

Rapid Pest Risk Analysis

Agrotis infusa



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Authors

Prepared by SLU Risk Assessment of Plant Pests Swedish University of Agricultural Sciences

Name of Pest Risk Analysts:

Niklas Björklund, Dept. of Ecology, Swedish University of Agricultural Sciences, P.O. Box 7044, SE-750 07 Uppsala, Sweden. Visiting address: Ulls väg 16, E-mail:

Niklas.Bjorklund@slu.se

Johanna Boberg, Dept. of Forest Mycology and Plant Pathology, Swedish University of Agricultural Sciences, PO Box 7026, SE-750 07 Uppsala, Sweden. Visiting address: Almas allé 5, E-mail: Johanna.Boberg@slu.se

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Terms of reference

Following an application to import the currently un-regulated pest *Agrotis infusa* for research purposes in Sweden, the Swedish Board of Agriculture has requested SLU Risk Assessment of Plant Pests to perform a rapid PRA of the species. The PRA should provide a description of the pest and focus on the likelihood of establishment, potential magnitude of spread and potential impact and whether the corresponding criteria for a quarantine pest could be fulfilled. The risk assessment area is Sweden, but within the context of the whole EU. The format of this rapid PRA is an adapted version of the EPPO Express PRA scheme (EPPO 2012; 2019).

Summary

Agrotis infusa, with the common names Bogong moth or Common cutworm, is a nocturnal moth native to Australia. The species is well known for its annual long-distance migrations from the breeding areas to the Australian Alps where the moth hibernates during the summer, referred to as aestivation. The species is a very polyphagous pest and feeds on a range of different plants including species of cereals, vegetables, grasses, legumes, weeds as well as pine seedlings.

Presence

Agrotis infusa is native in Australia and has not been reported as established anywhere else. The moth is frequently observed in New Zealand but has not established populations there.

Entry, establishment and spread

The likelihood of entry was not evaluated since the PRA was initiated as a response to an application to import *A. infusa*.

The likelihood of establishment in Sweden was assessed as very low (with medium uncertainty) mainly due to unfavourable climatic conditions. In the southern and western parts of the EU, where the climate is comparable to that in the native range and host plants are available, the likelihood of establishment is assessed as higher than in Sweden. If *A. infusa* establish in more southern parts of the EU, annual migration of the pest into Sweden could occur.

Agrotis infusa is able to disperse very long distances but potentially strong Allee effects may reduce the spread rate. If established, the magnitude of spread was assessed as high with medium uncertainty.

Impact

Damage by *Agrotis infusa* is caused by larval feeding and many host plants in the native range are also found in Sweden and the EU. The magnitude of potential impact in Sweden was assessed as very low (with low uncertainty) mainly due to unfavourable climatic conditions.

At the EU-level the endangered area would be regions in western and southern parts of the EU where climatic conditions are conducive and host plants are available. The potential impact in these areas would presumably be similar to that in the native range, i.e. moderate economic impact with medium uncertainty, low environmental and social impact with medium and low uncertainty respectively.

Assessment in relation to the definition of a quarantine pest

The following conclusions were made in relation to the conditions required for a quarantine pest (EU 2016/2031);

- (a) *Agrotis infusa* is a plant pest whose identity is established (b) *Agrotis infusa* is not present in the EU.
- (c) Whether *A. infusa* is capable of entering into the EU was not assessed since the PRA was initiated as a response to an application to import the species for research purposes. Following potential entry, the likelihood of establishment in Sweden was assessed as very low and the criteria of being capable of becoming established is assessed to not be fulfilled. The likelihood of establishment was assessed to be higher in some other parts of the EU but further analysis would be required to determine if the criteria of establishment at the EU-level is fulfilled.
- (d) A detailed description of the current impact of *A. infusa*, and an assessment of potential impact in Sweden/EU is provided in this PRA to support a decision of whether the potential impact should be considered to be “unacceptable”.
- (e) Whether effective measures are available to prevent the entry of *A. infusa* was not assessed since this PRA was initiated as a response to an application to import the species for research purposes.

Key uncertainties and further investigation needed

The main uncertainty is associated with the potential establishment of *A. infusa*. In particular, there is a lack of information about the climatic requirements for non-migratory populations of the pest and whether other factors prevent establishment outside the native range, e.g. strong Allee effects. There is also a lack of quantitative estimates of damage in the literature. Further analysis is needed to improve the assessment of the endangered area in the EU.

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Pest risk assessment

1. Name of the pest

Latin name: *Agrotis infusa* (Boisduval)

Synonyms: *Euxoa infusa* (Boisduval), *Agrotis spina* Guenée, *Noctua infusa* Boisduval (EPPO 2020); *Agrotis diffusa* (Capinera 2008); *Agrotis cordata* Walker, *Agrotis spina* Guenée, *Agrotis vastator* Scott, *Mamestra nitida* Walker, *Mamestra tenebrosa* Walker (Australian Biosecurity 2020).

Common names: Bogong moth (EPPO 2020); Common Cutworm (Umina et al. 2015).

Taxonomic position: Domain: Eukaryota, Kingdom: Animalia, Phylum: Arthropoda, Subphylum: Hexapoda, Class: Insecta, Order: Lepidoptera, Family: Noctuidae, Genus: *Agrotis*, Species: *Agrotis infusa*.

EPPO code: EUXOIN

Two morphs of the species occurs, one dark with blackish brown hind wings, which is referred to as the typical form, and one pale with whitish hind wings (Common 1954; 1958). The dark form is reported to migrate annually, while the pale morph is suggested to be non-migratory (Common 1954; 1958). Individuals of both morphs can have offspring that differ from the parent form and the offspring may also have intermediate colouring (Common 1958).

2. Pest overview

2.1 Morphology

A detailed description of *A. infusa* is provided by Rawat (1957). An overview of the morphology of *A. infusa* is provided below.

- Eggs are dome-shaped and measures about 0.5 mm in width and 0.35 mm in height (Rawat 1957).
- Larvae are black, green-brown or grey without characteristic hairs or markings and have a greasy appearance (Hopkins and McDonald 2007). The larva goes through six to nine larval instars and grow from 1 mm up to 50 mm long (Rawat 1957; Hopkins and McDonald 2007; McQuillan et al. 2007).
- Pupae measure 16 – 22 mm in length and 5 – 7 mm in width and are shiny brown (Rawat 1957; McQuillan et al. 2007).
- Adults have dark brown or grey-black forewings with black or grey markings near the centre (Hopkins and McDonald 2007). The hindwings may be dark or white (Common 1954). The wingspan is approximately 45 mm (McQuillan et al. 2007).

Bellati et al. (2010) provides distinguishing characteristics between *A. infusa*, *A. munda* and *A. ipsilon* however, distinguishing characters were considered obscure for the larval stage.

2.2 Life cycle

Eggs are usually laid in irregular clusters in the soil, on loose material on the soil surface or on plants if the soil is too wet or dry (Rawat 1957; McQuillan et al. 2007). One single female can lay up to 2 000 eggs (Common 1981). Larvae go through six to nine larval instars (Rawat 1957). Initially the larvae stay continuously on the foliage but later instars generally hide in the soil during the day and feed during night (McQuillan et al. 2007). Pupation occurs in the soil at 2-15 cm depth (McQuillan et al. 2007). Adults may feed on nectar from flowers (see Section 9) and maturation feeding has been shown to be required before mating (Rawat 1957).

Eggs develop in a few days up to more than four weeks, larval development takes 3-12 weeks and pupation can take 11 days to 2 months depending mainly on the temperature conditions (Common 1954; Rawat 1957; McQuillan et al. 2007). At 24°C the development from egg to adult can be reached in about 7 weeks (Common 1954).

Agrotis infusa is usually described as a mainly migratory species with one generation produced per year (Common 1954; Warrant et al. 2016). However, *A. infusa* is a multivoltine species, possibly able to produce up to three-four generations per year when environmental conditions are suitable and larval food plants, i.e. annual dicotyledons, are continuously available (Common 1954).

In large part of the species range, breeding occurs only during the winter due to unfavourable conditions through the hot summers (Common 1954; Warrant et al. 2016). During the summers when the availability of larval food plants is limited, the adult moths migrate over very long distances to hibernate in the cooler Australian Alps (Common 1954). This state of dormancy during the summer, which is called aestivation, is a rather uncommon phenomenon in adult Lepidoptera (Hinks and Byers 1976). The moths aggregate in crevices and caves at high altitudes where they aestivate for several weeks up to 4 months (Broome 2001; Common 1954). In the autumn the same individuals migrate back to their breeding areas which cover cropping and grazing regions extending from southern Queensland, across New South Wales to Northern Victoria (Common 1954; Green 2008).

During the summer, part of the migrating population may also breed (instead of aestivating). This has been observed in Canberra, the area of Adelaide and Tasmania (Common 1954; Rawat 1958; Hill 2007; McQuillan et al. 2007; Warrant et al. 2016). In Tasmania, adults arrive from the mainland in the spring (September-November) and may either shelter in the mountains in the northern parts of Tasmania or reproduce in suitable agricultural areas (Hill 2007; McQuillan et al. 2007). It is uncertain whether there is a migration back to the mainland from Tasmania in the autumn (February-April) (McQuillan et al. 2007). It is suggested that some moths may overwinter in Tasmania but infestations during this season have not been reported and very few adult moths are caught in traps (Hill 2007; McQuillan et al. 2007). Hill (2007) concludes that there is no indication of a permanent population in Tasmania.

There are also non-migratory populations of *A. infusa* in the Australian Capital Territory, e.g. in Canberra, and in south-eastern New South Wales and possibly south of Perth in Western Australia as well as in Adelaide (Rawat 1958; Warrant et al. 2016). Reports of larvae during the summer in the Canberra region are uncommon (Common 1954). According to Green (2006) the

non-migrating populations have spring and autumn generations, but it is not clear which specific locations this refers to. In Adelaide moths are trapped around the year with peaks in the spring and autumn (Rawat 1958). Combining experimental data and captures of different life stages, Rawat (1958), identified areas around Adelaide with permanent populations and areas where breeding can only occur part of the year. Further, partial migration, where a proportion of a population migrates, while other individuals remain resident, may occur. At least it is a common phenomenon in migratory insects (Menz et al. 2019).

Migratory and non-migratory populations are suggested to be different morphs, i.e. dark and pale hind wings, respectively (Common 1954; Common 1958; Warrant et al. 2016). For example, specimens of the morph with pale hind wings were captured between May-September in Canberra (during winter-spring), while only the dark morph was caught during spring to summer (i.e. presumably migrating individuals flying southwards towards the Alps) (Common 1954). The pale morph has not been observed aestivating in the Australian Alps (Common 1954). In Tasmania the pale morph occurs uncommonly in trap catches and is mainly found during August-October and in April while the dark morph is more common and dominates in the mountains during summer (Hill 2007). Adults reared in the laboratory from larvae collected from fields in Tasmania are reported to often consist of pale morph (Hill 2007). This may be an indication of a non-migratory population in Tasmania since the pale morph is considered to be non-migratory (Common 1954).

During the aestivation some activity appear to be common, e.g. crawling and sometimes flying (Common 1954). Experiments indicate that the flying moths during this period do not search for food or water, but the moths appear to drink rainwater during aestivation (Common 1954). Facultative diapause has been suggested for adults of the migrating moths and that maturation feeding is required after aestivation prior to mating and oviposition (Common 1954). No diapause during the larval stage occurs (Common 1954).

2.3 Temperature and humidity requirements

In laboratory experiments, Rawat (1957) investigated the effect of different temperature and humidity regimes on the development of different stages of development and some of the results, with a focus on low temperature thresholds, are summarized here:

- Eggs hatched at temperatures of 9.3 – 33.8°C with a mean incubation period of 32.5 - 2.4 days. Eggs kept at 7°C for 40 days (followed by a period of 26°C) did not hatch. Eggs hatched after exposure to 0.8°C for 14 days (followed by 26°C) while none hatched after 15 days of exposure to 0.8°C. Eggs which had reached half of their development (at 26°C) were not affected by exposure to 0.8°C for up to 10 days. A saturation deficit of 3 mm Hg was optimal at most temperatures while especially higher saturation deficits had a negative effect on egg survival.
- Optimal temperature for larval development was 20-26°C. Larvae did not develop completely in 6.8°C and 8.0°C, and at 13.4°C survival rate was only 5%.
- Complete pupal development was observed between 13.4-34.5°C. No moth emerged at temperatures of 6.8°C and 9.0°C. When the pupae had reached 70% of the pupal development time (after 10 days at 26°C), one out of six pupae survived exposure to 6.8°C while six out of six survived 13.4°C. Highest survival was observed at a

saturation deficit of 0 mm Hg (at temperatures 20.3 or 26°C) while higher saturation deficit had a negative effect on pupal development.

- Newly emerged adults survived without food and water at 6.8°C for 26 days (mean of 2 individuals) and moths kept at temperatures alternating between 5.8°C (15 hours) and 20°C (9 hours) with food survived for 58 days (mean of 9 individuals).

In addition, laboratory experiments by Common (1954) show that eggs failed to hatch at 4.5°C and larvae survived 4 weeks at 4.5°C if kept at higher temperatures before and after (no details were provided of the experimental set-up).

2.4 Population dynamics

The availability of resources and environmental conditions are considered to be the most important factors affecting the abundance of cutworms (Farrow and McDonald 1987; Woods et al 1990; Mansergh and Heinze 2019). However, a range of different fungal diseases, parasitoids and predators attack cutworms and may also influence population levels (Woods et al. 1990; Moir et al. 2007; Bailey 2007). Several non-specified species of braconid and ichneumonid wasps have been found parasitizing the larvae of *Agrotis infusa* (Hopkins and McDonald 2007). However, no information was provided about the effects on the population of the pest.

During aestivation the adult moths are subjected to both predation and parasitism. Different species of mammals and birds feed on the moth and ravens, bush rats, pipits and foxes were estimated to be the main predators (Green 2011). Species of mermithid nematodes adapted to parasitize on the adult moth are found in the aestivation caves (Common 1954, Warrant et al 2016). During aestivation, predation was estimated to cause three times higher mortality than other causes, e.g. due to parasites or weather (Green 2011).

2.5 Type of damage

The plant damage caused by *A. infusa* is a consequence of larval feeding on the above ground parts of plants. When the larvae are small they feed on the surface tissues of the plants but as they grow they start to cut off plants at the ground level and drag them into shallow larval burrows in the soil (Common 1990; Micic and Severtson 2020).

Agrotis infusa can be a nuisance when they for example invade cities in large numbers (Capinera 2008; New 2007) but it is also considered to be an iconic species which provided an important food resource for Aboriginal people and it is an important food resource for e.g. the endangered mountain pygmy-possum (*Burramys parvus*) (Gibson et al. 2018; Australian Museum 2020). However, since such impacts are not phytosanitary, they are not falling within the scope of this PRA (IPPC 2019).

3. Is the pest a vector?

- No
 Yes

4. Is a vector needed?

- No
 Yes

5. Regulatory status of the pest

Agrotis infusa is not listed as regulated in the EU plant health regulation (EU 2016/2031; 2019/2072). The pest is not listed nor has been listed by EPPO. “*Agrotis* sp.” is listed in the U.S. Regulated Plant Pest Table (USDA-APHIS 2020). To our knowledge, *A. infusa* is not species specifically regulated anywhere but no systematic review of all countries lists of regulated species were performed (c.f. FAO 2020).

6. Describe the results of earlier PRAs

Information relevant for the current PRA is available in the following three risk assessments. However, in these assessments, *A. infusa* is only one of several pest species that were evaluated and mainly since they contain little species-specific information, they do not replace the need to perform a risk assessment for Sweden.

- In an assessment of risks associated with *Pinus* imports to USA from Australia, *A. infusa* was listed as an insect of potential concern but no pest risk assessment was done for this species (seedlings of *Pinus radiata* were listed as hosts; Kliejunas et al. 2006).
- A risk assessment was conducted for pests potentially entering New Zealand as hitchhikers on vessels (Ministry for Primary Industries 2016). The likelihood of entry of *A. infusa* was assessed as high given certain circumstances, the likelihood of establishment was assessed as uncertain but non-negligible and the consequences of an establishment were assessed to be moderate (Ministry for Primary Industries 2016).
- In a report evaluating the effects of climate change on current and potential biosecurity pests and diseases in New Zealand, *A. infusa* was listed as an example of a species with potential to establish in New Zealand as a result of increased westerly winds, that would increase the inflow of specimens from Australia, and warmer temperatures (Kean et al. 2015).

7. Current area of distribution

7.1 Native range

Agrotis infusa is native to Australia and has mainly been recorded from the south-eastern and southwestern parts of the country (Figure 1A; GBIF.org 2020; Common 1990). According to the Australian Biosecurity (2020) the distribution of *A. infusa* includes the Australian Capital Territory, Lord Howe Island, New South Wales, Norfolk Island, Queensland, South Australia, Tasmania, Victoria, and Western Australia. However, the species does not have permanent populations in all these areas (see Section 11).

7.2 Observations in areas outside the native range

Agrotis infusa is a long-distance migrating species and has frequently been observed outside its native range but has never managed to establish outside of Australia. Observations of *A. infusa* from New Zealand were reported already in the book "The butterflies and moths of New Zealand" published in 1928 (Common 1958). Later, Fox (1969), reports findings of large numbers of *A. infusa* in New Zealand after periods with very strong winds from the west. He states that although *A. infusa* has been found many times in New Zealand the probability that adults survive long enough to reach sexual maturity, which it does in late summer, and thereafter find suitable oviposition areas in the face of a New Zealand winter are probably small (Fox 1969). In a later study, Fox (1978) reports that the moth has been found in traps in New Zealand in five years during 1968-1976, and also found breeding in the summer months and yet do not seem to survive the winter. Similarly, during the 1980s and 1990s *A. infusa* was trapped in four out of 13 years (in total 46 specimens) and although larvae were found in February (i.e. during the end of the New Zealand summer) there were no indications that *A. infusa* can survive the winter in New Zealand (Bullians et al. 2006; Hartnett et al. 2008). Gibbs (2007) also states that *A. infusa* is a long-distance traveller that regularly ends up in New Zealand and breed for a generation or two before they die out. *Agrotis infusa* has also frequently been found on Norfolk Island, e.g. it arrived in all years from 1976-1980 (Holloway 1977; 1982).

Altogether, there appears to be no evidence of established populations either in New Zealand (Ministry for Primary Industries 2016; G. Walker and R. Hoare, pers. comm. 2020) nor on Norfolk Island (Holloway 1982; Hopkins and McDonald 2007).

8. Is the pest present and is it widely distributed¹ in Sweden?

Agrotis infusa is not known to be present in Sweden nor in any other country in the EU.

9. Host plants and their occurrence in Sweden

Agrotis infusa is very polyphagous and larvae have been recorded on many different plant species (Table 1). Most of them are however not plants that are native to Australia and in pre-European times *A. infusa* was most likely dependent on saltbushes (*Atriplex*) (Keaney 2016). Feeding larvae have been found on cereals and vegetables, in pastures, forestry nurseries, weeds and domestic lawns (Common 1954; Moore 1962; Hill 2007). *Medicago* spp. appear to be the most important host and larvae usually avoid grasses (Common 1954). However, there are numerous reports of *A. infusa* feeding on grasses and cereals etc. (e.g. Common 1954; Hill 2007; Beehag et al. 2016).

The adult moths feed on nectar from flowers of many different plants, e.g. forest and orchard trees, garden flowers and shrubs (Green 2006 citing McCarthy 1945). During their migration flights, feeding has been observed on e.g. *Eucalyptus* spp., *Epacris* sp. *Grevillea lanigera* and *Xanthorrhoea australis* (Common 1954; Common 1990). Feeding from honeydew produced by lerp insects has also been observed before migration north (Green 2006).

¹ Definition can be found in ISPM 5, Supplement 1.

Most of the cultivated plants known as hosts (Table 1) are also grown extensively in Sweden and different parts of the EU. The host list is most likely not exhaustive and other plant species found in Sweden and the EU may also be suitable hosts.

Table 1. Plants recorded as hosts of *Agrotis infusa*

Plant name	Comments	Reference
Agricultural plants		
<i>Avena sativa</i> (oat)	Larvae	Hopkins and McDonald 2007
<i>Beta</i> spp. (beets, e.g. sugar beet, silver beet)	Larvae	Common 1954; Hill 2007; Robinson et al. 2010
<i>Brassica</i> spp. (cabbages, cauliflowers, Chinese cabbages, swede)	Larvae	Common 1954; Gregg et al. 1993; Hill 2007; Robinson et al. 2010
<i>Cucurbita</i> sp. (squash)	Larvae	Hill 2007
<i>Daucus carota</i> subsp. <i>sativus</i> (carrot)	Larvae	Hill 2007
<i>Gossypium</i> sp (cotton)	Larvae	Wilson et al. 2007
<i>Hordeum</i> spp. (Barleys)	e.g. larvae on barley	Hill 2007; Hopkins and McDonald 2007; Robinson et al. 2010
<i>Humulus lupulus</i> (hops)	Larvae	Hill 2007
<i>Lactuca sativa</i> (lettuce)	Larvae	Bullians et al 2007; Hill 2007
<i>Linum</i> (e.g. linseed)	Larvae	Common 1954; Robinson et al. 2010
<i>Medicago</i> spp. (e.g. lucerne)	Suggested as a main host, larvae	Common 1954 and references therein; Rawat 1957; Robinson et al. 2010
<i>Mentha</i> spp.	Larvae	Australian Biosecurity 2020
<i>Papaver somniferum</i> (poppy)	Larvae	Hill 2007

Plant name	Comments	Reference
<i>Pastinaca sativa</i> (parsnip)	Larvae	Hill 2007
<i>Pisum sativum</i> (peas)	Larvae	Common 1954; Robinson et al. 2010
<i>Phaseolus vulgaris</i> (green bean)	Larvae	Hill 2007
<i>Secale cereale</i> (rye corn)	Larvae	Hill 2007
<i>Solanum tuberosum</i> (potato)	Larvae	Common 1954; Hill 2007; Robinson et al. 2010
<i>Trifolium</i> sp.	Larvae	Hill 2007
<i>Triticum</i> spp. (wheat)	Larvae	Common 1954; Rawat 1957; Hopkins and McDonald 2007; Robinson et al. 2010
<i>Zea mays</i> (maize)	Larvae	Hill 2007
Weeds and wild plants		
<i>Arctotis calendula</i> (Capeweed)	Larvae	Rawat 1957; Keaney (2016) citing Hughes (1975)
<i>Atriplex</i> (e.g. saltbush)	Larvae	Keaney (2016) citing Hughes (1975)
<i>Erodium cicutarium</i> (stork's bill)	Growing among green beans, larvae	Hill 2007
<i>Malva</i> (mallow)	Larvae	Hill 2007
<i>Rumex</i> (dock)	Larvae on docks in fallow	Hill 2007
Trees and shrubs		
<i>Acer</i> sp. (red maple)	The host status is uncertain since it is only based on eggs collected on the foliage and reared to the adult stage for identification.	Hill 2007
<i>Pinus radiata</i> (radiata pine)	Damage on seedlings	Moore 1962; Robinson et al. 2010

Plant name	Comments	Reference
Flowering plants		
e.g. <i>Eucalyptus</i> spp., <i>Epacris</i> sp. <i>Grevillea lanigera</i> and <i>Xanthorrhoea australis</i>	Adults feeding on nectar (and honeydew)	Common 1954; Common 1990

10. Pathways and likelihood of entry into Sweden

Not applicable since the PRA was initiated as a response to a request to import the pest for research purposes (see Terms of reference section). It could be noted that there are no reports of interceptions of *A. infusa* in the EU (EUROPHYT 2020).

11. Likelihood of establishment in Sweden

11.1 Establishment outdoors

Host plants

Host plants are widely available in agricultural and urban land in Sweden, at least parts of the year, and the availability of host plants would probably not limit the establishment of *A. infusa* (see Section 6).

Natural enemies

A wide range of predators, parasites and pathogens attack *A. infusa* both at larval stages and as adults in its native range (see Section 2.4). Most of the species considered to be the main predators of the adult moth according to Green (2011) are also present in Sweden and the EU, i.e. ravens, pipits and foxes. For the related species *A. segetum* and *A. ipsilon*, which are present in the EU, a wide range of different natural enemies are recorded, many of them are generalists (CABI 2020a, b). At least some are recorded as present in the EU (Cabello 1989; CABI 2020c). Based on this information the potential establishment of *A. infusa* in the EU is not expected to be facilitated by a lack of natural enemies.

Köppen-Geiger climate zones

Agrotis infusa has been recorded from a wide range of climate types; mainly arid, temperate and cold climate types (Figure 1A and Table 2). However, because *A. infusa* is a long-distance migrating species, which frequently ends up far away from the region where it is established, e.g. in New Zealand, single recordings should not be interpreted as evidence of establishment. Further, the moth does not complete its life cycle in all these climates.

Non-migratory populations are found in Southeastern New South Wales and in the Australian Capital Territory (Warrant et al. 2016), with the climate type Cfb, i.e. temperate with no dry season and warm summer (Figure 1A, insert). Permanent populations are also reported from the area around Adelaide (Rawat 1958) and possibly there is also a non-migratory population South of Perth in Western Australia (Warrant et al. (2016) citing personal communication). These regions are represented by temperate climate with dry and warm/hot summers (i.e. Csa and Csb) and the arid climate type BSk.

In the southern parts of Queensland, northern and western parts of New South Wales and western Victoria the species is only found during the cooler part of the year (Warrant et al. 2016). These areas are characterized by arid and temperate climates (e.g. BWh, BWk, BSh, BSk, Cfa and Cfb). In the Australian Alps the moth is only present during the summer aestivation (Common 1954; Warrant et al. 2016) and the area has a Köppen-Geiger climate categorised as cold (Dfb and Dfc).

It should be noted that *A. infusa* has not established neither in New Zealand nor on Norfolk Islands, despite the fact that it frequently arrives there (see Section 7) and that the climatic conditions there are similar to those in Australia where the pest is established, e.g. temperate zones Cfb and Cfa, respectively.

Sweden is represented by cold climate types (i.e. Dfb and Dfc) where the pest is not known to reproduce or survive the winter (Figure 1B). The climate types in areas with assumed permanent populations (i.e. Csb, Cfb, BSk and possibly Csa) are found in the southern and western parts of Europe reaching up to Denmark and along the western coast of Norway. Climate types in areas used by migratory populations for breeding during the winter are found in some regions in southern Europe (e.g. Cfa).

It should be noted that some of the observations of the species were made prior to the time period for which the Köppen-Geiger climate zones shown in Figure 1 were based on. Thus, the designation of the different climate zones as suitable for breeding and permanent populations of *A. infusa* are approximate.

Table 2. The Köppen-Geiger climate zones where the moth has been observed in Australia, a description of the climate zones according to Beck et al. (2018) and presence of migratory or non-migratory populations estimated based on information provided in the given references.

Köppen-Geiger climate zones	Description	Migratory / Non-migratory populations ¹	Reference(s)
Am	Tropical, monsoon	Not known	-
BWh	Arid, desert, hot	Migratory	Green 2008
BWk	Arid, desert, cold	Migratory	Rawat 1958; Green 2008
BSh	Arid, steppe, hot	Migratory	Common 1954; Green 2008
BSk	Arid, steppe, cold	Migratory and Non-migratory	Common 1954*; Rawat 1958, Green 2008
Csa	Temperate, dry summer, hot summer	Non-migratory ²	Warrant et al. 2016
Csb	Temperate, dry summer, warm summer	Non-migratory	Rawat 1958; Warrant et al. 2016
Cfa	Temperate, no dry season, hot summer	Migratory	Common 1954*
Cfb	Temperate, no dry season, warm summer	Migratory and Non-migratory	Common 1954*; Hill 2007; McQuillan et al. 2007; Warrant et al. 2016
Cfc	Temperate, no dry season, cold summer	Migratory	Hill 2007; McQuillan et al. 2007
Dfb	Cold, no dry season, warm summer	Migratory ³	Common 1954; Warrant et al. 2016
Dfc	Cold, no dry season, cold summer	Migratory ³	Common 1954; Warrant et al. 2016

*Including data from Froggatt 1900.

¹ It should be noted that the designation of the population type is approximate, e.g. since some of the records were made prior to the time period used for calculating the Köppen-Geiger climate zones.

² Uncertain, non-migratory population south of Perth may include Köppen-Geiger climate zones Csa and Csb.

³ Area used only for aestivating.

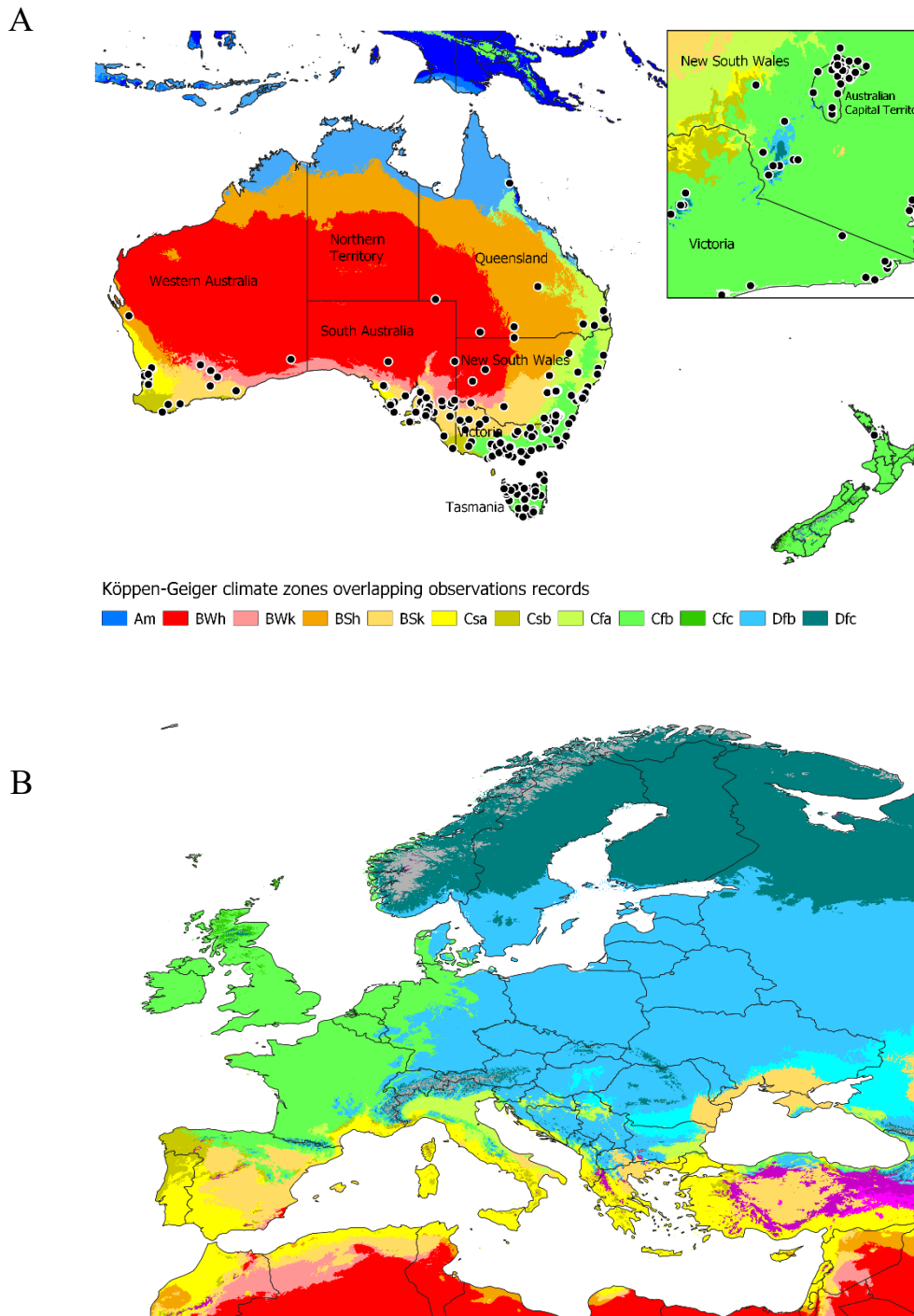


Figure 1. Occurrence records of *A. infusa* in Australia and New Zealand from GBIF.org (2020) and overlapping Köppen-Geiger climate zones (A) and Köppen-Geiger zones in EU (B). Inserted map in A shows a close-up of the south-eastern region of Australia which includes part of the Australian Alps with Köppen-Geiger zones Dfb and Dfc. The Köppen-Geiger climate classifications maps are from Beck et al. (2018) and based on the climate during the period 1980-2016 (available under the CC BY-NC 4.0 license, downloaded from www.gloh2o.org/koppen and here displayed in a modified version). Country borders, states and territories are from naturalearthdata.com. The maps were created using qGIS (QGIS Development Team 2020).

Low temperature thresholds

The complicated life cycle of the moth and the fact that both migratory and non-migratory populations exist and appear to have overlapping distributions, at least in parts of the range, makes it difficult to estimate the climatic conditions allowing the fulfilment of a complete life cycle.

Climatic parameters of aestivation sites were estimated by Keaney (2016) and the minimum temperature during the summer ranged from ca 5.2 – 6.8°C. Temperatures measured by Common (1954) within an aestivation cave dropped below 0°C a few times during the studied period.

Adult moths in the Australian Alps have been observed to fly at temperatures below 7°C (Common 1954). The moth leaves the area before the winter period starts (Common 1954). Common (1990) states that the larvae cannot survive the extremely cold winter temperatures in this region.

Mean temperatures during winter in the regions where the migrating moth reproduces in southern Queensland, New South Wales and Victoria are approximately 6-15°C and minimum temperatures 3-9°C (average daily 1961-1990)(Commonwealth Australia, 2005a, b). Common (1954, citing other sources) reported that in areas of New South Wales, occupied by high numbers of larvae, severe frosts can occur during winter. Note that migrating moths may also reproduce during the summer, e.g. in Tasmania, Canberra and Adelaide, which all have temperate climate.

It is not clear whether non-migrating moths in south-eastern New South Wales and the Australian Capital Territory reproduce year round or in what life stage the moth survives the coldest part of the year. However, both migrating and non-migrating moths are assumed to spend the winter as larvae (Warrant et al. 2016). Temperatures in this region may drop below 0°C during the winter. For example, the number of potential frost days (the average number of days annually when the minimum temperature is <0°C) in this region is estimated to range up to 75 days around Canberra while temperatures <-5°C appear to be very rare (Commonwealth Australia, 2006). It should be noted that these temperatures are air temperatures and the larvae may avoid some of the impact of low temperatures by digging into the soil, where temperatures are buffered (Leather et al. 1995).

Although both larvae and adults appear to survive short periods at temperatures below 0°C and a few weeks at 4.5°C (Section 2.2), it is unknown if some life stage is able to survive longer periods at the low temperatures that occur during the winter in Sweden. In southern Sweden the mean daily winter temperatures (Dec-Feb) are projected to range between 0-4°C (during the time period 2021-2050; SMHI, 2020) and host plants are not available for larval feeding. Facultative diapause has been suggested for the adults as part of the aestivation period, but it is not known whether aestivation could occur in environmental conditions found in the EU, which may differ from the very specific conditions found in the caves in the Australian Alps. Further, presumably very specific physiological adaptations are necessary for the species to switch from aestivation to winter hibernation.

Despite frequent introductions into New Zealand and Norfolk Island, *A. infusa* has not been able to establish there (see Section 7). The reason for this is not known. There are regions in the northern parts of New Zealand that are frost free and where host plants are available year around (G. Walker, pers. comm. 2020). The fact that there are non-migratory populations and that also migratory populations may reproduce instead of aestivating (e.g. in Tasmania) indicate that migration and aestivation are not required for the species.

Different random events, e.g. weather, and Allee effects can prevent introduced populations to establish (Taylor and Hastings 2005; Liebhold and Tobin 2008). However, as populations have been naturally introduced frequently to New Zealand and Norfolk Island for a very long time it is unlikely that random events could themselves explain why *A. infusa* has not established there. Potentially strong Allee effect may have prevented establishment. *A. infusa* have several characteristics that can contribute to an Allee effect, e.g. a high dispersal capacity, overlapping generations, and no ability to reproduce asexually (Liebhold and Tobin 2008; Warrant et al. 2016). In support of this, attempts to establish Lepidopteran species frequently fail, but for example the closely related, *A. segetum* has been reported to “establish easily” when introduced to remote islands (Dray and Wheeler 2001; references in Moir et al. (2007)). Regardless of the mechanism, the example of New Zealand and Norfolk Island clearly show that some factor(s), e.g. a strong Allee effect, prevents this pests from establishing in new areas despite the otherwise seemingly suitable characteristics, i.e. a suitable Köppen-Geiger climate zone and suitable hosts plants.

11.2 Establishment under protected cultivation

There are *Agrotis* species that are important pests in protected cultivations, e.g. *A. ipsilon* and *A. segetum* which are pests of lettuce and *Agrotis* spp. causing damage to nurseries with tomato and *Capsicum* sp. (Reddy 2016). There are, however, fewer problems with cutworm damage where there is regular irrigation (EPPO 2000).

Some hosts of *A. infusa* are grown in protected cultivations in Sweden, e.g. lettuce and *Mentha* spp. (Table 1) and the temperature in many protected cultivations is probably suitable (see above). However, we could not find a single report stating that *A. infusa* has been found in protected cultivations.

In this rapid PRA the only pathway considered was import of living *A. infusa* for research purposes and the likelihood of potential introductions from this pathway directly to plants that are commercially grown under protected cultivation is assessed to be negligible. Therefore, under those limitations, we assess that the risk of establishment is related to open field conditions rather than protected conditions.

11.3 Conclusion

The likelihood of establishment in Sweden is assessed as very low, with medium uncertainty, mainly due to the climatic conditions. Annual migration of the pest into Sweden can not be excluded, if the pest would establish in more southern parts of the EU.

In the southern and western parts of the EU, where climate is comparable to that in the native range and host plants are available, the likelihood of establishment is assessed as higher than in Sweden. Those conditions were however also fulfilled in New Zealand and the Norfolk Islands where the pest has not managed to establish despite frequent introductions which indicate that some factor, e.g. strong Allee effects, reduce the likelihood of establishment.

The main sources of uncertainty are the specific climatic requirements for permanent populations, whether migratory behaviour could occur in the EU and why populations fail to establish in New Zealand and the Norfolk Islands.

Rating of the likelihood of establishment in Sweden

	Very low	Low	Moderate	High	Very high	Uncertainty rating ^a
Outdoors	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Medium

^aLow/medium/high

12. Potential spread after introduction

Agrotis infusa is well known for its long-distance migration, travelling distances up to 1 000 km, from the breeding areas in southern Queensland, western and north-western New South Wales and western Victoria to the mountain caves in the Australian Alps (Common 1954; Warrant et al. 2006). The frequent findings of *A. infusa* in New Zealand and Norfolk Island, where the pest is not established, provide further evidence of long distance migration events (see Section 7.2). There is support for *A. infusa* being transported downwind but also that their migration is dependent on active flight (Farrow and McDonald 1987; Fox 1978; Green 2006).

Agrotis infusa may spread with traded commodities. In a risk management standard for vessels in New Zealand, *A. infusa* was considered an example organism of “Aggregated vessel jumpers” since it has been intercepted at ships, is able to leave a vessel on its own, and have traits that result in aggregation (Ministry for Primary Industries 2016). The likelihood of entry of *A. infusa* was assessed to be high when vessels are loaded at the times of the year when *A. infusa* is migrating and when there are strong winds from the west (Ministry for Primary Industries 2016). Likewise spread via transport of goods within Sweden and the EU could also occur. Potentially the species could also be transported in soil because eggs as well as the larvae and pupae are found in soil and have been associated with seedlings in forest nurseries (Moore 1962).

The spread rate after an introduction may initially be low due to possible strong Allee effects when relatively few individuals enter a new area (see Section 11). Spread to new areas after an introduction may therefore require that a relatively large number of individuals end up at the same place after migration, or after spread with traded commodities, which would reduce the spread rate.

The wide range of host plants that are widely distributed in Sweden/EU would enhance the spread rate of *A. infusa*. The adults are relatively long-lived which facilitates the spread, i.e. 6-8 month in the wild (Elder 2007; E. Warrant, pers. comm. 2020). The pest is assessed to have the potential for natural spread to all production areas in the region where the climate is suitable.

12.1 Conclusion

The spread rate was assessed as low in the beginning of a potential invasion but very high during the latter part of it. The average spread rate over time was assessed to be high. The uncertainty was assessed to be medium mainly due to lack of information about spread rates outside the pest's native area.

Rating of the magnitude of spread

	Very low	Low	Moderate rate	High	Very high	Uncertainty rating ^a
Spread rate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Medium

^aLow/medium/high

13. Impact in the current area of distribution

Agrotis infusa has a wide host plant range (Table 1). It has also been reported to be a pest on a large number of agricultural crops and pastures, i.e. alfalfa, barley, cabbage, cauliflower, flax, lucerne, linseed, mint, oats, pea, potato, silver beet, wheat (Common 1990; Hopkins and McDonald 2007; Capinera 2008; Australian Biosecurity 2020). In addition, it has been reported to cause damages to foliage, roots and bark of nursery stock, e.g. *Pinus radiata*, which is sometimes severe (Moore 1962).

Two or three large larvae are enough to seriously damage a square metre of crop (Woods et al. 1990). The damage may be patchy but, when the pest is present more generally throughout a crop, replanting may be necessary (Common 1990). The damage usually occurs during the Australian late autumn and winter when the larvae approach maturity (Hopkins and McDonald 2007) and it is usually crops growing in heavy soils, that are damaged (Common 1990).

The main difficulty in assessing the impact of *A. infusa* is that there are several species in Australia that are similar in appearance (i.e. *A. munda* and *A. ipsilon*), they hide under the soil surface during the day, and they cause similar damage (Bellati et al. 2010; Umina et al 2015). This species group is called “cutworms” and since the control measures are not species specific, they are in practise treated as a group (Bellati et al. 2010; Hopkins and McDonald 2007; McQuillan et al. 2007; Micic and Severtson 2020; S. Micic, pers. comm. 2020; PestFax Map 2020; Woods et al. 1990).

To our knowledge, there are no quantitative estimations of the overall damage that *A. infusa* cause. There are however several qualitative assessments that range from classifying it as a minor pest to a serious pest;

- Common (1954) cites a study by Froggat (1900) who reports a widespread outbreak in many districts in the Tablelands, Western Slopes and Western Plains of New South Wales.
- Rawat (1957) states that there are many records of *A. infusa* causing damage, especially on wheat, but he claims that there are grave doubts regarding the identification made by earlier observers.
- Common (1958) considers *A. infusa* to be a serious pest of field and vegetable crops and pastures.
- Somerfield (1977) considered *A. infusa* to be an insect of economic significance.
- Farrow and McDonald (1987) claim that *A. infusa* is an important pasture and crop pest in Australia.
- Woods et al. (1990) state that cutworms, including *A. infusa*, are not regular pests but large areas may be affected.
- Elder (2007) state that the pest status of *A. infusa* in pastures is minor, widespread, and irregular.
- Hopkins and McDonald (2007) state that the pest status of *A. infusa* in cereals is minor, restricted and irregular.
- McQuillan et al. (2007) state that *A. infusa* is recorded as a regular pest in Tasmania.
- Moir et al. (2007) consider *A. infusa* to be a serious pest of field and vegetable crops and pastures.
- Capinera (2008) claims that *A. infusa* is considered to be damaging to some crops.
- Hartnett et al. (2008), classifying pests as either “major pests” or “minor pests”, classified *A. infusa* as a “major pest”.
- Bellati et al. (2010) states that cutworms, including *A. infusa*, are not regular pests but large areas may be affected in some seasons. Outbreaks are usually easy to control with pyrethroids.
- Kumar and Singh (2015) list *A. infusa* as an important insect pest of *Brassica* crops.
- Beehag et al. (2016) state that *A. infusa* is an occasional pest of turf grass in isolated areas.
- MacFadyen and Hill (2017) consider *A. infusa* to be a pest of *Brassica napus*.
- According to the Australian Museum (2020), *A. infusa* is considered to be an agricultural pest causing significant damage to crops.
- Micic and Severtson (2020) state that *A. infusa* has been extremely damaging in most parts of the agricultural areas of Western Australia from time to time. However, it is considered to be a minor pest these days as this pest is readily controlled by prophylactic spray applications of synthetic pyrethroids (S. Micic, pers. comm. 2020).
- D. Hardie (pers. comm. 2020) states he currently receives fewer reports of damage and that *A. infusa* is currently kept at bay with for example bare earth treatment with bifenthrin (a pyrethroid insecticide) and seed treatment with imidacloprid (a neonicotinoid insecticide)*.

* It should be noted that the use of bifenthrin is not approved in the EU (EU Pesticides database 2020) and that all outdoor uses of imidacloprid is banned and only the use in permanent greenhouses remains possible (see European Commission (2020) for current status of the neonicotinoids in the EU).

13.1 Conclusion

Our assessment is that *A. infusa* currently has a moderate economic impact at the scale of its whole distribution area with a medium uncertainty. Although it has the potential to cause severe damage, the damage appears to only occur sporadically, and mostly at a local scale, and the damage can, if necessary, be controlled effectively by the use of insecticides. The environmental impact is rated as low with a medium uncertainty because it is restricted to the negative impact of the use of insecticides. The social impact is assessed to be low with a low uncertainty as the impact is restricted to the negative social impact of only sporadically high levels of damage of crops. It should also be noted that the rating scale used in the assessment covers a wide range since it is adapted for assessing the relative impact of all types of plant pests, i.e. also pests that extirpate important plants from large regions (EPPO 2011).

The main uncertainties are the lack of quantitative data on damages for the pest and limited information regarding the amount of insecticides used and their environmental effects.

Rating of the magnitude of potential impact in the current area of distribution

	Very low	Low	Moderate	High	Very high	Uncertainty rating ^a
Economic	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Medium
Environmental	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Medium
Social	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Low

^aLow/medium/high

14. Potential impact in the PRA area

Agrotis infusa belongs to a genus of moths that includes several species native to Sweden, e.g. *Agrotis segetum* (Sådesbroddsfly) which is a pest on for example potato (Viketoft et al. 2019). Pest management options for *A. segetum* includes watering during the time when the larvae is in its early development and/or by applying Fastac[®], which is a pyrethroid insecticide (Swedish Board of Agriculture 2017; 2019; Swedish Chemicals Agency 2020).

The potential impact of *A. infusa* in Sweden is assessed to be very low since no permanent populations are expected (see Section 11) and no damage has been reported from areas in Australia where climatic conditions are similar to those in Sweden (Figure 1A). Thus, the potential economic, environmental and social impact in Sweden are all assessed to be very low with low uncertainty.

The climatic conditions in many other EU-countries, south of Sweden, are however similar to those in Australia where *A. infusa* cause damage (Figure 1). Should the pest become established, the potential impact in those areas is assessed to be similar to that of their counterparts in

Australia since suitable host plants, that *A. infusa* is considered to be a pest on, are common and widespread in both environments.

The main uncertainties are due to that; there is no information about the impact of this species outside its native area (since it has not spread outside its native range), the lack of quantitative data on damages for the pest, and the limited information regarding the amount of insecticides used and their environmental effects.

Rating of the magnitude of potential impact within Sweden

	Very low	Low	Moderate	High	Very high	Uncertainty rating ^a
Economic	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Low
Environmental	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Low
Social	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Low

^{a)}Low/medium/high

15. Identification of the endangered area

Sweden is assessed not to be part of the endangered area mainly due to unfavourable climatic conditions. However, in regions in western and southern parts of Europe where climatic conditions are conducive and host plants are available *A. infusa* could potentially establish and cause damage.

16. Risk management options

Not applicable since the reason for performing this PRA was a request to import *A. infusa* for research purposes (see Terms of reference section).

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