, tree removal) in accordance with chapter 15.09 RCW. The county also contracts for apple maggot control services for known or recently discovered infestations in the county. The control coordinator and contractor(s) will use an integrated pest management approach that incorporates, tree and/or fruit removal, insect life history, and insecticide application. The County ensures contracting procedures are in compliance with all applicable laws, rules, regulations, and ordinances. All control methods employed are consistent with the rules and regulations of Washington State and the County.

In addition there is a public outreach programme (Klaus *et al*., 2007) which should help reduce pest prevalence in the PRA area:
'WSU County Extension efforts inform the public on the need to maintain backyard fruit trees and on not transporting backyard fruit out of quarantine areas'.

Klaus also advised that: '*many local County Horticultural Pest and Disease Boards discourage purchases* [public purchases of fruiting hosts] *due to pest issues such as codling moth, leafrollers and more recently, apple maggot concerns. Some Pest Boards even offer incentives to have backyard fruit trees removed by offering vouchers for non-fruiting trees.* Klaus (WSDA, USA, *personal communication*, April, 2016).

See 5.01 for more current practices.

Beyond this targeted effort which is aimed at maintaining the PFA status in the PRA area and which will therefore reduce the risk of establishment, normal pest management practices in apple orchards and host plant nurseries will also influence the suitability of these locations for establishment of *R. pomonella*.

Orchard management

In response to a questionnaire provided by the PRA team in the autumn of 2015 to Willett (formerly Northwest Horticultural Council; now at the Washington Tree Fruit Research Commission) he provided an Excel spreadsheet that outlined a typical apple orchard pest control programme used in 2009 focusing primarily on codling moth (*Cydia pomonella*) (but which also included treatments against scale insects, mites, leaf rollers and aphids). He advised that two of the products used against codling moth would also provide control of *R. pomonella* in the early part of the growing season:

- Delegate 25WG – spinetoram- applied 4 June and 2 July
- Altacor 35WDG – chlorantraniliprole - applied 18 July and 1 August

However, referring to Schotzko (1982) and Dowell (1990) he felt that an additional one to three applications would be needed to control flies of *R. pomonella* emerging later in the season. He also advised that '*Dr Betsy Beers (Washington State University Department of Entomology) noted that although there are not official WSU recommendations for AM control in commercial orchards Assail (acetamiprid) has been recommended for use*' but no details of timings etc. were given.

Washington State University gives details of a range of products (including acetamiprid, spinetoram and chlorantranipole) that are used in pest management programmes for apple orchards, rating their efficacy against a wide-range of apple pests but as noted above, there are no ratings for efficacy of any of these products against *R. pomonella.* Accessed 23 February 2016:
http://www.tfrec.wsu.edu/pages/cpg/Apple_Programs

The Washington State University advice on *R. pomonella* suggests that the products that can be used in commercial apple orchards are shown in the '*regular recommendation'* section in the period late spring and summer and the pre-harvest period. Accessed 3 March 2016:
http://www.tfrec.wsu.edu/pages/cpg/Apple_Maggot

Klaus (WSDA, USA, *personal communication*, March 2016) advised that growers can check with their County Washington State University Agent for advice on pest and disease control. This information can also be obtained through the WSU Decision Aid System (DAS)
http://das.wsu.edu/site_being_updated.php

The Penn State Extension Service gives information on pest control in apples and rates some of the products for their efficacy against *R. pomonella*:
http://extension.psu.edu/plants/tree-fruit/insects-mites/insecticides-and-miticides/apples-insecticide-and-miticide-efficacy

Of the chemicals mentioned by Willett in the autumn of 2015, spinetoram (Delegate) is a non-organic form of spinosad; acetamiprid (Assail) is a conventional pesticide; both are rated 3 out of 4 for control of *R. pomonella*.

Adult flies of *R. pomonella* normally emerge from pupae from June through to September and they can live for up to 40 days. Under the current spray regime for apple orchards which targets codling moth, any flies of *R. pomonella* emerging during the period that pesticides are normally applied would be unlikely to survive and reproduce on ripening fruit within the orchards. After the last application has become ineffective, any remaining flies or newly-emerging flies may be able to reproduce within these orchards depending upon the effects of any other pest management practices that are used.

<u>Nursery stock: apples and ornamentals</u>
Willett advised that fruit nurseries are not targeting *R. pomonella* specifically at this time. The Northwest Nursery Improvement Centre (Washington State) advised him that a typical pesticide programme for a fruit tree nursery for 2015 would be:

- Lorsban (chlorpyrifos) applied early May, mid-June, and early to mid-July
- Diazinon (a.i.) applied early to mid-August

These chemicals should be effective against flies of *R. pomonella* emerging in June through to August but depending upon the latest date at which the last spray is applied and when it becomes ineffective there may be some flies that could infest apple nursery stock but only if fruit are on the trees in these situations and if other pest management practices are ineffective.

The nurseries in the state of Washington that produce planting material for apple orchards are all located in the PFA (the PRA area). (Howell, Northwest Nursery Improvement Centre, USA, *personal communication* to Sansford, UK, February 2016).

The planting material of apples produced in the PFA of the state of Washington is ≤2 years old when the material is sold. There may be some trees that bear blossom but they would not bear fruit. However, some '*big box'* nurseries (large retail nurseries for the public) may sell trees bearing fruit but there are no data on these (Cooper, WSDA, USA, *personal communication* to Reynolds, USA, February, 2016). Pest management practices for the '*big box*' (large retail) sector in the PFA (if they exist) were not investigated.

For ornamental nurseries no pest management programmes have been obtained for this PRA since the variety of plants that are grown in the part of the PFA where these may be located is unknown. Klaus (WSDA, USA, *personal communication*, April 2016) advised that '*In Washington state, it is rare if not unheard of, for nurseries to sell trees that already (pre-sale) have fruit on them. Some nurseries may sell bare root or potted trees that are capable of bearing fruit the year they are planted. Most trees are small unbranched or feathered bare root trees that don't fruit until the second year at the earliest. Most of these trees are purchased in the late winter or spring and are without leaves or fruit. Also, note that many local County Horticultural Pest and Disease Boards discourage such purchases due to pest issues such as codling moth, leafrollers and more recently, apple maggot concerns*'. However he also commented that he has occasionally seen plants bearing fruit on nurseries where clean-up had not been 100%.

<u>Organic production</u>
The pest control programmes used in organic orchards and for organic production of nursery stock

of fruit-bearing hosts (if this sector exists in the PRA area[22]) of *R. pomonella* have not been fully investigated. Knight (2010) presented some background information on practices that have been used against a variety of pests in organic apple orchards including codling moth (*C. pomonella*). Products that were used include spinosad, *Bacillus thuringiensis*, mating disruption with pheromones and kaolin sprays. Of these spinosad and kaolin would have some efficacy against *R. pomonella* if they were targeted at the period when *R. pomonella* adults are in flight. It is unknown how effective these materials would be in a pest control programme targeted at a range of pests. Spinosad acts primarily through ingestion and so it relies on adult flies feeding on it before the female mates and lays her eggs in host fruit. Pelz *et al*. (2005) showed infestation in apples was reduced by 67% in 2002 after weekly application of the bait formulation of spinosad (GF-120) for 6 weeks. The Penn State '*Basic IPM for Organic Apple in Pennsylvania*' document only lists two products for use in organic apple production against *R. pomonella* (both containing spinosad); Entrust and GF-120, but does not rate them for efficacy.
http://extension.psu.edu/pests/ipm/agriculture/nrcs/programs/treefruit/basicapples accessed 8 March 2016.

Yee (USDA, ARS, USA, personal communication, April 2016) advised GF-120 is effective '*even under high fly pressure seen in abandoned trees*' based on Yee (2007).

Changes in pest management practices
A personal communication from Klaus (WSDA, USA) to Reynolds (USA) (February 2016) advised the following:

'As has been mentioned by myself, several WSU Extension agents, researchers and numerous pest consultants, it is recognised that the fairly recent loss of Guthion (azinphosmethyl) registrations along with the increase in organic production of apples, the risk of apple maggot becoming established in commercial orchards is probably increasing.

It is believed that in the past, applications of azinphosmethyl directed towards codling moth coincidentally helped control any possible introductions of apple maggot in commercial apples.

Currently, most orchards use pheromone based mating disruption [for codling moth] *along with newer 'softer' chemicals as part of an overall Integrated Pest Management approach. Many of these new chemistries will also help control apple maggot. Organically produced apples have fewer options for control of insects such as apple maggot at this time.*

A research project has been funded to fully assess this new situation'.

Overall, depending upon the pest management practices that currently operate in conventional apple orchards (which are not exclusively pesticide based), and nurseries producing host planting material for fruit growers (bearing in mind that the planting material for apple orchards produced in the PFA does not bear fruit; retail nurseries may have some material in fruit) there are likely to some parts of the season when emerging flies of *R. pomonella* cannot infest host fruit where it is ripening on growing material. However it seems that flies emerging late in the season may have opportunities to reproduce in apple orchards as well as fruit tree nurseries in the PRA area when

[22] Current indications are that there are no large organic nurseries that supply fruit-bearing nursery stock raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016)

susceptible ripening fruit is borne on the hosts. This is because current controls aimed at codling moth which would also be effective against *R. pomonella* are not applied after a certain point. This also depends upon the efficacy of any other pest management practices which are deployed.

The pest management situation in ornamental nurseries growing outdoor stock of host plants is unknown. However, it is thought that commercial nurseries supplying growers do not have plants bearing fruit except occasionally if clean-up has not been 100%. Retail nurseries may have stock bearing fruit.

Pest management practices in organic orchards may have some efficacy against *R. pomonella* but a full investigation has not been conducted. Management practices on organic host plant nurseries are not known, however, current indications are that there are no large organic nurseries that supply fruit-bearing nursery stock raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016). The indication from the personal communication by Klaus (February 2016) is that an increase in organic apple production is occurring and that this would increase the risk of establishment of the pest. Since then, Willett (Washington Tree Fruit Research Commission) has advised that approximately 10% of the apple area in the state is certified as organic but there is a transition in progress which means this may increase to 20% (*personal communication* to Reynolds, USA, February 2016).

In addition to existing pest management practices in commercial orchards and nurseries, pest management conducted by the County Pest Boards in response to detections of *R. pomonella* in the WSDA annual survey (part of the management strategy) has helped maintain much of the PFA status along with the public outreach programme which can also be considered to be part of the pest management practices.

The ongoing surveillance and trapping undertaken by the WSDA has led to the detection of low numbers of adult flies of *R. pomonella* on traps in host trees located outside of commercial apple orchards in the PRA area (the current PFA). Fruit harvested from these trees has been incubated. In some years juvenile forms of *R. pomonella* have developed and some parts of the old PFA were added to the quarantine area, most recently as a result of findings of adults and (later) larvae incubated from fruit in Chelan County in 2011. There has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). However, the pest has not been detected in commercial apple fruit harvested in the current PFA of the state. (Klaus *et al*., 2016).

This lack of findings of the pest in commercial apple orchards in the PFA indicates that the risk of establishment is relatively low under current pest prevalence and this may in part be related to existing pest management practices.

Changes in pest management practices related to loss of pesticides that may have been efficacious against the pest and an increase in organic apple production may increase the risk of establishment in apple orchards.

Protected Cultivation

3.07 - Are the hosts grown in protected cultivation in the PRA area? If the pest is a plant, has it been recorded as a weed in protected cultivation elsewhere?

No. The hosts are not grown in protected cultivation (under glass or polythene) in the PRA area.

3.08 - By combining the cumulative responses to previous questions with the response to question 3.07, identify the part of the PRA area where the presence of host plants or suitable habitats and other factors favour the establishment of the pest.

The parts of the PRA area which are suitable for establishment of *R. pomonella* are located in areas with moderate summer temperatures, and high precipitation or irrigation or in riparian or other wet habitats. These include a) apple orchards and host plant nurseries where plants bear fruit and where pest management practices are not totally effective against the pest either due to the timings of application, the products that are used or other pest management strategies being ineffective; b) yards and landscaped areas where host plants are present and c) areas along creeks and ditches (etc.) in the wider environment where hosts such as hawthorn and feral apple trees can survive. Establishment may also be possible in the areas where the climate is less favourable (hotter, drier) but the levels of infestation that might occur may be reduced.

Host plants and suitable habitats

3.09 - How likely is the distribution of hosts or suitable habitats in the area of potential establishment to favour establishment?

Likely

Level of uncertainty: *Low*

R. pomonella can complete its lifecycle on all of the 55 hosts recorded across its current area of distribution (USA, Mexico and Canada) (see Table 1). However, it has not been recorded on all of the 55 known hosts in every location including in the state of Washington. The main hosts of *R. pomonella* on which it reproduces are apples (*Malus* spp.) and hawthorns (*Crataegus* spp.) (28 recorded hosts) although not all species or varieties are suitable. See Yee *et al*. (2014).

Adult flies live for up to 40 days and feed on plant leachates and insect honeydew when available, as well as liquid from plant glands, wounds and oviposition stings; also possibly bacteria, yeasts and fungal spores (these flies are opportunistic and apparently indiscriminate feeders). These food sources can be obtained on non-host plants as well as on host plants and possibly from other surfaces (although this is not proven). It is assumed that flies may be able to travel 1 to 3 miles to find a food source if necessary. The longer, 3 mile, distance was found in flight mill studies and the shorter distance from results of field releases. Because of the difficulties in conducting mark-recapture studies with any insect which is made more difficult because of the short-range attraction of the traps for *R. pomonella*, conclusive studies on dispersal have not been conducted in areas that can compare with the PRA area in terms of host density or distribution of in other biotic or abiotic factors. Adults feed for 7 to 10 days after emergence before they reach sexual maturity and continue to feed thereafter. In order to reproduce they need to find host plants bearing susceptible fruit. Feeding can continue on substrates on non-host trees and possibly on other surfaces; this may include feeding on leachates at the composting facilities upon emergence.

In the state of Washington, the main hosts are apples (*Malus* spp.) and several species of hawthorn including black hawthorn (*C. douglasii*). However, there have also been records of the pest in the state on various species of cotoneaster (*Cotoneaster* spp.), mountain ash (*Sorbus* spp.), *Prunus* spp. (apricots, various cherries and various plums), as well as common and Asian pear (*Pyrus* spp.).

Of these, apples, black hawthorn and oneseed hawthorn (*C. monogyna*) are considered to be of high importance for the pest and several species are of medium importance including smooth hawthorn (*C. laevigata*), Suksdorf's hawthorn (*C. suksforfii*), and Asian pear (*P. pyrifolia*).

See section 1.06 and Yee *et al*. (2014).

It has to be assumed that the host species or varieties recorded in the state of Washington are those that *R. pomonella* will attack and reproduce on in the PRA area if it is introduced.

Other than maps of commercial apple orchards and nurseries (less host specific) (see later Figures), with respect to which of these host species are present in the parts of the PRA area which are favourable for establishment and what their abundance is, there are no complete distribution maps. Irrigation in the PRA area outside of orchards allows the presence of feral/backyard apples, crab apples (*Malus* spp.); and ornamental hawthorns (*C. monogyna* and *C. laevigata*) to grow and native black hawthorn (principally *C. douglasii*) can be found in wild riparian areas (Yee and Klaus, 2015). Wild apples and crab apples of many varieties can be found anywhere in the PRA area where there is sufficient water – streams, high elevations, towns, cities, homesteads etc. Ornamental hawthorns are found in most urban areas. (Klaus, WSDA, USA, *personal communication*, December 2015).

The distribution of one of the major *Crataegus* hosts in the PRA area, black hawthorn (*C. douglasii*) is considered to be discontinuous (Hood *et al*., 2013). See also:
http://www.plantmaps.com/nrm/crataegus-douglasii-black-hawthorn-native-range-map.php

East of the Cascade Mountain range in the areas that they sampled (which are not in the current PFA) Hood *et al.* (2013) found that ornamental hawthorns (*C. monogyna*) were rare and not infested with *R. pomonella* and black hawthorn infestations were patchy. However, the authors sampled in wild habitats.

Yee (2008) studied the host plant use of *Rhagoletis* spp. outside of commercial orchards in 5 locations in south central Washington between 2002 and 2006: Yakima and vicinity, Wenas, the Nile Valley (Yakima County); Ellensburg and vicinity (Kittitas County); Goldendale (Klickitat County). These are currently in the quarantine area of the state but border the PFA (the PRA area) and so give an indication of the availability of hosts in the PRA area. A reasonable range of hosts were available for *R. pomonella* in the sampled areas (Table 2, Yee 2008) but the ecosystems in which they occurred were described as sagebrush/bunchgrass, bunchgrass and ponderosa pine (also referred to by Yee *et al*., 2012 as '*relatively dry*').

Klaus *et al.* (2007) describe the procedures for the WSDA's annual survey for *R. pomonella*. As part of the General Survey, the WSDA hangs traps in all species of apple, crab apple, ornamental hawthorn and native hawthorn in their targeted area when fruit is on the tree. The main focus for trapping is non-commercial residential host trees in populated areas, abandoned apple orchards, and feral, roadside trees since these are considered to pose the greatest risk of introduction of the pest.

Traps are placed in the PFA in a targeted way based upon the following guidelines:

1. Trap host trees in residential areas, in roadside host trees and other wild host trees near commercial orchards.
2. Trap accessible host trees along borders with quarantined counties.
3. Trap host trees along highways, other roadways and stream drainages leading up to commercial orchard areas
4. Once a transient apple maggot is detected during the season then high density trapping will be deployed as described in 'delimiting trapping procedures'

In 2015, the survey was extended to trap as many hosts as possible within a 5-mile radius around the four composting facilities. Maps of the hosts which were trapped and the proximity of commercial apple orchards to these facilities were presented and discussed under the risk of entry section (2.0) of this PRA (Figures 13, 16, 19 and 24); reproduced here in miniature as Figure 34.

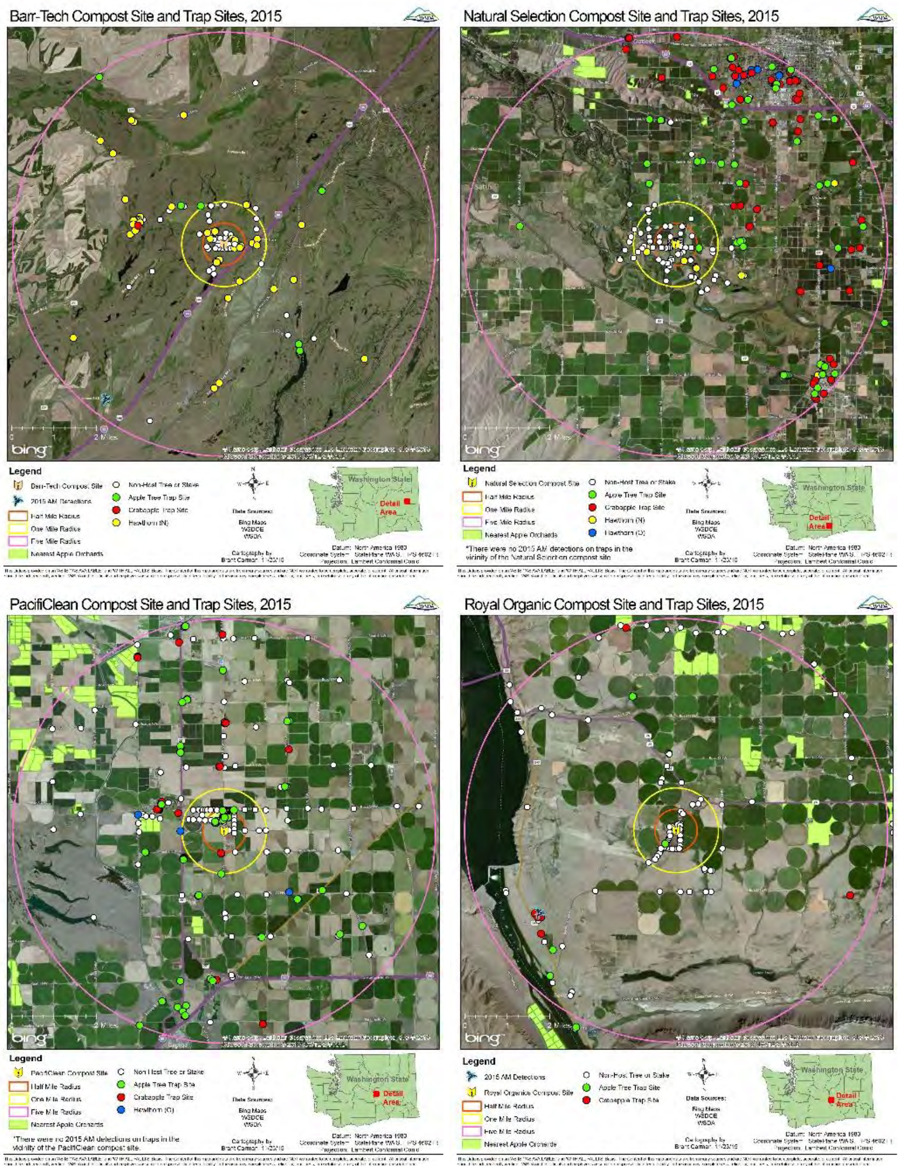


Figure 34. Host trees trapped by the WSDA within a 5-mile radius of the 4 composting facilities, 2015 (source WSDA). Key: Circles - green = apples, red = crab apples, yellow = native hawthorn and blue = ornamental hawthorn; pale green blocks = apple orchards

Figure 34 (and the original figures 13, 16, 19 and 24) shows that there are non-orchard hosts of *R.*

pomonella within a 5 mile radius around the composting facilities. The abundance of hosts around the facilities varies between the sites. Other than the Barr-Tech LLC facility, commercial apple orchards are located within a 5 mile radius of the sites. As noted above, adults of *R. pomonella* can feed on substrates on non-host trees and possibly other surfaces (including possibly leachates at the composting facilities if they contain sugars) so it has potential to obtain nutrition for flights to reproduce on host trees.

Maps of the four main categories of hosts that were trapped across the state by the WSDA in 2015 in relation to the 4 composting facilities are presented below (Figures 35, 36, 37 and 38). Of course not all of the host trees/plants in the PFA bear traps and the number of traps in each county for the General Survey varies between counties but the maps illustrating the locations of traps give a good indication of where host trees/plants are located in the vicinity of commercial orchards (guideline number 3 from Klaus *et al.* 2007, above).

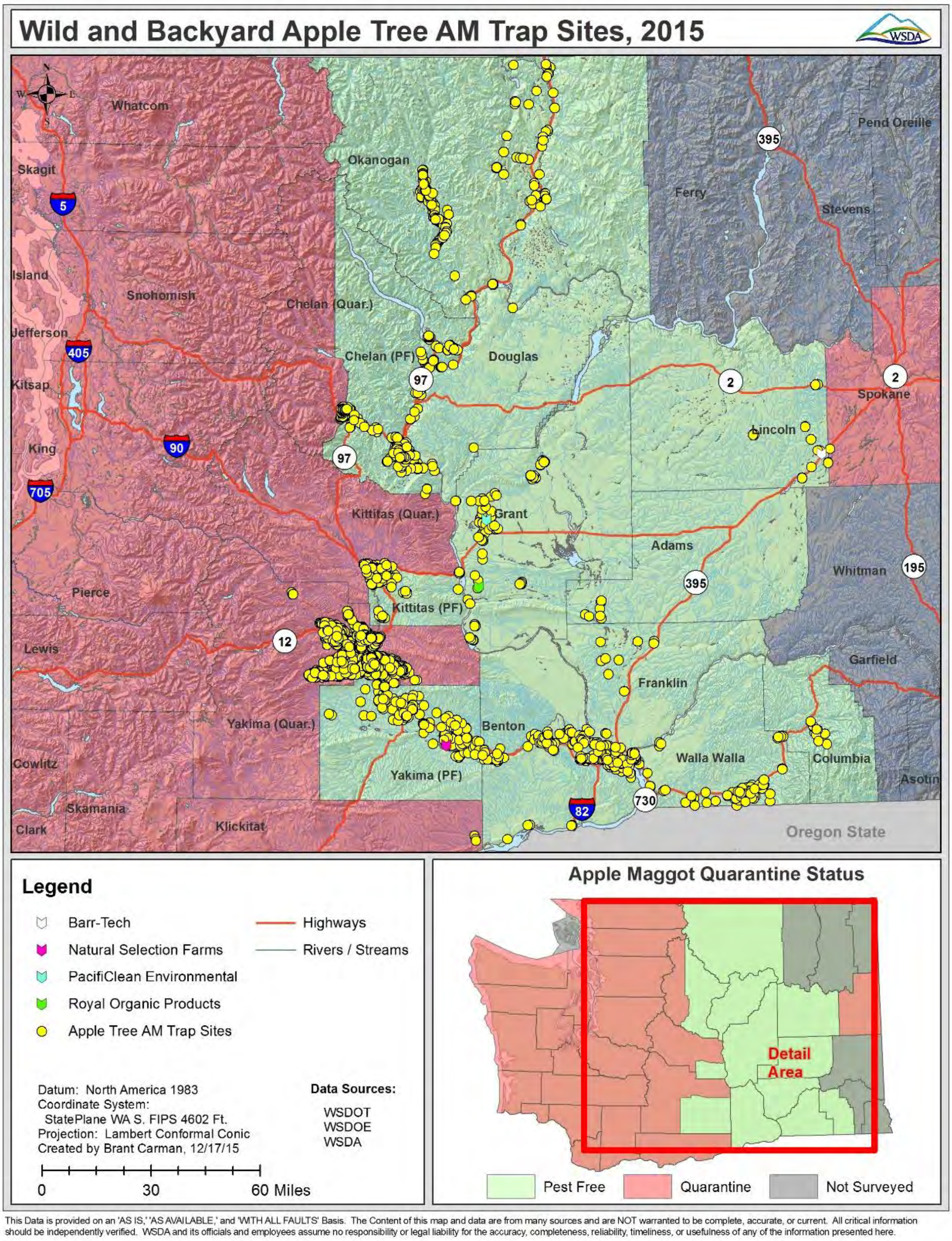


Figure 35. Map of non-orchard apple trees trapped in the 2015 WSDA state of Washington survey for *R. pomonella* in relation to the four composting facilities (source WSDA).

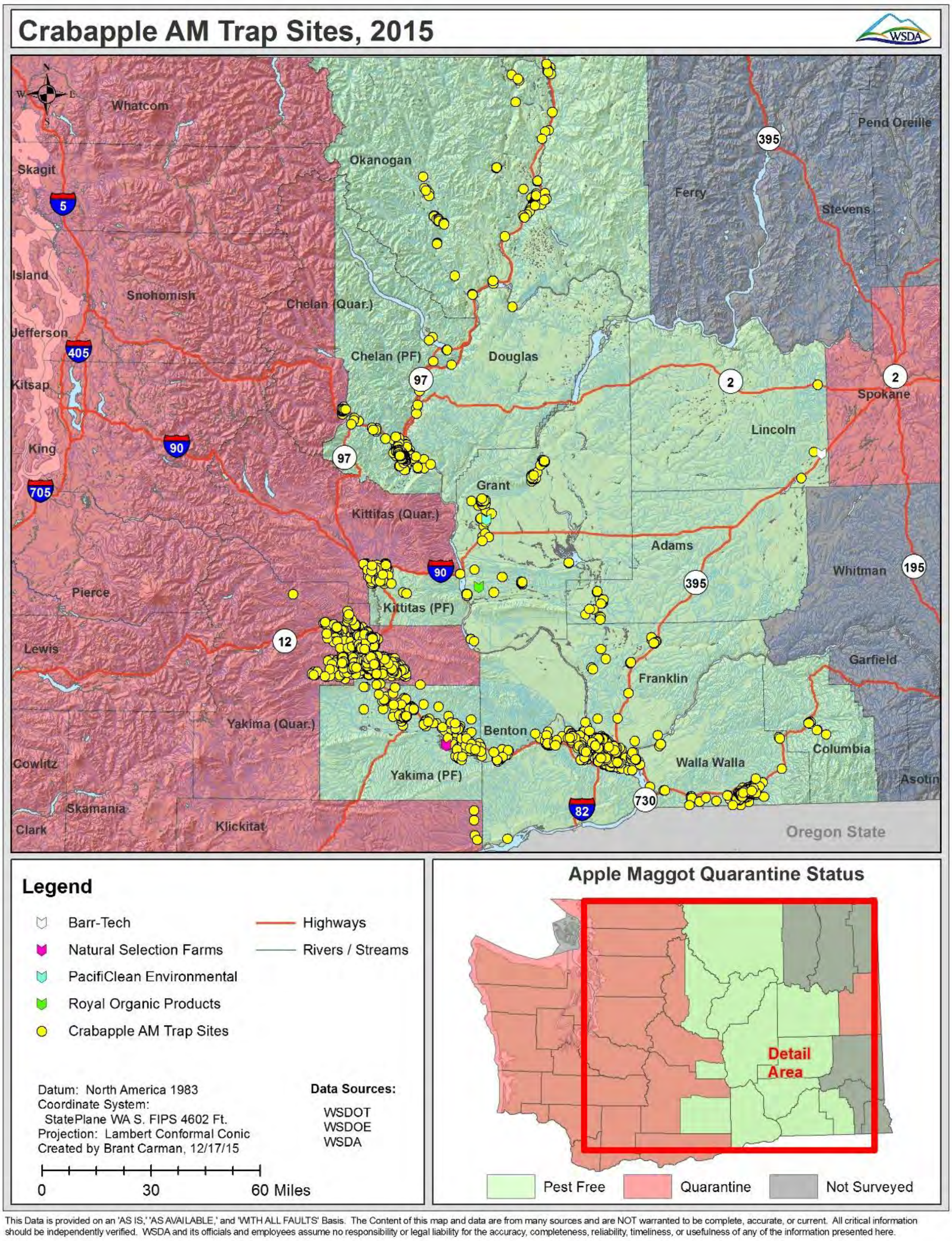


Figure 36. Map of crab apple trees trapped in the 2015 WSDA state of Washington survey for *R. pomonella* in relation to the four composting facilities (source WSDA).

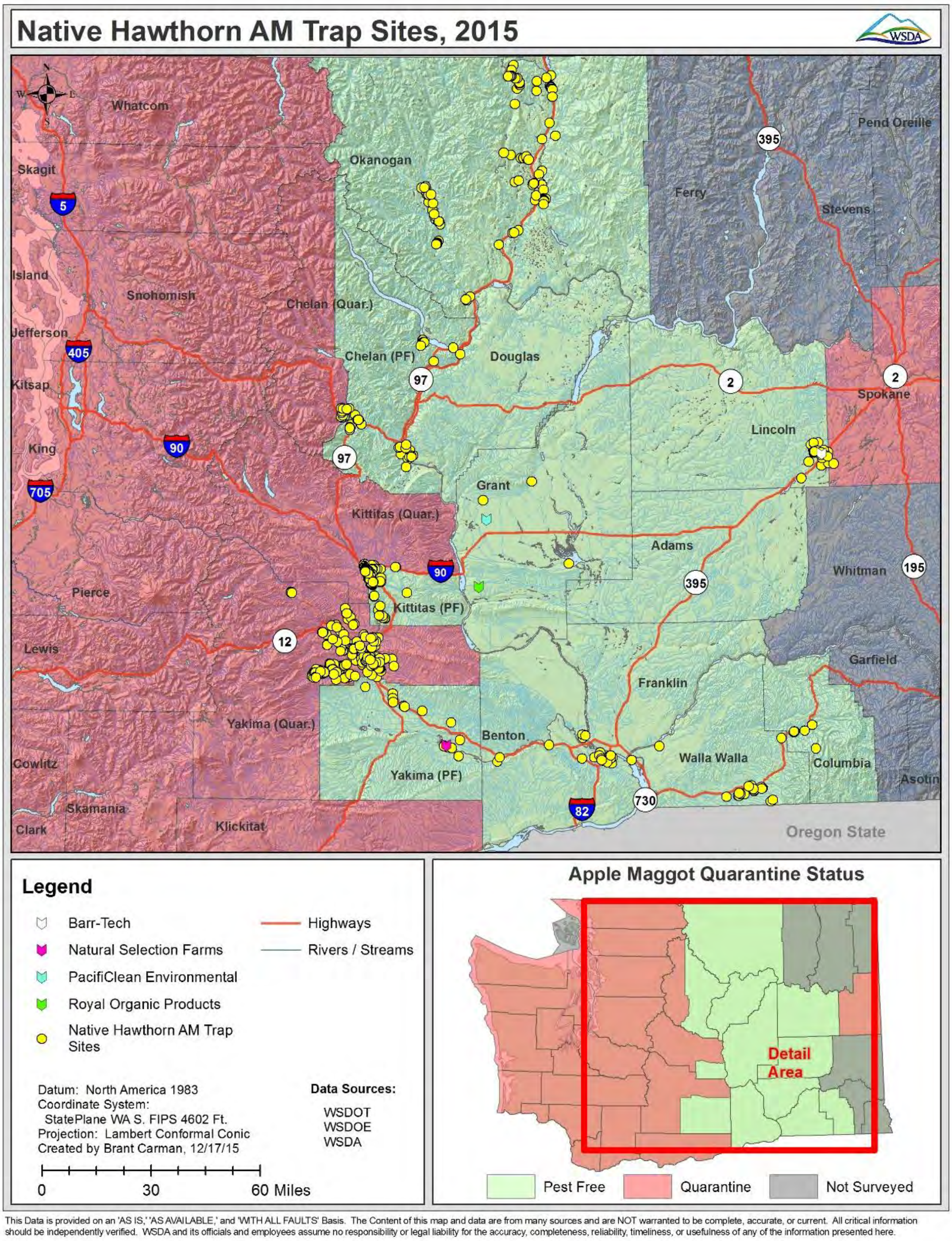


Figure 37. Map of native hawthorn trapped in the 2015 WSDA state of Washington survey for *R. pomonella* in relation to the four composting facilities (source WSDA).

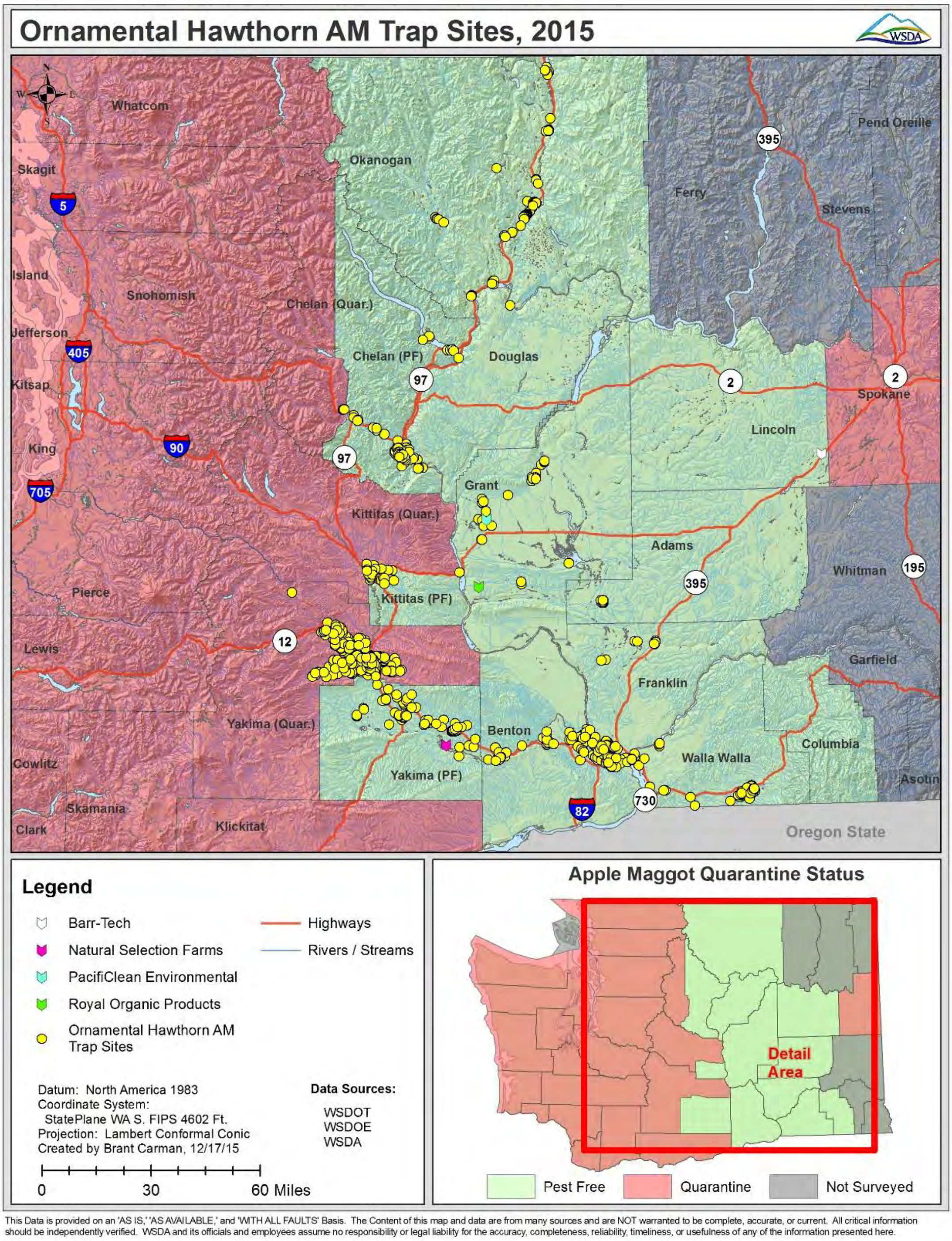


Figure 38. Map of ornamental hawthorn trapped in the 2015 WSDA state of Washington survey for *R. pomonella* in relation to the four composting facilities (source WSDA).

It is clear that there are hosts available for *R. pomonella* outside of commercial orchards including the major hosts, apples (*Malus* spp.) and hawthorns (*Crataegus* spp.), but their abundance and distribution across the area is limited by availability of water. See 3.03. These hosts are largely restricted to riparian habitats or situations where irrigation is applied (backyards, landscaped area, commercial nurseries if plants bear fruit). However, it is these areas which are more likely to be favourable to establishment of the pest.

A map of the distribution of apple orchards in the PFA is presented below (Figure 39).

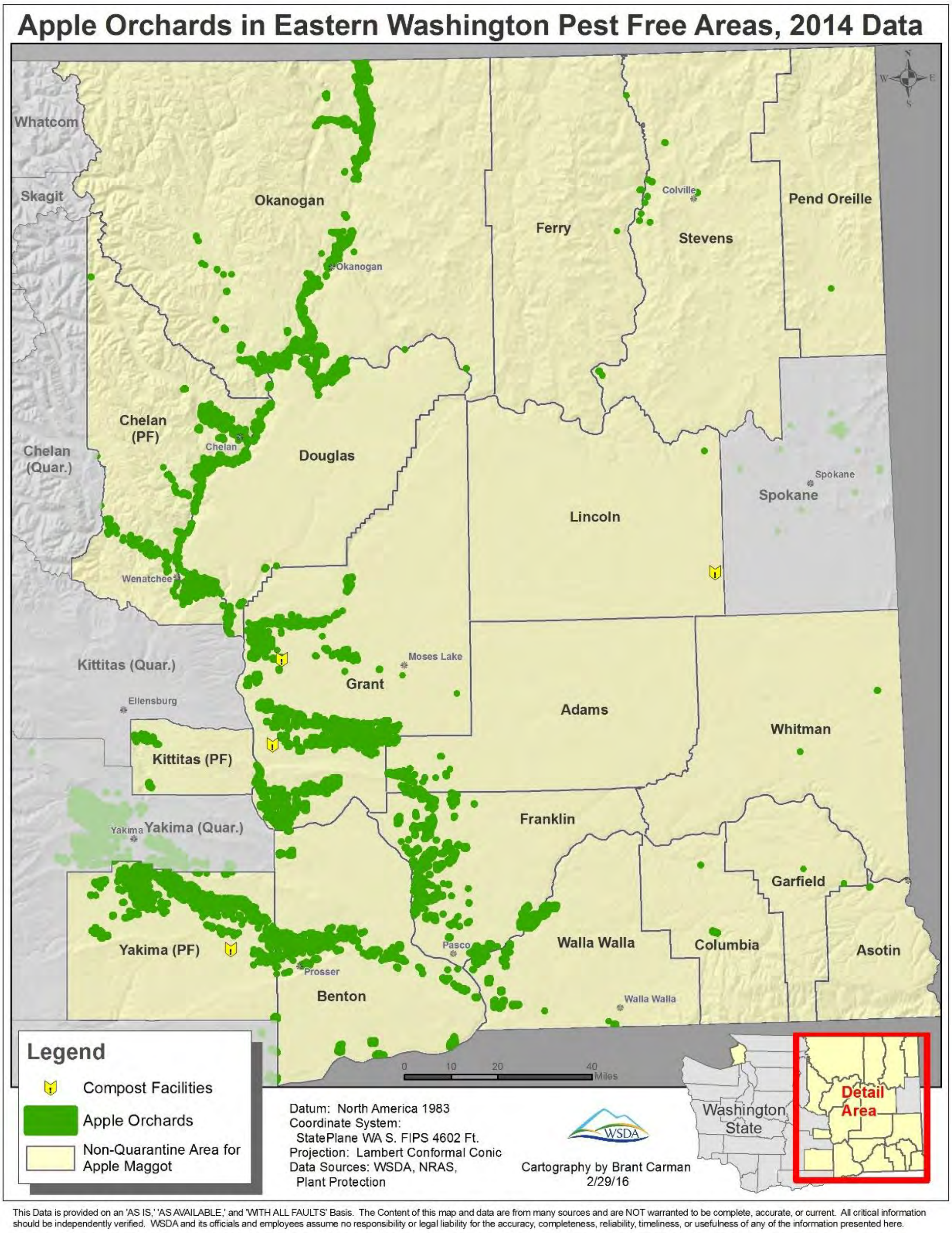


Figure 39. Map of commercial apple orchards in the PFA of the state of Washington (source WSDA)

According to the Washington Apple Commission there are 175000 acres of apple orchards in the eastern foothills of the Cascade Mountains with an average area of around 100 acres. http://bestapples.com/washington-orchards/history/ accessed March 4th 2016. USDA (2011) specifies 167489 acres in the state of Washington some of which is located in the quarantine area. The distribution of the orchards in the PFA in Figure 39 is similar to that of the non-commercial hosts targeted for placing traps by the WSDA.

Maps of a category known as '*Nursery, Orchard/Vineyard*' (which includes all varieties of apples and grapes in a nursery setting) (Figure 40) and ornamental nurseries (Figure 41) in the PFA are presented below.

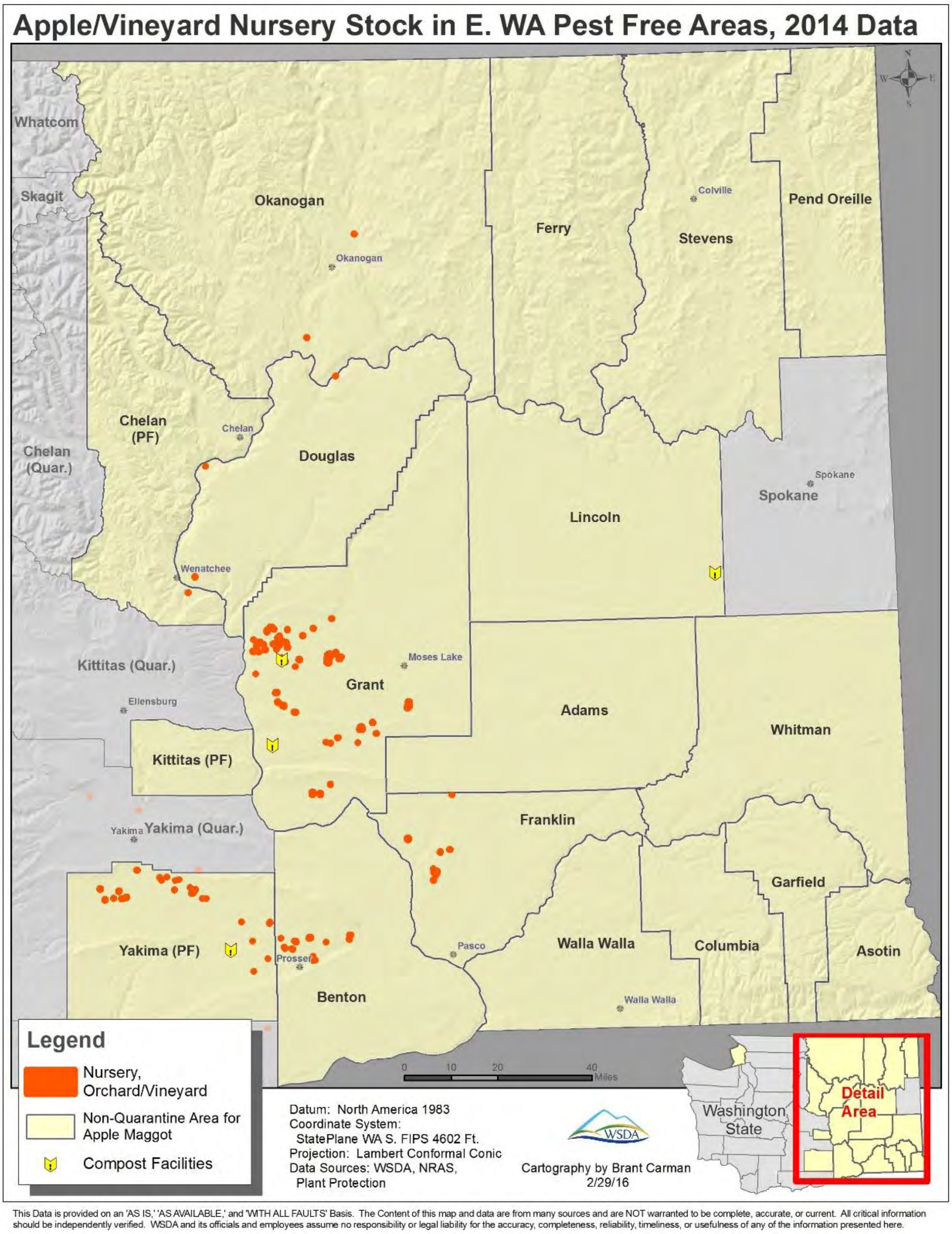


Figure 40. Map of commercial nurseries producing apples and grapevines in the PFA of the state of Washington (source WSDA)

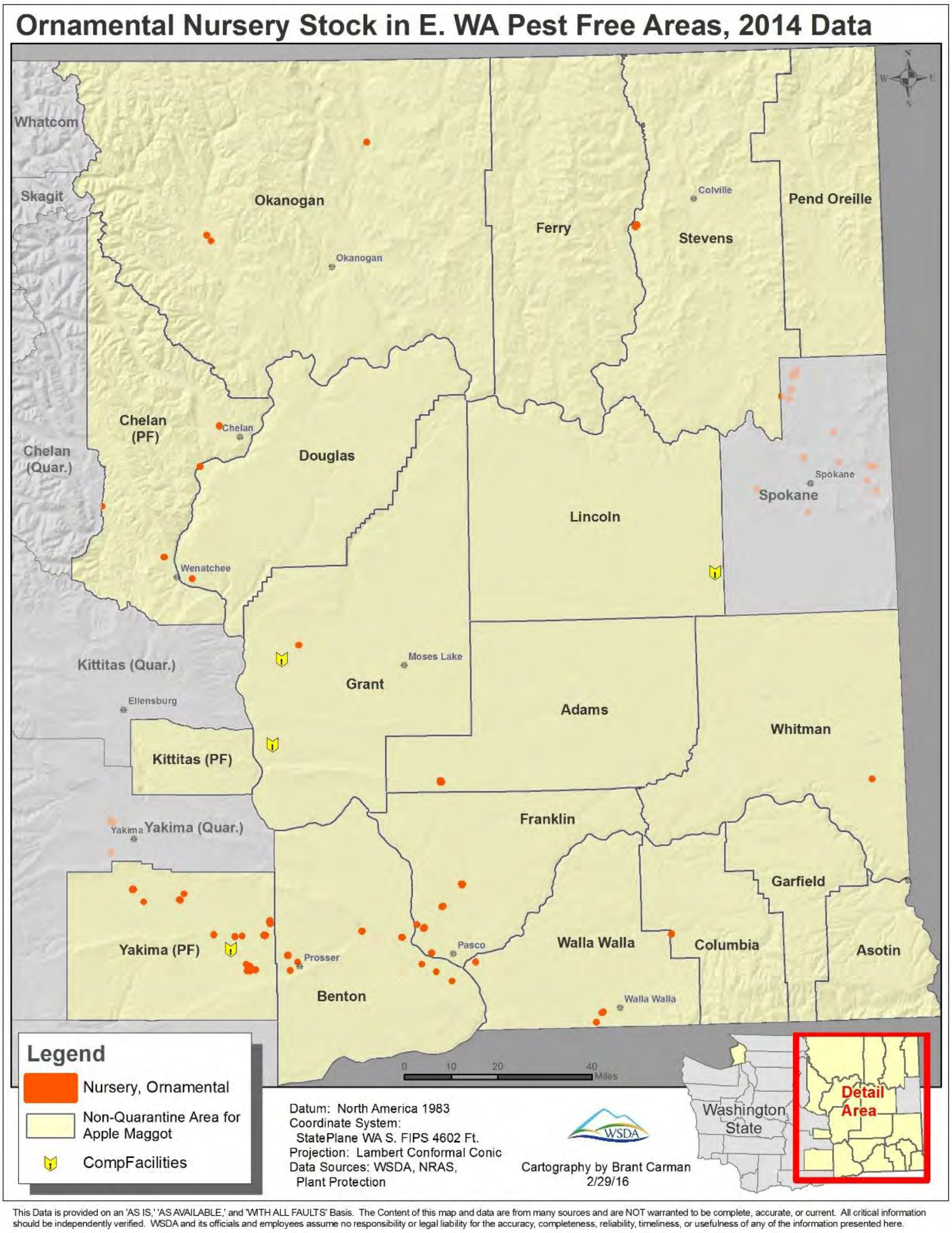


Figure 41. Map of commercial nurseries producing ornamental plants in the PFA of the state of Washington (source WSDA)

Although Figures 40 and 41 do not specifically show nurseries that produce apple planting material and ornamentals that are hosts of *R. pomonella*, the nurseries are less prevalent than apple orchards and hosts in the wider environment. The nurseries in the state of Washington that produce planting material for apple orchards are all located in the PFA (the PRA area); Howell, Northwest Nursery Improvement Centre, USA, *personal communication* to Sansford, UK, February 2016. The planting material of apples produced in the PFA of the state of Washington is <u><</u>2 years old when the material is sold. Although some may bear blossom they would not bear fruit which means they are not at risk of infestation. However, some '*big box'* nurseries (large retail nurseries for the public) may sell trees bearing fruit but there are no data on these (Cooper, WSDA, USA, *personal communication* to Reynolds, USA, February, 2016). Ornamentals produced in the nursery trade such as hawthorn or crab apple may bear fruit although Klaus (WSDA, USA, *personal communication*, April 2016) thought this unlikely except where nurseries had failed to clean up at the end of the season.

Overall the host distribution is discontinuous but it is considered *likely* that the distribution of hosts or suitable habitats in the area of potential establishment will favour establishment with *low uncertainty*.

Determination of the suitability of the delimited area (within the PRA area) for establishment

Alternate hosts and other essential species

3.10 - How likely is the distribution of alternate hosts or other species critical to the pest's life cycle in the area of potential establishment to favour establishment?

Not applicable.

R. pomonella does not require alternate hosts or other species to complete its lifecycle and so this will have no influence on the favourability of the area of potential establishment,

Climatic suitability

3.11 - Based on the area of potential establishment already identified, how similar are the climatic conditions that would affect pest establishment to those in the current area of distribution?

Moderately similar

Level of uncertainty: *Low*

Recent work by Kumar (Colorado State University, 2016) (and others) (see Figures 32 and 33) shows that parts of the areas where host plants occur have a medium probability of being favourable for *R. pomonella* whereas others have a high probability.

Yee and Klaus (2015) commented on the low abundance of *R. pomonella* in the central and eastern parts of the state of Washington and felt that that high temperatures, low precipitation and '*other factors*' (rather than host plant availability) may be responsible. They explained that even where black hawthorn trees are abundant in riparian zones at low altitudes in central Washington, larval infestations in its fruit are low. They postulated that this might be because intense summer heat causes fruit to desiccate before flies can oviposit or larvae can develop. By contrast, at higher altitudes in central Washington where temperatures are cooler, *R. pomonella* abundance in black hawthorn fruit is greater (Yee 2008).

The cooler irrigated environment in some of the apple orchards would favour establishment of *R. pomonella*.

Based on this, overall the area of potential establishment for *R. pomonella* in the PRA area has *moderately similar* climatic conditions to those in the current area of distribution with *low uncertainty.*

Other abiotic factors

3.12 - Based on the area suitable for establishment already identified, how similar are other abiotic factors that would affect pest establishment to those in the current area of distribution?
Not applicable.

The only abiotic factor that might influence the timing of the lifecycle of *R. pomonella* is soil type. However, although soil type will vary within the area suitable for establishment as well as in all the other areas where the pest is currently established it is not a factor that is considered to affect the risk of establishment.

Competition and natural enemies

3.13 - Based on the area suitable for establishment already identified, how likely is it that establishment will occur despite competition from existing species, and/or despite natural enemies already present?

Very likely

Level of uncertainty: *Low*

Although there has been no attempt to fully-review the competitors and natural enemies of *R. pomonella* in the areas where it is currently established or in the area that is suitable for establishment within the PRA area, this factor is not likely to influence the overall risk of establishment. Competitors and natural enemies have not prevented *R. pomonella* from establishing in areas outside of or even close to the current PFA of the state of Washington and it seems unlikely that this will occur in the areas of the PFA where host plants and a suitable climate occur.

It is *very likely* that *R. pomonella* could establish in the area favourable for establishment despite the presence of competitors or natural enemies with *low uncertainty*.

The managed environment

3.14 - How favourable for establishment is the managed environment in the area of potential establishment?

Very highly favourable

Level of uncertainty: *Low*

The managed environment in the area of potential establishment includes apple orchards and nurseries growing host planting material (apple trees and ornamentals if they bear fruit). Apple orchards in the area of potential establishment are ideal environments for *R. pomonella* with abundant hosts and irrigation. Nurseries growing apple trees and ornamentals which have substrates suitable for pupation (soil or soil substitutes) would also be favourable if they bear fruit.

Overall the managed environment in the area of potential establishment is considered to *very highly favourable* with *low uncertainty*.

3.15 - How likely is the pest to establish despite existing pest management practice?

Moderately likely

Level of uncertainty: *Medium*

Pest management on commercial premises in the area where *R. pomonella* has the potential to establish in the PRA area is currently not targeted at *R. pomonella*. However, treatments aimed at other pests have some efficacy against the pest. Pesticides currently used in conventional apple orchards aimed at codling moth (*C. pomonella*) would have some efficacy against *R. pomonella* up to the point that the last spray is applied and remains active; but thereafter (likely to be in mid-August) any emerging flies have potential to enter the orchards and reproduce. A similar scenario is envisaged for commercial nurseries that produce apple trees where fruit is on these trees. Nurseries that produce planting material for apple orchards in the PFA do not sell plants that have fruited (they are ≤ 2 years old and may bear blossom but not fruit). However, '*big box*' (large retail) nurseries may sell trees which bear fruit. It is not known if these occur in the current PFA (the PRA area). Pest management practices on conventional nurseries producing ornamentals will vary but it is thought that commercial nurseries are unlikely to have hosts bearing fruit except where clean-up has not been 100%; retail nurseries may have hosts bearing fruit. Practices in organic apple production in the PRA area may have some efficacy against *R. pomonella* but may be less effective against *R. pomonella* than those deployed in conventional orchards; similarly with organic production of host planting material (fruit and ornamentals if they bear fruit) if it exists in the PRA area. Current indications are that there are no large organic nurseries that supply fruit-bearing nursery stock raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016).

The County Pest Boards take action on detection of *R. pomonella* in the WSDA surveys to eradicate the pest from the affected trees.

The WSDA surveys for *R. pomonella* have led to the detection of low numbers of adult flies of *R. pomonella* on traps in host trees located <u>outside</u> of commercial apple orchards in parts of the area that is favourable for establishment but fruit harvested from these trees has been incubated and no juvenile forms of *R. pomonella* developed in the current PRA area. However, in the past there have been parts of the PFA that have been changed to become part of the quarantine area as a result of findings of juvenile forms in fruit incubated from positively-trapped trees outside of commercial orchards. This happened in 2012 as a result of finds in Chelan County in 2011. There has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). The pest has not been detected in commercial apple fruit harvested in this area of the state. (Klaus *et al*., 2016).

This indicates that current pest management practices at least in commercial apple orchards seem to be having a protective effect against establishment of *R. pomonella* on those premises. Outside of these premises the low detection rate of the pest in the area is related to a number of factors, particularly climate and in some cases the discontinuity of major hosts such as black hawthorn, but pest control in orchards may be contributing to this. Public outreach (Klaus *et al.,* 2007) and the prohibition of the movement of host fruit from areas where the pest is established into the PFA unless it has been cold treated or can be certified as pest-free (see 6.04) has also reduced the risk of movement of the pest into the PFA which has also contributed to the low detection rate.

It is considered *moderately likely* that *R. pomonella* will establish in the area that is favourable for the pest despite existing management practices with *medium uncertainty*.

Protected Cultivation

3.16 Is the pest likely to establish in protected cultivation in the PRA area?

No.

Level of uncertainty: *Low*

R. pomonella is not a pest of protected crops.

3.17 - How likely are the reproductive strategy of the pest and the duration of its life cycle to aid establishment?

Very likely

Level of uncertainty: *Low*

The normal lifecycle of *R. pomonella* is *ca*. 1 year but where diapause does not occur it can lead to a partial second generation or even in warm climates it can complete a second generation. In other cases it may diapause as a pupa for two or more years. If two generations are completed in the same year this would increase its annual reproductive capacity. The female lays large numbers of eggs ($\geq$200) in host fruit where the larvae develop. Although many may be taken by predators, parasitised, or die through other means, a sufficient number will survive to go on to pupate in the soil or, in some instances, within the fruit. The pupal stage can survive in soil for up to at least 2 years which can maintain a population in unfavourable years of poor fruit production or climate, complicating eradication attempts.

3.18 - Is the pest highly adaptable?

Yes, *R. pomonella* is *highly* or *very highly adaptable*.

Level of uncertainty: *Low*

Since *R. pomonella* was first described in 1867 from the eastern side of the USA it has been intensively-studied. Its ancestral host is hawthorn (*Crataegus* spp.) but it developed the capacity to attack and reproduce on apples (*Malus* spp.) *ca*. ≥150 years ago and is considered to exist, as at least two races in the eastern part of the United States. These are the ancestral hawthorn race and the more recent apple race. However, the hawthorn race can also attack apples. The pest is considered to have been introduced more recently to the western part of the USA (first reported in 1979 in Oregon and in 1980 in the state of Washington) probably on infested apples. There is some behavioural evidence of different races in this area too. The host-range of *R. pomonella* has increased since records began and it is now considered to be able to reproduce on 55 hosts (54 if *C. invisa* is synonymous with *C. mollis*) in ten genera, but with far fewer hosts (17, in 6 genera) recorded in the state of Washington. This shows it is highly adaptable.

Its lifecycle is adaptable in so much as in some climatically-favourable years it is possible the pest can complete 2 generations thus increasing pest prevalence. Its ability to survive for up to at least 2 years in the soil as pupae means it can extend its capacity to establish in areas where it has been introduced.

In terms of its distribution and ability to adapt to different climates, *R. pomonella* occurs throughout North America. Yee *et al*. (2014) recently provided a detailed summary of the status of *Rhagoletis* pest species, including *R. pomonella, in* North America. Table 2 summarises the official status of *R. pomonella* across its range.

Geng *et al*. (2011) stated that '*in 1973, the distribution included the central and eastern areas of the United States and the adjoining provinces of south eastern Canada: from the north eastern boundaries of the United States to northern Florida, eastern Texas and eastern North Dakota (Dean and Chapman, 1973). Subsequently, this fruit fly established new populations in Oregon in 1981, from where it spread through the Pacific northwest, as far east as Nebraska by 1991 (Featured Creatures, 2002). More recently, infestations have been found in southern Saskatchewan in Canada (EPPO, 2006), and the Rio Arriba and Santa Fe counties in the northern part of New Mexico (New Mexico Department of Agriculture, 2007)*.

Bush (1966) noted the characteristics of specimens of *R. pomonella* from locations in Mexico. Rull *et al.* (2006) conducted extensive surveys for the pest in Mexico and found it was widespread but in discontinuous populations. They also found it infesting 5 of the 13 native *Cratae*gus species but noted that additional work needed to be done to determine its utilisation of the remaining species. Rull *et al*. (2006, 2011) and Feder (2003) showed genetic evidence and concluded that these isolated populations in Mexico diverged from the more northern United States populations about 1.5 million years ago.

Thus *R. pomonella* is able to adapt to a range of climates.

Currently there is no evidence of pesticide resistance for *R. pomonella* but there is evidence that this may be developing in other flies in the family Tephritidae (Vontas *et al*., 2011).

3.19 - How widely has the pest established in new areas outside its original area of distribution? (specify the instances, if possible; note that if the original area is not known, answer the question only based on the countries/continents where it is known to occur)

Widely

Level of uncertainty: *Low*

See 3.18. *R. pomonella* is native to the eastern side of the USA but is now present in most regions of the USA, southern parts of Canada, and central parts of Mexico In the USA it has been reported in 40 states (see 1.07 and Table 2). Although it has not been reported from other continents this represents a wide area of establishment beyond its native area with *low uncertainty*.

3.20 - The overall probability of establishment should be described.

R. pomonella has a *medium probability* of establishment in the areas of the PFA of the state of Washington (the PRA area) where hosts occur in commercial apple orchards, commercial nurseries if hosts bear fruit, backyards and the wider environment.

The level of uncertainty is *low*.

R. pomonella has been found outside of commercial orchards in the area of the PFA which is favourable for the pest and in some locations it has been found to be reproducing resulting in a transfer of parts of the old PFA to the quarantine area (most recently finds in Chelan County in 2011 led to part of the county being quarantined in 2012). There has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). Pest prevalence outside of commercial orchards is considered to be low. Host plants, principally apples (*Malus* spp.) and hawthorns (*Crataegus* spp.) are present but discontinuous in the PRA area albeit there are abundant monocultures of apple orchards in the five main apple-growing regions. The climate in the area where the hosts occur is moderately similar (hotter and drier overall) compared to the western side of the state of Washington where the pest is established. However, the use of irrigation in commercial orchards and the location of some of them in cooler and for some – riparian environments; plus the presence of hosts in riparian/wet/irrigated habitats outside of commercial premises (wild areas, backyards, etc.) will make these more favourable areas for establishment of the pest. Pest management practices in commercial apple orchards and nurseries producing planting material of apples (albeit those nurseries supplying commercial orchards do not produce plants bearing fruit) are likely to reduce the risk of establishment. Current practices for apples (orchard and nurseries) include treatments effective against codling moth (*C. pomonella*) and these may have some efficacy against *R. pomonella.* Codling moth sprays finish before adult fly activity ceases and this may give opportunities for the pest to invade and reproduce in commercial orchards or on nurseries producing host apple planting material (if these bear ripening fruit – unlikely for commercial orchards), late in the season. However, newer chemicals and other pest management practices may reduce this risk. Currently the pest has not been reported from commercial apple orchards so this may suggest that the regimes are having some preventative effect against infestation. However, the reported increase in organic apple production where pest management practices are likely to be less effective may increase the risk. Practices on nurseries (conventional and organic) producing ornamentals (if they bear fruit) were not investigated. Current indications are that there are no large organic nurseries that supply nursery stock bearing fruit raised from organically-produced stock to commercial growers in the PRA area (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016). On nurseries the pest has potential to establish on site if there are hosts bearing fruit, and there is a suitable substrate (soil or soil substitutes) for the pest to pupate. *R. pomonella* has a reproductive strategy which makes it very likely to establish in favourable areas. It produces high numbers of eggs and these develop within host fruit which protects the pest to some extent from fluctuations in the environment. However, high summer temperatures can desiccate smaller fruit of hawthorns which may limit pest prevalence through reduced oviposition or larval development. The pest normally overwinters as a diapausing pupa, emerging the following summer. However, there is potential for survival for at least 2 years. This favours the risk of establishment since it perpetuates the pest in an area even where eradication attempts are undertaken by the County Pest Boards. In some years with elevated temperatures two generations of flies are possible if the first generation of the pest do not diapause. This could increase pest prevalence. *R. pomonella* has demonstrated its adaptability as a pest by its ability to spread and establish beyond its native range in the eastern part of the USA to most regions of the USA, and southern parts of Canada.

The areas of uncertainty are:

- The distribution and extent of non-orchard hosts in the PRA area outside of commercial premises
- The prevalence of the production of organic planting material bearing fruit (apples and ornamental hosts) in the PRA area[23]
- The prevalence of the production of conventionally-produced ornamental hosts bearing fruit in the PRA area
- The prevalence of '*box nurseries*' (large retail nurseries) supplying planting material of apples that may be fruiting in the PRA area
- The efficacy of current pest management practices against *R. pomonella* in conventional apple orchards in the PRA area (seemingly effective but currently being investigated as part of a new research project as advised by Klaus)
- Organic production pest management methods (orchards – some details; and nurseries[24] producing fruit-bearing apple and ornamentals – no details) and their efficacy against *R. pomonella*

Pest management practices on conventional ornamental nurseries if plants bear fruit and their efficacy against *R. pomonella*

[23] Current indications are that there are no large organic nurseries that supply fruit-bearing nursery stock raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016).

[24] Current indications are that there are no large organic nurseries that supply fruit-bearing nursery stock raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016).

c1 – Conclusion on the probability of introduction

Introduction is defined as the *entry* of a pest resulting in its *establishment* (FAO, 2015).

The overall probability of entry of *R. pomonella* to the PRA area on municipal green waste originating in the quarantine area of the state of Washington (and Oregon) is considered to be *likely* with *low uncertainty*. The overall probability of establishment in the parts of the PRA area where hosts and a suitable climate occur is considered to be *medium* with *low uncertainty*.

Probability of spread

Spread is defined as the expansion of the geographical distribution of a pest within an area. Spread potential is an important element in determining how quickly impact is expressed and how readily a pest can be contained. In the case of intentionally imported plants, the assessment of spread concerns spread from the intended habitat or the intended use to an unintended habitat, where the pest may establish. Further spread may then occur to other unintended habitats. The nature and extent of the intended habitat and the nature and amount of the intended use in that habitat will also influence the probability of spread. Some pests may not have injurious effects on plants immediately after they establish, and in particular may only spread after a certain time. In assessing the probability of spread, this should be considered, based on evidence of such behaviour.

4.01 - What is the most likely rate of spread by natural means (in the PRA area)?

Moderate rate of spread

Level of uncertainty: *Low*

Within the CAPRA system, a moderate rate of spread implies the pest has a '*medium mobility (1km to 10km per year) (note that spreading to occupy a circular area at a linear speed of between 1 and 10 km per year would, within 4 years, lead to between approximately 50 km2 and 5,000 km2 being occupied)'.*

Adult flies of *R. pomonella* normally travel relatively short distances when host plants are abundant, fruiting, ripening and therefore susceptible to infestation. However, they may travel longer distances where this is not the case. All of the dispersal studies that have been done in the field were conducted in the east of the USA where hosts were abundant.

The maximum published flight distance for *R. pomonella* in the field is *ca.* 1 mile with a single laboratory study indicating potential for greater than *ca.* 3 miles. Adult flies can live for up to 40 days. They can feed on substrates on non-host plants (and possibly on other surfaces) which means that the need to travel to reproduce depends on the proximity of food substrates and of host plants with ripening fruit (which may also serve as food). A single fly could travel a large distance depending upon its behavioural preferences, need to travel and availability of hosts. In years where 2 generations occur this could increase the range.

4.02 - What is the most likely rate of spread by human assistance (in the PRA area)?

High rate of spread

Level of uncertainty: *Medium*

In the CAPRA system a high rate of spread results from a '*yes*' answer to the first two of the following questions and a '*no*' answer to the third question *(italicised in blue):*

Has a pathway that is not natural spread been identified for this pest?

Yes. The pathway of spread by human assistance that has been assessed in this PRA is the movement of municipal green waste moving from the quarantine area of the state of Washington to the PFA (the PRA area). There are other pathways of spread by human assistance including the movement of infested host fruit as a commodity (currently regulated) and infested home-grown fruit, principally apples.

Another pathway of movement by human assistance is the movement of host plants with associated soil that may be infested with pupae of *R. pomonella*.

Can the pest be transmitted by pollen, seed or (other) plants for planting (cuttings, budwood grafted plants, etc.), plant products, with packaging, conveyance machinery?

Yes. The pest can be transferred in the waste in soil containing pupae and infested host fruit. There is also a possibility that if a composting process has not eliminated the pest, that movement of this material as a product will spread the pest. However, we have no evidence that this occurs.

Is the pathway on which the pest is likely to be present widely distributed in the PRA area (trade or movement with persons) or is the pest likely to be moved intentionally by persons in the PRA area?

No. The waste is not distributed widely in the PRA area since it is transferred to four facilities. The destination of the finished compost varies however. The pest itself is not being intentionally moved by people. Its movement is inadvertent when it is associated with the intentional movement of waste that may be infested.

4.03 - Describe the overall rate of spread

High rate of spread

Level of uncertainty: *Medium*

In the CAPRA system, a high rate of spread results from the responses made to questions 4.01 and 4.02. The level of uncertainty is *medium* because of the uncertainties associated with the pathways of entry described for each of the pathways:

- The amount and type of infested host material in the waste stream at different times of year
- The amount of infested soil in the waste stream at different times of year
- The longevity of pupae of *R. pomonella* on a hard surface or in material being composted
- The proportion of infested host fruit which remain intact or partially-intact with the different grinders (likely to be variable even with the same grinder)
- The lethal time x temperature duration for all life stages of *R. pomonella* within any intact of partially intact fruit that may escape the grinding process
- Whether all the waste is fully exposed to this lethal time x temperature
- The distribution of hosts in the PRA area other than the maps of hosts that are trapped by the WSDA
- Whether adults of *R. pomonella* will feed on leachates from compost piles

The levels of infestation in some of the areas of origin of the waste has not been determined for some years but has been estimated based on expert judgement.

4.04 - What is your best estimate of the time needed for the pest to reach its maximum extent in the PRA area?

This is unknown since it relies on many factors and cannot be easily estimated.

4.05 - Based on your responses to questions 4.01, 4.02, and 4.04 while taking into account any current presence of the pest, what proportion of the area of potential establishment do you expect to have been invaded by the organism after 5 years?

As with 4.4 this is also unknown and cannot be estimated.

Eradication, containment of the pest and transient populations

5.01 - Based on its biological characteristics, how likely is it that the pest could survive eradication programmes in the area of potential establishment?

Likely

Level of uncertainty: *Low*

A rating of likely in the CAPRA system results from selecting the following set of responses for a fixed set of italicised statements (in blue) (not all of which apply to *R. pomonella* but which fit the best):

Detection
The pest and its symptoms are not visible in the first years of infection.
It is present as latent infections or in asymptomatic plants.
It can establish without symptom expression.

Although *R. pomonella* is a visible pest the detection efficiency of the best available traps used for the annual WSDA survey used in even the most efficient way is unknown and may result in undetected populations of the pest. Finding all host material outside of orchards that may be infested is also a challenge.

The efficacy of the trapping methodology used to detect a population of a flying insect such as *R. pomonella* depends on a number of factors including:

- The number of traps in an area (trap density): for the WSDA General Survey traps for *R. pomonella* are placed on host trees at a rough density of 1/square mile (rotated yearly for optimal sampling within the area as a reflection of the low host density in the PFA). Traps are placed in host trees with fruit whenever possible. Within the square mile area, using records of the previous year's programme, trappers begin the season by placing traps on trees that have been used previously. They are continuously trying to locate additional trees to use as trap sites and when they check traps they relocate them as needed to trees that are bearing fruit. Note that *R. pomonella* is not attracted to traps further than *ca*. 2 metres so traps have to be located with care. Traps are thought to capture only a small percentage (ca. 25%), (Brunner, Washington State University, *personal communication* to Mastro, USA) of the flies occupying the tree that the trap is placed in.

- The size of the population - which for *R. pomonella* is low in the PFA

And

- The efficiency of the traps

AliNiazee (1990) was one of the first, working in the Pacific Northwest, to suggest that relative trap performance was conditional and possibly based on a variety of factors including: trap positions in the canopy, the availability of maturing fruit, the stage of maturity of adult flies and environmental conditions.

The standard trap and lure combination used by the WSDA is the yellow sticky panel trap (Pherocon AM) with an ammonium carbonate lure. The major alternative trap is the red sticky sphere. A number of alternative lures (to ammonium carbonate), were first developed in the eastern part of the United States, based on fruit volatiles (Zhang *et al*., 1999; Fein *et al*., 1982; Reissig *et al*., 1982).

In a study in the state of Washington Yee *et al*. (2005) found that traps baited with ammonium carbonate were more attractive than the volatile blends which previously had been found most effective in the east (Reynolds and Prokopy, 1997). Ammonium carbonate had been recognised as a bait by Hudson as early as 1948 (<u>in</u> Yee, 2014). In the most recent studies by Yee (2014) using fruit volatile blends designed for western host species he found that ammonium carbonate was still more effective than fruit volatiles when used in either the yellow panel trap or in a red sphere trap.

Yee (2015) discussed the use of fruit volatiles to attract flies of *R. pomonella* and stated: *'Despite attraction of flies to fruit volatiles, extensive testing showed that yellow sticky traps baited with ammonium carbonate are better at detecting WA apple maggots in hawthorn and apple trees'*.

Traps in the WSDA survey are placed to take advantage of host tree cues. They are placed only in fruiting hosts, when possible, taking advantage of the visual cues identified by Prokopy (1968). The yellow panel is thought to mimic the tree foliage (Prokopy, 1968). However, Yee and Landolt (2004) found that the red spheres are more effective at trapping *R. pomonella* than the yellow panels used in the state of Washington. The WSDA survey continues to use the yellow panels for a number of reasons. Captured flies are hard to see on the dark surface of the red spheres leading to trap checking errors and also the labour cost involved in cleaning and recoating the spheres with sticky material is expensive. Even with the development of a disposable red sphere handling problems remain. The overall effectiveness or trap efficiency of any of the possible trap and lure combinations is unknown and could only be determined if marked (sterile) flies were released into grids of traps in the WSDA programme area. Recovery rates from eastern USA studies to determine dispersal distances were conducted under very different environmental and host conditions and not with the trap and lure combination used in the WSDA survey so cannot be compared (Bourne, 1934; Green *et al*., 1994; Maxwell and Parsons, 1968; Neilson 1971 reviewed by Brunner 1987). It is however of note that the WSDA detection/survey programme in its entirety has never detected a large infestation of *R. pomonella* beyond the initial finds at the programme's inception (i.e. in Seattle and Yakima). Also as is noted in other sections of this PRA, the pest has never been found in any of the commercial apple fruit inspections that have been carried out in the survey area. However, Brunner (1987), citing others stated that '*There are documented instances where trees have been monitored with the Pherocon AM trap, not caught AM and yet inspection of the fruit revealed the presence of AM larvae. Other instances have been reported where AM has been caught on Pherocon AM traps placed in a host tree and inspection of the fruit has revealed no AM larvae*' Nevertheless he concluded that 'In *the Western U.S. where AM surveys are conducted in native and urban areas, no traps has been shown to be clearly superior to the Pherocon AM trap in detecting AM, especially in low populations*'.

Thus the WSDA are trapping effectively within the bounds of the available traps and methodology for the pest. However, their efficiency in detecting adult flies beyond a 2m distance means that there may some situations where flies are present but not detectable.

The WSDA '*Apple Maggot Detection and Response Plan*' (Klaus, 2000) presented a table of factors that influenced the ease of achieving eradication. Amongst these it was stated:

'*Earliness of detection and speed in mounting eradication campaign'* - 'BAD *difficult (and expensive to detect)*' and there is a '*low probability of early detection'*.

'*Availability of powerful methods to detect low populations' – 'VERY BAD – Not available'.*

Natural spread
Spread can happen unseen.
The pest spreads quickly by natural means.
It is difficult to prevent spread by vector.

Although *R. pomonella* has a moderate rate of spread by natural means, unless it is detected by trap it has the potential to move to new areas and remain undetected.

Although difficult to design and conduct and expensive to carry out, well-designed mark recapture experiments in quarantined areas in the western part of the United Stated that is similar in host type and density could be immensely beneficial in the design of apple maggot surveys and interpretation of the results.

Reproduction
The reproductive strategy is very effective.

R. pomonella is a fecund insect with an ability to survive in an area for at least 2 years as pupae in the soil. Klaus (2000) rated the reproductive capacity as '*BAD – High'*.

Climatic condition and hosts and habitats
Climate is suitable. Host plants are widely distributed, e.g. in private gardens.

The climate in the PRA area has a medium to high favourability for establishment of the pest. There are many apple orchards in five regions which are potentially favourable due to irrigation or riparian habitats. Although the distribution of native black hawthorn *C. douglasii* is discontinuous, it is present in the area. Ornamental hawthorns are also available, both cultivated and feral. Feral apple trees are also available.

Klaus (2000) commented that '*infestation of native hawthorn along streams would effectively eliminate the eradication option because pesticides could not be used nor could the trees be removed in this habitat*'. They rated the number of host species as '*BAD – High'*.

Relevant other biological characteristics of the pest
Asymptomatic weeds, contaminated irrigation water and crop debris act as reservoirs for the pest.
Long term survival of the pest in soil or host tissue is possible.

The pest can survive outside of orchards in riparian habitats where non-commercial hosts are present. It can survive for up to at least 2 years in the soil.

There have been no findings of the pest in commercial orchards in the PRA area and this may in part be due to the efficacy of the current pest management practices in commercial orchards and the WSDA's detection and response plan (Klaus, 2000). Working with the WSDA, the County Pest Boards are swift to act in response to findings of the pest in the WSDA annual surveys. Nevertheless the PFA is reviewed each year and there have been changes made to its delimiting boundaries which in part relate to the non-eradication of the pest in what was part of the PFA. This occurred most recently in Chelan County which was part-quarantined in 2012 (Klaus *et al*., 2016). There has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016).

The current response to a detection of *R. pomonella* in the PFA (the PRA area) was described as follows (Klaus, WSDA, USA, *personal communication* to Reynolds, USA, October 2015).

'WSDA Pest Program Detects AM in Non- Quarantined Counties – County Horticultural Pest and Disease Board is notified and decides what measure(s) to take depending on time of season, host tree situation, location and other factors. The Board usually strips and destroys all fruit (if physically feasible) after a WSDA fruit sample is taken, may also treat tree with GF 120 http://www.cdms.net/ldat/ld67P008.pdf

If complete fruit removal is not practical, the tree is treated with the GF 120 or similar formulation. Pest Board then later attempts to have tree(s) removed. http://ext100.wsu.edu/benton-franklin/agriculture/pests/bentonfranklincohortpestdiseaseboards/

The Yakima County Pest Board also conducts suppression measures at positive sites within the quarantined area as funds and time permits. So far, they have been able to deal with all sites. http://www.yakimacounty.us/386/Horticulture

WSDA Pest Program (PP) – Notifies WSDA Commodity Inspection (who also notifies affected growers) of threatened orchards and arranges for any needed fruit inspection. WSDA PP will also initiate high density trapping within ½ mile around positive catch site if time permits that season. If a late season catch, a less than ½ mile zone may be used to try to get more trap data before fly activity ceases and then a complete ½ mile high density trap zone is set-up in the following survey season'.

More recent details for action taken by the WSDA when *R. pomonella* is detected in traps in the PFA (Klaus, WSDA, USA, *personal communication* to Mastro and Reynolds, USA, March 2016) are listed below:

1. WSDA Pest Program (PP) staff - Site is visited, trap checked again,

2. PP staff - fruit sample collected (~5-10 lbs. or all of the fruit if a small tree) Sample is tested in lab. (AM larva or pupae will prompt AM Working Group to consider quarantine change.

3. County Horticultural Pest and Disease Board is notified

4. WSDA Fruit and Vegetable is notified using the Threatened Orchard Notification System (TONS) if a commercial orchard is located within ½ mile of detection.

5. WSDA Pest Program assists WSDA F&V in contacting orchard for inspections.
It is up to the County Horticultural Pest and Disease Board to determine what course of action to take. They may strip fruit, spray and later remove the tree. Or they may just spray if the tree is too large to strip fruit. The choice of chemical is up to them after consultation with their WSU Extension agent. WSDA is not involved in any pesticide activities or recommendations.

Klaus (2000) states:

Eradication of AM has never been accomplished. There are many reasons for this:
1. AM pupae can survive for up to five years in soil.

2. The detection trap does not usually attract AM from any significant distance beyond the tree in which it is placed.

3. An abundance of alternate hosts (esp. wild hawthorn) in an area will make eradication difficult.

4. All hosts must be trapped to properly delimit the infestation. This requires a very labor intensive survey.

5. It is possible to have infested fruit on a tree and not be able to catch adult flies on traps.

6. Prolonged adult flight means sprays must be applied from July to mid Sept.

Early detection of AM will provide the best chance for eradication. If AM becomes established in streamside host trees, the battle will likely be lost since streams are protected areas for fish and wildlife. However, AM is most likely to become first established in urban trees. It will then spread out from tree to tree'.

Thus it considered *likely* with *low uncertainty* that *R. pomonella* could survive eradication programmes in the potential area of establishment in the PRA area.

5.02 - Based on its biological characteristics, how likely is it that the pest will not be contained in case of an outbreak within the PRA area ?

Moderately likely

Level of uncertainty: *Medium*

Working with the WSDA, County Pest Boards are swift to act on detection and completion of the identification of the pest in the PRA area and would normally aim to contain a pest outbreak with a view to eradication. However, the success of containment depends on the level of infestation. If it is one male fly that is detected in a trap and there are no larvae obtained from incubating fruit from the trapped tree then it could be assumed there is no reproducing population. If a female fly or more than one is trapped and it is found to contain fertile eggs, and larvae are obtained from incubating host fruit from the same tree, then it is possible that there is a reproducing population and containment would possibly not be effective. The ongoing surveillance and trapping undertaken by the WSDA has led to the detection of low numbers of adult flies of *R. pomonella* on traps in host trees located outside of commercial apple orchards in the PRA area (the current

PFA). Fruit harvested from these trees has been incubated. In some years juvenile forms of *R. pomonella* have developed and some parts of the old PFA were added to the quarantine area as a result, most recently stemming from finds in Chelan County in 2011. There has recently been a proposal to make part of Lincoln County subject to quarantine resulting from finds in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). However, the pest has not been detected in commercial apple fruit harvested in the current PFA of the state. (Klaus *et al*., 2016).

The rating of *moderately likely* with *medium uncertainty* reflects these varying situations.

5.03 - Are transient populations likely to occur in the PRA area through natural migration or entry through man's activities (including intentional release into the environment) or spread from established populations?

Yes

Level of uncertainty: *Low*

R. pomonella is capable of natural spread and human-assisted movement. It can establish in new areas either transiently or permanently.

Assessment of potential economic consequences

6.01 - How great a negative effect does the pest have on *crop yield and/or quality* of cultivated plants or on *control costs* within its current area of distribution?

Major

Level of uncertainty: *Low*

- The main negative effect in the areas where the pest is established outside of the PRA area (outside of the PFA of the state of Washington; in much of the USA, parts of Mexico and Canada) is the cost of control (regular and statutory) in apple orchards and other situations as described below
- Within the PRA area, although the pest is not considered to be established there, the main negative effect arises from the cost of the WSDA surveys and the cost of the response to findings of the pest in the survey. For the purposes of this PRA these can be considered to be control costs since they are necessary to maintain the PFA. These costs are included in this section

The response to this and subsequent relevant questions concentrates almost entirely on cultivated apples in commercial orchards as few data were readily-available on the impacts and controls for other types of cultivated hosts, although they are mentioned. Potential impacts to other commercially-produced fruit have not been assessed but it is assumed that those host species which are currently known to be attacked by *R. pomonella* in the state of Washington (plums – various species; common and Asian pear, and apricot) are at risk. Sweet cherry is the other commercial fruit host attacked outside of the state of Washington and this may be at risk in the PRA area if the biology of the pest changes in the state.

Direct damage to host fruit

Of the cultivated crops affected by *R. pomonella*, the main hosts in its current area of distribution are commercially-grown apples. Pears, plums, cherries and apricots are also hosts. Cultivated ornamental hosts occur in several genera but the main hosts in this category are hawthorns (*Crataegus* spp.). Crab apples are also cultivated ornamentals albeit they are considered to be of low importance for the pest (Yee *et al*.,2014).

Direct damage is caused by the female fly laying her fertilised eggs beneath the surface of host fruit leaving a puncture wound. The flesh around the puncture wound often fails to grow resulting in a sunken spot on the surface of the fruit. Emerging larvae feed on the flesh of the fruit leaving a brown trail of rotting flesh in their wake. See Figure 42

Figure 42. Apple fruit showing surface and internal damage caused by *R. pomonella*
Source: EPPO Global Database https://gd.eppo.int/taxon/RHAGPO/photos
Accessed 26 February 2016
Images courtesy of New York State Agricultural Experimental Station.

The appearance of the injury varies with the variety of apple. Puncture wounds caused by oviposition are small and only become obvious in soft-fleshed varieties when the tissue surrounding the wound starts to decay. In harder-fleshed varieties the punctures result in pronounced dimpling and the fruit may become distorted when infestation is heavy. Soft-fleshed varieties rot more readily than those with harder-flesh. Damaged fruit normally drops prematurely, rotting on the ground. Exit holes are made by the larvae when they emerge from the fruit and are ready to burrow into the soil to pupate, although some may remain in the fruit to pupate (Dean and Chapman, 1973).

R. pomonella obviously affects the quality of fruit as well as the overall yield of an apple orchard since infested fruit is unfit for human consumption. Infested fruit may be disposed of or used for other enterprises of less value than the fresh fruit market. For apple planting stock as well as other trees grown for their fruit, and for cultivated ornamental hosts such as hawthorns and crab apples, the <u>quality</u> of the plants will be negatively affected if they are bearing infested fruit when they are marketed due to the effect on their appearance. No recent estimates of yield and quality losses for cultivated apples in commercial orchards in the absence of treatment were available in the scientific literature. However Dean and Chapman (1973) documented the history of apple maggot control in the state of New York and commented that (at that time), the pest persisted in unsprayed apple trees. With few exceptions it had caused no significant damage in orchards which were well-managed. They stated that once foreign embargoes were introduced against *R. pomonella* in 1930, the growers in the state strived hard to meet export requirements for their fruit, leading to a decrease in apple maggot infestation. The introduction of azinphosmethyl as a summer spray against codling moth (*C. pomonella*) was also effective against *R. pomonella* if applied at appropriate times. This chemical was considered to play an important part in the success of the control of the pest in the state thus reducing losses.

It is routine to treat against *R. pomonella* in commercial apple orchards in areas where the pest is established. Because of this, yield and quality losses are likely to be minimal in these areas, only increasing if pest management fails, which can happen for a range of reasons. It is the cost of routine control which is the significant component of the impact that *R. pomonella* causes since the pest has to be specifically targeted. Klaus (2000) commented that in the state of New York, codling moth (*C. pomonella*), the other major pest of apples in the USA, is controlled by sprays which are timed specifically to control *R. pomonella* (rather than the other way round) since the latter must be controlled over a longer period than codling moth, thus extending pesticide sprays into the early autumn. No figures were obtained for current costs (but see 6.05 for examples of the likely costs of additional sprays in the PRA area).

There are no readily-available data on quality losses incurred by commercial producers of planting material of host fruit trees or ornamental plants in areas where the pest is established; these might arise if they are bearing infested fruit while on the premises. However, it might be assumed that as the pest is so well-documented, the risks it poses in these areas to yield and quality are well-known and are accounted for in pest management programmes, thus minimising any potential losses. Control costs are likely to be the main negative effect; again no figures were obtained.

Cultivated non-commercial fruit trees and ornamental plants bearing fruit are the most likely groups to suffer yield and quality losses in areas where the pest is established, except where the grower takes a serious interest in proactive monitoring and pest management, since a range of controls are available to the amateur, albeit the choice of pesticides is more limited without an applicator's licence.

<u>Control costs arising from regulation in all areas where the pest is established and in the PFA of the state of Washington</u>

Regulatory practices also help minimise yield and quality losses for cultivated plants in the areas where *R. pomonella* is established (e.g. if growers wish to certify their fruit they may have to comply with certain regulations which could benefit yield and quality), or present but not established (e.g. the PFA of the state of Washington). These have associated costs:

Commercial apple growers

In all of the areas where *R. pomonella* is established and subject to quarantine regulations then the requirements of the regulations are also likely to result in additional costs for apple growers, as well as the regulatory authority, if the growers wish to move fruit (and maybe in some circumstances other commodities such as nursery stock) into (e.g.) the PFA of the state of Washington, or other areas officially-designated as pest-free and to other countries which have regulations against the pest. This will include (e.g.) the costs of pest control, certification where necessary to show pest-freedom, and treatment of harvested fruit depending on the requirements of the regulation.

For exports of apples overseas the US Export Apple Act requires as a minimum:
'*That apples for export to any foreign destination do not contain apple maggot, and do not have more than 2 percent, by count, of apples with apple maggot injury'*
Source: https://www.law.cornell.edu/cfr/text/7/33.10

A list of regulations for *R. pomonella* in the state of Washington is provided under Washington State Legislature Chapter 16-470 WAC - QUARANTINE—AGRICULTURAL PESTS:
http://apps.leg.wa.gov/wac/default.aspx?dispo=true&cite=16-470&full=true

Quoting from this website 16-470-103 provides the definitions used in the regulations:

The following definitions shall apply to WAC 16-470-101 through 16-470-130:

(1) "Established" means present in a country, state, county or other area, multiplying and expected to continue.

(2) "Threatened with infestation" means that any life stage of apple maggot or plum curculio has been found within one-half mile of an orchard or other production site, including any portion of an orchard outside or beyond the one-half mile area. ***Orchards or production sites in a <u>quarantined</u> area, which are <u>not</u> surveyed by a plant protection organization, are considered to be threatened with infestation****. An orchard or other production site will be removed from threatened with infestation status, if* ***control measures are performed at the detection site*** *and survey by the department shows no further detection(s) within the one-half mile area around the orchard or other production site throughout the subsequent full growing season.*

Klaus (WSDA, USA, *personal communication*, March 2016) (not quoted verbatim) explained that the '*threatened with infestation*' status for orchards in a quarantined area which are not being surveyed by a plant protection organisation was included to account for places (such as Whatcom and Skagit County in the state of Washington) where the WSDA survey was no longer deemed practical due to the constant and repeated finds of *R. pomonella*. The WSDA and the local growers realised that the pest would always pose a threat to the orchards and so the growers decided to have their fruit inspected instead.

Treatment at the '*detection site'* is determined by the County Pest Boards in response to delimitation surveys undertaken by the WSDA as described below.

16-470-105 describes the PFA in the state of Washington and the quarantine areas that are subject to the regulations of the WSDA. These are the counties of the state of Washington outside of the PFA as well as:

'All states or foreign countries where apple maggot is established. The area under quarantine includes, but is not limited to, the states of Idaho, Oregon, Utah, and California, and, in the eastern United States, all states and districts east of and including North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas, and any other areas where apple maggot is established'.

In the state of Washington, the purpose of the quarantine is:

'To facilitate the movement of commercial fruit to domestic and international markets by providing shippers with one of two types of WSDA documents certifying their fruit is apple-maggot free. One certificate states no apple maggot flies were caught within a half-mile of the orchard shipping the fruit. The other certificate states flies were caught within a half-mile of the orchard, but WSDA inspection revealed no apple maggot larvae in the fruit'.
http://agr.wa.gov/plantsinsects/insectpests/applemaggot/ accessed 7 March 2016

To ensure that all commercial fruit of apple harvested in the state of Washington and intended for shipping is free from *R. pomonella*, the WSDA in cooperation with the County Pest Boards manages the annual apple maggot survey and the detection response and control programme throughout the apple growing areas in the state of Washington. The results of the survey which is conducted by the WSDA determines what is required to certify apples as free of the pest based on

the WSDA regulations for *R. pomonella*.
The survey uses three types of trapping densities:

- General detection trapping
- Delimiting (high density trapping)
- Orchard certification trapping

General detection traps are placed in the PFA to determine if the area continues to be pest-free. Delimiting traps (high density trapping) are deployed in response to one or more fly catches to identify the location of a newly introduced population. Certification traps are placed within a half-mile buffer of each commercial orchard, in the quarantine area to determine if the orchard is free from *R. pomonella.*

Within the PFA of the state of Washington, all commercial apples are certified as being free of *R. pomonella* unless an adult fly is trapped within half a mile of the orchard as part of the General Survey.

In the quarantine area, although there may be some general surveillance of host trees outside of orchards, those orchards wishing to be certified as pest-free have to be subject to certification trapping where all host trees located within half a mile of a commercial orchard are trapped to determine the orchards '*threatened*' or '*non-threatened'* status. However, as previously stated, orchards or production sites in a quarantined area, which are not surveyed by a plant protection organisation (in this case the WSDA), are also considered to be '*threatened with infestation*' (WSDA regulation 16-470-103).

Any orchard within or outside of the PFA with a trap that is within a half mile of the orchard which is positive for *R. pomonella* is considered to be '*threatened with infestation'*.

In the WSDA General Survey in the PFA, as a result of a positive detection within the PFA, a high density/delimiting trapping programme is initiated whereby all fruit-bearing host trees within half mile of the site will be trapped and fruit from positively-trapped trees will be incubated to determine the presence of other life stages (egg, larva, pupa) of the pest in the fruit. Results of the incubation will determine whether that county or a portion of that county will be recommended for quarantine. For orchards '*threatened with infestation'* a delimiting survey will have to be undertaken using high density trapping. It will only be removed from this status if control measures are performed at the detection site, and if survey by the department shows no further detection(s) within the half mile area around the site through the following growing season**.**

Klaus (WSDA, USA, *personal communication*, March 2016) explained that (as an example) Skagit County (now in the quarantine area) gave up trying to perform control measures as there were too many positive sites and so control was too difficult and costly to carry out. Conversely, counties such as Franklin or Grant (both in the PFA) will '*pursue the control measures and eventually have enough success to remain in PFA and to even end up non-threated as well*'.

In the quarantine area where some surveillance by the WSDA may be undertaken but also where certification trapping is undertaken, if a fly is found within half a mile of an orchard or other production site it also becomes '*threatened with infestation'*, and, as in the PFA, it will also only be removed from '*threatened with infestation'* status, if control measures are performed at the detection site, and if survey by the department shows no further detection(s) within the half mile area around the site through the following growing season; as in the PFA this is done by high density trapping.

In both cases, depending upon the results, an appropriate control/eradication response is initiated by the Country Pest Board. This might include spraying, host removal or fruit stripping. Also the owner(s) of the orchard(s) are advised of the detection and the '*threatened with infestation'* status. They may begin to treat with insecticides. This is described below. The Washington State University is responsible for providing recommendations for treatment albeit there are no official recommendations on their website. Klaus (WSDA, USA, *personal communication*, March 2016) explained that growers can check with their County Washington State University Agent to get information on what chemicals/methods to perform. The information can also be obtained through the WSU Decision Aid System (DAS) http://das.wsu.edu/site_being_updated.php
There is however no Washington State regulatory requirement to treat a threatened orchard.

Before apples from any '*threatened with infestation'* orchards can be certified free from *R. pomonella*, the orchard must be inspected by the WSDA Fruit and Vegetable Inspection Service using a biometrically based method to verify that the pest is not present in fruit in the orchard. If the pest is found in the fruit (this has never happened), the fruit must be treated with an approved cold treatment (≥90 days at ≤37.9°F or ≥ 40 days at 32°F) for it to be certified as free from the pest.

Phytosanitary bilateral trade agreements are negotiated with different trading partners, to agree on the basis for recognising freedom from *R. pomonella*. See Table 19 for specific requirements.

These types of activities incur costs within the state of Washington (or elsewhere where the pest is established or regulated in a PFA) and these may be apportioned to the grower or the regulatory authority or both.

<u>Detail of controls arising from regulation of *R. pomonella* in the state of Washington</u>

As stated previously (3.06), the only control work being undertaken specifically against *R. pomonella* in the PFA of the state of Washington is done by the County Pest Boards responding to detections made in the trapping and certification programme. Quoting from Klaus *et al*. (2007):

County Horticultural Pest and Disease Boards conduct apple maggot control measures in cooperation with the apple maggot survey. These measures include tree and fruit removal, pesticide applications or other control treatments approved by Washington State University and the Washington State Department of Agriculture.

Several counties conduct apple maggot pest prevention and control activities under interagency agreements with the Washington State Department of Agriculture and in accordance with state regulations as defined by RCW 15.09. Pest Board efforts focus on containing existing populations identified by the state survey program, preventing establishment and spread to adjacent areas, and eradicating new infestations where possible.

The Washington State Department of Agriculture provides notification of all new positive sites to the County Horticultural Pest and Disease Board Control Coordinator (hereafter known as the control coordinator). Specifically, counties contract for the services of a control coordinator. The control coordinator conducts initial and follow-up contacts with affected landowners and provides oversight for direct apple maggot control of all types (i.e. insecticide application, fruit removal, tree *removal) in accordance with chapter 15.09 RCW. The county also contracts for apple maggot control services for known or recently discovered infestations in the county. The control coordinator and contractor(s) will use an integrated pest management approach that incorporates, tree and/or fruit removal, insect life history, and insecticide application. The County ensures contracting procedures are in compliance with all applicable laws, rules, regulations, and ordinances. All control methods employed are consistent with the rules and regulations of Washington State and the County.*

In addition there is a public outreach programme (Klaus *et al*., 2007):
'WSU County Extension efforts inform the public on the need to maintain backyard fruit trees and on not transporting backyard fruit out of quarantine areas'.

Klaus also advised that: '*many local County Horticultural Pest and Disease Boards discourage purchases* [public purchases of fruiting hosts] *due to pest issues such as codling moth, leafrollers and more recently, apple maggot concerns. Some Pest Boards even offer incentives to have backyard fruit trees removed by offering vouchers for non-fruiting trees.* Klaus (WSDA, USA, *personal communication*, April, 2016).

The current response to a detection of *R. pomonella* in the PRA area was summarised as follows (quoted from Klaus, WSDA, USA, *personal communication* to Reynolds, USA, October 2015):

'WSDA Pest Program Detects AM in Non- Quarantined Counties – County Horticultural Pest and Disease Board is notified and decides what measure(s) to take depending on time of season, host tree situation, location and other factors. The Board usually strips and destroys all fruit (if physically feasible) after a WSDA fruit sample is taken, may also treat tree with GF-120
http://www.cdms.net/ldat/ld67P008.pdf

If complete fruit removal is not practical, the tree is treated with the GF-120 or similar formulation[25]. Pest Board then later attempts to have tree(s) removed.
http://ext100.wsu.edu/benton-franklin/agriculture/pests/bentonfranklincohortpestdiseaseboards/

The Yakima County Pest Board also conducts suppression measures at positive sites within the quarantined area as funds and time permits. So far, they have been able to deal with all sites.
http://www.yakimacounty.us/386/Horticulture

WSDA Pest Program (PP) – Notifies WSDA Commodity Inspection (who also notifies affected growers) of threatened orchards and arranges for any needed fruit inspection. WSDA PP will also initiate high density trapping within ½ mile around positive catch site if time permits that season. If a late season catch, a less than ½ mile zone may be used to try to get more trap data before fly activity ceases and then a complete ½ mile high density trap zone is set-up in the following survey season'.

GF-120 is a bait spray which contains spinosad. This material costs about $30 per acre (24 ounces of GF-120 per acre). It is applied using an all-terrain vehicle (ATV) with two coarse nozzles mounted on the rear of the vehicle. An acre can be treated in about 5 minutes which means that application costs are only *ca*. $1 per acre giving a total cost of about $31 per acre.

[25] Likely to mean an alternative product

This product can be used in both conventional and organic orchards. Other formulations (non-bait) include a product called Success which can be used in conventional orchards at a cost of $60 per acre or Entrust (non-bait) which can be used in organic orchards at cost of $104 per acre; both are applied at a rate of 8 ounces of formulated product per acre with an additional application cost of $20 per acre using a conventional air blast sprayer. This increases the total costs to $80 per acre in conventional orchards and $124 per acre for organic orchards per treatment respectively. Willett (Washington Tree Fruit Research Commission, USA, *personal communication*, March 2016)[26].

More recent details for action taken by the WSDA when *R. pomonella* is detected in traps in the PFA in the WSDA survey (Klaus, WSDA, USA, *personal communication* to Mastro and Reynolds, USA, March 2016) are listed below:

1. WSDA Pest Program (PP) staff - Site is visited, trap checked again,

2. PP staff - fruit sample collected (~5-10 lbs. or all of the fruit if a small tree) Sample is tested in lab. (AM larva or pupae will prompt AM Working Group to consider quarantine change.

3. County Horticultural Pest and Disease Board is notified

4. WSDA Fruit and Vegetable is notified using the Threatened Orchard Notification System (TONS) if a commercial orchard is located within ½ mile of detection.

5. WSDA Pest Program assists WSDA F&V in contacting orchard for inspections.

It is up to the County Horticultural Pest and Disease Board to determine what course of action to take. They may strip fruit, spray and later remove the tree. Or they may just spray if the tree is too large to strip fruit. The choice of chemical is up to them after consultation with their WSU Extension agent. WSDA is not involved in any pesticide activities or recommendations.

All of these activities (surveillance, trapping and certification) result in additional costs which are funded by payments made by apple growers into a budget held by the WSDA. Certification using the survey method is described under regulation WAC 16-390-230:

<u>Apple maggot survey fees.</u>

The fee for the apple maggot survey program on all apples grown or packed in Washington State and introduced into commerce for sale or shipment as fresh apples is $.015 per CWT. This fee is assessed by the director on all certificates of compliance and all shipping permits.

Treatments for all response activities outside of an orchard are paid for by the respective County Pest Boards. Each County has their own method of funding their Board operations (Klaus, WSDA, USA, *personal communication*, March 2016). County Pest Board control costs for Yakima County (a county split between the PFA and the quarantine area) for 2013, 2014 and 2015 were $44,125, $58,951 and $61918 respectively. These costs were incurred in the quarantine area. For Okanogan County which is all in the PFA, costs were small in 2015 ($1,250) but likely to rise in 2016. These figures represent all that was spent in responding to detections of *R. pomonella* in

[26] Note other products are available and these are discussed under 6.04

those counties. The costs of operating the boards are substantially higher. (Willett, Washington Tree Fruit Research Commission, USA, *personal communication*, March, 2016). It is not known whether other counties incurred costs but this is a possibility as there were some detections of *R. pomonella* beyond Yakima and Okanogan County (Klaus, 2016).

The growers pay for any treatments in their orchards.

<u>Overall control costs arising from regulation in the state of Washington</u>
In 2014 the WSDA listed the overall costs (*not split between the quarantine area and the PFA*) as: $668,063 for certification, zero for control, and $27,367 for dealing with abandoned orchards. The industry funds the work through payments made for certification.

The cost of control in response to a detection of the pest is funded by the County Pest Boards whose budgets and methods of funding vary. In 2014 Yakima County spent $58,951 in the quarantine area and Okanogan County spent $1,250 (all PFA) responding to detections of *R. pomonella*. It is not known if other County Pest Boards incurred costs dealing with detections but the annual WSDA survey report for 2015 (Klaus, 2016) indicates that there are other counties where *R. pomonella* was detected.

Control costs deployed by growers in the quarantine area of the state and in all areas where *R. pomonella* is established are not known but overall they are likely to be major.

Overall the effect of *R. pomonella* on the costs of control (and to a lesser extent on yield and quality because of the control) is *major* in areas where the pest is currently distributed with *low uncertainty*.

6.02 - How great a negative effect is the pest likely to have on crop yield and/or quality of cultivated plants in the PRA area <u>without any control measures</u>?

Massive

Level of uncertainty: *Low*

The overall probability of establishment of *R. pomonella* in the parts of the PRA area where hosts and a suitable climate occur is considered to be *medium* with *low* uncertainty. However, this accounted for the statutory controls that are in place in the PRA area (the PFA). It also accounted for the existing pesticide programmes used in apple orchards which include pesticides used for codling moth (*C. pomonella*) which have some efficacy against *R. pomonella*; as well as pesticides used on apple nurseries which are also effective, in both cases preventing infestation of fruit (in the case of nurseries where borne, most likely on retail sites), up to *ca.* mid to late August.

Without the WSDA survey and detection and response plan (a control measure) the pest could spread undetected and any findings would not be investigated or subject to pest management where deemed necessary.

Without any of the current pest management programmes in apple orchards or on other cultivated hosts that bear fruit in the PRA area there would be nothing to prevent infestation and the risk of establishment would increase. The limitation to establishment is the climate in some areas outside of commercial orchards which if hot and dry, could keep pest prevalence low. However, wild hosts in climatically-favourable areas would allow *R. pomonella* to establish and populations outside of orchards could increase. If the pest entered the apple orchards then these monocultures of host plants, with irrigation, where located in cooler areas are very favourable for establishment. Nursery environments for hosts bearing fruit (seemingly unlikely for commercial nurseries supplying commercial growers) would also potentially be more favourable without any of their current controls.

For cultivated plants that are bearing fruit the absence of any type of control (regulatory or standard pest management) would make them totally vulnerable to attack in areas favourable for establishment. Fruit loss in commercial apple orchards would be massive (not just from apple maggot but also from codling moth) resulting in massive quality and yield losses. Planting material of apples and other host fruit if bearing fruit, and ornamentals bearing fruit would also be infested reducing their quality. As detailed under 3.06, the nurseries in the state of Washington that produce planting material for apple orchards are all located in the PFA (the PRA area). Willett (Washington Tree Fruit Research Commission, USA, *personal communication*, January 2016) provided data from Howell (Northwest Nursery Improvement Institute (NNII), USA) who estimated that about 12 million apple trees were produced in the PFA (the PRA area) each year over the past three years at a value of about $8.00 per nursery tree. About 25% of these trees are shipped to other states and countries. However, the planting material of apples produced in the PFA of the state of Washington for commercial orchards is ≤2 years old when it is sold and it is thought to bear blossom but not fruit, so these are unlikely to be affected by the pest. Some of the retail nurseries may sell apple trees and other hosts bearing fruit and without any controls these could potentially become infested leading to a loss of quality.

Overall, losses in yield and quality in the PRA area would be *massive* in the absence of any type of control (both statutory and non-statutory) with *low uncertainty.*

6.03 - How great a negative effect is the pest likely to have on yield and/or quality of cultivated plants in the PRA area <u>without any *additional* control measures</u>?

Moderate to *major*

Level of uncertainty: *Low* to *medium*

In the PRA area (the PFA) the existing controls for cultivated plants are

- the WSDA survey and detection and response plan for *R. pomonella* outlined in 6.01
- the current pest management practices used in apple orchards and in nurseries producing apple planting material and ornamental hosts bearing fruit, described in section 3.06, which are not targeted at the pest

Without <u>additional</u> control measures, (statutory and non-statutory), the main sector to be affected by *R. pomonella* would be commercial apple orchards (and possibly other commercial host fruit orchards but these have not been assessed). These could become infested late in the season when codling moth (*C. pomonella*) pesticide applications cease. The likelihood of this happening depends in part on the prevalence of *R. pomonella* in the proximity of the orchards. Currently commercial orchards in the PRA area have remained pest-free without the addition of more controls. The most recent change to the PFA was in 2012 when part of the area became included in the quarantine area as a result of the pest being considered to be established there based on findings in Chelan County in the 2011 survey. However, in March 2016 there was a proposal to make part of Lincoln County subject to quarantine resulting from finds of the pest in the county in 2015 (Klaus, WSDA, USA, *personal communication*, March 2016). If pest prevalence increases then without additional controls, orchards may become '*threatened with infestation'* or ultimately become infested. In this case, yield and quality would be negatively affected without additional controls.

Commercial and non-commercial growers of planting material of ornamentals bearing fruit, particularly hawthorns and crab apples (unlikely to be commercial nurseries supplying commercial growers but possibly retail nurseries), as well as some of the (potentially older) retail nursery stock of apples which may bear fruit may also become infested without additional controls to target the pest. Commercial nurseries producing planting material are likely to have a pest management programme which may have some efficacy against the pest. However retail nurseries selling plants to the public are less likely to have a programme. Without additional controls targeted at *R. pomonella*, this could result in quality losses. Planting material of apples produced for the commercial orchard sector would not be affected by the pest as these plants/trees do not bear fruit.

Without any additional controls, the effect of the pest on yield and/or quality in the PRA area is likely to be *moderate* to *major* with *low* to *medium uncertainty*. This depends upon the scenario. Apples that ripen late in the season are most vulnerable to attack by *R. pomonella*.

In areas where the pest is not increasing significantly in the surrounding area the effect would be *moderate* and in areas where it increases significantly it would be *major;* uncertainty is *low* to *medium* in both cases.

6.04 - How great a negative effect is the pest likely to have on yield and/or quality of cultivated plants in the PRA area when all potential measures legally available to the producer are applied, <u>without phytosanitary measures</u>?

Moderate

Level of uncertainty: *Medium*

The PRA area is currently a PFA for *R. pomonella* and so there are already phytosanitary measures in place. These include the WSDA apple maggot survey and the detection and response plan. There are also measures in place prohibiting the movement of host fruit from areas where the pest is established into the PFA unless it has been cold treated or can be certified as pest-free.

As previously stated, the regulations for *R. pomonella* in the state of Washington are listed under Washington State Legislature Chapter 16-470 WAC - QUARANTINE—AGRICULTURAL PESTS: http://apps.leg.wa.gov/wac/default.aspx?dispo=true&cite=16-470&full=true

The removal of the existing measures would allow unhindered movement of fruit of host plants into the PRA area from areas where the pest is established. If any fruit were infested this would go undetected and would pose a risk of entry of the pest to areas where it could establish. If this is close to commercial orchards then entry of the pest to these orchards would require additional treatments over and above current pest control programmes. Additional pest monitoring would also be required in order to accurately time spray applications.

In areas where the pest is established, for example in the eastern side of the USA it is possible to control the pest with minimal damage, at least in conventional apple production.

R. pomonella would need to be controlled up to the end of adult flight activity. The flies emerge from pupae from late June or early July through to September and they can live for up to 40 days. Once programmes aimed at codling moth (*C. pomonella*) (which will have some efficacy against *R. pomonella*) become ineffective then further controls will need to be applied.

As described under 3.06, there are currently no official Washington State University ratings for efficacy of pesticides for control of *R. pomonella* on their website:
http://www.tfrec.wsu.edu/pages/cpg/Apple_Programs accessed March 19th 2016
although the products that can be used in commercial apple orchards against other pests are shown in the '*regular recommendation'* section of their website. For *R. pomonella* these were recommended to be used in the period late spring and summer and the pre-harvest period.

Willett (Washington Tree Fruit Research Commission, USA) advised that (from a typical pest control programme for apple orchards in 2009 provided to the PRA team in the autumn of 2015) that two of the products used against codling moth (*C. pomonella*) would also provide control of *R. pomonella* in the early part of the growing season:

- Delegate 25WG – spinetoram- applied 4 June and 2 July
- Altacor 35WDG – chlorantraniliprole - applied 18 July and 1 August

He also advised that based on the earlier work by Schotzko (1982) an additional 1 to 3 applications of an appropriate pesticide would be required after the codling moth control became ineffective, suggesting that acetamiprid, which is registered for use in apple orchards, but not officially recommended by Washington State University might be used.

In April 2016 he advised that '*in the past, acetamiprid (TriStar, a formulation that was registered for use in home landscapes) was recommended by WSU for use by pest boards but the home landscape label was limited to ornamental landscape plants and could no longer be used on home fruit trees which might host AM. While there are some consumer formulations of acetamiprid available in small, ready-to-use spray bottles, no commercial acetamiprid formulations are available for use by the pest boards in dooryard tree fruit gardens'. Currently, most pest boards are using a formulation of spinosad (a bait formulation: GF-120). A number of products containing spinosad or acetamiprid are registered for use in commercial orchards in Washington. Either of those materials could be used for AM control in orchards should treatment be need*ed'.

There are various resources on the internet that list products that can be used against *R. pomonella* in apple orchards.

The Penn State Extension Service website rates them (see 3.06 for more detail):
http://extension.psu.edu/plants/tree-fruit/insects-mites/insecticides-and-miticides/apples-insecticide-and-miticide-efficacy

The Pacific Northwest Insect Management Handbook (a collaborative publication prepared by Oregon State University, Washington State University[27] and the University of Idaho) http://insect.pnwhandbooks.org/tree-fruit/apple/apple-apple-maggot accessed 29 January 2016 listed the following products along with their pre-harvest interval (PHI) for commercial use against *R. pomonella*:

- acetamiprid – PHI 7 days
- chloranthraniliprole - PHI 14 days
- clothianidin - PHI 7 days
- indoxacarb - PHI 14 days
- spinetoram - PHI 7 days (larvicidal)
- spinosad - PHI 7 days (larvicidal) – also listed for organic use

The use of registered products against the pest should minimise the effect on yield and quality in conventional apple orchards if they are applied at appropriate times and cover the period up to harvest within the limits of the PHI.

In organic apple orchards, which amount to about 10% of the area in the state of Washington, the pest control programmes have not been fully-investigated. Spinosad and kaolin are permitted to be used, and are likely to have efficacy against *R. pomonella* when applied in conjunction with trapping to determine when to apply treatments. (See 3.06). It is assumed control of *R. pomonella* would be more difficult in organic orchards because there are fewer products available to the grower. No figures on losses for organic production of apples in areas where the pest is established were obtained. Losses in yield and quality could be minimised if organic orchards resorted to conventional production (albeit there would be losses in the premium paid for organic fruit – this is not accounted for in this question).

In backyards there is advice available to homeowners including spray programmes. For example the County Pest Board for Benton and Franklin County (in the PFA) advise that in addition to notifying their suspicion of a finding of *R. pomonella* to the authorities that they can use acetamiprid[28], kaolin, esfenvalerate or spinosad. The advice is to apply kaolin by mid-June and to keep the foliage and fruit coated which might require reapplication every 7 – 10 days until harvest. They also advise that this type of control can be achieved by enclosing young fruit in wax-coated white bags or small brown bags while on the tree. The remaining products were advised to be applied every 10 days starting in mid-June and continuing to harvest.

See: http://ext100.wsu.edu/benton-franklin/wp-content/uploads/sites/22/2015/05/Backyard-Apple-Pear-pest-mgmt-2015.pdf accessed 3 March 2016.

Cultural control measures for all orchards include the removal and destruction of any dropped fruit; see e.g. http://cru.cahe.wsu.edu/CEPublications/eb1928/EB1928.pdf. The use of traps in

[27] Note there are no ratings for efficacy of pesticides against *R. pomonella* on the Washington State University website: http://www.tfrec.wsu.edu/pages/cpg/Apple_Programs

[28] Willett (Washington Tree Fruit Research Commission, USA) advised (in April 2016) '*in the past, acetamiprid (TriStar, a formulation that was registered for use in home landscapes) was recommended by WSU for use by pest boards but the home landscape label was limited to ornamental landscape plants and could no longer be used on home fruit trees which might host AM. While there are some consumer formulations of acetamiprid available in small, ready-to-use spray bottles, no commercial acetamiprid formulations are available for use by the pest boards in dooryard tree fruit gardens*'

commercial or non-commercial areas can be used both for forecasting timings of applications of pest control treatments as well as in small orchards or homeowner situations to help reduce fly populations. The removal of other host plants and trees including hawthorn and crab apple around orchards can also help reduce fly populations.

For nurseries producing hosts that bear fruit then they will need to adjust their pest control programmes to minimise any loss in quality (appearance) resulting from infestation of fruit. This is unlikely for commercial nurseries supplying commercial growers since it is thought the plants are not bearing fruit up to the point they are sold, but it may occur on retail nurseries. However, this was not investigated.

Overall it is thought that the negative effect caused by the pest on yield and quality of cultivated plants (including non-commercial hosts) in the PRA area (the PFA of the state of Washington) when all additional controls legally-available to the producer without phytosanitary measures is likely to be *moderate* with *medium* uncertainty.

6.05 - How great an increase in production costs (including control costs) is likely to be caused by the pest in the PRA area in the absence of phytosanitary measures?

Major

Level of uncertainty: *Low*

In the absence of phytosanitary measures then the increase in production costs is that associated with conventional pest control where it is necessary. This would be required where *R. pomonella* becomes established in the vicinity of commercial orchards and nurseries if they grow host plants that bear fruit (note earlier comments about nurseries).

Although there is a list of products registered for use against *R. pomonella*, costs have not been obtained for all of them since programmes chosen by growers will vary. However, costs were obtained for acetamaprid and spinosad both of which could be used to control *R. pomonella* (Willett, Washington Tree Fruit Research Commission, USA, *personal communication*, February 2016).

Willett (January 2016) advised that:

'Although there are no official WSU recommendations for AM control in commercial orchards Assail (acetamiprid) has been recommended for use. The cost of acetamiprid at the recommended rate (3.4 oz per acre) is $50 per acre. From the spreadsheet the cost of application is $20 per acre for a total cost for a single application of acetamiprid of $70 per acre. If three applications were needed the cost would be $210 per acre. If all 167,489 acres of apple in the free areas and in the current area of low prevalence (western Yakima County) required three additional pesticide applications to protect against AM and acetamiprid was used, the cost would be $35,172,690 annually'

The west side of Yakima County ('*area of low pest prevalence*') is in the quarantine area.

As detailed under 6.01, Willett (March 2016) also advised that spinosad comes in various formulations and the cost of application is dependent upon the formulation. GF-120 is a bait spray which costs *ca*. $31 per acre applied using an all-terrain vehicle (ATV) with two coarse nozzles mounted on the rear of the vehicle which can be used in both conventional and organic orchards. Other formulations include Success used in conventional orchards at a cost of *ca*. $80 per acre or Entrust which is used in organic orchards at cost of $124 per acre. These are applied using a conventional air blast sprayer.

The only recent published report of apple production per county was USDA (2011). More recent figures have been provided by the WSDA (Carman, WSDA, USA, March 2016, *personal communication*). These figures include non-commercial orchards. The data were calculated using WSDA Apple Orchard polygon data, which contains data from many sources. These data are from the WSDA NRAS 2014 Crop Data which does not exclusively represent orchards within Washington State. See Table 15 for a breakdown of acreage in each county split between the PFA and the quarantine area of the state of Washington.

Table 15. Acreage of apples grown in commercial and non-commercial orchards in Washington State in 2014*

COUNTY	PFA acres	COUNTY	Quarantine acres
Adams	4626.65	Chelan (quarantine)	3.51
Asotin	8.98	Clallam	7.63
Benton	12354.58	Clark	7.78
Chelan (PF)	6814.36	Cowlitz	0.54
Columbia	162.17	Grays Harbor	3.97
Douglas	10194.45	Island	8.71
Ferry	28.71	Jefferson	11.95
Franklin	15025.53	King	11.85
Garfield	3.30	Kitsap	0.00
Grant	49598.54	Kittitas (quarantine)	0.00
Kittitas (PF)	1748.79	Klickitat	1574.59
Lincoln	0.84	Lewis	11.55
Okanogan	18489.13	Mason	0.00
Pend Oreille	0.73	Pacific	0.00
San Juan	10.37	Pierce	23.94
Stevens	71.12	Skagit	92.34
Walla Walla	8848.83	Skamania	2.80
Whitman	13.21	Snohomish	66.25
Yakima (PF)	27794.82	Spokane	140.52
TOTAL	**155795.12**	Thurston	1.57
		Wahkiakum	0.99
		Whatcom	91.56
		Yakima (quarantine)	23088.22
		TOTAL	**25150.28**

*Figures include abandoned orchards

A total of 180945 acres of apples were grown in the state of Washington in 2014. This is a slight overestimation of commercial production as it includes some abandoned orchards and non-commercial areas. There were 155795 acres in the PFA and 25150 acres in the quarantine area of which 23088 acres was in the quarantine area of Yakima County. This gives a total of 178883 acres in the PFA and the '*area of low pest prevalence*' in Yakima County. It is thought that *ca.* 10% of the area is in organic production giving 17888 acres of organic and 160995 acres of conventional orchards.

An additional 3 sprays of acetamaprid in the conventional orchards across the whole of the PFA would cost $32,716,950. Using Success would cost $37,390,800. For organic orchards using GF-120 would cost $1,663,584 and using Entrust would cost $6,654,336.

6.06 - Based on the total market, i.e. the size of the domestic market plus any export market, for the plants and plant product(s) at risk, what will be the likely impact of a loss in export markets, e.g. as a result of trading partners imposing export bans from the PRA area?

Moderate to major

Level of uncertainty: *Medium*

The majority of apples in the state of Washington are produced in the PRA area (the PFA) (USDA, 2011).

Table 16 summarises shipments from the state from 2008 to 2014.

Table 16. Total fresh apple shipments for Washington State, 2008 to 2014

Season	Thousands of 40# boxes	Weight (metric tonnes)
2008 - 2009	108301	1964981
2009 - 2010	102711	1863558
2010 - 2011	109464	1986082
2011 - 2012	108748	1973091
2012 - 2013	128295	2327746
2013 - 2014	115169	2089592

Extracted from Table 1, WSTFA, 2015.
A 40# box weighs 40 pounds = 18.1437kg

Approximately 6% of the shipments of apples made between 2010 and 2014 were organic (Table 5 of WSTFA, 2015).

Numerous countries received apples from Washington State between 2008 to 2014 with greater than *ca.* 30% (by weight) of the crop being exported (Table 46, WSTFA, 2015).

The top ten export destinations are presented below in Table 17 and Figure 43 (reproduced from Table 45 and the associated figure of WSTFA, 2015 with their permission) (Willett , Washington Tree Fruit Research Commission, USA, *personal communication,* March 2016):

Table 17. Export shipments as a % of the total crop for Washington State by destination: top ten 2011 to 2014

	2013-14			2012-13			2011-12			3 Year Average		
Country	Shipments	% of Exports	% of Total Crop	Shipments	% of Expo rts	% of Total Crop	Shipments	% of Exports	% of Total Crop	Shipments	% of Exports	% of Total Crop
Mexico	11.055.731	29,0	9,6	14.317.376	34,2	11,2	10.705.101	28,6	9,8	12.026.069	30,7	10,2
Canada	6.129.885	16,1	5,3	6.520.735	15,6	5,1	5.006.168	13,4	4,6	5.885.596	15,0	5,0
Taiwan	2.487.203	6,5	2,2	3.236.639	7,7	2,5	2.386.091	6,4	2,2	2.703.311	6,9	2,3
India	2.392.996	6,3	2,1	2.716.580	6,5	2,1	4.085.368	10,9	3,8	3.064.981	7,8	2,6
Indonesia	1.850.463	4,8	1,6	1.546.917	3,7	1,2	2.521.096	6,7	2,3	1.972.825	5,0	1,7
Hong Kong	1.623.388	4,3	1,4	2.098.062	5,0	1,6	2.147.808	5,7	2,0	1.956.419	5,0	1,7
Dubai	2.625.225	6,9	2,3	2.369.549	5,7	1,8	1.454.136	3,9	1,3	2.149.637	5,5	1,8
Saudi Arabia	1.000.958	2,6	0,9	871.294	2,1	0,7	751.966	2,0	0,7	874.739	2,2	0,7
Thailand	901.287	2,4	0,8	973.027	2,3	0,8	973.580	2,6	0,9	949.298	2,4	0,8
Vietnam	1.718.097	4,5	1,5	715.046	1,7	0,6	559.283	1,5	0,5	997.475	2,5	0,8
Other Destinations	6.398.389	16,8	5,6	6.441.044	15,4	5,0	6.841.718	18,3	6,3	6.560.384	16,8	5,6
Total	**38.183.622**	**100**	**33,2**	**41.806.269**	**100**	**32,6**	**37.432.315**	**100**	**34,4**	**39.140.735**	**100**	**33,3**
Total Crop	**115.171.521**	**-----**	**100**	**128.294.131**	**-----**	**100**	**108.747.720**	**-----**	**100**	**117.404.457**	**-----**	**100**

Reproduced from Table 45, WSTFA 2015

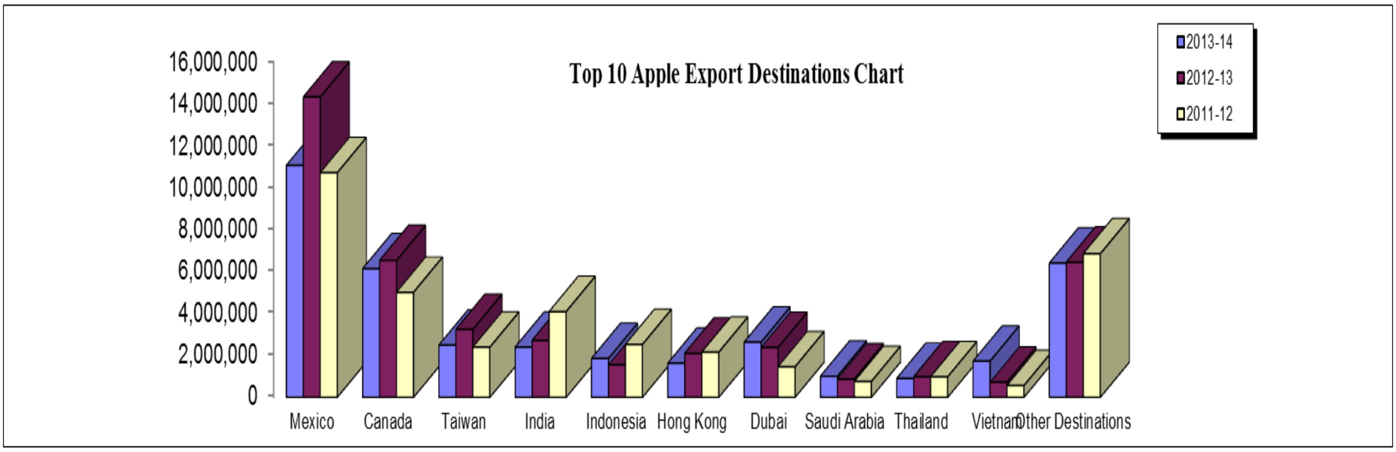


Figure 43. Number of export shipments of fresh apples made from Washington State by destination: top ten 2011 to 2014
Reproduced from Table 45, WSTFA 2015

The value of exports of fresh apples from the state between 2012 and 2015 was valued at 825, 845, 838, and 797 million US$ respectively.
Source accessed 4 March 2016:
https://www.census.gov/foreign-trade/statistics/state/data/wa.html

The US Export Apple Act requires as a minimum:
'*That apples for export to any foreign destination do not contain apple maggot, and do not have more than 2 percent, by count, of apples with apple maggot injury'*
Source: https://www.law.cornell.edu/cfr/text/7/33.10

EPPO (2016) list the countries and Regional Plant Protection Organisations (RPPOs) that specifically categorise *R. pomonella* as a quarantine pest (includes the EU). This is summarised in Table 18.

Table 18. Categorisation of *R. pomonella* by country, RPPO or the EU

Continent/Organisation	Country, RPPO or EU	Status*	Year added
Africa	East Africa	A1 list	2001
	Southern Africa	A1 list	2001
Americas	Argentina	A1 list	1995
	Brazil	A1 list	1992
	Canada	A2 list	1989
	Chile	A1 list	1992
	Paraguay	A1 list	1992
	Uruguay	A1 list	1992
Asia	China	A2 list	1993
	Jordan	Quarantine pest	2007
	Kazakhstan	A1 list	2009
	Uzbekistan	A1 list	2008
Europe	Azerbaijan	A1 list	2007
	Belarus	Quarantine pest	1994
	Moldova	A1 list	2006
	Norway	Quarantine pest	2012
	Russia	A1 list	2014
	Turkey	A1 list	2007
	Ukraine	A1 list	2010
Oceania	New Zealand	Quarantine pest	2000
RPPO	APPPC	A1 list	1993
RPPO	COSAVE	A1 list	1992
RPPO	EPPO	A1 list	1975
RPPO	OIRSA	A1 list	1992
EU	EU	Annex I/A1	1992

Source: EPPO, 2016.

*Status varies with the source. However, A1 or 1/A1 usually means a pest is absent in the country or region and subject to regulation. '*Quarantine pest*' is defined as '*A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled'*. China categorises *R. pomonella* as an A2 pest. It is assumed this means that it is regulated on imports of certain host material.

Countries with specific requirements for *R. pomonella* are listed in Table 19 (provided by Willett, now at the Washington Tree Fruit Research Commission, USA).

Table 19. Apple export markets with specific phytosanitary restrictions for *R. pomonella* and associated inspection/treatment requirements

Country	Fruit must be free of apple maggot	Fruit must come from apple maggot free area	Cold treatment option (if fruit is not from a free area)	Other certification options/requirements
Argentina	Yes	Yes		
British Columbia, Canada	Yes	Yes	33°F for 42 days OR 37°9F for 90 days	All fruit transiting BC must meet requirements for *R. pomonella*
Brazil	Yes	Yes	32°F for 40 days OR 36°F for 55 days OR 37°9 F for 90 days	Systems approach used in eastern U.S. for apples
Chile	Yes	Yes	No option	
China	Yes	No	32°F for 40 days OR 37°9 F for 90 days for apples	Shipping from certified areas of low pest prevalence without cold treatment is allowed
Cuba	Yes	Yes		
Indonesia	Apples cannot be shipped to Indonesia without cold treatment			Phytosanitary Certificate and Import Permit Required. Cold treatment requirements are listed on import permits and range from 12 days at 0°C to 18 days at 2.2°C.
Israel	Yes	Yes	0°C or below for a period of no less than 40 days; 0°C to 0.6°C or below for a period of no less than 42 days; 3.3°C or below for a period of no less than 90 days; 2.2 °C or below for a period of no less than 55 days.	Phytosanitary Certificate and Import Permit Required
Japan	Yes	No	Fumigation is required for apples.	
Mexico	Yes	No		Cold treatment required: 32°F for 40 days OR 37°9 F for 90 days for apples
South Africa	Yes	No		
Uruguay	Yes	Yes		

Information from USDA Animal and Plant Health Inspection Service Phytosanitary Export Database (PExD). Footnotes include information regarding pears and/or cherries. Countries without footnotes have no specific restrictions for those crops. All apples for export must also be free of apple maggot under the requirements of the U.S. Apple Export Act. Revised by Mike Willett, Northwest Horticultural Council, October 28, 2015. Countries in red type do not appear to offer an alternative to fruit originating in a pest-free area.

If *R. pomonella* establishes in parts of the PFA then those parts will be moved to the quarantine area of the state of Washington. In order to be able to export fruit from these orchards then they will need to meet the requirements laid-down in the WSDA regulations and those of the importing country.

The PRA team raised questions relevant to the impacts that may arise with Dr Mike Willett (Washington Tree Fruit Research Commission, USA) in March 2016 and these and the responses are quoted below:

Would orchards in the PFA that end up being moved to the quarantine area treat routinely against the apple maggot or would they opt for certification trapping and respond accordingly?

I believe that the initial preference would be to conduct certification trapping and respond accordingly until and if certification trapping routinely caught AM flies in an area. If certain growers were being asked to spray each year based on certification trap catch, I would think that they would opt for planned prophylactic treatments. However, if the upper (western part) Yakima Valley can be used as an example, as long as AM populations remain below the low pest prevalence threshold, certification trapping is valuable to be able to move apples into markets which have agreed to this approach.

Impact on socioeconomics if orchards move from the PFA to the quarantine area (employment, business etc.). If apple maggot became generally infested throughout the current PFA, would significant numbers of apple growers discontinue growing apples leading to reduced employment?

Apple production would continue with a commensurate increase in costs. Organic growers might not be able to continue, given the limited number of insecticides approved for use in certified organic programs. In that case, those orchards would drop from organic certification and revert to being farmed conventionally.

Spray programme adjustments are accounted for under 6.05.

It seems that apple production will continue in parts of the PFA that become part of the quarantine area of the state despite the establishment of *R. pomonella*. Any direct effect loss of exports will depend upon the importing countries requirements as well as their ability to source apples elsewhere.

In this respect, although there is a long list of countries and RPPOs that consider *R. pomonella* to be a quarantine pest (Table 18) those that specifically require apples from the USA to come from a PFA with no other option are Argentina, Chile, Cuba, and Uruguay (Table 19).

None of these are listed in the top ten destinations for exports from the state of Washington (Table 17 above). WSTFA (2015) lists the actual destinations for exports in more detail from 2008 to 2014 (their Table 46). Of the four that require fruit comes from a PFA, only Chile is specifically mentioned receiving an average of 0.11% of the total exports per year between 2008 and 2014. This is low in percentage terms and based upon the average number of 40 pound boxes (39,759) amounted to an average of 721 metric tonnes respectively per year over the period stated. The remaining countries (Argentina, Cuba and Uruguay) must be included as relatively low amounts in '*other destinations*' grouped by region (their Table 46).

If parts of the PFA become quarantined as a result of the establishment of *R. pomonella*, the impact on this part of the export trade looks to be relatively minor and depends upon whether these few countries change their regulations to continue to facilitate trade from these areas, or source their apple imports from elsewhere.

An example of imports being facilitated from the quarantine area of the state of Washington is China which allows shipments of apples from the USA from areas of '*low pest prevalence*' (e.g. the quarantined area of Yakima County) even if the pest '*threatens the orchard'* (trapped within half a mile of the orchard by the WSDA) provided they are '*treated in a timely manner*'. Willett (Washington Tree Fruit Research Commission, USA, *personal communication*, March 2016).

A further question to Willett (Washington Tree Fruit Research Commission, USA, from Reynolds USA, March 2016) was raised and the response is quoted below:

I believe you have stated that if the Pest Free Area was generally infested with apple maggots that there would be a loss (added expense) to the growers in the current PFA in that most apples would be required to be cold treated to sell. Also that this would not only increase the cost to ship/sell apples to many trading partners but it would also impact the market price of early season apples since they would be delayed about 30 days, due to the time it takes to cold treat them, missing the early season premium price niche. Is this correct and if so any idea what the value of such a market loss could be? We would appreciate your thoughts.

The problem that a cold treatment requirement causes is that shippers miss the first 40 to 90 days (generally a 90 day cold treatment period is used because it is harder to ensure that storage/cold treatment chamber temperatures stay at or below 0°C long enough to allow the room to qualify for the shorter treatment without becoming too cold, resulting in fruit freezing) of the marketing season in the given market. Those sales are lost forever. As to the cost, for example if we shipped to China from an AM infested area (and did not want to spend the money to conduct regulatory trapping around each orchard) fruit would have to be cold treated. If we use September 1 as the start date for the shipping season, Washington sent 477,053 cartons to apples to China from September 1 to November 30. If a 90 day cold treatment was used the industry would have lost $11,926,325 in sales into China at an estimated $25 per box. Of course this would be a worst case scenario in which no AM-free areas existed in Washington State.

In addition to the loss in sales outlined above, there is also the cost of the cold treatment.

Of the countries which have specific requirements for *R. pomonella* listed in Table 19, those which allow cold treatment as an alternative to apples originating in a PFA are Brazil, China and Israel as well as British Columbia (BC) in Canada

The amount of fruit specifically exported to BC is not known but Canada is the second largest importer of apples from the state of Washington receiving an average of 15.17% of the total exports per year between 2008 and 2014 with an average number of 40 pound boxes (5,654,079) amounting to 102586 metric tonnes per year over the 6-yr period (WSTFA, 2015). The Washington State Tree Fruit Association (WSTFA) advised that they could not say specifically how much of the fruit going to Canada went to BC as *ca.* half of the shipments have no provincial destination stated in the accompanying form; however *ca*. 10% of the total shipments to Canada up to March 8th 2016 were specified as going to BC (DeVaney, Washington State Tree Fruit Association, *personal communication*, March, 2016). However, Willett (Washington Tree Fruit Research Commission, USA, *personal communication*, April 2016April 2016) advised that '*the impact on exports to Canada is also likely to be higher as the shortest route to reach the TransCanada Highway (and the quickest route to eastern Canada markets) crosses the southeastern corner of BC and all shipments transiting BC must meet its AM quarantine requirements as if BC was the destination. If PFAs were not maintained, in the early part of the shipping season, trucking costs would increase'*.

Brazil, China and Israel received an average of 0.01%, 1.26% and 0.56% respectively of the total exports per year between 2008 and 2014 with an average number of 40 pound boxes (4,685; 467,749; and 206,897 respectively) amounting to 85, 8487, and 3754 metric tonnes per year over the 6-yr period (WSTFA, 2016).

Any move of the PFA to the quarantine area of the state of Washington would not prevent exports to these locations but the delay in shipping resulting from cold treatment may affect sales, and the associated cost of treatment would also have an economic impact. The size of this is difficult to estimate without knowing how much of the exports to Canada go to or through BC.

Schotzko (1982) also suggested there would be a need to change marketing strategies suggesting that the introduction of *R. pomonella* to the major commercial apple-growing areas in the state of Washington could result in buyers that continue to allow imports attempting to obtain a reduction in price that is '*greater than necessary'.* He believed sellers would have to accept this to ensure early season movement of fruit. Further reductions in prices may occur if markets that are closed delay lifting restrictions (if they lift them) because of the delay in movement. Schotzko (1982) acknowledges that large domestic markets such as the state of California have facilitated movement of apples from areas where *R. pomonella* is established by requiring treatment (such as cold treatment) of the fruit. He felt that the likelihood of complete closure of a domestic market such as this was very small, but that there would be a knock-on effect in price reduction since the supply of domestic fruit will increase pending the facilitation of necessary and costly treatments. The author also suggested that the presence of *R. pomonella* in the commercial growing areas of the state of Washington could influence entry into new markets.

Globalwise (2014) suggest that the loss of a small share of export markets would mean lower prices for apple growers when the displaced sales move to the domestic market. They state that if 5000 carlots[29] of apples (90718.5 metric tonnes) were added to domestic sales the growers would lose $116.7 million in income. With indirect and induced losses the total decrease in output would be $272 million. They forecast other consequences including job losses (see 6.11) and large reductions in employee compensation ($45.5 million), federal tax revenue ($12.8 million), as well as state and local taxes ($12.8 million). Whether this amount of loss of exports would occur is uncertain given the choice of phytosanitary options as alternatives to originating in a PFA.

The overall impact of losses associated with export markets arising from *R. pomonella* establishing in the PRA area depends upon the extent to which the current PFA moves to the

[29] A carlot is 1000 40 pound boxes of apples; a 40 pound box weighs18.1437kg; so 1000 boxes weighs 18143.7kg; 5000 carlots weighs 90718.5 metric tonnes

quarantine area, which in turn depends upon the rate at which the pest establishes there. Firstly, the four countries that specify that fruit must originate in a PFA import relatively low amounts of apples from the state of Washington. However, even if the amount of fruit that can no longer be exported is relatively low, a loss in export markets will have a knock-on effect on the domestic market (however temporary) since there will be an increase in supply, however small. This may reduce the price that sellers can expect for their fruit. In addition there is the potential for loss in sales and associated costs where cold treatments are used to facilitate exports to the three countries and one province of Canada that allow exports from quarantine areas provided the fruit has been subject to such treatment.

No attempt has been made to make a full economic impact assessment since as Zhao *et al* (2007) illustrate this depends on many factors not least of which is the extent to which *R. pomonella* establishes in the affected area. It is estimated that these losses will vary from *moderate* to *major* with *medium* uncertainty.

6.07 - To what extent will direct impacts be borne by producers?

Major extent

Level of uncertainty: *Low*

As a result of the establishment of *R. pomonella* in the PFA, the affected area will become part of the quarantine area. Apple production is likely to continue but organic production, which currently accounts for about 10% of the acreage in the state of Washington [and is projected to rise by about half again over the next two years (http://www.tfrec.wsu.edu/pdfs/P2957.pdf)], may have to revert to conventional production. This would increase the supply of non-organic fruit resulting in price reductions across the market. Also, if a premium is paid for organic fruit then affected growers will suffer additional losses.

In addition to this, the direct impacts borne by the producer are a *moderate* loss in yield and quality (6.04 – *medium uncertainty*), a *major* increase in production costs with the addition of 1 to 3 pesticide applications per season (*low uncertainty*) (6.05), and the effects arising from the impact on export markets which will lead to losses in sales and lower prices; this may also increase costs (such as cold treatment for fruit). This will occur if exports are facilitated by a request for compliance with alternatives to fruit originating in a PFA. The effect arising from impacts on export markets is rated at *moderate to major* with *medium uncertainty* (6.06); however, according to Globalwise (2014) a lot of the impacts will be borne by the economy overall.

6.08.0A - Do you consider that the question on the environmental impact caused by the pest within its <u>current</u> area of invasion can be answered?

No, but there is some evidence that the environmental impact may be significant in the PRA area. *R. pomonella* attacks a wide range of hosts including native species such as the hawthorns *C. douglasii* (reported in the states of California, Colorado, Idaho, Oregon and Utah – as well as Washington) and *C. suksdorfii* (Washington) as well as wild plants including crab apples (*Malus* spp.) in a wide range of locations. Ecologically-important host species that provide fruit and shelter to wildlife are likely to be infested in areas where the pest is established. In commercial orchards and possibly on nurseries producing host plants bearing fruit, *R. pomonella* is controlled in part by the use of targeted pesticide applications. A full environmental impact assessment for the PRA area is not possible due to a lack of published data on the impact it has in the areas where it is currently established.

6.09 - How important is the environmental impact likely to be in the PRA area?

Major

Level of uncertainty: *Medium*

Depending upon the extent of establishment of *R. pomonella* in the PRA area it has the potential to infest environmentally-important areas with ecologically important plant species. It will also require additional pesticide applications for control of the pest in commercial orchards and possibly on nurseries producing plants bearing fruit.

6.09.01 - What is the risk that the host range of the pest includes native plants in the PRA area?

High risk

Level of uncertainty: *Low*

The host- range of *R. pomonella* is wide (55 hosts in the family Rosaceae) but it is less so in the state of Washington where it is currently established. It has been recorded in the state on 17 hosts in 6 genera including native hawthorns *C. douglasii* and *C. suksdorfii*.

6.09.02 - What is the level of damage likely to be caused by the organism on its major native host plants in the PRA area? (If possible, this question should be answered by taking account the impacts on its major host plants in the PRA area. If the effects on the host plants in the PRA area are not well known, then the answer should be based on damage levels in other areas, but with a higher level of uncertainty).

Medium to low level

Level of uncertainty: *Medium*

Black hawthorn (*C. douglasii*) is a major native host in the PRA area but the distribution is discontinuous and it is generally found in riparian and wet areas. Infestation of this plant has been found to be patchy to the east of the Cascade Mountains (Hood *et al*., 2013). Yee (2008) investigated host plant use by *R. pomonella* in south central Washington from 2004 to 2006 and found that 0 to 22.5% of wild black hawthorn (*C. douglasii*) was infested. The climate in the PRA area is generally hotter and drier than in areas of western Washington where the pest is established. *R. pomonella* is likely to infest fruit of native hosts such as *C. douglasii* but damage may be lower in the hotter drier areas due to the prevailing climate.

Klaus (WSDA, USA, *personal communication*, March 2016) advised that most of eastern Washington is considered to be sagebrush steppe habitat. However, moisture availability due to irrigation, reservoirs, towns etc. creates other habitats suitable for the pest and where there are host plants including native hawthorn (*C. douglasii*) along streams these are more likely to favour establishment. Other areas at higher (cooler) elevations with similar vegetation will be favourable.

His experience was these areas are the following rivers or creeks: Yakima, Wenatchee, Okanogan, Portions of the Columbia, Entiat, Methow, Naches, Walla Walla, Touchet, Tucannon, Squilchuck creek (near Wenatchee); as well as around lakes: Chelan, Entiat, Palmer, Roosevelt and Osoyoos. It is these areas where the pest is more likely to infest at a high rate leading to direct damage to host fruit.

However, *R. pomonella* does not kill host plants directly, rather it infests and damages host fruit. This may reduce reproductive capacity by reducing the numbers of viable seed. The impact depends upon the numbers of fruit that are affected. Unfortunately there are no data available on this aspect.

Consequently the potential damage to native plants such as *C. douglasii* is considered to be likely with *medium* to *low uncertainty*.

Impact on ecosystem patterns and processes

6.09.03 - What is the ecological importance of the host plants in the PRA area?

High importance

Level of uncertainty: *Low*

Concentrating on black hawthorn (*C. douglasii*) it plays a vital role in stream stabilisation and provides food and shelter for a variety of animals in places where it occurs. No detail of the situation in the PRA area has been obtained but it is assumed that it is of high ecological importance there.

Extensive details of the ecological importance of this plant (as an example of a host of ecological importance) are available at:
http://eol.org/pages/630576/details

A brief excerpt from this site is quoted below (accessed 15 March 2016:

'Douglas hawthorn thickets produce an abundant amount of food and cover for wildlife species. Dried fruits and stems provide autumn food for frugivorous birds such as blue and sharp-tailed grouse in Washington and Idaho. Mule deer and small mammals consume dry Douglas hawthorn fruits in Utah during winter. Sharp-tailed grouse in western Idaho fed exclusively on Douglas hawthorn fruits'.

Conservation impacts

6.09.04 - To what extent do the host plants occur in ecologically sensitive habitats (includes all officially protected nature conservation habitats)?

High extent

Level of uncertainty: *Low*

Maps of host plants outside of commercial orchards that are trapped by the WSDA are presented in Figures 35 (wild and backyard apple trees), 36 (crab apple), 37 and 38 (native and ornamental hawthorn respectively).

Figure 44 (below) obtained from: http://www.blm.gov/or/districts/spokane/plans/ewsjrmp/files/Map_36.pdf indicates ecologically-important habitats in parts of the PRA area. It is assumed that at least some of the hosts of *R. pomonella* occur in these habitats.

More information of ecologically sensitive habitats can be obtained here. http://www.landscope.org/washington/ecosystems/

A detailed study has not been undertaken.

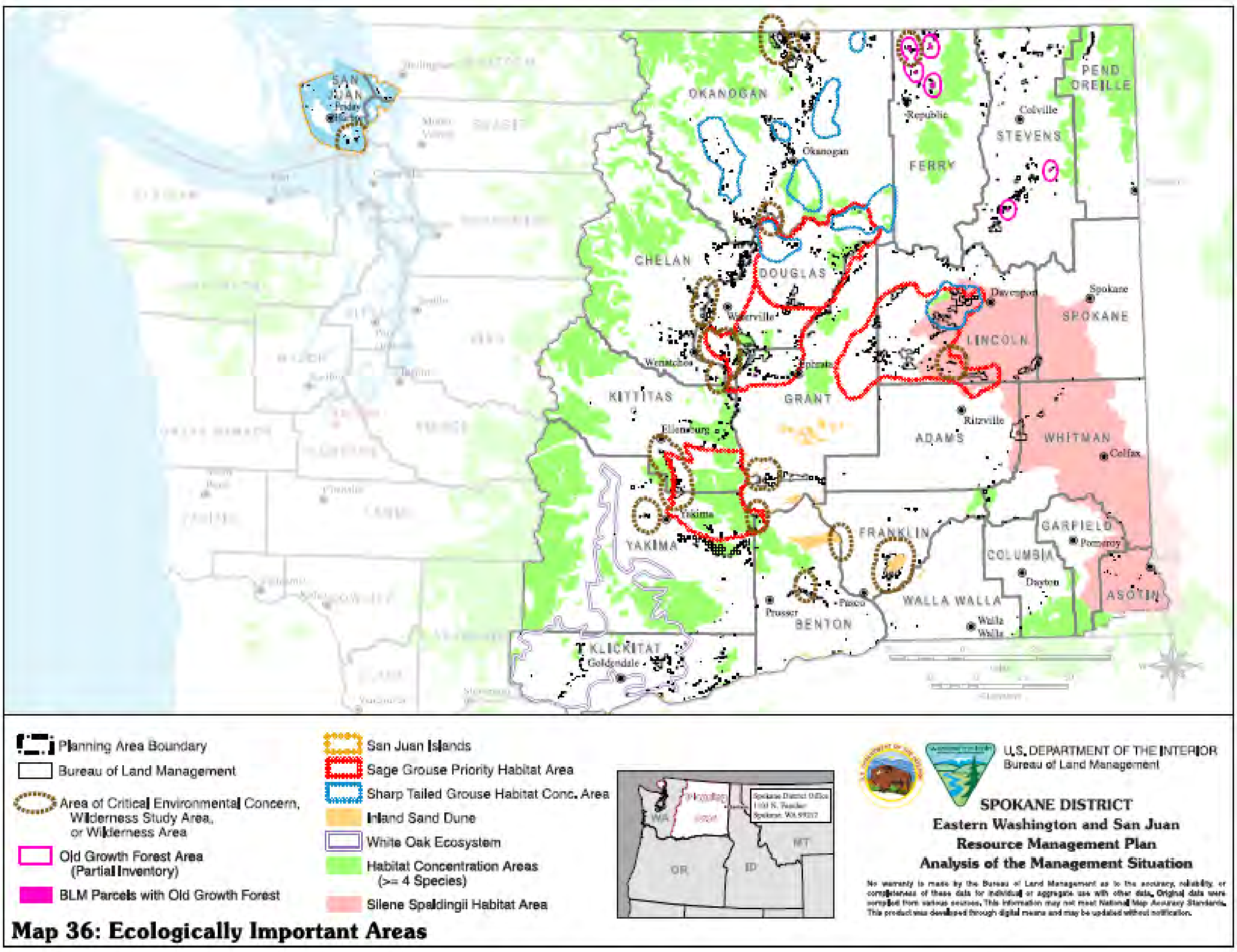


Figure 44. Map of ecologically important areas indicating areas in the PRA area of Washington state.
Source: http://www.blm.gov/or/districts/spokane/plans/ewsjrmp/files/Map_36.pdf

6.09.05 - What is the risk that the pest would harm rare or vulnerable species? (includes all

species classified as rare, vulnerable or endangered in official national or regional lists within the PRA area)

Medium risk

Level of uncertainty: *High*

It is not known whether the hosts that *R. pomonella* attacks are considered to be rare or vulnerable in the PRA area or whether any of the organisms that depend upon the host fruit are rare or vulnerable. Currently the pest is known to attack 17 host species in the state of Washington and it if widens its host range (currently it attacks 55 hosts in total – see Table 1) in the PRA area it has the potential to damage rare/vulnerable species.

<u>Impact of pesticides</u>

6.09.06 - What is the risk that the presence of the pest would result in an increased and intensive use of pesticides?

High risk

Level of uncertainty: *Low*

The presence of *R. pomonella* in commercial orchards and possibly on nurseries growing plants that bear fruit while still at the nursery will result in increased and intensive use of pesticides aimed at controlling it. These may also be used by County Pest Boards outside of commercial premises to control outbreaks in feral and wild host plants. However, the use of pesticides in riparian areas is prohibited limiting the impact of pesticides on some of the potentially important ecosystems. The amount of pesticide use depends on the extent to which the pest establishes in the PRA area.

6.10 - How important is social damage caused by the pest within its current area of distribution?

Minor

Level of uncertainty: *High*

No detailed study was possible so the level of uncertainty is high, but it is assumed some loss of employment might occur as a result of an uncontrolled outbreak of *R. pomonella* in commercial situations in the current area of distribution of the pest, albeit control strategies are well-understood. Affected growers will need time to respond and adjust their pest management programmes. Plants with landscape value are usually considered to be trees so in this respect, the impact of the pest is likely to be minimal in the current area of distribution.

6.11 - How important is the social damage likely to be in the PRA area?

Moderate

Level of uncertainty: *Medium*

Social damage is limited to the loss of employment. The likelihood of this happening as a result of the establishment of *R. pomonella* in the PRA area is thought to be *moderate* with *medium uncertainty* as it is assumed that growers will continue to produce apples (the main host affected by the pest in places of employment). However there will be a period of adjustment needed to account for required changes in pest management as well as in the effects on exports. Globalwise (2014) suggest that the loss of a share of export markets (5000 carlots[30] = 90718.5 metric tonnes) would lead to a loss of around 1100 jobs in the commercial apple industry in the state of Washington.

THE EPPO CAPRA SYSTEM STATES:
*As your responses to question 6.04 and **6.05** were '**major**' or 'massive' <u>or</u> any of the responses to questions 6.06, **6.09** and 6.11 is '**major**' or 'massive' or 'very likely' or 'certain', and the answers given to these questions do not have a high level of uncertainty, questions 6.12 to 6.14 are skipped.*

6.15a - Describe the overall economic impact *(sensus stricto)*
The sectors likely to be affected by the establishment of *R. pomonella* in the PRA area are:

- Commercial apple orchards
- Commercial nurseries producing fruit-bearing plants that are bearing fruit on the nurseries pre-sale. These are unlikely to be producing apple planting material apart from for the retail trade. They are more likely to be nurseries producing ornamentals such as hawthorn and crab apple which may bear fruit prior to sale although this is considered rare on commercial nurseries
- Non-commercial situations cultivating hosts bearing fruit such as in backyards, parks or community projects
- Ecologically-important areas where host plants are established

Potential impacts to other commercially-produced fruit have not been assessed but it is assumed that those host species which are currently known to be attacked by *R. pomonella* in the state of Washington (plums – various species; common and Asian pear, and apricots) are at risk. Sweet cherry is the other commercial fruit host attacked outside of the state of Washington and this may be at risk in the PRA area if the biology of the pest changes in the state.

The main impact that *R. pomonella* has in areas where it is established is on control costs in apple orchards, both statutory and non-statutory (although other host fruits are affected). It is a regulated pest in many countries and is listed by a number of NPPOs and RPPOs. Consequently regulations are in place in areas such as the state of Washington to ensure that fruit of apples is traded without it being infested with the pest. Standard pest management practice in areas where it is established is to treat it routinely, at least in commercial apple orchards. This minimises yield and quality losses. The other main pest in apple-growing areas is the codling moth (*C. pomonella*). Early season sprays against this pest in apple orchards are likely to afford some protection against fruit infestation by *R. pomonella.*

[30] A carlot is 1000 40 pound boxes of apples; a 40 pound box weighs18.1437kg; so 1000 boxes weighs 18143.7kg; 5000 carlots weighs 90718.5 metric tonnes)

As a result of the establishment of *R. pomonella* in the PFA (the PRA area), the affected area will become part of the quarantine area. Without any form of pest control (statutory or pest management), *R. pomonella* is likely to cause *massive* losses in yield and quality of host fruit with *low* uncertainty. Without additional controls (over and above what is already being undertaken in the PRA area) targeted at the pest then yield and quality losses are likely to be *moderate* to *major* with *low* to *medium* uncertainty. This depends upon the extent of establishment of the pest, and whether apples being grown are late-ripening susceptible varieties. Late-ripening varieties are more vulnerable due to the cessation of codling moth sprays prior to the end of the flight period of *R. pomonella*. When all potential measures legally-available to growers are applied without any phytosanitary measures, yield and quality losses are likely to be *moderate* with *medium* uncertainty. The increase in production costs associated with the establishment of *R. pomonella* in the PRA area is likely to be *major* with *low* uncertainty since up to 3 additional sprays will be required at the end of the growing season which are targeted at the pest. Organic growers may have to revert to conventional production and will suffer a loss in premium where this is paid for organic fruit. Organic fruit will add to the supply of conventional fruit leading to reduction in prices. The effects arising from the impact on export markets are likely to be *moderate* to *major* with *medium uncertainty*. This will result from losses in export sales, lower prices due to increased supply, and possibly increased costs (such as that associated with cold treatment for fruit) which will occur if exports are facilitated by a request for compliance with alternatives to fruit originating in a PFA. There will be other knock-on effects on the economy overall according to Globalwise (2014).

Commercial nurseries producing hosts that are bearing fruit on the nursery may also suffer losses in quality (poor appearance of fruit) due to the establishment of *R. pomonella* in the PRA area. It is less likely that fruit will be borne on planting material on commercial nurseries supplying commercial growers but this may occur on retail nurseries. Existing pest control programmes may limit this but additional treatment may be necessary. Retail nurseries selling plants bearing fruit are more likely to suffer impacts as it is less likely they will have a routine pest control programme in place.

Cultivated non-commercial fruit trees and ornamental plants bearing fruit are the most likely groups to suffer yield and quality losses in areas where the pest might establish in the PRA area, except where the grower takes a serious interest in proactive monitoring and pest management, since a range of controls are available to the amateur.

Environmental impacts arising from the establishment of *R. pomonella* in the PRA area were difficult to assess since the ecological impact of the pest is not well-documented. However, the likely impact is assessed overall as *major* with *medium* uncertainty. The pest already attacks ecologically-important native plants such as black hawthorn (*C. douglasii*) and other native hawthorns such as *C. suksdorfii* which occur in ecologically-important locations in the state of Washington. It has potential to expand its host-range beyond what it is already known to infest in the state. However, although it attacks the fruit of host plants it is unlikely to result in their death. But it may result in a reduction in food supply to those species which rely on it as a source of nutrition. The likely increase in the use of pesticides (albeit not permitted in riparian areas) that will be required to be used as a result of establishment of *R. pomonella* in the PRA area has potential for affecting the environment via the effect on other species such as insect pollinators.

Social damage is likely to be *moderate* with *medium* uncertainty with potential for job losses arising from businesses adapting to the need to manage the risk posed by establishment of the pest in the PRA area.

The main uncertainties are:

- Impacts of *R. pomonella* in organic apple orchards where the pest is established
- Control and efficacy of control against *R. pomonella* in commercial nurseries producing fruit-bearing hosts including ornamentals
- Environmental impact of *R. pomonella* in areas where it is established
- Full ecological significance of host plants in the PRA area

6.15b - With reference to the area of potential establishment identified in Q3.08, identify the area which is at highest risk from economic, environmental and social impacts. Summarise the impact and indicate how these may change in future.

The parts of the PRA area which are suitable for establishment of *R. pomonella* are located in areas with moderate summer temperatures, and high precipitation or irrigation or in riparian or other wet habitats. These include a) apple orchards and host plant nurseries bearing fruit where pest management practices are not totally effective against the pest either due to the timings of application, the products that are used or other pest management strategies being ineffective; b) yards and landscaped areas where host plants are present and c) areas in the wider environment where host plants are present. Establishment may also be possible in the areas where the climate is less favourable (hotter, drier) but the levels of infestation that might occur may be reduced.

The overall probability of establishment in the parts of the PRA area where hosts and a suitable climate occur is considered to be *medium* with *low uncertainty*. This accounted for the effect of existing controls; both statutory and non-statutory.

If introduced, *R. pomonella* is most likely to establish outside of commercial premises in the first instance. This will include wild areas and backyards as well as landscape plantings of host plants. These are likely to suffer impacts arising from fruit infestation since pest control either will not be enacted or is not feasible. Where commercial apple orchards fail to respond to the increased prevalence of *R. pomonella* in the surrounding vicinity then they may suffer direct yield and quality losses. This will affect their ability to ship fruit. If it is possible to suppress the pest (an additional cost) to the point that WSDA certification methods are effective, some fruit may be able to be shipped. In some cases where infestations of the pest increase to high levels because of conditions which are favourable to the pest it may not be possible to certify fruit from orchards. Conventional apple orchards are more likely to be able to adjust to establishment of the pest in the PRA area since organic orchards, currently accounting for around 10% of the acreage in the PFA, have fewer options for pest control. Once the pest has established in a part of the PRA area, then that area will be moved to the quarantine area of the state. Organic orchards may be forced to produce apples conventionally which will incur costs for additional pesticide sprays (as with conventional orchards) but will also result in a loss of premium for the prices that are paid for organic fruit. The majority of the export markets either have no specific requirements for *R. pomonella* (other than considering it to be a quarantine pest) or the markets to which apples are exported which do not offer other options such as cold treatments are relatively small. However, for markets which do offer cold treatment as an alternative to PFA certification there will be a delay while fruit is treated which could lead to large losses in sales as well as incurring the cost of treatment.

Impacts to other commercial fruit (plums, pears, apricots and possibly sweet cherries) in the PRA area have not been assessed.

Environmental impacts would arise from an increase in the amount of pesticide that was used to specifically control *R. pomonella*. There is also a potential for environmental impacts arising from direct damage to ecologically-important hosts albeit this has not been documented in areas where the pest is established.

Social damage may arise from job losses arising from the need to adapt to managing the pest in the PRA area.

c2 - Degree of uncertainty and Conclusion of the pest risk assessment

The uncertainties identified for the probability of entry, establishment, and spread of *R. pomonella* in the PRA area (the PFA of the state of Washington) as well as the likely impact are summarised below, along with suggestions for actions that could be taken to address them.

1. <u>Probability of entry of *R. pomonella* to the PRA area (the PFA of the state of Washington), on pathways originating in the quarantine area of the state of Washington[31] where the pest is established</u>

Overall the probability of entry is *likely* with *low uncertainty*

The ratings for each of the four pathways also had associated low uncertainty.

1. Municipal green waste moving to Barr-Tech LLC, Lincoln County from the quarantine area of the state of Washington – likely with low uncertainty

2. Municipal green waste moving to Natural Selection Farms, Yakima County from the quarantine area of the state of Washington – moderately likely with low uncertainty

3. Municipal green waste moving to Pacificlean Environmental, Grant County from the quarantine area of the state of Washington – very likely with low uncertainty

4. Municipal green waste moving to Royal Organic Products, Grant County from the quarantine area of the state of Washington (and from one county in Oregon) – very likely with low uncertainty

Although the level of uncertainty associated with the responses to each of the questions for each pathway was low there remain areas of uncertainty that are common to all four pathways. These are listed below in Table 20 with suggested actions to address them where deemed necessary by the WSDA and feasible. Of course all field studies involving the pest would have to be conducted away from the PFA of the state of Washington.

[31] Pathway 4, Royal Organic Products also received waste from Multnomah County in Oregon

Table 20. Areas of uncertainty in the assessment of the risk of entry and suggested actions to address them

UNCERTAINTY – RISK OF ENTRY	SUGGESTED ACTIONS
Amount and type of infested host material in the waste stream at different times of year	Surveillance and sampling of waste streams
Amount of infested soil in the waste stream at different times of year	Surveillance and sampling of waste streams
Longevity of pupae of *R. pomonella* on a hard surface	Field survival studies of pupae on the types of surfaces used for storage and composting of waste at each facility
The longevity of pupae of *R. pomonella* in material being composted (other than fruit or soil clods)	Scaled-up survival studies of pupae in municipal green waste (added to the bags used to test the pupae) based upon Yee and Chapman's '*manuscript in preparation'*
The proportion of infested host fruit which remain intact or partially-intact with the different grinders	Tests of the impact of grinding on infested host fruit including apples, hawthorns and crab apples using the grinders deployed at the transfer stations and at the composting facilities
The proportion of soil clods which may escape the grinding process	Tests of the impact of grinding on soil clods of a range of soil types using the grinders deployed at the transfer stations and at the composting facilities
The impact of grinding on pupae of *R. pomonella*	Tests of the impact of grinding on pupae of *R. pomonella* using the grinders deployed at the transfer stations and at the composting facilities
The lethal time x temperature duration for all life stages of *R. pomonella* within any intact fruit that may escape the grinding process	Oven tests of survival of eggs, larvae and pupae in infested fruit based upon Yee and Chapman's '*manuscript in preparation'* as well as Yee's more recent work
The lethal time x temperature duration for late third instars and pupae of *R. pomonella* within any intact soil clods that may escape the grinding process	Oven tests of survival of late third instars and pupae in soil clods based upon Yee and Chapman's '*manuscript in preparation'* as well as Yee's more recent work
Whether all the waste is fully exposed to lethal time x temperatures	Temperature monitoring of surfaces of windrows and static piles from 0 to 30cm depth at all facilities at different times of year (NB this does not account for internal cold spots)
Impact of curing on pupae of *R. pomonella*	Survival studies of pupae of *R. pomonella* during the curing process in compost ready for curing obtained from each of the four facilities
Whether adults of *R. pomonella* will feed on leachates from compost piles	Feeding experiments
Pathway 4 – effect of the material that is placed on top of the aerated static pile on temperatures at the surface of the pile	Temperature monitoring of the surface of the static piles (under the covering) from 0 to 30cm depth at Royal Organic Products at different times of year
Pathway 4 – effect of the material that is placed on top of the aerated static pile on mortality of pupae of *R. pomonella* and likelihood of escape of adult flies	Scaled-up survival studies of pupae in municipal green waste (added to the bags used to test the pupae) with '*overs*' placed on top of the pile based upon Yee and Chapman's '*manuscript in preparation'*
The distribution of hosts in the PRA area	Vegetation survey
Pathways 3 and 4 – actual levels of infestation of *R. pomonella* in areas of western Washington and Oregon (pathway 4) where waste originates – currently based upon expert judgement	WSDA survey extended to include areas of western Washington and Oregon where waste originates for pathways 3 and 4

2. Probability of establishment of *R. pomonella* in the PRA area (the PFA of the state of Washington)

The overall probability of establishment of *R. pomonella* in the PRA area (the PFA of the state of Washington) where hosts occur in commercial apple orchards, commercial nurseries where hosts bear fruit, backyards and the wider environment is *medium* with *low uncertainty*.

The answers to all but one of the questions had *low uncertainty* associated with them. Existing pest management practices in the PRA area on commercial premises other than commercial apple orchards were not known and had a *medium* level of uncertainty. There were other areas of uncertainty in addition to this. Table 21 lists these along with suggested actions to address them where deemed necessary by the WSDA.

Table 21. Areas of uncertainty in the assessment of the risk of establishment and suggested actions to address them

UNCERTAINTY – RISK OF ESTABLISHMENT	SUGGESTED ACTIONS
The distribution and extent of non-orchard hosts in the PRA area outside of commercial premises	Vegetation survey in the PFA
The prevalence of the production of organic planting material bearing fruit (apples and ornamental hosts) in the PRA area. Current indications are that there are no large organic nurseries that supply nursery stock bearing fruit raised from organically-produced stock to commercial growers in the PFA (based upon *personal communication* from Cooper, WSDA, USA, to Reynolds, USA, April 2016).	Verification of numbers of organic nurseries and volume of material produced (apples and ornamental hosts) in the PFA, and whether this bears fruit while on the premises.
The prevalence of the production of conventionally-produced ornamental hosts bearing fruit in the PRA area	Survey of numbers of conventional nurseries (including retail) and volume of material produced (ornamental hosts) in the PFA, and whether this bears fruit while on the premises.
The prevalence of '*box nurseries*' (large retail nurseries) supplying planting material of apples that may be fruiting in the PRA area	Survey of numbers of retail nurseries supplying planting material of apples in the PFA, volume of material, and whether this bears fruit while on the premises.
The efficacy of current pest management practices against *R. pomonella* in conventional apple orchards in the PRA area	Survey of current pest management practice in conventional apple orchards in the PFA. Compare practices with efficacy ratings of products and methods against *R. pomonella* awarded by extension services where the pest is established.
Organic production pest management methods (orchards – some details were available; for nurseries producing fruit-bearing planting material of apples and ornamentals there were no details); and their efficacy against *R. pomonella*	Survey of current pest management practice in organic orchards and nurseries (apples and host ornamentals bearing fruit if there are any) in the PFA. Compare practices with efficacy ratings of products and methods against *R. pomonella* awarded by extension services where the pest is established
Pest management practices on conventional ornamental nurseries if plants bear fruit and their efficacy against *R. pomonella*	Survey of current pest management practices on conventional ornamental nurseries (including retail) producing host plants bearing fruit. Compare practices with efficacy ratings of products and methods against *R. pomonella* awarded by extension services where the pest is established

3. <u>Probability of spread of *R. pomonella* in the PRA area (the PFA of the state of Washington)</u>

The overall probability of spread of *R. pomonella* in the PRA area (the PFA of the state of Washington) is *high* but with *medium uncertainty.*

This is mainly because the rate of spread by human assistance was assessed as *high* with *medium uncertainty*. This is because of the uncertainties associated with the pathways of entry outlined in Table 20. If deemed necessary by the WSDA, actions suggested to address these are provided in the table.

In addition, it is not known how quickly the pest would spread outside of apple orchards in the PRA area. To address this it would be necessary to undertake studies on the spread *of R. pomonella* in quarantine areas with similar vegetation and climate to the PRA area.

4. Potential impact of *R. pomonella* in the PRA area (the PFA of the state of Washington)
The overall impact of *R. pomonella* establishing in the PRA area is likely to be *major* with *low uncertainty*. A number of questions had medium uncertainty associated with them. The main areas of uncertainty are listed in Table 22 with suggestions for actions to address them where deemed necessary by the WSDA.

Table 22. Areas of uncertainty in the assessment of the potential impact of *R. pomo*nella in the PRA area and suggested actions to address them

UNCERTAINTY – ECONOMIC IMPACT	SUGGESTED ACTIONS
Yield and quality losses for apple growers in the PRA area without additional controls (pest management and regulatory). This varies with the scenario. Apples that ripen late in the season are most vulnerable to attack by *R. pomonella* because codling moth sprays have ceased. In areas where the pest is not increasing significantly in the surrounding area the effect would be *moderate* and in areas where it increases significantly it would be *major*; uncertainty is *low* to *medium* in both cases.	Not possible to address as scenario-dependent
Yield and quality losses for all cultivated plants in the PRA area when all potential measures legally available to the producer are applied, without phytosanitary measures. Assessed as *moderate* with *medium uncertainty*	Determination of the impacts of *R. pomonella* in organic apple orchards where the pest is established Determination of the control and efficacy of control against R. *pomonella* in commercial nurseries producing fruit-bearing hosts including apples and ornamentals (see Table 21)
Effects arising from impacts on export markets. Assessed as *moderate* to *major* with *medium uncertainty*.	Full economic impact assessment
Social damage in the PRA area. Assessed as *moderate* with *medium uncertainty*.	Full economic impact assessment
Environmental impacts arising from the establishment of *R. pomonella* in the PRA area. Assessed as *major* with *medium uncertainty*	Determination of the direct and indirect ecological impact of *R. pomonella* in areas where it is established. Vegetation survey to determine types and prevalence of ecologically-important hosts in the PFA. Study of the ecological significance of host plants in the PRA area including a study of species that are dependent upon them in the area.

c3- Conclusion on the pest risk assessment

R. pomonella is an insect pest with a host range of 55 plant species in ten genera in the family Rosaceae. It is widespread in the USA and has a restricted distribution in Canada and Mexico. It is endemic in the east of the USA and is considered to have been introduced to the Pacific

Northwest including the state of Washington, most likely as result of the movement of infested apple fruit. In the state of Washington there are records of the pest on 17 plant species in six genera including apples and 4 species of hawthorns (its native host). *R. pomonella* lays its eggs in host fruit within which the larvae develop. This results in direct yield and quality losses in areas where the pest is established and increased control costs in commercial premises. In WSDA surveys of the pest, it has been recorded on traps in the PRA area (the PFA of the state of Washington) outside of commercial orchards, but it has not been found in commercial apple fruit in the area.

R. pomonella is already regulated in the state of Washington as well as in other areas where it occurs and it is listed as a quarantine pest by a number of National and Regional Plant Protection Organisations. Around 2 million metric tonnes of apple fruit, representing 30% of the crop produced in the PRA area is exported annually to a wide range of destinations around the world; this is facilitated by the pest-free status of the area where the majority of the state's orchards are located. Regulated articles in the state of Washington are fruit of a range of hosts of the pest including apple, crab apple and hawthorn originating in quarantine areas. These cannot be moved into the PFA of the state without meeting certain requirements to ensure that *R. pomonella* is not introduced to the area.

Municipal green waste containing host fruit originating in quarantine areas was only recently-identified as a potential pathway of entry of the pest to the PRA area when a new composting facility started operating in Grant County in 2015. There are four composting facilities in this part of the state, three of which have been processing waste, including yard waste for a number of years originating in the quarantine area of the state of Washington, as well as one (Royal Organic Products - ROP) which also processes waste from Multnomah County, Oregon, an area where *R. pomonella* is established.

Municipal green waste from the quarantine area moving to all four facilities poses a risk of entry of *R. pomonella* to the PRA area which is considered to be *likely* with *low uncertainty*. The most likely (*very likely*) pathways are waste moving to Pacificlean Environmental and ROP in Grant County, in part (but not solely) because the waste they receive is yard debris originating in the western side of the state of Washington (and also from Oregon for ROP) where the levels of infestation with *R. pomonella* are thought to be high. The least likely pathway (*moderately likely*) is waste moving to Natural Selection Farms in Yakima County; the waste originates in the eastern side of the state (a lower level of infestation) and volumes processed are low relative to the other facilities. BarrTech LLC receives high volumes of waste but this also originates in the eastern side of the state making entry *likely*. For all of them there is a period of time at the start of onsite processing when transfer of *R. pomonella* to the PRA area may occur from flies eclosing from pupae in the waste during the flight period of the pest. This is because the waste takes time to heat up during the composting process. Surface temperatures on windrows or static piles will not become lethal to the pest immediately. This may be protracted if the waste is never turned as occurs at ROP.

If *R. pomonella* enters the PRA area on these pathways it has a *medium* probability of establishment in the areas of the PFA of the state of Washington (the PRA area) where hosts occur in commercial apple orchards, commercial nurseries where plants bear fruit, backyards and the wider environment. The climate is not completely favourable to population growth (with hot dry summers) and current pest management practice in apple orchards will limit infestation until the end of codling moth treatments. Nevertheless, establishment could occur.

Eradication or containment of *R. pomonella* would be difficult because a) the pest is a flying insect with a maximum reported flight distance from flight mill studies of 3 miles, and *ca.* 1 mile from field studies b) traps to detect populations are only effective in close proximity to the pest, and c) the pupal stage resides in the soil (sometimes in fruit) where it can survive for at least 2 years. Spread by natural means is considered to be *moderate* but spread with human assistance (infested fruit or soil) is likely to be *high* and can be inadvertent until the regulatory authorities take control of an outbreak. Historically, parts of the PFA have become quarantined as a result of finding reproducing populations outside of orchards, with the most recent proposal arising from finds in the WSDA survey for the pest in Lincoln County in 2015. This is in spite of the efforts of County Pest Boards taking action as a result of detections made by the WSDA.

Introduction of *R. pomonella* to the PRA area is likely to result in major economic impacts resulting largely from the increased cost of control in commercial premises, particularly apple orchards, costs and losses related to the effects on export markets, as well as environmental impacts arising from increased pesticide use, and potentially the effect of the pest on ecologically-important plant species.

Impacts to other commercially-produced fruit in the PRA area have not been assessed.

Pest Risk Management

A decision has to be made to determine whether the risk from any pest/pathway combination is an acceptable risk. This decision will be based on the relationship between the level of risk identified in the pest risk assessment stage (i.e. the combination of the probability of introduction and the potential economic impact) and the importance/desirability of the trade that carries the risk of introduction of the pest.

7.01 - Is the risk identified in the Pest Risk Assessment stage for all pest/pathway combinations an acceptable risk?

No.

R. pomonella has the potential to enter the PRA area (the PFA of the state of Washington) on municipal green waste from the quarantine area of the state of Washington (and Oregon) with a *medium* potential for establishment in commercial apple orchards, commercial nurseries growing fruit-bearing hosts, in backyards and in the wider environment in the PRA area. It poses a risk of *major* economic impact to the apple industry, and potentially to the ornamental industry if they grow fruit-bearing host plants (most likely to be the retail sector). Its introduction to the PRA area also poses a risk to the environment resulting from the potential need for an increase in pesticide applications in commercial premises; but also the direct damage it may cause to ecologically-significant plant species and ecosystems (currently undocumented but a potential risk). The pest is already regulated as a quarantine pest in the state of Washington and elsewhere, including internationally, by National and Regional Plant Protection Organisations.

7.02 - Is natural spread one of the pathways?

No.

All four pathways that have been examined in this PRA are the movement by humans of municipal green waste from quarantine areas for *R. pomonella* into the PRA area.

Preamble to management of each pathway

Normally when using the EPPO PRA scheme, each pathway is assessed separately.

However, for this PRA, the responses are the same for each pathway (with some variation in the responses to question 7.10).

Municipal green waste as a commodity on which a pest can move to a new area has not been assessed using the EPPO PRA scheme previously; the responses to the questions reflect this.

The pathways that have been assessed collectively for risk management are:

1. Municipal green waste moving to Barr-Tech LLC, Lincoln County from the quarantine area of the state of Washington

2. Municipal green waste moving to Natural Selection Farms, Yakima County from the quarantine area of the state of Washington

3. Municipal green waste moving to Pacificlean Environmental, Grant County from the quarantine area of the state of Washington

4. Municipal green waste moving to Royal Organic Products (ROP), Grant County from the quarantine area of the state of Washington (and from one county in Oregon)

Because natural spread is not one of the pathways the EPPO scheme starts at question 7.06.

7.06 - Is the pathway that is being considered a commodity of plants and plant products?

Yes.

The commodity being moved on all four pathways is municipal green waste. This is comprised of waste plant material. Depending upon the origin, it may contain grass clippings, fruit from private yards, municipal spaces and discarded from fruit collection programmes, shrub and tree trimmings, whole plants with roots and associated soil, agricultural waste and fruit from commercial premises.

For this PRA, the origin and type of municipal green waste varies for each of the four pathways and it is not strictly-defined, apart from broad categories of waste used by the composting facilities in their annual reports. It is described under 2.03 for each of the pathways. All of the pathways move yard waste and all except pathway 2 (Natural Selection Farms) move mixed food and yard waste which originates in the quarantine area for *R. pomonella*. The food component of mixed food and yard waste is unknown. Waste from commercial premises such as grocery stores for pathway 4 (Royal Organic Products) has not been assessed in this PRA as the origin of the waste cannot be determined.

The EPPO scheme proceeds to question 7.09.

7.09 - If the pest is a plant, is it the commodity itself?

No.

The pest is an insect that may be associated with the commodity.

7.10 - Are there any existing phytosanitary measures applied[32] on the pathway that could prevent the introduction of the pest? (If yes, specify the measures in the justification).

Yes.

Level of uncertainty: *Low*

Pathway 1 – Barr-Tech LLC
Municipal green waste from the quarantine area of the state of Washington moving to Barr-Tech LLC is not subject to direct phytosanitary measures. However, the facility and a 5-mile radius around the facility were included in the 2015 WSDA survey for *R. pomonella*.

Pathways 2, 3 and 4 – Natural Selection Farms, Pacificlean Environmental and Royal Organic Products
Currently these facilities are prohibited from processing municipal green waste originating in quarantine areas for *R. pomonella*. As with Barr-Tech LLC, they were also included in the 2015

[32] This response only accounts for current measures. No consideration of the WSDA Special Permits for Waste Transport and Distribution in relation to *R. pomonella* has been made. See: http://agr.wa.gov/LawsRules/Rulemaking/PP/wastetransportationpermit030215.aspx

WSDA survey for *R. pomonella.*

7.11 - Are the measures likely to change in the foreseeable future?

No judgement is made in response to this question. The decision is that of the WSDA.

Level of uncertainty: *Low*

7.12 - Do you conclude that other measures should be considered?

Yes.

Level of uncertainty: *Low*

Currently the WSDA has regulatory requirements for the movement of host fruit into the PRA area from quarantine areas for *R. pomonella* which include options for treatment to ensure that the fruit is free from the pest.

A list of regulations for *R. pomonella* in the state of Washington is provided under Washington State Legislature Chapter 16-470 WAC - QUARANTINE—AGRICULTURAL PESTS
http://apps.leg.wa.gov/wac/default.aspx?dispo=true&cite=16-470&full=true

The details of regulations for fruit are given below:

16-470-111

What commodities are regulated for apple maggot?

All fresh fruit of apple (including crab apple), cherry (except cherries that are commercial fruit), hawthorn (haw), pear (except pears that are commercial fruit from California, Idaho, Oregon, Utah, and Washington), plum, prune, and quince are regulated under quarantine for apple maggot. [Statutory Authority: Chapters 17.24 and 34.05 RCW. WSR 06-14-004, § 16-470-111, filed 6/22/06, effective 8/1/06. Statutory Authority: Chapter 17.24 RCW. WSR 01-14-075, § 16-470-111, filed 7/3/01, effective 8/3/01.]

There are various options for permitting fruit of these hosts to enter the PRA area depending upon the origin and these include two options for cold treatments aimed at destroying the juvenile stages of the pest:

(*a) The shipment is composed of apples, which have undergone cold treatment for a continuous period of at least ninety days. During this ninety days, the temperature within the storage room must be maintained at thirty-seven and nine-tenths (37.9) degrees Fahrenheit or less.*

(b) The shipment is composed of regulated commodities, which have undergone cold treatment for a continuous period of forty days or more. During this forty days, the temperature within the storage room must be maintained at thirty-two (32) degrees Fahrenheit or less.

As municipal green waste originating in the quarantine area is likely to contain host fruit that may be infested with *R. pomonella*, it would seem appropriate to consider options for measures that include treatment of the waste in the quarantine area. These options should be aimed at reducing the viability of the juvenile stages of the pest, particularly the pupae. This is discussed under 7.24.

There may be other actions which could be considered for inclusion in a systems approach for managing the risk if they are deemed to be practical. This is discussed under 7.25.

Options at the place of production

7.13 - Can the pest be reliably detected by visual inspection at the place of production (if the answer is yes specify the period and if possible appropriate frequency, if only certain stages of the pest can be detected answer yes as the measure could be considered in combination with other measures in a Systems Approach)?

No.

Level of uncertainty: *Low*

In this case the '*place of production*' is mainly non-commercial premises including backyards, parks, maybe other municipal areas. . Visual inspection would involve detection of the adult fly using traps which have to be within 2m of the insect, inspection of fruit from a range of hosts, and looking for pupae in soil associated with host plants. This is not feasible or reliable given the range and number of locations that municipal green waste might be collected from.

7.14 - Can the pest be reliably detected by testing at the place of production? (If only certain stages of the pest can be detected by testing answer yes as the measure could be considered in combination with other measures in a Systems Approach).

No.

Level of uncertainty: *Low*

See answer to 7.13. Testing would involve cutting fruit, or incubation of fruit, collected from a wide range and number of locations in insect rearing chambers to determine the presence of a reproducing population of *R. pomonella*. As is the case with visual inspection, this is not feasible or reliable given the range and number of locations that municipal green waste might be collected from.

7.15 - Can infestation of the commodity be reliably prevented by treatment of the crop?

No.

Level of uncertainty: *Low*

Host plants growing in backyards and other non-commercial premises cannot be reliably treated to prevent infestation of fruit or soil associated with host plants by *R. pomonella*.

7.16 - Can infestation of the commodity be reliably prevented by growing resistant cultivars? (This question is not relevant for pest plants).

No.

Level of uncertainty: *Low*

There is no true resistance to *R. pomonella* across its range of hosts although there are examples from published research which show that oviposition may occur (leading to punctures in host fruit) but that larvae did not develop (e.g. tests of *Malus* accessions by Myers *et al*., 2008).

Even if resistant cultivars of host plants were available this is not an appropriate option for managing the risk posed by the movement of potentially-infested municipal green waste as it is harvested from a range of a sources.

7.17 - Can infestation of the commodity be reliably prevented by growing the crop in specified conditions (e.g. protected conditions such as screened greenhouses, physical isolation, sterilized growing medium, exclusion of running water, etc.)?

No.

Level of uncertainty: *Low*

This is not an appropriate option for municipal green waste.

7.18 - Can infestation of the commodity be reliably prevented by harvesting only at certain times of the year, at specific crop ages or growth stages?

No.

Level of uncertainty: *Low*

See Table 23.

Table 23. Periods when eggs, larvae, and pupae can be in municipal green waste originating in the quarantine areas of the state of Washington and Oregon.

Life stage	**Eastern Washington**		**Western Washington and Oregon**	
	Start date	End date	Start date	End date
Eggs (in fruit)	Mid to late June	Late September to October* depending on date of first hard freezing temperatures	Early to mid-June	Late October depending on date of first hard freezing temperatures
Larvae (in fruit)	Mid to late June	Early November depending on date of first hard freezing temperatures	Early to mid-June	End of November into early December depending on date of first hard freezing temperatures
Pupae	. In fruit, soil , growing media, or in the sod or duff at any time of the year[33]			

*Because the populations are so sparse or nonexistent in areas in central Washington (Yee *et al*., 2012) the seasonality or even the entire host range of the apple maggot is uncertain on the eastern side of the Cascade mountain range. The timing provided in the table is based on what is known and assumes that the same host range exists on the eastern side as on the western side of the state.

The most likely period when infested fruit may be in the waste stream depends upon whether it originates in the western side of the state of Washington, Oregon, or from eastern Washington. This is discussed under question 2.03 for each of the pathways. Pathways 1 and 2 process

[33] Only soil is mentioned in the main text for the assessment but the other substrates are relevant

municipal green waste from eastern Washington, Pathway 3 from western Washington, and Pathway 4 mostly processes waste from western Washington and from Oregon. A broad assumption would be that infested fruit could be present in municipal green waste from mid-June to early November for Pathways 1 and 2, and early June to early December for Pathways 3 and 4.

However, pupae in soil associated with host plants could be in municipal green waste all year round.

7.19 - Can infestation of the commodity be reliably prevented by production in a certification scheme (i.e. official scheme for the production of healthy plants for planting)?

No.

Level of uncertainty: *Low*

This is not an appropriate option for municipal green waste.

7.20 - Based on your answer to question 4.01 (with uncertainty), select the rate of spread.

R. pomonella has a *moderate* rate of spread (see 4.01).

Level of uncertainty: *Low*

Based upon this answer the EPPO PRA scheme suggests that a pest-free place of production or pest-free area may be an option for consideration as a phytosanitary measure. See 7.21.

7.21 - The possible measure is: pest-free place of production or pest-free area
Can this be reliably guaranteed?

No.

Level of uncertainty: *Low*

The origin of the municipal green waste for all pathways is the quarantine area of the state of Washington as well as Oregon for Pathway 4. Pest-freedom cannot be reliably guaranteed.

Options after harvest, at pre-clearance or during transport

7.22 - Can the pest be reliably detected by a visual inspection of a consignment at the time of export, during transport/storage or at import?

No.

Level of uncertainty: *Low*

Municipal green waste is a heterogeneous commodity which is shipped in large volumes. Detection of the pest in infested fruit and soil that may be in the waste as well as free within the waste at the time of movement from the quarantine area, during transport/storage, and at arrival at the four composting facilities would be possible to a limited degree. However, it is not reliable as it is not possible to visually inspect all of the waste.

7.23 - Can the pest be reliably detected by testing of the commodity (e.g. for pest plant, seeds in a consignment)?

No.

Level of uncertainty: *Low*

See answer to 7.22.

7.24 - Can the pest be effectively destroyed in the consignment by treatment (chemical, thermal, irradiation, physical)?

Yes either as a one-step treatment or in a '*systems approach'.*

Level of uncertainty: *Medium*

The EPPO PRA scheme suggests that specified treatment of the consignment may be an option for managing the risk posed by *R. pomonella* on the four pathways that have been assessed.

The pupa is the life stage of the pest that poses the greatest risk of transfer to the PRA area. As would be expected for an insect pest, there is evidence that heat treatment of the pupae of *R. pomonella* in the laboratory, or composting under certain conditions can result in 100% mortality. The evidence that it can be eliminated has been described in the preamble to the risk of entry section and it is summarised again below:

Yee and Chapman (*manuscript in preparation*) achieved 100% mortality of pupae of *R. pomonella* (free from host material and soil) in the laboratory by ramping-up temperatures (as would be expected at the start of the composting process) from 27°C for 1 day, then 38°C for 1 day followed by 3 days at 56 to 58°C; or from 27°C for 1 day, then 3 or 7 days at 50.5°C. The relative humidity during the tests was 100%. As part of the same study, the effect of composting on pupae was investigated between October and December 2015 at the Terrace Heights transfer station in the quarantine area of Yakima in the state of Washington. Pupae were held in bags in ground residential yard waste (waste dimensions less than 5cm) at 0cm, 5cm and 46cm depth in piles of waste which were approximately 30yd^3 with 60-65% moisture. The study found that 100% mortality of pupae was achieved in an uncovered pile in October 2015 when they were held at 46cm depth and exposed to a mean temperature of 59°C for 4 days. This was also achieved in a tarped pile in November 2015 at 5cm (38°C) or 46cm depth (52°C) for 7 days; and, in December 2015 in a pile covered with two tarpaulins with reflective insulation sandwiched in-between for pupae held for 9 days at 0cm (39°C), 5cm (44°C) and 46cm (58°C). Temperatures in the waste pile were always highest at the 46cm depth.

More recent laboratory work by Yee (USDA, ARS, USA, *personal communication*, March 2016) showed that pupae of *R. pomonella* held at lower temperatures in the laboratory needed longer exposure to heat to achieve mortality compared to unpublished work by Neven (USDA, ARS, USA, *personal communication*, January 2016). Yee showed that 1 day at 45.3°C was insufficient to kill all pupae but 3 days at 46.3°C led to eradication (100% RH); Neven showed that 20 minutes at 50°C led to 100% pupal mortality (%RH unknown). These results do not account for any other factors that may influence mortality during the composting process.

The results of these studies show that it is possible to kill the pupae of *R. pomonella*:

- Under laboratory conditions when free of host material or soil or surrounded by municipal green waste
- As free pupae in small-scale composting of ground yard waste

At the industrial-scale, the most critical thing to consider when composting municipal green waste that may contain the pest in host fruit, soil, or mixed into the waste, is to ensure that all of the pupae are exposed to lethal temperatures. Although there may be other factors in the composting process that influence mortality of the pest, such as the effect of toxic conversion products or lytic enzymes, this has never been investigated for *R. pomonella* (or as far as we know for other insect pests). Unlike temperature this would be difficult to monitor for process control.

EPPO, the Regional Plant Protection Organisation for Europe and the Mediterranean countries, make specific recommendations for treatment of waste that may pose a phytosanitary risk including temperature regimes during composting waste of this type (EPPO, 2008), extracts[34] of which are quoted below:

Before end-use in agriculture, horticulture, silviculture or landscaping, biowaste [municipal green waste] *should be treated by the methods described below in order to destroy plant pests, and tested by the methods described below to determine their compliance with the requirement for freedom from the majority of plant pests or, where known or suspected to be present, freedom from quarantine pests and heat-tolerant pests. If the treated biowaste* [municipal green waste] *is mixed with other materials, the mixture components should, as relevant, comply with these requirements or be shown to be free from pests.*

The treatment process will differ depending upon whether the waste is high risk or low risk.

***High risk waste is waste containing or suspected to contain quarantine pests or heat-tolerant pests**.*

Other waste is considered to be low risk. Where there is any doubt about the phytosanitary risk posed by the waste the National Plant Protection Organisation[35] (NPPO) should be consulted.

Minimum requirements aimed at eliminating most plant pests are defined below.

Additional specific requirements related to biowaste [municipal green waste] *known or suspected to contain **quarantine pests** or heat-tolerant pests are presented in the next section.*

In order to prevent potential contamination, all treated material should be stored in such a way as to avoid any contact with untreated materials (direct contact, or contact though runoff water, wind, machinery, tools, storage containers, etc.).

Minimum requirements

The processes at composting facilities should be managed in such a way as to guarantee a thermophilic temperature range and a high level of biological activity over a period of several

[34] Text in blue, or emboldened in black font is particularly relevant to *R. pomonella*

[35] Or other regulatory authority, such as the WSDA

weeks. This should be achieved under appropriate conditions of humidity and nutrients, as well as by optimum structure and optimum air conduction. In general, the water content should be at least 40%. In the course of the composting process, the entire quantity of materials being treated should be exposed either to a temperature of at least 55°C for a continuous period of two weeks, or to a temperature of at least 65°C over a continuous period of one week (or, in the case of enclosed composting facilities, at least 60°C). A minimum number of turnings may be required to ensure that the whole mass is exposed to this temperature.

The time/temperature combinations for composting mentioned above will eliminate most plant pests. However, there are reports in the scientific literature, based on various experimental methods, which have shown that some heat tolerant organisms have survived these time/temperature combinations.

Specific requirements for biowaste [municipal green waste] ***containing quarantine pests or heat-tolerant pests***
Biowaste of plant origin known or suspected to contain any quarantine pests or heat-tolerant pests should receive a special heat treatment: 74°C for 4 h (Marcinisyn et al.*, 2003), 80°C for 2 h or 90°C for 1 h (Lorenz, 2006) using wet heat, either before or after processing.*

Where biowaste [municipal green waste] *is known or suspected to contain any* ***quarantine pests*** *the treatment and the whole process should be authorized and supervised by the NPPO, including confinement conditions to prevent escape of any quarantine pest, testing of the resulting treated biowaste* [municipal green waste] (*which should be found free from the quarantine pest by appropriate methods i.e. EPPO Standards in series PM 7 Diagnostics when available) and, if appropriate, specification of a 'non-risk' outlet for the end-use*.

Exceptionally, the NPPO may decide not to apply the heat treatment and to rely on the minimal requirements for the treatment process described above if:

• *The treatment process has undergone direct process validation* <u>*and*</u> *given the characteristics of the pest it can be concluded that this treatment is effective in eliminating it*

Or

• *There is pest-specific scientific evidence showing that the treatment process is effective in eliminating the pest of concern.*

Compliance
In general, both 'indirect process supervision' and 'product analyses' [explained below] *are used to determine whether treated biowaste* [municipal green waste] *complies with requirements. Treated biowaste* [municipal green waste] *should not be released for end-use unless all requirements are satisfied. Products having failed to meet any of the requirements should be treated again or should not be used for the end use specified in this standard. Direct process validation may be required if the untreated biowaste* [municipal green waste] *is known or suspected to be infested with a quarantine pest or a heat-tolerant pest (see above).*

Heat treatment facilities should be verified before the first treatment and at regular intervals (preferably yearly) thereafter by a technical expert.

'Indirect process supervision' is temperature monitoring; '*product analyses*' include testing for

viable seeds, other plant parts or specific pests/pathogens to ensure the product meets phytosanitary standards. Full detail on the processes proposed by EPPO and the terms used are available in (EPPO, 2008).

<u>How the EPPO Phytosanitary Procedure PM 3/66 (2) (EPPO, 2008) relates to managing the risk posed by *R. pomonella* in municipal green waste from the quarantine area</u>

EPPO minimum requirements - option 1

Although *R. pomonella* is a quarantine pest there is '*pest-specific scientific evidence*' arising from the composting field study of Yee and Chapman (*manuscript in preparation*) and information from Neven (USDA, ARS, USA, *personal communication*, January 2016) which suggests that starting the composting process of quarantine waste in the quarantine area, as per the minimum requirements of EPPO (2008), could be a viable option to manage the risks posed by the pest. While Yee and Chapman's field study was effective in achieving 100% mortality of pupae and it is similar to the minimum requirements proposed by EPPO, it was done at a much smaller-scale than industrial composting and the waste was not turned. As discussed in section 2.0 (risk of entry), it is possible that the edges of a pile of waste, including the bottom of the pile can be cooler than the inner part of the pile. Without turning this can persist. In Yee and Chapman's study the pupae that were tested were free from host material and soil and were not placed at all depths of a pile/windrow that would represent an industrial composting operation. Their study would need to be expanded to account for the variables presented by an industrial process if this was devised for testing in a location/locations in the quarantine area. Also, if undertaken, these new studies would have to test sufficient pupae of *R. pomonella* to provide the level of confidence that would be required by the WSDA. The process recommended for the minimum requirements of EPPO (2008) may be conducted in open windrows or enclosed in e.g. an insulated container, or a building (tunnel composting). Tunnel composting is an option that could be investigated since it would provide more control over the processes than composting outdoors. Yee (USDA, ARS, USA, *personal communication*, April 2016) will be investigating the potential for heating infested waste in trailers with a composting company in Seattle once oven heating tests have been completed.

If this is option is to be developed, the need to be able to conduct '*direct process validation*' (as described below) would have to be accounted for in the design.

Direct process validation is verification that the treatment process has efficacy in destroying the pest under conditions similar to what would occur in practice. It may be carried out once using indicator organisms to determine efficacy of the treatment, such as those described in EPPO (2008) which are quite easily obtained, or in this case, pupae of *R. pomonella* if this is feasible. Indicator organisms are buried in all representative decomposition zones in the waste, or are introduced in the process stages responsible for their inactivation, in this case the thermophilic stage of the '*pre-composting'* step. After completion of the process, they are removed, and tested for survival or infectivity. Careful monitoring of temperatures (or thermal mapping) would provide confidence that the heating was adequate through the pile. This is discussed in 7.30.

Once verified and adopted this treatment should be undertaken in the quarantine area before moving the treated waste to the composting facilities in the PRA area to continue processing.

With respect to '*appropriate conditions*' these are outlined in the preamble to section 2.0 of this PRA. Some of the aspects that should be considered are that mechanical reduction of the waste (as is being done by the composters currently) to smaller sized particles prior to composting will facilitate more even and rapid heating. There is no specified particle size for the EPPO (2008) recommendations for the minimum requirements. However, they do prescribe turning the waste a minimum number of times to ensure all the ground waste will be exposed to the heating regimes specified in their requirements. This would need to be verified by daily temperature monitoring (indirect process supervision). If turning is not used there needs to be good evidence that all of the waste is exposed to the required heating regime (temperature monitoring, thermal mapping). Good hygiene and strict management would also need to be undertaken to ensure that all waste is exposed to the specified temperature regime.

EPPO specific requirements for biowaste [municipal green waste] *containing quarantine pests or heat-tolerant pests – option 2*

An alternative to the first option would be the treatment recommended by EPPO for biowaste of plant origin known or suspected to contain any quarantine pests or heat-tolerant pests. This would require that all of the material is exposed to 74°C for 4 hours, 80°C for 2 hours or 90°C for 1 hour using wet heat before it is despatched to the PRA area for composting. It should be possible to reduce the time x temperature combinations based upon the evidence that mortality of pupae can be achieved at lower temperatures but this would need to be validated at an industrial scale. The minimum regime tested by Yee and Chapman (*manuscript in preparation*) in the laboratory showed that 50.5°C for 3 days led to 100% mortality of pupae whereas Neven (USDA, ARS, USA, *personal communication*, January 2016) showed that 50°C for 20 minutes was effective. This could be investigated as a treatment for pupae of *R. pomonella* in municipal green waste using the methods of Yee and Chapman (*manuscript in preparation*). If the waste was not mechanically reduced, it would be appropriate to include infested fruit and soil in the tests. However, mechanical reduction of the waste prior to heating to achieve small particles would help facilitate heat exposure of viable pupae. As with composting there is no recommended particle size for this treatment. Careful validation of a heating process would require monitoring of temperatures throughout (thermal mapping) any heating chamber. Heat could be applied to the waste using a variety of methods including vapour heat, vacuum steam, forced hot air, non-ionising radiation (microwave or radio frequency) etc.

It could be assumed that these treatments would be effective provided they were strictly-managed.

The uncertainty associated with the effectiveness of these measures is *medium* because they have not been validated at the industrial scale for *R. pomonella*.

Of note is that APHIS (2016) recently made the following announcement:
'*On March 10, CPHST AQI Raleigh approved a shredder/steamer (STI Series 2000) for APHIS moist quarantine heat treatments at 212°F and below. CPHST tested the shredder/steamer in a two-year study for suitability to sanitize quarantine material. The STI Series 2000 can decontaminate 1,000 pounds/hour of quarantine plant pest material. This gives APHIS the ability to treat large amounts of quarantine material in a short time frame. Bio-Safe Engineering offers the STI Series 2000 for sale or as a fee-for-service'*. This may warrant investigation at the industrial scale for treatment of municipal green waste again using the methods deployed by Yee and Chapman (*manuscript in preparation*).

Other options

There are other treatments which have not been tested for efficacy against *R. pomonella* in municipal green waste. They may not be practical, cost-effective or reliable. However, they could be considered for research if deemed appropriate. Some of these are mentioned above under option 2: vacuum steam, vapour heat, dry heat, non-ionising radiation (microwave or radio frequency). Others to consider are: irradiation, fumigation and vacuum fumigation, modified atmosphere, cold treatment, solarisation.

7.25 - Does the pest occur only on certain parts of the plant or plant products (e.g. bark, flowers), which can be removed without reducing the value of the consignment? (This question is not relevant for pest plants).

Yes

Level of uncertainty: *Medium*

The pest may be present in municipal green waste in infested fruit of a range of hosts including apples, hawthorns and crab apples. It may also be present in soil associated with host plants. Removal of this material would reduce the risk. Whether removal of host fruit reduces the value of the commodity depends upon the composting facility and its ability to source and process municipal green waste without fruit. Removal of the soil would help the composting process. There may be some pupae that are free of host material or soil within the waste and it would not be possible to remove these.

However, this is unlikely to be feasible in practice.

The uncertainty associated with the effectiveness of this measure is *medium* because there may be some pupae that are free from host material or soil within the waste that would not be removed by this process. It is also not known if this would reduce the value of the consignment to the composters.

7.26 - Can infestation of the consignment be reliably prevented by handling and packing methods?

No.

Level of uncertainty: *Low*

This is not applicable to municipal green waste.

Options that can be implemented after entry of consignments

7.27 - Can the pest be reliably detected during post-entry quarantine?

No.

Level of uncertainty: *Low*

Post-entry quarantine is not feasible for storage of municipal green waste. Detection of the pest in the waste may be possible but not all of the waste can be inspected and tested.

7.28 - Could consignments that may be infested be accepted without risk for certain end

uses, limited distribution in the PRA area, or limited periods of entry, and can such limitations be applied in practice?

No.

Level of uncertainty: *Medium*

End use
It would not be practical to restrict end-use since the current host-range of *R. pomonella* across its area of distribution extends to 55 hosts. It has the potential to increase its host range.

Limited distribution in the PRA area
Limiting distribution of consignments of waste within the PRA area would not be appropriate since the whole area is a PFA for *R. pomonella*.

Limited periods of entry
The period of highest risk of escape of flies eclosing from pupae in consignments of municipal green waste is when favourable temperatures occur between June and October (the normal flight period of *R. pomonella* in the state of Washington). However, diapausing pupae can remain viable for 2 years or longer. Emerging adults can live for up to 40 days depending upon the environment and availability of food sources.

Although the pest may be present in waste all year round, in theory there may be a limited period during the winter when composting of municipal green waste from the quarantine area could be done in the PRA area. However this would necessitate that composting operations are carried out in a manner such that all pupae are rapidly killed. Buffers of time would have to be built in at the beginning and end of the cold period to ensure that any emerging flies would perish from the lack of hosts or because of the environmental conditions. This strategy has not been demonstrated in practice and would require investigation and monitoring. Composting in the open will be slower over the winter months which could mean that pupae may be viable for longer over that period. Nullifying the risk would require that all of the processes from the time of arrival of the waste at the facility to the time the finished compost is despatched are very strictly-managed and undertaken in as an efficient way as possible without scope for erring from the process due to e.g. operational difficulties. The heterogeneous nature of the waste being received for processing in the PRA area is such that it cannot be guaranteed that receiving waste at a particular time of year will be less risky than receipt at another time of year. The uncertainties associated with each of the pathways identified in section 2.0 suggests that this would not be a reliable approach for reducing the risk associated with *R. pomonella*

7.29 - Are there effective measures that could be taken in the importing country[36] (surveillance, eradication, containment) to prevent establishment and/or economic or other impacts?

No.

Level of uncertainty: *Low*

[36] In this case this refers to the PRA area which is the PFA of the state of Washington

As standalone measures to reduce the risk posed by the movement of municipal green waste from the quarantine area, none of these options could totally prevent the establishment of *R. pomonella* in the PRA area and/or economic or other impacts arising from the detection or establishment of the pest in the area.

However, they are of course essential in the campaign to maintain the PFA in the state of Washington

Surveillance for *R. pomonella* is undertaken each year by the WSDA. It is a useful measure to include in a systems approach to monitor any potential outbreaks of the pest around the composting facilities in the PRA area and was deployed in 2015 for this purpose.

In response to detections of the pest, containment with a view to eradication by the County Pest Boards can be attempted but it relies on early detection of the pest and in some circumstances may not be achieved.

7.30 - Have any measures been identified during the present analysis that will reduce the risk of introduction of the pest?

Yes.

Q.	Standalone	System Approach	Possible Measure	Uncertainty
7.24	**X**	**X**	**Specified treatment of the consignment**	**Medium**

The uncertainty associated with 7.24 is *medium* because the treatments have not been validated at the industrial scale for *R. pomonella*.

Treatment of the municipal green waste in the quarantine area following the EPPO (2008) options as outlined in 7.24 will reduce the risk of introduction of *R. pomonella* to the PRA area.

For treatment of the municipal green waste in the quarantine area there are two options.

For both options, the waste would need to be mechanically reduced to a particle size that would be small enough to increase the rate of heating of the waste but not so small as to limit aeration of the waste being treated.

For the first treatment option, composting to ensure exposure of all of the ground material to at least 55°C for a continuous period of two weeks, or to a temperature of at least 65°C over a continuous period of one week would ensure eradication of any pupae within the waste. This should be achieved under appropriate conditions of humidity and nutrients, as well as by optimum structure and optimum air conduction. In general, the water content should be at least 40%. Repeated turning of the waste in accordance with the results of daily temperature monitoring would ensure it was exposed to the required temperature.

For temperature monitoring, EPPO (2008) advise that '*Temperatures should be recorded at regular intervals throughout the processing of the biowaste* [municipal green waste]. *If possible,* *these measurements should be continuous. They should be recorded in at least three representative zones of the biowaste* [municipal green waste] *unless the technical equipment of the process prevents access to these zones. During the thermal inactivation stage, the temperature should be recorded at least once every working day.*' Evanylo *et al*. (2009) suggests that thermometers should be placed in the windrows approximately every 50 feet (15.24m) and the temperatures recorded daily and that turning should be undertaken when the temperature reaches 140°F (60°C). This could be adjusted to 55°C or 65°C according to which of the options prescribed by EPPO (2008) is chosen. The USDA advise that for windrow composting, measurements should be taken at close increments to obtain an initial idea of variability, and that if there is less than 10°F between comparable locations then it would be safe to increase the distance between monitoring locations. They advise that probes should be placed at the outside edges of a pile of waste as well as the centre, every 10 to 20 feet along its length. https://aglearn.usda.gov/customcontent/APHIS/APHIS-CarcassDisposal-OutdoorComposting-01/scopage_dir/intro/main.html accessed 4 April 2016

Clearly there is variability in the options for monitoring temperature but it would need to be done regularly and at sufficiently representative locations to ensure all the waste is exposed to temperatures that are lethal to *R. pomonella*.

This treatment should be effective but may warrant validation at the industrial scale using the methods of Yee and Chapman (*manuscript in preparation*).

For the second treatment option, EPPO (2008) requires that all of the mechanically-reduced material is exposed to 74°C for 4 hours, 80°C for 2 hours or 90°C for 1 hour using wet heat. This treatment could be adjusted to a lower temperature regime because laboratory results of free pupae showed that 50.5°C over 3 days at 100% achieved 100% mortality of pupae (Yee and Chapman, *manuscript in preparation*) as did 50°C for 20 minutes (Neven, USDA, ARS, USA, *personal communication*, January 2016). It could be that a period $\geq$ 30 minutes at 50°C would be effective but this would rely on all pupae, in whatever material they are located being exposed. This needs to be validated at the industrial scale.

EPPO (2008) advise that '*If the biowaste* [municipal green waste] *is subjected to a specific heat treatment, the temperature should be monitored and recorded continuously and automatically for each treatment period'*.

For both options, great care (including strict hygiene) would need to be undertaken to ensure that all of the waste is fully-exposed to the specified temperature regime.

Once the chosen treatment has been applied it would be possible to move the processed waste to the facilities in the PRA area to continue processing.

Any trailers used to transport the treated material would have to be clean and free of any potentially-infested material.

7.31 - Does each of the individual measures identified reduce the risk to an acceptable level?

Yes.

Level of uncertainty: *Low*

Treatment of the waste in the way described in 7.24 would reduce the risk to an acceptable level provided it was strictly-managed, monitored and supervised by the WSDA. These suggestions if considered appropriate warrant validation at the industrial scale.

The EPPO scheme proceeds to 7.34.

7.34 - Estimate to what extent the measures (or combination of measures) being considered interfere with international trade.

Level of uncertainty: *Low*

The measures will interfere with the current pathways of movement of municipal green waste but not with international trade.

7.35 - Estimate to what extent the measures (or combination of measures) being considered are cost-effective, or have undesirable social or environmental consequences.

Level of uncertainty: *Medium*

The cost-effectiveness of the measures cannot be assessed without a full cost-benefit analysis. The costs of the suggested measures are not known.

For background, WSDA (2015) prepared an economic impact statement when considered options in a consultation on the issuance of special permits to move municipal green waste from the quarantine area to protect the state's apple industry from *R. pomonella*.

They stated that '*based on the 2013 crop year data, the apple industry contributed an estimated $2.19 billion a year to the state's economy'*.

Their proposals for the movement of waste from the quarantine area were not the same as the treatments suggested in 7.24.

They suggested that costs to the waste industry (including the transfer stations) from implementing the requirements of a special permit were labour costs and the costs of survey for *R. pomonella*.

In assessing the impact of their proposals to the compost industry they stated that '*of the more than 60 compost facilities in operation in Washington State, the proposed rule will affect a small number of compost facilities that choose to transport municipal solid waste or organic waste from the apple maggot quarantine area to the pest-free area. Only four composting facilities are currently requesting coverage under a permit. The proposed rule will require these commercial composters to comply with the terms and conditions of a special permit before the Department authorizes the transport of regulated items across the quarantine boundary. Conditions of the permit go beyond current Washington State Department of Ecology rules for regulating pests and disease in solid municipal waste and green waste. These facilities, therefore, may be required to alter their current practices in ways that increase the cost of operations, if they choose to continue to transport green waste from the quarantine area. The financial cost of compliance will vary with each facility depending on their current practices and conditions at the facility'.*

With respect to jobs created or lost, WSDA (2015) also stated*: 'The exact costs of compliance for the four compost facilities known to transport organic waste from the apple maggot quarantine area to the pest free area cannot be determined until the conditions of the permit are determined for each of the four compost facilities. Therefore, an estimate of the number of jobs that will be created or lost, if any, cannot be determined at this time'.*

With respect to the whether there was a disproportionate impact to small businesses, WSDA (2015) found none.

The PRA team's questionnaire to the four composting facilities in the autumn of 2015 asked two related questions:

What is a reasonable estimate of the value of your composting business? (About how much would the business and assets be worth if sold)?

What are the consequences to your operations/business and other associated operations/businesses, if you cannot receive Municipal Green Waste from the apple maggot quarantine areas?

Replies were received to either or both questions from each of the facilities. Although in relation to Washington's apple industry as a whole, the financial value of the businesses is low, it is clear that there would be impacts from not being allowed to receive municipal green waste from the quarantine area. This would affect the facilities' businesses directly as well as the areas from which the waste is sourced. Such waste would most likely be diverted to landfill which would incur financial costs as well as having an impact on the environment.

Clearly there would be major economic impacts arising from the establishment of *R. pomonella* in the PRA area but it is reasonable to at least consider alternatives to prohibition for managing the risk posed by movement of municipal green waste from the quarantine area. This could reduce the risk posed by the pest to an acceptable level while having the potential to facilitate composting of the waste within the PRA area.

No further assessment of the cost-effectiveness of the options for measures or how undesirable the consequences of the measures were in social or environmental terms was possible.

7.36 - Have measures (or combination of measures) been identified that reduce the risk for this pathway, and do not unduly interfere with international trade, are cost-effective and have no undesirable social or environmental consequences?

Yes.

Treatment of the waste in the quarantine area before moving to the PRA area as suggested in 7.24. This requires validation at the industrial scale.

7.38 Have all major pathways been analysed (for a pest-initiated analysis)?

Yes.

The EPPO PRA scheme takes the risk analyst(s) to 7.41.

7.41 Consider the relative importance of the pathways identified in the conclusion to the entry section of the pest risk assessment
Note: the relative importance of the pathways is an important element to consider in formulating phytosanitary regulation. Regulation of pathways presenting similar risks should be consistent.

Despite the lack of detailed data on the amount of infested fruit and soil in the waste stream, there is enough evidence to indicate that movement of municipal green waste from the quarantine area of the state of Washington along the four pathways poses a risk of introduction of *R. pomonella* to the PRA area (the PFA of Washington State) and that the consequences of introduction are not acceptable.

The four pathways are rated in order of the likelihood of the risk of entry of the pest to the PRA area:

1. Municipal green waste moving to Royal Organic Products, Grant County from the quarantine area of the state of Washington (and from one county in Oregon) – *very likely* with *low uncertainty*

2. Municipal green waste moving to Pacificlean Environmental, Grant County from the quarantine area of the state of Washington – *very likely* with *low uncertainty*

3. Municipal green waste moving to Barr-Tech LLC, Lincoln County from the quarantine area of the state of Washington – *likely* with *low uncertainty*

4. Municipal green waste moving to Natural Selection Farms, Yakima County from the quarantine area of the state of Washington – *moderately likely with low uncertainty*

7.42 All the measures or combination of measures identified as being appropriate for each pathway or for the commodity can be considered for inclusion in phytosanitary regulations in order to offer a choice of different measures to trading partners. Data requirements for surveillance and monitoring to be provided by the exporting country should be specified.

A range of host fruit of *R. pomonella* is already subject to regulation by the WSDA before it can enter the PRA area from a quarantine area. Amongst the options for allowing its entry there are two cold treatment options.

Currently only one of the four pathways is permitted to continue moving municipal green waste from the quarantine area into the PRA area. Because the waste is likely to contain host fruit and possibly soil infested with the pest (as well as loose pupae) it would seem appropriate to consider options for treatment of the waste in the quarantine area before moving it to the PRA area, as an alternative to prohibition if this is acceptable.

EPPO (the Regional Plant Protection Organisation for the European and Mediterranean region) already recognises the risk posed by this type of pathway and has recommended measures that can be undertaken to mitigate the risk (EPPO, 2008). These, along with the need to validate the options at the industrial scale as well as any scientifically-validated modifications, could be considered by the WSDA.

There may be other treatment options that would be effective but these have not been tested against *R. pomonella* in municipal green waste. They would require investigation and validation before they could be considered.

7.43 In addition to the measure(s) selected to be applied by the exporting country, a phytosanitary certificate (PC) may be required for certain commodities. The PC is an attestation by the exporting country that the requirements of the importing country have been fulfilled. In certain circumstances, an additional declaration on the PC may be needed (see EPPO Standard PM 1/1(2) Use of phytosanitary certificates).

The issuance of a Phytosanitary Certificate is not appropriate. However, the WSDA would need to consider what would be required to certify that the municipal green waste met any new requirements that might be added to their regulations for *R. pomonella*.

7.44 If there are no measures that reduce the risk for a pathway, or if the only effective measures unduly interfere with international trade (e.g. prohibition), are not cost-effective or have undesirable social or environmental consequences, the conclusion of the pest risk management stage may be that introduction cannot be prevented. In the case of pest with a high natural spread capacity, regional communication and collaboration is important.

The measures that have been proposed for consideration by the WSDA would reduce the risk posed by *R. pomonella* in municipal green waste from the quarantine area being moved to the PRA area (the PFA of the state of Washington). They would not interfere with international trade. A cost-benefit analysis of the measures was not possible as the costs, and who would bear them is not known. The social and environmental consequences have also not been estimated.

Conclusion of Pest Risk Management

Summarise the conclusions of the Pest Risk Management stage. List all potential management options and indicate their effectiveness. Uncertainties should be identified.

The potential measures that could be considered by the WSDA for managing the risks posed by *R. pomonella* moving on municipal green waste from the quarantine area to the PFA of the state of Washington (the PRA area) are outlined below:

1. That waste from the quarantine area is mechanically-processed in the quarantine area to a particle size small enough to aid heat exposure but large enough to produce a feedstock suitable for composting.

And

2. The entire quantity of material that has been processed according to 1. is composted in the quarantine area and is exposed either to a temperature of at least 55°C for a continuous period of two weeks, or to a temperature of at least 65°C over a continuous period of one week (or, in the case of enclosed composting facilities, at least 60°C). A minimum number of turnings may be required to ensure that the whole mass is exposed to this temperature. Moisture content should be at least 40%.

Or

3. The entire quantity of material that has been processed according to 1. is exposed to 74°C for 4 hours, 80°C for 2 hours or 90°C for 1 hour using wet heat. This treatment could be adjusted to a lower temperature regime because unpublished results suggest that free-living pupae can be rendered non-viable in the laboratory at lower temperatures (50.5°C for 3 days or 50°C for 20 minutes).

These suggested measures may require validation in the quarantine area at an industrial scale.

For both options EPPO (2008) specifies that monitoring of the temperature (indirect process supervision) would have to be done to validate the treatments each time they are used. Product analysis would also have to be undertaken every 6 months for facilities processing <3000t and every 3 months for facilities processing more than this. Products that fail to meet requirements would have to be treated again if they are to be moved to the PRA area. Direct process validation should be undertaken for the composting treatment option at least the first time it is used; indicator organisms could either be the pupae of *R. pomonella* as deployed by Yee and Chapman (*manuscript in preparation*) or the other indicator organisms described by EPPO (2008). This has to done in two separate tests, one of which should be carried-out in the winter months. It is not necessary for the heat treatment option. Heat treatment facilities should be verified before the first treatment and at regular intervals (preferably yearly) thereafter by a technical expert.

Good hygiene would be required for all stages of treatment to ensure that all pupae of *R. pomonella* that may be present in the waste are exposed to lethal temperatures.

Once treatment is completed then processed waste can be moved to the PFA to finish the composting and curing process. Trailers used to move treated waste should be thoroughly cleaned prior to movement to ensure they are free of the pest.

Although EPPO (2008) provides detailed generic instructions, the WSDA would need to determine how to monitor and certify that waste from the quarantine area had been effectively treated to negate the risk posed by *R. pomonella*, and, when it was safe to move it to the PFA.

There are other treatments which have not been tested on *R. pomonella* in municipal green waste. They may not be practical, cost-effective or reliable. However, they could be considered for research if deemed appropriate. These are: vacuum steam, vapour heat, dry heat, irradiation, non-ionising radiation (microwave or radio frequency), fumigation and vacuum fumigation, modified atmosphere, cold treatment, solarisation. Tunnel composting could be investigated as a method of composting as it provides greater control of the process.

Uncertainties and suggested actions to address them if the WSDA considers them necessary are listed in the table below.

Table 24. Areas of uncertainty in the assessment of risk management options for *R. pomo*nella moving on municipal green waste from the quarantine area to the PRA area and suggested actions to address them

UNCERTAINTY – RISK MANAGEMENT	SUGGESTED ACTIONS
The effectiveness of treatment options (composting or heat treatment at the industrial scale).	Validation using bags of pupae at facilities in the quarantine area as per Yee and Chapman (*manuscript in preparation*).
Cost-effectiveness, social and environmental consequences of suggested measures.	Cost-benefit analysis.
Efficacy of alternative measures.	Investigation of alternatives for cost-effectiveness and feasibility and testing using the methods of Yee and Chapman (manuscript in preparation) and EPPO (2008)

Monitoring and review of the measures

Performance of measure(s) should be monitored to ensure that the aim is being achieved. This is often carried out by inspection of the commodity on arrival, noting any detection in consignments or any entries of the pest to the PRA area.

Although guidance on monitoring and review of measures is given by EPPO, the WSDA would need to determine how best to monitor the effectiveness of the measures if they are considered appropriate. Monitoring in the quarantine area would be the most effective approach. Full details of the recommendations made by EPPO are given in EPPO (2008).

Monitoring and review of the PRA: EPPO recommendations

Information supporting the Pest Risk Analysis should be reviewed periodically by the pest risk analyst(s) to ensure that any new information that becomes available does not invalidate the decision taken.

This can be undertaken if the WSDA considers this to be necessary.

Acknowledgements

The following people are acknowledged for their contribution to the production of this PRA:

Jay Brunner, Washington State University (retired)

Michael R. Bush, Washington State University

Andy Bary, Washington State University

Barb Burrill, City Fruit Organization

Brant Carman, WSDA

Nehemias Chalma, Natural Selection Farms

J. Scott Deatherage, Barr-Tech LLC

Jon Devaney, Washington State Tree Fruit Association

Chelsea Cisca Durfey, Natural Selection Farms

Ted Durfey, Natural Selection Farms

Chuck Graaff, Royal Organic Products

Mary Harrington, Washington State Department of Ecology

Vince Jones, Washington State University

Sunil Kumar, Colorado State University

Michael Klaus, WSDA

Ryan Leon, Pacificlean Environmental

James Marra, WSDA

Travis Maynard, Pacificlean Environmental

Lisa Neven, USDA, ARS

Catherine Morrison, City Fruit Organisation

Todd Phillips, Grant County Environmental Health Services

Lucy Reid, USDA, APHIS

Thad Schutt, Royal Organic Products

Marni Solheim, Washington State Department of Ecology

Randy Taylor, WSDA

Marilyn Tilbury, private citizen and dedicated fruit grower

Terry Tomlinson, President, Tahoma Chapter Western Cascade Fruit Society

Desiree Whittenberg, WSDA

Mike Willett, Washington Tree Fruit Research Commission

Wee Yee, USDA, ARS

References

AliNiazee MT, Penrose RL (1981). Apple maggot in Oregon: a possible new threat to the Northwest apple industry. *Bulletin of the Entomological Society of America*, **27**, 245-246.

AliNiazee MT (1990). Evaluating Apple Maggot Traps in the West, Chapter 5 in Apple Maggot in the West: History, Biology, and Control. Editors RV Dowell and LT Wilson. University of California, Division of Natural Resources, Publication 334, Vol 95. 59-61.

Allen WR, Hagley EA (1990). Epigeal arthropods as predators of mature larvae and pupae of the apple maggot (Diptera: Tephritidae). *Environmental entomology*, **19**, 309 - 312.

Anon. (*undated*). Climate of Washington. http://www.wrcc.dri.edu/narratives/WASHINGTON.htm

Anon. (2015). Eastern Washington. https://en.wikipedia.org/wiki/Eastern_Washington

Anon. (2016). Yakima County Horticultural Pest & Disease Board January 2016 Update. 2pp.

APHIS (2016). Science and Technology Weekly Internal Report, APHIS PPQ Science and Technology Weekly Internal Report. March 16, 2016.

Armstrong JW, Follett PA (2007). Hot-water immersion quarantine treatment against Mediterranean fruit fly and oriental fruit fly (Diptera: Tephritidae) eggs and larvae in litchi and longan fruit exported from Hawaii. *Journal of Economic Entomology*, **100**, 1091–1097.

Bary A (*undated*). Composting. Powerpoint presentation. Washington State University. 20 slides. http://www.puyallup.wsu.edu/soilmgmt

Berlocher SH, 2000. Radiation and divergence in the *Rhagoletis pomonella* species group: inferences from allozymes. *Evolution*, **54,** 543-557.

Bi C, Saunders MC, McPheron BA, 2007. Wing pattern-based classification of the *Rhagoletis pomonella* species complex using genetic neural networks. *International Journal of Computer Science and Application*, **4,** 1-14.

Bollen GJ (1993a). Factors involved in inactivation of plant pathogens during composting of crop residues. In: Hoitink HAJ, Keener HM (Eds.), Science and engineering of composting: Design, environmental, microbiological and utilization aspects. Renaissance Publications, Worthington, Ohio, USA, pp. 301-318.

Bollen GJ, Volker D (1996). Phytohygienic aspects of composting. In: de Bertoldi M, Sequi P, Lemmes B, Papi T (Eds.). The science of composting - Part 1. Chapman and Hall, London, pp. 233-246.

Boulanger LW, Stanton GE, Padula AL (1969). Continuous rearing of the apple maggot. *Journal of Economic Entomology*. **62**, 748-749.

Bourne AI, Thies WH, Shaw FR (1934). Some observations of long distance dispersal of apple maggot flies. *Journal of Economic Entomology*, **27**, 352–355.

Brunner JF (1987). Apple maggot in Washington state. A review with special reference to its status in other western states. *Melanderia,* **45**, 33-51.

Bush GL (1966). Taxonomy, cytology and evolution of the genus *Rhagoletis* in North America (Diptera: Tephritidae). *Bulletin of the Museum of Comparative Zoology*, **134**, 431-562.

Bush GL (1969). Sympatric host formation and speciation in frugivorous flies of the genus *Rhagoletis*. *Evolution*, **23**, 237-25.

Bush GL (1993). Host race formation and sympatric speciation in *Rhagoletis* fruit flies (Diptera: Tephritidae). *Psyche*, **99**, 335-357.

CABI (2015). Datasheet for *Rhagoletis pomonella*. CABI Invasive Species Compendium, 22 May 2015. http://www.cabi.org/isc/datasheet/47060

Crohn DM, Farber B, Downer AJ, Daugovish O (2008). Probabilities for survival of glassy-winged sharpshooter and olive fruit fly pests in urban yard waste piles. *Bioresource Technology*, **99**, 1425-1432.

Dean RW, Chapman PJ (1973). Bionomics of the apple maggot in eastern New York. *Search Agriculture*, *Entomology*, **3**, 1-64.

DEP (*undated*). Leaf and yard waste composting guidance document. Department of Environmental Protection, Boston, Massachusetts. 29pp.

Dowell RV (1990). History of apple maggot in the western United States. Chapter 1. In: *Apple maggot in the west. History, biology and control*. Editors Dowell RV and Wilson LT. pp1-22.

EPPO (2006). Datasheets on quarantine pests: *Rhagoletis pomonella.* http://www.eppo.org/QUARANTINE/insects/Rhagoletis_pomonella/RHAGPO_ds.pdf

EPPO (2008). Guidelines for the management of plant health risks of biowaste of plant origin. EPPO Phytosanitary Procedure PM 3/66 (2). *EPPO Bulletin* **38**, 4–9.

EPPO (2011). EPPO Standard PM 5/3(5) Guidelines on Pest Risk Analysis: Decision-support scheme for quarantine pests, 11- 17053 PM 5/3 (5). 44pp.

EPPO (2015). Plant Quarantine Retrieval System version 5.3.5 of 2015-09-28.

EPPO (2016). EPPO Global Database. *Rhagoletis pomonella*. Accessed 4 March 2016. https://gd.eppo.int/taxon/RHAGPO/categorization

Evanylo GK, Sherony CA, May JH, Simpson TW, Christian AH (2009). The Virginia Yard-Waste Management Manual Second Edition. Department of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, Virginia. https://pubs.ext.vt.edu/452/452-055/452-055_pdf.pdf

FAO (1995). *Requirements for the establishment of pest free areas*. International Standards for

Phytosanitary Measures, **4**, International Plant Protection Convention Secretariat, Rome.

FAO (2006). Pest Risk Analysis for quarantine pests including analysis of environmental risks and living modified organisms. *International Standards for Phytosanitary Measures*, **4**, International Plant Protection Convention Secretariat, Rome. 26pp**.**

FAO (2011). Determination of pest status in an area. International Standards for Phytosanitary Measures, **8.** 14pp.

FAO (2015). Glossary of Phytosanitary Terms. International Standards for Phytosanitary Measures, **5**. International Plant Protection Convention Secretariat, Rome. 34pp. https://www.ippc.int/static/media/files/publication/en/2015/05/ISPM_05_En_2015-05-29_CPM-10.pdf

Featured Creatures (2002) Apple maggot. http://creatures.ifas.ufl.edu/fruit/tropical/apple_maggot_fly.htm

Feder JL (1995). The effects of parasitoids on sympatric host races of *Rhagoletis pomonella* (Diptera: Tephritidae). *Ecology*, 801- 813.

Feder JL, Berlocher SH, Roethele JB, Dambroski H, Smith JJ, Perry WL, Gavrilovic V, Filchak KE, Rull J, Aluja M (2003). Allopatric genetic origins for sympatric host-plant shifts and race formation in *Rhagoletis. Proceedings of the National Academy of Science USA*, **100,** 10314-10319.

Feder JL, Chilcote CA, Bush GL (1988). Genetic differentiation between sympatric host races of *Rhagoletis pomonella. Nature* **336**, 61-64.

Fein BL, Reissig WH, Roelofs WL (1982). Identification of apple volatiles attractive to the apple maggot *Rhagoletis pomonella. Journal of Chemical Ecology*, **8**, 1473-1487.

Foote RH, Blanc FL, Norrbom AL (1993). Handbook of the fruit flies (Diptera: Tephritidae) of America north of Mexico. Cornell University Press, Ithaca, NY.

Geng J, Li ZH, Rajotte EG, Wan FH, Lu XY, Wang ZL (2011). Potential geographical distribution of *Rhagoletis pomonella* (Diptera: Tephritidae) in China. *Insect science*, **18**, 575 - 582.

Globalwise (2014). The Washington Apple Industry. Updated Evaluation of Contributions to the State Economy and the Important Role of Exports. Globalwise Inc., in association with Belrose Inc. Washington State. 26pp.

Golueke CG (1982). When is compost “safe”? A review of criteria for assessing the destruction of pathogens in composting. Biocycle March/April, 28-38.

Gould WP (1994). Heat quarantine treatments for guavas infested with the Caribbean fruit fly. Proceedings Florida State Horticultural Society, **107**, 240-242.

Green TA, Prokopy RJ, Hosmer DW (1994). Distance of response to host tree models by female apple maggot flies *Rhagoletis pomonella* (Walsh) (Diptera: Tephritidae): Interaction of visual and olfactory stimuli. *Journal of Chemical Ecology*, **20,** 2393-2412.

Gut LJ, Brunner JF (1994). Parasitism of the apple maggot, *Rhagoletis pomonella*, infesting hawthorns in Washington. *Entomophaga*, **39**, 41 - 49.

Hallman GJ (*undated*). Irradiation and Heat Disinfestation Treatments for Apple Maggot. Research Report, ARS-Westaco TX. 3pp

Hay JC (1996). Pathogen destruction and biosolids composting. In: *Biocycle*, **37**, 67-76.

Hendrichs J, Prokopy RJ (1990). Where do apple maggot flies find food in nature? *Massachusetts Fruit Notes,* **55**, 1-3.

Hoitink HAJ, Fahy PC (1986). Basis for the control of soilborne plant pathogens with composts. *Annual Review of Phytopathology*, **24**, 93-114.

Hodgson PJ, Sivinski LJ, Quintero G, Aluja M (1998). Depth of pupation and survival of fruit fly (*Anastrepha* spp.: Tephritidae) pupae in a range of agricultural habitats. *Environmental Entomology*, **27**, 1310-1314.

Hood GR, Yee W, Goughnour RB, Sim SB, Egan SP, Arcella T, Saint-Jean G, Powell THQ, Xu CY, Feder JL (2013). The geographic distribution of *Rhagoletis pomonella* (Diptera: Tephritidae) in the western United States: Introduced species or native population? *Annals of the Entomological Society of America*. **106**, 59-65.

Hudson AJ (1948). Further studies of lures attractive to the apple maggot. *Journal of Economic Entomology*, **41**, 61-66.

Illingworth JF (1912). A study of the biology of the apple maggot *Rhagoletis pomonella*, together with an investigation of methods of control. *New York (Cornell) Agricultural Experiment Station Bulletin*, **324**.

Jones ME, Paine TD (2015). Effect of chipping and solarization on emergence and boring activity of a recently introduced ambrosia beetle (*Euwallacea* sp. Coleopteran: Curculionidae: Scolytinae) in southern California. *Journal of Economic Entomology*, **108**, 1852-1859.

Kendra PE, Hennessey MK, Montgomery WS, Jones EM, Epsky ND (2007). Residential composting of infested fruit: A potential pathway for spread of *Anastrepha* fruit flies (Diptera: Tephritidae). *Florida entomologist* **90**, 314-320.

Klaus MW (1985). North-eastern Washington Insect Detection and Eradication Report. October 31st 1985. 7pp.

Klaus MW (1996). 1996 WSDA apple maggot summary report. Washington State Department of Agriculture, Plant Protection Division, Yakima, WA.

Klaus MW (2000). Apple maggot detection response plan. 22pp.

Klaus MW (2013). WSDA 2014 Apple maggot survey report. 17pp.

Klaus MW (2014). 2014 Apple Maggot Survey Summary Report. WSDA. 20pp.

Klaus MW (2016). 2015 Apple Maggot Survey Summary Report. WSDA. 26pp

Klaus MW, Buckley K, Carman B (2016). Apple Maggot Pest Risk Analysis Information WSDA, Yakima. January 7, 2016. 6pp.

Klaus MW, Sandoe T, Marra J (2007). Washington State Department of Agriculture Standard Operating Procedures for Apple Maggot Survey. 11pp.

Knight A (2010). Organic Codling Moth Management in Washington State and the World. Powerpoint presentation.
http://jenny.tfrec.wsu.edu/CSANR/publications/presentations/Knight_WSHA2010.pdf

Kumar S, Yee WL, Neven LG (*draft*) (2016). Mapping Global Potential Risk of Establishment of *Rhagoletis pomonella* (Diptera: Tephritidae) using MaxEnt and CLIMEX Niche Models. *Journal of Economic Entomology.*

Larney FJ, Olson AF (2006). Windrow temperatures and chemical properties during active and passive aeration composting of beef cattle feedlot manure. *Canadian Journal of Soil Science*, **86**, 783-797.

Lopez-Martinez G, Denlinger DL (2008). Regulation of heat shock proteins in the apple maggot *Rhagoletis pomonella* during hot summer days and overwintering diapause. *Physiological Entomology*, **33**, 346-352.

Lorenz H (2006) Phyto-hygiene of the biological waste treatment during composting and anaerobic digestions. Dissertation, 344 pages. Mensch and Buch Verlag, Berlin (DE) (*in German*).

Linn C.E Jr., Feder JL, Nojima S, Dambroski HR, Berlocher SH, Roelofs WL (2003). Fruit odor discrimination and sympatric host race formation in *Rhagoletis. Proceedings of the National Academy of Science USA*, **100**, 11490-11493.

Linn CE Jr., Yee WL, Sim SB, Cha DH, Powell THQ, Goughnour RB, Feder JL (2012). Behavioural evidence for fruit odor discrimination and sympatric host races of *Rhagoletis pomonella* flies in the western United States. *Evolution,* **66,** 3632-3641

Marra J (*undated*). Primer on apple maggot life cycle. 1pp.

Marcinizyn E, Heckmann J, Klages S, Schwab M, Philipp W (2003). Optimization of the anaerobic technology for the treatment of biowaste from the sanitary perspective as well as development of a sanitary test system for anaerobic treatment plants] 139 pp., Darmstadt (DE) (*in German*).
http://www.eko-plant.com/dbu/dbu15008p3.php (accessed February 2008)

Mattsson M, Hood GR, Feder, JL, Ruedas LA (2015). Rapid and repeated shifts in the life-history timing of *Rhagoletis pomonella* (Diptera: Tephritidae) following colonization of novel host plants in the Pacific Northwestern United States. *Ecology and Evolution* **5**, 5823-5837.

Maxwell CW (1968). Apple Maggot Adult Dispersion in a New Brunswick Apple Orchard. *Journal of Economic Entomology*. **61**, 103-106.

Maxwell CW, Parson EC (1968). The recapture of marked apple maggot adults in several orchards from one release point. *Journal of Economic Entomology*, **61**, 1157-1159.

Mayr E (1963). Animal species and evolution. Harvard University Press. Cambridge, Massachusetts, 797 pp.

McCullough DG, Poland TM, Cappert D, Clark EL, Fraser I, Mastro V, Smith S, Pell C (2007). Effects of chipping, grinding and heat on survival of emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), in chips. *Journal of Economic Entomology*, **100**, 1304-1315.

Meck MC, Walgenbach JF, Kennedy GG (2008). Phenology of the apple maggot (Diptera: Tephritidae) in the southern Appalachian Mountains, **37**, 1154-1161.

Michel AP, Rull J, Aluja M, Feder JL (2007). The genetic structure of hawthorn-infesting *Rhagoletis pomonella* populations in Mexico: implications for sympatric host race formation. *Molecular Ecology*, **16,** 2867-2878.

Myers CT, Reissig WH, Forsline PL (2008). Susceptibility of fruit from diverse apple and crab apple germplasm to attack from apple maggot (Diptera: Tephritidae). *Journal of Economic Entomology*, **101**, 206-15.

Neilson WTA (1964). Some effects of relative humidity on development of pupae of the apple maggot, *Rhagoletis pomonella* (Walsh). *The Canadian Entomologist*, **96**, 810 – 811.

Neilson WTA (1967). Development and mortality of the apple maggot, *Rhagoletis pomonella*, in crab apples. *The Canadian Entomologist*, **99**, 217-219.

Neilson WTA (1971). Dispersal studies of a natural population of apple maggot adults. *Journal of Economic Entomology*, **64**, 648-653.

Neven LG, Rehfield-Ray L (2006). Combined heat and controlled atmosphere quarantine treatments for control of western cherry fruit fly in sweet cherries. *Journal of Economic Entomology*, **99**, 658–663.

New Mexico Department of Agriculture (2007) Surveys. http://nmdaweb.nmsu.edu/animal-and-plant-protection/nursery-hidden-folder/Surveys.html.

Noble R, Roberts SJ (2004). Eradication of plant pathogens and nematodes during composting: a review. *Plant Pathology*, **53**, 548–568.

Pelz KS, Isaacs R, Wise JC, Gut LJ (2005). Protection of fruit against infestation by apple maggot and blueberry maggot (Diptera: Tephritidae) using compounds containing spinosad. *Journal of Economic Entomology*, 98, 432 - 437.

O'Kane WC (1914). The apple maggot. *New Hampshire Experimental Station Bulletin*, **171**, 120pp.

Pickett AD, Neary ME (1940). Further studies on *Rhagoletis pomonella* (Walsh). *Scientific Agriculture*, **20**, 551-556.

Porter BA (1928). The apple maggot. *USDA Technical Bulletin*, **66**.

Prokopy RJ (1968). Visual responses of apple maggot flies *Rhagoletis pomonella* (Diptera: Tephritidae): Orchard studies. *Entomology Experimental and Applied*, **11**, 403-422.

Rebhan RO (1980). Apple maggot memorandum. Washington State Department of Agriculture. 1p.

Reissig WH, Brown SK, Lamb RC, Cummins JN (1990). Laboratory and field studies of resistance of crab apple clones to *Rhagoletis pomonella* (Diptera: Tephritidae). *Environmental Entomology*, **19**, 565-72.

Reissig WH, Fein BL, Roelofs WL (1982). Field test of synthetic apple volatiles as apple maggot attractants. *Environmental Entomology*, **11**, 1294-1298.

Reissig WH, Smith DC (1978). Bionomics of *Rhagoletis* in *Crataegus. Annals of the Entomological Society of America*, **2**, 155-159.

Reynolds AH, Prokopy RJ (1997). Evaluation of odor lures for use with sticky spheres to trap apple maggot (Diptera: Tephritidae). *Journal of Economic Entomology*, **90**, 1655-1660.

Rull J, Aluja M, Feder J, Berlocher S (2006). Distribution and host range of hawthorn-infesting *Rhagoletis* (Diptera: Tephritidae) in Mexico. *Annals of the Entomological Society of America*, **99**, 662-672.

Rull J, Aluja M, Feder JL (2011). Distribution and basic biology of black cherry-infesting *Rhagoletis* (Diptera: Tephritidae) in Mexico. *Annals of the Entomological Society of America*. **104**, 202 - 211.

Ryckeboer J (2001). Biowaste and yard waste composts: Microbiological and hygienic aspects - Suppressiveness to plant diseases. PhD Dissertation, Katholieke Universiteit Leuven, Belgium, 278p.

Ryckeboer JS, Cops S, Coosemans J (2002). The fate of plant pathogens and seeds during backyard composting of vegetable, fruit and garden wastes. In: Insam H, Riddech N, Klammer S (eds.). Microbiology of Composting. Springer-Verlag, Heidelberg, pp. 527-537.

Sansford C (2003). Plant pathogens and pests in composting. Proceedings of the '*Pathogen control in composting and anaerobic digestion: ABPO 2002, current knowledge, and technology aspects conference*'; York, UK, May 8th 2003. Cal Recovery Europe Ltd, Contemporary Waste Management Series. pp9-29.

Schotzko RT (1982). Estimated economic impact of the apple maggot. Washington State University Co-operative Extension Service Bulletin. **1132,** 8pp.

Schwarz D, Matta BM, Shakir-Botteri NL, McPheron BA (2005). Host shift to an invasive plant triggers rapid animal hybrid speciation. *Nature*, **436,** 546-549.

Self G, Ducamp MN, Thaunay P, Vayssières JF (2012). The effects of phytosanitary hot water treatments on West African mangoes infested with *Bactrocera invadens* (Diptera: Tephritidae). *Fruits*. **6**, 439-449.

Sharp JL (1978). Tethered flight of apple maggot flies. *Florida Entomologist*, **61**, 199-200.

Shellie KC, Mangan RL (2000). Postharvest disinfestation heat treatments: response of fruit and fruit fly larvae to different heating media. *Postharvest Biology and Technology*, **21**, 51–60.

Sherman R (*undated*). Large-scale organic materials composting. North Carolina State University Co-operative Extension, 16pp.

Smith TJ (2001). Crop Profile for apples in Washington. http://www.ipmcenters.org/CropProfiles/docs/WAApples.pdf

Snodgrass RE (1924). Anatomy and metamorphosis of the apple maggot, *Rhagoletis pomonella*, Walsh. *Journal of Agricultural Research*, **XXVIII**, 1-36.

Snow, WA (1894). Descriptions of North American Trypetidae, with notes. *Kansas University Quarterly*, **2**, 1159-1174.

Spence DJ, Smith JA, Ploetz R, Hulcr J, Stelinski LL (2013). Effect of chipping on emergence of the redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) and recovery of the laurel wilt pathogen from infested wood chips. *Journal of Economic Entomology*. **106**, 2093-2100.

Teutli M, Jiménez, Lozano, Peláez, Roque J, González (2010)[37]. Heat Flux Predictions for a 3-D Compost Model. Excerpt from the Proceedings of the COMSOL Conference 2010 Boston. 5pp. http://www.comsol.com/paper/download/62727/teutli_paper.pdf

Tracewski KT, Brunner JF, Hoyt SC (1985). Apple maggot in Washington: 1982 – 1985. Terminal report to the Washington Tree Fruit Research Commission. Washington State University Tree Fruit Research Center, Washington. 19pp.

USDA (2011). Washington Tree Fruit Acreage Report 2011. National Agricultural Statistics Service, United States Department of Agriculture. 67pp.

USDA (2015). Treatment manual. 938pp. 11-2015-128. https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf

Vanacker L, Braeckevelt A, De Rocker E, Vande Ryse G, Vandenbroek K (1996). Praktijkgids compost. Vlaco, Mechelen.

Velazquez G, Candelario HE, Ramirez JA, Montoya P, Loera-Gallardo J, Vázquez M (2010). An improved quarantine method for mangoes against the Mexican fruit fly based on high-pressure processing combined with heat. *Foodborne Pathogens and Disease*, **7**, 493–498.

Vontas J, Hernández-Crespo P, Margaritopoulos JT, Ortego F, Feng HT, Mathiopoulos KD, Hsu JC (2011). Insecticide resistance in Tephritid flies. *Pesticide biochemistry and physiology*. **100**, 199-205.

Walsh BD (1867). The apple-worm and the apple-maggot. *Journal of Horticulture*, **2**, 338-343.

[37] No initials were provided for some of the authors

Wang B, Mastro VC, McLane WH (2000). Impacts of chipping for the longhorned beetle *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in logs. *Journal of Economic Entomology*, **93**, 1832-1836.

Westcott RL (1982). Differentiating adults of apple maggot, *Rhagoletis pomonella* (Walsh) from snowberry maggot, *Rhagoletis zephyria* Snow (Diptera: Tephritidae), in Oregon. *Pan-Pacific Entomologist*, **58**, 25-30.

WSDA (2015). Small business economic impact statement for proposed rules to Chapter 16-470 WAC. August 28 2015. 13pp. http://agr.wa.gov/LawsRules/Rulemaking/PP/docs/WasteTransportationPermitSBEIS_082815.pdf accessed 27 March 2016.

WSTFA (2015). Washington State Tree Fruit Association. A statistical review of Washington State Fresh Apple Crops. 2013-2014. 71pp.

Xie X, Michel AP, Schwarz D, Rull J, Velez S, Forbes AA, Aluja M, Feder JL (2008). Radiation and divergence in the *Rhagoletis pomonella* species group: inferences from DNA sequence data. *Journal of Evolutionary Biology*, **21**, 900-909.

Yee, WL (2007). Attraction, feeding, and control of *Rhagoletis pomonella* (Diptera: Tephritidae) using GF-120 with added ammonia in Washington state. *Florida Entomologist*, **90,** 665–673.

Yee WL (2008). Host plant use by apple maggot, western cherry fruit fly, and other *Rhagoletis* species (Diptera: Tephritidae) in central Washington state. *Pan-Pacific Entomologist*, **84**, 163-178.

Yee WL (2014). Ammonium carbonate is more attractive than apple and hawthorn fruit volatile lures to *Rhagoletis pomonella* (Diptera: Tephritidae) in Washington State. *Environmental Entomology*, **43**, 957-968.

Yee WL (2015). Pest Status of Apple Maggot in Washington State. Powerpoint presentation. The 99th Annual Meeting of the Pacific Branch of the Entomological Society of America, April 12-15, 2015. Idaho, USA.

Yee WL, Chapman PS, Sheets HD (2013). Comparative body size and shape analyses of F1 hybrid *Rhagoletis pomonella* and *Rhagoletis zephyria* (Diptera: Tephritidae). *Annals of the Entomological Society of America*. **106**, 410-423.

Yee WL, Chapman PS, Sheets HD, Unruh TR (2009). Analysis of body measurements and wing shape to discriminate *Rhagoletis pomonella* and *Rhagoletis zephyria* (Diptera: Tephritidae) in Washington State. *Annals of the Entomological Society of America*, **102**, 1013 - 1028.

Yee WL, Goughnour RB (2008). Host plant use by and new records of apple maggot, western cherry fruit fly, and other *Rhagoletis* species (Diptera: Tephritidae) in western Washington State. *The Pan-Pacific Entomologist*, **84**, 179-193.

Yee WL, Hernandez-Ortiz V, Rull J, Sinclair BJ, Neven LG (2014). Status of *Rhagoletis* (Diptera: Tephritidae) Pests in the NAPPO Countries. Review: Commodity Treatment and Quarantine Entomology. *Journal of Economic Entomology*, **107**, 11-28. http://jee.oxfordjournals.org/content/107/1/11

Yee WL, Klaus MW (2015). Implications of *Rhagoletis zephyria* Snow, 1894 (Diptera: Tephritidae) captures for apple maggot surveys and fly ecology in Washington State, USA. *The Pan-Pacific Entomologist*, **91**, 1-13.

Yee WL, Klaus MW, Cha DH, Linn CE, Goughnour RB, Feder JL (2012). Abundance of apple maggot, *Rhagoletis pomonella*, across different areas in central Washington, with special reference to black-fruited hawthorns. *Journal of Insect Science*, **1**, 124.

Yee WL, Landolt PJ (2004). Response of apple maggot (Diptera: Tephritidae) to ammonium hydroxide lures. *Canadian Entomology*, **22**, 133-149.

Yee WL, Landolt PJ, Darnell TJ (2005). Attraction of apple maggot (Diptera: Tephritidae) and non-target flies to traps baited with ammonium carbonate and fruit volatile lures in Washington and Oregon. *Journal of Agricultural and Urban Entomology*, **22**, 133-149.

Yee WL, Lawrence TW, Hood GR. Feder JL (2015). New records of *Rhagoletis* Loew, 1862 (Diptera: Tephritidae) and their host plants in western Montana, USA. *The Pan-Pacific Entomologist*. **91**, 39–57.

Yee WL, Sheets HD, Chapman PS (2011). Analysis of surstylus and aculeus shape and size using geometric morphometrics to discriminate *Rhagoletis pomonella* and *Rhagoletis zephyria* (Diptera: Tephritidae). *Annals of the Entomological Society of America,* **104**, 105-114.

Yuen GY, Raabe RD (1984). Effects of small-scale aerobic composting on survival of some fungal plant pathogens. *Plant Disease*, **68**, 134-136.

Zhang AC, Linn C, Wright S, Prokopy R, Reissig W, Roelofs WL (1999). Identification of a new blend of apple volatiles attractive to the apple maggot. *Journal of Chemical Ecology*, **25**, 1221-1232.

Zhao Z, Wahl T, Marsh T (2007). Economic effects of mitigating apple maggot spread. *Canadian Journal of Agricultural Economics* **55**, 499–514.