Symposium contribution

Nonindigenous species introductions: a threat to Canada’s forests and forest economy[1]

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Abstract: When organisms are moved from their natural range to new ecosystems, they are considered nonindigenous, invasive, or exotic species. Movement of exotic or native species may be international or from areas within Canada. Historically, Canada’s forests have felt the effects of nonindigenous species introductions, as for example, Dutch elm disease, white pine blister rust, gypsy moth, and pine shoot beetle. With changes in global trade patterns, novel introductions will continue to occur. Although most of the research and regulatory efforts to control the movement of nonindigenous species has focused on insects, projects are underway to study fungal organisms and their association with insect vectors. International quarantine standards are being developed to minimize the risk associated with solid wood packing materials, a major entry pathway for nonindigenous organisms. Research needs include the development of enhanced detection capabilities, improved diagnostic tools, effective mitigation measures, as well as socio-economic impact assessments and basic biological information about nonindigenous species and their interactions with hosts.

Key words: nonindigenous species, invasive, exotic pests, quarantine, forestry, introductions.

Résumé : Lorsque des organismes sont transférés de leur aire naturelle à de nouveaux écosystèmes, ils sont vus comme des espèces étrangères, envahissantes ou exotiques. Les déplacements des espèces exotiques ou indigènes peuvent être internationaux ou se faire entre des régions du Canada. Historiquement, les forêts canadiennes ont subi les contrecoups d’introductions d’espèces étrangères; prenons pour exemples la maladie hollandaise de l’orme, la rouille vésiculeuse du pin blanc, la spongieuse et le grand hylésine des pins. Avec les changements associés à la mondialisation des échanges, de nouvelles introductions continueront à se produire. Bien que la plupart des efforts de recherche et de réglementation pour limiter les déplacements d’espèces étrangères aient été centrés sur les insectes, des projets sont en cours pour étudier des organismes fongiques et leur association avec des insectes vecteurs. Des règles internationales de quarantaine sont développées afin de minimiser les risques associés aux matériaux d’emballage en bois massif, une porte d’entrée importante pour les organismes étrangers. Les besoins de recherche incluent le développement de moyens de détection améliorés, des outils diagnostiques améliorés, des mesures d’atténuation efficaces, aussi bien que l’évaluation des impacts socio-économiques et des connaissances fondamentales sur la biologie des espèces étrangères et de leurs interactions avec les hôtes.

Mots clés : espèces étrangères, envahissants, ravageurs exotiques, quarantaine, foresterie, introductions.

Introduction

When plants, animals, and microbial organisms are accidentally or intentionally moved by man beyond their natural ranges, they are considered nonindigenous, invasive, or exotic species. The dispersal of species into new environments is a normal and arguably necessary part of ecosystem development and evolution. Ecosystem development on newly formed volcanic islands, for example, relies entirely on colonization by naturally dispersing species. Similarly, the repopulation of areas of newly created habitat or those denuded by catastrophic disturbances, such as ice ages, major fires, and volcanic activity, depends largely on immigration of species from adjoining unaffected areas, but also from novel species introductions. The rate of colonization is dependent upon the distance from source populations and the size of the area disturbed. In natural systems, the rate of colonization of isolated islands by new species is very slow and has been estimated for the Hawaiian Islands at the rate of one new insect species every 50 000 years (Loope and Mueller-Dombois 1989). In comparison, the anthropogenically influenced introduction rates this century ap-

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Table 1. Significant forest diseases introduced into Canada (after Canadian Forest Service 1999).

Disease	Year introduced	Primary host(s)
Beech bark disease [*Nectria coccinea* var. *faginata*] and beech scale [*Cryptococcus fagisuga*]	1890	American beech
Dothichiza canker [*Cryptodiaporthe populea*]	Pre-1900	Poplars
Chestnut blight [*Cryphonectria parasitica*]	Post-1904	American chestnut
White pine blister rust [*Cronartium ribicola*]	1910	White pine
Willow blight [*Venturia saliciperda*]	ca. 1925	Willows
Dutch elm disease [*Ophiostoma ulmi*]	1944	Elms
Scleroderris canker (European race) [*Gremmeniella abietina*]	1978	Pines
European larch canker [*Lachnellula willkommii*]	1980	Larches
Butternut canker [*Sirococcus clavigignenti*]	1991	Butternut

proaches 18 species per year (Beardsly 1979). Such increased introduction rates are largely the result of contemporary trends in global commerce, the diversity of trading partners, and the efficiency by which trade goods are transported.

The introduction of nonindigenous species can have serious effects on ecosystem structure and function and have profound economic implications (Liebhold et al. 1995; Wallner 1996). This paper discusses the nature and impact of invasive species in Canadian forests.

History of some nonindigenous pathogen establishments in Canada

Many documented exotic species introductions have occurred in the past century, some with devastating effects on forest ecosystems (Tables 1, 2). We are likely more aware of insect introductions because of their increased visibility, ease of detection, and relative ease in interception. Disease organisms, particularly those that are cryptic or do not result in serious economic damage, are less likely to be detected.

Chestnut blight, caused by *Cryphonectria parasitica* (Murrill) Barr, was first found in New York in 1904 and is thought to have entered into Canada in the early 1920s (McKeen 1995). Over the next several decades, this fungus killed an estimated 4×10^9 trees and essentially removed the American chestnut (*Castanea dentata* (Marsh.) Borkh.) as a key component of eastern hardwood forests. By the 1950s, virtually all mature American chestnuts had succumbed to the disease. American chestnut is now a minor understory component, existing as sprouts from old stumps and root systems (Anagnostakis 1995). Although slow recovery of chestnut populations has been observed in Canada and the United States, the species is unlikely to regain its historical dominance in eastern forest ecosystems. As a point of historical interest, the U.S. government responded to the chestnut blight by enacting the first plant quarantine regulations in 1912 (Waterford and White 1982).

Cronartium ribicola J.C. Fisch., the causal agent of white pine blister rust, is another fungal organism that has caused serious damage to forest ecosystems. This rust, native to Asia, was introduced to both Europe and North America in the late 1800s. In Canada, there were separate introductions; the disease was introduced on nursery stock to British Columbia in 1910 and to Quebec and Ontario in 1911. It is now widely distributed through most North American stands of white pine (all native five-needle or “soft” pines are susceptible). The impact of the disease is due to both high levels of mortality (over 90% mortality has been observed (Hagel et al. 1989)) and the modification of ecosystem structure resulting from white pine extirpation. The ecological impact of the disease on whitebark pine (*Pinus albicaulis* Engelm.) has even affected populations of grizzly bears and nuthatches, which depend on the seeds of the species as a food resource (Kendall and Schirokauer 1997). White pine blister rust is probably the most serious conifer disease in Canada. The commercial use of what was once an extremely valuable species is now very restricted because of the limited and unpredictable inventory of trees.

The geographic origin(s) of the causal agents of Dutch elm disease (DED), *Ophiostoma ulmi* (Buisman) Nannf., and *Ophiostoma novo-ulmi* Brasier, remains controversial. Various hypotheses, including introduction from China or the Far East, the recent evolution of more virulent races in Europe and North America, or introduction of the pathogens from the Himalayan region, have been proposed and are reviewed by Brasier (1990). The disease appeared in Europe during the late 1800s and spread to North America on wooden crates made with infected elm wood in the 1930s. It first appeared in Canada in 1945 in Quebec and since then has spread to all areas of North America except Newfoundland, British Columbia, and Alberta (one diseased tree was confirmed in Alberta in 1998, but was destroyed, leaving Alberta officially DED free). Millions of trees have died and the American elm is no longer a prominent feature in natural or urban landscapes.

One of the factors that has contributed to the successful spread of the pathogen is that it is vectored by insects, specifically species of the genus *Scolytus* in Europe and by the native elm bark beetle, *Hylurgopinus rufipes* (Eichhoff), in North America.

Spread of DED

The history of DED in North America, its fungus–vector relationships, and disease development demonstrate a number of important points regarding nonindigenous species introductions. Transmission and spread of the pathogen is dependent on transfer of spores to uninfected trees during maturation feeding by various bark beetles. In Europe, species of *Scolytus*, including *Scolytus multistriatus* (Marsham), *Scolytus pygmaeus* (Fabricius), *Scolytus kirschii* (Skalitzky),

Table 2. Significant forest insect pests introduced into Canada (after Canadian Forest Service 1999).

Insect pest	Year introduced	Primary host(s)
Larch sawfly (*Pristiphora erichsonii*)	1882	Larches
Browntail moth *(Euproctis chrysorrhea)*	1902	All deciduous species
Poplar sawfly *(Trichiocampus viminalis*)	1904	Trembling aspen, largetooth aspen, balsam poplar
Larch casebearer (*Coleophora laricella*)	1905	Larches
Late birch leaf edgeminer (*Heterarthus nemoratus*)	1905	Birches
Balsam woolly adelgid (*Adelges piceae*)	1908	Balsam fir, grand fir, subalpine fir, Pacific silver fir
Satin moth (*Leucoma salicis*)	1920	Poplars
European spruce sawfly (*Gilpinia hercyniae)*	1922	Spruces
Gypsy moth (*Lymantria dispar*)	1924	Oaks, birches, larches, willows, basswood, Manitoba maple
European pine shoot moth (*Rhyacionia buoliana*)	1925	Red pine, jack pine, Scots pine
Winter moth (*Operophtera brumata*)	1920s	Oaks, maples, willows
Mountain-ash sawfly (*Pristiphora geniculata*)	1926	Mountain-ash
Birch leafminer (*Fenusa pusilla*)	1929	Birches
Introduced pine sawfly (*Diprion similis*)	1931	Pines
Birch casebearer (*Coleophora serratella*)	1933	Poplars
European pine sawfly (*Neodiprion sertifer*)	1939	Red pine, Scots pine
Elm leaf beetle (*Pyrrhalta luteola*)	1945	Elms
Smaller European elm bark beetle (*Scolytus multistriatus*)	1946	Elms
Ambermarked birch leafminer (*Profenusa thomsoni*)	1948	Birches
Apple ermine moth (*Yponomeuta malinella*)	1957	Apple
European pine needle midge (*Contarinia baeri*)	1964	Red pine, Scots pine
Early birch leaf edgeminer (*Messa nana*)	1967	Birches
Pine false webworm (*Acantholyda erythrocephala*)	1961	Pines
Pear thrips (*Taeniothrips inconsequens*)	1989	Sugar maple, red maple
Brown spruce longhorn beetle (*Tetropium fuscum*)	1990	Pines, spruces, true firs
Pine shoot beetle (*Tomicus piniperda*)	1993	Pines, spruces

Scolytus sulcifrons Rey, and *Scolytus scolytus* (Fabricius), are known or suspected to vector the causal agents of DED (Brasier 1990; Basset et al. 1992; Favaro and Battisti 1993; Faccoli and Battisti 1997; Webber 1990). In North America, the principle vectors consist of the native elm bark beetle, *Hylurgopinus rufipes*, and the introduced European elm bark beetle, *S. multistriatus* (Bright 1976; Wood 1982). Effectiveness of the vectors in transmission of the disease is related to spore loads carried by the beetles and location of beetle pupation sites (Webber 1990), with large species (e.g., *S. scolytus*) being more effective as vectors.

The introduction and spread of DED into North America provides an example of the development of a novel relationship between an exotic pathogen and a native vector. Prior to the introduction of the *Ophiostoma* spp., *H. rufipes* was considered a nonaggressive secondary species and was of limited economic importance (Wood 1982). It is now a key vector of DED (Bright 1976). While the initial establishment of the disease likely involved transmission to elms by exotic *Scolytus* spp. present in imported logs, its further transmission and persistence in North America was not dependent on introduced vectors. Similarly, since none of the European bark beetle vectors of DED (Bright and Skidmore 1997; Wood and Bright 1992) are known to occur in the Himalayas, the development of the relationship between the scolytid vectors and *Ophiostoma* spp. in Europe would also have to be considered a novel association, should that region be conclusively demonstrated to be a geographic origin of the pathogens (Brasier 1990).

Introduction of additional vectors could exacerbate the spread of DED in North America. The larger European elm bark beetle, *S. scolytus*, has been intercepted on numerous occasions in the United States, but is not known to have established (Wood 1982). Higher spore loads carried by such larger species (Webber 1990) could increase the rate of spread or efficiency of transmission of the disease in North America.

In North America, only a few regions remain free of DED. The pathogen is not present in British Columbia, although populations of *S. multistriatus* were widespread in the southern portions of the province when surveys using pheromones were first conducted (Van Sickle and Fiddick 1982). Should the fungus arrive in the province through movement of diseased ornamentals or in infested firewood, a widely established vector population already exists, even in the absence of the native elm bark beetle (*H. rufipes*), which does not occur west of the rocky Mountains (Wood 1982; Bright 1976). The absence of DED despite the discovery of the introduced vector well after the disease was widespread in both Europe and North America may be a consequence of the rarity of elms in British Columbia. It is conceivable that the disease was present in populations of *S. multistriatus* at the time of their original introduction but failed to establish. Although primarily associated with elms, *S. multistriatus* has been recorded from a range of deciduous hosts, including alders, poplars, and trembling aspen, pears, oak, cherries, and plums (Wood and Bright 1992; Bright and Skidmore 1997). In the absence of elms at the point(s) of introduction, *S. multistriatus* may have initially established and persisted on other deciduous species that were not suitable as hosts for *O. ulmi*. Consequently only the scolytid persisted.

The absence of sufficient phytosanitary controls on the movement of host material may have allowed the introduction of the more virulent North American strains into Europe. This has resulted in a complex of virulent strains in Europe.

Which exotic pests threaten our forests?

This question has no simple answer. The number of organisms not native to Canada that could damage our forest species likely is in the thousands. In general, however, it is reasonable to assume that organisms from other north temperate forests associated with congeneric hosts of North American taxa could be problematic should they establish here. Limiting our concern to non-native "pests" is inadequate, since many organisms that are benign in their native habitat flourish on new hosts in the absence of the regulating effects of their natural predators and parasites. What is needed in this regard is an international database of forest-inhabiting organisms, to identify their hosts and their life histories, including biological and environmental constraints. With such information, accurate pest risk analyses could be developed. Such analyses can be used to predict what to look for and where to look for it as well as to guide research needs for the development of detection tools, survey methodologies, and damage appraisal studies. Efforts like this have been initiated, for example, Exotic Forest Pest Information System for North America (http://www.exoticforestpests.org/) but need to be expanded to include georeferenced collection data of specimens confirmed by taxonomic authorities and biogeoclimatic profiles across the native ranges of nonindigenous species.

One method to narrow down the list of pests entering the country is to examine quarantine interception records. Such data, however, do not provide an accurate sample of the total population of introduced organisms. The number and variety of organisms identified through quarantine surveys is limited by factors such as the nature of the import commodities sampled, the methods and intensity of sampling, and the diagnostic capability to identify samples (e.g., insect larvae, fungal spores, and vegetative tissues). In addition, routine surveys rarely quantify interceptions on the basis of volume or commodity type. For a more complete analysis, it is necessary to expand existing surveys and augment interception data with studies of introduced species that have already established in forest ecosystems. This requires the development of detection methodologies and diagnostic tools designed to identify a broad range of organisms. Detection technology is well developed for some species recognized as pests within their native range (e.g., semiochemicals for bark beetles and defoliators). Other groups such as the Cerambycidae and Buprestidae show a limited response to semiochemicals and are more problematic to detect.

Another approach to dealing with the risk to Canadian forests posed by nonindigenous species is to examine the species complexes associated with our tree species used in exotic plantations in other parts of the world. While such surveys will not identify the role these species will play if accidentally introduced into North America, it will help to focus limited research resources to study exotic taxa that attack those hosts.

Traditional diagnostic methods for identifying fungi in and on wood need to be expanded using molecular techniques. Such tools can provide greater diagnostic precision for fungal organisms that are very difficult to identify using traditional morphology-based techniques (Seifert et al. 1995). Similarly, insect larvae are very difficult to identify to species level. Larval keys are lacking for many groups, and expertise to work with them is limited. There is a clear need to further develop and maintain our taxonomic and diagnostic expertise for key groups of insects, fungi, and other microorganisms.

A valuable approach to studying nonindigenous species introductions is through careful processing of suspect wood pieces under quarantine conditions, providing temperature and moisture conditions that favor the development of a range of organisms. Fungi, nematodes, and bacteria can generally be isolated from wood as it arrives, whereas insects may need to be reared from immature to adult stages. Using this method, more than just the immediately obvious organisms can be identified; populations can be quantified, and the succession of communities of organisms can be elucidated. This approach was used to examine nonindigenous species associated with green Norway spruce (*Picea abies* (L.) Karsten) bolts used to brace imported blocks of granite from Norway. In July 1998, live beetles were found associated with shipments of granite from Norway. The shipments had entered Canada at the port of Montréal and had been shipped by rail to Vancouver, where the containers were unpacked and the dunnage was discarded. Green spruce bolts had been used to brace large granite blocks inside shipping containers. The intercepted dunnage was brought to the Candian Forest Service quarantine facility in Victoria and held under containment for emergence of the arthropod fauna. More than 2500 adult insects representing more than 40 species of bark beetles, wood borers, and their associated parasitoids, predators and scavengers, blue-stain fungi, and nematodes were recovered from 29 log bolts (Table 3). At least three species of Scolytidae of quarantine significance (*Pityogenes chalcographus*, *Polygraphus poligraphus*, and *Ips typographus*) were recovered from these bolts. To date, none of these species have been found as established populations in British Columbia. However, the European cerambycid, *Tetropium fuscum* Fabricius, has recently been discovered in Halifax, N.S. (Smith and Hurley 2000), where it has been recovered from dead and dying red spruce (*Picea rubens* Sarg.). This cerambycid is a secondary pest of *Picea* in Europe and until now has not been considered to be of quarantine significance. This highlights the need for concern for all nonindigenous introductions rather than only those considered pests in their native range. This type of evaluation emphasizes the cryptic nature of many organ-

Table 3. Bark and wood-boring beetles and wasps reared from intercepted spruce bolts from Norway used as dunnage.

Species and family	No. individuals
Scolytidae	
Pityophthorus micrographus	942
Pityogenes chalcographus	284
Polygraphus poligraphus	207
Ips typographus	27
Crypturgus hispidulus	16
Pityophthorus pityographus	1
Cerambycidae	
Tetropium fuscum	44
Callidium coriaceum	3
Molorchus minor	1
Pogonocherus fasciculatus	1
Semanotus undatus	1
Anobiidae	
Anobium sp.	10
Ernobius explanatus	4
Curculionidae	
Rhyncholus sp.	1
Melandryidae	
Serropalpus barbatus	7
Siricidae	
Sirex juvencus	21

isms and the need for focused, in-depth studies to form a clear picture of the diversity and magnitude of organisms entering Canada.

With an understanding of the species composition of our forests and the identity of exotic species identified through the methods described above, some adventive species or groups can be targeted as extremely high risk and then be the focus of risk assessments, biological studies, and surveys. Fungi in the genus *Ophiostoma*, for example, affect a broad range of tree species. Some of these fungi cause surface staining, resulting in reductions in lumber quality, while some species are the causal agents of tree-killing problems, such as DED and damage related to mountain pine beetle (Solheim 1993; Uzunovic et al. 1999).

How are exotic pests entering into and moving within Canada?

Analyzing the pathways by which nonindigenous species enter and move within the country is critical to developing monitoring and control strategies. This involves an understanding of trade commodities, the countries from which they originate, the packing material with which they are shipped, and how they are handled upon arrival. Assessing trade patterns and shipping methods is key to the development of meaningful pest risk assessments.

In recent years, the importance of nonmanufactured solid wood packing materials as a pathway for nonindigenous species has become evident. This has required quarantine officials to rethink how imported materials are surveyed, since historically, risk assessments and quarantine regulations focused on commodities rather than on the packaging accompanying them. Until recently, wood packing material (crating, pallets, dunnage) was unregulated as a quarantine concern. The establishment of the Asian Longhorned beetle (*Anoplophora glabripennis* (Motchulsky)) in the United States and concerns about its establishment in other countries stimulated the formation of regulations specifically aimed at controlling the importation of wood packing materials (Canadian Food Inspection Agency 1998; Cavey 1998). Further efforts have been made through the adoption of an international standard for the movement of wood packing material that is treated to minimize phytosanitary risk.

It is difficult to make generalizations about risks associated with solid wood packing materials. Some are constructed from hardwoods, others from softwoods, and sometimes they are mixed. They are often made from low-grade wood, the leftovers from lumber processing, but sometimes kiln-dried wood is used where the packing, (e.g., pallets) is intended to be reused. The level of infestation in the wood is also difficult to predict. If a major forest disturbance event occurs, such as a large-scale windstorm, insect infestation, or fire, packing materials may, for a period, be constructed using highly infested wood from these sources. When the use of less infested wood resumes, phytosanitary risks are reduced. The commodity associated with the packing material can also contribute to its risk. In some cases, low-quality steel cable, intended for single use in forestry operations, is shipped on wooden spools. It is not uncommon for the spools when empty to be discarded into the forest, where, being largely biodegradable, they slowly rot. However, if the spools are infested with nonindigenous organisms this turns out to be an unintentional method of delivering the organisms directly to the resource that they threaten.

A 1997 Canadian Forest Service audit of 50 Chinese wire rope spools revealed that 24% of the spools examined still contained live wood borers, while a total of 31% of the spools had some evidence of past woodborer activity. Six species of longhorned wood borers (Cerambycidae), including *Monochamus alternatus* Hope, *Hesperophanes* (= *Trichoferus*) *campestris* Fald., *Ceresium flavipes* Fabricius, *Psacothea hilaris* (Pascoe), *Megopis sinica* White, *Rhagium inquisitor* L., and one species of Anobiidae (*Ptilineurus* sp.) were reared from these spools. When these spools had entered Canada is not known, but it was likely that they had been in the country for at least two years. In 1998, 16 additional Chinese-made spools that had recently arrived in Canada were examined. These showed similar levels of infestation to the 1997 spools, and 22% had live insects associated with them. There was often no visible external evidence of the presence of live wood borers in these spools: 63% showed external signs of wood borer activity, while all were found to have some evidence of past insect activity when disassembled. Forty-one Canadian-made spools were examined from suppliers in Vancouver, Edmonton, Sault Ste. Marie, and Fredericton. These were found to be of superior construction and comprised higher quality materials than the Chinese spools. Less evidence of insect activity was visible, and no live insects were found.

Historically, most establishments of exotic pest populations have occurred in or near shipping ports. Recently, with a shift to the use of containers in the transport of trade goods, a sealed container may be offloaded at a port, then moved long distances by truck or rail before being opened anywhere in Canada. This provides much more opportunity for nonindigenous organisms to successfully establish in ecosystems remote from port areas. Quarantine inspection of import goods is also more difficult, since activities cannot be focussed at ports alone. Notwithstanding the above, forest landscapes at the highest risk tend to be at the urban-forest interface. Where people and the goods that they import coincide is where nonindigenous organisms are introduced and have a chance to become established (Humble and Allen 1999).

The rate at which populations of newly established organisms spread depends on the nature of the organisms and the extent to which humans aid in dispersal. Insect populations, for example, tend to be mobile and within one generation can disperse over distances of metres to kilometres. Long-distance spread is aided by humans through the movement of the insects themselves (e.g., Gypsy moth egg masses are continually being transported from infested areas in eastern Canada to uninfested areas in the west by "hitchhiking" on vehicles) or the movement of wood that the insects inhabit (DED vectors are widely moved in firewood).

In contrast, fungi are less mobile and rely entirely on spore dissemination methods or animal vectors for dispersal. Macrofungi, predominantly basidiomycetes, sporulate externally on living or dead trees, for example, bracket fungi and mushrooms associated with wood decay and root disease in trees. These fruiting bodies are generally removed during wood processing, and it is highly unlikely that new fruiting structures will develop on processed wood, since most fruiting bodies require months to years to develop under the proper environmental conditions. Furthermore, spores produced by these fungi tend to be short-lived. Vegetative growth of fungi that may survive in wood material in contact with the soil tends to be very slow and subject to aggressive competition by native mycota. Introduced fungi that have become established with serious consequences have characteristics that endow them with unprecedented advantages in new ecosystems. Examples include fungi with insect vectors (*O. ulmi*), resilient spores that are easily wind disseminated and rapidly infect living host tissue (rusts), saprophytic mold stages that produce copious numbers of spores on dead or dying host tissue (*Heterobasidion annosum* (Fr.:Fr.) Bref.), fungi carried with introduced living plant material (*C. ribicola*), and seed-borne fungi (*Pythium* spp.).

Not all nonindigenous organisms necessarily originate from outside of Canada. Our forests have many organisms that are specific to regional ecosystems. Movement of such organisms to other ecosystems should be considered as nonindigenous introductions. An example is *Xyloterinus politus* (Say) (Humble 2001). This might also include exotic species whose establishment is restricted to one part of the country (e.g., *Tomicus piniperda* (L.), *Lymantria dispar* (L.), the European race of *Ascocalyx abietina* (Lag.) Schläpfer). It is very important that we develop effective domestic movement policies to minimize the spread of such organisms within our borders.

Table 4. Effects of nonindigenous plant pathogens and insects (after Office of Technology and Assessment 1993).

Organism	% harmful	% neutral	% beneficial
Plant pathogens (*n* = 54)	91	6	4
Insects (*n* = 1059)	35	33	31

Note: Percentages do not total 100% because of rounding.

What threat do nonindigenous pests pose to our forests and forest economies?

As previously discussed, the establishment of exotic species in our forests can have devastating effects, yet not all such introductions have had deleterious consequences. Although many are harmful, some introduced species are benign and some have had beneficial effects (Table 4). Some species are intentionally introduced as crops or ornamentals (e.g., most agricultural crop plants, honey bees (*Apis mellifera* L.), *Pinus radiata* D. Don, *Pseudotsuga menziesii* (Mirb.) Franco, *Pinus contorta* Dougl. & Loud., and Scotch broom (*Cytisus scoparius* L.)). Other species are introduced unintentionally but appear to have no damaging effects on native species or ecosystem structure and integrity. Predators, parasites, or parasitoids of native or introduced pests are seen as beneficial to humans and have been imported as biological control agents. Forestry examples include control of *Adelges piceae* (Ratzeburg) and *Orgyia pseudotsugata* (McDunnough). These and other examples are summarized in a compilation of case studies (Kelleher and Hulme 1984).

Introduced species that are perceived to cause harm do so in a variety of ways (Krcmar-Nozic et al. 2000a, 2000b), the most common of which are direct, measurable economic costs. These include damage to timber resource value, tree mortality or reductions in growth or wood quality, costs of control and the implementation of regulations, unrealized revenue from recreation and tourism opportunities, and reductions in property value (especially in urban–forest situations). Estimates of economic losses, while difficult to calculate, have been developed for some forest pests (USDA Forest Service 1991, 1998).

Economic losses also occur through lost trade due to international trade restrictions. Such restrictions may be applied by countries that import Canadian forest products if they are concerned about the introduction of native Canadian organisms to their forests. An example is the regulations imposed by the European Union concerning the possible movement of pinewood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) associated with Canadian wood products (Dwinell and Nickle 1989; EEC 1992). These regulations have had a profound effect on Canada's forest product exports to Europe. Similar concerns are being expressed by Australian plant quarantine officials regarding the importation of green lumber from Canada. More than 1800 interceptions of native Canadian insects were made on lumber shipments between 1985 and 1998 (Australian Quarantine Inspection Service 1998). Treatment requirements to reduce the risk associated with such movements could jeopardize Canada's share in this market.

Similarly, trade restrictions may also be enacted over concerns by our trading partners regarding the movement of exotics that have established in Canada. In 1999, the United States imposed regulations on the movement of goods from British Columbia to the western states over concerns about a population of gypsy moth in Victoria.

In addition to direct economic impacts, serious ecological effects to forest ecosystems can result from nonindigenous introductions. These may be as dramatic as the extirpation of species (e.g., chestnut blight), changes in ecosystem structure, interspecies dynamics (e.g., white pine blister rust), and changes (increases or decreases) in biological diversity. Other impacts include social consequences such as job losses and degradation of aesthetic values.

What is being done to reduce the risk from nonindigenous pests?

As a consequence of the serious impacts that historical nonindigenous introductions have had on agricultural and forest economies, most countries have plant quarantine agencies, whose job it is to monitor the influx of nonindigenous organisms, to identify the pathways by which they are entering, and attempt to prevent their entry. Inspection and quarantine systems have been implemented by most nations to prevent introductions of new harmful invasive species or to limit the spread of already established species. In Canada, this task falls to the Canadian Food Inspection Agency. This organization, in cooperation with the Canadian Forest Service and similar regulatory and research groups around the world, has been analyzing exotic pest risks for more than a decade. Recently, expanded efforts have been made to identify pathways through which exotics are entering and to quantify their risk. This type of analysis has clearly identified solid wood packing material (SWPM) as a key, underregulated pathway. In response, in April 2002 plant protection organizations around the world adopted an international standard setting guidelines for regulating wood packaging material in international trade. When implemented, this standard is expected to significantly decrease the phytosanitary risks associated with SWPM. Although the initiative will result in added costs to shipping and packing industries, it is clear that the phytosanitary benefits of such a program will be worthwhile. This type of approach, in conjunction with enhanced surveillance using improved detection tools and inspection methods, will greatly reduce the negative impacts of nonindigenous species.

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