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Contaminating organisms affecting trade in wood commodities and forestry products

Prepared by the members of the NAPPO Forestry Expert Group

Meghan Noseworthy (NR Canada; Chairperson); Arvind Vasudevan (CFIA), John Tyrone Jones, II (APHIS-PPQ), Ron Mack (APHIS-PPQ), María Eugenia Guerrero Alarcón (SEMARNAT), Norma Patricia Miranda González (SEMARNAT), Gustavo Hernández Sánchez (SEMARNAT), Clemente de Jesús García Ávila (SENASICA), Chuck Dentelbeck (Canada Industry), Scott Geffros (Canada Industry), Paul Conway (U.S. Industry), Dave Kretschmann (U.S. Industry), Faith Campbell (CISP), Eric Allen (Retired) and Brad Gething (U.S. Industry; Vice-Chair).

The Secretariat of the North American Plant Protection Organization (NAPPO)
1730 Varsity Drive, Suite 145
Raleigh, NC 27606-5202
United States of America

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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 – ***Contaminating organisms affecting trade in wood commodities and forestry products*** - 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 Executive Committee Member Canada Date XXXX, 2021	**Osama El-Lissy** Executive Committee Member United States Date XXXX, 2021

Francisco Ramírez y Ramírez
Executive Committee Member
Mexico
Date XXXX, 2021

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1. INTRODUCTION

International trade is widely recognized as the primary pathway for the spread of plants, animals (including insects, fungi and nematodes), and microorganisms, many of which are considered plant pests. When introduced to new environments, these organisms are commonly referred to as "non-indigenous" and can cause serious environmental, ecological, and economic damage if they become pests (Liebhold *et al.,* 1995; Allen and Humble, 2002). Non-indigenous pests can move internationally in association with infested plant substrates such as live plants and plant parts, including wood. In many cases, non-indigenous plant pests are unintentionally introduced on an article or surface they are not infesting. These pests are referred to as hitchhiking or contaminating pests. A contaminating pest is defined in the International Standard for Phytosanitary Measures 5, the *Glossary of phytosanitary terms*[1] (ISPM 5) as: "*a pest that is carried by a commodity, packaging, conveyance or container, or present in a storage place and that, in the case of plants and plant products does not infest them*[2]". Important to this definition is the concept of "infestation," which is defined by the International Plant Protection Convention (IPPC) as "presence in a commodity of a living pest of the plant or plant product concerned. Infestation includes infection" (ISPM 5). Infection refers to the invasion of tissues, which is a defining difference between infesting and contaminating organisms. More generally, infestation implies an intimate biological interaction between the infesting organism and its host whereby the infesting organism derives nutrition or other necessary requirements to carry out its life cycle. In contrast, contaminating pests lack this physiological or physical relationship (MAF, 2008; Lemay and Meissner, 2008). Contaminating pests can be found on a wide range of surfaces, including plants or plant products, conveyances (e.g., airplanes, ships), shipping containers, machinery, vehicles etc.

The IPPC provides a framework for signatory countries, also known as contracting parties (CPs), to develop harmonized standards with guidelines to reduce the international movement of pests associated with the trade of plants, plant products and other regulated articles. The Convention also recognizes that pests can move in association with packaging, conveyances, containers, growing media or any other organism, object, or material capable of harboring or spreading plant pests. For example, the *International movement of used vehicles, machinery, and equipment* (ISPM 41, 2017) and the Sea Container Task Force (SCTF) provide guidance on the best practices to reduce the spread of pests on commodities they do not infest (FAO, 2020a).

To determine whether an organism is a potential pest of plants and therefore subject to regulation, a pest risk analysis (PRA) is conducted by the importing country (ISPM 2, 2019; ISPM 11, 2019). This formal process, central to phytosanitary regulation, considers technical, scientific, and economic information to determine whether any organism can be considered a regulated pest. Regulated pests are recognized by the IPPC as quarantine pests or regulated, non-quarantine

[1] ISPM 5 is updated annually and is available on the International Phytosanitary Portal (IPP – www.IPPC.int) at: https://www.ippc.int/en/core-activities/standardssetting/ispms/

pests. PRA helps determine this distinction and what, if any, phytosanitary measures might be utilized to mitigate pests potentially harmful to plants and plant products.

NOTE: Initiation of a PRA involves the identification of pests or pathways for which a PRA is needed. By definition, a PRA must be conducted to determine whether an organism is a pest. This NAPPO science and technology document refers to species that contaminate commodities as ***contaminating organisms*** unless an organism has undergone PRA and has been identified as a pest or ***contaminating pest***.

There are a number of pathways on which contaminating organisms may be transported. While the scope of this document is restricted to contaminating organisms found with wood commodities and wood packaging materials, it could be applicable to other commodities and types of transportation (e.g., cardboard or plastic boxes). This document does not deal with inanimate contaminants, such as straw or particulates. The biology of the contaminating organisms and contaminating pests found with wood commodities, wood packaging materials, and conveyances are described to inform NPPOs in the development of PRAs and subsequent phytosanitary policy and measures.

1.1 Objective

The objective of this NAPPO science and technology document is to provide scientific information on living contaminating organisms associated with trade of wood commodities and wood packaging material and their associated conveyances, and to provide support for policy decisions addressing phytosanitary risks.

2. CONTAMINATING ORGANISMS AND CONTAMINATING PESTS

2.1. What are considered contaminating pests by countries?

Contaminating organisms, which might meet the definition of contaminating pests on wood or wood products, represent a wide variety of organism groups. These most notably include vertebrates, insects, mollusks, seeds, and fungi. Incidence of these intercepted pests by importing countries is subject to factors such as trade patterns, inspection activity, and seasonality, among others. Individual countries differ in their pest interception data collection methods. Resultant records often do not recognize “contaminating” as a distinct field, but close inspection of the interception data (e.g., pest species, commodity) may reveal if an interception should be considered a contaminating pest.

Countries generally recognize quarantine pests through a regulated pest list, which also includes contaminating pests.

Canada, the United States, and Mexico each develop and maintain a list of regulated, quarantine pests (and pollutants) under their respective plant protection acts (or standards), which must meet the following criteria:

1. they meet the IPPC definition of a regulated pest
2. they must be a quarantine pest for all parts of the country

(Government of Canada, 1990; USDA, 2020a).

Mexico has compiled a list of quarantine pests and pollutants intercepted in various imported forest products and by-products. The list is published as part of the Official Mexican Standards (NOM, Secretaría de Medio Ambiente y Recursos Naturales, 2021) that regulate phytosanitary imports of forest raw materials, products and by-products, specifically natural Christmas trees; new sawn wood; and bamboo, wicker, vine, or rattan, as raw materials used in basketry or plaiting.

New Zealand's Biosecurity Organisms Register for Imported Commodities (BORIC) database allows users to find the status of quarantine pests, both regulated and non-regulated (New Zealand Ministry for Primary Industries, 2021). New Zealand and other countries also employ more generalized "Contaminant Charts" for the benefit of biosecurity inspectors at ports of entry (New Zealand Ministry for Primary Industries, 2020). Databases have been shown to be helpful to inspectors in differentiating between contaminating organisms and infesting quarantine pests.

2.1.1. Interception data

The difficulty of associating contaminating organisms with certain pathways due to their opportunistic nature has been studied (Toy and Newfield, 2010). The most useful approach to obtain this kind of information is the examination of interception data. Most, if not all, countries conducting trade have instituted quarantine record-keeping systems designed to centralize interception data storage for easy and reliable access, analysis, and protection. While interception data can indicate entry pathways for contaminating organisms, it is difficult to quantitatively analyze this type of data as different pathways have different levels of inspection, reporting, identification, and recording (Turner *et al.,* 2020). An examination of the interception data gathered in the last twenty years for eight world regions (New Zealand, Australia, South Korea, Japan, United States, Canada, United Kingdom, and the greater Europe and Mediterranean) illustrates the lack of uniformity required for analysis (Rebecca Turner personal communication). For example, the South Korean dataset includes only interception frequency per species, while other countries like the United States of America record pathway, year, source country, and interceptions identified largely to higher taxonomic levels. Most countries have some form of host or commodity data column, but it's not always clear whether the intercepted specimen was infesting the commodity or was a contaminating organism (Turner *et al.,* 2020). The US Port Information Network (PIN) database has a host proximity column with in/on/with options, but other country's structure this differently. In many cases, contaminating status is based on limited quarantine information. Overall, the data provide a first step to identifying the types of organisms that are moving in international trade. Currently, inspecting and recording contaminating organisms presents challenges for global inspection protocols. Countries such as New Zealand and Australia have largely used inspection of the vehicle pathway to focus attention on contaminating ants, Asian gypsy moth (*Lymantria dispar asiatica* Vnukovskij, *Lymantria dispar japonica* Motschulsky, *Lymantria albescens* Hori and Umeno, *Lymantria umbrosa* Butler, *Lymantria postalba* Inoue) and brown marmorated stink bug (BMSB, *Halyomorpha halys* Stål).

Contaminating organisms and pests detected on imports to Australia were documented and summarized in a recent Commission on Phytosanitary Measure recommendation (CPM; FAO, 2018). Organisms listed as contaminating pests included insects, plant diseases, weeds, seeds, reptiles, scales, snails, slugs, and viruses. Additional analyses on the types of commodities contaminated with organisms coming into Australia have been conducted as part of a pest risk assessment for the contaminating pest brown marmorated stink bug (Australian Department of Agriculture, 2019).

The US Agricultural Quarantine Activity System (AQAS) and, more recently, Agricultural Risk Management (ARM) record quarantine activities conducted by the Department of Homeland Security (DHS), Customs and Border Protection (CBP), and APHIS Plant Protection and Quarantine (PPQ) at the ports of entry into the United States (USDA, 2011a). In Mexico, the Forest Health Analysis and Reference Laboratory from SEMARNAT General Directorate for Forestry and Soil Management has a database with records of organisms intercepted on inspections of wood packaging, products, and by-products. Canada's NPPO, the Canadian Food Inspection Agency (CFIA), in collaboration with the Canadian Border Services Agency (CBSA) collects and identifies suspect interceptions on various commodities and records this information in an internal database.

2.2 Wood commodities and conveyances that could carry contaminating organisms

Virtually anything that moves in international trade - including commodities, packaging, and conveyances they move with can provide a surface for contaminating organisms. Furthermore, contaminating organisms can originate in any country from which shipments originate or transit through. As such, contaminating organisms are truly a global issue.

For the most part, existing literature on contaminating organisms and pest interception and introduction is tied to a conveyance or pathway, not host or commodity, although there are exceptions. Contaminating pests, by definition, are not associated with particular hosts or commodities, although certain predilections do exist. For example, non-marine gastropods (snails and slugs) are commonly found on ceramic, marble, and cement tile consignments (Robinson, 1999). The khapra beetle (*Trogoderma granarium,* Everts), a NAPPO region regulated quarantine pest, is commonly associated with containers and conveyances where larvae that undergo long periods of diapause can remain hidden in cracks and crevices (NAPPO, 2019a).

2.2.1 Conveyances

A conveyance is broadly defined as something that is used to transport goods or people. While any conveyance has the potential to carry a contaminating organism, this document will focus more specifically on conveyances that are used to transport wood products in international trade. These conveyances are larger and typically travel longer distances and thus represent the greatest risk of carrying contaminating organisms from one area to another.

Sea containers

Since approximately 90% of world trade travels inside sea containers they are an important pathway for contaminating pest introductions. Sea containers may be referred to as shipping containers, twenty-foot equivalent units (TEUs) or freight containers. A freight container is defined in the Cargo Transport Code (CTU) "as an article of transport equipment that is of permanent character and accordingly strong enough to be suitable for repeated use; specially designed to facilitate the transport of goods, by one or other modes of transport, without intermediate reloading: designed to be secured and/ or readily handled, having fittings for these purposes, and approved in accordance with the International Convention for Safe Containers (CSC), 1972, as amended. The term "freight container" includes neither vehicle nor packaging; however, a freight container that is carried on a chassis is included" (IMO, 2014).

A study on interior and exterior contamination of empty containers in New Zealand found soil and associated pathogens, plant product (seeds), invertebrates (insects, spiders, snails), and reptiles in decreasing order of incidence (Brockerhoff, 2016). To reduce the risk of contaminating organisms moving with sea containers, New Zealand designed and implemented a sea container hygiene system which includes certified best practices such as cleaning and pest control (MAF, 2009).

Additional documentation on the heightened pest risk of contaminating pests on or in sea containers is widely available (Stanaway *et al.,* 2001; Gadgil *et al.,* 2002). In recognition of the importance of this pathway, a draft International Standard for Phytosanitary Measures, *Minimizing pest movement by sea containers* was added to the List of Topics for IPPC standards at CPM 3 in 2008 (Draft ISPM 2008-01). Most recently, the Sea Container Task Force (SCTF) has worked to determine if interim solutions have been effective and will make a recommendation at the end of 2021 to the CPM regarding the results of the initiative to raise awareness around the importance of sea container cleanliness. The SCTF recently published guidance on the best practices to reduce the spread of pests on commodities they do not infest (FAO, 2020a).

The North American Sea Container Initiative (NASCI) is working to provide guidance to border protection agencies and global shipping container companies for cleaning and inspecting sea containers (NAPPO, 2019b). NASCI compliments the International Maritime Organization's Code of Practice for Packing Cargo Transport Units (IMO, 2014). Since the CTU Code was updated in 2014, a supplementary document, *Prevention of Pest Contamination of Containers: Joint Industry Guidelines for Cleaning Containers,* was prepared in 2016 (COA *et al.,* 2016).

Maritime vessels

Maritime vessels are similarly involved in contaminating organism movement and offer a range of opportunity for organisms on decks, holds and stores (Lemay and Meissner, 2008). Asian gypsy moth (AGM) egg masses on ships are routinely intercepted in North America and other countries that have formal inspection programs which specifically target this pest (see section 3.7.1). In New Zealand, the burnt pine longicorn beetle, *Arhopalus ferus* (Mulsant), is a regular hitchhiker on timber cargo being shipped to Australia and has been more effectively managed with an improved understanding of pest biology and climatic data (Pawson, 2009).

Trucks and trailers

Reports of contaminating organisms on land transport are generally less well documented (Meurisse *et al.*, 2019). A great number of trucks, trailers and trains are used to forward sea containers, an important consideration in fully characterizing the truck, trailer and train conveyance pathway. Transport data from the Organization for Economic Cooperation and Development (OECD) demonstrate that road and rail are predominant modes for both freight and passenger transportation in most countries (ITF, 2017; Meurisse *et al*., 2019). Field observations of European gypsy moth (*Lymantria dispar* L.) egg masses on the surface of commercial land carriers are commonplace, and adults of emerald ash borer (*Agrilus planipennis* Fairmaire) are known to advance secondary spread in this manner (Buck and Marshall, 2009). Spotted lanternfly (*Lycorma delicatula* (White)) egg masses, nymphs, and adults can be transported on non-plant structures such as outdoor equipment and transports such as all-terrain vehicles, trailers, lawn tractors, and trucks (Pennsylvania Department of Agriculture, 2019). The potential for moving contaminating organisms, including those of quarantine significance, by land transport varies considerably and depends on pest life stage, time of year, and frequency of transport among other factors.

Compared to active land transport, there is considerable information on new and used vehicles as shipped commodities that potentially harbor contaminating organisms. Military vehicles are also a significant pathway for introductions as they are moved between countries. Used vehicles are viewed as higher risk due to factors that include storage and longer time for introduction of contaminating pests. New Zealand and Australia have implemented safeguarding programs for vehicle importation that consider BMSB and other contaminating pests (Australian Department of Agriculture, 2019). While incidence of a particular contaminating pest on imported vehicles may be low, overall introduction can be high due to sheer number of vehicles imported (MAF, 2008; Toy and Newfield, 2010).

Airplanes

Airplanes have long been recognized as a transport risk for contaminating pests. Over a 10-year period from 1997–2007, more than 1900 live pest interceptions, including insects, weeds, mollusks, and mites were recorded from aircraft holds in the United States (Meissner *et al.*, 2009). High profile pests of aircraft holds like Japanese beetle (*Popillia japonica* Newman) have prompted the use of exclusion devices on planes at the point of origin so that cargo can be successfully moved and accepted by western states (USDA, 2020b). Invasive plant pests were transported across the globe on or in plane cargo during World War 2, including the brown tree snakes, *Boiga irregularis* (Bechstein)) which were accidently introduced to Guam (Richmond *et al.,* 2015). Management of the brown tree snake in Guam is focused on limiting further dispersal by aircraft (Engeman *et al.*, 2018).

2.2.2. Wood commodities

A wide range of things that are considered “wood” are moved in international trade. These commodities may include, for example, unprocessed round wood, sawn wood, plywood, oriented strand board, or by-products from the manufacture of these, such as sawdust or wood chips. Wood moving in trade may also be the packaging used to contain or support a commodity, e.g., pallets, crates, or dunnage. Contaminating pests may be found in association with any of these wooden articles.

Round wood may be referred to as logs, poles, posts, timber, or pilings and is defined as “wood not sawn longitudinally, carrying its natural rounded surface, with or without bark” (ISPM 5). Round wood may be attractive to organisms that do not infest it. For example, the western conifer seed bug *Leptoglossus occidentalis* (Heidemann) may be found perching on logs or wood in the fall when looking for places to overwinter. Bark beetles may be attracted to round wood due to volatiles emitted by the wood (see section 2.3.1 Semiochemical attractants) but are not able to infest the wood. These organisms are often referred to as perching insects.

Sawn wood (lumber) is defined as “wood sawn longitudinally, with or without its natural rounded surface with or without bark” (ISPM 5). Sawn wood may include squared pieces of wood without bark or partially squared wood with one or more curved edges that may or may not include bark. In the commercial production and sale of sawn hardwood commodities, curved edges are commonly left for subsequent trimming (NAPPO, 2018).

With increased level of processing, wood becomes less attractive to organisms that are attracted by volatile compounds emitted by recently cut wood. Heat treated wood is less attractive to insects for example (Haack and Petrice, 2009). Some organisms may be attracted to stacks of lumber for refuge. Other insects, such as the BMSB *Halyomorpha halys,* (Stål; see section 2.2.2) are attracted to light patterns created by the spaces between boards.

Wood chips are wood fragments, with or without bark, produced mechanically from various harvested tree parts and processing residues or post-consumer wood material (EPPO, 2015). Some insects are attracted to the volatile compounds given off by freshly cut wood, and in rare instances may infest freshly processed wood chips. More frequently, insects attracted to freshly chipped wood will be present as contaminants. Many species of pathogenic decay fungi, canker fungi and nematodes may be present in wood chips with or without bark (RSPM 41, 2018), but most of these would have originated from infestation of the wood prior to chipping.

Wood packaging material (WPM) (including pallets, skids, pallet collars (collapsible sidewalls for a pallet base), containers, crating/crates, boxes, cases, bins, reels, drums, load boards, and dunnage) is constructed from solid or processed wood. When compliant with the ISPM 15 treatment, wood packaging is rendered essentially free of quarantine pests at the time of treatment. However, as with any other conveyance, contaminating organisms may become associated with any type of wood packaging material at any point while in service. The presence of contaminating organisms on ISPM 15 certified material does not necessarily indicate a failure of ISPM 15 treatment and should not automatically be reported as such. When an organism is detected on ISPM 15 certified wood packaging material, it could be a result of several factors including fraud, inadequate treatment, or contamination after treatment (Haack *et al.*, 2014). This should be taken into consideration when an importing NPPO is reporting a 'notification of non-compliance' to the exporting NPPO (ISPM 13, 2016). The most likely cause of a contaminating pest should be included in any notification given to the exporting NPPO.

Research has indicated that drying wood (whether through kiln treatment or equilibration to ambient moisture condition over time) may change the types of pests attracted to it (Naves *et al.*, 2019). This may be relevant for contaminating organisms that are attracted to host chemical volatiles in untreated wood with higher moisture content. The design structure of wood packaging material lends itself to refuge opportunities for some contaminating organisms. The likelihood of contamination may depend on the design of a particular type of wood packaging and the subsequent attractive qualities (see section 2.3.2 Visual Cues for further explanation).

2.3. Why do organisms contaminate wood commodities?

Contaminating organisms are found in association with virtually all internationally traded wood commodities, including forest products such as round and sawn wood, wood chips, wood packaging material, plywood, etc. How and why they become associated with wood varies with both the nature of the contaminating organisms and wood substrate. Some contaminating organisms are passively deposited from the air or in water droplets (this applies to most fungi) or are vectored by insects or other intermediary organisms (some fungi and nematodes), and finally others actively arrive under their own locomotion (by flying, crawling, slithering (snakes), or by adhesive locomotion (slugs)). In some cases, organisms are attracted to a substrate by sensory stimulation through chemical, thermal, auditory or visual cues, and in other situations they arrive by chance (Bell, 1990; Saint-Germain *et al.,* 2007). Certain biological traits increase the likelihood of invasion, primarily affinity to human activity (e.g., light and sound production) and human-related objects (e.g., surfaces for gypsy moth oviposition) (Leibhold, 1995). Other traits of successful contaminating organisms include: ability to complete the life cycle in highly disturbed habitats; a life stage that seeks sheltered areas; a life stage with dormancy that enables survival during transit; and association with common contaminants of commodities such as soil (Toy and Newfield, 2010).

Contamination on internationally traded wood commodities can occur at any point after pest mitigation measures, including: prior departure from the exporting country; in transit (following departure from the exporting country) via cross-contamination from other cargo or improperly cleaned ship's holds; or as a result of post-entry contamination in the importing country.

2.3.1. Semiochemical attractants

Insects can be attracted by volatile organic compounds that are naturally produced by the wood of living trees and wood products such as sawn wood, wood chips, etc. (Moeck, 1970; Wallin and Raffa, 2002; Saint-Germain *et al.*, 2007) or by other insects (Borden, 1989; Allison *et al.*, 2004).

Wood-produced chemicals, generally alcohols or terpenes, are used by insects to detect suitable hosts (Kirkendall *et al.*, 2008; Miller and Rabaglia, 2009; Oliver and Mannion, 2001; Roling and Kirby, 1975). Ethanol, a product of anaerobic metabolism, is released by weakened, stressed trees, sawn wood and wood products (Gara *et al.*, 1993; Kimmerer and Kozlowski, 1982; Steckel *et al*., 2010; Pohleven *et al*., 2019). It is attractive to many species of bark and ambrosia beetles (Graham, 1968; Hayes *et al.*, 2007; Miller and Rabaglia, 2009; Montgomery and Wargo, 1983). Some of these chemicals continue to be emitted long after the wood is cut and dried, although they are considerably reduced through heat treatment at high temperatures (Kačík *et al.*, 2012; Pohleven *et al.*, 2019).

When colonizing a new breeding substrate, insects often release aggregation and sex pheromones. Many insects are attracted to combinations of host volatiles and pheromones produced by other insects, suggesting that a suite of attractants are used by these organisms to find host material. Although this is likely more pertinent to the attack of trees, insects that are associated with any wood commodity could release semiochemicals, attracting other insects to the wood.

2.3.2. Visual cues

Insects employ a variety of sensors and inputs to orient themselves toward food, oviposition sites and mates. In some cases, visual and olfactory cues are used together to find an appropriate object or condition. Terrestrial gastropods have a range of visual quality and may use visual stimuli for locomotion toward food or away from predators (Chernorizov and Sokolov, 2010; Bobkova *et al.*, 2004).

Light (phototaxis)

Many insects are attracted to light. A well-known example of contaminating insect movement due to light attraction (positive phototaxis), is found in the Asian gypsy moth spread to North America. AGM are attracted to lights at ports where they deposit eggs on cargo and ships and upon arrival at North American ports, the larvae disperse (Schaefer and Wallner, 1992; Wallner *et al.*,1995). A number of Lymantriid moths are specifically attracted to light in the 480-520 (blue-green region) and 340-380 nm range (Crook *et al.*, 2014). Wallner *et al.* (1995) found that use of UV and blue light blocking filters made lights less attractive to female moths in the Russian Far East.

Most adult insects whose larvae develop in freshwater possess positive polarotaxis, i.e., are attracted to a source of horizontally polarized light which can include attraction to vertical glass surfaces and other artificial surfaces (e.g., asphalt roads, black plastic sheets, dark colored cars, dark glass surfaces, solar panels) that are reflecting highly and horizontally polarized light (Kriska *et al.*, 2008). Similar studies on tabanid flies have found that repellency and protection of livestock is improved with spotted, striped or white coat as background, effectively depolarizing light (Horváth *et al.*, 2017; Blaho *et al.*, 2013).

Shapes

Many bark beetles use a combination of cues to locate a host. For example, *Dendroctonus* species use cues to locate trees, and are attracted to objects that are upright, cylindrical shapes, similar to the silhouette and color of a host tree (Campbell and Borden, 2006). This information led to the design of funnel traps which mimic the silhouette of an upright tree. Some insects, like *Triatoma infestans* (Klug), exhibit a strong negative reaction to light and are attracted to black patches, potentially for shelter with and without olfactory cues (Reisenman *et al.*, 2000). Bees and wasps are attracted to dark cavities for nesting. Attraction to different patterns associated with shadows and cracks could also be associated with cardboard, metal, plastic or other materials.

2.3.3. Sound

Acoustic communication is generally widespread among vertebrate animals, but insects are the lone invertebrate group where sound production and hearing are widespread (Hoy, 1998; Pollack, 2017). Sound is generally divided into “airborne sound” and “sensing of vibration in the substrate,” the former being less prevalent in insects due to short wavelength constraints. Sound production when emitted is used to attract, repel or threaten. Sound is also used for detecting and locating predators, hosts and mates (Pollack, 2017). Sound is used, with varying degrees of success, as the basis for pest management programs focused on mating disruption and repellency. (Gammon, 2015; Mankin, 2012).

A variety of beetles use acoustic sounds or “chirping” produced by the friction of body surfaces to communicate. They use these calls to signal aggression and mating readiness (Barr, 1969; Rudinsky and Michael, 1973). Sound production can also be used for predator avoidance (Spangler, 1988) or host detection in the case of parasitic insects such as the tachinid fly (Lehmann and Heller, 1998). Arthropods and vertebrates generally produce sound for communication in the range of 1-10kHz; abiotic noise is typically below this level (Luther and Gentry, 2013). However, anthropogenic noise can be heard at a wide range of frequencies. Depending on the species, it can lead to interference of communication, altered behaviors, confusion, or attraction to auditory cues of human origin (Bunkley *et al.*, 2017). Some organisms, particularly those with fast reproduction and short life cycles, such as *Oecanthus* tree crickets, adapt to noise pollution quickly with little interference to communication (Costello and Symes, 2014). The emergence of data on the effect of anthropogenic sound on insect communities has important implications for the management of shipped commodities. Bunkley *et al.* (2017) conducted studies on industrial natural gas fields with elevated noise levels due to compressors and other increased background noise and confirmed distributional change in insect communities as a result. Commercial activities around ports and other industrial locations, involving shipping and storage could have similar effects on the nature and potential of contaminating organism levels present.

2.3.4. Temperature

Thermal signals may be detected by insects in search of food sources and habitat. The western conifer seed bug, *Leptoglossus occidentalis*, has specialized organs that detect infrared radiation emitted by their main food source, conifer cones (Takács *et al.*, 2009). Multiple insect orders are attracted from great distances to infrared radiation emitted by fires. As the fires subside these insects attack the damaged trees that would otherwise be uninhabitable. *Melanophila acuminata* (DeGeer) has been reported to fly up to 80km to reach burning materials (Evans, 1964; Schmitz and Bleckmann, 1998).

Thermoreceptors on insects vary greatly by species. Some insects can detect minor temperature changes, such as conifer cones that are 15 °C warmer than conifer needles. Others can sense large spikes in temperature, such as fires ranging from 500 to over 1000 °C (Takács *et al.*, 2009; Schmitz and Bleckmann, 1998). This attraction to heat may pose a risk during wood processing and storage. For example, wood with residual heat following kiln treatment or wood exposed to sunlight may result in attractiveness to a range of contaminating organisms.

2.3.5. Moisture

Olfactory receptors are used by many organisms to locate sources of water vital for metabolic function. Odorant receptors in vertebrates are comprised of two major classes of receptor genes. The first class is believed to detect water soluble odorants primarily found in fish, amphibians, and some mammals. The second class found in tetrapods, likely detects airborne odorants (Freitag *et al.*, 1998). Insects such as the blowfly, *Phormia regina* (Meigen), detect water with chemoreceptors in their antennae and tarsi. The presence of hygroreceptors in insects also gives some species the ability to detect moisture and humidity (Tichy and Kallina, 2013; Wigglesworth, 1972).

While organisms use various methods to locate water directly, others may use indirect methods such as detecting volatile organic compounds (VOC's) that can be emitted from other biotic components of the ecosystem that are associated with water. Fungi and microbes cause the release of VOC's when they decompose wood, which can attract symbiotic insects that make use of the altered substrate and food source. Predatory or parasitic insects may also be attracted to these conditions (Mali *et al.*, 2019; Kandasamy *et al.*, 2016). Small, slow moving vertebrates such as snails and slugs similarly use VOC's, released by plants, diatoms and algae, to locate a moist habitat that contains sustenance (Brönmark and Hansson, 2012; Hanley *et al.*, 2018).

2.4. Behavioral considerations

Contaminating organisms may choose a wood substrate based on its suitability to increase survival. This can include features that increase predator avoidance and provide protection from the elements, both short and long-term depending on each species seasonal movements. The characteristics of the substrate and surrounding habitat may also be chosen for its abundance of nest-building materials and possible nest locations. Organisms that rely on passive dispersal may be more likely to reach certain substrates based on the movement of wind and water through the natural landscape.

2.4.1. Refuge

Following arrival on a substrate, many insects assess the conditions for refuge (moisture content, light/dark, temperature), oviposition (bark presence), negative and positive geotaxis and determine suitability for refuge. Many organisms make use of camouflage within their environment to avoid predators. The Tulip-tree beauty moth, *Epimecis hortaria* (Fabricius), finds shelter on matching tree bark making it very difficult to locate. Other species make use of holes and crevices or hide under bark or in hollow logs. These shelters also provide protection from the elements such as extreme temperatures, precipitation, and wind.

2.4.2. Rest

In some cases, insects rest on objects when searching for or travelling to food, mates, or shelter. Migratory behavior can result in sudden arrival of insects that are travelling toward wintering sites or making the return trip. This can sometimes take place over multiple generations in which case each generation stops and lays eggs before dying. The offspring then continue migrating and repeat the process in a new location. Migration can take place over long distances or locally depending on the species and location. Some species such as the red palm weevil, *Rhynchophorus ferrugineus* (Olivier), fly short distances at a time before resting while others use the wind to propel them great distances, as is the case with the cabbage webworm, *Hellula undalis* (Fabricius) (Ávalos *et al.*, 2014; Shirai and Yano, 1994).

2.4.3. Nesting

Wood which is stored undisturbed for a length of time may provide suitable nesting sites for a range of organisms including, but not limited to, solitary wasps, bees, spiders, moths and ants. Leaf-cutting bees (*Megachilidae* species) use crevices and pre-existing cavities in wood for nesting sites (Michener, 2000). The giant wasp *Vespa mandarinia* Smith also build nests in pre-existing cavities in wood but are more often found in subterranean, concealed cavities (Matsuura and Sakagami, 1973).

Conveyances such as sea containers can also provide suitable nesting sites for a range of vertebrates and invertebrates (see section 2.2.1). The interior of sea containers, including under the floors, provide suitable refuge and nesting sites for stored product pests, wasps and more (Stanaway *et al.*, 2001).

2.4.4. Wind, water dispersal

Some organisms or materials, for example fungi, nematodes, seeds, or soil, that could be considered contaminants do not actively sense, assess and choose substrates but are deposited passively by means of wind, water, or vectoring organisms.

Fungal spores, for example are able to disperse considerable distances, and many are spread via wind (Anemotaxis). Spores can also be dispersed by vectoring insects, animals, or rain. Rust spores have been shown to travel as contaminating organisms on commodities or packaging as in the case of *Austropuccinia psidii* G Winter in (Grgurinovic *et al.*, 2006); but their survival and risk of spread is extremely low (Lana *et al.*, 2012). Spore longevity varies greatly among fungal species and should be considered in assessing risk of fungal spores as contaminants (Sussman, 1982). Fungal spores are very common in the air and could be detected as contaminants on wood products, especially with highly sensitive molecular detection methods. Their presence, however, does not necessarily imply risk, and careful evaluation of the potential for transmission to new hosts should be considered.

Some nematode species can survive for long periods of time, in some cases decades (Wharton, 1986), in a desiccated state (anhydrobiosis) and be wind-dispersed with fine soil particles (Fielding, 1951; Carroll and Viglierchio, 1981; Guar, 1988; Treonis and Wall, 2005; Nkem *et al.*, 2006). When they land on moist surfaces (including stacks of sawn wood), these nematodes can rehydrate and feed on fungi and bacteria. Foliar nematodes (e.g., *Aphelenchoides*) can be dispersed by water droplets to nearby surfaces (other vegetation or wood) (Kohl *et al.*, 2010).

Other passively dispersed organisms such as bacteria and pollen could be considered contaminants. Plant pathogenic bacteria, for example *Erwinia amylovora* (Burr.) Winsl. *et al.* and *Ralstonia solanacearum* (Smith) Yabuuchi, Kosako, Yano, Hotta & Nishiuchi have been reported as contaminants on fruit crates and wood (Ceroni *et al.*, 2004; di Bisceglie *et al.*, 2005).

2.5. Biological considerations of risk

An understanding of the biology of the organisms associated with a commodity, including which life stages could be transported and survive the duration of the voyage, existing climatic conditions en route, and post-shipment host contact is essential to determine risk. These biological considerations of risk are factors considered in the pest risk assessment stage of a pest risk analysis (PRA) (ISPM 2, 11 and 21).

2.5.1. Life stage

Different life stages of contaminating organisms have different inherent risks depending on factors such as the commodity, transport pathway on, and post-entry conditions. The life stage of a given organism may create a greater or lesser risk. For example, life stages which can withstand unfavorable conditions pose more risk than a life stage with specific needs. Khapra beetle larvae exhibit hardiness, withstanding long periods of diapause under various conditions in cracks and crevices of containers and conveyances (Ahmedani *et al.*, 2007; NAPPO, 2019). Eggs of many organisms are difficult to detect and have varying levels of hardiness which enable them to be translocated successfully attached to the exterior of a human-made object (see AGM example, section 2.3.2).

2.5.2. Physiological requirements

The physiological requirements of a given contaminating organism determine the level of risk and are taken into consideration when conducting a pest risk analysis. For example, an obligatory rest period (e.g., diapause) or an alternate host may be required for an organism to complete its lifecycle. In such cases, the inherent risk associated with that organism may be very low if the required conditions are not met during transport or upon arrival. These risk factors would be assessed in a pest risk analysis.

Diapause is a state of dormancy often entered by organisms to survive extreme environmental conditions. In some cases, diapause is triggered by environmental conditions (facultative) and in others it is obligatory depending on life stage (Kostál, 2006). If diapause requirements are not met for a particular life stage on the pathway, then the risk is negated (e.g., temperature requirements in degree days for egg hatch).

The germination of spores of some fungi, notably rusts, is stimulated or suppressed by host-derived volatile compounds (French, 1992). When such compounds are absent, as would likely be the case for passively deposited fungal spores, germination would not occur or would be very low. For example, urediniospores of *Puccinia* (*Austropuccinia*) *psidii* did not germinate in distilled water but showed 88% germination when exposed to the host volatile compound Hentriacontane (Tessman and Dianese, 2002).

2.5.3. Reproductive considerations

Reproductive status or reproductive strategies of contaminating organisms factor into assessing risk. For example, a single gravid (mated) female carries more potential for successful invasion than an unmated female or single male insect, mollusk, or vertebrate organism. The potential for a large egg batch size further increases the associated pest risk of a mated female. Reproductive strategy (for example, parthenogenetic (asexual) organisms such as the hemlock woolly adelgid, *Adelges tsugae* (Annand) (Havill *et al.*, 2006) versus sexual organisms) is also an important consideration. Likewise, organisms with haplo-diploid strategies where sib-mating and oedipal-mating occur do not require a sexual mate, and thus have an advantage in a new environment. (Kirkendall *et al.*, 2015).

2.5.4. Establishment potential

The probability of establishment can be estimated using information about a given contaminating organism such as its life cycle, availability of suitable hosts, suitable environment, reproductive strategies, natural dispersal mechanisms, and other factors affecting its survival in areas where it naturally occurs. These can be considered in a pest risk analysis conducted by the importing country. Training material on pest risk analysis, including establishment potential, is provided by the IPPC and is based on IPPC standards ISPM 2, ISPM 11 and ISPM 21 (FAO, 2020b).

3. PHYTOSANITARY MEASURES TO REDUCE THE INCIDENCE OF CONTAMINATING ORGANISMS

Specific measures were discussed in previous sections on a case-by-case basis. Listed below are examples of existing programs and associated best practices which have been implemented to reduce the risk of specific contaminating pests. The individual measures identified below are not intended to provide a comprehensive list of approaches to mitigate contamination. Furthermore, the absence of a measure in this list is not a reflection of that measure's effectiveness in mitigating contamination.

3.1 Measures applied immediately prior to shipping

Treatment immediately prior to shipping is meant to mitigate specific contaminating pests, i.e., regulated quarantine pests. While this practice decreases the risk of contamination, its applicability and effectiveness may be limited by the nature of the commodity, timing of contamination, the best management practices utilized post treatment (e.g., physical barriers), and the types of treatment available. The risk-reduction options outlined below may be used to mitigate the presence of non-regulated contaminating organisms as well.

Treatments for wood commodities can generally be separated into two major categories, chemical or non-chemical. Fumigants dominate the chemical category, with methyl bromide most commonly used in both containers and under tarpaulin. Many countries are moving away from methyl bromide due to environmental concerns (Velders *et al.*, 2007). In addition, aerosols, dips, dusts, and sprays are featured as chemical treatment options in certain instances. Among non-chemical treatments, heat treatment in various forms is the most commonly utilized. Cold treatment and irradiation are also classified as non-chemical treatments, with use mostly restricted to perishables. Treatments for conveyances could include fumigation, pesticide application, inspection, and cleaning.

Heat treatment

Heat treatments (including conventional dry heat treatment, forced hot air, steam, vapor heat and hot water immersion) are effective for a wide variety of contaminating organisms. Schedules will vary depending on the contaminating pest, the nature of the commodity, and other circumstances. Dielectric heat, which includes microwave and radio frequency, is recognized as a treatment alternative in ISPM 15 for solid wood packaging material (ISPM 15, 2019). Products sensitive to heat, such as living plants or Christmas trees, will not be able to undergo heat treatment (NAPPO, 2014).

Fumigation

Fumigation is widely available and is generally easy to apply to consignments of commodities and containers, but efficacy may be a concern depending on the type of forest product commodity and proper application among other factors. Furthermore, fumigation may not be applicable because of chemical absorption, toxicity or environmental and health concerns. Processes to recapture methyl bromide to fumigate forest commodities have also been successfully developed. Sulfuryl fluoride and phosphine are also listed as alternative fumigants for certain commodity categories. Proper application of fumigation requires a licensed professional who is certified.

Physical removal of pests

In some cases, commodities can be cleaned of contaminating pests prior to shipping. For example, as recommended in RSPM 37, *Integrated measures for the trade of Christmas trees,* trees

> "may be mechanically shaken using a motor or tractor driven shaking unit. This method is considered to be effective in reducing the incidence of some pests on trees. Each unbound tree should be shaken with sufficient intensity and duration to dislodge insects and other contaminants, and until most of the dead needle fall is eliminated" (RSPM 37, 2012).

This procedure has been shown to be effective in the removal of yellow jackets (*Vespula* spp.) (Hollingsworth *et al.*, 2009) and has been implemented in import regulations for Christmas trees to Hawaii and other countries. Signs of contaminating pests may also be identified through inspection and removed (e.g., ant or wasp nests).

In sawn wood production, processing steps such as debarking, squaring of round wood, and plaining of sawn wood can physically remove infesting and contaminating pests which may be present (RSPM 41, 2018).

Timing

Most measures that are applied have no lasting effect against contaminating organisms, unless they are chemical treatments (e.g., preservatives, anti-sap stain, fungicides, and insecticides) that remain in the treated material or on the surface at sufficient concentrations to provide residual protection. However, some organisms may contaminate commodities regardless of any residual level of chemical remaining on or in the material.

Because of the temporary effectiveness of these measures, there is no guarantee that treated materials are free of contaminating organisms. The likelihood of contamination will increase with time after treatment, and storage conditions should also be taken into consideration when assessing the likelihood of contamination. A system of approaches commensurate with the determined likelihood of contamination should be implemented to prevent transportation of these organisms.

Inspection

Inspection may occur as a measure applied immediately prior to shipping. Even with its limitations, inspection may be the most appropriate measure. A sampling intensity level can be developed from information found in the AQIM Manual (USDA, 2011b), or equivalent guidance from other countries, or ISPM 31 (2016), which contains detail on inspection in section 3.9.

3.2 Pesticide application

The international trade in WPM mandates use of approved fumigants (methyl bromide, sulfuryl fluoride) along with heat or dielectric treatment as described in ISPM 15 but does not recommend topically applied pesticides. However, the use of topically applied pesticides in liquid form is used extensively on logs and processed wood by a number of countries, primarily for domestic protection at commercial wood processing facilities, as is the use of aerosols for the protection of containers and conveyances. Large-wood treatment companies have formed specific divisions to address pest deterrence and improved wood preservation.

The application of pesticides can provide an added layer of protection against contamination. Pesticides are typically applied to wood with treatments such as spraying, rolling, dipping or vacuum/pressure impregnation. A variety of formulations exist that can be used for pesticide application (Lebow, 2010). Pesticides that are applied to commodities such as wood are generally applied during processing and prior to shipment. Conveyance or container applications are generally applied pre-shipping (MAF, 2009). Most onboard pesticide applications are related to ship management and restricted to rodents, cockroaches, and stored product pests (United States Navy, 2008).

Toxicity of chemicals used as treatments can be a concern for human health. There may also be safety concerns with handling due to surface residues. Also, importing and exporting countries need to agree upon what substances are permitted and at what concentrations. Pesticide schedules can be customized to meet the required duration of protection in accordance with the label specifications.

3.3 Shipping season

Contaminating pests associated with wood commodities may show seasonal development and be dormant or in immature life stages at certain times of the year. Also, some pests are only associated with commodities or conveyances at certain times of the year, for example at the time of feeding, oviposition, or overwintering site selection. During these times, the cold or dry season for example, it may be possible to export wood commodities with little risk of transporting life stages capable of establishing in a new environment. However, when commodities are shipped from cold to warm climates, pests may become activated if dormancy requirements have been met (e.g., diapause in some insects). For example, Asian gypsy moth eggs laid on the side of shipping containers or other substrates or conveyances may complete development requirements en route and be ready to hatch and disperse upon arrival (models for shipping route development of AGM illustrate this example, Gray, 2016). Vessels visiting AGM infested areas are regulated during periods of the year when female flight occurs (RSPM 33, 2017). An example from the USA is exportation of heat-treated lumber outside the flight season (October–April) of sawyer beetles, *Monochamus* spp. This ensures that neither pinewood nematode, *Bursaphelenchus xylophilus*

(Steiner and Buhrer) Nickle nor its vector, *Monochamus* spp. are transported (Bragard *et al.*, 2018). Careful consideration of pest life cycles, shipping windows and transit across seasonal temperature zones should be made in assessing pest risk and developing import regulations.

3.4 Areas of pest freedom or low pest prevalence and pest free areas of production

Pest free areas (PFAs) are a valuable mitigation strategy because once they are identified, certified, and fully implemented, they do not require further action from a shipper to ensure freedom from contaminating pests in cargo (FAO, 2019). Pest free areas are defined as "an area in which a specific pest is absent as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained" (ISPM 5, 2021). An area of low pest prevalence (ALPP) is defined as "an area, whether all of a country, part of a country, or all or parts of several countries, as identified by the competent authorities, in which a specific pest is present at low levels and which is subject to effective surveillance or control measures" (ISPM 5, 2021).

Pest free areas can be difficult to establish, certify and maintain and assessment is specific to each pest. PFAs do not preclude the transport of non-quarantine pests or organisms that have not been identified. They require a thorough and effective certification process to ensure that the area is free from pests or poses an acceptable reduced risk. This certification process also needs to be clearly developed, communicated, and agreed upon by the importing and exporting NPPOs (ISPM 4, 2017).

3.5 Storage

When schedules do not permit shipment of commodity immediately following processing, storage options may be considered. Commodities may be stored in a variety of places and conditions using best management practices, depending on the risks associated with contaminating organisms that may be present Producers, processors, and shippers should be aware of contaminating organism concerns in markets they are shipping to and should develop mitigation procedures accordingly. Storage options may vary depending on the type of commodity, environmental conditions (temperature, relative humidity), time of year and potential associated contaminating pest risks.

Proper storage of products includes the implementation of best practices that have proven to be effective over time in reducing the likelihood of (or eliminating altogether) contaminating organisms. The effectiveness and application of these practices can be dependent on the type of pest in question as well as ambient environmental conditions. Importing and exporting countries should share information on what are the most effective practices and how to implement them. Ideally, shippers, freight forwarders, and shipping equipment manufacturers should all be involved in developing effective practices that do not create barriers to trade.

Best management practices should be used to minimize the risk of wood commodities becoming contaminated. Examples of these practices are related to storage as well as handling. They include but are not limited to:

Storage:

- Store indoor when at all possible;
- When stored outdoors, cover with shade or anti-pest organism net;
- Store as far away from live trees and shrubs as possible;
- Do not store under bright lights, particularly at night;
- Store off the ground, ideally on a dry riser and/or a solid surface;
- Do not store in weedy or grassy open yard areas;
- Avoid contact with water and other fluids.

Handling:

- Inspect wood commodities for contamination before use;
- Sweep or spray wood commodities with compressed air to remove any contaminants;
- Rotate inventory as much as possible (first in, first out approach) to prevent wood from sitting in one place for too long.

Protecting:

- Store logs under water or spraying water (hardwood and softwood) as a protection;
- Use anti-aggregation pheromones to deter secondary insect contamination (Hughes *et al*., 2017; Borden *et al.*, 2001).

Other:

- Maintain clean floors, containment, wrapping, and yards (e.g., sanitation may include bark removal in log yard);
- Decrease storage periods;
- Conduct surveillance on three party import operations;
- Conduct surveillance on courier shipments.

3.6 Systems Approaches

Systems approaches may provide an option for mitigating the occurrence of contaminating pests on forest products. A systems approach is defined as “a pest risk management option that integrates different measures, at least two of which act independently, with cumulative effect” (ISPM 5, 2021). Systems approaches for forest products as outlined in RSPM 41 (2018) include mitigation options employed at different critical control points along the production pathway to the final import destination where post-shipping treatments may be applied. Mitigation options may be implemented during production, storage, shipping and post shipping, for example. At each point an option is employed to reduce the risk of a given pest. Systems approaches may be designed for contaminating organisms or pests in the same way they are used for infesting pests – using biological information about a given pest and applying sound scientific approaches to pest mitigation. An example of a systems approach used for a contaminating pest is the Canadian Sawn wood Certification Program which combines inspection, segregation of organism-free wood, specified storage conditions, oversight, traceability and a manual specifying the components of the system -- including inspection procedures for brown marmorated stink bug (CFIA, 2019). New Zealand has implemented a systems approach to mitigate contaminating organisms moving with sea containers in the Pacific Island region which combines cleaning, storage on hard surfaces, pest control, reducing pest habitat in port areas, auditing, and certification (MAF, 2009; Ashcroft *et al.*, 2008).

3.7 Post-shipping risk-reduction

Contaminating organisms may become associated with a commodity or conveyance at a number of points along its export-import pathway, from the site of production to the final destination. Post-shipping treatments provide an opportunity to address contaminating pests before they leave the commodity or conveyance they are contaminating and potentially establish in a new environment. Post-shipping mitigation may include any post-production measures applied before shipping (listed in Section 3), such as physical removal of organisms, pesticide treatment, fumigation, heat treatment, etc. Storage, restricted use, and/or limited distribution at destination are alternative options used to address contaminating organisms associated with a product (for example, wood chips to be used for pulp or biofuel). Processing post-shipping in conjunction with careful storage requirements may be deemed a risk-reduction option.

3.7.1 RSPM 33 Pre-entry inspection for Asian gypsy moth

RSPM 33 (2017) provides guidelines for risk management practices to minimize the entry and establishment of the Asian gypsy moth (AGM) which are specifically related to inspection procedures and subsequent certification of vessels prior to reaching a port of entry. These practices can be applied to other contaminating organisms as well. They include inspection and certification of the vessel by an NPPO official prior to departure and ongoing intensive inspections by vessel crew while en route to the destination. If any signs of AGM or other pests are discovered, they are removed and disposed of or destroyed. The Manual for Agricultural Clearance (USDA, 2012) also provides special procedural guidance and a protocol for suspect Asian gypsy moth on ships.

This approach poses nominal disruption to trade for compliant vessels while reducing risk of contamination. It does require enhanced communication between importing and exporting NPPOs to agree upon inspection and certification approaches, as well as training of NPPO officials and vessel crew.

3.8. Inspection

Inspection is commonly used by both exporting and importing countries to certify pest presence/absence or phytosanitary status of wood commodities and transport vessels. Inspection is defined as the “official visual examination of plants, plant products or other regulated articles to determine if pests are present or to determine compliance with phytosanitary regulations” (ISPM 5, 2021). ISPM 23 (*Guidelines for Inspection*) and ISPM 31 (*Methodologies for Sampling of Consignments*) support the use of inspection as a phytosanitary measure. Each country can stipulate its own inspection rules and the comprehensiveness of its policies. Varying levels of inspection frequency and scrutiny can be a challenge for importing and exporting NPPOs reaching agreement on acceptable protocols. Moreover, inspection requires appropriate infrastructure at ports of entry. The importing country must also determine how to handle contaminated shipments and must develop appropriate courses of action, e.g., fines or penalties, for non-compliant cargo found during inspection.

There are specific drawbacks to inspection. Inspection requires well-trained personnel to be effective. In addition, because inspection is time and resource intensive only a small percentage of imported goods are typically inspected. Challenges are magnified by the cryptic nature of contaminating organisms. Contaminating organisms can found in tight crevices and be well-camouflaged.

Inspection success can be improved through the identification of higher-risk pathways and/or lower risk shippers. By using a risk-based sampling approach (See Section 3.8.1 below) to identify high risk pathways inspectors can focus efforts on the most likely sources of contaminating organisms. Voluntary programs, such as Customs Trade Partnership Against Terrorism (CTPAT) in the United States, help to identify shippers who are willing to adhere to strict guidelines to ensure minimal phytosanitary risk, so that resources can be devoted to higher risk pathways (US Customs and Border Protection, 2021).

Inspection of commodities and conveyances may take place at any point along the commodity pathway. Mandated cleanliness of the commodity after phytosanitary measures have been applied is typically determined in consultation with the producer and the exporting NPPO. Inspection details and record keeping are part of a production manual approved and certified by the NPPO of the exporting country.

In Mexico, the verification of imported forest products and by-products is overseen by the official personnel of the Federal Attorney for Environmental Protection (Procuraduría Federal de Proteccion al Ambiente-PROFEPA), and then carried out in the facilities of ports, airports, and national borders. The official procedures for the phytosanitary inspection and for the decision making that are mandatory in this regard are established in the *Manual of Procedures for the Import and Export of Wildlife, Forest Products and By-Products, and Hazardous Materials and Residues, subject to Regulation by the Ministry of Environment and Natural Resources (Manual de Procedimientos para la Importación y Exportación de Vida Silvestre, Productos y Subproductos Forestales, y Materiales y Residuos Peligrosos, Sujetos a Regulación por parte de la Secretaría de Medio Ambiente y Recursos Naturales)* which has been published in the Official Gazette of the Federation since 2004.

3.8.1 Risk-based sampling

Inspection for the detection of pests is a sampling process based on the statistical concepts associated with the probability of detection. Risk-based sampling (RBS) is defined as:

> "sampling that takes account of the probability of detection to determine the sample size for an inspection. The number of items to be inspected will vary depending on the level of infestation to be detected, the size of the consignment, and the pest risk. In RBS, sampling

frequencies are based on the relationship between actionable pest detections and specific inspection variables (e.g., type of commodity, origin, consignee, etc.)" (NAPPO, 2017).

By designing inspection processes around basic statistical concepts, inspection programs better identify and rank non-compliant imports. This has been used by countries for identifying high risk commodities associated with contaminating pests.

The United States of America use an improved risk sampling approach that requires the use of a tiered sampling process to estimate the amount and kind of quarantine pests approaching a location via various known pathways of pest entry (USDA, 2011b). In the past, selective criteria (targeting) were employed to choose inspectional units that were considered to have a higher likelihood of harboring pests. Under the current AQIM, sampling for information is randomized to create a better representation of an entire population and allow for statistical analysis of data. Based on gathered information and statistical analysis, sampling for detection can be accomplished to ensure that certain members of the population have a higher probability of being sampled if necessary. Sampling schemes are often designed specifically for each inspection location to reflect unique characteristics of that location and its personnel. Recommended hypergeometric tables (sample size calculator) for random sampling in commodity inspection across major pathways are included in the AQIM manual, with noted reference to hitchhiker pests as part of the inspection procedure. Canada uses both a target-based approach for a commodity or pest and a randomized sampling approach for determining sampling lots, and inspection units.

The size of a sample for inspection purposes usually depends on a risk-based sampling objective. The sampling objective is influenced by the risk associated with a specified regulated pest of a specific commodity from a particular origin (*i.e*., country, grower, exporter) (Plant Health Import Inspection Manual, USDA 2012). The NAPPO *Risk-Based Sampling Manual – Part I*, outlines how to design, evaluate, and manage risk-based sampling (NAPPO, 2021). Europe, Australia, and many other importing countries all have individualized risk-based sampling programs that combine elements of random and targeted sampling. Operational costs and other considerations often dictate that targeted-based inspection sampling be the favored approach.

3.8.2 Manual

When a manual is required to address a specific contaminating pest, it may contain, as appropriate, the following:

- best practices in consignment inspection and risk assessment;
- record maintenance;
- development of phytosanitary management systems to align with requirements of importing countries.

For example, the AQIM Handbook provides a decision-making process from which a manual can be created. The handbook includes decision tables, where 'hitchhiking' (contaminating) pests are used as a recognized category. Inspection information is then entered into the Agricultural Quarantine Activity System (AQAS) database.

3.8.3 Training

Training and competency of inspectors and other personnel are an important aspect of verifying that pathways and products are free from contaminating pests. An accredited body or institution should provide training for quality and consistency. Training should address the facility and exporting country's NPPO (accreditation body) requirements.

3.8.4 Audit

In some instances, phytosanitary requirements are formally agreed between trading partners. Audits and oversight of the inspection, certification, and phytosanitary management aspects of these agreements, plus authorized certification are critical to ensure integrity and maintain transparency. Audits of authorized facilities are important for identifying non-conformances, corrective actions, and the need for follow-up audits. Corrective actions may be monitored by the NPPO. The NPPO of the importing country may request the NPPO of the exporting country to provide reports on audits undertaken.

3.9 Traceability

Traceability as a phytosanitary management tool was introduced in 2013 as an element of the draft specification for a proposed IPPC standard for the international movement of grain. Concern that "traceability" required further discussion and understanding beyond the scope of the grain standard prompted its removal from the standard at that time (IPPC, 2014). In subsequent review of existing standards and ISPM's, traceability generally described concepts of origin, trace-forward, and trace-back. The 2013 Grain Strategic Experts Meeting Report (IPPC, 2013 cited in IPPC 2014) describes traceability as "a program management tool and documentation responsibility (of the NPPO) that facilitates distinguishing lots of commodities in trade based on the type of product, pest risks, and specific procedures that are applied to meet particular phytosanitary objectives (e.g., pest free area)". More recently, traceability was defined in RSPM 41 as "the documentation and verification of the movement of the commodity from the initial control point to the final product" (RSPM 41, 2018). This is accomplished through universal recognition and use of phytosanitary certificates or third-party certificates (under NPPO oversight) as an instrument that guarantees regulated articles meet specified phytosanitary import requirements.

The vast majority of successful trace-back and trace-forward programs have been restricted to positive pest/host relationship, *i.e.*, infested wood material. Contaminating organisms are not host specific and can contaminate a commodity in many places along the commodity pathway, thus traceability can be more difficult to achieve when required. For this reason, successful trace-back and trace-forward programs should be designed with flexibility that considers cost, difficulty of identifying a product to origin, transportation and distribution logistics, and other factors. It may be advantageous to broaden focus from commodities to include conveyance and pathway, as focus on the commodity alone may not be beneficial in some cases. Successful trace-back programs for Asian gypsy moth on ships, snails on military ordinance containers, and brown marmorated stink bug on vehicles are but a few examples. Bilateral agreement between industry and regulatory authorities is essential in developing and maximizing the potential of traceability programs.

4. CONCLUSIONS

A wide range of organisms move with commodities and conveyances in international trade. These organisms can be categorized in two ways: by the damage they cause (quarantine or non-quarantine pests), and the nature of their association with commodities or conveyances (infesting or contaminating organisms). Historically, most of the regulatory focus has been on infesting organisms, and phytosanitary measures have been developed to prevent their movement. Contaminating organisms can be more difficult to predict, and where they are deemed to be quarantine pests, different approaches may be needed to prevent their movement. Many kinds of organisms can be considered as contaminating and their respective mitigation strategies vary greatly. Some, through the PRA process, may be determined to be non-problematic and are not regulated as quarantine pests. Others might be determined to be regulated quarantine pests, and mitigation options should be developed. This paper provides scientific information related to how and why contaminating organisms become associated with commodities and conveyances and provides information that can be used to develop science-based tools to identify and mitigate the risk of their movement with wood products.

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