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# Rapid Pest Risk Analysis (PRA) for *Lambdina fiscellaria*

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Larva of the eastern hemlock looper, *Lambdina fiscellaria fiscellaria*. Image courtesy Connecticut Agricultural Experiment Station, Bugwood.org

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# Executive Summary

The hemlock looper, *Lambdina fiscellaria*, is a North American forest pest of coniferous and broadleaved trees. The pest has a complicated taxonomy. It is widely reported as having three subspecies on the basis of differences in feeding preferences of the larval stages, but there are no morphological differences and some authors argue the pest should be treated as a single species. All three subspecies are considered in this PRA, which examines the risk of this pest to the island of Ireland (the PRA area), consisting of Ireland and Northern Ireland.

*Lambdina fiscellaria fiscellaria*, also known as the eastern hemlock looper, is distributed in eastern North America and larvae show a preference for *Abies balsamea* (balsam fir) but will also feed on *Picea glauca* (white spruce), *Tsuga canadensis* (eastern hemlock) and a number of broadleaved trees. *Lambdina fiscellaria lugubrosa*, also known as the western hemlock looper, is distributed in the Pacific Northwest, with a larval feeding preference of *Tsuga heterophylla* (western hemlock), though the pest has also been recorded infesting stands of *Picea sitchensis* (Sitka spruce). *Lambdina fiscellaria somniaria*, also known as the Garry oak looper or western oak looper, is found in Oregon, Washington and south coastal British Columbia and shows a strong preference for *Quercus garryana* (Garry oak) as larvae, sometimes spreading into *Pseudotsuga menziesii* plantations.

All three subspecies cause periodic mass outbreaks in forest stands in North America which have very large economic impacts. The fist instars (very young caterpillars) of *L. fiscellaria* require freshly flushed foliage in order to survive, but as larvae mature they can feed on older foliage. During outbreak years, larvae can be found feeding on a significant number of tree species as well as understory plants. Recorded outbreaks have led to high mortality of trees and losses in timber. For example between 1910 and 1975, Natural Resources Canada estimate outbreaks of *L. f. fiscellaria* have caused losses of 36 million cubic metres of timber in the provinces of Newfoundland and Quebec. Economic impacts of the pest in its current distribution are very large, with low uncertainty.

*Lambdina fiscellaria* is considered unlikely to enter the PRA area. The pest is largely restricted to forested areas, and reports of infestations in nurseries are rare. Damage to trees is normally severe enough that plants would be unmarketable, making entry in association with plants for planting very unlikely. *Lambdina fiscellaria* lays its eggs, and pupates within, the mosses and lichens found on the trunks and branches of trees as well as fallen logs, stumps and the forest floor. In North America, these mosses and lichens are sometimes harvested and exported, fresh, including to the UK which includes Northern Ireland, within the PRA area. First instar larvae of *L. fiscellaria* do have some natural dispersal capacity, as eggs are often not laid directly on suitable host trees, and so there is a risk of larvae hatching from eggs inadvertently imported along this pathway and transferring to a suitable host, depending on the final use of the mosses and lichens. Overall likelihood of entry on this pathway was rated as unlikely, with high uncertainty, as more information is required on the final use of imported fresh mosses and lichens from the USA. Wood that has not been subject to any treatments (e.g. debarking, heat treatment) is also considered to pose a risk of introducing the pest, as egg masses and pupae may be associated with this commodity. Woods of the preferred hosts of *L. fiscellaria* are subject to phytosanitary measures that should eliminate the risk of the pest being associated with the commodity, but during outbreak year's pupation and egg laying may occur on a very diverse range of timber species. Overall risk of entry on this pathway is unlikely, with high uncertainty.

The different subspecies of *L. fiscellaria* were judged to have different risks of establishing in the PRA area. All three subspecies are present in regions with similar climates to the PRA area, though *L. f. fiscellaria* is generally present in regions which have colder winters. It is uncertain if *L. fiscellaria* could adapt to feed on species within the PRA area as its primary host, especially *L. f. somniaria* which shows a very strong preference for *Quercus garryana,* a species not found in the PRA area. Likelihood of establishment of *L. f. somniaria* is moderately likely with high uncertainty, as it is unknown if larvae could adapt to feed on European species of oak. Likelihood of establishment of *L. f. fiscellaria* was rated as likely, with high uncertainty – this is because of the potential for the milder winters of the PRA area to cause earlier egg hatch of this subspecies. There may potentially be asynchrony between egg hatch and bud burst of suitable hosts, meaning larvae would starve. It is also uncertain if this subspecies could adapt to using *P. sitchensis* or other hosts grown in the PRA area as a primary host. Likelihood of establishment of *L. f. lugubrosa* is very likely with medium uncertainty; this species is present in regions with a very similar climate to the PRA area and feeds on hosts that are widespread on the island of Ireland including *P. sitchensis*.

Potential impacts in the PRA area are subject to high uncertainty. This is due to several reasons, one of the main reasons is it is uncertain what hosts in the PRA area will prove to be suitable for *L. fiscellaria*. It is also uncertain if conditions in the PRA area are suitable for the build up of outbreak populations. Most outbreaks in North America initiate in mature or over-mature coniferous stands (>100 years old), and the majority of coniferous stands in the PRA are < 50 years old. The pest also has a low capacity for natural spread. *Lambdina fiscellaria* are slugglish fliers, especially females that are heavily burdened by eggs and cannot fly long distances. This means that should the pest be introduced, industry would be able to adapt by developing monitoring and control techniques well ahead of the pest reaching its maximum distribution within the PRA area. Containment of outbreaks is also feasible due to the pest's limited dispersal capacity, but outbreaks could still occur on a local scale and cause defoliation and death of trees. Potential economic impacts in the PRA area were rated as moderate, with high uncertainty.

Potential environmental impacts are also highly uncertain, as this will depend on where outbreaks occur and again, what species *L. fiscellaria* may be able to feed on in the PRA area. Environmental impacts may also be incurred if control measures such as felling or aerially spraying of control products is necessary, and potential environmental impacts were rated as moderate with high uncertainty.

*Lambdina fiscellaria* may cause social impacts by causing outbreaks in forested areas used for recreation, defoliating trees and killing them, reducing their aesthetic value. Killed trees may also pose a safety hazard, meaning public access has to be limited to some sites. Visitor numbers may be reduced as infested sites, leading to knock on impacts for the local economy. Potential social impacts in the PRA area are rated as moderate, with high uncertainty.

Exclusion is the best risk management option for the pest. *Lambdina fiscellaria* is a potential pest not only for the island of Ireland but for a number of EU Member States. Since it is absent from the EU, it could be regulated as a quarantine pest in the plant health legislation (Plant Health Directive 2000/29/EC). It is recommended that this pest is subject to a PRA at EU or EPPO level to further analyse if regulation of the pest is technically justified.

More research is needed to ascertain what the potential host range of *L. fiscellaria* in the PRA area could be. In addition, there needs to be further analysis to ascertain if egg hatch of *L. fiscellaria* in the PRA area would occur in relative synchrony with bud burst, which is necessary for high survival of the first instar larvae.

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# Stage 1: Initiation

## *1.1 What is the name of the pest?*

*Lambdina fiscellaria* (Guenée, [1858]) (Lepidoptera: Geometridae).

*Lambdina fiscellaria* has numerous common names, some of which may only be used to refer to a specific subspecies as detailed in section 1.1.2 below. Common names include, but are not limited to, hemlock looper, eastern hemlock looper, Garry oak looper and western oak looper.

Synonyms:

*Ellopia fiscellaria* Guenée

*Ellopia fervidaria* Hubner

*Ellopia somniaria* Hulst

*Lambdina flagitiaria* Guenée, (1858)

*Lambdina peccataria* Guenée, (1858)

*Lambdina johnsoni* Swett, 1913

*Lambdina turbataria* Barnes & McDunnough, 1916

*Therina fiscellaria*

### 1.1.2 Special notes on taxonomy

The hemlock looper is split into three subspecies:

- *Lambdina fiscellaria fiscellaria* (*L. f. fiscellaria*) – eastern hemlock looper
- *Lambdina fiscellaria lugubrosa* (*L. f lugubrosa*) – western hemlock looper
- *Lambdina fiscellaria somniaria* (*L. f. somniaria*) – western oak looper

The morphological differences between these subspecies are inconsistent and relatively minor, and the taxonomy of this pest remains uncertain. Originally, *L. f. lugubrosa* and *L. f. somniaria* were considered different species (*Ellopia fervidaria* and *Ellopia somniaria* respectively), but work by Chamberlin (1931) questioned this and the author suggested they were treated as a single species.

Traditionally the subspecies have been separated on the basis of their larval host food preferences and pheromones. Larval host preferences are covered in detail in section 2.4. There are significant differences between the pheromones of *L. f. fiscellaria* and *L. f. lugubrosa*, which have been used to support their taxonomic division (Gries *et al* 1993).

Genetic studies, looking into differences between the mitochondrial DNA of the three subspecies, were carried out by Sperling *et al* (1999). Two distinct mitochondrial DNA lineages were found between western and eastern populations, but there was an absence in genetic differences between *L. f. lugubrosa* and *L. f. somniaria*. Therefore the subspecific divisions remain unclear. Hérbert and Jobin (2001) state that on the basis of a lack of morphological differences and the findings of Sperling *et al* (1999), *L. f. fiscellaria* and *L. f. lugubrosa* should now be treated as a single species, however later publications by other authors are still treating the subspecies separately.

There is no indication of a formal agreement in the literature over the status of the subspecies of *L. fiscellaria*. For this reason, all three subspecies are considered within this rapid PRA, **however there is a need for more clarity regarding the subspecific divisions and this is a source of major uncertainty.** This should be taken into consideration in those sections where separate ratings are applied: if subspecific divisions are not valid, the different subspecies may be more adaptable than it appears from the literature.

## *1.2 What initiated this rapid PRA?*

*Lambdina fiscellaria* was identified as part of the DAFM funded FORM project, whose aim was to identify potential pest threats to Sitka spruce in Ireland. This rapid PRA has been initiated in order to assess if phytosanitary regulations are justified against this pest.

## *1.2 What is the PRA area?*

The PRA area is the island of Ireland.

## *1.3 Are there any previous PRAs on the pest(s)?*

No published Pest Risk Analyses for *Lambdina fiscellaria* are available.

# Stage 2: Pest Risk Assessment

## *2.1 Is the pest present in the PRA area?*

There are no records of *Lambdina fiscellaria* in the PRA area. The pest has never been intercepted.

## 2.2 What is the pest's current geographical distribution?

The distribution of *L. fiscellaria* is summarised in Table 1. The pest is only recorded to date from North America. The different subspecies of *L. fiscellaria* vary in their distribution. *Lambdina fiscellaria fiscellaria* is found in Eastern North America. In Canada, the distribution is described as "from the Atlantic coast to Alberta" (van Frankenhuyzen *et al* 2002) and south to Georgia in the Eastern States (USDA 1985), and west to Wisconsin (Randall 2005). *Lambdina fiscellaria lugubrosa* is found from Oregon north through to British Columbia and southeast Alaska (Randall 2005). *Lambdina fiscellaria somniaria* is found in Oregon, Washington and south coastal British Columbia (Willhite 2018).

CABI (2018) do not list the pest as present in those states between Pennsylvania and Georgia, such as the Carolinas, Maryland, Virginia and West Virginia. Websites where amateur Lepidopterists can submit records provide evidence that the pest is present in additional southern States (Butterflies and Moths of North America 2018, Moth Photographer's Group 2018) and it is likely that *L. f. fiscellaria* is resident in these states.

| **Table 1: Distribution of *Lambdina fiscellaria* (CABI 2018)** | |
|---|---|
| Africa | No records. |
| Asia | No records. |
| Europe | No records. |
| North America | Canada (British Columbia, New Brunswick, Newfoundland, Nova Scotia, Ontario, Prince Edward Island, Quebec), USA (Alaska, California, Connecticut, Georgia, Idaho, Maine, Massachusetts, Michigan, Minnesota, Montana, New Hampshire, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, Wisconsin) |
| South America | No records. |
| Central America and the Caribbean | No records. |
| Oceania | No records. |

## 2.3 What is the regulatory status of the pest?

This pest is not listed in the Plant Health Directive 2000/29/EC, nor is it recommended for regulation by the European and Mediterranean Plant Protection Organisation (EPPO).

# 2.4 What are the pests host plants?

The preferred larval host plants of *L. fiscellaria* vary depending on the subspecies. The diet of the first instars is more restricted than later instars, which are very polyphagous and in outbreak years may be found feeding on a very large number of different tree and understory species. For this reason, **this section should not be considered a fully comprehensive host list.**

## 2.4.1 *Lambdina fiscellaria fiscellaria*

In Maine, *L. f. fiscellaria* has been recorded from "every native conifer and many deciduous hosts" with *Abies balsamea* (balsam fir), *Tsuga* spp. (hemlock) and *Picea glauca* (white spruce) considered to be the hosts most at risk (Maine Forest Service 2001). Iqbal *et al* 2010 state the main host is *A. balsamea*, but that in Canada other trees like *Acer saccharum* (sugar maple), *Betula papyrifera* (white birch), *P. glauca* and *Picea mariana* (black spruce) are defoliated.

Carroll (1956) noted larvae of *L. f. fiscellaria* on a wide range of plants just after emergence from eggs, which had been laid near to these plants. In laboratory studies, it was investigated if any of these hosts were suitable for larvae to complete their development. Larvae were reared successfully from the following hosts: "new" foliage of *A. balsamea* or *P. glauca*, *Acer rubrum* (red maple), *A. spicatum* (mountain maple) and *Betula papyrifera* (paper birch). Carroll (1956) found that first instar larvae **did not survive** when restricted to the following diets: "old" needles of *A. balsamea* or *P. glauca* (the author does not specify what is meant by old but it is very likely to be previous year needles), *Alnus rugosa* (speckled alder), *Cornus canadensis* (bunchberry), *Sorbus americana* (American mountain ash), *Sphagnum* (moss) and *Rubus idaeus* (raspberry). Carroll (1956) concludes that young (presumably first year needles) foliage of *A. balsamea* or *P. glauca* or leaves of *Betula* or *Acer* are required for the survival of the first instars, though later instars can feed on older needs of *A. balsamea* and *P. glauca*.

Larvae of *L. f. fiscellaria* collected from mature *A. balsamea* stands on Anticosti Island, Quebec, Canada were reared in the laboratory on *A. balsamea, T. canadensis* and *A. saccharum*. Larval survival was high on all three species (Hérbert *et al* 2006). Though *L. f. fiscellaria* does show a strong preference for *A. balsamea*, it appears larvae can survive well under experimental conditions in the absence of this host when other suitable hosts are provided.

Kerr (1971) describes an outbreak in a nursery on *Thuja* and *Juniperus* (juniper). These were later instar larvae that had moved in from a nearby infested forest.

## 2.4.2 *Lambdina fiscellaria lugubrosa*

*Lambina fiscellaria lugubrosa* has a preference for the western hemlock, *Tsuga heterophylla* (Randall 2010). Natural Resources Canada (2015) list the hosts of

*L. f. lugubrosa* as: *Abies amabilis* (Amabilis fir), *Abies grandis* (grand fir), *Abies lasiocarpa* (subalpine fir), *Larix occidentalis* (western larch), *Picea engelmannii* (Engelmann spruce), *P. glauca*, *Picea sitchensis* (Sitka spruce), *Pseudotsuga menziesii* var. *glauca* (Rocky mountain Douglas fir), *Thuja plicata* (western redcedar) and *Tsuga heterophylla* (western hemlock). Natural Resources Canada (2015) also state that during outbreak years the pest will also be found feeding on understory shrubs.

In an outbreak in Alaska, *L. f. lugubrosa* was recorded as preferring *P. sitchensis* over *T. heterophylla* (Toregensen and Baker 1967). Holsten (2001) states the preferred host in Alaska is Sitka spruce, but also states the only outbreak was that reported by Toregensen and Baker (1967) so it is assumed that the host preference is based on only this, and not further observations.

### 2.4.3 Lambdina fiscellaria somniaria

The primary host of *L. f. somniaria* is *Quercus garryana* (Garry oak), but will feed on other oak species native to the Pacific Northwest. During outbreaks larvae have been recorded feeding on additional coniferous and hardwood species including: *Abies grandis* (grand fir), *Acer macrophyllum* (big leaf maple), *Fraxinus latifolia* (Oregon ash) and *Pseudotsuga menziesii.* In an outbreak in Corvallis, Oregon, from 2011-2013 *F. latifolia* was the preferred host (Willhite 2018).

Chamberlin (1931) found that though *L. f. somniaria* showed a very strong preference for the native oaks of the Pacific Northwest, later instar larvae fed on numerous other hosts including: *Cirsium arvense* (creeping thistle), *Corylus* (hazel), *Crataegus* spp. (hawthorn), *Pyrus* (pear) and *Toxicodendron diversilobum.* They were also found feeding on hosts associated with *L. f. lugubrosa*: *Tsuga* and *Pseudotsuga*, though there was heavy mortality of the larvae when confined to those two hosts under experimental conditions. It is uncertain, however, if the *L. f. somniaria* larvae were given current year needles or older needles – if given older needles the larvae may have starved due to the needles being too tough to consume.

### 2.4.4 Additional Hosts

Robinson *et al* (2010) contains additional host records for *L. fiscellaria* that are not assigned to any subspecies. It is very likely these represent hosts that *L. fiscellaria* has only been recorded on in outbreak years, and thus are probably fed on by later instar larvae. Hosts listed by Robinson *et al* (2010) not covered above are: *Acer circinatum* (vine maple), *Acer spicatum* (mountain maple), *Betula alleghaniensis* (yellow birch), *Fagus grandifolia* (American beech), *Hamamelis virginiana* (common witch-hazel), *Hylocomium splendens* (glittering woodmoss), *Larix laricina* (tamarack), *Ostrya virginiana* (American hophornbeam), *Picea rubens* (red spruce), *Pinus banksiana* (jack pine), *Pinus contorta* (lodgepole pine), *Pinus engelmannii* (Apache pine), *Pinus monticola* (western white pine), *Pinus strobus* (eastern white pine), *Pleurozium schreberi* (red-stemmed feathermoss), *Populus balsamifera* (balsam poplar), *Populus tremuloides* (trembling aspen), *Prunus serotina* (black cherry), *Prunus virginiana* (chokecherry), *Ptilium crista-castrensis* (knights plum moss), *Quercus alba* (white oak), *Quercus rubra* (northern red oak), *Salix* (willow), *Toxicodendron pubescens* (Atlantic poison oak), *Ulmus americana* (American elm) and *Usnea longissima* (old man's beard).

### 2.4.5 What host plants are of economic or environmental importance in the PRA area?

Given the polyphagous nature of late instar larvae of *L. fiscellaria* during outbreak years, many coniferous and broadleaved trees are potentially at risk from this pest. *Picea sitchensis* is the most important commercial forestry tree in Ireland. Over fifty percent of the Irish forest estate is made up of *Picea sitchensis* plantations.

If *L. f. somniaria* is able to adapt to European species of *Quercus,* potentially native Irish oaks could be at risk. Native Irish woodlands only take up a small percentage of the island and so environmentally are very valuable. In one outbreak of *L. f. somniaria*, a preference was shown for the ash species *F. latifolia* – it is not known if the European ash, *F. excelsior*, would be a suitable host for this pest.

*L. f. fiscellaria* has also been recorded to survive well on several *Acer* species. Potentially *Acer* species grown for forestry purposes in the PRA area such as *A. pseudoplatanus* (sycamore) may be endangered by the pest.

It is considered likely that *L. fiscellaria* will be able to adapt to at least some European species of the genera of plants that are hosts for the pest in North America, but the potential host range of the pest in the PRA area is subject to high uncertainty.

## *2.5 What is the lifecycle of the pest?*

The life history of the pest has been described by several different authors across the range of *L. fiscellaria*. In all regions, the pest only has a single generation a year. The number of larval instars varies depending on the latitude of the population. It is reported in the literature that there are two ecotypes of *L. fiscellaria*: in the southern part of the range, the larval stage has five instars whereas in the north it has only four. The author of this study found that major outbreaks of *L. fiscellaria* are most strongly associated with regions where the four larval instars ecotype occurs (Berthiaume 2007). It was noted in the Alaskan outbreak that *L. f. lugubrosa* had only four larval instars, though five had been recorded from British Columbia, Oregon and Washington (Toregensen and Baker 1967). Berthiaume (2007) only studied the populations of the pest in Quebec, and found that the change in the number of instars occurs between 48°43 and 48°73, it is uncertain if this also applies to the western subspecies of *L. fiscellaria*. British Columbia is above the 49° parallel, but five larval instars have been recorded there (Hopping 1934), though a later publication on *L. f. somniaria* only records four larval instars (Hardy 1950). In Newfoundland, a population was recorded where the majority of the larvae had 4 instars, but more than one third of females had five instars (Berthiuaume *et al* 2007). Studies by Delisle *et al* (2016) suggested that the fifth instar of more southern populations of *L. fiscellaria* may be an adaptive mechanism delaying reproduction and egg laying until later in the year when temperatures are cooler, as experimental analysis showed high temperatures had a deleterious effect on egg fertility.

Eggs are the overwintering stage of *L. fiscellaria*. Eggs undergo diapause for a period of three months – this is a fixed time, and not affected by photoperiod or temperature. Eggs then enter a post-diapause stage where they will resume development once spring temperatures are favourable and mass hatching will occur of all eggs. Temperature therefore has a major effect on the development of the eggs and hatching time (Delisle 2010). Females may lay between 100 and 300 eggs in their lifetime (Hérbert and Jobin 2001).

### 2.5.1 *Lambdina fiscellaria fiscellaria*

Of the three subspecies, the lifecycle of *L. f. fiscellaria* has been studied in the most detail.

Carroll (1956) describes the life history of *L. f. fiscellaria* in Newfoundland. Eggs are usually laid singly or in groups of two or three on moss and lichens on the tree trunks, under old bark scales or in the mossy covering of stumps and logs. The egg is the overwintering stage. In Newfoundland the larvae have four instars, the first two instars are described as relatively inconspicuous by Carroll (1956), but the wasteful feeding of the latter instars is easy to detect. Later instars of larvae are highly active, dropping from trees onto the ground via silk threads and ascending the trunks of nearby trees irrespective of size or species.

Preferred pupation sites were dry, decayed stumps, bark crevices, and among lichens on the tree trunk – pupae were sometimes found on the forest floor. Adults emerged in late August and early September and largely flew in the late afternoon and evening. A study in Quebec over three years found that pupation sites varied depending on the larval density. Hérbert *et al* (2001) found during surveys most pupae were observed on branches within the crown which is in contrast to the results of Carroll (1956) and Otvos (1974) who largely found pupae on the stem. The theory put forward by the authors is that when food is abundant, larvae will not waste energy on moving to new locations and will largely pupate near where they feed.

Mating usually takes place soon after female emergence, and egg laying begins within 24 hours of emergence. Virgin females are receptive for at least six days after emergence (Ostaff *et al* 1974a). Females produce a sex pheromone to attract males (Otvos 1972).

### 2.5.2 *Lambdina fiscellaria lugubrosa*

Natural Resources Canada (2015) describes the lifecycle of *L. f. lugubrosa*. As for *L. f. fiscellaria*, overwintering occurs in the egg stage with eggs hatching from May to early June. Young larvae feed on new foliage and may move onto older foliage as they mature, with mature larvae reaching 30 mm long. Pupation begins in late July and continues until early September, with favoured pupation sites being on tree trunks or in the forest duff. Pupation takes approximately 10-14 days, and adults are in flight from September to October.

### 2.5.3 *Lambdina fiscellaria somniaria*

Chamberlin (1931) describes the life history of *L. f. somniaria* in Oregon. Life history is similar to *L. f. fiscellaria*, with eggs being the overwintering stage laid in moss or bark crevices. Egg hatching begins in April according to Chamberlin (1931), though Natural Resources Canada (2015) state it is similar to *L. f. lugubrosa* occurring from May to early June. The larvae are abundant by May, and defoliate oaks. When oak foliage is dried up in August, larvae will actively migrate falling to the ground and then ascending the first object with which they come into contact – including stumps and fence posts. Pupation took place in late August and early September. Natural Resources Canada (2015) states pupation begins in late July and continues into early September, with adults emerging after 10-14 days and being in flight in September and October. Favoured pupation sites are similar to *L. f. lugubrosa,* though *L. f. somniaria* is also reported as pupating within the foliage.

## 2.6 What pathways provide an opportunity for the pest to enter the PRA area and transfer to a suitable host, and what is the likelihood of the pest entering the PRA area?

### 2.6.1 Plants for planting

The various factors that affect the risk of *L. fiscellaria* entering on the plants for planting pathway are discussed below.

*Current Regulations*

*Lambdina fiscellaria* is not a regulated pest, but current phytosanitary measures on imports of some host plants of *L. fiscellaria* affect the risk of the pest being associated with the plants for planting pathway. These measures are described below.

Plant Health Directive 2000/29/EC prohibits the import of the following coniferous plants from non-European countries: *Abies* (fir), *Cedrus* (cedar), *Chamaecyparis* (cypress), *Juniperus* (juniper), *Larix* (larch), *Picea* (spruce), *Pinus* (pines), *Pseudotsuga* (Douglas fir) and *Tsuga* (hemlock). This list includes several preferred hosts of *L. fiscellaria.* The risk of *L. fiscellaria* entering on any of these host plants for planting is negligible with low uncertainty, since their import is prohibited from the known range of the pest.

Other coniferous species can be imported from non-European countries. Conifers from non-European countries imported into the EU must have been produced in a nursery, and that nursery must be a pest free place of production for *Pissodes* spp. (non-European). Where plants of conifers being imported from non-European countries are over 3 metres tall, the nursery shall also be a pest free place of production for non-European Scolytinae. It is likely that nurseries will be able to meet these requirements within the range of *L. fiscellaria*. Though many nurseries will not be pest free places of production for non-European Scolytinae, as ambrosia beetles are common pests in North American tree nurseries, the majority of exported trees will not be greater than 3 metres and so will not have to meet this requirement.

*Quercus,* the preferred host of *L. f. somniaria*, can only be imported from non-European countries if free from leaves, and so is very unlikely to be associated with larvae or pupae since these life stages occur when trees are in leaf. Eggs, the overwintering stage, may be present on *Quercus* plants for planting. Plants of *Quercus* originating from North American countries must originate from an area known to be free of the oak wilt fungus *Ceratocystis fagacearum.* The range of *C. fagacearum* in North America does not cross over with the range of *L. f. somniaria*, and so this phytosanitary measure is not judged to reduce the likelihood of *L. f. somniaria* being associated with imported *Quercus*.

*Life stages associated with the pathway*

Eggs are unlikely to be associated with plants for planting since these are largely laid on trunks of more mature trees covered in moss or lichen. It is uncertain at what age a tree may become attractive as an egg laying site for a female, but presence of eggs is strongly associated with the abundance of epiphytic lichens (Hérbert and Jobin 2001 citing Jobin 1973). Liang *et al* (1999) found no significant relationship between height, diameter at breast height (DBH), crown length, crown width and presence of heart rot on *L. f. lugubrosa* egg density. Oviposition preference experiments were carried out on young trees (<5 years) under experimental conditions (Steinbauer and Carroll 2011), but this may not represent the age of trees *L. f. lugubrosa* would choose to lay eggs on in the wild.

Later instar larvae are more likely to be associated with plants for planting. This is because later instars of *L. fiscellaria* larvae are highly mobile. As described in section 2.5, later instars drop from trees and move along the ground, ascending new trees irrespective of their height or age and can be found on a range of plants at this stage. Young, recently hatched larvae may also be dispersed by the wind (Hérbert and Jobin 2001). If nurseries were in close proximity to infested forests, larvae could inadvertently become associated with plants for planting. The voracious appetite of the larvae and the highly conspicuous nature of their wasteful feeding means that it is likely that growers would take action against such infestation in order to prevent trees from becoming unmarketable.

An account is given by Kerr (1971) of *L. fiscellaria* infesting nursery trees in Rhode Island. Larval numbers were so high that they were becoming attached to the clothes of the workers in the nursery. The pest was attacking *Thuja* and *Juniperus* plants of marketable size. The pest appears to have invaded from a nearby site where there was an abundance of wild hosts. Kerr (1971) notes this was the first outbreak he had seen of the pest in 24 years of working as an entomologist, suggesting that such infestations of nurseries are rare. The pest pupated on the *Thuja* trees, attached to the leaves by strands of silk. Chemical control was applied by the grower. Schuh and Mote (1948) note that *L. f. lugubrosa* is largely a pest of forest trees but has "occasionally been of concern on ornamental and nursery trees which it attacks". No evidence of *L. f. somniaria* outbreaks in nurseries could be found in the literature.

*Trade*

Trade in plants for planting between North America and the PRA area occurs at relatively low levels. Data was extracted from Eurostat on trade in plants for planting under various commodities over a five year period from 2013 to 2017, and this is summarised in Annex I. Total import under commodity codes associated with trees, shrubs and bushes into Ireland from the USA and Canada was less than 700 kg and the UK imported approximately 65 tonnes. Import for live outdoor plants was also very small, Ireland imported <500kg in the same time period, and the UK imported approximately 1.8 tonnes.

Import under these commodity codes will include plants that are a) not hosts of *L. fiscellaria* b) originate from areas where *L. fiscellaria* is not known to occur and a large proportion will be c) too small/young to be infested by *L. fiscellaria*. It is also not known what proportion of imports into the UK was destined for Northern Ireland.

Plants for planting imported from North America would be subject to inspection upon landing and the pest would be easy to detect, with the exception of pupae which may be hidden in bark crevices on larger imported trees.

*Conclusion*

**Likelihood of entry on plants for planting is very unlikely with low uncertainty**. There are only a few reports in the literature of *L. fiscellaria* on nursery plants for planting. If during outbreak years the pest moves into a nursery, levels are likely to be high enough that the grower takes action to eliminate the pest (e.g. chemical sprays), reducing the likelihood of *L. fiscellaria* being associated with this pathway. The majority of trees are moved in winter months when dormant, egg masses of *L. fiscellaria* are most often laid on mature trees, on tree stumps or in the forest duff and are unlikely to be found on plants moving in trade. The pest is also likely to be detected on imported plants during official inspections.

*Likelihood*

| Negligible | | Very unlikely | ✓ | Unlikely | | Moderately likely | | Likely | | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | ✓ | Medium | | High | |
|---|---|---|---|---|---|

## 2.6.2 Cut foliage

Larvae of *L. fiscellaria* may be associated with cut foliage of their hosts. As later instars of *L. fiscellaria* are highly mobile, they may be found on plants on the forest floor even though these are not preferred hosts. Cut branches for export are collected from forest understory in Canada. In October 2016 the Netherlands intercepted adult balsam fir sawfly, *Neodriprion abietis*, on this pathway though the species of cut foliage it was intercepted on, *Gaultheria,* is not a host of *N. abieties* (EPPO 2017). These branches were for use in ornamental bouquets.

Import data on cut foliage from Canada and the USA into Ireland and the UK was extracted from Eurostat for the five year period from 2013 to 2017. Trade in cut flowers of commercial ornamental species such as roses, lilies or gladioli were not considered because these species a) are not recorded as hosts and b) are usually produced on specific commercial sites and subject to high levels of pest control. Direct trade into Ireland of cut foliage from North America is very small. From 2012-2017, less than 100kg of was imported into Ireland from the United States under the commodity code "foliage, branches and other parts of plants, without flowers or flower bus, and grasses, fresh, suitable for bouquets or ornamental purposes (excl. Christmas trees and conifer branches)". No import from Canada into Ireland under this commodity code was recorded. Imports into the UK under this commodity code were larger, with approximately 942 tonnes imported from Canada and the USA from 2013 to 2017. It is not known what proportion of these imports was destined for Northern Ireland, or what proportion were hosts of *L. fiscellaria* and originated from the range of the pest.

Cut foliage for bouquets will usually have very high quality standards, and it is very unlikely that the damage caused by the wasteful feeding of *L. fiscellaria* larvae would be tolerated. Where cut foliage is subject to official inspection upon entry larvae are very likely to be detected. Foliage damaged by larvae may also be discarded by importers due to the damage, though if discarded outside this may provide larvae with an opportunity to transfer to a suitable host especially as later instars are highly active.

There is a low risk of transfer of larvae from cut foliage to a suitable living host. This can only occur when cut foliage is kept or disposed of outdoors in close proximity to suitable host plants, as later instar larvae are highly active and may be able to seek out a new host. This may occur in areas such as cemeteries, but in many instances cut foliage will be kept in indoor displays reducing the likelihood of transfer.

**Likelihood of entry on cut foliage is very unlikely with medium uncertainty.** The high quality standards required for cut foliage for ornamental purposes means that damage from larvae will be easily detected and may make the foliage unmarketable, and the presence of any larvae would not be tolerated. There is also a low risk of the pest transferring to a suitable host. Uncertainty is medium, as it is not known what proportion of imported cut foliage a) is a host of the pest, b) is imported from the range of the pest and c) if there are any instances of cut branches/foliage being imported from forested areas – where there is a much higher risk of *L. fiscellaria* becoming associated with the pathway.

*Likelihood*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Negligible | | Very unlikely | ✓ | Unlikely | | Moderately likely | | Likely | | Very likely | |

*Uncertainty*

| | | | | | |
|---|---|---|---|---|---|
| Low | | Medium | ✓ | High | |

### 2.6.3 Mosses and lichens

Fresh mosses and lichens are imported for use in various ornamental displays which may include bouquets, wreaths and hanging baskets. There are no phytosanitary requirements on the import of this commodity. The pest is known to pupate under mosses and lichens, and lay eggs within mosses and lichens on the tree trunks and branches, and so there is a risk of the pest being associated with this pathway. These mosses and lichens may also be harvested from forested lands and removed from trunks, branches, logs and rocks, with hundreds of thousands of kg harvested each year in the Pacific Northwest (Muir 2004). The two most popular regions for the commercial harvest of mosses and lichens from forests are the Pacific Northwest and the Appalachians in the Eastern United States (Peck *et al* 2001), *L. fiscellaria* is found in both of these regions.

Import under the commodity code "mosses and lichens, suitable for bouquets or ornamental purposes, fresh (excl. reindeer moss)" into the PRA area was investigated. From 2013 to 2017, Ireland did not import any material under this commodity code and the UK imported approximately 29 tonnes from the USA. It is not known what proportion of imports into the UK was destined for Northern Ireland. It should be noted that imports may originate from areas of the USA where *L. fiscellaria* is not known to occur, but this is considered very unlikely since only two regions of the USA are commercially viable for harvesting of mosses and lichens and the pest is present in both of these regions.

There is an additional commodity code for dried or impregnated mosses, this pathway was not considered a risk as it is likely the process of drying or chemically impregnating the moss will make the associated pest life stages unviable.

As material may be imported into other Member States and then re-exported to the PRA area, import of mosses and lichens was also extracted for all 28 EU Member States. In most years only the UK imported mosses and lichens from the USA. The majority of material imported under this commodity code from 2013-2017 was imported in the years of 2016 and 2017 – indicating this may be a relatively new trade.

Since only two life stages of the pest would be associated with this pathway, mosses and lichens only pose a risk when harvested and exported at specific times of the year. Trade data of mosses and lichens was examined by month to examine the risk of pest association. This is displayed in Table 2 below.

**Table 2**: Import by month from 2013 to 2017, in 100kg, under the commodity code "mosses and lichens, suitable for bouquets or ornamental purposes, fresh (excl. reindeer moss)" into the United Kingdom from the USA.

| Month | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| January | | | | | 8 |
| February | | | | | 4 |
| March | | | | | 14 |
| April | | | | 8 | 10 |
| May | | | | 29 | 17 |
| June | | | | 27 | 14 |
| July | | | 19 | 22 | 11 |
| August | | | | 15 | 10 |
| September | | 8 | | 22 | 16 |
| October | | | | 12 | |
| November | | | | 7 | |
| December | | | | 21 | |

Mosses and lichens imported in June and July pose a low risk of being associated with the pest, as this is when the larval stages are active in the foliage. This assumes export takes place relatively close to harvest – since this commodity code is specifically used for "fresh" mosses and lichens this is likely. Mosses and lichens imported in late July, August and September may contain pupae. Emerging adults are capable of flight should be able to transfer to a suitable host, though they are very sluggish flyers. As described in section 2.9.1, female *L. fiscellaria* are burdened by eggs and in the field will often drop to the ground when disturbed rather than fly great distances (Ostaff *et al* 1974b). This reduces their capacity to reach a suitable egg laying site. There are no studies on the flight capacity of *L. fiscellaria* though, and so it is not known how far females may be able to fly in order to seek a suitable oviposition sites. In addition, at least one female and one male would have to emerge relatively close to each other and a breeding site; females release pheromones to attract males which may help them locate each other.

Material imported between late September and April/May may contain egg masses – it is uncertain how long egg masses may stay viable within mosses and lichens used for floral displays, in hanging baskets etc. Only material imported in March/April/May may stay viable long enough to pose any real risk of larvae hatching and being able to transfer to a suitable host. It will depend on the final use of the imported mosses and lichens and how they are treated.

First instar larvae do have capacity to seek out new hosts, as in their native range they may emerge from egg masses laid on the forest floor and need to move to find a suitable host tree. Steinbauer and Carroll (2011) state that the egg laying habits of *L. fiscellaria* mean that first instar larvae may have to travel "considerable distances before being able to feed", but no data could be found in the literature concerning the maximum dispersal capacity of a first instar larvae. Young, recently hatched larvae may also be dispersed by the wind (Hérbert and Jobin 2001), which may be particularly relevant if mosses/lichens containing egg masses are used in displays such as hanging baskets.

Shore (1990) studied the number of eggs of *L. f. lugubrosa* per 100g of lichen collected from different parts of the tree. The average varied greatly depending on the plot from which lichen was collected – mean number of eggs collected from the upper crown varied from 12 to 75 per 100g, 62 to 3 per 100g from the mid crown and 47 to 7 per 100g from the lower crown.

In April and May 2017, the months when *L. fiscellaria* eggs would usually hatch, the UK imported approximately 2.7 tonnes of mosses and lichens from the USA. If, as is very likely, these mosses were collected from the range of *L. fiscellaria,* then based on the results of Shore (1990) **in a worst case scenario** at current import levels eggs could be imported in the tens of thousands each year into the UK in association with this pathway. It should be noted that **the number of**

**eggs does not represent the potential number of larvae** – some eggs will have been parasitized or be unviable for other reasons.

Air drying of mosses may occur before export, and it is uncertain if this would affect the viability of eggs, it is unlikely to affect pupae. The commodity code is for "fresh lichens" and, since there is an additional commodity code for dried lichens, it is unlikely that lichens will undergo significant drying if imported under this code. It is not known if harvesters check material for invertebrates before export, or if imports are inspected for pests upon landing. If mosses and lichens are imported in large volumes (e.g. in crates and not small, individual packets), pupae and egg masses will be hidden within the moss and lichens and be very difficult to detect.

The risk of the pest being able to transfer from this pathway to a suitable host is judged to be small. Since mosses and lichens are being imported for use for ornamental purposes, it is likely that upon import the consignments will be rapidly split up into many bouquets/hanging baskets and maybe sold and stored indoors. Though, as noted above, even a 100g of mosses/lichens can contain a relatively high number of eggs. Where bouquets/hanging baskets are used outdoors, there is a risk of transfer if suitable hosts are nearby. Many potential hosts of *L. fiscellaria* are widespread in the PRA area and may be common in gardens, parks etc such as *Abies, Acer, Betula* and *Quercus.*

**Likelihood of entry on fresh mosses/lichens for ornamental purposes is unlikely with high uncertainty.** Mosses and lichens are imported into the UK from the USA, though direct import into Ireland is very small. This commodity may be associated eggs and pupae of *L. fiscellaria* - but the final use of these commodities means that the pest is unlikely to be able to transfer to a suitable host in the PRA area. That being said, there has been a recent increase in the import of fresh mosses and lichens into the UK and at the current levels imported there is potential for very high numbers of eggs to be associated with this pathway.

Uncertainty is high for a number of reasons. It is unclear how imported mosses and lichens are processed and stored, and how often imports of these commodities are subject to official inspection. The final use of the imported mosses and lichens will also affect the risk of the pest being able to transfer – use of this commodity for use in lining hanging baskets or in other large outdoor ornamental displays could allow for first instar larvae to crawl or balloon onto suitable host plants if these are in relative proximity, or for adults to fly to suitable oviposition sites. More information is required on the dispersal capacity of first instar larvae. Uncertainty is also high as import levels of mosses and lichens from the USA into the UK increased sharply in 2016 and 2017 – it is uncertain if this increase will continue. Finally, it is not known if European species of *Acer, Betula, Quercus* and other widespread genera those first instars larvae are known to be able to survive on are suitable hosts for the pest, though this is considered likely.

*Likelihood*

| Negligible | | Very unlikely | | Unlikely | | Moderately likely | | Likely | | Very likely |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ✓ | | | | | | |

*Uncertainty*

| Low | | Medium | | High |
|---|---|---|---|---|
| | | | | ✓ |

## 2.6.4 Wood

This section covers wood in the form of:

- Raw timber (in the rough with bark)
- Squared timber (having had the natural round surface removed
- Wood fuel
- Wood packaging material

*Life stages associated with the pathway*

Eggs masses and pupae are the life stages that are likely to be associated with timber. As described in section 2.5 egg masses are often laid on the trunk of trees under lichen and pupation may occur in bark crevices or under lichens on the trunk.

*Phytosanitary Requirements*

Though *L. fiscellaria* is not a regulated pest, current phytosanitary measures on imports on timber of some hosts of *L. fiscellaria* affect the risk of the pest being associated with this pathway, and so are described below. **This section concentrates on describing requirements on timber of the preferred hosts of *L. fiscellaria.***

Wood of conifers, excluding *Thuja* and *Taxus*, must meet certain phytosanitary requirements in order to enter the EU from Canada and the USA if originating from an area where the pinewood nematode, *Bursaphelenchus xylophilus,* is known to occur. *Bursaphelenchus xylophilus* is recorded across much of the range of *L. fiscellaria*, but EPPO (2018) do not record the pest as present in Washington or Alaska, though an earlier publication lists it as "probably" present in Washington (CABI and EPPO 1990). A rapid literature review did not find any records of *B. xylophilus* in Washington or Alaska, and therefore wood imported into the EU from these locations does not have to meet the following requirements.

Wood of conifers originating from parts of North America where *B. xylophilus* is known to occur, excluding *Thuja* and *Taxus*, other than wood packaging material, wood chips and wood waste, must have:

a) Undergone heat treatment to achieve a minimum temperature of 56°C for a minimum duration of 30 minutes throughout the entire profile of the wood OR

b) Been subject to fumigation with an approved product OR

c) Been subject to chemical impregnation with an approved product

Wood of *Thuja* and *Taxus* originating from parts of North America where *B. xylophilus* is known to occur, other than wood packaging material, wood chips and wood waste, must either be bark free, have undergone kiln drying to below 20% moisture content, or undergone appropriate heat treatment, fumigation or chemical fumigation as detailed above.

Wood of ALL conifers originating from where *B. xylophilus* is known to occur, in the form of wood chips/wood waste must be subjected to either the heat treatment or fumigation. Wood packaging material must be ISPM 15 compliant (IPPC 2009).

It is very likely that these treatments will also be effective at removing or killing *L. fiscellaria* pupae and eggs if they were present on timber.

Wood of conifers originating from Alaska and Washington must comply with other phytosanitary requirements. Wood of conifers originating from these states, excluding that in the form of wood chips/wood waste or wood packaging material, must:

a) Be bark free and free from grub holes caused by the genus *Monochamus*, defined as those larger than 3mm across OR

b) Been subject to kiln drying to less than 20% moisture content OR

c) Been subject to fumigation with an approved product OR

d) Been subject to chemical impregnation with an approved product OR

2) Undergone an appropriate heat treatment to achieve a minimum temperature of 56°C for a minimum of 30 continuous minutes throughout the entire profile of the wood.

Wood originating from Alaska or Washington in the form of wood/chips or wood waste that consists partially or entirely of wood of coniferous origin must either:

a) Originated in areas known to be free from non-European species of *Monochamus, Pissodes* or Scolytinae (bark beetles) OR

b) Have been produced from debarked round wood OR

c) Been subject to kiln drying to less than 20% moisture content OR

d) Been subject to fumigation with an approved product OR

e) Undergone an appropriate heat treatment to achieve a minimum temperature of 56°C for a minimum of 30 continuous minutes throughout the entire profile of the wood.

The states of Washington and Alaska will not be able to fulfil the criteria of being free from non-European species of *Monochamus, Pissodes* or Scolytinae – and as such any imported wood will either have been treated or will be bark free. As egg masses are on the outside of the trunk of the tree, and pupae found within sheltered locations such as bark crevices, removal of bark would very likely also remove the risk of *L. fiscellaria* being associated with the timber. Kiln drying, heat treatment, fumigation and chemical impregnation are also very likely to be effective at eliminating the pest.

There are phytosanitary requirements on the import of wood of *Quercus* from North American countries into the EU, as laid out in Plant Health Directive 2000/29/EC. The wood shall be stripped of its bark AND:

a) Either be squared so as to remove entirely the rounded surface OR

b) Is bark free and the water content is less than 20% expressed as a percentage of the dry matter

c) Is bark free and has been disinfected by an appropriate hot air or hot water treatment OR

d) If sawn, with or without residual bark attached, has undergone kiln drying to below 20% moisture content as expressed as a percentage of the dry matter

These treatments are likely to remove any *L. fiscellaria* life stages that are associated with the timber.

**Egg masses and pupae may be found in association with timber of other species**. This is especially true during outbreak years, when the highly mobile later instar larvae will feed on a range of host trees. Presumably, pupation may also occur on these trees – as well as stumps pupation may occur in bark crevices or under lichens on the trunk. Carrol (1956) noted that egg masses also occurred on a range of species. Annex II summarises the requirements on timber of various hardwood species that can be imported from the range of *L. fiscellaria*. This includes requirements on wood of *Acer saccharum* (sugar maple), *Betula* (birch), *Fraxinus* (ash), *Juglans ailantofolia* (Japanese walnut), *Juglans mandshurica* (Manchurian walnut), *Platanus* (plane), *Populus* (poplar), *Pterocarya rhoifolia* and *Ulmus davidiana* (the David). To summarise:

- Current Phytosanitary measures on *Betula* wood will also be effective at mitigating the risk of *L. fiscellaria* being associated with this pathway.
- Measures on wood of *Fraxinus, Juglans, Pterocarya rhoifolia* and *Ulmus davidiana* only apply when the wood is entering from an area where *Agrilus planipennis* (emerald ash borer) is known to occur. The range of *A. planipennis* is currently limited to Eastern North America, and states

where the subspecies *L. f. lugubrosa* and *L. f. somniaria* occur are recognised as free of the pest and so wood can be imported untreated and *L. fiscellaria* may still be associated with the commodity. Wood of these species originating from states/Provinces where *A. planipennis* is known to occur will have been treated in a manner that should mitigate against the risk of *L. fiscellaria* being associated with the commodity.

- Phytosanitary requirements on wood of *Platanus* originating from the USA would also be effective at mitigating the risk of *L. fiscellaria* being associated with the commodity, but there are no requirements on wood of *Platanus* originating from Canada.
- Phytosanitary requirements on wood of *Populas* and *Acer saccharum* originating from North America would also be effective at reducing the risk of *L. fiscellaria* being associated with the commodity.

**It is likely that there are species on which egg masses or pupae may be found for which there are no phytosanitary requirements, however it is highly uncertain how often *L. fiscellaria* may be found pupating/lay egg mass on such hosts.**

*Trade*

Trade in various wood commodities is summarised in Appendix I. Trade data was extracted from Eurostat. To take into account the fact that trade patterns change over time, five years worth of data (2012-2017) was extracted. As the PRA area is the island of Ireland, trade data was extracted for both Ireland and the UK. It is not known what proportion of imports into the UK was destined for Northern Ireland.

Coniferous and oak timber products are imported into Ireland and the UK from North America, though as described above the current phytosanitary measures on these imports should eliminate the risk of the pest being associated with the commodity. There are sometimes cases of non-compliance.

Under the commodity code for "wood in the rough", which will exclude wood from conifers or wood of *Betula, Eucalyptus, Populas,* and *Quercus* as they have their own commodity codes, Ireland imported approximately 81 tonnes from 2013 to 2017 from the USA, and the UK imported approximately 1261 tonnes, and 2872 tonnes from Canada. There was also import of fuel wood from North America. Imports into Ireland were very low, <200kg over a five year period. Into the UK approximately 160 tonnes was imported, both coniferous and non-coniferous. The UK imported approximately 145 tonnes of wood waste and scrap in the same time period, Ireland imported <200 kg. Railway sleepers, or cross-ties, can act as a pathway for introduction of pests especially if imported as raw wood – for example the ambrosia beetle *Xylosandrus crassicusculus* was thought to have been introduced to Oregon on raw wood railway ties that were left outside to dry (LaBonte 2011). Ireland imported approximately 2600 tonnes of railway sleepers from Canada from 2013 to 2017 and in the same time period the UK imported approximately 5400 tonnes, it is not known what percentage of these were raw timber.

Imports under all of these commodity codes will include a) wood of species not infested by *L. fiscellaria,* b) wood originating from states where *L. fiscellaria* is not known to occur and c) wood that may have been treated in a manner that reduces the risk of *L. fiscellaria* being associated e.g. debarked wood, squared timber.

The largest risk will be wood that is imported in its raw form, with associated bark. It is likely that most wood imported into Ireland has at least undergone some level of seasoning/drying in the country of export. In order to decrease uncertainty, more data is required on the species and state (e.g. with/without bark, dried/undried, treated/untreated etc) of the timber being imported into the PRA area from the range of the pest.

*Transfer*

To have "entered" the PRA area, *L. fiscellaria* must transfer off the commodity and onto a suitable host. Suitable host species are abundant in Ireland, as long as the pest can adapt to European species of the genera attacked in North America which is considered likely.

Where imported wood is stored outside, adults emerging from pupae may be able to locate new hosts. Females of *L. fiscellaria* are relatively sluggish and often lay eggs close to pupation sites (Ostaff *et al* 1974b), so wood would also need to be stored close to suitable hosts for transfer to occur.

Young larvae hatching from egg masses will also be mobile and seek nearby hosts, in their natural environment *L. fiscellaria* will lay eggs on tree stumps and may have to travel "considerable distances" to find a suitable host tree (Steinbauer and Carroll 2011). It is uncertain how far a larvae can travel, they can spread on air currents to try to land on new foliage if at a height (Hérbert and Jobin 2001), and if wood is being stored close to appropriate hosts transfer is possible, though unlikely. More information is required on the dispersal capacity of first instar larvae.

*Conclusions*

**Likelihood of entry on wood is unlikely with high uncertainty**.

For the principle hosts of *L. fiscellaria*, the current phytosanitary measures will be effective against this pest, however in outbreak year's egg masses and pupation may occur on a very large number of species which will include those whose timber can be imported raw. Trade levels are relatively low compared to import from European countries. Where wood is stored outside before processing, adults emerging from pupae are likely to be able to locate suitable host trees for egg laying. Larvae hatching from eggs have some mobility, but stored timber will need to be in close proximity to suitable hosts and therefore egg masses pose a lower risk than pupae. The greatest risk of entry is on wood of species that is not currently subject to any phytosanitary measures, and uncertainty is high as it is a) uncertain how often such species would be utilised as egg laying or oviposition sites by *L. fiscellaria* and b) there is a lack of data concerning the trade in such hosts, and what treatment it may have been subjected to (e.g. raw timber imports versus debarked imports).

*Likelihood*

| Negligible | | Very unlikely | | Unlikely | ✓ | Moderately likely | | Likely | | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

# 2.7 Does the pest require a vector and is that vector present in the PRA area?

*Lambdina fiscellaria* is a free living organism and does not require a vector.

# 2.8 How likely is the pest to establish outdoors or under protection in the PRA area?

## 2.8.1 Establishment outdoors

Several different factors affect the likelihood of *L. fiscellaria* establishing in the PRA area, and these are discussed below.

*Climate*

*Lambdina fiscellaria lugubrosa* and *L. f. somniarai* are distributed in the Pacific Northwest of North America, which has an Oceanic climate similar to the PRA area. It is very likely that the climate of the PRA area is suitable to allow these pests to complete their lifecycle.

*Lambdina fiscellaria fiscellaria* ranges across several climate types. It has been recorded causing outbreaks as far north as Newfoundland (Carroll 1956), which has average summer temperatures of 16°C (Newfoundland and Labrador Tourism 2018), cooler than those of the PRA area where inland summer temperatures are between 18 to 20 °C (Met Éireann 2017). Hérbert and Jobin (2001) state outbreaks often occur near the coast and that the pest may therefore prefer an oceanic climate. The pest is also present in regions with colder winters than the PRA area and eggs of *L. f. fiscellaria* have been shown to survive temperatures as low as -40°C (Rochefort *et al* 2011). It is therefore very likely that the climate of the PRA area will also be suitable for *L. f. fiscellaria* to complete its development, though as discussed later in this section the timing of egg hatch and bud burst may affect the ability of the pest to establish.

*Larval food preferences*

It is uncertain if the larval food preferences of the subspecies of *L. fiscellaria* may limit their establishment potential. All subspecies are polyphagous, but do have preferred hosts.

For *L. f. fiscellaria* the main host is *A. balsamea*, which is not grown extensively in the PRA area. Other species of *Abies* are grown in the PRA area, often for Christmas tree production. The National Forestry Inventory 2012 for Ireland recorded 1650 ha of *Abies procera* (noble fir), 590 ha of *Abies grandis* (grand fir) and 360 ha of *Abies alba* (silver fir). No information regarding the host status of *A. alba* and *A. procera* could be found – the native distribution of all three species of *Abies* commonly grown in the PRA area does not cross over with the native range of *L. f. fiscellaria*. *Abies grandis* has been recorded as a host of *L. f. lugubrosa,* it is likely that *L. f. fiscellaria* can also feed on this host. Other species of *Abies* will also be widespread in parks and gardens as ornamentals.

Within the laboratory, *L. f. fiscellaria* first instar larvae have been reared successfully on foliage from a number of hosts the pest has also been recorded on in the wider environment including *P. glauca*, *T. canadensis* a number of *Acer* species and *Betula papyrifera*. The pest may show a preference for *A. balsamea* in its native range but clearly has some ecological plasticity on host choices. Hérbert *et al* (2006) note high larval survival rated on *A. balsamea, T. canadensis* and *Acer saccharum*. It is considered likely that *L. f. fiscellaria* could adapt to species of *Abies, Acer* and *Picea* grown in the PRA area.

The preferred host of *L. f. lugubrosa* is the western hemlock, *T. heterophylla*, though it has been recorded on a range of conifers and broadleaved trees (Randall 2005). This includes an outbreak where *Picea sitchensis* was the preferred host (Torgensen and Baker 1969). Though western hemlock is not grown extensively in the PRA area, with approximately 570 ha, it is considered likely that *L. f. lugubrosa* could adapt to hosts such as *P. sitchensis* and other conifers grown in the PRA area. There is no indication in the literature that *L. f. lububrosa*, like *L. f. fiscellaria*, times larval emergence with bud burst – however even if this is the case since the pest is native to a region with a very similar climate to the PRA area it is likely that bud burst of conifers in the PRA area will occur at a similar time to the pest's native distribution.

The main host of *L. f. somniarai* is *Quercus garryana*, the Garry oak and the range of this subspecies corresponds to the native range of *Q. garryana*. Though *L. f. somniarai* has been recorded on other *Quercus* species, outbreaks usually only occur where *Q. garryana* is the dominant species (Willhite 2018). The host status of European species of *Quercus* is not known, experts on *L. f. somniaria* were contacted but were unaware of records of the pest feeding on *Q. petraea* and *Q. robur,* the two species of oak native to the PRA area. The pest will also colonise *Pseudotsuga menziesii* and *Tsuga* adjacent to infested oak stands, but when larvae were restricted to a diet of just conifer needs high mortality was seen (Chamberlin 1931). It is not known if Chamberlin (1931) supplied larvae with current year needles of *P. menziesii* – if the needles were from previous seasons, this may explain the high mortality rate, as described below larvae need fresh flushed foliage in their early instars. It is uncertain if *L. f. somniarai* could adapt to European species of *Quercus*, or to utilise *P. menziesii* which is grown in the PRA area as a primary host. However there has been an outbreak where an alternative host was favoured, *F. latifolia* (Willhite 2018), so the pest does show some ecological plasticity in host choices.

*Bud burst*

The timing of bud burst of potential hosts in the PRA area may affect the ability of *L. f. fiscellaria* to establish. Larvae consume both old and new foliage, **but require new foliage to survive**. Synchrony between egg hatch of *L. f. fiscellaria* and budburst of *A. balsamea* was found to be critical to the survival of larvae – twice as many survived if reared in synchrony with bud burst compared to those whose egg hatch was delayed until two weeks after bud burst (Carroll 1999). A study by Butt *et al* (2010) concluded that emergence of *L. f. fiscellaria* is synchronised not with the timing of budburst, but with a period approximately one week post-budburst. Delisle (2010) states that diapause of eggs takes exactly three months, after which temperature is the major factor which influences egg hatch time. As winters are milder in the PRA area compared to some regions where *L. f. fiscellaria* is present, egg hatch may occur earlier – perhaps before bud burst of trees which may lead to starvation of larvae. Without access to the data on temperature requirements for egg hatch in *L. f. fiscellaria* it is difficult to judge if asynchrony of egg hatch and bud burst would occur.

The timing of budburst of *Picea sitchensis*, which is the predominate conifer in the PRA area is related to a) the number of "chilling days" (days during winter where temperature is ≤5°C) experienced by the tree and b) the number of day degrees >5°C after February (Cannell and Smith 1983). It should be noted that the model developed by Cannell and Smith (1983) was for Scotland, and may not be valid in the PRA area. In Ireland, budburst usually takes place from the end of April to the end of May, and timing is related to accumulated temperature and lack of cold (Niall Farrelly, *personal communication*). *Lambdina fiscellaria fiscellaria* can survive on other host species, including species of *Acer* etc, and if bud burst has not occurred of *P. sitchensis* or other conifers at the time of hatching suitable alternative hosts maybe available.

More research is required to ascertain if egg hatch of *L. f. fiscellaria* would occur in conjunction with bud burst of *P. sitchensis*, or other potential hosts, in the PRA area. An egg hatch model based on temperature has been developed for *L. fiscellaria* (Delisle 2010), but at this time has not been published.

The literature only contains information concerning hatching and bud burst for *L. fiscellaria*, and **it is not known if other subspecies of *L. fiscellaria* also time egg hatching for bud burst**. Due to their morphological similarities, it is considered likely that synchrony between hatching and bud burst is also important in the western subspecies of *L. fiscellaria*.

The different subspecies of *L. fiscellaria* are considered to have different likelihoods of establishment.

*Lambdina fiscellaria fiscellaria*

*Lambdina fiscellaria fiscellaria* ranges north into regions with cooler summers and colder winters than the PRA area, and so is very likely to be able to survive the climate of the PRA area. The preferred host is *A. balsamea*, but it has been recorded on a number of other coniferous species and is considered likely to adapt to those *Abies* and *Picea* species grown in the PRA area, as well as potentially some broadleaved *Acer* and *Betula* hosts. This pest may potentially be able to utilise additional host species in the PRA area which it has not yet been exposed to in its native distribution.

**Likelihood of establishment is likely with high uncertainty**. Host status and susceptibility of key conifer species grown in the PRA area, in particular *P. sitchensis* and those species of *Abies* grown as Christmas trees, is one of the key uncertainties. More research is required to ascertain if under the climate conditions in the PRA area, larval emergence would occur in synchrony with bud burst of the key conifers and broadleaved trees at risk from this pest.

*Likelihood*

| Negligible | | Very unlikely | | Unlikely | | Moderately likely | | Likely | ✓ | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

*Lambdina fiscellaria lugubrosa*

The primary and secondary hosts of *L. f. lugubrosa* are found in the PRA area, and this pest has also been recorded utilising *Picea sitchensis* as a preferred host on at least one occasion. It is distributed in regions with a highly similar climate to the PRA area. **Likelihood of establishment is very likely with medium uncertainty**. There remains uncertainty about the capacity of *L. f. lugubrosa* to utilise *Picea sitchensis*, the predominate forest species in the PRA area, as a primary host in the absence of extensive plantings of its preferred host *Tsuga heterophylla*.

*Likelihood*

| Negligible | | Very unlikely | | Unlikely | | Moderately likely | | Likely | | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | ✓ |

*Uncertainty*

| Low | | Medium | | High | |
|---|---|---|---|---|---|
| | | | ✓ | | |

<u>*Lambdina fiscellaria somniarai*</u>

Though the climate of the PRA area is likely to be suitable for establishment, *L. f. somniarai* shows a very strong preference for *Q. garryana* which is a host not grown in the PRA area except as an occasional ornamental or specimen tree. The ability of the pest to establish is entirely dependent on if the larvae can adapt to a) utilising those species of *Quercus* grown in the PRA area as a primary host or b) utilising the known secondary host *P. menziesii*. The latter is uncertain, as when larvae were restricted to a diet of *P. menziesii* under experimental conditions high levels of mortality occurred (Chamberlin 1931), but it is unclear if the author was using current year needles, as older needles would have also led to starvation of first instar larvae. There is a risk that the host range of *L. f. somniarai* is larger than currently recorded and that other trees grown in the PRA area may be suitable hosts.

**Likelihood of establishment is moderately likely with high uncertainty**. This rating is based on the pest adapting to use species of *Quercus* grown in the PRA area as the primary host. Ireland does not have extensive oak woodlands, in 2012 plantations of *Q. petraea* were estimated at 6350 hectares, about 1% of the total forest estate (Forest Service 2012). It is not known how many hectares of *Quercus* are grown in Northern Ireland. Absence of significant stands of *Quercus* will limit the establishment of the pest. Uncertainty is high as the host status of *Q. petraea* is not known. It is also not known if *L. f. somniarai* would adapt to using the secondary host *P. menziesii* as a primary host or adapt to another species in the PRA area.

Uncertainty is also high as there remains very little evidence of subspecific division between *L. f. somniarai* and *L. f. lugubrosa.* Both have a highly similar range, and there is no evidence of significant differences between their genetics or pheromones. The subspecific division is made only on the basis of the preferred larval food plant.

*Likelihood*

| Negligible | | Very unlikely | | Unlikely | | Moderately likely | | Likely | | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ✓ | | | | |

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

### 2.8.2 Establishment under protection

Host species are not usually grown under protection. **Likelihood of establishment under protection is very unlikely with low uncertainty.**

*Likelihood*

| Negligible | | Very unlikely | ✓ | Unlikely | | Moderately likely | | Likely | | Very likely | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | ✓ | Medium | | High | |
|---|---|---|---|---|---|

## 2.9 How quickly could the pest spread in the PRA area?

### 2.9.1 Natural spread

Carroll (1956) states that males are more active flyers than females, and that fully gravid females are "very sluggish and are able to fly only a short distance at a time". The author notes that outbreak regions in Newfoundland tended to have very defined boundaries, and related this to the limited natural spread capacity of the female moths.

Adult females may begin to lay eggs almost immediately after mating, in the field they were often found near the base of trees, heavy bodied and not easily disturbed, and had probably not moved far from their pupation site. If disturbed, they dropped to the ground rather than flying away as males did (Ostaff *et al* 1974b). Delisle *et al* (1998) looked at the performance of pheromone and light traps at catching both sexes of *L. fiscellaria*. Females usually began to be caught in traps approximately a week after emergence; the majority had already been mated and had already laid 50% of their eggs. This suggests females are more active fliers when their egg burden is reduced, with Delisle *et al* (1998) stating that virgin females have a very low capacity for flight.

Wind plays a relatively minor role in the spread of adults of *L. fiscellaria*, though in Newfoundland spread of outbreaks in the general direction of the prevailing wind has been noted (Otvos *et al* 1979).

First instar larvae are capable of moving to find a suitable host, as eggs are often laid on old stumps, moss covered logs and on the forest floor and the larvae must seek out a host tree (Steinbauer and Carroll 2001). After hatching, young larvae may be dispersed on a local level by the wind (Hérbert and Jobin 2001). Very local natural spread will also occur via the movement of late instar larvae, which once a tree has been defoliated drop to the ground and actively seek out new hosts. Such larvae have been observed, however, to climb the first structure they come into contact with which can include stumps, fence posts etc as well as trees (Chamberlin 1931). Long distance spread via this pathway is therefore very unlikely.

Due to the limited capacity for flight of the females recorded in the literature, **rate of natural spread is slowly with medium uncertainty.** No specific studies could be found on the flight distance that female *L. fiscellaria* are capable of with flight distances described in qualitative terms, contributing to uncertainty.

*Rate*

| Negligible | | Very slowly | | Slowly | | Moderately pace | | Quickly | | Very quickly | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ✓ | | | | | | |

*Uncertainty*

| Low | | Medium | | High | |
|---|---|---|---|---|---|
| | | | ✓ | | |

## 2.9.2 Spread with trade

*Lambdina fiscellaria* could spread in trade of host commodities. As described for risk of entry, this pest is rarely recorded in nurseries except during outbreak years when infestations are severe enough that action is likely to be taken against the grower against the pest.

Pupae hidden in bark crevices and under lichen and egg masses laid on the trunks of trees that are then felled and transported could provide a pathway of long distance spread for the pest.

Felling operations will usually take place outside of the breeding season of key bird and mammal species that may use the forest (Forest Service 2010). This means the majority of felling will take place in autumn and winter months, and that egg masses are the most likely life stage to be associated with the timber.

Felled timber may be moved to another site for processing. There may be a period of time where timber is left outside (e.g. to dry) and this may allow egg masses enough time to hatch. However, timber would have to be left close enough to suitable host species if the emerging larvae are to be able to survive.

**Rate of spread with trade is rated as slowly with medium uncertainty**. Signs and symptoms of the pest on plants for planting mean it is very unlikely to spread on this pathway. Timber could act as a pathway of long distance spread, with egg masses being the most likely life stage to be associated with this commodity. For spread of the pest to be successful, timber would need to be stored outdoors until egg hatch and relatively close to suitable host plants in order to allow for the transfer and survival of the first instar larvae. Spread along this pathway is unlikely but if the pest was introduced, occasional long distance spread could occur.

*Rate*

| Negligible | | Very slowly | | Slowly | ✓ | Moderately pace | | Quickly | | Very quickly | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | ✓ | High | |
|---|---|---|---|---|---|

# 2.10 What is the pest's potential as a vector of plant pathogens?

*Lambdina fiscellaria* is not recorded as a vector of plant pathogens.

# 2.11 What is the pest's economic, environmental and social impact within its existing distribution?

## 2.11.1 Economic impacts

Economic impacts attributed to each subspecies are recorded below, but a single overall economic impact rating is provided for *L. fiscellaria* in its current range.

As a species, *L. fiscellaria* is recorded as a "wasteful feeder"- that is, not consuming entire leaves or needles but only eating a small portion before moving on to the next needle. Every needle on a tree may be partially damaged by the pest. Partially eaten needles will still die, and so in this way *L. fiscellaria* is more damaging than those pests which consume the whole of the needle (Carroll 1956; Thomsen 1957; Randall 2005). On broadleaved hosts skeletonised leaves may be left behind (Natural Resources Canada 2015).

Periodic outbreaks are caused by *L. fiscellaria* across the range of the pest, and the damage from these outbreaks is outlined by subspecies below. There are various reasons why outbreak populations crash. Carroll (1956) stated that starvation of first instar larvae plays a factor, when trees have been completely defoliated in previous seasons and fail to produce any new foliage.

*Lambdina fiscellaria fiscellaria*

Carroll (1956) summarised early reports of outbreaks of this pest in Newfoundland, stating that there were records of 4 outbreaks between 1912 and 1955. The best details are available are for those that occurred across sites on the island from 1947 onwards. In two locations, extensive outbreaks occurred that led to death of *A. balsamea*, but salvage of the killed timber was possible. In the 20 square mile outbreak in 1949 at St John's Bay, timber could not be salvaged as the location was impractical for its movement. The most severe outbreak recorded by Carroll (1956) took place at Hare Bay. It is described as developing very rapidly and is estimated to, from 1952 to 1955, have caused mortality of 300 000 cords of *A. balsamea*, which is **very approximately** 1 million $m^3$, though about 50 – 70% was thought to be salvageable. Carrol (1956) noted that outbreaks were largely concentrated along the coast. Carrol thought this related to the distribution of the preferred host of *L. f. fiscellaria*, *A. balsamea,* rather than any climatic factors.

Carroll (1956) noted that all severe outbreaks originated in stands where mature or over-mature *A. balsamea* predominated. Severe attacks commenced where 70% of the stand consisted of *A. balsamea*, and it appears that an increase in *Picea* in the stands decreases the likelihood of an outbreak. Annual radial growth measurements were also taken at the outbreak sites, it was found that a decrease in growth had begun in all areas prior to the outbreak and the author suggested this may be due to climatic conditions that stressed trees and predisposed them to attack by *L. fiscellaria*.

A sudden and severe outbreak occurred between 1966 and 1972 at various locations across the island. As described by Otvos *et al* (1979), it developed very suddenly, a warm dry summer in 1966 favoured larval development and weather conditions were also favourable for mating in the autumn. Epidemic populations occurred the next year, covering approximately 48 780 ha. This corresponded to an estimated 2 410 000 $m^3$ of merchantable wood being infested, of which approximately 60% was killed or severely damaged. A chemical control programme was undertaken in 1968 and 1969 to minimize further damage. The outbreak collapsed in 1972, though tree morality continued for several years after and the 1966-72 outbreak was estimated in total to have killed 723 000 $m^3$ of timber, with less than 17% of the killed wood was salvaged.

Otvos *et al* (1979) notes that though normally confined to mature *A. balsamea* stands, occasionally severe damage has been recorded on younger stands though these are often adjacent to mature stands from where the outbreak may "spill over". Stand vulnerability to infestation is also increased by attack from other pests and diseases, or by trees suffering from drought stress.

Otvos *et al* (1979) and Hudak *et al* (1996) summarises the history of *L. f. fiscellaria* outbreaks in Newfoundland, and Table 3 detailing outbreaks of *L. f. fiscellaria* in Newfoundland is adapted from information in these publications. Data from Hudak *et al* (1996) is displayed for each year of the outbreak in the 1990s, starting from the year in which tree mortality was first recorded. As can be seen from the data in Table 3 – tree morality continues after population crashes and salvage operations are necessary for several years afterwards. As per earlier outbreaks, a certain percentage of killed timber was successfully salvaged. In total the 1985-1995 outbreak caused an estimated 11 300 000 $m^3$ of tree mortality and caused additional growth loss in excess of 1 000 000 $m^3$.

Though salvage of timber is possible, action must be taken quickly by forest managers to salvage timber whilst it is still marketable. The deterioration of killed *A. balsamea* timber and its utilisation has been studied by Warren (1996). Both immature and semi-mature even aged balsam fir stands were susceptible to high tree mortality, and in the studied outbreak (1983, Newfoundland) 99% and 94% were killed respectively, after 1 – 2 years of severe defoliation. Mature all aged stands suffered 44% mortality. Brown stain began to develop in trees within 1 – 2 years, and took up about 35% of tree volume after 4-5 years. Secondary pest infestations of bark beetles and wood wasps occurred, with 20% of killed trees infested by wood wasps and 3.2 % by bark beetles 4-5 years after tree death, both pests carry associated fungi which cause decay of the wood. The authors concluded that there were limited early salvage losses, due to the low incidence of bark beetle activity. Field inspections have found sound standing timber up to 7 years after tree mortality.

Hiscock *et al* (1978) studied the effect of sap rot on pulping properties of *A. balsamea* killed by *L. f. fiscellaria* in Newfoundland. Dead trees yielded lower amount and inferior quality wood pulp compared to that harvested from live trees. The authors concluded from their observations trees should be utilised within 4 years of death to minimise the increased costs associated with processing wood suffering decay.

**Table 3**: Outbreaks of *L. f. fiscellaria* in Newfoundland from 1910 – 1994. Data on outbreaks up until 1972 is taken from Otvos *et al* (1979). Data on defoliation caused by *L. f. fiscellaria* from 1986 onwards is taken from Hudak *et al* (1986).

| Outbreak years | Area defoliated (hectares) | Tree Mortality (timber $m^3$) | Salvage (timber $m^3$) |
|---|---|---|---|
| 1910-1915 | Light - Unknown<br>Moderate/Severe – 12 100 | 180 800 | Unknown |
| 1920-1926 | Light - Unknown<br>Moderate/Severe - 8300 | 723 000 | Unknown |
| 1929-1935 | Light - unknown<br>Moderate/Severe - ≈56 900 | 24 100 | Unknown |
| 1946-1955 | Light - Unknown<br>Moderate/Severe - ≈127 600 | 1 205 000 | Unknown |
| 1959-1964 | Light - Unknown<br>Moderate/Severe - 4300 | 1 446 000 | 96 400 |
| 1966-1972 | Light – 194 600<br>Moderate/Severe – 526 500 | 8 633 500 | 1 437 400 |
| 1986 | Light – 116 000<br>Moderate/Severe – 215 500 | 3 207 000 | 339 000 |
| 1987 | Light - 8700<br>Moderate/severe – 152 000 | 4 592 000 | 191 000 |

| Outbreak years | Area defoliated (hectares) | Tree Mortality (timber m$^3$) | Salvage (timber m$^3$) |
|---|---|---|---|
| 1988 | Light - 4700<br>Moderate/Severe – 12 900 | 281 600 | 191 000 |
| 1989 | Light - 3900<br>Moderate/Severe – 9500 | 852 000 | 149 000 |
| 1990 | Light – 10 600<br>Moderate/Severe - 1900 | 95 000 | 165 000 |
| 1991 | Light - 400<br>Moderate/Severe - 2600 | 1 715 000 | 144 000 |
| 1992 | Light - 1600<br>Moderate/Severe - 4000 | 355 000 | 97 000 |
| 1993 | Light - 3700<br>Moderate/Severe - 5800 | N/A | 60 000 |
| 1994 | Light - 1900<br>Moderate/Severe - 9700 | 32 900 | 29 000 |
| 1995 | Light – 26 900<br>Moderate/Severe – 21 400 | 158 800 | 20 000 |

Iqbal *et al* (2011) studied the impact of *L. f. fiscellaria* defoliation on the growth and survival of *A. balsamea, P. mariana* and *B. papyrifera* in Newfoundland. Trees were placed into classes based on the severity of defoliation experienced, and their age class was also recorded. The severity classes were as follows: severity class 1 - one year of moderate defoliation, class 2: one year of severe defoliation, class 3: two years of moderate defoliation and class 4: two years of severe defoliation. Survival of trees was then calculated over the 10 year study period. *Abies balsamea* had the lowest survival rate of the species studied at all severity classes, with close to 100% mortality in those trees in class 4 and 60-80% mortality in the lower severity classes. There was very little mortality of *B. papyrifera* and *P. mariana* at the lower severity classes, in the highest class 20% mortality was observed.

Iqbal *et al* (2011) also studied the effect of defoliation on growth of the trees by severity class and species. Growth reductions of *A. balsamea* in severity classes 1 and 3 had maximum growth reductions of 10-20%, those in severity class 2 showed 20-40% growth reduction and class 4 30-50% growth reduction for 2 -3 years after defoliation. Growth change results for *B. papyrifera* and *Picea mariana* were highly variable. Class 4 *B. paryrifera* suffered a growth reduction of 10 – 20 %. For *P. mariana* in class 4, a maximum growth reduction of 35% was seen. For both species, trees recovered quickly as the *A. balsamea* began to die within the plots.

_*Lambdina fiscellaria lugubrosa*_

Outbreak populations of *L. f. lugubrosa* attain epidemic proportions every 8 to 16 years (Johnson *et al* 1970), with 14 outbreaks recorded over an 87 year period in British Columbia (Borecky and Otvos 2001). In Oregon, outbreaks tend to occur in valley bottom stands of mature and old-growth western hemlock, but have occurred in stands as young as 60 years of age. Stands predominated by tree species other than western hemlock or a mix of western hemlock and western red cedar are reported to appear to be resistant to *L. f. lugubrosa* outbreaks (Mellen-McLean *et al* 2017). Western hemlock trees are relatively intolerant to defoliation, and they tend to die when more than 75% of the crown is lost to the pest (Goheen and Willhite 2006).

Furniss and Carolin (1977) report on the earliest recorded outbreak, from 1889 to 1891, in which a vast amount of timber in Oregon and Washington was destroyed. A severe outbreak took place in Washington from 1929-1982, causing losses of 200 million board feet (roughly 4700 $m^3$) of hemlock timber. The authors also conclude that though outbreaks come to an end naturally, vast amounts of timber can be saved if artificial control measures such as aerial spraying of forests are applied.

An outbreak in British Columbia in 1945 affected approximately 140 square miles of high quality *T. heterophylla* and *P. menziesii* stands with high levels of defoliation observed, up to 81% in some areas of Vancouver Island (Richmond 1946). An outbreak took place in Interior British Columbia in 1991, with severe defoliation over 3650 ha and moderate over 15 000 ha, primarily mature and overly mature *T. heterophylla* was defoliated (Koot 1991). This outbreak continued to grow in 1992, affecting 186 000 ha of mature to over-mature western-hemlock-western red cedar stands, with approximately half the area suffering severe defoliation (Humphreys *et al* 1992). Though Humphreys *et al* (1992) predicted severe defoliation to occur the next year, the outbreak declined in area to 92 750 ha, with about half the area severely defoliated. This was attributed to larval mortality caused by disease and parasites. Tree morality was recorded in 1993 on previously defoliated sites, with up to 40% of trees in some plots designated for monitoring being killed, but in other areas mortality was as low as 6% and some severely defoliated stands suffered no mortality (Wood and Van Sickle 1993).

Johnson *et al* (1970) reported on the tree mortality caused in Washington State by the 1963 outbreak of *L. f. lugubrosa*. The outbreak took place in south-western Washington over approximately 28 000 ha primarily affecting *T. heterophylla*, with pesticides applied to limit the timber losses having some affect at reducing impacts. In the experimental plots established, 23% of infested trees were killed over the three year study period and of the trees not killed, many had top-kill. Johnson *et al* (1970) also looked at deterioration rate of dead timber. Advanced decay caused volume losses of 2.1% one year after tree death, 10.7% two years after and 20.8% three years after tree death. Standing trees were found to deteriorate faster than those that were felled after death and left on the ground.

The impacts of the 1992-1994 outbreak in the Prince George Forest Region of British Columbia were studied in more detail by Alfaro *et al* (1999). In this region the infestation was about 200 ha when discovered in 1992, increased to 44 000 ha by 1994, with a population crash in 1995 due to high levels of larval parasitism and disease. Alfaro *et al* (1999) studied the percentage defoliation by *L. f. lugubrosa* in this district by tree species. Though *Tsuga* is widely reported as the preferred host of this pest, *Abies lasiocarpa* (alpine fir) sustained significantly higher defoliation, followed by *T. heterophylla, T. plicata and P. glauca.* There was also a significant difference in mortality by species. In 1995, 89% of *A. lasiocarpa,* 58% of *T. heterophylla,* 67% of *P. glauca* and 46% of *T. plicata* had died in the severely defoliated stands. The authors proposed that the higher defoliation and mortality of *A. lasiocarpa* was due to the preference of the hemlock looper for feeding on this species, as well as its lack of ability to recover from defoliation. In this study, it was also noted that *P. glauca* was then infested by the spruce bark beetle *Dendroctonus rufipennis*. It was later reported that the total area defoliated in this outbreak was 272 000 ha, with 63 000 ha killed (Borecky and Otvos 2001).

Torgensen and Baker (1967) describe an outbreak on Wrangell Island, Alaska, that took place in 1965. This was the first record of *L. f. lugubrosa* in Alaska. In this outbreak, *P. sitchensis* was the preferred host over *T. heterophylla*. Approximately 390 ha of *P. sitchensis* was heavily defoliated, with larval feeding and subsequent needle fall stripping some trees entirely of their foliage. *Tsuga heterophylla* was not heavily attacked even when *P. sitchensis* had been completely defoliated. Some understory plants, including *Vaccinium* spp. and *Cornus stolonifera* (redosier dogwood) were also infested with the pest with feeding leading to skeletonised leaves. In 1966 a salvage logging operation took place (Torgersen 1971), suggesting damage was severe enough that mortality of the trees was expected or occurred, but the specific reasons were not recorded by the author.

In Oregon outbreaks that spread into *Picea sitchensis* stands are reported to cause complete defoliation and death within one year, and outbreaks are usually on stands older than 80 years (Reeb and Shaw 2015).

*Lambdina fiscellaria somniaria*

Chamberlin (1931) states that based on past observations *L. f. somniaria* reaches epidemic levels every 7$^{th}$ to 8$^{th}$ year in the Willamette Valley of Oregon, causes extensive defoliation of *Q. garryana* for two to three years and then populations suffers rapid decline. Willhite (2018) states outbreaks tend to be short lived and typically last two to three years, though on one occasion a recurring outbreak lasted as long as 24 years.

*Quercus garryana* tolerates defoliation by the pest reasonably well, however when the pest spreads onto *P. menziesii* this host can be seriously weakened and may subsequently be killed by *Dendroctonus pseudotsugae* (Douglas fir bark beetle) (Natural Resources Canada 2015). Furniss and Carolin (1977) state permanent damage is not caused to *Q. garryana* due to the oaks being able to leaf out again the following year.

An outbreak occurred in 1995 on Saltspring Island, British Columbia, caused extensive death of *Q. garryana* and *P. menziesii* over approximately 50 ha. The pest was noted as not usually causing tree mortality. Tree mortality was thought to have been caused on this occasion due to the extended length of the infestation and abiotic factors, including the fact the infested site was poor and naturally dry and recent summer temperatures had been higher than average (Humphreys 1995).

Severe defoliation was seen in a highly localised area of the Willamette valley in Western Oregon in 2013 and 2014. Unusually, in one wildlife refuge, *Fraxinus latifolia* was the preferred host (Flowers *et al* 2014).

Conclusion

All three subspecies of *L. fiscellaria* are highly destructive defoliators causing widespread mortality of their coniferous hosts during outbreak years. A certain percentage of timber is salvaged during outbreaks, which helps o provide continuous wood supply, but it is unquestionable that significant volumes of timber are lost during each outbreak. Though outbreaks are only periodic, their vast scale leads to an **economic impact rating of very large with low uncertainty**.

*Economic Impacts*

| Negligible | | Very small | | Small | | Moderate | | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | ✓ |

*Uncertainty*

| Low | | Medium | | High | |
|---|---|---|---|---|---|
| | ✓ | | | | |

### 2.11.2 Environmental impacts

All subspecies of *L. fiscellaria* are considered to cause similar environmental impacts, and so the species is reviewed as a whole here.

Outbreaks of *L. fiscellaria* are a natural part of the forest cycle in North America, the killing of mature trees creates gaps in the canopy that allow for growth of new trees (Connolly 2006). The direct environmental impacts of *L. fiscellaria* are therefore relatively small. During outbreaks competition may occur between *L. fiscellaria* and other species that feed on its hosts – but this has not been recorded in the literature and any impacts on biodiversity are likely to be local and temporary.

It should be noted, however, that due to the need to have a continuous wood supply, control measures are used in forests against this pest in North America. These measures will have environmental impacts as they may affect non-target invertebrates. No specific studies could be found concerning impacts on non-target organisms by control measures put into place against outbreaks of *L. fiscellaria,* and so this section draws evidence from studies into the use of pesticides against other major forest defoliating pests in North America. As this is a rapid PRA, this section will provide **a brief overview of research in the area of impacts on non-target Lepidoptera and is not an in-depth analysis.**

In the past, control methods used against the pest included pesticides such as DDT that were broad spectrum with a high toxicity to non-target invertebrates and in some cases, vertebrates such as birds, small mammals and amphibians (Buffam 1964). Use of these products would have had large environmental impacts. Since these products are now prohibited, their past use is not taken into account and the impacts are only judged on control methods currently in use in the pest's native distribution.

The main control agent used against *L. fiscellaria* in North America are aerial sprays of the biological control agent *Bacillus thuringiensis* variety *kurstaki* (Delisle *et al* 2016), which is specific to Lepidoptera. Use of this product will affect other, non-target Lepidoptera, where it is sprayed. For example Johnson *et al* (1995) found that *B. thuringiensis* sprays can persist and be harmful to non-target Lepidoptera for at least 30 days after spraying, but estimates for the persistence of *B. thuringiensis* var *kurstaki* in the environment vary greatly (Biosecurity New Zealand 2003).

There is conflicting evidence in the literature concerning the impacts of *B. thuringiensis* var *kurstaki* against non-target Lepidoptera. Thompson (2011) reviewed the ecological impacts of the use of *B. thuringiensis* var *kurstaki* (and other pesticides) in forestry contexts. The author notes a number of studies have shown that applications of *B. thuringiensis* var *kurstaki* cause immediate reductions in the abundance and species richness of non-target Lepidoptera. Longer term studies have concluded that there is recovery of non-target Lepidoptera at treated sites. Boulton *et al* (2002) monitored larvae of *Gelechia ribesella* and *Euhyponomeutoides gracilariella* feeding on the understory plant *Ribes cereum* in a Douglas-fir forest treated during a western spruce budworm (*Choristoneura freemani*) outbreak. An initial significant reduction in larvae occurred, but both species had recovered by 2 years after the outbreak, but other more rarely recorded species at the site had not fully recovered. (Boulton and Otvos 2004). Boulton *et al* (2007) looked at recovery of non-target Lepidoptera at a site treated during a *L. dispar* outbreak. The site was treated in 1999, and eleven non-target species were found to suffer immediate significant reductions in populations. By 2003, populations of all monitored species had increased again, with only 4 out of the 11 still being significantly reduced in the treatment sites.

Studies have also documented indirect ecological impacts of sprays of *B. thuringiensis* var *kurstaki,* as reduction in Lepidoptera larvae may have knock on impacts for those species that feed on them such as birds and small mammals (Thompson 2011).

Scriber (2004) summarised studies into the use of *B. thuringiensis* var *kurstaki* to control forest defoliators, and its effects on non-target Lepidoptera. The author concluded that the decision not to spray may have equal impacts upon non-target Lepidoptera, due to the direct (e.g. consuming the food source) and indirect (e.g. attracting parasites and predators) competition of the defoliators with the non-target organisms. Manderion (2014), looking at the use of *B. thuringiensis* var *kurstaki* against the gypsy moth, *Lymantria dispar*, concluded that non-target Geometridae were benefited by the use of the biopesticide which reduced defoliation by *L. dispar* (Manderino *et al* 2014). Use of *B. thuringiensis* var *kurstaki* against *L. dispar* was also found to be potentially benefiting for forest beetles (Wayland *et al* 2015).

There is no evidence of direct environmental impacts of *L. fiscellaria* in the literature reviewed for this PRA. Environmental impacts of *L. fiscellaria* in its current distribution are primarily related to the indirect impacts of aerial applications of *B. thuringiensis* var *kurstaki.* Evidence in the literature is conflicting, with studies showing an immediate reduction in non-target Lepidoptera whilst others show no long term affects, and even hypothesise that use of pesticides to control outbreaks may be more beneficial to non-target invertebrates. Long term studies currently indicate that the impacts of *B. thuringiensis* on non-target organisms are temporary and reversible. **Environmental impacts are small with high uncertainty**, additional longer term studies are required into the direct and indirect impacts of aerial spraying of *B. thuringiensis* var *kurstaki* in forestry situations. In addition, no studies could be found in the literature concerning environmental impacts of *B. thuringiensis* var *kurstaki* when used to control *L. fiscellaria* outbreaks, so these conclusions have been extrapolated from other studies in different forestry contexts to where *L. fiscellaria* outbreaks occur.

*Environmental Impacts*

| Negligible | | Very small | | Small | ✓ | Moderate | | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

### 2.11.3 Social impacts

All subspecies of *L. fiscellaria* are considered to cause similar social impacts, and so the species is reviewed as a whole here.

A socio-economic analysis of *L. f. fiscellaria* in Newfoundland was carried out by Wernerheim and Parsons (1996). They found that the control programme of *L. f. fiscellaria* provided a positive social net benefit when timber values are considered, due to the importance of timber to the Newfoundland economy. Many sawmills are small and very local, and would rely on regular wood supply to survive – something that *L. f. fiscellaria* can endanger during outbreak years. Non-timber values, such as aesthetic beauty of forests and their use for recreation, also added to the social benefit of the control programme – but these were only studied in qualitative terms and not monetised for use in the calculations.

It is difficult to judge what the unmitigated social impacts of *L. f. fiscellaria* would be, since this pest is largely controlled in its native range. The work of Wernerheim and Parsons (1996) indicates that without control there would be considerably high losses due to tree mortality which would presumably impact upon the local economy and therefore have social impacts for those who work in the timber industry.

The authors assume that there would, without the control programme, also be social impacts due to loss of aesthetic value, wildlife habitats and soil erosion. Presumably, even where control programmes are in place, there are social impacts due to these factors. Outbreaks of *L. fiscellaria* have occurred in parks used for recreational purposes. For example severe defoliation was recorded along Hobson Lake in Wells Gray Park (Koot 1991), British Columbia, a provincial park with extensive recreation activities. Social impacts were not specifically mentioned by Koot (1991), but the defoliation and top kill reported very likely greatly reduced the aesthetic value of the trees. It has been reported that topkill and mortality caused by *L. f. lugubrosa* can cause detrimental effects to aesthetic values and public safety in recreational areas (Mellen-Mclean *et al* 2017).

Though largely a forest pest, *L. f. somniaria* has also been reported in residential areas causing heavy defoliation (Flowers *et al* 2013). Presumably here defoliation of trees also had social impacts by reducing their aesthetic value, but this was not recorded by the authors. Damage caused by *L. f. somniaria* in the Willamette Valley, Oregon, attracted attention in the local media (Mentzer 2014; Salem News Journal Staff 2014) with Grearson (2013) describing landowners calling state and local agencies concerned their trees were dying. Trees were described as looking scorched and as if autumn had arrived early.

Kheraj (2013) summarised findings by Swaine (1914) which could not be accessed for this report. A large outbreak of *L. fiscellaria* took place in Stanley Park, British Columbia and it was reported that after the outbreak dead hemlocks comprised of the majority of trees in Stanley Park, and that they were extremely unsightly.

Social impacts can also be incurred due to public concern about the use of pesticides in forestry contexts to control defoliators such as *L. fiscellaria* (Thompson 2011).

Active forest management of the pest in its current distribution, including the operation of salvage programmes after tree mortality, reduces social impacts by ensuring future wood supply. It is assumed that the pest causes social impacts on a local level when heavy defoliation reduces the aesthetic value of trees, though this is not reported in the literature. **Social impacts are rated as moderate with high uncertainty** due to a lack of data concerning the social impacts of this pest; including factors such as how often it invades residential areas.

*Social Impacts*

| Negligible | | Very small | | Small | | Moderate | | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ☐ | | ☐ | | ☐ | | ✓ | | ☐ | | ☐ |

*Uncertainty*

| Low | | Medium | | High | |
|---|---|---|---|---|---|
| | ☐ | | ☐ | | ✓ |

# 2.12 What is the pest's potential to cause economic, environmental and social impacts in the PRA area?

## 2.12.1 Economic impacts

All three subspecies are considered together in this section. There are many factors that could influence impacts of *L. fiscellaria* which are discussed in the sections below.

*Climate*

In Newfoundland, outbreaks are favoured by a few years of optimal conditions for *L. f. fiscellaria*, namely warmer than average temperatures and lower than average precipitation (Carroll 1996). It is not known how many years occur in the PRA area that would be ideal for the development of pest populations to epidemic levels, though generally the winters of the PRA area are milder than those of Newfoundland and a high survival of overwintering eggs of *L. fiscellaria* would be expected in the PRA area. The climate of Newfoundland in years before major outbreaks could be compared to the climate of the PRA area in order to gain more information concerning the potential of climate to influence outbreaks.

*Bud burst*

*Lambdina fiscellaria fiscellaria* hatching is closely linked to budburst of *Abies balsamea,* and survival rate of larvae if lower is hatching is asynchronous. No evidence linking hatching of the over subspecies of *L. fiscellaria* to budburst could be found in the literature, but it is known the larvae of *L. f. lugubrosa* and *L. f. somniaria* need current year needles/foliage to survive and so is considered likely that some level of synchrony to bud burst would be required for there to be a high survival rate of first instar larvae.

As previously stated in section 2.8.1, more research is required into the potential for synchrony between hatching of *L. fiscellaria* and bud burst of *P. sitchensis* and other potential coniferous and broadleaved hosts in the PRA area. If hatching and budburst are likely to be relatively asynchronous, this could reduce survival rates of the pest and therefore impacts. As western subspecies of this pest are distributed in regions with a similar climate to the PRA area, it is considered likely that there would be relative synchrony between their hatch time and bud burst in the PRA area – but this is subject to uncertainty.

*Natural Enemies*

Potential impacts can be influenced by the presence or absence of natural enemies of *L. fiscellaria*, as such organisms can help to reduce outbreak populations. Natural enemies of *L. fiscellaria* in its native range, and their status in the PRA area, are summarised in Table 4.

Very little parasitism of the larval stage of *L. fiscellaria* is observed in North America, and so West and Kenis (1997) trialled four parasites of Geometridae larvae collected from the Swiss Alps against the pest: *Dusona contumax, Dusona* sp., *Aleiodes* cf. *gastritor* and an *Aleiodes* sp. None of these species were successful at attacking larvae of *L. fiscellaria,* though they were reared successfully on their native hosts within the lab. West and Kenis (1997) note that closely related species of *L. fiscellaria* do not exist outside of North America, and therefore oligophagous parasitoids collected from European geometrids are likely to be incompatible with hemlock looper. It is considered unlikely that suitable larval parasites will be present in the PRA area that could help control outbreaks of *L. fiscellaria*.

Birds have been recorded feeding on *L. f. fiscellaria* larvae, and in some cases the larvae formed a significant portion of some North American warbler species diet (Otvos and Taylor 1970). It is not known if birds in the PRA area would feed on *L. fiscellaria* larvae but it is considered very likely. There has also been observed predation of larvae by ground beetles and Hemiptera (Otvos 1973), and it is likely that potential invertebrate predators of *L. fiscellaria* are also present in the PRA area.

**Table 4:** Natural enemies of *Lambdina fiscellaria* in North America and their status in the PRA area.

| Name | Taxon | Life stage Attacked | Status in PRA area | Notes | References |
|---|---|---|---|---|---|
| *Aoplus velox* | Hymenoptera | Pupae | Absent | The most abundant parasite reared from pupae of *L. fiscellaria* in Alaska. | Toregensen (1971) |
| *Apechthis ontario* | Hymenoptera | Pupae | Absent | This parasitic wasp was found infesting late pupae in the field in Alaska and may overwinter in these pupae. | Toregensen (1971) |
| *Cratichneumon ashmeadi* | Hymenoptera | Pupae | Absent | A single specimen was reared from a pupae collected in Alaska. | Toregensen (1971) |
| *Entomophthora egressa* | Fungi | Larvae | Not recorded | Otvos *et al* (1973) state that of all the natural control agents, fungi appear to be the most important. These two fungi were observed to cause severe mortality of larvae during the 1966 outbreak in Newfoundland. Observations indicated that fungal infection builds up under favourable weather conditions in two years from the time defoliation is first evidence and causes collapse of outbreaks in the second of third year. | Otvos *et al* (1973) |
| *Entomophthora sphaerosperma* | Fungi | Larvae | Present | | Natural enemy of *L. fiscellaria* - Otvos *et al* (1973)<br>Presence in Ireland - Muskett and Malone (1984) |

| | | | | | |
|---|---|---|---|---|---|
| *Heterorhabditis heliothidis* | Nematode | Larvae | Used as a biological control agent | This nematode is used as a biological control agent and does not naturally infect *L. fiscellaria* in the wild. Trials showed substantial mortality of larvae occurred under experimental conditions. This biological control agent not suitable for outdoor use in Ireland, due to the optimum temperature for activity being approximately 28°C which is warmer than average summer temperatures in the PRA area. | As a biocontrol agent: Finney and Bennet (1984)<br>Temperature limitations: Blackshaw and Newell (1987) |
| *Itoplectis quadricingulatus* | Hymenoptera | Pupae | Absent | Parasitic wasp usually associated with *Acleris gloverana* and *Neodriprion tsugae* in Alaska. | Toregensen (1971) |
| *Leidyana canadensis* | Eugregarinida | Larvae | Not recorded | A gregarine is a microscopic wormlike protozoan parasites. A species of gregarine, *Leidyana canadensis*, was isolated from *L. f. fiscellaria*. High levels were found in association with a declining population in New Brunswick, making it appear to be the agent responsible for the population crash. Gregarines are not usually considered highly pathogenic to their hosts. It is not known if gregarine species are present in the PRA area which could infect *L. fiscellaria* and help control outbreak populations – it is considered unlikely, especially as gregarines are not usually pathogenic to their hosts. | Clopton and Lucarotti (1997)<br>Lucarotti and Leclerc (1997) |
| *Mastrus laplantei* | Hymenoptera | Pupae | Absent | A single specimen was reared from a pupae collected in Alaska. | Toregensen (1971) |
| Nuclear polyhedrosis viruses | Virus | Larvae | Uncertain | In North America infection of larvae with nuclear polyhedrosis viruses have been recorded in association with the collapse of outbreaks. Inoculation experiments in order to ascertain if nuclear polyhedrosis viruses isolated from other Lepidoptera would be effective at infecting and causing mortality of *L. f. lugubrosa* and *L. f. somniaria* larvae. Viruses obtained from the tussock moth, *Orgyia pseudotsuga* and the grey forest looper, *Caripeta divisata*, were effective at infecting and killing *L. fiscellaria*. It is not known if there are nuclear polyhedrosis viruses in Ireland which could infect and kill *L. fiscellaria*. | Morris (1964) |
| *Pimpla* spp. | Hymenoptera | Pupae | Members of the *Pimpla* genus are present | In Alaska three species of the parasitoid wasp genus *Pimpla* were isolated from pupae: *P. pendalis, P. aquiliona* and *P. Hesperus*, of these three species *P. pendalis* was the most abundant. Species of *Pimpla* are recorded in Ireland, and it is not known if Irish *Pimpla* spp. would also parasitize *L. fiscellaria*, but a review of the literature does not indicate that *Pimpla* are host specific and it is considered likely. | As a parasite of *L. fiscellaria*: Toregensen (1971)<br>*Pimpla* in Ireland: O'Connor *et al* 2007 |

| | | | | | |
|---|---|---|---|---|---|
| *Telenomus* spp. | Hymenoptera | Egg | Members of the *Telenomus* genus are present | Species of the genus *Telenomus* are considered efficient egg parasitoids of defoliating Lepidoptera including *L. fiscellaria*, and are associated with good population control. Not all reports specifiy species of *Telenomus* identified parasitizing *L. fiscellaria* eggs but three known parasites are *T. coloradensis T. droozi* and *T. flavotibiae*, with *T. coloradensis* being the most significant egg parasite. These three species are not present in the PRA area. Other members of the *Telenomus* genus are, but their hosts are often unknown. It is unlikely those species native to Ireland would attack eggs of *L. fiscellaria*, as species within the *Telenomus* genus are often species of genus specific. | As a parasite:<br>Carleton *et al* (2010)<br>Hérbert *et al* (2001)<br>Pelletier and Piché (2003)<br>*Telenomus* in Ireland: O'Connor and Notton (2013) |
| *Trichogramma* spp. | Hymenoptera | Egg | Not recorded | A low rate of parasitism of eggs by *Trichogramma* spp. (3.8% of surveyed eggs) was seen during studies of egg parasites in Quebec. | Hérbert *et al* (2001) |
| *Winthemia occidentis* | Diptera | Larvae | Absent | A parasite of *L. fiscellaria* in British Columbia that was then released in Newfoundland. Usually parasitizes the forth instar larvae with adults emerging from the pupae. Considered the most important parasitoid attacking late instar larvae. | Otvos (1973)<br>Hérbert and Brodeur (2013) |

Many of the effective parasites of *L. fiscellaria* in North America are not recorded in the PRA area, and it is highly uncertain if related species will parasitize *L. fiscellaria*. In particular, egg parasites are very important in North America for the control of *L. fiscellaria*, and rate of egg parasitism is often taken into consideration when deciding to spray against outbreaks (Hartling *et al* 1999). *Telenomus* species are the main egg parasites. Though there are *Telenomus* species present in the PRA area, often their hosts are unknown (O'Connor and Notton 2013), it is highly uncertain if they could parasitise *L. fiscellaria.*

In conclusion, there appears to be a lack of suitable natural enemies in the PRA area that could control *L. fiscellaria* outbreaks. There is a risk that outbreaks may therefore be sustained for longer periods, unless other factors recorded as collapsing outbreaks in North America such as poor weather or starvation cause population crashes. However, it should be noted that the factors that lead to population crashes in North America are still not fully understood, and so it is uncertain if an absence of natural enemies of *L. fiscellaria* from the PRA area would lead to more sustained outbreaks.

*Stand Characteristics and Native Pests*

In its native range, *L. f. fiscellaria* and *L. f. lugubrosa* are most often recorded causing outbreaks in mature or over-mature forests of their preferred host species, where trees are often <100 years old (Carroll 1956; Otvos *et al* 1979; Humphreys *et al* 1992; Reeb and Shaw 2015 etc). In the PRA area, the predominate forest species is *P. sitchensis*, which is grown on a short rotation length of, on average, 30 – 50 years (Teagasc 2018). This means the majority of forest stands in the PRA area are very young and vigorous, and may therefore be less susceptible to outbreaks of *L. fiscellaria*. Outbreaks have been recorded on younger stands in North America, though these are usually in proximity to over-mature or mature stands where the outbreak initiated. Under experimental conditions *L. fiscellaria* showed a preference for egg laying on the largest and most vigorous trees (Steinbauer and Carroll 2011) – so younger vigorous stands may be infested, but potentially are less likely to be damaged or suitable for the build up of outbreak populations.

It has also been noted that outbreaks occur in stands that may be suffering from other biotic and abiotic stress factors. Though stands of *P. sitchensis* are generally younger than those stands attacked in the native range of the pest – they are subject to other stresses which may cause them to be favourable for the development of an *L. fiscellaria* outbreak. *Elatobium abietinum* (green spruce aphid) is a significant pest of *P. sitchensis* in the PRA area. This pest causes loss of old needs, and can cause very high levels of defoliation of old needles when mild winters lead to a high survival rate. However, current year needles are left untouched (Day 2002), and so trees are able to survive. If *L. fiscellaria* can adapt to using *P. sitchensis* as a primary host – it may infest stands already stressed by *E. abietinum* and cause accumulative impacts in conjunction with *E.*

*abietinum*, consuming current year needles as well as older needles and potentially causing complete defoliation of the tree.

*Spread of the pest*

As discussed in section 2.9.1, *L. fiscellaria* has a relatively low capacity for natural spread due to the poor flight capacity of the females, who are heavily burdened by eggs. This means that, under a mitigated scenario, containment of *L. fiscellaria* outbreaks is very likely to be possible – reducing the potential for impacts. The limited spread capacity of the pest also means that both the National Plant Protection Organisations of Ireland and Northern Ireland, and foresters, are likely to have time to be able to prepare for the spread of the pest into new regions, and develop monitoring techniques and control options far ahead of the pest spreading to its full extent in the PRA area, reducing economic impacts.

*Conclusion*

In an unmitigated scenario, where no measures are put in place to control *L. fiscellaria*, this pest has potential to build up damaging populations over several decades that could potentially lead to large to very large impacts in the PRA area. The lack of known natural predators of *L. fiscellaria* in the PRA area means that outbreaks have potential to be more sustained than those experienced in the native range of the pest, unless weather events, starvation or application of control methods are able to cause a population collapse. This assertion is subject to high uncertainty, as the cause of population crashes in North America is not always understood.

The rating of potential economic impacts in the PRA area needs to take into account the fact that the capacity for *L. fiscellaria* to spread after introduction is limited. Females are very poor fliers, and spread with trade was also considered to only have potential to occur slowly. This slow spread rate would provide industry and Government with time to develop monitoring and control methods well ahead of the pest reaching its maximum extent in the PRA area. In addition, there is little evidence of *L. fiscellaria* causing outbreaks in younger stands of its coniferous hosts, and the short rotation time of *P. sitchensis* may also reduce the impacts of the pest on this hosts. Accumulative impacts may occur in conjunction with other pests of *P. sitchensis*, in particular by defoliating trees that have already lost a significant portion of older needles due to the feeding activity of *E. abietinum*.

**Potential economic impacts are rated as moderate with high uncertainty**. Outbreaks of *L. fiscellaria* are cyclical in nature and would not be expected to occur in every year. The slow natural spread capacity of the pest, combined with its limited ability to spread with trade, would provide growers and policy makers with time to adapt to the presence of the pest and put into place monitoring and control programmes, which would reduce impacts. Uncertainty is high as it remains unclear if the pest could adapt to the hosts grown in the PRA area as primary hosts, e.g. *Picea sitchensis* and European species of *Acer* and

*Quercus*, and it is not known if egg hatching and bud burst would occur synchronously in the PRA area. In addition, stands of *P. sitchensis* are generally younger than those coniferous stands infested in the native range of the pest, and it is uncertain is this will affect impacts. It is also uncertain if the lack of known natural enemies of *L. fiscellaria* in the PRA area could lead to increased impacts due to longer and more sustained outbreaks, as other factors could cause population crashes.

*Economic Impacts*

| Negligible | | Very small | | Small | | Moderate | ✓ | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

### 2.12.2 Environmental impacts

*Lambdina fiscellaria*, in particular in outbreak years, may cause environmental impacts in the PRA area a) by out-competing other, native, species for food resources and b) killing trees and therefore removing them as a resource from the environment.

It is not within the scope of this rapid PRA to do a detailed analysis of the potential impacts on biodiversity outbreaks of *L. fiscellaria* could lead to. Any impacts on biodiversity would be dependent on a) the scale of outbreaks influenced by factors as discussed in section 2.12.1 and b) where in the PRA area outbreaks occur. Environmental impacts would be greater if outbreaks occur within forests that support rare or environmentally important species (such as those classed as Special Areas of Conservation in Ireland or an Area of Special Scientific Interest in Northern Ireland) compared to outbreaks within coniferous forestry monocultures. Outbreaks in ecologically sensitive woodlands could impact on both invertebrates which are outcompeted by *L. fiscellaria*, as well as potentially rare species of understory plant since at later instar stages *L. fiscellaria* become mobile and will feed on plants on the forest floor.

The main coniferous forest species that may be a host for *L. fiscellaria* grown in the PRA area are not native species, but there still may be rare species within these environments that could be threatened if trees are killed by *L. fiscellaria* outbreaks. As discussed, *L. fiscellaria* may potentially be able to infest native Irish broadleaves such as *Q. robur* and *F. excelsior.* In the current distribution of the pest, impacts on these hosts appear to be relatively small as they are able to flush out and produce new foliage the next year. *Lambdina fiscellaria* infestations may hasten the death of trees that are stressed from other factors, such as ash dieback (*Hymenoschyphus fraxineus*). There are only limited areas of native woodland in Ireland, and much of this is very fragmented with 50% of sites surveyed by the National Parks and Wildlife Service being less than 6ha (Cross 2009). A significant outbreak within native woodland could therefore have large environmental impacts on a local scale.

If the policy in the event of an outbreak was to utilise aerial applications of control products, impacts may be incurred on non-target organisms as described in section 2.11.2 for the current range of the pest, but more research is required into the long term effects of the use of Lepidoptera specific control products such as *B. thuringiensis* var *kurstaki* on non-target organisms.

It is very difficult to judge the potential environmental impacts of *L. fiscellaria* in the PRA area due to the uncertainty surrounding the pest's potential host range. Though direct environmental impacts are not reported in the pest's native range, unlike North America the PRA area does not have any major defoliating pests of woodlands. Therefore if outbreak populations of the pest occur in the PRA area, environmental impacts are very likely, in particular if *L. f. somniaria* or other subspecies cause significant defoliation in natural or semi-natural native woodlands. However, as discussed in section 2.12.1, impacts need to take into account the limited capacity of *L. fiscellaria* to spread after introduction. It is reasonable to expect that environmental impacts would occur on a local scale close to points of introduction. On this local level, significant decline of hosts could be seen and there may also be long term affects on biodiversity.

**Environmental impacts are rated as moderate with high uncertainty** – and will depend upon which hosts *L. fiscellaria* can infest in the PRA area and if outbreaks may occur in wooded areas of conservation importance. Factors that influence the high uncertainty of economic impacts as described in section 2.12.1 also influence the high uncertainty of the potential environmental impacts rating.

*Environmental Impacts*

| Negligible | | Very small | | Small | | Moderate | ✓ | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|

*Uncertainty*

| Low | | Medium | | High | ✓ |
|---|---|---|---|---|---|

## 2.12.3 Social impacts

Woodlands are used for recreation in the PRA area. Coillte, a state owned forest business, has 290 recreational sites around Ireland (Coillte 2018), many of which will include areas forested with hosts of the various subspecies of *L. fiscellaria*. A large number of forests are also publically owned in Northern Ireland, and open to the public (NIdirect government services 2018).

The defoliation of trees during outbreaks of *L. fiscellaria*, and their potential mortality, will have social impacts by a) reducing the aesthetic value of trees, b) dead trees may pose potential safety hazards, and public access may have to be limited and c) access may have to be limited to areas if control measures including felling or spraying are carried out.

If outbreaks occur in tourist locations or woodlands used for recreation, leading to dieback and mortality of trees, visitor numbers may be reduced. This could have knock-on effects for the local economy (e.g. shops, cafes etc), affecting local employment. Local residents derive a benefit from being close to forests in terms of access for recreation, but also in house prices (Tyrävinen and Miettinen2000; Pearce 2001). It should be noted that studies on this phenomenon in the PRA area could not be found, but as it has been recorded in both North America and Northern European countries it is considered very likely to also apply in the PRA area. Therefore a significant outbreak in a forest, which leads to dieback and tree mortality and potentially felling of the forest, could also cause social impacts by affecting local house prices.

There may be significant island-wide public concern if native broadleaved species, such as *Quercus* and *Fraxinus*, are infested by the pest. *Fraxinus* is already endangered in the PRA area by ash dieback disease (*Hymenoschyphus fraxineus*) – and *Fraxinus* is a culturally important tree on the island with its wood traditionally used in the production of hurls (McCracken *et al* 2017).

Outbreaks of *L. f. somniaria* have been recorded on *Q. garryana* in residential areas in North America, and therefore potentially *L. fiscellaria* could become a pest on amenity trees in residential areas in the PRA area where suitable hosts are grown. Amenity trees and public green spaces in urban/residential areas provide many social benefits, including improved air quality (Beckett *et al* 1998), reducing surface water runoff (Armson 2013) and increased property prices (McCord *et al* 2004) as well as generally having a benefit on physical and mental health (Tyrävinen *et al* 2005). Outbreaks in residential or urban areas on amenity trees could reduce these benefits they provide, in particular when trees are killed. However it should be noted it is highly uncertain how often outbreaks may occur in such situations, as they are not widely recorded occurring often in North America and may be a relatively rare occurrence.

Outbreaks of *L. fiscellaria* may lead to closure or loss of areas currently used for recreation if measures such as clear felling are necessary to control the pest, or if areas of forests are killed by the pest and it is necessary to salvage the timber. In an unmitigated scenario, over many decades where no control measures are put in place against the pest, potential social impacts are large with high uncertainty. However, the limited natural spread capacity of the pest and the potential to contain outbreaks needs to be taken into account in the rating – as discussed in economic and environmental impacts, it is likely that the majority of social impacts would be limited to the local area close to where the pest is introduced. Permanent changes to human activities (e.g. due to the closure of woodlands) etc would be expected on a very local level, and it is likely that outbreaks of the pest would attract island-wide attention and concern. **Potential social impacts are moderate with high uncertainty**. It is unclear how often outbreaks of *L. fiscellaria* may occur in urban or residential areas. Factors that influence the high uncertainty of economic impacts as described in section 2.12.1, including the fact that it is uncertain what the host range of *L. fiscellaria* may be in the PRA area, also influence the high uncertainty of the potential social impacts rating.

*Social Impacts*

| Negligible | | Very small | | Small | | Moderate | | Large | | Very large | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ✓ | | | | |

*Uncertainty*

| Low | | Medium | | High | |
|---|---|---|---|---|---|
| | | | | | ✓ |

## 2.13 What is the area endangered by the pest?

All coniferous forestry stands and potentially some broadleaved stands (especially those with a high percentage of *Acer* or *Quercus*) in the PRA area are endangered by the pest.

# Stage 3: Pest Risk Management

## *3.1 What are the risk management options for the PRA area?*

### 3.1.1 Exclusion

Exclusion is the best risk management strategy for this pest. Currently, phytosanitary measures designed against other North American pests are also mitigating against the risk of entry of *L. fiscellaria* on several pathways. Additional measures could be considered in order to further reduce risk.

As this pest poses a threat not only to the PRA area but potentially forestry across the EU, listing in Annex IAI of the plant health directive could be considered. Additional phytosanitary measures could then be included on key hosts of *L. fiscellaria* in Annex IVAI of the plant health directive, though due to the very wide host range of *L. fiscellaria* during outbreak years it may be difficult to analyse to which species measures should be applied.

At a minimum, this PRA recommends that plants of *Acer, Betula, Fraxinus, Juniperus, Quercus, Thuja* from countries where the pest is known to occur be sourced from an official pest free place of production, and be accompanied by a phytosanitary certificate stating that no signs of the pest have been seen at the place of production or in the immediate vicinity during the last complete cycle of vegetation. In addition, the named host plants imported from countries where the pest is known to occur could be imported from an official pest free area. The hosts chosen for regulation are based on the fact that either a) the young larvae have been successfully reared on the hosts or b) outbreaks have been recorded on the hosts. Regulations are not required on some hosts as they are already prohibited from import from the range of the pest.

Phytosanitary measures may also be technically justified on the import of lichens and mosses from the range of the pest, since these can act as a pathway of entry for pupae and egg masses. Suggested measures include a pest free area – but other phytosanitary treatments such as fumigation with a suitable product may also be effective at eliminating the pest.

It is difficult to identify measures on wood as eggs masses may be made, pupation of the pest could occur, on a very wide range of species. As mentioned there are already general requirements on wood of various species from North America. Potentially, a recommendation could be introduced that covers all wood species from North America, though this may be difficult to technically justify. Debarking of wood would mitigate against the risk of pupae and egg masses being associated, fumigation and heat treatment are also potential phytosanitary measures that could be considered.

### 3.1.2 Eradication and containment

Eradication of outbreaks in the wider environment may be feasible if the pest is detected early. In the event of a finding of *L. fiscellaria* in the wider environment, a delimitating survey should be carried out to assess the extent of the outbreak. The nature of the survey will depend on the life stage detected: adults and larvae are the most likely stage to be detected. Pheromone traps can be used to attract adults, visual surveys would be necessary for larvae and this may be difficult in dense forestry stands. Measures in this section relating to eradication and containment are based on the biology of the pest.

Action to eradicate the pest will depend upon which life stage is detected. Aerial spraying with Lepidoptera specific pesticides such as *B. thuringiensis* var. *kurstaki* is usually carried out in North America when hatching is complete whilst first instar larvae are feeding on the new foliage (Hérbert and Brodeur 2013). At this stage the pest is relatively inconspicuous, and unlikely to be detected. At any larval stage, aerial spraying alone is unlikely to achieve eradication of the pest.

If later instar larvae are detected, felling of infested trees is the most likely way to ensure eradication. Trees will need to be destroyed by chipping or incineration to ensure the destruction of pest. The area to be destroyed will be based on the findings of the delimitating survey, and the area of the outbreak, and surrounding areas, would need to be carefully monitored using pheromone traps and other surveillance techniques for a period of at least two years to make sure eradication was successful. In this time period, there should be control of movement of host plants for planting and timber from the infested area and a buffer zone of appropriate diameter – as females are poor fliers, a buffer zone of no more than 500 metres should be sufficient.

Detection of low levels of adults, in particular adult males, may necessitate waiting until the next spring/summer before action can be taken. This is due to the fact that adults, especially adult males, may have flown some distance away from their hatching sites. Signs of larval infestation can be surveyed for the following year, by beating trees. In the autumn light and pheromone traps can be deployed at forested sites to monitor for adults.

Where an infested site is identified by the presence of multiple adult males and females, sanitation felling without replanting is recommended. Hérbert and Jobin (2001) state that though eggs laid in the forest duff or on stumps may hatch the following year – larvae will likely starve without access to high quality food. Again, control of the movement of plants and timber and monitoring using appropriate phremone or light traps should continue in the infested area and a buffer zone for at least two years to ensure eradication has been successful.

As adult moths have limited flight capacity, containment of an outbreak of *L. fiscellaria* is feasible. Once a delimitating survey has established the size of an outbreak area, an appropriate buffer zone would need to be designated. Movement of commodities outside of the outbreak area and buffer zone that could transport *L. fiscellaria* should be controlled. Plants for planting should be subject to official inspections for signs of the pest before being moved out of the area. Timber should be harvested in the time period between egg laying and egg hatch, roughly November to March. Any harvested timber should then be treated in a manner that will remove the risk of the pest being associated. Such treatments could include:

- Debarking of wood and appropriate destruction or treatment of the bark
- Kiln drying to less than 20% moisture content
- Heat treatment to achieve a temperature of 56°C throughout the profile of the wood for at least 30 minutes
- Fumigation with an appropriate chemical substance

There should be regular monitoring for the pest within the buffer zone and a second, larger, surveillance zone using pheromone traps and light trapping.

### 3.1.3 Non-statutory controls

In outbreak years defoliation may only be detected in the last two to three weeks of feeding, which is usually too late for the application of control methods. Outbreak years can be detected in the year prior by ground surveys during the winter months to monitor egg levels, or may be indicated by a large number of adult moths being present during the autumn months (Thomsen 1957). Early detection is critical to management of *L. fiscellaria* outbreaks (Hudak *et al* 1996). Several methods have been developed to help monitor *L. fiscellaria* populations.

Egg sampling is a common method. Shore (1990) surveyed eggs on felled trees and found them to be distributed relatively evenly from the base to the crown of the tree. The findings of Liang *et al* (1996) agreed with Shore (1990) that eggs are distributed evenly across the trunk of the tree, and that accurate egg sampling can be carried out without the need to fell trees. Some species of *Telenomus* may not attack eggs of *L. fiscellaria* until spring, and so if rate of egg parasitism is to be used as a deciding factor in taking action this needs to be taken into account in surveys (Hartling *et al* 1999).

If egg sampling indicates the potential for an outbreak year, use of aerial sprays timed for egg hatch may therefore be justified.

Otvos (1974) used burlap sacks wrapped around tree trunks to catch pupae and estimated this method caught about 20% of the pupae occurring on the tree.

The use of biological control agents against *L. fiscellaria* in Canada has been summarised by Hérbert and Brodeur (2013). During outbreak years the primary product used against *L. fiscellaria* is the biological insecticide *Bacillus thuringiensis* serovar. *kurstaki.* Chemical control options used against *L. fiscellaria* in the past in North America include two sprays of fenitrothion (West *et al* 1989), as well as use of other chemical agents such as DDT which are now prohibited due to their harmful environmental effects.

Treatments need to be carried out before larvae complete their second instar in order to be successful at eliminating the pest and preventing defoliation (West *et al* 1989) Parasitism of eggs by *Telenomus* spp. plays a major role in population dynamics, in Canada populations of these parasites are monitored to aid in decision making in the use of control agents. The use of these parasites as part of a biological control programme, by mass release, has been proposed (Hérbert and Brodeur 2013).

Otvos *et al.* (1973) proposed artificially introducing *Entomophthora* fungi into an outbreak area, and were able to demonstrate effectiveness of this method by releasing larvae that had been artificially infected. It appears that release of the fungi has not been used in any official control programmes.

Widespread use of *Bacillus thuringiensis* serovar. *kurstaki* may not be suitable in the PRA area due to its affects on other non-target Lepidoptera. **A specific cost-benefit analysis including potential environmental impacts would be required to assess the potential use of the biocontrol agent, which is not within the scope of this PRA**. Some studies in North America have shown, however, that the decision not to spray against forest defoliators could be as bad or worse for non-target Lepidoptera, as severe defoliation by a single pest (in this case *Lymantria dispar*) reduces the quality of the host for all other species (Scriber 2004).

Impacts may also be reduced by changing the composition of stands. In North American outbreaks, even aged stands suffered considerably high mortality than all aged stands (Warren 1996) – though more research is required to establish if continuous cover forest model would reduce potential impacts of *L. fiscellaria.*

# Conclusion and Summary

## 4.1 Is statutory action against the pest technically justified?

All of the subspecies of *L. fiscellaria* are highly destructive defoliators in North America, with potential to cause impacts in the PRA area as well as other EU Member States. Statutory action against interceptions and outbreaks of the pest is technically justified.

## 4.2 Is a more detailed PRA required?

It is recommended that *Lambdina fiscellaria* is subject to a PRA at EU or EPPO level, to further investigate the risk to the EU and EPPO region as a whole and identify appropriate risk management measures for the EU.

## *4.3 What are the key uncertainties or areas that could benefit from additional research?*

The risk of introduction of the pest along the mosses and lichens pathway should be considered in more detail. It should be noted that mosses and lichens harvested from the Pacific Northwest may be associated with additional species that are a pest risk to *Picea sitchensis,* which is native to this region. For example, *Pissodes strobi* is one of the most economically important pests of Sitka spruce in North America. This pest usually overwinters in the leaf litter, but in regions with mild winters may be found overwintering on boles or branches of *P. sitchensis* (van der Sar 1977). The pest could inadvertently be harvested with mosses and lichens. This would be similar to a recent case of the balsam fir sawfly, which was found on cut branches of non-host plants collected from the forest understory. Therefore, a full pathway risk analysis of mosses and lichens imported from North America is recommended. In order to complete this commodity PRA, more information is also needed concerning the final use of fresh mosses and lichens that are being imported into the EU. This data could also reduce uncertainty regarding the risk of entry of *L. fiscellaria* on this pathway.

More research is required to ascertain if egg hatch of *L. fiscellaria* would occur in the PRA in synchrony with bid burst of suitable host species, and if climatic conditions on the PRA area are conducive to the build up of outbreak populations. Data on the host status and susceptibility of potential hosts in the PRA area – including European species of *Abies, Acer, Betula, Fraxinus, Picea* and *Quercus* is also required. Host range trials to ascertain the ability of first instar larvae to survive on fresh flushed foliage of potential European hosts could be considered to reduce uncertainty.

Additional data on the dispersal capacity of *L. fiscellaria* adults and first instar larvae are required. Females are described as sluggish fliers and it is uncertain how far they are able to fly, it appears they are able to fly greater distances once some of their egg burden has been reduced. It is also known that first instar larvae have some capacity for spread. This would help reduce uncertainty regarding the ability of the pest to transfer from pathways such as wood, cut foliage and mosses and lichens.

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# Annex I – Detailed Trade Statistics

**Table 5** – imports of plants for planting under various commodity codes from Canada and the USA into Ireland and the UK. The commodity codes considered will include a) species that are not known to be hosts of *L. fiscellaria* and b) imports from areas where *L. fiscellaria* is not known to occur. It is not known what proportion of imports into the UK were destined for Northern Ireland.

| Commodity | Exporting Country | IE | UK |
|---|---|---|---|
| Trees, shrubs and bushes, grafted or not, of kinds which bear edible fruit or nuts (excl. with bare roots, citrus and vine slips). | Canada | | >100kg |
| | USA | | |
| Trees, shrubs and bushes, grafted or not, of kinds which bear edible fruit or nuts (excl. vine slips) | Canada | <100 kg | ≈4.4 tonnes |
| | USA | <100 kg | |
| Live forest trees | Canada | | |
| | USA | | ≈500 kg |
| Outdoor rooted cuttings and young plants of trees, shrubs and bushes (excl. fruit, nut and forest trees) | Canada | | <200 kg |
| | USA | ≈300 kg | ≈ 60 tonnes |
| Outdoor trees, shrubs and bushes, incl. their roots (excl. with bare roots, cuttings, slips, young plants, conifers, evergreens and fruit, nut and forest trees) | Canada | | ≈400 kg |
| | USA | <100kg | |
| Outdoor trees, shrubs and bushes, incl. their roots (excl. cuttings, slips and young plants, and fruit, nut and forest trees) | Canada | | |
| | USA | <100kg | |
| Live outdoor plants, incl. their roots (excl. bulbs, tuberous roots, corms, crowns and rhizomes, incl. chicory plants and roots, unrooted cuttings, slips, Rhododendrons, azaleas, roses, mushroom spawn, pineapple plants, vegetable and strawberry plants, trees shrubs and bushes) | Canada | | <100 kg |
| | USA | <500kg | ≈1.8 tonnes |

**Table 6**: Import of various wood commodities from Canada and the USA into Ireland and the UK, which *L. fiscellaria* pupae or egg masses may be associated with. It should be noted that all of these commodity codes will include a) timber from species of tree not infested by *L. fiscellaria*, b) timber originating from areas where *L. fiscellaria* is not known to occur and c) timber that may have been treated in a manner that removes the risk of *L. fiscellaria* being associated (e.g. debarked timber, heat treated timber).

| Commodity | Exporting Country | IE | UK |
|---|---|---|---|
| Fuel wood in logs, billets, twigs, faggots or similar forms | Canada | | ≈100 kg |
| | USA | ≈100-200 kg | ≈120 tonnes |
| Fuel wood in logs, billets, twigs, faggots or similar forms (coniferous) | Canada | | |
| | USA | | ≈13 tonnes |
| Fuel wood in logs, billets, twigs, faggots or similar forms (non-coniferous) | Canada | | ≈700 kg |
| | USA | | ≈28 tonnes |
| Wood waste and scrap, not agglomerated (excl. sawdust) | Canada | | ≈700 kg |
| | USA | < 200kg | ≈1045 tonnes |
| Coniferous wood in the rough, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; rough-cut wood for walking sticks, umbrellas, tool shafts and the life; railway sleepers; wood cut into boards or beams etc; and wood of the species *Picea abies*, *Abies alba* and *Pinus sylvestris*) | Canada | ≈178 tonnes | ≈514 tonnes |
| | USA | ≈405 tonnes | ≈27 tonnes |
| Fir "*Abies* spp." and spruce "*Picea* spp." in the rough, of which any cross-sectional dimension is >15 cm, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; wood in the form of railway sleepers; wood cut into beams, etc.; wood treated with paint, stains or creosote or other preservatives) | Canada | | |
| | USA | <100kg | |
| Oak "*Quercus* spp." in the rough, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; rough-cut wood for walking sticks, umbrellas, tool shafts and the life; wood in the form of railway sleepers; wood cut into boards or beams, etc.; wood treated with paint, stains creosote or other preservatives.) | Canada | ≈26 tonnes | ≈213 tonnes |
| | USA | ≈ 441 tonnes | ≈1404 tonnes |
| Poplar in the rough, whether or not stripped of bark or sapwood, or roughly squared (excl. rough-cut wood for walking sticks, umbrellas, tool shafts and the life; wood cut into boards or beams, etc.; wood treated with paint, stains, creosote or other preservatives) | Canada | | |
| | USA | ≈ 117 tonnes | ≈119 tonnes |

| | | | |
|---|---|---|---|
| Birch, in the rough, whether or not stripped of bark or sapwood, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; rough-cut wood for walking sticks, umbrellas, tool shafts and the like; wood cut into boards or beams, etc.; wood treated with paint, stains, creosote or other preservatives) | Canada | | |
| | USA | | ≈500 kg |
| Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared (excl. rough cut wood for walking sticks, umbrellas, tool shafts and the like; wood cut into boards or beams, etc.; wood treated with paint, stains, creosote or other preservatives, tropical wood and coniferous wood, oak, poplar, Eucalyptus and birch wood) | Canada | | ≈2872 tonnes |
| | USA | ≈81 tonnes | ≈1261 tonnes |
| Railway or tramway sleepers "cross-ties" of wood, not impregnated. | Canada | ≈1041 tonnes | ≈5203 tonnes |
| | USA | | |
| Railway or tramway sleepers "cross-ties" of wood, not impregnated, coniferous | Canada | | ≈208 tonnes |
| | USA | | |
| Railway or tramway sleepers "cross-ties" of wood, not impregnated, non-coniferous | Canada | ≈1556 tonnes | |
| | USA | ≈2088 tonnes | |
| Railway or tramway sleepers "cross-ties" of wood, impregnated, coniferous | Canada | | ≈6 tonnes |
| | USA | | ≈5 tonnes |
| Sawlogs of spruce of the species "*Picea abies* Karst." or silver fir "*Abies alba* Mill.", whether or not stripped of bark or sapwood, or roughly squared. | Canada | | |
| | USA | | ≈500 kg |
| Fir "*Abies* spp." and spruce "*Picea* spp." in the rough, of which any cross-sectional dimension is >15 cm, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; wood in the form of railway sleepers; wood cut into beams, etc.; wood treated with paint, stains, creosote or other preservatives) | Canada | | |
| | USA | | <100kg |
| Sawlogs of oak "*Quercus* spp.", whether or not stripped of bark or sapwood, or roughly squared. | Canada | | |
| | USA | ≈91 tonnes | |
| Birch, in the rough, whether or not stripped of bark or sapwood, or roughly squared (excl. sawlogs; rough-cut wood for walking sticks, umbrella, tool shafts and the like; wood cut into boards or beams, etc.; wood treated with pain, stains, creosote or other preservatives | Canada | | |
| | USA | | ≈500kg |

# Annex II – Phytosanitary Requirements on Wood from North America

**Table 7**: Phytosanitary treatments against various species of wood originating from Canada and the USA as laid down in the Plant Health Direction 2000/29/EC, and their effectiveness at eliminating *L. fiscellaria* from being associated with the commodity.

| Commodity | Requirements | Effectiveness |
|---|---|---|
| Wood of *Acer saccharum* (excluding wood in the form of chips, particles, sawdust, shavings, wood waste and scrap) | Kiln drying to below 20% moisture content, expressed as a percentage of dry matter | This treatment should be effective at killing any associated *L. fiscellaria* eggs or pupae. |
| Wood of *Fraxinus, Juglans ailantifolia, J. mandshurica, Ulmus davidiana, Pterocarya rhoifolia* (excluding wood in the form of chips, particles, sawdust, shavings, wood waste and scrap) | a) the wood originates in an area recognised as being free from *Agrilus planipennis* OR<br>b) the bark and at least 2.5 cm of the outer sapwood are removed OR<br>c) the wood has undergone ionizing radiation to achieve a minimum absorbed dose of 1kGy throughout the wood | Options b and c should be effective at removing any associated *L. fiscellaria* eggs or pupae. There are regions that are recognised as officially pest free for *A. planipennis* but where *L. fiscellaria* is still present, and so timber of these species imported under option a may not be free of *L. fiscellaria* |
| Wood of *Betula* (excluding wood in the form of chips, particles, sawdust, shavings, wood waste and scrap) | a) the bark and at least 2.5 cm of the outer sapwood are removed<br>b) the wood has undergone ionizing radiation to achieve a minimum absorbed dose of 1kGy throughout the wood | This treatment should be effective at killing any associated *L. fiscellaria* eggs or pupae. |
| Wood of *Platanus* (excluding wood in the form | Kiln drying to below 20% moisture content, | This treatment should be effective at killing any |

| | | |
|---|---|---|
| of chips, particles, sawdust, shavings, wood waste and scrap) | expressed as a percentage of dry matter | associated *L. fiscellaria* eggs or pupae. |
| Wood of *Populus* (excluding wood in the form of chips, particles, sawdust, shavings, wood waste and scrap) | Wood should be bark free OR kiln dried to below 20% moisture content, expressed as a percentage of dry matter | Both treatment options should be effective at killing any associated *L. fiscellaria* eggs or pupae. |
| Wood of *Fraxinus, Juglans ailantifolia, J. mandshurica, Ulmus davidiana, Pterocarya rhoifolia* in the form of chips, particles, sawdust, shavings, wood waste and scrap | Official statement that the wood originates in an area recognised as being free from *Agrilus plannipennis* | There are regions that are recognised as officially pest free for *A. planipennis* but where *L. fiscellaria* is still present, and so wood of these species still carry a risk of being associated with *L. fiscellaria*. |
| Wood of *Betula* in the form of chips, particles, sawdust, shavings, wood waste and scrap | Must originate in a country known to be free of *Agrilus anxius* | *Agrilus anxius* is present in both the Canada and USA, and therefore this commodity cannot be imported from the range of *L. fiscellaria* |
| Wood of *Acer saccharum* and *Populus* in the form of chips, particles, sawdust, shavings, wood waste and scrap | Either the wood must:<br>a) have been produced from debarked round wood OR<br>b) undergone kiln drying to below 20% moisture content, expressed as a percentage of dry matter OR<br>c) undergone appropriate fumigation OR<br>d) undergone appropriate heat treatment to achieve a minimum temperature of 56°C for a 30 continuous minutes throughout the profile of the wood | All treatments will reduce the risk of *L. fiscellaria* being associated with the commodity |
| Wood of *Platanus* in the | The wood must either: | All treatments will reduce the |

| | | |
|---|---|---|
| form of chips, particles, sawdust, shavings, wood waste and scrap | a) undergone kiln drying to below 20% moisture content, expressed as a percentage of dry matter OR<br><br>b) undergone appropriate fumigation OR<br><br>c) undergone appropriate heat treatment to achieve a minimum temperature of 56°C for a 30 continuous minutes throughout the profile of the wood | risk of *L. fiscellaria* being associated with the commodity |