SCEPTREPLUS

Final Report

Trial code:	2018 SP23
Title:	A review of key current control measures for sciarid and shore flies on protected ornamentals and 'pot worms' on orchid in the UK and overseas.
Crop	Protected ornamentals and protected pot orchid
Target	Sciarid fly (*Bradysia difformis*), shore fly (*Scatella tenuicosta*) and 'pot worm' (e.g. *Lyprauta* spp.)
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ORETO Number: (certificate should be attached)	409

I the undersigned, hereby declare that the work was performed according to the procedures herein described and that this report is an accurate and faithful record of the results obtained

……13/7/2018……
Date

J A Bennison

Review Summary

Introduction

Sciarid and shore flies are very common in protected ornamentals as they thrive in warm, moist conditions. Sciarid fly larvae feed on rotting organic matter but can also feed on roots, weakening or killing plants. Shore fly larvae feed on algae and do not damage plants, but the adults can be a nuisance to nursery staff and like sciarids, they can spread diseases and can be contaminants at market. 'Pot worms' are larvae of fly species that damage orchid root tips, reducing plant growth and increasing the time to produce high quality plants to meet retail standards.

Summary

A review was completed on current knowledge on presently used and potential future control measures for the three fly species in the UK and overseas. The review included a literature search and discussions with selected growers with a history of problems with the flies and with key consultants, suppliers and other researchers in the UK and overseas.

Growers are currently using cultural and biological control methods within IPM programmes for control of sciarid fly, shore fly and 'pot worm'. IPM programmes for sciarid and shore flies are not always fully effective and there is no current effective biological or chemical control method for pot worms. Growers need additional IPM-compatible control methods to improve control and to reduce current losses.

Next Steps

New potential control methods for the three fly pests were identified. If further funding is available for efficacy trials next year, candidate IPM-compatible treatments will be selected as having a clear route to market if not already approved in the UK. Treatments may include both conventional chemical plant protection products and microbial and botanical biopesticides.

Take home message:

New potential control methods for sciarid fly, shore fly and 'potworm' were identified and could be tested next year in trials. It is recommended that an updated Factsheet is provided for growers on the control of sciarid and shore flies on protected ornamentals, preferably after any further research is carried out.

Objective: Review key current knowledge on control measures for sciarid and shore flies on protected ornamentals and 'pot worms' on orchid in the UK and overseas.

Methods

1. Discussions with key industry representatives

Growers of protected ornamentals with a history of problems with sciarid and shore flies or 'pot worms' were visited and current control measures for the three fly species, control problems and grower needs were discussed. Key consultants, other researchers, biological control suppliers and plant protection manufacturers in the UK and overseas were also contacted to gain additional information on both research work and commercial experience in managing the flies. Plant protection product manufacturers and biological control suppliers were also asked if they have any novel products with a clear route to market that could be considered as candidate treatments for efficacy trials.

2. Complete a focussed review of peer reviewed scientific and relevant 'grey' literature on control of the three fly species

A focussed peer reviewed literature search on control of the three fly species was completed using Web of Science and Google Scholar. Only the more recent papers on chemical control of the flies was included as many of the older insecticides are no longer approved or are incompatible with IPM. In addition, as the biology of the various species of 'pot worms' is still poorly understood, any published information on their life cycle, development times and behaviour on potted orchid (*Phalaenopsis* species) was reviewed. Brief details of published information on the life cycle, development times and behaviour of sciarid and shore flies were also included as this information is critical to planning effective control measures. Relevant 'grey' literature including HDC, AHDB Horticulture, Defra and HortLINK funded project reports on the control of sciarid and shore flies and any relevant conference proceedings on control of the three fly species was also reviewed.

3. Collate and summarise key relevant knowledge

Using information from 1. and 2., key knowledge on the biology and current and potential future control methods to meet grower needs for improved integrated management for the three fly species was summarised.

Results

Discussions with key industry representatives

Sciarid flies

Three growers of protected ornamentals with a history of sciarid fly problems were visited and current control methods and any problems and further grower needs were discussed.

Grower 1 (bedding and pot plant grower and propagator)

Sciarid fly problems

Sciarid flies can be a problem on cyclamen, poinsettia and occasionally ranunculus. Problems tend to occur early on in younger crops but become less of an issue as the plants get older.

Current control methods

- Entomopathogenic nematodes (*Steinernema feltiae)* are viewed as expensive and it can be difficult to fit the drenches around other product applications. Nematodes are applied twice to cyclamen and four times to poinsettia at the label rate for curative control. All applications are made before plant spacing.
- The predatory beetles *Dalotia* (formerly known as *Atheta) coriaria* are reared on site in the glasshouses and are considered by the grower to contribute to sciarid control without interfering with a busy application schedule.
- Four applications of the predatory mite *Macrocheles robustulus* are also applied as these are considered on the nursery to be more effective than *Stratiolaelaps scimitus* (formerly known as *Hypoaspis miles*.) *Macrocheles* are recommended at 250 per m^2 as a single release but the grower splits this into four applications at 60 per m^2.
- Thiacloprid (Calypso) has an EAMU for use as a drench for control of sciarid flies just before dispatch and this used to be an option on the nursery for the smaller plugs if numbers got out of hand, but with most retailers now specifying that plants are not treated with any neonicotinoids at all the nursery no longer uses any neonicotinoid products.
- The entomopathogenic fungus *Metarhizium brunneum (anisopliae)* (Met52 granular bioinsecticide) is incorporated into the growing media for vine weevil control on perennial crops and this may also be contributing to sciarid fly control.
- Sciarid fly larvae infected with the naturally-occurring fungus *Furia sciarae* are sometimes seen on the surface of the growing media (This grower was involved in HortLINK project HL 0193, PC 283 (Chandler, 2011) so is aware of how to recognise infected sciarid fly larvae).

Further grower needs

Despite the range of biological control agents available, the grower considered that ideally more products would be helpful e.g. if the biologicals fail to keep the pest numbers low then a quick knockdown product would be very useful. Research in HNS 195 on application of nematodes through the overhead irrigation for vine weevil control was discussed. The grower considered that if a quick knockdown product was available it could potentially be applied overhead or through the drip irrigation if use of a drench was impractical or expensive.

Grower 2 (pot plant grower)

Sciarid fly problems

Sciarid flies have been more of a problem on pot rose than on other potted ornamental crops grown on site. Customers have complained about adult sciarid flies flying out of the plastic sleeves at the retail outlet.

Current control methods

- Since using *Dalotia* (*Atheta*) *coriaria* on the pot rose crop sciarid fly has been controlled very well. They are released rather than bred on the nursery as the 'DIY' system is considered too time-consuming. *Dalotia* are released at the rate of one per m^2 four weeks after uncovering the crop after rooting. This is lower than the recommended rate (5-10 per m^2) but seems to be effective. During the visit *Dalotia* adults were easily seen running over the growing media and between the pots.
- In addition, the growing media has been changed to a reduced peat media which also seems to have helped to reduce sciarid fly problems.

Further grower needs

Currently the grower is satisfied with the biological control of sciarid flies on the nursery.

Grower 3 (bedding and pot plant grower and propagator)

Sciarid fly problems

Sciarid fly has been the biggest problem on poinsettia where the pest has caused both direct damage and is also considered to have spread *Pythium*, both of which have led to significant plant losses. Sciarid fly can also be a problem on cyclamen and begonia.

Current control methods

- The growing media has been changed to a new mix which contains less peat and more perlite which seems to have reduced sciarid fly numbers.
- Irrigation is reduced where possible to help reduce sciarid fly problems.
- Both *Stratiolaelaps* (*Hypoaspis*) and *Dalotia* (*Atheta*) are released to susceptible crops.
- For problem plants, such as begonia, cyclamen and poinsettia, nematode drenches (*Steinernema feltiae*) are also used. On begonia and cyclamen in propagation these are used weekly and on poinsettia they are used once or

twice in the early production stage. The grower used to use one fifth of the rate of both *S. feltiae* (for sciarid flies) and *S. carpocapsae* (for shore flies) every week throughout the propagation area but last year changed to using full rate every week only on highly susceptible crops.

Further grower needs

The grower would like sciarid fly control to be more effective on poinsettia, to reduce both sciarid fly problems and potential problems with spread of *Pythium*.

Shore flies

Current control methods and problems with control of shore flies were discussed with the same three growers of protected ornamentals visited to discuss sciarid fly control.

Grower 1

Shore fly problems

Shore flies are a problem on bedding plants in propagation especially in warm weather when they breed and increase in numbers so quickly that the biological controls are unable to maintain control. The biggest problems are on plug trays which are densely packed and watered frequently which allows algae to grow on the surface of the growing media, giving shore flies perfect feeding and breeding conditions. As the plants grow they reduce the light available for algal growth on the growing media and thus shore flies are less of a problem. The flies are a nuisance to nursery staff but also the frass visible on leaves can lead to customer complaints.

Current control methods

- Good nursery hygiene is considered to be the basis of shore fly management. Hydrogen peroxide is used on the glasshouse floors to help clean and remove algal growth.
- The grower was not aware that a nematode (*Steinernema carpocapsae*) is available for control of shore fly.
- The predatory beetles *Dalotia* (formerly known as *Atheta*) *coriaria* are reared on site in the glasshouses and as for sciarid fly they are considered by the grower to contribute to control of shore fly.
- *Macrocheles* are used on susceptible crops e.g. cyclamen and as for sciarid fly, are considered to give some control of shore fly.
- If shore fly numbers get out of hand a tank mix of *Beauveria bassiana (*Naturalis-L) and spinosad (Conserve) is used for a quick knockdown. Naturalis-L is approved for use as a foliar spray for whitefly control on protected ornamentals and Conserve is approved as a foliar spray for thrips control.
- *Metarhizium brunneum (anisopliae)* (Met52 granular bioinsecticide) is incorporated into the growing media for vine weevil control on perennial crops and as for sciarid fly this may also be contributing to shore fly control.

- Naturally-occurring shore fly parasitoids (*Kleidotoma* spp.) are frequently seen on the growing media and benches and these will be contributing to control. (This grower was involved in PC 239, Bennison 2007) so is aware of how to recognise shore fly parasitoids).

Further grower needs

As for sciarid fly, the grower considered that ideally more products would be helpful for control of shore fly to use as a quick knockdown if the biologicals fail to keep the pest numbers low.

Grower 2

Shore fly problems

Shore fly used to be a problem in the early stages of begonia production but begonia is no longer grown on the nursery. Shore fly can be more of a problem on pot rose than on other potted ornamental crops. The nursery uses both bore hole and reservoir water which contains algae and does not use chlorine dioxide as an algaecide.

Current control methods

- As for sciarid fly, since using *Dalotia* (*Atheta*) *coriaria* on the pot rose crop shore fly has been controlled very well (see sciarid fly section above for details).
- As for sciarid fly, the growing media has been changed to a reduced peat media which also seems to have helped to reduce shore fly problems.

Further grower needs

Currently the grower is satisfied with the biological control of shore flies on the nursery

Grower 3

Shore fly problems

Shore fly can be a big problem on some slow-growing crops such as cyclamen and begonia which allow more algal growth on the surface of the growing media. The flies are a nuisance to nursery staff and frass on the leaves have led to customer complaints, so only low numbers of shore fly can be tolerated.

Current control methods

- Avoiding over-watering is one of the cultural controls used for shore fly.
- In addition, the benches and floors are cleaned and disinfected with Unifect G in between crops but at busy times of the year this is not done due to lack of time and this allows algal growth which encourages shore fly populations to increase.
- Nematodes are used routinely for shore fly control. The nursery experimented with using low rates of *Steinernema carpocapsae* (Nemasys C) at one fifth of the recommended rate, every week throughout the propagation area. Last year the strategy was changed to using full rate Nemasys C every week only on highly susceptible crops such as begonia and cyclamen. Nematodes are applied using an automatic overhead boom and a Dosatron.
- As for sciarid fly, both *Stratiolaelaps* (*Hypoaspis*) and *Dalotia* (*Atheta*) are released to susceptible crops.
- If the biological controls fail to maintain adequate shore fly control, a tank mix of Naturalis L and Conserve is used. However, this is used less frequently since the grower noticed a lack of control after three consecutive applications and speculated that resistance to Conserve might be developing.

Further grower needs

The grower would be interested in any new products for shore fly control particularly if they could be used as a knock-down if biological control agents fail to maintain control.

‘Pot worms’

One grower was visited with a history of problems with ‘pot worm’ on potted *Phalaenopsis* orchids. These are not worms, but the larvae of flies in the Keroplatidae family.

‘Pot worm’ problems

The larvae feed on the root tips, causing reduced water uptake and slower growth, thus increasing the time needed to produce high quality plants to meet stringent retail standards. The pest is causing significant financial losses as *Phalaenopsis* is a high value crop. The pest is not native to the UK but was imported along with young plants some years ago and has now established on the nursery. In addition to a UK IPM adviser, the nursery also uses a Dutch adviser with experience of ‘pot worm’ problems in the Netherlands, where more orchids are grown and where the pest is an increasing problem. There is currently no effective control method in either the UK or the Netherlands.

Current control methods

- Blue light traps are used in the roof space, together with yellow or black traps in the base to trap the adult flies.
- The grower is aware that a ‘pot worm’ lure is available which is claimed to increase the number of adults trapped but is currently not using these.

- Nematodes have been tried, using weekly drenches, but have given no control of larvae, probably due to the dry bark growing media used and to the high temperatures (28°C) used during production, both of which will adversely affect nematode survival and movement.
- *Macrocheles* predatory mites have been tried but have given no apparent control.
- *Stratiolaelaps scimitus* are currently being used at a high release rate (600 per m^2) after potting and after plant spacing and are considered to be giving some control.

Further grower needs

Further knowledge on 'pot worm' biology and behaviour is needed in order to develop an effective IPM strategy. Currently the available cultural and biological controls are not effective so new methods need development.

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Literature review and discussions with other researchers and consultants and with commercial suppliers

Sciarid fly

Sciarid fly species, food sources and plant damage, biology and behaviour

Species

There are over 200 species of *Sciaridae* in the British isles with only a few being known as pest species (Menzel *et al*, 2006)). The most common of the pest species occurring within UK protected crops is *Bradysia difformis*, formerly known as *Bradysia paupera* (Chandler, 2011). Both *Bradysia coprophila* and *Bradysia impatiens* are also commonly found within glasshouses in North America (Cloyd, 2008). Sciarid flies are also common pests of mushrooms, where the most common species in the UK are *Lycoriella solani* and *L. auripila*.

Food sources and plant damage

Sciarid flies are mostly found in damp habitats and the larvae have a wide food range including decaying organic matter, plants and fungi, thus they can be found throughout most of the world (Lewandowski *et al,* 2004; Smith & Menzel, 2007). In North America they are known as 'fungus gnats' due to their association with diseased plant tissue. Although sciarid flies are often secondary to disease the larvae can also cause primary plant damage to roots, stem bases and lower leaves touching the growing media, particularly to young seedlings and cuttings. Feeding damage by the larvae causes poor plant vigour, wilting and even death. The adults can also be contaminants at marketing where their presence can cause customer complaints or crop rejections and they can also spread diseases including *Pythium* spp., *Fusarium* spp. and *Verticillium* spp. (Scarlett *et al*, 2013; Kalb & Millar, 1986). However, research in South Africa indicated that *B. difformis* is not a major contributing factor in the spread of diseases (Hurley *et al*, 2007). Plants at risk from sciarid fly damage include ornamentals, potted herbs (Bennison *et al* (2005); Bennison & Green (updated 2016) http://herbs.ahdb.org.uk/b3-sciarid-flies/) and mushrooms (Kühne & Heller, 2010; Georgis *et al,* 2006).

Biology and behaviour

Sciarid adults fly both during the day and at night and at night they can be attracted to light (Cloyd *et al*, 2007). Adult females attract males through release of pheromones, then lay between 47 and 200 eggs after mating (Alberts *et al,* 1981; Frouz & Nováková, 2001; Cloyd, 2008). Adult females are attracted to damp fresh growing media or to plants infected with fungal pathogens to lay eggs. Growing media with a high proportion of green waste led to the development of higher sciarid fly populations than in standard peat-based growing media or those containing wood fibre on basil on a commercial herb nursery (Chandler *et al*, 2009).

The eggs hatch into larvae and there are four larval stages followed by a pupal stage which emerges into the adult. The development time of the larval stages of *B. difformis* at different temperatures range from 16 days at 15°C to five days at 25-30°C and the larvae do not complete development at 10°C (Chandler *et al*, 2010). Total time from egg to adult ranges from 30 days at 15°C to 13-14 days at 25-30°C. Adults live for approximately a week.

References

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Cultural control

Cultural control is the basis of an effective IPM programme for sciarid fly management. As sciarid flies thrive in moist growing media and in infected root tissue, good glasshouse hygiene, keeping benches and floors clean, removal of heavily infested and diseased plant material, keeping stocks of growing media covered, avoiding over-watering and giving adequate ventilation are key cultural control methods (Buxton, 2008; O'Neill *et al*, 2007; Bennison & Green, updated 2016).

Choice of growing media can help to reduce favourable conditions for sciarid fly development. Growing media with a high proportion of green waste led to the development of higher sciarid fly populations than in standard peat-based growing media or those containing wood fibre on basil on a commercial herb nursery (Chandler *et al*, 2009). One of the growers visited in this review reported that changing the growing media to one with less peat and more perlite for better drainage has helped to reduce sciarid fly problems.

Research has been carried out to try to make the growing media less attractive for sciarid fly egg laying. Diatomaceous earth added to the top of the media did not reduce numbers (Cloyd & Dickinson, 2005; Cloyd *et al*, 2007).

Yellow sticky traps catch significantly more sciarid fly adults than white or blue traps (Sahin *et al*, 2016). Yellow sticky traps are commonly used by UK growers of protected ornamentals and herbs to monitor numbers of sciarid flies adults. Long roller traps will catch more adults but should be used with care in IPM programmes as they will not control sciarid fly in their own right and will also catch flying beneficial insects.

Sciarid fly adults are attracted to light so light trapping could potentially be used for killing and trapping adults (Cloyd *et al*, 2007).

References

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Biological control

Nematodes

Entomopathogenic nematodes are commonly used by growers to control sciarid flies in protected crops including ornamentals and herbs. Both *Steinernema feltiae* and *S. carpocapsae* will kill various species of sciarid fly larvae but *S. feltiae* is more effective (Gouge & Hague, 1995a; Harris *et al*, 1995). Gouge & Hague reported that *S. feltiae* can also infect adult sciarid flies, which then introduced the nematodes to untreated growing media by flying to untreated areas before death. Currently in the UK, *S. feltiae* is the standard species used for control of sciarid flies. This species has been shown to lead to over 90% mortality of sciarid fly larvae in the laboratory and further testing on glasshouse fuchsia showed that applications of *S. feltiae* resulted in a 92% population decrease in *Bradysia paupera* (now renamed *B. difformis*), (Gouge & Hague, 1995).

Research on poinsettia has shown that applications of *S. feltiae* gave equal control of *Bradysia coprophila* to that given by diazinon and was more effective than *Bacillus thuringiensis israelensis* (Harris *et* al, 1995).

Research on mushrooms has shown that two reduced rate applications of *S. feltiae* at 1 million per m^2 one week apart gave equal control of *Lycoriella auripila* to a single

full rate application at 3 million per m^2 (Fenton *et al*. 2002). These two reduced rate applications are now recommended on the Nemasys M® label for mushroom sciarid fly control. This 'little and often' approach has also been shown to give effective control of vine weevil, *Otiorhynchus sulcatus* on hardy nursery stock (Bennison *et al,* 2017; 2017a and 2018). Currently recommended rates for *S. feltiae* for control of sciarid flies in protected crops other than mushrooms are 0.5 million per m^2 (preventive use) and 1 million per m^2 (curative use). Applications are recommended to be made every 2-6 weeks in propagation areas, depending on pest pressure. *Steinernema feltiae* was shown to be effective against sciarid flies for six weeks using sub-irrigation but for only four weeks using overhead irrigation (Sanderson *et al*, 2017).

It is important for growers to follow nematode product application recommendations carefully for optimum control. Varying degrees of commercial success have been reported, potentially due to poor handling and application of the product or due to use at incorrect temperature ranges (Georgis *et al*, 2006). For example, on one nursery, poor commercial control of sciarid flies by *S. feltiae* was observed to be due to failure to agitate the nematode holding tank during application (Bennison, unpublished data).

Dalotia (Atheta) coriaria

The predatory staphylinid beetle *Dalotia* (previously named *Atheta*) *coriaria* was first studied as a biological control agent for sciarid and shore flies in Canada, after these naturally-occurring beetles were observed feeding on sciarid fly larvae in laboratory cultures (Carney *et al,* 2002). A culturing technique using trout food pellets was developed in order to investigate its potential against the ground-dwelling stages of sciarid flies, shore flies and western flower thrips (WFT). Preliminary laboratory studies showed that *Dalotia* was a good predator of both the eggs and larvae of sciarid and shore flies and of WFT larvae and pupae.

Research on the compatibility between *Dalotia* and *S. feltiae* showed that the two were compatible in IPM programmes. *Dalotia* adults were not susceptible to infection by *S. feltiae* but the larvae were susceptible (Jandricic 2005 and Jandricic *et al* 2005). However, only 13 and 25% of *Dalotia* larvae were killed by the preventive and curative rates of *S. feltiae* respectively, these mortality rates are classed as 'safe' and 'slightly harmful' using the IOBC (International Organisation for Biological Control) testing scheme for side effects of plant protection products on beneficial organisms.

Dalotia became commercially available for control of sciarid and shore flies in the UK around the year 2000, recommended for use in the early stages of infestation. However, direct releases by growers led to variable results and the higher release rates needed in greater pest densities were expensive, so a 'DIY' system for growers to rear their own *Dalotia* on the nursery was developed (Bennison, 2007, 2007a, 2008, 2008a and 2010). This research showed that using the 'DIY' rearing and release system could offer cheaper and equally as effective alternative to using high release rates of the commercial product. This led to the commercial use of 'DIY' systems for rearing *Dalotia* for control of sciarid and shore flies in the UK, particularly in propagation houses. Although some growers still rear their own *Dalotia*, others have discontinued rearing them due to the time needed to maintain healthy and productive cultures and now buy them from commercial suppliers instead.

Predatory mites

The predatory mites *Stratiolaelaps scimitus* (formerly known as *Hypoaspis miles*) and *Macrocheles robustulus* are commonly used for sciarid fly control in IPM programmes, often together with *S. feltiae* and *Dalotia*. However, *Dalotia* and *S. scimitus* will feed on each other (Jandricic *et al*, 2006). When *Dalotia* were released to sciarid fly infested pots of parsley in high numbers using the 'DIY' rearing system together with the curative rate of *S. scimitus*, they significantly reduced numbers of *S. scimitus*, suggesting that high densities of *Dalotia* are detrimental to the predatory mites (Bennison, 2008).

Macrocheles robustulus is used on some nurseries for sciarid fly control as an alternative to *S. scimitus*. Research on pot chrysanthemum showed that *Macrocheles* reduced a population of sciarid fly by 97.1% compared with the control (Grosman *et al*, 2011). It was also found that adding the product Biotop ®, a mulch product derived from potato skin, to the top of the pots further increased the control to 99.5%, almost eradicating the sciarid flies (Grosman *et al*, 2011). This improved control with Biotop® was likely to be due to higher numbers of *Macrocheles* due to the availability of increased numbers of astigmatic mite prey that were feeding on fungi growing on the mulch layer. Biotop® could possibly be used to reduce the cost of using predatory mites for sciarid fly control by supporting their population growth.

Naturally-occurring predators and parasitoids

The hunter fly, *Coenosia attenuata* is a predatory fly that occurs naturally in glasshouses in both North America and the UK, particularly when IPM is being used with minimal use of chemical plant protection products. *Coenosia* adults catch their prey in flight and will predate both sciarid and shore fly adults and the larvae live in the growing media and predate on other invertebrates including sciarid and shore fly larvae (Sensenbach *et al*, 2005; Ferguson *et al*, 2014).

Synacra sp. is a naturally-occurring parasitoid of *Bradysia difformis* larvae reported from Sweden (Hellqvisist, 1994) but also commonly found in UK glasshouses where IPM is used (Bennison, unpublished data).

Entomopathogenic fungi

The commercial products *Metarhizium brunneum (anisopliae*) (Met52), *Beauveria bassiana* (Naturalis-L) and a *Lecanicillium* sp. isolate from naturally-infected *Bradysia difformis* were shown to infect sciarid fly larvae in laboratory tests but only 25-40% control was given (Chandler *et al* 2010 & 2011). Control was better when the fungi were applied to second and third instar larvae than when applied before egg hatch. This result could have been due to either low fungal persistence or to the first instar larvae escaping infection by moulting the spores off before they had germinated and grown into the insect gut. Met52 is currently approved for use in UK protected ornamentals as Met52 granular biopesticide for growing media incorporation and also as Met52 OD for use as a foliar spray but this formulation is not yet commercially available. Met52 granular biopesticide also has an EAMU for use as a mulch after planting ornamentals when incorporated into growing media. Naturalis-L is currently approved for use in UK protected crops as a foliar spray for whitefly control.

Another commercial *Beauveria* product, Botanigard® ES and two other formulations of *Beauveria bassiana* strain GSA were tested against the mushroom sciarid fly

Lycoriella ingenua in the United States (Andreadis *et al,* 2016). Eggs and larval stages were not susceptible to any of the fungi but pupae were infected (41% mortality) and adults were the most susceptible life stage (100% mortality within eight days). Botanigard WP is currently approved for use in UK protected ornamentals as a foliar spray for whitefly control.

In 2009 some UK growers observed a natural fungal infection of sciarid fly larvae in protected ornamentals and pot herbs (Chandler *et al*, 2009). The infected larvae were opaque white and visible on the surface of the growing media. The fungus was identified as *Furia sciarae* and was giving good natural control on nurseries using IPM programmes. *Furia sciarae* is still observed on some of these nurseries where the fungus has become established.

Bacillus thuringiensis subsp. israelensis (Bti)

The bacterium *Bacillus thuringiensis* subsp. *israelensis* (Bti) is already available in North America for sciarid fly control. In the UK, a Bti product (Gnatrol SC) currently has an EAMU for control of chironomid midges in watercress and has recently gained approval for use on protected ornamentals for sciarid fly control. After being ingested by sciarid fly larvae the bacteria break down the gut wall and the larvae stop feeding and die within 1-3 days. Younger larvae are reported to be more susceptible than older larvae (Mahr *et al*, 2001; Ferguson *et al*, 2014).Gnatrol is reported to be effective for only 48 hrs (Bush *et al*, 2006) therefore repeated applications are needed for effective control (Bealmer, 2010, Ferguson *et al*, 2014).

When tested against *Bradysia coprophila* 92% control was given in laboratory tests where sciarid fly larvae had constant exposure to Bti, but was ineffective when applied as a single application on a commercial protected ornamental crop (Osborne *et al*, 1985). Research on poinsettia showed that three applications of Bti gave 61% control of *B. coprophila* compared with the water control (Harris *et* al, 1995).

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Management with plant protection products

Chemical plant protection products

- Thiacloprid (Exemptor) is currently approved in the UK for control of sciarid fly when incorporated into growing media for growing both outdoor and protected ornamentals. The product gives up to six weeks control of sciarid fly larvae. Thiacloprid (Calypso) has an EAMU for use on protected ornamentals as a drench for control of sciarid flies just before dispatch. However, as thiacloprid is a neonicotinoid, many growers do not use it due to their retail customers demanding that neonicotinoids are not used during production.
- Imidacloprid (Imidasect 5GR) is currently approved in the UK for use for control of sciarid fly when incorporated into growing media for growing protected ornamentals. The product gives up to 12 months control of sciarid fly larvae. However, as imidacloprid is a neonicotinoid subject to current EC restrictions, it may only be used in glasshouses and treated plants must not be moved outdoors until they have finished flowering. In addition, as for thiacloprid, many growers do not use it due to their retail customers demanding that neonicotinoids are not used during production.
- Diflubenzuron (Dimilin Flo) is an insect growth regulator currently approved in the UK for use on ornamentals as a foliar spray for caterpillar control. It used to be recommended as a growing media drench for sciarid fly control but is no longer recommended for this use due to the risk of phytotoxicity. The current label advises it not to be used as a drench for sciarid fly control. Dimilin Flo is still approved for control of sciarid fly in mushrooms and can give 90 – 95% control of sciarid flies (Staunton *et al*, 1999).
- Pyriproxyfen is an insect growth regulator that has been shown to give effective control of *Bradysia* sp. on African violets in the United States when used as a drench (Ludwig *et al*, 2003). Pyriproxyfen is not approved for use in the UK.
- The insect growth regulators novaluron and pyriproxyfen were shown to give effective control of *Lycoriella ingenua* on mushrooms when used as a drench (Erler *et al*, 2011). Neither of these active ingredients are approved for use in the UK.

Botanical biopesticides

There are no botanical biopesticides currently approved for control of sciarid flies in the UK. However, research has been done on the effect of some botanical biopesticides and plant volatiles on sciarid flies:

- Azadirachtin (Azatin) is currently approved in the UK as a foliar spray for control of thrips. Azadirachtin has also been shown to be very effective in controlling sciarid fly larvae when applied as a drench (Bush *et al*, 2006).

- Garlic products are approved for use in the UK for controlling nematodes in amenity turf, carrot and parsnip. Products include granules for soil incorporation and liquid formulations for use as a drench. Garlic is not currently approved for use on protected ornamentals but garlic oil has been shown to repel *Lycoriella ingenua* in laboratory olfactometer studies and to reduce adult emergence from treated spawned mushroom compost (Jess *et al*, 2017).
- In a laboratory test, in Petri dishes at 22°C, filter paper soaked in peppermint oil and spearmint oil killed 50-100% of sciarid fly larvae through their volatile action (Massy, 2014). However, sciarid fly larval mortality was lower (9-27% in a glasshouse with fluctuating temperatures between 10 and 20°C. Linalool gave variable results over the course of several laboratory bioassays at 22°C (13-100% mortality) and in a glasshouse with fluctuating temperatures between 10 and 20°C (16-83% mortality depending on dose rate).
- Linalool is a component of the fabric softener Bounce®. In laboratory bioassays, chambers containing portions of Bounce® dryer sheets had a repellent effect on sciarid fly adults, attracting significantly fewer (12-18%) of sciarid adults compared with chambers without Bounce® which attracted 33-48% adults (Cloyd *et al*, 2010).

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Shore fly

Shore fly species, food sources, problems for growers and biology and behaviour

Species

Shore flies in protected UK crops were previously reported as *Scatella stagnalis*, but identification of shore flies in AHDB Horticulture funded project PC 239 confirmed that often these had been misidentified and that the most common species of shore fly on protected ornamentals herbs and celery is *Scatella tenuicosta* (Bennison, 2007).

Food sources and problems for growers

Shore flies feed on algae in the *Chlorophyceae, Diatomae, Tribophyceae, Cyanophyceae* and *Euglenophyceae* families (Vanninen, 2001; Sanderson, 2017).
The larvae have also been observed feeding on the roots of cucumber plants infected with *Pythium* sp. (Goldberg & Stanghellini, 1990). Shore flies do not damage plants directly, but can cause customer complaints or crop rejection due to the presence of flies or frass (droppings) on the plants at marketing (Lubiarz *et al,* 2013) and (Castrillo *et al*, 2007). In addition, shore flies can spread diseases. The adults can carry mature oospores of *Pythium* species in their gut, which can germinate after excretion (Goldberg & Stanghellini, 1990). The adults can also spread *Fusarium oxysporum* (Gillespie & Menzies, 1993) and *Theilaviopsis basicola* (Stanghellini *et al,* 1999; Horimoto *et al,* 2003). Shore flies are also a nuisance to nursery staff and have been recorded as causing respiratory problems (Lubiarz *et al,* 2013; Morton & Garcia del Pino, 2007).

Biology and behaviour

Shore flies breed in wet areas where fresh algae grow. The adults are active flyers and migrate onto young plants with fresh algal growth on the compost. Slow-growing plants such as begonia and cyclamen and some herb plants e.g. mint are particularly susceptible to infestation as they allow more light to reach the growing media which in turn allow fresh algal growth. As plants grow and shield the growing media from the light they become less susceptible to infestation. However, shore flies can also breed on algae on wet bench and floor coverings. Capillary matting often has high populations as it remains continuously wet (Casey *et al*, 1999).

Shore fly population increase is favoured by warm temperatures. Very few shore flies complete their development below 10°C (Jacobson, 1997). Research in Finland determined the biology of shore fly at various temperatures (Vanninen, 2001). The minimum temperature for development from egg to adult is 6.4°C. The development time from egg to adult decreases with increasing temperature, e.g. this takes a mean of 15.9 days at constant 20°C, 11.4 days at constant 25°C and 10.1 days at fluctuating summer glasshouse temperatures of 23-34°C (mean 28.5°C). The population can double in 5.3 days at constant 25°C.

Shore fly females can lay an average of 315 eggs in their life time (Deonier, 1972) and (Vänninen, 2001). These hatch into larvae and there are three larval stages before the pupal stage. Male *S. tenuicosta* can live for an average of 18 days at a constant 20°C, 24 days at a constant 26°C and 14 days at a constant 28.5°C. Females live for an average 21 days at a constant 20°C, 19 days at a constant 26°C and 15 days at a constant 28.5°C (Ugine *et al,* 2014). The adults are sometimes drawn to lights (Deyrup & Deyrup, 2008).

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Cultural control

As for sciarid fly, cultural control is the basis of an effective IPM programme for shore fly management. As shore flies feed on algae, the same nursery hygiene measures used for control of sciarid flies will also help to reduce shore fly populations (see sciarid fly section for details). In addition, disinfectants can be used e.g. one of the growers visited during this review uses hydrogen peroxide on the glasshouse floors to help clean and remove algal growth. Removal and cleaning of algae from the glasshouse reduces food and egg laying sources (Castrillo *et al*, 2008, Tilley *et al*, 2011).

Significantly more shore fly eggs and larvae were recorded on the growing media with a high proportion of green waste than on standard peat-based or organic growing media (Chandler *et al*, 2009). It was observed that the green waste growing media had more algal growth on the surface than the other two media, which will have attracted shore fly females to lay eggs and provided a food source.

Horticultural fleece is sometimes used in protected herbs in the early stages of production, to reduce shore fly egg-laying on the growing media.

Many growers use yellow sticky traps for monitoring both sciarid and shore flies. One UK grower of protected herbs has observed that horizontal traps are more effective for trapping shore flies than vertical ones. These can be placed on or above benches or floors. A large suction trap positioned above potted herbs on moving benches on one UK nursery has successfully removed shore flies from the crop just before packing.

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Biological control

Nematodes

Entomopathogenic nematodes (*Steinernema carpocapsae*) are commonly used by UK growers to control shore fly larvae in protected crops including ornamentals and herbs. Research has shown that although *S. feltiae*, commonly used for sciarid fly control, will also infect shore fly larvae, they do not control shore fly at the rates recommended for sciarid fly control (Bennison & Green, 2007). This result agreed with that by Finnish researchers (Vänninen & Koskula, 2010) who reported that five or 20 million per m^2 application rates of both nematode species were more effective than one or 2.5 million per m^2 in controlling shore fly in peat pots or rockwool blocks. The Finnish research showed that even weekly applications did not slow down shore fly population increase during the summer when rapid breeding occurs and that nematode applications should be combined with strict nursery hygiene measures. The current recommended rate for *S. carpocapsae* (Nemasys C) for shore fly control is 0.5 million per m^2.

Heterorhabditis bacteriophora (used in the UK for vine weevil control) has also been shown to infect shore fly larvae but was less effective than *Steinernema* spp. (Morton & Garcia del pino, 2007).

Dalotia (Atheta) coriaria

Dalotia (*Atheta*) *coriaria* will predate shore fly eggs, larvae and pupae in addition to those of sciarid fly (see sciarid fly section for details). One of the growers visited during this review uses *Dalotia* as the only method for shore fly control and this is very effective.

Predatory mites

The ground-dwelling predatory mites *Stratiolaelaps scimitus (Hypoaspis miles)* and *Gaeolaelaps* (*Hypoaspis*) *aculeifer* are used for the control of sciarid flies, and are generally regarded by growers as giving some reduction of shore flies. However, research demonstrated that *G. aculeifer* at the rate recommended for sciarid fly control did not reduce numbers of shore flies on potted mint at a commercial nursery when compared with untreated controls (Bennison & Green, 2007). This result agreed with those of Finnish researchers, who reported that a much higher application rate of both *S. scimitus* and *G. aculeifer* than that used for sciarid fly control was needed for effective shore fly control. The Finnish research showed that a release rate of 5,000 per m^2 for both species was needed for effective shore fly control on mint in peat pots (Vanninen & Koskula, 2004). Currently recommended release rate for *S. scimitus* for sciarid fly control are 100m^2 for preventive use and 200-500 per m^2 for curative use. Although growers often release these predatory mites for both sciarid and shore fly control, the biological control suppliers only recommend them for control of sciarid flies.

Naturally-occurring predators and parasitoids

The hunter fly, *Coenosia attenuata* will feed on shore fly as well as sciarid fly (see sciarid fly section for details).

Aphaereta debilitata is a naturally-occurring parasitoid of shore fly larvae reported from Finland (Vanninen & Koskula, 2010) and also from the UK (Bennison, 2007; Tilley *et al*, 2011). Where *Dalotia coriaria* were released to a commercial crop of potted mint, 78% of the shore fly larvae were naturally parasitised by *Aphaereta* (Bennison, 2007). *Aphaereta* was found to commonly occur in UK glasshouses and another naturally-occurring shore fly parasitoid, *Kleidotoma psiloides* was less common (Tilley *et al*, 2011). Research in Finland showed that release of the parasitoid in a cage trial reduced the shore fly population by 50-92% (Vänninen & Linnamäki, 2005), however the parasitoid is not commercially available.

Entomopathogenic fungi

The “Naturalis-L” strain *of Beauveria bassiana* has also been shown to be pathogenic to adult stages of shore flies in laboratory experiments, although larvae and pupae were not susceptible to the fungus (Castrillo *et al*., 2008). While this mortality was achieved by direct spraying adults, it was also noted high levels of mortality can be

achieved by emerging adults picking up spores from sprayed pupae via secondary acquisition. In a glasshouse experiment, another strain of *B. bassiana* gave 100% control of shore fly populations when applied as fungus-colonised millet seeds broadcast onto the surface of the potting medium and this strain was also reported to be pathogenic to shore fly larvae (Stanghellini & El-Hamalawi, 2005). *Beauveria bassiana* was also shown to infect shore fly larvae in the UK (Jacobson 1997).

(Naturalis-L) is currently approved for use as a biopesticide on all protected edible and ornamental crops, but only as a foliar spray for control of whiteflies and thrips. However, Naturalis-L is used by several growers of ornamentals for shore fly control, often as a tank mix with spinosad (Conserve) and with *Steinernema carpocapsae* (Helyer, personal communication and discussions with growers during this review).

Shore fly adults and pupae naturally infected with *B. bassiana* have been found in herb crops in the UK and another, rare insect-pathogenic fungus, *Torrubiella* sp., has also been found on one UK herb crop. (Chandler *et al*, 2009).

Bacillus thuringiensis subsp. israelensis (Bti)

As Bti has been commercially available in North America for longer than in the UK, an IPM adviser in Canada was contacted to ask if Bti will control shore flies in addition to sciarid flies. The adviser had already contacted Valent Biosciences who make all Bti products and they confirmed that Bti will not control shore flies (Murphy, personal communication).

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Management with plant protection products

Chemical plant protection products

There are no chemical plant protection products currently approved for control of shore fly in the UK. In the United States the insect growth regulators cyromazine, diflubenzuron and pryiproxyfen are used for both sciarid and shore fly control (Cloyd & Sadof, 2010; Willmott & Yates, 2010). Spinosad used as a foliar spray is not recommended for control of sciarid or shore flies in the United States or the UK but in the US growers have reported control of adults of both sciarid and shore flies.

Botanical biopesticides

There are no botanical biopesticides currently approved for control of shore fly in the UK. However, azadirachtin (Azatin) has recently gained approval for use against thrips in protected ornamentals and in the United States azadirachtin is recommended for use as a drench for control of both sciarid and shore flies (Cloyd & Sadof, 2010; Willmott & Yates, 2010).

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'Pot worms'

Pot worm species, food sources, plant damage and biology and behaviour

Species

The Dutch orchid industry refer to the fly larvae damaging *Phaelaeonopsis* and 'Cambria' orchids as 'potworms'. However, 'potworms' are small worms in the family Enchytraeidae which are not plant pests. The 'potworms' damaging orchids are fly larvae in the Keroplatidae family (Pijnakker *et* al, 2010; Pijnakker & Leman, 2013;

Humala *et al*, 2017). In the Netherlands, three species of pot worm have been identified: *Lyprauta chacoensis*, *Lyprauta cambria* and *Proceroplatus trinidadensis*. These are neotropical species and only occur in glasshouses in Europe (Evenhuis, 2006; Chandler & Pijnakker, 2009; Humala *et al*, 2017). During this review, adult 'potworms' were collected from the UK nursery growing orchids where the pests have become established. Photographs were sent to Joop Woelke at Wageningen who identified them to be almost certainly *L. cambria* (Woelke, personal communication).

Food sources and plant damage

The larvae of the species found in orchids are primarily predatory on other insects including sciarid fly larvae (Pijnakker & Leman, 2013; Humala *et al*, 2017) and can also be cannibalistic (Anthura and IMAC, 2016). 'Potworms' can also occur in Anthurium, gerbera and in some 'green' foliage plants in the Netherlands where they do not cause any plant damage (Pijnakker & Leman, 2013). However, since 2002 Dutch growers began to notice damage to *Phalaenopsis* and *Cambria* orchid roots suspected to be caused by fly larvae which were longer and thinner than that of sciarid fly (Pijnakker *et al*, 2010). Feeding damage causes circular pits in the surface of the root tips, leading to retarded growth due to the plant taking up less water and nutrients in the first few weeks of production. Infested plants produce less stems than healthy plants and they become vegetative and lighter and the production period is extended (Pijnakker & Leman, 2013 and Braime, personal communication). Damage on the UK nursery is worse in spring and autumn when environmental conditions are less hot and dry (Braime, personal communication). In the Netherlands, losses are estimated at 17% of sales (Pijnakker & Leman, 2013). In the UK it is estimated that on the nursery where the pest has become established, 20% of Phalaenopsis grown in 12cm pots are downgraded to single-stemmed plants and estimated losses of 17% are the same as in the Netherlands (Braime, personal communication).

Biology and behaviour

Very little information is available on the biology of 'potworms' in orchids. Eggs are laid in moist substrate. It is not known how long the eggs take to hatch, but it is estimated that the egg stage lasts for an average of seven days (Anthura & IMAC 2016). The first larvae can be found in the substrate 2-3 weeks after potting. Pot worms prefer a damper environment which allows them to progress through their larval stages more quickly (Anthura & IMAC, 2016; Floricultura, 2014).

The larvae live between the roots of the orchids and the bark substrate, producing acid webs (pH 2.7 or less) consisting of tubes along which they move. In these webs there are also "net-like" sections which contain droplets of saliva containing oxalic acid which they use for catching and killing prey (Humala *et al*, 2017). The larval stages last for 21-35 days depending on temperature and moisture levels and the pupal stage lasts for 4-8 days before emergence. After emergence the adults start to fly and are active mainly in the evening and at night. Numbers of adults caught in light traps increase after the orchids are potted into fresh bark substrate (Alkemade, personal communication).

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Cultural control

Keeping the bark substrate as dry as possible during the first ten weeks of production helps to reduce 'potworm' problems as the larvae cannot move so well as in moister substrate (Anthura & IMAC, 2016; Alkemade, personal communication). Adding a wetting agent with the irrigation water increases the drying of the substrate and could possibly inhibit the 'potworm' larvae from making slime trails. However, growing in a drier substrate leads to retarded plant growth. Using a medium coarse bark/coir growing medium rather than a coarse one can reduce numbers of 'potworms' (Alkemade, personal communication). Good nursery hygiene and avoiding wet areas on the glasshouse floor are additional cultural control methods.

Both Dutch growers and the UK grower use blue light traps to catch and monitor for adult 'potworms'. More adults (80%) are trapped during the evening and night than during the day (20%), Anthura & IMAC, 2016). Fifty traps per ha are advised for monitoring (equivalent to one per 200m^2), (Pijnakker & Leman, 2013). The UK grower uses sticky traps in the trap bases to catch the adults. In the Netherlands, growers have observed that when the number of light traps was increased, the number of adult 'potworms' and larval damage was reduced, therefore it is recommended to install a minimum of one lamp per 150m^2 with the aim of catching the females before they lay eggs (Anthura & IMAC, 2016).

A 'potworm' lure is available which claims to attract the adults and increase numbers caught in light traps. The lure is made up of 'composite attractants'. http://www.pro4agri.nl/action/webshop/productdetails/2044/pro4agri-fix-phalaenopsis-108-stuks-17.33-/stuk

This lure was discussed with Professor David Hall at NRI, Greenwich University. He is not aware of any published research on developing the lure or on attractants for flies in the Keroplatidae family. He considered that it if funding was available, research would be justified on lures used for mosquitos e.g. 1-octen-3-ol (Kline, 1994). This compound is now used in the widely available 'Mosquito Magnet' trap and in attractants for other fly species e.g. biting midges (Isberg *et al*, 2017).

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Biological control

Research was done at Wageningen on the efficacy of various biological control agents including the nematode species *Steinernema feltiae*, *Heterorhabditis bacteriophora*, the predatory mites *Macrocheles robustulus* and *Hypoaspis miles* (now renamed *Stratiolaelaps scimitus*) and *Dalotia* (*Atheta*) *coriaria* (Pijnakker & Ramakers, 2010; Pijnakker & Leman, 2013). In the 2010 report, laboratory studies showed that none of the predators ate 'potworm' larvae but both nematode species successfully parasitized them. In the 2013 work, *Macrocheles* were reported to feed on young 'potworm' larvae but an experiment using caged *Phalaenopsis* in a research glasshouse infested with 1cm-long 'potworm' larvae from commercial nurseries reported that none of the treatments reduced numbers of larvae compared with the untreated control. It was concluded that nematodes probably cannot move or persist in the dry bark growing media. However, it was recommended that further work using predatory mites against small 'potworm' larvae was justified.

Koppert BV were contacted to ask which species of predatory mite they recommend for control of 'potworms' on orchids in the Netherlands. Koppert reported that both *Macrocheles* and *Stratiolaelaps* can feed on young *Lyprauta* larvae but they do not give sufficient control in practice (Knapp, personal communication). Koppert advisers usually recommend *Macrocheles* and have observed positive effects on some nurseries, but they should not be considered as the solution to the problem. Koppert consider that the biology of the pest needs to be further understood and the whole production system looked at to develop an effective management strategy.

An adviser at IMAC was contacted to discuss use of predatory mites against the pest. The adviser replied that currently Dutch growers are getting better results with *Stratiolaelaps* than *Macrocheles*, using weekly releases of 150-300 per m^2 (Gobielje, personal communication).

At the UK nursery where 'potworm' has established, nematodes have been tried, using weekly drenches, but have given no control of larvae, probably due to the dry bark growing media used and to the high temperatures (28°C) used during production, both of which will adversely affect nematode survival and movement (Braime, personal communication). *Macrocheles* predatory mites have been tried but have given no apparent control. *Stratiolaelaps scimitus* are currently being used at a high release rate (600 per m^2) after potting and after plant spacing and are considered to be giving some control.

A naturally-occurring parasitoid, *Megastylus wolkei* (new species) was identified from infested 'potworm larvae' on a commercial orchid nursery in the Netherlands (Humala *et al*, 2017). Three species of 'potworm' adults were confirmed on the nursery i.e. *Lyprauta chacoensis*. *L. cambria* and a single specimen of *Proceroplatus trinidadensis*. It is likely that all three species were parasitized by *M. wolkei* as when the parasitic wasps became abundant in the glasshouse numbers of adult 'potworms'

in the traps were negligible. The parasitoids have now died out on the nursery due to lack of 'potworm' larvae (Woelke, personal communication). Further research is justified on this parasitoid if any more can be found as it is capable of eradicating 'potworm' populations.

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Management with plant protection products

Chemical and biopesticide plant protection products

Research was done at Wageningen on the efficacy of a range of selective chemical pesticides and biopesticides including pyrethrum, cyromazine, Bt, Bti, chorantraniliprole, azadirachtin and pyridalyl (Pijnakker & Leman, 2013). None of the treatments significantly reduced numbers of the pest compared with the control. The authors recommended that in high pest pressure, a pyrethrum spray or deltamethrin fog should be used.

During this review, in discussions with Certis over potential novel products for 'potworm' control, liquid garlic was reported to show promise in a preliminary investigation (Horgan, personal communication).

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Conclusions on current and potential future control methods for sciarid fly, shore fly and 'potworm'

Sciarid fly

Currently used control methods within IPM programmes in the UK include:

- Cultural control methods including nursery hygiene, avoidance of over-watering, adequate ventilation and using reduced peat growing media play a key role in sciarid fly management.
- Biological control agents used within IPM programmes include entomopathogenic nematodes (*Steinernema feltiae*), the predatory beetle *Dalotia* (*Atheta*) *coriaria*, the predatory mites *Macrocheles robustulus* and *Stratiolaelaps scimitus*. The entomopathogenic fungus *Metarhizium brunneum* (*anisopliae*) (Met52 granular bioinsecticide) is used for vine weevil control on some perennial plants and may also be contributing to sciarid fly control.
- Naturally-occurring biological control agents include the entomopathogenic fungus *Furia sciarae,* the parasitoid *Synacra* sp. and the hunter fly *Coenosia attenuata*.
- Growers avoid using the neonicotinoid insecticides thiacloprid (Exemptor and Calypso) due to many retail customers not accepting plants treated with any neonicotinoid.
- Growers would like more IPM-compatible control options to be available to improve sciarid fly control on highly susceptible plants such as cyclamen and poinsettia and in propagation. They would also like a quick knockdown product to be available if biological control methods fail to give adequate control.

Potential future control methods include:

- *Bacillus thuringiensis* subsp. *israelensis* (Bti). Gnatrol SC is now approved in the UK for sciarid fly control on protected ornamentals.
- Azadirachtin (Azatin) is approved in the UK as a foliar spray for thrips control in protected ornamentals. This active ingredient has been shown to be effective against sciarid fly in the US when used as a drench.
- Garlic products are approved in the UK for control of nematodes in amenity turf, carrot and parsnip. Garlic oil has been shown to repel mushroom sciarid fly adults and to reduce adult emergence from treated spawned mushroom compost.
- Botanical biopesticides containing essential oils such as peppermint and spearmint and plant volatiles such as linalool have potential for sciarid fly control and/or repellence.
- Chemical insect growth regulators used in the United States for sciarid fly control have potential if they have a clear route to market in the UK.

Shore fly

Currently used control methods within IPM programmes in the UK include:

- Cultural control methods including nursery hygiene, control of algae, avoidance of over-watering, adequate ventilation, using reduced peat growing media and using yellow sticky traps and suction methods.

- Biological control agents used within IPM programmes include entomopathogenic nematodes (*Steinernema carpocapsae*) and the predatory beetle *Dalotia* (*Atheta*) *coriaria*. Despite the predatory mites *Macrocheles robustulus* and *Stratiolaelaps scimitus* not being recommended for shore fly control, many growers use them for both sciarid and shore fly control.
- The entomopathogenic fungus *Beauveria bassiana* (Naturalis-L) is used if shore fly numbers are high, often in a tank mix with spinosad (Conserve) and/or *S. carpocapsae* for a quick knockdown.
- The entomopathogenic fungus *Metarhizium brunneum* (*anisopliae*) (Met52 granular bioinsecticide) is used for vine weevil control on some perennial plants and may be giving some incidental control of shore fly.
- Naturally-occurring biological control agents include the parasitoids *Aphaereta debilitata*, *Kleidotoma psiloides* and the hunter fly *Coenosia attenuata*.
- There are no chemical or biopesticide plant protection products approved in the UK for shore fly control. Bti (Gnatrol SC) has recently been approved for use in the UK for sciarid fly control on protected ornamentals but this will not control shore fly.
- Growers would like more IPM-compatible control options to be available to improve shore fly control on highly susceptible plants such as cyclamen and begonia and in propagation. They would also like a quick knockdown product to be available if biological control methods fail to give adequate control.

Potential future control methods include:

- It would be useful to evaluate the efficacy of spinosad (Conserve) against shore fly, alone and in combination with *Beauveria bassiana* and/or *Steinernema carpocapsae*.
- Azadirachtin (Azatin) is approved in the UK as a foliar spray for thrips control in protected ornamentals. This active ingredient has been shown to be effective against sciarid fly in the US when used as a drench.
- It would be useful to compare the control of shore fly by *Steinernema carpocapsae* applied in a 'little and often' approach with full rate applications.
- Chemical insect growth regulators used in the United States for sciarid fly control have potential if they have a clear route to market in the UK.

'Potworm'

Currently used control methods within IPM programmes in the UK include:

- Nursery hygiene and keeping the growing media as dry as possible in the early production stage.
- Blue light traps for monitoring.
- The predatory mites *Stratiolaelaps scimitus*.

Potential future control methods include:

- Increasing the number of light traps for control as well as monitoring.
- Using the commercially available lure together with the light traps.
- Testing other lures such as 1-octen-3-ol which is used in mosquito traps and attractants for other flies such as biting midges.

- Using more frequent applications of *S. scimitus.*
- Experimenting with different growing media to make it less favourable for 'potworms' and more favourable to entomopathogenic nematodes and predators.
- Identifying whether the natural parasitoid *Megastylus wolkei* is present on the nursery.
- Testing garlic products for control of larvae.
- Researchers at Wageningen working on 'potworm' have been contacted and we have offered to collaborate with them on future research. If this is possible, this could affect treatment selection so that any trial should ideally complement the Dutch research.

Further work

New potential control methods for the three fly pests were identified. If further funding is available for efficacy trials next year, candidate IPM-compatible treatments will be selected as having a clear route to market if not already approved in the UK. Treatments may include both conventional chemical plant protection products and microbial and botanical biopesticides. Treatments and methods will be discussed and agreed with the SCEPTREplus programme management team before trial protocols are confirmed.

It is recommended that an updated Factsheet is provided for growers to update them on current control measures available for sciarid and shore fly control on protected ornamentals. The Factsheet would be more useful if delayed until any further research is done in SCEPTREplus.

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- Professor David Hall, NRI, Greenwich University, for discussions on potential lures for 'potworm'.

- Alan Horgan, Certis, for discussions on potential novel treatments.