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ST XX.

Risks associated with the introduction of exotic lymantriid species (Lepidoptera: Erebidae: Lymantriinae) of potential concern to the NAPPO region

Prepared by members of the NAPPO Lymantriid Expert Group
Dave Holden, (CFIA), Thierry Poiré (CFIA), Glenn Fowler (APHIS-PPQ), Gericke Cook (APHIS-VS), Daniel Bravo (SENASICA), Norma Patricia Miranda (SEMARNAT), María Eugenia Guerrero (SEMARNAT), Eduardo Jiménez Quiroz (SEMARNAT), Gustavo Hernández (SEMARNAT), Clemente de Jesús García Ávila (SENASICA), Manuel Jiménez (SENASICA) and Oscar Trejo (SEMARNAT).

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1.0 Scope and Purpose

The subfamily Lymantriinae, also commonly referred to as tussock moths, but hereafter referred to as lymantriids, is a very important group of insect defoliators of forest and agricultural plant species throughout the world. Increases in global trade coupled with the diversity of lymantriids and the breadth of potential hosts make the risk of introduction and spread of some lymantriid species high in the NAPPO region. The economic impact of establishment of some lymantriid species in the NAPPO region (e.g., the Asian gypsy moth (AGM) *Lymantria dispar asiatica*) could be significant.

AGM is a quarantine significant pest in all three NAPPO member countries. Potential pathways for introduction of AGM include cargo shipments from marine vessels and other types of conveyances normally associated with international trade. NAPPO has developed a regional standard (RSPM 33 – *Guidelines for regulating the movement of ships and cargo from areas infested with the Asian gypsy moth*) to help reduce the risk of introducing AGM by certifying marine vessels moving commodities from regulated countries to the NAPPO region during the specified risk periods (SRP)[1].

However, the interception of egg masses of other lymandtriids (*Lymantria mathura*, *L. xylina* and *L. lucescens)* in Canada and the United States (U.S.) on vessels from Asia clearly illustrates a potential additional threat and the need for NAPPO to examine the potential for introduction of other lymantriid species into the NAPPO region. This study will assemble data on other economically important lymantriid species that can be used to support regulatory agencies as they develop programs and guidelines aimed at reducing the risk of introduction of lymantriid species of economic importance into the NAPPO region. The results of this study will also provide necessary information for future amendments to RSPM 33.

The objectives of this project are to support regulatory decisions by NAPPO member countries by:

1. providing a general perspective concerning exotic lymantriid species with the highest risk of introduction and potential impact to the NAPPO region arriving via international trade or other introduction pathways;
2. developing a risk assessment methodology that can be used to quickly screen large numbers of lymantriid species and efficiently characterize the pest risk posed by these species;
3. identifying and ranking lymantriid species based on their likelihood of introduction, spread and potential economic and/or environmental impact.

2.0 Taxonomy and Systematics

To date there has been no worldwide revision of the lymantriids. Most of the taxonomic and systematic development has been through regional faunal inventories, for example, the *Moths of North America* and the *Moths of Borneo* (Holloway 1999; Ferguson, 1978; Pogue and Schaefer, 2007). More recently, phylogenetic studies have re-classified the family Lymantriidae as the subfamily Lymantriinae of the recently created family Erebidae (Zahiri *et al.,* 2010; Zahiri *et al.,* 2012), and there have been worldwide generic revisions of *Calliteara* (Witt and Trofimova 2016) and *Lymantria* (Schintlmeister, 2004).

[1] Specified risk period defined as the time in each regulated area when there is a high risk of moth flight and egg mass deposition on marine vessels.

2.1 Number of Species and their Distribution

Lymantriids are an important group within the Erebidae family with species found in all continents except Antarctica. Most of the species diversity occurs in the tropical areas of Africa, India and Southeast Asia. Lymantriid species diversity in Madagascar is high, with 258 species registered, many of which are endemic (Griveaud, 1977). Lymantriids are noticeably absent in islands in New Zealand, the Antilles, Hawaii, and most of the South Pacific islands except for Fiji, New Caledonia and other islands in the Southeast (Ferguson, 1978; Holloway, 1979 and Schaefer,1989).

Heppner (1991) suggested dividing the 2416 species of the formerly Lymantriidae family according to the regions were they are present, classifying them as follows: Afrotropical (1004), Oriental east to Moluccas (742), Australian including New Guinea and islands to the East (255), Paleartic (203), Neotropical (180) and Nearctic (32).

As a result of several studies on regional fauna performed from the 1950´s to the beginning of the 1980´s, which have helped illustrate the abundance or scarcity of lymantriid in some areas, a tentative catalogue of lymantriid species including about 355 genera and 3065 known species (Schaefer, 1989) has been developed. Genera with 20 or more species is considered a "main genera". In this catalog, 21 genera have 2159 species, or over 70% of the overall known species (Schaefer, 1989).

3.0 Characteristics and Biology of Lymantriids

Lymantriids are characterized by the presence of tufts along the back of the larvae. Adults typically have cryptic coloration, which provides good camouflage for blending with the tree bark, lichens, or leaves where they are typically resting. Adults are dimorphic in most lymantriid species with males normally smaller and darker than females and with very prominent bi-pectinate antennae. Adults of many species are monochromatic (white or yellow tone). Lymantriid larvae are usually very colorful, with a large group of setae forming tufts. Some of them (for example, many species of the genus *Euproctis*) have urticating hairs which may cause serious allergic reactions if they come in contact with human skin. Larvae also have two medio-dorsal glands on abdominal segments 6 and 7. These glands are usually bright and colorful with red, orange or yellow tones. It is believed that the glands are used as a defense mechanism (Schaefer, 1989).

There are numerous examples of pest species within the lymantriid group, e.g., Gypsy moth (*Lymantria dispar*), brown tail moth (*Euproctis chrysorrhea*), painted apple moth (*Orgyia anartoides*) and nun moth (*Lymantria monacha*). These pest species have a high fecundity, producing large numbers of offspring in a generation. The ability of females from some species to fly, egg masses being transported long distances using different pathways, e.g., by deposition on ships or cargo, and the capacity of 1st instar larvae to spread long distances using the wind (ballooning), results in spread to new areas. Some lymantriid species undergo cyclical outbreaks with large-scale defoliation of their host plants. Outbreaks have also been associated with a high incidence of dermatitis and other skin conditions due to the urtricating nature of the larval setae.

Lymantriid larvae are highly polyphagous and many species within this subfamily are pests of agricultural and forest species. Adults do not feed and as such have a short lifespan of a few weeks. Some species have wingless females. In most species the females have a silk tuft on the posterior end of the abdomen used to cover and protect egg masses. Most species are nocturnal, univoltine and many are attracted to light (Grundy and Lowe, 2010; Herbison-Evans and Crossley, 2017; Waring and Townsend, 2017).

4.0 Hosts of Economic and Environmental Concern

Lymantriids are some of the world's most destructive forest pests (Pogue and Schaefer, 2007). They can also cause severe damage to agriculture and in urban settings. Their host plants are better known in temperate regions of the Northern Hemisphere. In tropical areas, where there is a high diversity of plant species, feeding habits are not well documented. However, in general terms, forest and shade trees serve as the main source of food. Shrubs, grapevines, herbs and grasses are less important. At least two species feed on lichens and one is known to feed on mistletoe (Schaefer, 1989).

Species within the genus Lymantria alone are known to feed on over 150 primary hosts, mainly forest species such as: alder (*Alnus* spp.), poplar (*Populus* spp.), birch (*Betula* spp), willow (*Salix* spp.), hawthorn (*Crataegus* spp.), larch (*Larix* spp.), tilia (*Tilia* spp.) and oak (*Quercus* spp.). Last instar larvae prefer species such as pine (*Pinus* spp.), beech (*Fagus* spp.), juniper (*Juniperus* spp.), chestnut (*Castanea* spp.) and *Tsuga* spp, among others.

In addition to the forest species mentioned above, they can feed on other species of agricultural concern, such as: plum (*Prunus domestica*), peach (*Prunus persica*), almond (*Prunus* spp.), apple (*Malus domestica*) and pistachio (*Pistacia vera*) (Fact sheet No. 65, May 2019. SADER-SENASICA, Mexico).

5.0 Regulatory and phytosanitary framework

NAPPO develops science-based regional standards which are intended to protect agricultural, forest and other plant resources of North America against regulated plant pests, while also facilitating safe trade. NAPPO's Regional Standard for Phytosanitary Measures 33 (RSPM 33) provides member countries with guidelines to minimize the entry and establishment of the Asian Gypsy Moth (AGM) in North America. RSPM 33 describes risk management options for ships leaving ports from AGM regulated countries during the specified risk periods (SRP). It also describes the necessary measures for ships coming from infested areas or in-transit in regulated countries during the SRPs and destined to North America.

NAPPO countries have established regulatory measures and directives to minimize the risk of introduction of lymantriid species, especially the Asian gypsy moth, via vessels or high-risk commodities like wood.

5.1 Canada

Lymantriid species listed in the Canadian Food Inspection Agency (CFIA) "Regulated Pest" list include *Euproctis chrysorrhoea*, *Lymantria albescens*, *Lymantria dispar*, *Lymantria dispar asiatica*, *Lymantria dispar japonica*, *Lymantria mathura*, *Lymantria monacha*, *Lymantria postalba*, *Lymantria umbrosa* and *Orgyia anartoides*.

More specifically, two policy directives have been adopted by CFIA to prevent the introduction and spread of gypsy moth. Directive D-95-03 describes regulatory measures to prevent the entry of the Asian strains of gypsy moth (*Lymantria dispar*, *L. albescens*, *L. postalba* and *L. umbrosa*) on vessels and their establishment in Canada. Domestically, directive D-98-09 lists the requirements for the movement within Canada, export from Canada to the United States and import from U.S. of regulated articles which may harbor any life stage of the European strain of gypsy moth. Regulated articles under this directive include nursery stock, Christmas trees, forestry products with bark attached, all outdoor household articles, military, recreational and personal vehicles and equipment. Additionally, many other policy directives, for instance directive D-01-12 on importation and movement of firewood, contain requirements aimed at preventing the introduction and spread of quarantine pests, including gypsy moth.

5.2 United States

In the United States, the genus *Lymantria* along with the species *L. dispar*, *L. mathura*, *L. monacha*, and *L. xyilina* are considered actionable pests at U.S. ports of entry (PestID, 2018). In addition, the United States maintains a domestic quarantine for gypsy moth infested states (7 CFR § 301.45, 2018). This quarantine regulates the movement of commodities likely to move gypsy moth life stages, e.g. logs, mobile homes, and Christmas trees, from infested to un-infested areas.

The United States also regulates at-risk articles from areas in Canada infested with gypsy moth (7 CFR § 319.77, 2018; 7 CFR § 330.301, 2018; USDA, 2017, 2018). Gypsy moth host material from Canada is regulated under 7 CFR § 319.77 and at-risk Canadian stone and quarry products are regulated under 7 CFR § 330.301.

5.3 Mexico

Mexico has Official Regulations (NOMs), through which phytosanitary requirements are established to comply with the importation of some forestry products. NOMs provide a list of regulated pests for those commodities that are of quarantine concern. European and Asiatic strains, *Lymantria dispar*, *L. dispar asiatica* and *L. dispar japonica*, are the only lymantriid species named in the NOMs. These regulations are listed below.

Mexican Official Regulation NOM-013-SEMARNAT-2010 regulates the importation of natural Christmas trees belonging to the genera *Pinus* and *Abies* and the species *Pseudotsuga menziesii*.

Mexican Official Regulation NOM-016-SEMARNAT-2013 regulates the importation of new sawn wood, and "the Agreement to determine the list of invasive exotic species for Mexico," published at the Federal Official Gazette on December 7, 2016 lists *Orgyia pseudotsugata* and *Lymantria dispar* as two exotic lymantriid species of concern for Mexico.

In Mexico, the family Erebidae, subfamily Lymantriinae is not widely studied in terms of species diversity, biology and habits, therefore little is known about the species diversity in Mexico.

6.0 Likelihood of introduction and spread of lymantriid species in the NAPPO Region. Information needs and gaps.

The likelihood of introduction of lymantriids into the NAPPO region is high due to the high volume of shipping containers and vessels moving from regulated countries to the NAPPO region, movement of other commodities, and the large number of host species in the NAPPO region.

There is evidence that lymantriids have been introduced into the NAPPO region and have become economically important pests. For example, gypsy moth *Lymantria dispar* (L.), was intentionally introduced into Massachusetts, in the United States in the late 1860s from Europe for silk production (Liebhold *et al*., 1989). Since that time, it has become widely distributed (Ref. CABI 2020) and has caused widespread damage to forest trees. *Euproctis chrysorrhoea* (L.), another serious pest of forest and shade trees in North America, was accidentally introduced into Massachusetts in 1897 from Europe. It was first detected in the Boston, Massachusetts area at the beginning of 1890, and since then has spread to parts of the Eastern United States and Canada (Triplehorn and Johnson, 2005) (CABI 2020).

All life stages of Asian gypsy moth (egg masses, larvae, pupae, and adults) and other lymantriid species (*Lymantria mathura, Leucoma salicis* and *Lymantria xylina* among others), have been intercepted in the NAPPO region primarily during maritime port inspections of ships and shipping containers from Asia (Russia, Japan, China, Philippines and Korea) and Europe. Interceptions of *Lymantria dispar* in Canada have also been reported on Christmas trees, propagative plant material and grain from the U.S. To a lesser extent, egg masses and pupal cases have been intercepted on/in passenger baggage at airport inspection points in the United States and Canada AQAS, 2019). Other pathways based on inspection data include movement of military and agricultural equipment, cut flowers, nursery stock, wood (wood packaging) and personal effects from countries where regulated species of lymantriids are found. Other less-documented pathways include e-commerce, smuggling, and other intentional or non-intentional movement of human-derived activities. The large number of interceptions reported in maritime vessels and shipping containers suggests that this is the most important pathway for entry into the NAPPO region.

The economic and environmental impact of the introduction and spread of lymantriid species into the NAPPO region could be significant due to the large number of potentially affected host species and suitable climatological conditions found in North America. A simple, efficient and quick risk assessment model would facilitate characterization and prioritization of the risks posed to North America. The model would improve our understanding of the species of major concern for the NAPPO region and inform decision making by North American plant health regulatory agencies. In addition, the information gathered could be used to amend the existing NAPPO regional standard on AGM, RSPM 33, by expanding the number of species and/or modifying the specified risk periods for the regulated areas.

7.0 Approach & Methods

7.1 Screening for species of potential concern to the NAPPO region

A target list of 189 lymantriid species of concern for the NAPPO region was generated for risk analyses by cross-referencing a host genera list of economic importance in each NAPPO member country against the lepidopteran HOST plant databases (http://www.nhm.ac.uk/our-science/data/hostplants/ and http://plants.usda.gov/java/).
The distribution of selected species was determined by web-crawling the FUNET museum archives and databases using a Python script (http://www.nic.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/noctuoidea/lymantriidae/). Available information, e.g., scientific literature, interception data, biological aspects (available for each of the species, e.g., geographic distribution, feeding habits, hosts, attraction to light, mode of spreading, damage to important agricultural and forestry plants species or humans) and host data was also considered when selecting species for risk analyses.

7.2 Risk analysis model and data sheet

With the information gathered as indicated in the previous section, a risk analysis data sheet was designed to allow for rapid screening and identification of lymantriid species based on their introduction and spread potential, impact into the NAPPO region and the potential economic and environmental damage (Appendix 1). Data sheet questions were based on expert group discussions, scientific information, and information gathered from other pest risk assessments obtained from databases and scientific literature revisions (Section 7.1).

The first section of the data sheet determines 1) known geographic distribution, 2) the amount of area in each NAPPO country that is at risk for establishment based on climate, and, 3) if the lymantriid species feeds on economic or environmental hosts of concern to the NAPPO region. To characterize the area in each NAPPO country at risk for establishment for each species, the species' known geographic distribution and the Köppen-Geiger climate classification system were used. The Köppen-Geiger system delineates geographic areas into climate regions based on temperature and precipitation patterns (Peel *et al*., 2007)). Predominant Köppen-Geiger classes occurring within each lymantriid species' known geographic distribution (based on published data) and the geospatial data layer reported by Peel *et al*. (2007) were determined first. (See Appendix 2; Figure 1). The areas of those classes in each NAPPO country were summed using GIS. The percentage of climatologically suitable area within each NAPPO country was determined by dividing the total climatologically suitable area by the NAPPO country's total area and then multiplying by 100. The result provided an estimate of each NAPPO country's area at risk for establishment by each lymantriid species in percentage terms. Scientific and technical sources were used to determine if the lymantriid species feed on economic or environmental hosts of concern to the NAPPO region (see Appendix 3 for useful data sources).

The next data sheet section consists of eight questions and associated numerical scores that evaluate the lymantriid species' capacity for introduction and spread. We provide guidance and data sources for answering these questions in Appendix 3. The eight questions are as follows:

1) Are adult females attracted to light? (*This question identifies species that are likely to be flying during SRPs and might infest vessels and/or their cargo.)*
2) Has the species been reported as a contaminant in its overwintering stage? (*This question identifies species that are likely to move via trade into the NAPPO region.)*
3) Is the species reported to cause damage resulting in economic or environmental losses in its native range? (*This question identifies species that are likely to be pests if introduced.)*
4) Does the species have larvae capable of ballooning? (*This question identifies species with larval stages that are capable of moving from ships to surrounding areas around ports and are likely to spread in the larval stage if introduced.)*
5) Does the species have adult females capable of flight? (*This question identifies species capable of flying and laying egg masses which would facilitate movement in trade and spread if introduced into the NAPPO region.*)
6) Does the species' life history include a dormant stage to withstand harsh environmental conditions? (*This question identifies species that are likely survive shipment to the NAPPO region and persist once introduced.*)
7) Is the species capable of natural dispersal farther than 1km/year? (*This question identifies species that are likely to spread long distances via one or more life stages once introduced.)*
8) Is the species reported to have allergenic properties? (*This question identifies species that might cause harmful health-related impacts once introduced.*)

Scores were assigned with 1 if the answer was yes, -1 if no, and 0 if no information is available, with exceptions noted as follows. For question 2, a value of 2 was assigned if the answer was

"Yes" and it moves in trade, 1 if yes and it moves by non-trade related means, -2 if no, and 0 if no information is available. For question 3, a score of 3 was assigned if it causes severe damage, 2 if it causes moderate damage, 1 if it causes low damage, -2 if it causes negligible damage, and 0 if no information is available. Questions 2 and 3 were given more weight because we considered them to have a greater effect on the likelihood of a lymantriid species being introduced and becoming a pest.

Based on the proposed risk score system, a maximum value of 11 and a minimum value of -10 can be assigned to species. The highest score indicates the highest likelihood that a species could potentially get introduced, spread and become a pest given the scoring parameters used in the risk analysis. Risk categories were established as follows:

Risk Category	Score Range	Justification
High	6 or higher	Species with female moths attracted to light and capable of flight, known to cause substantial economic and/or environmental damage, with the capacity to spread very quickly in large areas, that can be introduced through different pathways.
Medium	1 to 5	Species known to cause limited economic and/or environmental impact, with females not necessarily attracted to light, and limited capacity to spread.
Low	0 or lower	Species with little to no economic or environmental impact. Low scores may also occur when little or no information is available regarding a lymantriid species.

7.3 Uncertainty Analysis

To characterize uncertainty in the data sheet results we first calculated the percent of the time a question was answered "0" for each of the 81 analyzed species. We then calculated the average percentage of "0" responses for all eight questions for the 81 analyzed species along with the standard deviation and 95% confidence interval.

8.0 Results and Discussion

8.1 General findings

A risk assessment data sheet that can be useful as an initial filter to identify lymantriid species of most concern to the NAPPO region was developed.

Low, medium and high risk categories, based on the final scores, indicate the highest risk species for the NAPPO region, and facilitate prioritization for further research and for future amendments to regulatory programs.

The lack of information (e.g., biology and distribution) and the difficulty in translating the available information on certain lymantriid species to risk scores and possibly risk categories suggests the need for more information and/or more research. This is primarily an issue affecting species classified as “low risk” with scores between -10 and 0, because for most parameters evaluated, the information gathered for “low risk” species was insufficient. There is also the possibility that some species are misclassified as “low risk” because of insufficient data.

Conversely, the probability of misclassifying “high risk” species tends to be lower. Risk scores for “high risk” species tend to be more reliable because insects that cause economic or environmental damages are more widely studied and reliable information is available.

For this project 81 lymantriid species were evaluated and the highest risk species were identified (Table 1; Appendix 5). The total risk scores ranged from -4 to 11 (Figure 2). The average total risk score and standard deviation was 2.43 ± 2.99. The 95 percent confidence interval for the average was 1.77 to 3.09. Twelve species had a total risk score of “High” including *Lymantria monacha*, *L. mathura*, *L. lunata* and *L. xylina*, all of which have been intercepted at ports of entry in the NAPPO region.

These results can serve as a support tool for inspectors and to inform phytosanitary officials within the NAPPO region. For example, our data sheets can be used to inform risk assessments, port policy, surveys, and to update RSPM 33. Also, the mean total score provides a risk estimate for a typical lymantriid species which could serve as a baseline for evaluating the riskiness of lymantriid species that are analyzed with this data sheet in the future as more information becomes available

8.2 Characterizing Uncertainty

Many of the risk characterization questions for lymantriid species were scored zero to indicate uncertainty due to a lack of information. For example, on average, a question scored zero 66% ± 4.3 (95% confidence interval = 49% to 82%) of the time for the 81 lymantriid species analyzed. Also, there were two questions: 1) “Reports of contaminant during pest’s overwintering stage” and 2) “Capable of dispersing naturally more than 1km/year”, which scored zero for 83% and 90% of the time respectively (Figure 3). One of the potential uses of our analysis is identifying data gaps in lymantriid biology that can be used to inform future research.

9.0 Conclusions, recommendations and next steps

We recommend additional analyses on the highest risk lymantriid species to further inform policy and operational decisions in the NAPPO region. We suggest:

- focusing research and sharing interception information on the questions that scored uncertain which will allow us to provide useful information to risk assessors and decision makers;
- developing training materials for inspectors and regulatory tools for decision-makers based on the results presented herein.

Our analysis compliments the work being done by the NAPPO Asian gypsy moth Expert Group in that it identifies other high risk lymantriids that could move in trade. We suggest updating RSPM 33 to include the highest risk species identified in this study and incorporating associated risk management recommendations after more information is gathered from the species we have determined to be high risk, based on the flight periods and/or biological information that is relevant to regulatory actions.

Lastly, if other groups such as NPPOs and academia adopt or improve our approach, there is the potential to continue evaluating additional lymantriid species for pest risk. A database housing this information would be useful to NPPOs needing to prioritize risk management activities against members of this subfamily.

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12.0 Figures and tables

Figure 2. Frequency of total scores from the 81 lymantriid species analyzed

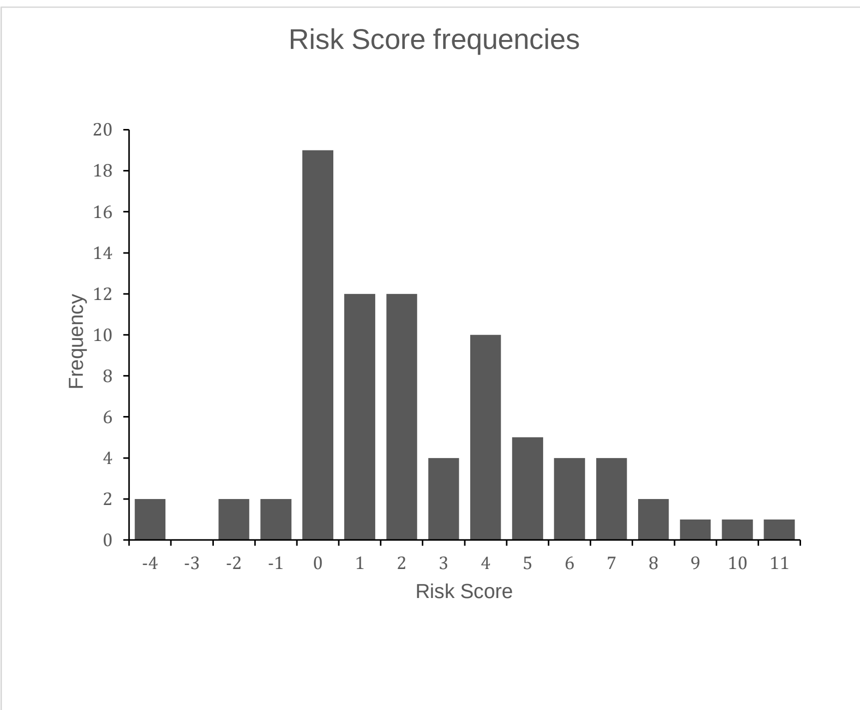

Figure 3. Percentage of uncertain responses for 81 lymantriid species.

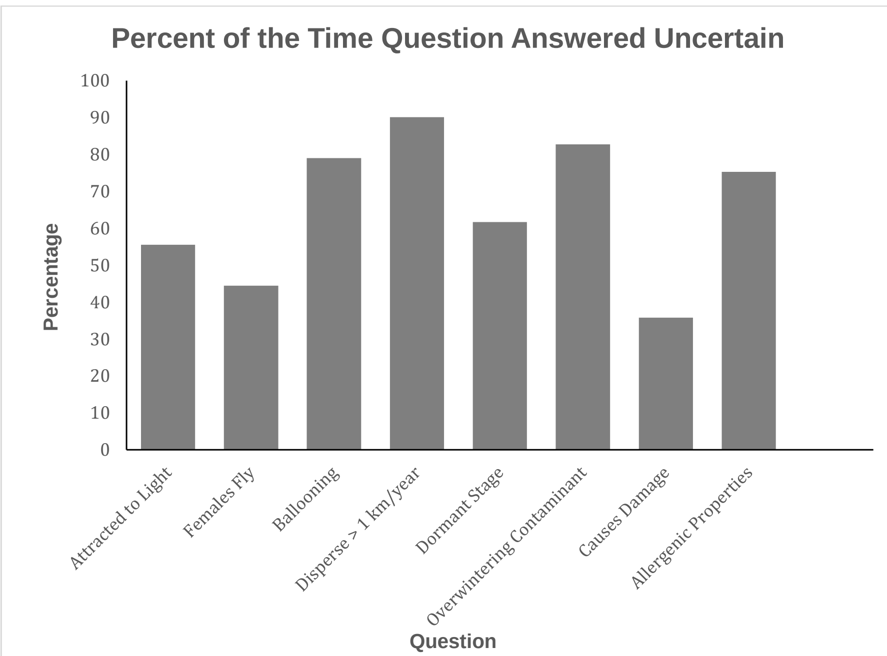

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Table 1. Detail of scores as determined for each question in the risk analyses for lymantriid species ranked "High Risk" (Total Risk Score = 6 or higher).

Species	Adult females attracted to light	Adult females capable of flight	First instar larvae capable of Ballooning	First instar larvae capable of dispersing naturally more than 1km/year	Life history contains dormant stage to withstand harsh environmental conditions	Reports of contaminant during pest's overwintering stage	Reported to cause damage in native range, causing economic or environmental losses	Reported to have allergenic properties	TOTAL SCORE
Lymantria monacha	1	1	1	1	1	2	3	1	**11**
Lymantria mathura	1	1	1	1	1	2	3	0	**10**
Euproctis kargalika	1	1	0	0	1	2	3	1	**9**
Lymantria lunata	1	1	0	1	1	0	3	1	**8**
Lymantria xylina	1	1	1	0	1	1	3	0	**8**
Euproctis subflava	1	1	1	0	0	0	3	1	**7**
Leucoma candida	0	1	0	0	1	2	3	0	**7**
Orgyia thyellina	1	1	1	0	1	2	0	1	**7**
Euproctis lunata	1	1	0	0	0	0	3	1	**6**
Leucoma wiltshirei	1	1	0	0	1	0	3	0	**6**
Lymantria fumida	1	1	-1	0	1	0	3	1	**6**
Sarsina violascens	1	1	0	0	0	0	3	1	**6**

13.0 Appendices

Appendix 1. Risk Analysis Data Sheet

Objective of the evaluation form and criteria considered to develop it.

RISK TEMPLATE
Species: Common name:
Geographic distribution:

Question	Answers	Score[2]	Comments/References
Amount of the NAPPO region with similar climate types to where the species occurs			Canada: XX% United States: XX% Mexico: XX%
Known to feed on hosts of economic or environmental concern to the NAPPO region	Yes/No*		
*Mandatory "yes" answer to both questions above before proceeding.			
Adult female moths attracted to light Yes (1) No (-1) Uncertain (0)			
Reports of contaminant during pest's overwintering stage Yes, trade-related (2) Yes, non-trade (1) No (-2) Uncertain (0)			
Reported to cause damage in native range, causing economic or environmental losses Severe (3) Moderate (2) Low (1) None/Negligible (-2) Uncertain (0)			
Larvae capable of ballooning			

[2] : No score is needed for the first two questions.

Yes (1) No (-1) Uncertain (0)			
Adult females capable of flight Yes (1) No (-1) Uncertain (0)			
Life history contains dormant stage to withstand harsh environmental conditions Yes (1) No (-1) Uncertain (0)			
Capable of dispersing naturally more than 1km/year Yes (1) No (-1) Uncertain (0)			
Reported to have allergenic properties Yes (1) No (-1) Uncertain (0)			
TOTAL SCORE			

Appendix 2. NAPPO Climate Risk Analysis Based on Köppen-Geiger Climate Zones

Purpose: Characterize how much of the NAPPO region is at risk for establishment by a lymantriid species based on similar climate characteristics and known global occurrences.

Method Used: Query known lymantriid geospatial occurrence records Good data sources for georeferenced species data include the Global Biodiversity Information Facility (https://www.gbif.org) and iNaturalist (https://www.inaturalist.org). By species, intersect the occurrence records with Köppen-Geiger climate zones (Figure 1) and report the climate types affected and which NAPPO countries have similar climate types to the known occurrences. Climate match percentage is calculated based on matching climate type in native range, as a percentage of the country's total area.

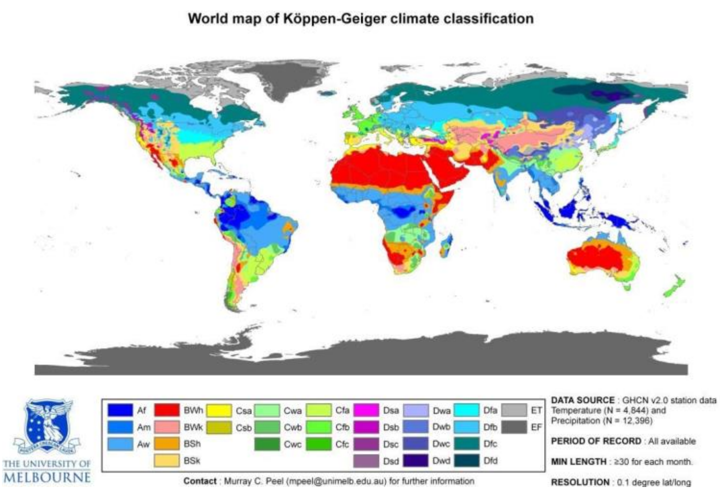

Figure 1. Global distribution map of the updated (2007) Köppen-Geiger climate zones. Source: http://people.eng.unimelb.edu.au/mpeel/koppen.html

Appendix 3. Tips/Notes on Answering Questions in the Lymantriid Decision Process

Overall suggestion: Consider reliability of the report when answering the questions (such as journal publication vs museum record vs internet report). Less credible sources will be answered as "uncertain" but make notes in the comments section, so we do not discard any information.

Naming Convention: Spp, Status, Score, Language (e/s)

Example: *Arctornis alba* Draft -1-e

1. **Amount of the NAPPO region with similar climate types to where the species occurs.**
   We have provided appendix 1 to help answer this question for a large number of lymantriid. May also use taxonomic databases like Finlands or the German Witt museum online database to look for occurrence data.

2. **Known to feed on hosts of economic or environmental concern to the NAPPO region.**
   There are a few online resources we have identified to help answer this question. First determine which host species the pest of interest targets:

   Lepidopteran host plant database:
   http://www.nhm.ac.uk/our-science/data/hostplants/http://www.nhm.ac.uk/our-science/data/hostplants/
   For some species, the Finland taxonomic database will have host information (usually near bottom of pest record):
   http://www.nic.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/noctuoidea/lymantriidae
   How to determine if economically important? If a pest feeds on a host included in a genus that has economic value in the NAPPO region, then it is a match.

   Then cross-reference the host list with some resource that indicates distribution and status (crop, culturally significant, noxious weed, T&T, etc.) such as the USDA Plants database: http://plants.usda.gov/java/ or foreign trade data on forest products: http://apps.fas.usda.gov/gats/default.aspx

3. **Adult female moths attracted to light?**
   When researching literature or museum collections, look for indication of whether the moth is caught in a light trap. Also, if a female is specifically caught in a light trap, we can also assume flight capable which will answer question7.

4. **Reports of contaminant during pest's overwintering stage?**
   Unless we can report the primary literature reference (or national interception data) that reports a contaminant event, we should report weakly reported risk associations (e.g. egg masses may be transported with lumber trade) using "Uncertain" and a value of zero. But use comments to document the possibility so that all data is retained.

5. **Reported to cause damage to trees of concern in native range, such that damage results in economic or environmental losses?**

6. **Larvae capable of ballooning?**

If there is no direct report of larval ballooning, we can investigate the morphological record for presence of secondary seta which indicates capacity to balloon.

7. Adult females capable of flight?

Evaluate the wing anatomy. With very few exceptions, full wing anatomy can be assumed to be flight capable. Vestigial wings will be answered as not flight capable, and no data, pictures, or info will be entered as “0” for uncertain. Also, there are odd exceptions like white spotted lymantriid, such that some generations can fly, and others have vestigial wings (and are incapable of flight).

8. Life history contains dormant stage (diapause, aestivation, cryptobiosis) enabling organism to withstand harsh environmental conditions?

9. Capable of dispersing naturally more than 1km/year?

Please report typical flight distance, ballooning distance, etc. in the comments.

10. Reported to have allergenic properties?

Severe allergenic reactions might include asthma, anaphylaxis, and blistering of the skin. Low to moderate reactions are not life threatening and may include skin rash, hives, runny nose, itchy eyes, and nausea.

Appendix 4. Example of a completed data sheet.

Species: ***Perina nuda*** **(Fabricius, 1787)**
Common name: Clear-winged Tussock Moth
Synonyms: *Stilpnotia subtinca* Walker, 1855, *Perina basalis* Walker, 1855, *Euproctis combinata* Walker, 1865, *Perina pura* Walker, 1869, *Acanthopsyche ritsemae* Heylaerts, 1881
Geographic Distribution: Indian subregion, Sri Lanka, to Southern China, Hong Kong, Thailand and Sundaland.

Question	Answer	Score	Comments/References
Amount of the NAPPO region with similar climate types to where the species occurs	---	---	Potential Climate Match: Canada: 0%, Mexico: 13.55%, United States: 21.23% Climate Types Affected: Af, Csc, Cwc (Butani, 1993; Peel *et al*., 2007; Wakamura *et al*., 2002; Zhang, 1994). Note: these were based on Koppen-Geiger climate types found in the majority of its distribution.
Known to feed on hosts of economic or environmental concern to the NAPPO region Yes/No	Yes	---	*Perina nuda* feeds on *Ficus* spp. (fig) and *Mangifera indica* (mango) which are agricultural crops in the NAPPO region (Butani, 1993; NASS, 2014).
Adult female moths attracted to light Yes (1) No (-1) Uncertain (0)	Yes	1	Moths were caught using a light trap (Khan et al., 1988) but the gender was not specified. In another study male moths were captured in a light trap (Symonds *et al*., 2012). Light trap collected females are reported from various collections. (Dave Holden pers. com)
Reports of contaminant during pest's overwintering stage Yes, trade-related (2) Yes, non-trade (1) No (-2) Uncertain (0)	Uncertain	0	*Pernia nuda* has never been intercepted at U.S. ports indicating it does not readily move in trade (PestID, 2017). Whether or not it can be transported in the overwintering stage is uncertain.
Reported to cause damage in native range, causing economic or environmental losses Severe (3) Moderate (2) Low (1) None/Negligible (-2) Uncertain (0)	Severe	3	*Perina nuba* is a major pest of *Ficus* spp. in Taiwan (Wang and Tsai, 1995).
Larvae capable of ballooning Yes (1) No (-1) Uncertain (0)	Uncertain	0	We found no evidence of this.
Adult females capable of flight Yes (1) No (-1) Uncertain (0)	Yes	1	Female moths are winged (ICAR, 2017) indicating they are capable of flight.

Life history contains dormant stage to withstand harsh environmental conditions Yes (1) No (-1) Uncertain (0)	Uncertain	0	We found no evidence of this.
Capable of dispersing naturally more than 1km/year Yes (1) No (-1) Uncertain (0)	Uncertain	0	Moths were caught using a light trap (Khan *et al*., 1988; Symonds *et al*., 2012) indicating they can fly but specific flight distances were not found.
Reported to have allergenic properties Yes (1) No (-1) Uncertain (0)	Uncertain	0	The larvae have urticating hairs that are used for defense (Cheanban *et al*., 2017) but we did not find reports of *P. nuda* causing allergies in humans.
TOTAL SCORE		**5**	

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Appendix 5. Datasheet results for the 81 lymantriid species analyzed

Species	Adult female moths attracted to light	Reports of contaminant during pest's overwintering stage	Reported to cause damage in native range, causing economic or environmental losses	Larvae capable of ballooning	Adult females capable of flight	Life history contains dormant stage to withstand harsh environmental conditions	Capable of dispersing naturally more than 1km/year	Reported to have allergenic properties	TOTAL SCORE
Acyphas semichrea	0	0	1	0	0	0	0	0	**1**
Arctornis alba	1	-2	0	0	0	1	0	0	**0**
Arctornis anserella	0	0	0	0	0	0	0	0	**0**
Arctornis chichibensis	1	0	0	0	0	0	0	0	**1**
Arctornis l-nigrum	1	0	1	0	1	1	0	0	**4**
Arctornis submarginata	1	0	3	1	0	0	0	0	**5**
Argyrostagma niobe	0	0	1	0	0	0	0	0	**1**
Arna bipunctapex	1	0	1	0	0	0	0	1	**3**
Arna perplexa	0	0	0	0	0	0	0	0	**0**
Aroa cometaris	0	0	0	0	0	0	0	0	**0**
Aroa melaneuca	0	0	0	0	0	0	0	0	**0**
Artaxa guttata	1	0	1	0	0	0	0	0	**2**
Bembina isabellina	0	0	0	0	0	0	0	0	**0**
Bracharoa quadripunctata	0	0	1	0	0	0	0	0	**1**
Calliteara abietis	1	-2	1	0	0	1	0	0	1
Calliteara argentata	0	0	1	0	0	1	0	0	**2**
Calliteara horsfieldii	0	0	2	0	0	0	0	0	**2**
Calliteara lunulata	1	0	0	0	1	0	0	0	**2**
Calliteara pudibunda	1	0	2	0	1	0	0	1	**5**
Calliteara strigata	0	0	0	0	0	0	0	0	**0**
Calliteara taiwana	0	0	0	0	0	0	0	0	**0**
Callitera rotunda	-1	0	0	1	-1	0	0	0	**-1**
Casama hemippa	0	0	0	0	0	0	0	0	**0**
Casama innotata	0	0	0	0	0	0	0	0	**0**
Casama vilis	0	0	0	0	0	0	0	0	**0**
Chionophasma lutea	0	0	0	0	0	0	0	0	**0**
Choerotrichia atrosquama	0	0	0	0	0	0	0	0	**0**
Cispia lunata	0	0	0	0	0	0	0	0	**0**
Creagra litura	0	0	0	0	0	0	0	0	**0**
Dasychira mendosa	0	0	1	-1	1	0	0	0	**1**
Euproctis aethiopica	0	0	1	0	1	0	0	0	**2**
Euproctis baliolali	0	-2	-2	0	1	0	0	1	**-2**
Euproctis chrysorrhoea	1	0	3	-1	1	1	1	1	**7**
Euproctis howra	0	-2	2	0	0	0	0	0	**0**
Euproctis kargalika	1	2	3	0	1	1	0	1	**9**
Euproctis lunata	1	0	3	0	1	0	0	1	**6**
Euproctis lyoma	0	0	0	0	0	0	0	0	**0**
Euproctis melania	0	-2	3	0	0	1	0	0	**2**
Euproctis molunduana	0	0	-2	0	0	0	0	0	**-2**
Euproctis producta	0	0	1	0	0	0	0	0	**1**
Euproctis pseudoconsper	0	0	3	0	0	1	0	1	**5**
Euproctis pulvera	1	0	1	0	1	0	0	1	**4**
Euproctis rubricosta	0	0	1	0	1	0	0	1	**3**
Euproctis semisignata	0	0	2	0	0	0	0	0	**2**
Euproctis similis	1	0	0	0	1	1	1	1	**5**
Euproctis subflava	1	0	3	1	1	0	0	1	**7**
Icta fulviceps	-1	0	-2	0	-1	0	0	0	**-4**
Lacipa florida	0	-2	-2	0	0	0	0	0	**-4**
Laelia clarki	0	0	0	0	0	0	0	0	**0**
Leucoma candida	0	2	3	0	1	1	0	0	**7**
Leucoma wiltshirei	1	0	3	0	1	1	0	0	**6**
Lymantria ampla	-1	0	2	0	-1	1	0	0	**1**
Lymantria concolor	0	0	3	0	1	1	0	0	**5**
Lymantria fumida	1	0	3	-1	1	1	0	1	**6**
Lymantria juglandis	0	0	0	0	0	1	0	0	**1**
Lymantria lucescens	1	0	0	0	1	1	1	0	**4**
Lymantria lunata	1	0	3	0	1	1	1	1	**8**
Lymantria marginalis	0	0	0	0	1	1	0	0	**2**
Lymantria mathura	1	2	3	1	1	1	1	0	10
Lymantria monacha	1	2	3	1	1	1	1	1	11
Lymantria obfuscata	-1	0	3	1	-1	1	0	0	**3**
Lymantria serva	0	0	0	0	1	1	0	0	**2**
Lymantria sinica	1	0	0	0	1	0	0	0	**2**
Lymantria xylina	1	1	3	1	1	1	0	0	**8**
Olene mendosa	0	0	1	-1	1	0	0	0	**1**
Oligeria hemicalla	-1	0	1	0	-1	0	0	0	**-1**
Orgyia anartoides	-1	1	1	1	-1	1	1	1	**4**
Orgyia osseata	0	0	1	0	1	0	0	0	**2**
Orgyia postica	-1	0	3	1	-1	1	0	1	**4**
Orgyia recens	-1	0	2	0	-1	1	0	0	**1**
Orgyia thyellina	1	2	0	1	1	1	0	1	**7**
Orgyia trigotephras	-1	0	1	1	-1	1	0	0	**1**
Orvasca subnotata	0	0	3	0	1	0	0	0	**4**
Parocneria furva	0	0	2	0	1	1	0	0	**4**
Parocneria terebinthi	0	0	0	0	0	0	0	0	**0**
Perina nuda	0	0	3	0	1	0	0	0	**4**
Psalis pennatula	0	0	3	-1	1	1	0	0	**4**
Sarsina violascens	1	0	3	0	1	0	0	1	**6**
Somena scintillans	0	0	1	0	1	0	0	0	**2**
Teia anartoides	-1	1	1	1	-1	1	1	1	**4**
Thagona tibialis	1	0	0	0	1	0	0	1	**3**