NAPPO Science and Technology Document

ST 07.

Risks Associated with the Introduction of Exotic Tussock Moth Species (Lepidoptera: Erebidae: Lymantriinae) of Potential Concern to the NAPPO Region

Prepared by the NAPPO Lymantriid Expert Group
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Virtual approval of NAPPO Products

Given the current travel restrictions brought about by the COVID-19 pandemic, the NAPPO Management Team unanimously endorsed a temporary process for virtual approval of its products.

Beginning in January 2021 and until further notice, this statement will be included with each approved NAPPO product in lieu of the Executive Committee original signature page.

The Science and Technology Document – ***Risks Associated with the Introduction of Exotic Tussock Moth Species (Lepidoptera: Erebidae: Lymantriinae) of Potential Concern to the NAPPO Region*** - was approved by the North American Plant Protection Organization (NAPPO) Executive Committee – see approval dates below each signature - and is effective from the latest date below.

Approved by:

Greg Wolff

Greg Wolff
Executive Committee Member
Canada
Date March 19, 2021

Osama El-Lissy

Osama El-Lissy
Executive Committee Member
United States
Date March 19, 2021

Francisco Ramírez y Ramírez

Francisco Ramírez y Ramírez
Executive Committee Member
Mexico
Date March 19, 2021

RE: Documento de CyT Limantridos - aprobacion virtual por parte del CE de la NAPPO / S&T document Lymantriids - virtual approval

WG Wolff, Greg (CFIA/ACIA) <greg.wolff@canada.ca>

To Stephanie Bloem; El-Lissy, Osama A - APHIS; John Greifer; francisco.ramirez@senasica.gob.mx

Cc Cote, Steve (CFIA/ACIA); Abad, Patricia V - APHIS; Dubon, Stephanie M - APHIS; Ana Lilia Montealegre; Alonso Suazo; Nedelka Marin-Martinez; Sofia Baez; Maribel Hurtado; Craig Regelbrugge; Mario Puente; Andrew Morse

Reply

You replied to this message on 3/19/2021 4:41 PM.

Congratulations to all again

Canada supports this

Regards

Greg

RE: Documento de CyT Limantridos - aprobacion virtual por parte del CE de la NAPPO / S&T document Lymantriids - virtual approval l

OE El-Lissy, Osama A - APHIS <osama.a.el-lissy@usda.gov>

To Stephanie Bloem; Wolff, Greg (CFIA/ACIA); Greifer, John K - APHIS; francisco.ramirez@senasica.gob.mx

Cc Cote, Steve (CFIA/ACIA); Abad, Patricia V - APHIS; Dubon, Stephanie M - APHIS; Ana Lilia Montealegre; Alonso Suazo; Nedelka Marin-Martinez; Sofia Baez; Maribel Hurtado; Craig Regelbrugge; Mario Puente; Andrew Morse

Reply

Hi Stephanie,

Wait no more, the US team appreciates the great work and support the approval of the document.

Have a great weekend, everyone!

Osama

Dr. Osama A. El-Lissy
Deputy Administrator
USDA APHIS Plant Protection and Quarantine

RE: Documento de CyT Limantridos - aprobacion virtual por parte del CE de la NAPPO / S&T document Lymantriids - virtual approval by the NAPPO EC

FR Francisco Ramirez y Ramirez <francisco.ramirez@senasica.gob.mx>

To Stephanie Bloem; Wolff, Greg (CFIA/ACIA); El-Lissy, Osama A - APHIS; John Greifer

Cc Cote, Steve (CFIA/ACIA); Abad, Patricia V - APHIS; Dubon, Stephanie M - APHIS; Ana Lilia Montealegre Lara; Alonso Suazo; Nedelka Marin-Martinez; Sofia Baez; Maribel Hurtado; Craig Regelbrugge; DC35; Andrew Morse

Thank you Stephanie, I welcome the news and take note of the adoption procedure. We support the proposal.

Regards,

Atentamente

Ing. Francisco Ramírez y Ramírez
Director General de Sanidad Vegetal

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Content **Page**

1.0 SCOPE AND PURPOSE

This project was conducted to collect additional information on exotic tussock moths and related species due to increased interceptions reported at various ports of entry in the North American Plant Protection Organization (NAPPO) region. Consequently, a need to further understand and characterize the increased risk of tussock moth introductions into the NAPPO region was highlighted.

The tussock moth family, previously known as the family Lymantriidae, was recently moved to the family Erebidae, subfamily Lymantriinae (Zahiri *et al.,* 2010). For simplicity, they will be referred to as lymantriids throughout the rest of this document.

The lymantriids are an important group of insect defoliators of forest and agricultural plants around the world. Increases in global trade, including in areas with high diversity of lymantriids, coupled with the large diversity of their potential hosts, makes the overall risk of introduction and spread of some lymantriid species high for the NAPPO region. Establishment of some lymantriids in the NAPPO region, such as the Asian gypsy moth (AGM) species complex (*Lymantria dispar asiatica, L. dispar japonica, L. albescens, L. umbrosa, and L. postalba)* (Pogue and Schaefer, 2007), could result in significant economic and environmental impacts to North America. Recently, Djoumad *et al*., (2019) classified *L. postalba* as a subspecies of *L. albescens*.

The AGM species complex are pests of quarantine significance in all NAPPO member countries. Potential pathways of introduction include cargo as well as marine vessels, and other types of conveyances associated with international trade. NAPPO developed a regional standard for phytosanitary measures (RSPM 33 – *Guidelines for regulating the movement of vessels from areas infested with the Asian gypsy moth*) to help reduce the risk of introduction of AGM by certifying marine vessels travelling from AGM regulated countries to the NAPPO region during the specified risk periods (SRP)[1] of moth flight and egg mass deposition.

Interception of egg masses belonging to other lymantriid species (= *Lymantria mathura*, *L. xylina* and *L. lucescens)* in both Canada and the United States (U.S.) on vessels originating in Asia (CFIA pest interceptions, 2020; PestID, 2020) clearly illustrate an additional risk of introduction and underscore the need for NAPPO member countries to examine this potential for other lymantriid species. This document summarizes data on additional economically important lymantriids to support the regulatory agencies in NAPPO member countries in developing programs and guidelines aimed at reducing the risk of their introduction into the NAPPO region. The information provided herein will also serve to broaden the scope of RSPM 33 thereby improving the perimeter protection for North America.

[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 and other items.

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

1. providing information on selected lymantriid species that could be introduced into our region via international trade or other pathways
2. developing and using a risk assessment methodology to quickly screen these species and efficiently characterize their pest risk, and
3. ranking these species based on their pest risk.

2.0 TAXONOMY AND SYSTEMATICS

Most taxonomic and systematic research on lymantriids has been captured in regional faunal inventories, for example, the *Moths of North America* and the *Moths of Borneo* (Ferguson, 1978; Holloway, 1999; Pogue and Schaefer, 2007). Additional information on lymantriid taxonomy can be found in Wang (2015) and Kristensen (1998). More recently, phylogenetic studies have re-classified the family Lymantriidae as the subfamily Lymantriinae within the recently created family Erebidae (Zahiri *et al.,* 2010; Zahiri *et al.,* 2012). The genera *Calliteara* (Witt and Trofimova, 2016) and *Lymantria* (Schintlmeister, 2004) within Lymantriinae have also been recently revised. Additionally, several regional studies have been performed that include several pest species of *Lymantria* (Arimoto and Iwaizumi, 2014; Djoumad *et al*., 2017; Djoumad *et al*., 2019; Inou *et al*., 2019).

2.1 Number of Species and Their Distribution

Lymantriids are an economically important group within the Erebidae, 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 catalogued, 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; Schaefer,1989; GBIF).

Heppner (1991) suggested dividing the 2,416 species of the former family Lymantriidae according to the regions where they are present, as follows: Afrotropical (1,004), Oriental east to Moluccas (742), Australian including New Guinea and islands to the East (255), Palearctic (203), Neotropical (180), and Nearctic (32).

As a result of several regional studies performed from the 1950s to the beginning of the 1980s, which illustrated the high density of species in some areas, a tentative catalogue of lymantriids including about 355 genera and 3,065 known species (Schaefer, 1989) was developed. Schaefer considered genera with 20 or more species as “main genera”. In the Schaefer catalog, 21 genera encompass 2,159 species, or over 70% of the known species (Schaefer, 1989), compared to more than 2,500 species in approximately 360 genera reported by Wang *et al*. (2015).

3.0 CHARACTERISTICS AND BIOLOGY OF LYMANTRIIDS

Many lymantriids are characterized by the presence of tufts along the dorsal surface of the larvae hence the name tussock moths (Scoble, 1992). Interestingly, these tussocks develop during later instars and are not present upon larval emergence from eggs. Many larvae are recognizable due to their colorful hair-like projections such as radiating setal tufts, dense tufts (as in *Orgyia* species), and hair pencils (Stehr, 1987). 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 (Scoble, 1992). Larvae have one or two medio-dorsal glands on abdominal segments 6 and 7 (Ferguson, 1978; Witt and Trofimova, 2016). The glands are usually bright and colorful, with red, orange, or yellow tones (Scoble, 1992). It is thought that the glands are used as a defense mechanism.

Adults typically have cryptic coloration, which provides good camouflage for blending with tree bark, lichens, or leaves where they are typically found resting. Adults are dimorphic in most species, with males normally smaller and darker than females, and with very prominent bi-pectinate antennae in males and less so in females. Divergent, bristle-like spinules at the tips of each antennal branch are diagnostic (Ferguson, 1978). Adults of many species are monochromatic (white or yellow tone) (Schaefer, 1989), have a reduced or absent haustellum, do not feed and, as such, have a short lifespan of a few weeks (Ferguson, 1978). 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 attracted to light (Grundy and Lowe, 2010; Herbison-Evans and Crossley, 2017; Waring and Townsend, 2017).

Lymantriids disperse in several ways: 1) females of some species are capable of flight, 2) resilient egg masses that are dormant for several months can be deposited on surfaces that are moved long distances via human activity (e.g., by deposition on ships, cargo, or personal items), or 3) by early instar larvae floating on wind currents (a behavior known as ballooning).

Larvae are highly polyphagous, and many species in the subfamily Lymantriinae are pests of agriculture and forestry. Examples of pest species include gypsy moth (*Lymantria dispar*), brown tail moth (*Euproctis chrysorrhoea*), painted apple moth (*Orgyia anartoides*) and nun moth (*Lymantria monacha*). These species have high fecundity, which can result in large population increases in a single generation. For example, in Taiwan, the Casuarina moth (*Lymantria xylina*) laid egg masses with a range of 180 to 1,544 eggs per mass (Chao *et al*., 2001). Like many economically important pests, some lymantriids undergo cyclical outbreaks resulting in large-scale defoliation of their host plants. Outbreaks have also been associated with a high incidence of dermatitis and other skin conditions in humans due to the urtricating nature of the larval setae (Scoble, 1992; Ooi *et al*. 1991).

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 to vegetation in urban settings, where they also can pose a health risk to the public. 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, lymantriid host plants and their associated feeding habits are not well documented. However, in general terms, forest and shade trees serve as the main sources of food. Shrubs, grapevines, herbs, and grasses are less important. At least two species of lymantriids feed on lichens and one is known to feed on mistletoe (Schaefer, 1989).

Species within the genus *Lymantria* are known to feed on over 150 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.), oak (*Quercus* spp.), pine (*Pinus* spp.), beech (*Fagus* spp.), juniper (*Juniperus* spp.), chestnut (*Castanea* spp.), hemlocks (*Tsuga* spp.), firs (*Abies* spp.), Australian pinetree (*Casuarina equisetifolia*), and spruce (*Picea* spp.) among others (Pogue and Schaefer, 2007).

In addition to the forest species mentioned above, species in the genus *Lymantria* can feed on agriculturally important plants, such as plum (*Prunus domestica*), peach (*Prunus persica*), almond (*Prunus* spp.), apple (*Malus domestica*), litchi (*Litchi chinensis),* longan (*Dimocarpus longan*) and pistachio (*Pistacia vera*) (Pogue and Schaefer, 2007).

5.0 REGULATORY AND PHYTOSANITARY FRAMEWORK

NAPPO develops science-based regional standards which are intended to protect the 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: *Guidelines for regulating the movement of vessels from areas infested with the Asian gypsy moth*) provides member countries with guidelines to minimize the entry and establishment of the Asian Gypsy Moth (AGM). RSPM 33 describes risk management options for vessels leaving ports located in AGM regulated countries during the specified (flight and egg-laying) risk periods (SRP) and that are destined to North America.

NAPPO countries have established regulatory measures and directives to minimize the risk of introduction of lymantriid species, especially AGM, via infested vessels or high-risk commodities such as forest products, vehicles, and Christmas trees.

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 umbrosa* and *Orgyia anartoides*.

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 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 of regulated articles from the United States which may harbor any life stage of the European 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, quarantine significant Lymantriid genera and species include *Dasychira, Euproctis, E. chrysorrhoea, E. similis, E. varians, Lymantria, L. dispar, L. dispar asiatica, L. dispar dispar*, *L. mathura*, *L. monacha*, *L. umbrosa*, *L. xylina, Nygmia varians, N. phaeorrhoea, Olene, Orgyia, O. thyellina, Somena scintillans,* and *Thagona* (PestID, 2020). *Lymantria albescens* is not listed in PestID but is still actionable because all species of the genus *Lymantria* are regulated. 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 that are likely pathways for gypsy moth life stages, e.g., logs, mobile homes, and Christmas trees.

The United States also regulates articles from areas in Canada that might be 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 Canadian stone and quarry products are regulated under 7 CFR § 330.301. Timber coming from other countries into the United States is treated, which mitigates the risk of infestation by gypsy moth.

In addition, the Plant Protection Act of 2000 (7 U.S.C. 7701-7772) gives the United States broad authority to regulate imports of, or interstate trade in, plants, plant products, biological control organisms, noxious weeds, articles and means of conveyance to prevent introduction or spread of plant pests or noxious weeds. This is the authority under which the United States Asian Gypsy Moth Offshore Vessel Inspection Program operates, to prevent the entry of the Asian strains of gypsy moth on vessels and their establishment in the United States.

5.3 Mexico

Mexico has official regulations (NOMs, Spanish acronym for standards in Mexico), through which phytosanitary requirements are established for the importation of some forestry products. NOMs provide a list of regulated pests for those commodities. *Lymantria dispar*, *L. dispar asiatica* and *L. dispar japonica*, are the only species named in the NOMs. The official Mexican 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 in the Federal Official Gazette on December 7, 2016 lists *Orgyia pseudotsugata* and *Lymantria dispar* as two exotic lymantriid species of concern for Mexico (SEMARNAT, 2016).

In Mexico, the family Erebidae, subfamily Lymantriinae is not well known in terms of species diversity, biology, and habits, therefore there is not much information concerning the species diversity of Lymantriinae in Mexico.

Note: The North American Sea Container Initiative (NASCI) is another program to prevent the introduction of invasive plant pests to North America – including forest and other pests of concern. This initiative acknowledges the risk posed by the movement of contaminated sea containers and focuses on sea container cleanliness, handling and shipping, education, and awareness and outreach to all involved parties to reduce the risk of contamination of sea containers with quarantine significant pests.

6.0 LIKELIHOOD OF INTRODUCTION AND SPREAD OF LYMANTRIID SPECIES IN THE NAPPO REGION - INFORMATION NEEDS AND GAPS

The likelihood of introduction of lymantriid species into the NAPPO region is high due to the large volume of vessels and their cargoes moving from regulated countries into the NAPPO region, the movement of other high-risk commodities, and the large number of lymantriid host species and suitable climatic conditions present/available in the NAPPO region.

Evidence indicates that lymantriids introduced into the NAPPO region have become economically important pests. For example, the European gypsy moth *Lymantria dispar dispar*, was intentionally imported into Massachusetts, United States, in the late 1860s from Europe to cross-breed with native moth species for silk production. Unfortunately, it was accidentally released into the environment (Liebhold *et al*., 1989). Since that time, it has become widely distributed in Eastern North America (USDA, 2019) and has caused widespread damage to forest trees. *Euproctis chrysorrhoea*, 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 area at the beginning of 1897, and since then has spread to parts of the Eastern United States and Canada (Fernald and Kirkland, 1903; Kniest and Hoffman, 1984; CABI, 2020). Five adults of *Lymantia monacha* were collected in Brooklyn, NY, United States at lights in the summer of 1901. It is believed that this species failed to establish since no additional adults were found in subsequent years (Holland, 1968).

All life stages of Asian gypsy moth (egg masses, larvae, pupae, and adults) and other lymantriid species (*Leucoma salicis, Lymantria mathura,* and *Lymantria xylina* among others), have been intercepted in the NAPPO region primarily during maritime port inspections of vessels and shipping containers originating in Asia (Russia, Japan, China, Philippines, and Korea) and Europe (CFIA Pest Interception Data, 2020; PestID, 2020). Interceptions of *Lymantria dispar* in Canada have also been reported on Christmas trees and propagative plant material from the United States (CFIA Pest Interception Data, 2020).

To a lesser extent, actionable lymantriid egg masses, larvae, pupae, and adults have been intercepted at airports in the United States and Canada from a variety of pathways including baggage, permit cargo, and general cargo (AQAS, 2019 and 2020; ARM, 2020; PestID, 2020). Other important pathways identified from inspection data include military and agricultural equipment, cut flowers, nursery stock, wood (wood packaging) and personal effects from countries where regulated species of lymantriids are found (PestID, 2020; CFIA data base). Other less-documented pathways include e-commerce and smuggling. The large number of interceptions reported on maritime vessels and shipping containers suggests that this is the most important pathway for entry into the NAPPO region.

The economic and environmental impacts 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 susceptible areas of 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 revise the NAPPO regional standard on AGM (RSPM 33), by expanding the number of species of concern, the number of regulated countries, and/or by modifying/updating the specified risk periods for the regulated areas.

7.0 APPROACH AND METHODOLOGY

7.1 Screening for Species of Potential Concern to the NAPPO Region

An initial target list of 189 lymantriid species of concern was generated by cross-referencing a list of host genera of economic importance in each NAPPO member country against the "HOSTS" database for lepidoptera host plants (http://www.nhm.ac.uk/our-science/data/hostplants/ and http://plants.usda.gov/java/). The distribution of the 189 lymantriid species target list was then determined by web-crawling the FUNET museum archives and databases using a Python script (https://www.nic.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/noctuoidea/erebidae/lymantriinae/).

Available information, such as interception data, scientific literature on biological aspects for each 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 considered when selecting species for risk assessment. Of the original 189 selected species, 79 were selected for further analysis because of resource limitations including amount of available information.

7.2 Risk Assessment Model and Data Sheet

A risk assessment data sheet was designed to allow for rapid screening of lymantriid species based on their introduction, potential spread, and impacts to the NAPPO region (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 datasheets for the 79 species analyzed in this study will be available in the NAPPO website (www.nappo.org) or upon request to the NAPPO Secretariat. Additional references for each species not listed in this document are listed in the risk assessment datasheets.

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 economically or environmentally important hosts to the NAPPO region.

To characterize the area in each NAPPO country at risk for establishment for each species, the known geographic distribution of the species 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 contained in the data sheets) and the geospatial data layer reported by Peel *et al*. (2007) were determined first. (See Appendix 2; Figure 3). The areas of those classes in each NAPPO country were summed using a geographic information system (GIS), ArcGIS 10.6. The percentage of climatologically suitable area within each NAPPO country was determined by dividing the total suitable area for establishment based on climate by the NAPPO country's total area and then multiplying by 100. The result provided an estimate of the area in each NAPPO country at risk for establishment by each lymantriid species as a percentage based solely on climatic suitability. Scientific and technical sources were used to determine if the lymantriid species fed on economically or environmentally important hosts 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 cargoes).*
2) Has the species been reported as a contaminant pest of commodities in trade in its overwintering stage? (*This question identifies species that are likely to move via trade into the NAPPO region and have the highest risk of survival and introduction).*
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. Damage in the introduced range could also be used but was not needed in the analysis).*
4) Does the species have larvae capable of ballooning? (*This question identifies species with larval stages capable of moving from vessels 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 to 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 human health-related impacts once introduced*).

Scores were assigned a "1" if the answer was "Yes", "-1" if the answer was "No", and "0" if no information was 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 was 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 was available. Questions 2 and 3 were given more weight because they were considered to have a greater effect on the likelihood of a lymantriid species being introduced and having unwanted impacts.

Based on the proposed risk score system, a maximum value of "11" and a minimum value of "-10" could be assigned to the species. The highest score indicates the highest likelihood that a species could potentially get introduced, spread, and have unwanted impacts given the scoring parameters used in the analysis. Three risk score categories were established as high, medium, and low risk. The value of "6", corresponding to the mid-point of the positive range values (1 to 11) was used to set the boundary between the medium and high-risk categories. A low-risk category was established for those risk score values below "1" (-4 to 0). Risk categories were established and described as follows:

Table 1. Risk scoring system for the data sheets.

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, and/or 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

Uncertainty was characterized in the data sheet results by calculating the percent of time that a question was answered “0” for each of the 79 species analyzed. The average percentage of “0” responses for all eight questions for the 79 species analyzed was calculated along with the standard deviation and a 95% confidence interval.

8.0 RESULTS AND DISCUSSION

8.1 General Findings

We developed a risk assessment data sheet that can be useful as an initial filter to identify lymantriid species of highest concern to the NAPPO region.

Based on the final scores, the highest-risk species for the NAPPO region are identified which will facilitate prioritization for further research and assist with future amendments to regulatory programs in North America.

The lack of information (e.g., biology and distribution) and the difficulty in translating information available in other languages (such as Russian) affected the risk scores and possibly the risk categories for certain species. This reality suggests the need for additional research and periodic review and update of the risk assessments once additional information becomes available. This issue primarily affects the species classified as “low-risk” with scores between “-10” and “0”, because for most parameters, the information gathered was insufficient. Consequently, there is high uncertainty associated with the low-risk rating.

Conversely, the probability of mis-classifying “high-risk” species tended to be lower. Risk scores for “high-risk” species tended to be more reliable because insects that cause economic or environmental damage are more widely studied and abundant, and reliable information is more readily available.

For this project, 79 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 1). The average total risk score and standard deviation was 2.44 ± 3.04. The 95% confidence interval for the average was 1.76 to 3.12. Thirteen species had a total risk score of “High” including *Lymantria monacha*, *L. mathura*, *L. lunata* and *L. xylina*, which is supported by their interceptions 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, to update RSPM 33 and to focus inspector taxonomic training on high-risk species. We found the mean total score provides a risk estimate for a typical lymantriid species to be medium (average=2.44). This risk rating and associated values could serve as a baseline for comparing the risk potential of other lymantriid species that are analyzed using this data sheet/questions/scoring. The average risk score could also be updated periodically with additional data to improve the baseline estimate.

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% ± 19.49 (95% confidence interval = 47% to 83%) of the time for the 79 lymantriid species analyzed and six of the eight questions scored zero greater than 50% of the time (Figure 2). 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 84% and 91% of the time, respectively (Figure 2). These results highlight that many of these species are not well described/studied. For example, there are some species that cause economic damage in their native range but are not rated high because of insufficient information. A potential use of these results is the identification of data gaps in lymantriid biology that can inform/direct future research.

9.0 CONCLUSIONS, RECOMMENDATIONS AND NEXT STEPS

This document is a general, practical, and quick screening tool and is not a rigorous risk assessment methodology. Consequently, 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 to improve the questions that had high uncertainty which will allow us to improve/refine the information provided to risk assessors and decision-makers.
- Developing training materials for inspectors and regulatory tools for decision-makers based on the results presented herein.
- Reevaluating these results using more rigorous risk assessment methodologies specific to each NAPPO country, e.g., climate matching to further inform the risk potential of these species.
- Conducting more in-depth uncertainty analysis to identify how the null values affect the risk scores. This information could be used to potentially update the data sheets and improve its performance characterizing the pest risk potential of lymantriid species.

Our analysis compliments the work being done by the NAPPO AGM Expert Group in that it identifies other high risk lymantriids that could move in trade. A logical next step might be to update RSPM 33 to include the highest risk species identified in this study. Additionally, we suggest gathering more information on the flight periods and/or biological information that is relevant to regulatory actions on high-risk species to be incorporated into risk management recommendations. There will also be a critical need for additional research into efficacious traps, lures, predictive phenology models, identification tools (e.g., molecular identification tools for any life stage of intercepted lymantriid based on DNA barcoding and well authenticated specimens), survey protocols and treatments for additional lymantriid species that may be eventually added to RSPM 33.

This science and technology document had the objective of identifying additional, potentially high-risk lymantriid species of concern to NAPPO member countries. These species may be added to the lists of regulated pests for each country. Note that the current surveillance and management programs for lymantriid species in NAPPO countries are limited to only a few species and subspecies. Approval for any follow-up actions in this regard would be subject to NPPO priorities, interests, approvals, and resource availability.

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

Any recommendation in this paper would need to be further developed by the member NPPOs of NAPPO, including consideration of additional regionally-focused work. Approval of any of suggested regional activities would be subject to review by NAPPO governance officials (e.g., Executive Committee and Advisory and Management Committee), in accordance with project prioritization criteria, and NPPO priorities, interests, and resource availability.

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12.0 FIGURES AND TABLES

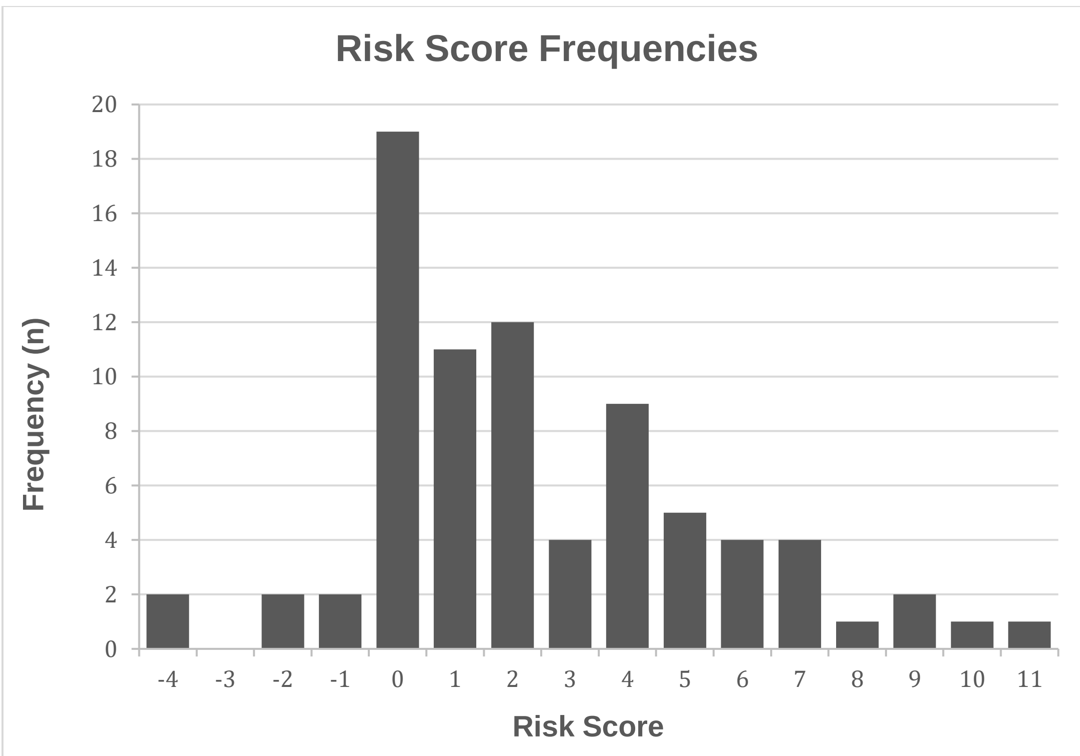

Figure 1. Frequency of total scores from the 79 lymantriid species analyzed.

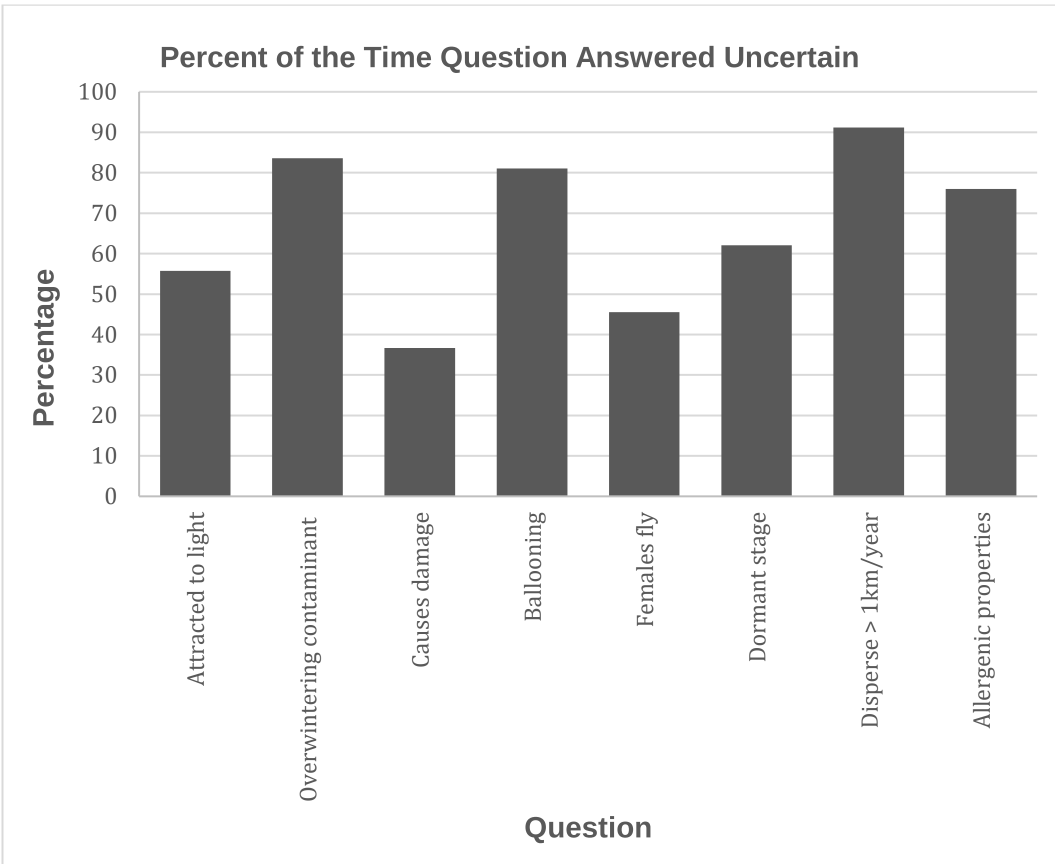

Figure 2. Percentage of uncertain responses for 79 lymantriid species.

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 xylina	1	1	1	0	1	2	3	0	**9**
Lymantria lunata	1	1	0	1	1	0	3	1	**8**
Euproctis subflava	1	1	1	0	0	0	3	1	**7**
Euproctis chrysorrhoea	1	1	-1	1	1	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 Assessment Data Sheet

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 (foot note: The NAPPO region has all the Koppen zones so the first question is always yes, which is why we simply report the percentage.)			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 this question 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)			

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

Low (1) None/Negligible (-2) Uncertain (0)			
Larvae capable of ballooning 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 Suitability 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.

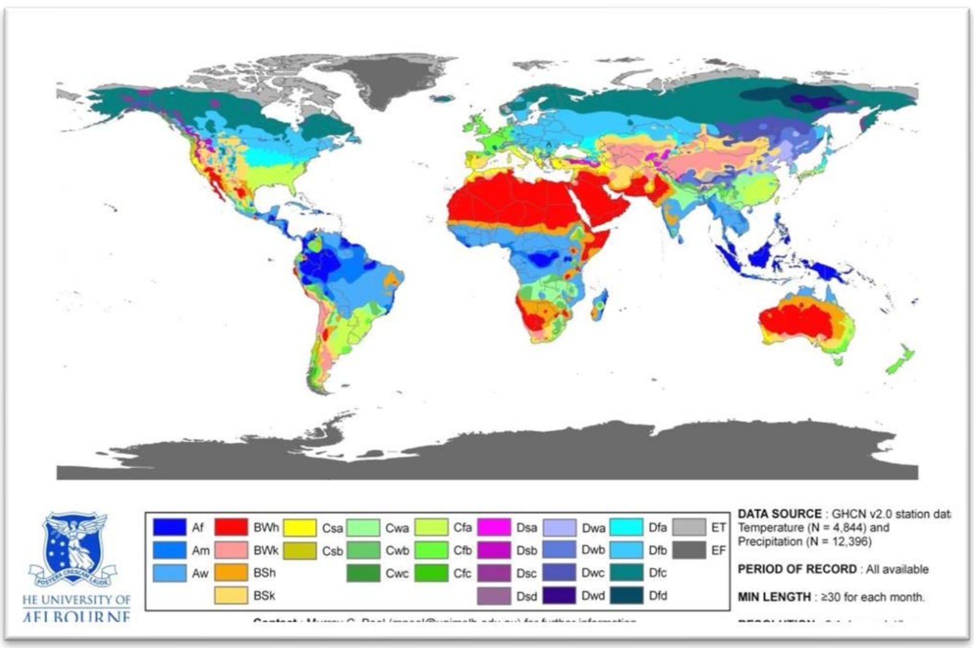

Figure 3. Global distribution map of the updated (2007) Köppen-Geiger climate zones. Source: http://people.eng.unimelb.edu.au/mpeel/koppen.html

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. **Area in the NAPPO region with similar climate types to where the species occurs.** We have provided appendix 2 to help answer this question for a large number of lymantriids. May also use the Finland taxonomic databases based on the database in question 2 or the German Witt museum online database to look for distribution 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):
   https://www.nic.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/noctuoidea/erebidae/
   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, according to the information sources below, then it is a match.

   Cross-reference the host list with some resource that indicates distribution and economic status (crop, culturally significant, noxious weed, endangered and threatened, 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 question 7.

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, report risk associations as weak (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?** Check primary sources, databases, and extension publications.

6. **Larvae capable of ballooning?**
   If there is no direct report of larval ballooning, we can investigate the morphological record for presence of special setae, e.g., aerophores, which may indicate 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). In cases where flight occurs at least sometimes during the life cycle these would be scored a "1".

8. **Life history contains dormant stage (diapause, aestivation, cryptobiosis) enabling organism to withstand harsh environmental conditions?** No additional guidance provided.

9. **Capable of dispersing naturally more than 1km/year?**
   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 (Malay Peninsula, Borneo, Java, Sumatra and surrounding small islands).

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, Cwa, Cfa (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	We found no evidence of this.

Uncertain (0)			
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 79 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
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 pseudoconspersa	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
Thagona tibialis	1	0	0	0	1	0	0	1	3