Contemporary issues in Québec's temperate forest — Part 2: Biological invasions

by François Guillemette[1]*, Steve Bédard1, Louis Duchesne[1] and Rock Ouimet[1]

ABSTRACT

This paper is the second in a series on the topic of contemporary issues in Québec's temperate forest. It considers biological invasions that may either cause new and significant mortality among indigenous trees or substantially alter those species' regeneration processes in the forest. Our review of government authority websites and scientific literature led us to identify 11 species that are vulnerable or highly vulnerable to exotic or emergent pests, 14 that are less vulnerable and 11 in an intermediate situation. The most vulnerable species do not include Québec's three most abundant temperate hardwood species, namely sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.) and yellow birch (*Betula alleghaniensis* Britt.). They do, however, include certain maple forest companion species. We also identified three animal groups, two tree species, three shrub species and five herbaceous species groups that, if they were to invade the forest, could have significant consequences for entire stands as opposed to specific tree species, by disturbing the undergrowth. Invasions such as these enhance the risk of losing biodiversity and forest productivity, thereby making productivity less predictable and creating challenges for assisted tree migration initiatives. On the other hand, they offer a potential opportunity for mitigating the invasiveness of certain other species such as the American beech (*Fagus grandifolia* Ehrh.).

Keywords: exotic, invasive, alien, pest, insect, disease, non-native

RÉSUMÉ

Cet article est le deuxième d'une série qui présentent les enjeux contemporains en forêt tempérée au Québec. Nous y abordons plus précisément les invasions biologiques susceptibles soit de causer de la mortalité nouvelle et notable aux arbres d'espèces indigènes, soit de modifier substantiellement les processus de régénération de ces essences en milieu forestier. Notre revue des sites Web d'autorités gouvernementales et de la littérature scientifique nous a permis d'identifier 11 essences vulnérables ou très vulnérables à des ravageurs exotiques ou émergents, 14 essences qui y sont peu vulnérables et 11 essences dans une situation intermédiaire. Les essences les plus vulnérables n'incluent pas les 3 essences feuillues tempérées les plus abondantes au Québec, soit l'érable à sucre (*Acer saccharum* Marsh.), l'érable rouge (*Acer rubrum* L.) et le bouleau jaune (*Betula alleghaniensis* Britt.), mais plutôt d'autres essences compagnes dans l'érablière. Nous avons aussi relevé 3 groupes d'animaux, 2 espèces d'arbres, 3 espèces d'arbustes et 5 groupes d'espèces herbacées dont l'invasion, en perturbant le sous-bois, pourrait avoir des conséquences importantes sur l'ensemble d'un peuplement plutôt que sur une essence forestière en particulier. Ces invasions entraînent des risques de perte de biodiversité et de productivité forestière, augmentent l'imprévisibilité quant à cette productivité et amènent des défis pour des projets de migration assistée des arbres. Cependant, elles sont aussi une occasion potentielle d'atténuer le caractère envahissant de certaines espèces comme le hêtre à grandes feuilles (*Fagus grandifolia* Ehrh.).

Mots-clés : exotique, envahissante, allochtone, ravageur forestier, insecte, maladie

Introduction

The term "biological invasion" refers to an expansion of a species' range, for example through the introduction of species from other continents (Liebhold *et al.* 1995). They are especially concerning when they involve new pests (animals, diseases) that attack species already present in the forest, or new invasive plants with the potential to alter forest regeneration processes (Lovett *et al.* 2016; Langmaier and Lapin 2020). Some invasions may be "wild cards in a card game" in that they occur unexpectedly and rarely but can trigger major changes in the outcome of the game (cf. Srivastava *et al.* 2021). This type of change occurs more frequently that we might think (Bengston 2023).

Northeastern North America's forest ecosystems have been altered significantly since the first Europeans arrived on the continent, introducing other species and causing other disturbances. According to estimates, more than 50 000 exotic species, including roughly 4500 a rthropod species, have been introduced into the United States since the early European settlers first arrived (Pimentel *et al.* 2005). As of 2010, they included at least 455 new forest insect species and 16 new forest pathogens (Aukema *et al.* 2010), as well as roughly 4500 new plants (Sieg *et al.* 2010). More specifically, the number of non-native terrestrial species in Canada was estimated at 3130 (Langor *et al.* 2014), including 329 arthropod species and 11 pathogens in Canada's Forest Invasive Alien Species (CanFIAS) database in 2015 (Nealis *et al.* 2016). These exotic species do not all have major impacts for trees (cf. Mech *et al.* 2019; Potter *et al.* 2019), and although almost every type of tree can host at least one of these new exotic species (Nealis *et al.* 2016), they are not necessarily threatened by them. Of the forest pests

[1] Direction de la recherche forestière, Ministère des Ressources naturelles et des Forêts, 2700 rue Einstein, Québec (Québec) G1P 3W9
*Author for correspondence: francois.guillemette@mrnf.gouv.qc.ca

identified in the United States, 62 insects and 16 pathogens are considered to have major impacts (mortality, defoliation, dieback, growth loss or regeneration loss) for at least one species (Aukema *et al.* 2010). Since 1860, these high-impact pests have entered the United States at a fairly stable rate of roughly four species per decade (Aukema *et al.* 2010). Some new animals including earthworms and new invasive and other plants have also been introduced into North America's forests up to the boreal forest (Sanderson *et al.* 2012).

This second paper in the series on contemporary issues in Québec's temperate forest summarizes the major impacts of biological invasions on the forest and considers other potential impacts that may occur in the coming decades. It also addresses the main issues associated with these invasions in both managed and unmanaged forests. The goal is to identify those invasions that cause mortality of mature indigenous tree species or constitute major obstacles to their natural regeneration (cf. Potter *et al.* 2019).

The forest under consideration, mainly contained within the northern temperate vegetation zone, was described in detail in the first paper of the series (Duchesne *et al.* [In press]). The three main species in the temperate forest are sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.) and yellow birch (*Betula alleghaniensis* Britt.). They are mixed with dozens of other species in what is a transition zone between the temperate and boreal forests (for a more complete list of species making up Québec's temperate forest, see part 1 — Duchesne *et al.* [In press]). Although our analysis targets Québec's forest because of the risk of exposure to the pests we have identified, it is also relevant to forests of the same type in other eastern Canadian provinces and in the northeastern American states.

Method

A number of biological invasions have already taken place, and their impacts are well-known, while others fall under the label of strategic foresight (cf. Bengston 2023). Our review encompasses past invasions and those with early indicators of potential changes in Québec before the end of the current century (cf. Amyot *et al.* 2022). However, the scope of our research is limited to invasions that have already occurred in North America and are likely to affect managed or unmanaged natural forests and indigenous trees in southern Québec.

New pests

The exhaustive list of indigenous, new and exotic forest pests in the United States published by Potter *et al.* (2019) served as the basis for our review. Among other things, they identified the insects and diseases that constitute the greatest threat to the United States' 419 indigenous tree species. Their identification and classification of pests by severity rating for each species was based on a literature review covering more than 200 sources and consultations with 22 American forest entomologists and pathologists. They assigned a severity rating on a scale of 1 to 10 to each combination of host species and pest. A rating of 10 was given to combinations that led to almost complete mortality of all mature trees in the host species, or an inability to reproduce. Combinations that led to almost complete mortality of one host species received a rating of 9, and a rating of 8 was given to host/pest combinations that led to significant mortality (usually approximately > 25 % and < 95 %) of mature trees in a host species. A rating of 5 was given to host/pest species that led to moderate mortality among mature host trees (generally between 10% and 25%), and a rating of 3 to combinations that led to lower rates of mortality (roughly between 1% and 10%) when combined with other threats such as stress from drought. Lastly, a rating of 1 was given to combinations causing minor levels of mortality, generally limited to host trees that were already vulnerable or under stress. This last rating was not used for our analysis. We updated Potter *et al.* (2019) analysis of the impacts of exotic and new pests on Québec's indigenous trees species by consulting more recent information (as of October 22, 2024) concerning species in southern Québec on the websites of the Canadian Food Inspection Agency (CFIA), Natural Resources Canada (NRCan), Québec's Ministère des Ressources naturelles et des Forêts (MRNF), the Invasive Species Centre (ISC), Nova Scotia's Invasive Species Council (NSISC), New Brunswick's Invasive Species Council (NBISC) and the USDA Animal and Plant Health Inspection Service (APHIS). If an additional pest was identified at any of these sites, then we sought the information required to assess their severity in scientific publications. We collected pest information for each tree species, but we grouped it at the tree genus level if the information was identical for all tree species of the same genus occurring naturally in Quebec.

These same sources, along with scientific publications, were used to clarify the current and anticipated level of exposure to these pests for species in southern Québec. Where available, we also used information on pest climate sensitivity outside Québec, since this is usually an important factor (Gougherty *et al.* 2024).

We created a 5-level exposure risk indicator on a scale of 1 to 10, similar to Potter *et al.* (2019) severity rating. Exposure risk levels 1 and 3 were used for pests already established in North America, with level 3 being reserved for cases in which southern Québec may become a potential habitat for the pest due to the anticipated effects of climate change before the end of the current century[2]. Exposure risk levels 5, 8 and 10 were assigned in cases where the current climate in southern Québec does not place limits on the pest's current habitat. Level 10 shows that the pest is present in southern Québec, level 8 that it is present in a neighbouring jurisdiction, and level 5 that it is present in North America. We did not include pests under surveillance that are not known to be present and reproducing viably in North America, such as the flighted spongy moth complex (formerly known as the Asian gypsy moth), or indigenous pests, even those that may have expanded their infestation range in response to current climate change. This type of exposure rating is primarily a risk communication tool. It must be interpreted with caution, as it has not been validated and does not replace modeling of the potential distribution and dispersal speed of pests. However, modeling also faces challenges, as there are often significant and difficult-to-predict jumps in the dispersal of invasive species (cf. Belouard *et al.* 2025).

Lastly, we calculated an overall pest vulnerability rating for each species. Vulnerability is defined by the species' sensitivity (the damage it suffers if exposed), its exposure risk and its adaptation capacity (cf. Williamson *et al.* 2012). We assumed that the species' genetic adaptation capacity would be expressed over a long period of several centuries or millennia, clearly exceeding the time horizon used for our analysis. We used Potter *et al.*'s (2019) severity rating to indicate each species' sensitivity. The vulnerability rating of a tree species was calculated by multiplying, for each pest, the severity rating by the exposure risk level, and then summing these products for all pests associated with that host species. Where there was considerable uncertainty about the value of any given factor, we noted the potential value interval. It is difficult to assess the level of risk posed by this type of change if it is not yet present in a given area (Edwards *et al*. 2015; Nealis *et al*. 2016; Mech *et al*. 2019). Information is often missing, for example on the pest's biological cycle or its potential behaviour in its new environment (Nealis *et al*. 2016).

One of the weaknesses of our approach is that it uses indicators with partly arbitrary values. On the other hand, one of its strengths is that it provides forestry decision-makers with a quantified overview of future risks and positions host species along a relative risk gradient. As an example, a species currently being invaded by a new pest that causes almost complete mortality of all its host species in North America would receive a vulnerability rating of 100: 10 for severity × 10 for exposure risk. Although the vulnerability rating is a numerical value, we caution the reader not to interpret it precisely, as if a rating twice as high for one species compared to another represents twice as high vulnerability. It is a communication tool to help put the vulnerability of species into perspective in the broad sense.

Other biological invasions

In addition to new forest pests, we reviewed online publications (as of October 31, 2024) on other invasive exotic animals and plants. The sources consulted were the same seven organizations mentioned earlier for new pests. For Québec, our main reference was the *Sentinelle* tool offered by the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs, and for the United States, it was the USDA National Invasive Species Information Centre. These sources, along with other scientific publications, were used to clarify the potential impacts of these invasive species and the current and anticipated invasion exposure level for southern Québec's forests. We identified the invasive species present in North America that are most likely to have significant impacts on undergrowth in Québec's temperate forests, and that might hinder natural regeneration if they become established and are not controlled. With respect to plants, the species concerned were mostly those that tolerate undergrowth shade. The impacts of these other types of biological invasions are less specific to particular species and tend to affect whole forest ecosystems instead.

Results and discussion

New pests

For the 36 host species listed, we identified 26 non-indigenous insects and diseases likely to cause significant mortality of otherwise healthy trees. Of these, 13 are already established in Québec, 10 are established in neighbouring jurisdictions and five are likely to reach Québec without the anticipated climate changes before the end of the current century (Table 1). Only five new pests could be added to the list as a result of anticipated climate warming: the balsam woolly adelgid (balsam fir, Quiring *et al*. 2008), thousand canker disease (black walnut), the mountain pine beetle (pine), the southern pine beetle (white pine and red pine) and the red pine scale (red pine).

The 10 species with the highest overall vulnerability rating (Table 1), i.e., a value of 100 or more, are: American beech (224), ash (130, three species), white pine (114 to 144), elm (114 to 134, two species), red oak (109 to 134), eastern hemlock (104) and butternut (100). These results are due either to the presence of a high-impact exotic pest affecting the species and already established in Québec, or an accumulation of several new pests, sometimes located in neighbouring jurisdictions and likely to migrate to Québec in the coming decades. The vulnerability rating of white pine (83 to 113) depends on the estimated severity rating for trees or regeneration, in particular due to white pine blister rust, which affects regeneration success. Red pine is also close behind (76 to 106), mainly because of three new potential pests, two of which would benefit from global warming. Red pine plantations in southern Québec are occasionally affected by annosum root rot, but symptoms and spread can be prevented by taking steps during thinning or final cutting (Dumas and Laflamme 2013). Migration of two beetles affecting pine trees is also being monitored in case they reach Québec. There is a high level of uncertainty about whether the mountain pine beetle could threaten eastern pines, particularly by passing through jack pine forests (Cooke and Carroll 2017; CCFM 2019). However, a recent study suggest that the presence of jack pine and hybrids with *Pinus contorta* (Dougl. ex Loud.), would slow the progression of epidemic (Srivastava and Carroll 2023). The southern pine beetle is near Québec and should find a suitable habitat here by the end of the century (Lesk *et al*. 2017). In a review of reports concerning new diseases identified as affecting non-tropical species in the northern hemisphere, Gougherty (2023) noted that *Pinus, Quercus* and *Juglans* were among the genera most affected by new diseases. In this regard, we note the emergence of new health issues in white pine that do not specifically come from exotic species: caliciopsis canker (*Caliciopsis pinea* Peck), eastern white pine bast scale (*Matsucoccus macrocicatrices* Richards), the interaction of these two species, as well as a complex of four diseases known as white pine needle damage (Costanza *et al*. 2018). These authors put forward hypotheses to try to explain why these native pests would now cause more dieback and mortality of white pine, perhaps an evolution of the scale insect that would allow it to be more virulent and by boring holes it would promote canker infestations, or perhaps climatic stresses would make the hosts more vulnerable or maybe the evolution of climatic conditions would be more favorable to the development and reproduction of fungi.

At the other end of the scale, the 14 species with the lowest vulnerability ratings were yellow birch (40), spruce (30, three species), jack pine (24), poplar (30, four species) and American basswood (30), plus four species for which no non-indigenous pests causing significant mortality of otherwise healthy trees were identified: bitternut hickory, shagbark hickory, black cherry and Eastern white cedar (Table 1). *Thuja*, *Tilia*, and *Betula* genera were also among those with the fewest published reports on new diseases affecting non-tropical trees in the northern hemisphere (Gougherty 2023).

Between these two extremities are 11 species that could undergo additional mortality caused by new pests by the end of the current century, but at a less severe level or potentially further down the line or at a time yet to be determined in the next two decades. The balsam woolly adelgid (fir vulnerability rating = 24 to 54) has already been observed in the far east of Quebec, but it has not been reported again and was probably not yet established (Table 1).

The impact of the Asian longhorned beetle is uncertain for maple species (4-species rating = 64) and is a factor in the white birch vulnerability rating (50 or 70). So far, the insect has been eradicated from 12 of the 16 sites at which it was known to exist in North America (Table 1). The insect has apparent limited dispersal by adults, a relatively slower rate of development in

Table 1. List of exotic or new pests likely to cause significant mortality among host species/genus or their regeneration, by severity rating and exposure risk in Québec (Expo.), and by each host's vulnerability rating to each pest. The pests mentioned, and their severity rating, are taken from Potter *et al.* (2019), unless the information is marked with an asterisk (*). CFIA: Canadian Food Inspection Agency (https://inspection.canada.ca), NRCan: Natural Resources Canada (https://www.exoticpests.gc.ca), ISC: Invasive Species Centre (https://www.invasivespeciescentre.ca), MRNF: Ministère des Ressources naturelles et des Forêts du Québec (https://mffp.gouv.qc.ca/les-forets/protection-milieu-forestier/protection-forets-insectes-maladies/maladies-fiches/), NSISC: Nova Scotia Invasive Species Council (https://nsinvasives.ca/fact-sheets/), NBISC: New Brunswick's Invasive Species Council (https://www.nbinvasives.ca/) and APHIS: U.S. Department of Agriculture Animal and Plant Health Inspection Service (https://www.aphis.usda.gov/plant-pests-diseases).

Host species or genus	Pest		Ratings			Notes	Sources
	Name	Type	Severity	Expo.	Vulnerability		
***Abies balsamea* (balsam fir)**	Balsam woolly adelgid (*Adelges piceae* Ratzeburg)	Sap-sucking insect	8	8	**Overall rating = 24 to 54**	Not found where normal January temperatures are below or equal to −11 °C. It was observed in the far east of Quebec in 2004 but has not been reported since; it therefore does not appear to be established.	Quiring *et al.* (2008), Langor *et al.* (2014), Nealis (2024), P. Therrien, entomologist, MRNF, personal communica-tion, June 2025.
	**Phytophthora abietivora* D.W. Li, N.P. Schultes, J.A. LaMondia, R.S. Cowles	Root disease	*0 to 3	10		First discovered in Connecticut in 2019 and subsequently also identified in Québec. Mainly a problem for Christmas tree production at this time.	Li *et al.* (2019), Charron *et al.* (2024).
***Acer* spp. (maple, 4 species)**	Asian long-horned beetle (*Anoplophora glabripennis* Motschulsky)	Wood-boring insect	8	8	**64**	Discovered in 16 locations in North America since 1996 and eradicated in 12 of those locations. It has apparent limited dispersal by adults, a relatively slower rate of development in Canada and a relatively low reproductive rate, which partly explains why the authorities have been able to eradicate it from most infested areas in the space of a few years.	APHIS, Coyle *et al.* (2021), Turgeon *et al.* (2022).
***Betula alleghaniensis* (yellow birch)**	Asian long-horned beetle	Wood-boring insect	5	8	**40**	See *Acer* spp. for exposure.	
***Betula papyrifera* (white birch)**	Asian long-horned beetle	Wood-boring insect	5	8	**Overall rating = 50 or 70**	See *Acer* spp. for exposure.	
	Birch leafminer (*Fenusa pumila* Leach)	Leaf-consuming insect	3 or 1*	10		Parasitoids were introduced in the 1970s to control this pest and this biological control generally appears to work well. Four other exotic birch-leafmining sawflies are observed in Canada, but they also cause little tree mortality.	Cheng and Leroux (1970), Guèvremont and Quednau (1977), Casagrande *et al.* (2009), Digweed *et al.* (2009).
***Carya* spp. (hickory, 2 species)**	None						

Host species or genus	Pest		Ratings			Notes	Sources
	Name	**Type**	**Severity**	**Expo.**	**Vulnerability**		
***Fagus grandifolia* (American beech)**	Beech bark disease: interaction between an exotic insect, the beech scale (*Cryptococcus fagisuga* Lindinger), and 2 diseases: *Neonectria faginata* (Lohman *et al.*) Castl. and Rossman, and *Neonectria ditissima* (Tul. and C. Tul.) Samuels and Rossman		8	10	**Overall rating = 224**	Beech scale is present in almost all of the beech distribution range in Québec, except for some small areas towards the species' northern limit.	Cale *et al.* (2017)
	*Beech leaf-mining weevil (*Orchestes fagi* Linnaeus)	Defoliating insect	*8	8		Discovered in Halifax in 2011, then on Prince Edward Island and New Brunswick in 2020. Research has been done in Europe to identify potential parasitoids to help control populations, but further studies are required before considering deploying actions (as of 2024).	Sweeney *et al.* (2020), Klymko and Anderson (2022), Johns *et al.* (2024).
	* Beech leaf disease (nematode *Litylenchus crenatae mccannii* (Handoo *et al.*))	Defoliating nematode	*10	8		Discovered in Ohio in 2012. Already spread to 8 American states and Ontario. After 7 years of monitoring, mortality appears to affect mainly seedlings and saplings. It is not yet certain if the northern portion of the beech distribution range in Québec might be viable for this pest, but recent clues suggest that it will be possible.	Ewing *et al.* (2019), Martin and Volk (2021), Reed *et al.* (2022), Zhao *et al.* (2023), Fitza *et al.* (2024).
***Fraxinus spp.* (ash, 3 species)**	Emerald ash borer (*Agrilus planipennis* Fairmaire)	Wood-boring insect	10	10	**Overall rating = 130**	Discovered in Québec in 2008. Exotic wasps were introduced as biological prevention agents, but their effect is still unknown (as of 2024).	MacQuarrie *et al.* (2024)
	Oystershell scale (*Lepidosaphes ulmi* L.)	Sap-sucking insect	3	10			Samarasinghe and Leroux (1966)
***Juglans cinerea* (butternut)**	Butternut canker (*Ophiognomonia clavigignenti-juglandacearum* (N.B. Nair, Kostichka & J.E. Kuntz) Broders & Boland)	Disease	10	10	**100**	Discovered in 1967 in Wisconsin, origin unknown, then introduced into Québec in 1990. The butternut is now listed as an endangered species in the *Species at Risk Act* (L.C. 2002, ch. 29).	Nair *et al.* (1979), Innes and Rainville (1996).

Host species or genus	Pest		Ratings			Notes	Sources
	Name	Type	Severity	Expo.	Vulnerability		
***Juglans nigra* (black walnut)**	Thousand canker disease (*Geosmithia morbida* Kolařík, Freeland, Utley, Tisserat)	Disease transported by insects: mainly the walnut leaf beetle (*Pityophthorus juglandis* Blackman)	5	3	**Overall rating = 39 to 79**	Discovered in the western United States in the 1990s. The disease and the insect originated in the southwestern portion of the United States and the insect subsequently began to migrate northwards and eastwards. Discovered in Pennsylvania in 2011 and in Ohio in 2012. Does not appear to have continued its northward progression since then. Recent evidence indicates that the disease may have been present throughout the United States, even in places where the insect was absent.	Moore *et al.* (2019), Juzwik *et al.* (2022).
	*Spotted lanternfly (*Lycorma delicatula* White)	Sap-sucking insect	*3 to 8	8		Discovered in Pennsylvania in 2014 and now present in at least 18 American states, including New York. Can be hosted by numerous plant species, including the exotic plant *Ailanthus altissima* (Mill.) Swingle, and the black walnut, which appears to be more vulnerable to the insect. Studies are underway to develop a biological control.	APHIS, Urban and Leach (2023), Zhao *et al.* (2024), Johnson *et al.* (2025).
***Larix laricina* (tamarack or American larch)**	Larch casebearer (*Coleophora laricella* Hubner)	Needle-browning insect	5 or *1	10	**Overall rating = from 40 to 80**	It was introduced into North America in the 1880's and it is generally well controlled by introduced parasitoids. Annual defoliation rarely leads to tree death and infestations appear to follow an 8-year cycle; mainly in plantations.	Cody *et al.* (1967), NRCan, MRNF (2009), Ward and Aukema (2019).
	Spongy moth (*Lymantria dispar dispar* Linnaeus)	Defoliating insect	3	10		Established in Québec since 1959. It has become one of the main hardwood defoliators in North America, but its impact in Québec is more moderate because of its many natural enemies, the fact that there are few oak trees in the landscape and the occurrence of very cold temperature (i.e. near −30 °C). Although the adult looks like a moth, the females do not fly and do not move around. Dispersal occurs over short distances by larvae (caterpillars) or over long distances by anthropogenic movement of eggs.	CFIA, NRCan, Régnière *et al.* (2008), Streifel *et al.* (2019).

Host species or genus	Pest		Ratings			Notes	Sources
	Name	Type	Severity	Expo.	Vulnerability		
***Picea spp.* (spruce, 3 species)**	*Brown spruce longhorn beetle (*Tetropium fuscum* Fabricius)	Wood-boring insect	*3	10	**30**	Discovered in Halifax in 1999 and found in Québec in 2024. Stressed or less vigorous spruce trees are at greater risk of infestation.	CFIA, MRNFP (2014), Anderson *et al.* (2022).
***Pinus banksiana* (jack pine)**	*Mountain pine beetle (*Dendroctonus ponderosae* Hopkins)	Wood-boring insect	*8	3	**24**	Indigenous to the west coast up to southern Saskatchewan, but recently expanded into the northern boreal forest. There is a high level of uncertainty about whether the insect could threaten eastern pines, particularly by passing through jack pine forests. However, the most recent studies suggest that the presence of jack pine, in trees or in the form of hybrids with *Pinus contorta* (Douglas ex Loudon), would slow the epidemic.	ISC, Clark *et al.* (2014), Cooke and Carroll (2017), CCFM (2019), Srivastava and Carroll (2023).
***Pinus resinosa* (red pine)**	*Mountain pine beetle	Wood-boring insect	*8	3	**Overall rating = 76 to 106**	See *Pinus banksiana* for exposure.	
	Red pine scale (*Matsucoccus matsumurae* Kuwana)	Sap-sucking insect	*5	8		Originated in Japan and found in Connecticut in 1949. Present in 8 American states south of Québec. Its northward migration appears to have accelerated in recent years. The insect is sensitive to high summer heat (e.g. 40°C) and winter cold (e.g. -23°C).	Bean and Godwin (1971), McClure (1983). Pureswaran and Garnas (2025).
	*Southern pine beetle (*Dendroctonus frontalis* Zimmermann)	Wood-boring insect	*5	8		Originated in the southern United States and Central America. In recent years, taking advantage of milder winters, it has moved toward northeastern United States. Although few insects survive at temperatures of −16 °C or below, the effects of climate change may make it possible for the insect to in Québec a suitable habitat near 2080.	Trân *et al.* (2007), Lesk *et al.* (2017), Kanaskie *et al.* (2023).
	*Annosum root disease (*Heterobasidion irregulare* Garbelotto)	Root disease	*0 or *3	10		In the last few centuries, the disease may have migrated from Mexico, reaching Ontario in 1955 and southern Québec in 1989. It is very difficult to eliminate the fungus once it has become established at a given site. Practices applied during harvesting can prevent the spread of the disease and its impacts.	MRNF, Dumas and Laflamme (2013), Bérubé *et al.* (2017, 2018)

Host species or genus	Pest		Ratings			Notes	Sources
	Name	Type	Severity	Expo.	Vulnerability		
Pinus strobus (white pine)	*Mountain pine beetle	Wood-boring insect	*8	3	**Overall rating = 114 to 144**	See *Pinus banksiana* for exposure.	
	White pine blister rust (*Cronartium ribicola* J. C. Fisch)	Disease	5 or *8	10		High rates of mortality occur mainly in regeneration (seedlings and saplings), thereby affecting the species' long-term future. Exposure to risk from this disease varies locally, particularly depending on indicators associated with the maintenance of cooler and more humid conditions.	Ostry *et al.* (2010).
	*Southern pine beetle	Wood-boring insect	*5	8		See *Pinus resinosa* for exposure.	
***Populus spp.* (poplars, 4 species)**	Spongy moth	Defoliating insect	3	10	**30**	See *Larix laricina* for exposure.	
***Prunus serotina* (black cherry)**	None						
***Quercus alba* (white oak)**	Oak wilt (*Bretziella fagacearum* Bretz)	Disease	3	8	**Overall rating = 54**	Discovered in 1942 in the United States. Of unknown origin, but probably Central or South America, or Mexico. Found in Ontario in 2023. Proximity to infected oak trees significantly increases the risk of spread via root grafts. Injured trees emit substances that attract insects which may carry the disease (from April to November). The severity rating varies from one oak species to another.	Juzwik *et al.* (2008), Pedlar *et al.* (2020), Gauthier *et al.* (2024).
	Spongy moth	Defoliating insect	3	10		See *Larix laricina* for exposure.	
***Quercus bicolor* and *Q. macrocarpa* (swamp white oak and bur oak)**	Oak wilt	Disease	5	8	**Overall rating = 70**	See *Quercus alba* for exposure.	
	Spongy moth	Defoliating insect	3	10		See *Larix laricina* for exposure.	
***Quercus rubra* (red oak)**	Oak wilt	Disease	8	8	**Overall rating = 109 to 134**	See *Quercus alba* for exposure.	
	Spongy moth	Defoliating insect	3	10		See *Larix laricina* for exposure.	
	*Sudden oak death (*Phytophthora ramorum* Werres, De Cock & Man in't Veld)	Disease	*3 to *8	5		Discovered in the early 1990s in California and Europe. The main risk for eastern North America is from movements of materials from west coast nurseries. The disease's agent was intercepted at a nursery in southern Québec in 2024, but it is too early to know whether or not it has become established here. The disease can be insidious, since it travels via plant species presenting few to no symptoms. We have listed this disease here, but it can also cause damage to several other species.	CFIA, APHIS, Grünwald *et al.* (2008), Grondin *et al.* (2013), Shamoun *et al.* (2018).

Host species or genus	Pest		Ratings			Notes	Sources
	Name	Type	Severity	Expo.	Vulnerability		
***Thuja occidentalis* (Eastern white cedar)**	None						
***Tilia americana* (American basswood)**	Spongy moth	Defoliating insect	3	10	**30**	See *Larix laricina* for exposure.	
***Tsuga canadensis* (Eastern hemlock)**	Hemlock woolly adelgid (*Adelges tsugae* Annand)	Needle-sucking insect	10	8	**Overall rating = 104**	This adelgid is invasive in eastern North America, but naturalized for a very long time on the west coast. Present in Nova Scotia, southern Ontario and the American states bordering Québec. Biological control efforts are currently being considered, with the introduction of adelgid predators.	Havrill *et al.* (2016), Elkinton *et al.* (2017), Mayfield *et al.* (2020), MacQuarrie *et al.* (2025).
	Elongated hemlock scale (*Fiorinia externa* Ferris)	Needle-sucking insect	3	8		Found in New York in 1908, now present in the American states bordering eastern Canada. Travels slowly, driven by the wind.	Venette *et al.* (2024)
***Ulmus americana* and *U. thomasii* (American elm and rock elm)**	Dutch elm disease (*Ophiostoma ulmi* [Buisman] Nannf. and *Ophiostoma novo ulmi* Brasier)	Disease carried by beetles (insects)	8	10	Overall rating = 114 to 134	Discovered in the United States in the 1930s and in Québec in 1944.	CFIA, ISC, NRCan, MRNF, NSISC, Copeland *et al.* (2023).
	Asian long-horned beetle	Wood-boring insect	3	8		See *Acer* spp. for exposure.	
	*Elm zigzag sawfly (*Aproceros leucopoda* Takeuchi)	Defoliating insect	*1 or *3	10		Discovered in Québec in 2020. Not much is known about its impacts in North America.	Martel *et al.* (2021).

Canada (observations near Toronto) and a relatively low reproductive rate (Turgeon *et al.* 2022), meaning that it can be controlled if it is detected quickly and vigorous eradication action is taken, followed by monitoring over a period of several years. The sites closest to Canada at which the insect has been found and from which it is being eradicated are in Massachusetts, New York (Long Island) and southern Ohio. It was officially declared to have been eradicated in 2020 at sites in Mississauga and Toronto (Ontario) after five years of non-detection.

There is still some uncertainty with respect to black walnut vulnerability in Québec (rating = 39 to 79). Thousand canker disease affects black walnut as far north as Ohio and Pennsylvania but does not appear to be spreading further north. Will anticipated climate change allow it to reach southern Canada? There have been reports that the spotted lanternfly, detected in Pennsylvania in 2014, has caused mortality of black walnut saplings (Leach 2023). However, this particular pest is still relatively new to North America, and its behaviour appears to be complex and difficult to anticipate. It feeds on sap from at least 70 species, meaning that it is still difficult to assess its impacts on forests (Urban 2019). We have chosen to list this pest for black walnut, but it also feeds on maple trees. Its impacts on the vulnerability of numerous species may therefore have to be reviewed in the coming years. Among other things, it can reduce soluble sugar rates in maple trees (Lavely *et al.* 2022), thereby rendering them less vigorous and affecting maple syrup production. The current climate in southern Québec offers the minimum conditions required for the spotted lanternfly to become established, but its range could expand northwards as a result of the anticipated effects of climate change (Zhao *et al.* 2024). Tamarack or American larch (rating = 40 to 80) is susceptible to damage from two exotic insects, but observed damage in Québec has been minimal so far. Since larch casebearer episodes usually cause very little damage (e.g., MRNF 2009), we assessed its severity rating at 1 instead of the 5 proposed by Potter *et al.* (2019). Tamarack is also subject to defoliation by the spongy moth, but the insect tends to focus its attacks on oak and poplar instead.

Lastly, oak from the white oak family, i.e., white oak (rating = 54), swamp white oak (rating = 70) and bur oak (rating = 70) differ from red oak in that they are less severely affected by oak wilt and are not killed by sudden oak death.

We remind readers to use the severity, exposure, and vulnerability ratings presented in this article with caution. They are primarily scientific communication tools to help practitioners and managers assimilate a complex body of information and determine which tree species are more or less vulnerable to new pests.

Other biological invasions

Three or four animal groups, two tree species, three shrub species and five herbaceous plant species (Table 2) were identified as potentially affecting entire forest stands as opposed to particular species or genera. The presence of European-origin earthworms, which have been observed in numerous locations since colonization, can lead to the development of mull humus as opposed to mor or moder humus. Humus can be altered significantly in locations inhabited by Asian earthworms. An alteration of this kind was observed for the first time in Québec at an urban site in 2022 (Saint-Jérôme). While the European wild boar has not yet become established in the wild in Canada to the east of Manitoba, it is farmed in the Eastern provinces. Provincial authorities are attempting to raise awareness of the associated risks, and public services have been set up to capture invasive animal species such as the wild boar. It seems that Eastern wild turkeys were not present in Québec at the time of European settlement, so their introduction or reintroduction may also impact the forests, but the species' repercussions have not been well documented (cf. Rinkes 2004).

Most invasive exotic tree, shrub and plant species identified in forest undergrowth have been found in urban, peri-urban or neighbouring areas and are still relatively rare in Québec's forests. The main threat to the forest is from buckthorn, which is already present extensively in many of southern Québec's private forests (see the interactive map in the Sentinelle tool offered by the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs: https://www.pub.enviroweb.gouv.qc.ca/scc/observation/carteobservations). A glossy buckthorn management guide is available for private woodlot owners (Martel 2021).

Every invasive plant has its own invasion mechanism, but dispersal capacity, soil conditions and disturbance history also tend to play an important role (Jones and Yamamoto 2024). Invasions tend to start in forests located close to residential areas (Potter *et al.* 2024).

Main issue for forest management

The main issue generated by these biological invasions is loss of biodiversity and forest productivity, either directly through species loss (e.g., butternut) or indirectly through the loss of a forest stand type or habitat for other species (e.g., Fig. 1). It is important to note that species loss may occur even in areas protected from forestry. Some ecosystems are damaged by biological invasions to such an extent that they are at risk of being converted into previously unknown ecosystems. We have focused our study mainly on the impacts of biological invasions for trees, but there is also a knock-on effect for the ecosystem as a whole (Seebens *et al.* 2017; Guo *et al.* 2023).

Recent progress in biotechnology (i.e., use of biology to solve problems) provides new opportunities to build pest resistance into species at risk prior to re-introduction. However, this type of technology requires significant investments, takes time and must be socially acceptable (Jacobs *et al.* 2023). Selection and recombination of individuals to create pest-resistant varieties are traditional approaches that can take decades to complete. An example would be the current work being done in the United States to reintroduce American chestnut (*Castanea dentata* (Marsh.) Borkh.) varieties that are resistant to chestnut blight (*Cryphonectria parasitica* (Murrill) M.E. Barr; Woodcock *et al.* 2019) and white pine varieties that are resistant to blister rust (Pike *et al.* 2018). Work is also underway to develop varieties resistant to pests in ash (e.g., Koch *et al.* 2012, Sun *et al.* 2024) and elm trees (e.g., Copeland *et al.* 2023; Martin *et al.* 2023).

Biological invasions can also lead to lower or less predictable forest productivity. Forest management rarely considers such unpredictable events and generally assumes that existing trends will continue (Bengston 2023). New disturbances must be well-established, and their damage documented before they are incorporated into forest maps and growth models that are used to update trends. This helps to avoid hasty decisions on hypothetical problems. However, given the scope of the potential effects of biological invasions, it is important to take preventive steps focused on species diversification where possible, as well as on the selection of more adapted populations or species and the development of healthy forests populated with vigorous trees. Some epidemics, for example those involving defoliating insects, can also be prevented by administering insecticides. The possibility of significantly increased mortality among American beech seedlings and saplings as a result of beech leaf disease (Martin and Volk 2021) may turn out to be positive from a forestry standpoint. Beech trees are not sought-after for forestry use but have proliferated through regeneration in recent decades (Zarfos *et al.* 2024). Forest managers could therefore take advantage of reduced beech proliferation as being potentially beneficial for other more sought-after forest species such as sugar maple, provided of course that beech trees do not become so rare as a result of all their potential pests that wildlife nutritional needs are not met, and biodiversity is adversely affected.

Lastly, biological invasions must be considered when designing assisted migration programs as part of a climate change adaptation strategy (Winder *et al.* 2011). It will be important to

Fig. 1. Succession of Japanese knotweed (left) and Norway maple (centre) in a red ash stand (mature trees), formerly with American elm, just before the anticipated mortality wave caused by the emerald ash borer.

Table 2. Brief description of the main invasive animals and exotic plants likely to disturb undergrowth in southern Québec's forests. The main sources of information and their acronyms are as for Table 1, plus the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs (MELCCFP, https://www.environnement.gouv.qc.ca/biodiversite/especes-exotiques-envahissantes/sentinelle.htm) and the USDA National Invasive Species Information Centre (USDA, https://www.invasivespeciesinfo.gov).

Organism's English and Latin names	Type of organism	Impacts	Invasion status and risk of spread	Additional information sources
Earthworms of European origin (18 species)	Animal	Produce mull-type humus which can trigger alterations to forest regeneration and undergrowth plant composition.	Present in different places in Québec since the beginning of European colonization. Sugar bush liming may increase the risk of invasion.	Drouin *et al*. (2016), Moore *et al*. (2015), Moore and Reynolds (2024).
Amynthas spp. (earthworms of Asian origin)	Animal	Alter soil structure and cause nutritional losses. Thought to be more active and more disruptive than European earthworms.	Discovered in the United States in the late 1800s and at one location in Québec in 2022. High risk of spread on warmer sites, but difficult to assess at this time for colder sites.	ISC, USDA, Laushman *et al*. (2018), Moore and Reynolds (2024).
Sus scrofa L. (wild boar)	Animal	Alters soil structure and grazes on regeneration. Digs into the soil for food.	Introduced into the UWnited States in the late 1800s and into Canada in the late 1900s. Observed in Ontario and New Hampshire. Isolated groups have already been eliminated in Québec. Low risk of spread when prevention and control measures are applied. Riparian areas and agro-forest landscapes are at greater risk.	ISC, APHIS, Gouvernement du Québec (https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/faune/animaux-sauvages-quebec/liste-des-especes-fauniques/sanglier)
Meleagris gallopavo silvestris L. (Eastern wild turkey): It is uncertain whether this species occupied southern Quebec at the time of European settlement.	Animal	Very little research on its impacts for forests, may disrupt seedling growth by scratching the ground in search of food (insects, grains).	Southern Ontario was probably the northern limit of this species' distribution before European settlement. Colder minimum temperatures and greater snow accumulation may have slowed the presence of this bird in southern Quebec. Initial evidence of wild turkey nesting in Québec was reported in 1984. Efforts have been made to foster economic activity from game hunting. These efforts, global warming and the presence of a mixture of forest and agricultural fields contribute to the development of populations.	Earl *et al*. (1990), Rinkes (2004), Lebel (2016).
Acer platanoides L. (Norway maple)	Hardwood tree	Invades forest undergrowth; hinders regeneration by other species.	Introduced into North America in 1756, and used widely in horticulture, including in Québec. The risk of spread is concentrated in urban and peri-urban areas, but the species can grow in a wide variety of conditions.	MELCCFP, NSISC, Galbraith-Kent and Handel (2018).
Ailanthus altissima (Mill.) Swingle (Chinese sumac)	Hardwood tree	Invades forests, especially after openings are created. Very difficult to eradicate afterwards. Favourite species of the spotted lanternfly, an exotic pest.	Introduced into the United States in 1784. Present in southern Québec and Ontario.	ISC, USDA
Berberis thunbergii DC. (Japanese barberry)	Hardwood shrub	Invades forest undergrowth and hinders regeneration by other species.	Introduced into the United States in 1875. Present in southern Québec and in the American states bordering Québec and Ontario. Low risk of spread because its presence appears to be limited to southern areas.	MELCCFP, NBISC
Rhamnus cathartica L. and *Rhamnus frangula* or *Franglula alnus* Miller, respectively (common buckthorn and glossy buckthorn)	Hardwood shrubs	Invades forest undergrowth and hinders regeneration by other species.	Introduced into North America and Canada during the 1800s. Mainly present in agri-forest areas. Currently invasive in southern Québec and potentially invasive at sites throughout the temperate forest zone.	MELCCFP, ISC, NBISC, NSISC, USDA, Lavoie (2019).

Organism's English and Latin names	Type of organism	Impacts	Invasion status and risk of spread	Additional information sources
Aegopodium podagraria Linné (goutweed)	Herbaceous plant	Invades forest undergrowth and hinders regeneration by other species.	Present in areas bordering Québec. Adapts to a wide variety of soil and light conditions.	ISC
Alliaria petiolata [M. Bieb.] Cavara & Grande (garlic mustard)	Herbaceous plant	Invades forest undergrowth and hinders regeneration by other species by producing allelopathic substances.	Discovered in the United States in 1868. Present in several Canadian provinces. Moderate risk of spread to Québec. Its spread may be limited by acid levels in many forest soils.	MELCCFP, ISC, NBISC, NSISC, USDA.
Fallopia japonica [Houtt.] Ronse Decr. (Japanese knotweed) 2 other Asian knotweeds that are often confused with it, and hybrids	Herbaceous plant	Invades forest undergrowth and hinders regeneration by other species.	Introduced into Québec in 1901 and present in several locations in the south of the province. Low risk of spread because it does not tolerate freezing conditions well.	MELCCFP, ISC, NBISC, NSISC, USDA, Dommanget *et al.* (2019).
Microstegium vimineum [Trin.] A. Camus (Japanese stiltgrass)	Herbaceous plant	Invades forest undergrowth and hinders regeneration by other species.	Discovered in the United States in 1919 and now present in Ontario and the American states bordering Québec. Low risk of spread in Québec, mainly in agri-forest areas. The species is regulated as a harmful organism in Canada.	CFIA, ISC, USDA
Vincetoxicum rossicum [Kleopow] Barbar (European swallow-wort)	Herbaceous plant	Invasion of forest undergrowth; may kill seedlings and saplings.	Introduced into North America in the late 1800s. Present in southern Québec, Ontario and the United States. Low risk of spread within Québec, because dispersal is relatively slow and the plant prefers calcium-rich soils that are rarer in Québec's forests.	MELCCFP, ISC, Winston *et al.* (2017), NSISC.

manage the risk of introducing or spreading a new pest within an ecosystem when transporting seeds or plants over long distances. This is the main avenue through which sudden oak death could be introduced into eastern North America (Grondin *et al.* 2013), since horticultural supplies from contaminated nurseries are the most likely vectors for accidentally introducing the disease (Liebhold *et al.* 2012). On the other hand, there are good reasons to question the relevance of investing in migration if the survival of the species in question could be threatened by a pest becoming established at the new site. Here again, advances in biotechnology may help in building pest resistance into the plants of species targeted for assisted migration (Jacobs *et al.* 2023).

Conclusion

We have identified the forest-related consequences and issues caused by the main biological invasions that have occurred in Québec so far or are likely to occur by the end of the current century. Some of these invasions may act jointly with current climate change (cf. Frelich and Reich 2010; Ramsfield *et al.* 2016), and we will address this in the next paper in this series (Duchesne *et al.* [Under review]). However, many will also have independent impacts (Fisichelli *et al.* 2014).

The number of biological invasions has increased over the last century and continues to grow. These invasions are concerning because they often trigger repercussions for both biodiversity and forest productivity. So far, most of their impacts have been limited in Québec's temperate forest. None of the economically important abundant species have been eradicated. The most obvious consequences so far include extensive American elm losses and a high mortality rate among ash, especially in urban areas. There have been no reports of forest canopies being inadvertently taken over by exotic species.

Despite this, eight mainly secondary or companion indigenous species are no longer able to develop as in the past. They are American beech, three ash species, two elm species, as well as butternut and white pine. Similarly, three other species, red pine, red oak and eastern hemlock, are highly vulnerable to pests that are moving closer to southern Québec. Undergrowth has also been invaded by exotic species in some stands, instead of natural regeneration composed of desired species such as sugar maple and various other plants.

It is difficult to believe that all these biological invasions will not result in a significant and persistent degradation of affected forest ecosystems in the long term. According to Hudgins *et al.* (2024), creative and collaborative solutions will be needed to protect the forests from the impacts of these invasions, and this, in turn, may require better coordination of funding, media attention and risk perception by forest experts, especially in the case of urban forests and horticulture. Public awareness of the potential negative impacts of these biological invasions is key to slowing down their spread and improving the chances of early detection. The fight against invasive species and ecosystem monitoring to detect new threats are significant challenges for contemporary forest management.

Acknowledgements

We would like to thank Julie Bouchard and Pierre Therrien from the Direction de la protection des forêts at the Ministère des Ressources naturelles et des Forêts du Québec for their comments on an earlier version of this paper. We also thank

Denise Tousignant for revising the original French version of the manuscript as well as Christine Gardner for its translation to English. Finally, we thank the two anonymous reviewers and the associate editor for their constructive comments.

References

Amyot, M.-A., D.N. Bengston, J. Crabtree, F. Fleischman, J. Garcia, C. Mann, B. Perrin, L. Westphal and M. Wheeler. 2022. Strategic foresight in forestry: How Canada and the United States use a neglected tool to build a green, healthy and resilient future. *In*: Proceedings, XV World Forestry Congress. Food and Agriculture Organization of the United Nations (FAO); 2–6 May 2022; Seoul, Republic of Korea. 8 p. https://www.fs.usda.gov/nrs/pubs/jrnl/2022/nrs_2022_amyot_001.pdf

Anderson, J.L., S.B. Heard, J. Sweeney and D.S. Pureswaran. 2022. Mate choice errors may contribute to slow spread of an invasive Eurasian longhorn beetle in North America. NeoBiota (71): 71-89. https://doi.org/10.3897/neobiota.71.72843

Aukema, J.E., D.G. McCullough, B. Von Holle, A.M. Liebhold, K. Britton and S.J. Frankel. 2010. Historical accumulation of nonindigenous forest pests in the continental United States. BioSci. 60(11): 886–897. https://doi.org/10.1525/bio.2010.60.11.5

Bean, J.L. and P.A. Godwin. 1971. Red pine scale. U.S. Department of Agriculture, Forest Service, For. Pest Leaflet 10. 6 p. https://www.fs.usda.gov/foresthealth/docs/fidls/FIDL-10-RedPineScale.pdf

Belouard, N., S. De Bona, M.R. Helmus, I.G. Smith and J.E. Behm. 2025. A method to quantify jump dispersal of invasive species from occurrence data: the case of the spotted lanternfly, *Lycorma delicatula*. NeoBiota 98: 319–334. https://doi.org/10.3897/neobiota.98.147310

Bengston, D.N. 2023. Wild cards in natural resource planning: high impact surprises that shape the future. Nat. Res. J. 63(1): 70-87. https://digitalrepository.unm.edu/nrj/vol63/iss1/4/

Bérubé, J.A., A. Potvin and D. Stewart. 2017. Importance of local and long-distance *Heterobasidion irregulare* aerial basidiospore dispersal for future infection centres in thinned red pine plantations in Quebec. The Forestry Chronicle 93(3): 241-245. https://doi.org/10.5558/tfc2017-032

Bérubé, J.A., J. Dubé and A. Potvin. 2018. Incidence of *Heterobasidion irregulare* aerial basidiospores at different locations in southern Quebec. Canadian Journal of Plant Pathology 40(1): 34-38. https://doi.org/10.1080/07060661.2017.1393007

Cale, J.A., T.M. Garrison-Johnston, S.A. Teale and J.D. Castello. 2017. Beech bark disease in North America: Over a century of research revisited. Forest Ecology and Management 394: 86-103. https://doi.org/10.1016/j.foreco.2017.03.031

Casagrande, R., R.G. van Driesche, M. Mayer, R. Fuester, D. Gilrein, L. Tewksbury and H. Faubert. 2009. Biological control of *Fenusa pusilla* (Hymenoptera: Tenthredinidae) in the Northeastern United States: A thirty-four year perspective on efficacy. Florida Entomol. 92(2): 243-247.

CCFM. 2019. [Canadian Council of Forest Ministers]. Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests. Prepared for the Forest Pest Working Group of the Canadian Council of Forest Ministers. 65 p. https://www.ccfm.org/wp-content/uploads/2019/08/Risk-assessment-of-the-threat-of-mountain-pine-beetle-to-Canadas-Boreal-and-Eastern-pine-forests.pdf

Charron, G., J. Yergeau, H. Van der Heyden, G.J. Bilodeau, C. Beaulieu and P. Tanguay. 2024. Survey of *Phytophthora* diversity reveals *P. abietivora* as a potential *Phytophthora* root rot pathogen in Québec Christmas tree plantations. Plant Disease 108(6): 1445-1454. https://doi.org/10.1094/PDIS-12-23-2670-SR

Cheng, H.H. and E.J. Leroux. 1970. Major factors in survival of the immature stages of *Fenusa pusilla* in southwestern Quebec. Can. Entomol. 102: 995-1002.

Clark E.L., C. Pitt, A.L. Carroll, B.S. Lindgren and D.P.W. Huber. 2014. Comparison of lodgepole and jack pine resin chemistry: implications for range expansion by the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Curculionidae). PeerJ 2: e240. https://doi.org/10.7717/peerj.240

Cody, J.B., F.B. Knight and S.A. Graham. 1967. The hymenopterous parasites *Agathis pumila* (Braconidae) and *Epilampsis laricinellae* (Eulophidae) on the Larch casebearer (Lepidoptera: Coleophoridae) in the Northern Lake States. Great Lakes Entomol. 1(5): 159-167. https://doi.org/10.22543/0090-0222.1054

Cooke, B.J. and A.L. Carroll. 2017. Predicting the risk of mountain pine beetle spread to eastern pine forests: Considering uncertainty in uncertain times. For. Ecol. Manag. 396: 11-25. https://doi.org/10.1016/j.foreco.2017.04.008

Copeland, C.A., R.W. Harper, N.J. Brazee and F.J. Bowlick. 2023. A review of Dutch elm disease and new prospects for *Ulmus americana* in the urban environment. Arboric. J. 45(1): 3-29. https://doi.org/10.1080/03071375.2022.2082177

Costanza, K.K., T.D. Whitney, C.D. McIntire, W.H. Livingston and K.J Gandhi. 2018. A synthesis of emerging health issues of eastern white pine (*Pinus strobus*) in eastern North America. For. Ecol. Manag.t 423: 3-17. https://doi.org/10.1016/j.foreco.2018.02.049

Coyle, D.R., R.T. Trotter, M.S. Bean and S.E. Pfister. 2021. First recorded Asian longhorned beetle (Coleoptera: Cerambycidae) infestation in the southern United States. J. Integ. Pest Manag. 12(1): 10. https://doi.org/10.1093/jipm/pmab007

Digweed, S.C., C.J. MacQuarrie, D.W. Langor, D.J. Williams, J.R. Spence, K.L. Nystrom and L. Morneau. 2009. Current status of invasive alien birch-leafmining sawflies (Hymenoptera: Tenthredinidae) in Canada, with keys to species. Can. Entomol. 141(3): 201-235. https://doi.org/10.4039/n09-003

Dommanget, F., A. Evette, F.-M. Martin, F. Piola, M. Thiébaut, S. Rouifed, A. Dutartre, E. Sarat, C. Lavoie *et al.* 2019. Les renouées asiatiques, espèces exotiques envahissantes. Sciences, Eaux & Territoires 27: 8–13. https://doi.org/10.14758/SET-REVUE.2019.1.02

Duchesne, L., F. Guillemette, S., Bédard and R. Ouimet. (In press). Contemporary Issues in Québec's Temperate Forest — Part 1: Profile of the Forests. For. Chron.

Dumas, M.T. and G. Laflamme. 2013. Efficacy of two *Phlebiopsisgigantea* formulations in preventing *Heterobasidion irregulare* colonization of red pine stumps in eastern Canada. Phytoprotec. 93(1): 25–31. https://doi.org/10.7202/1018887ar

Drouin, M., Bradley, R. and L. Lapointe. 2016. Linkage between exotic earthworms, understory vegetation and soil properties in sugar maple forests. For. Ecol. Manage. 364: 113–121. https://doi.org/10.1016/j.foreco.2016.01.010

Earl, J., C. Mary and R.B. Kennamer. 1990. History of the wild turkey in North America. National Wild Turkey Federation Bulletin 15: 1-8. https://enfilade18thc.com/wp-content/uploads/2012/11/bulletin_14.pdf

Edwards, J.E., C. Pearce, A.E. Ogden and T.B. Williamson. 2015. Climate change and sustainable forest management in Canada: A guidebook for assessing vulnerability and mainstreaming adaptation into decision making. Canadian Council of Forest Ministers, Ottawa, Ontario. 160 p. https://ostr-backend-prod.azurewebsites.net/server/api/core/bitstreams/d70b1608-aa58-48be-9a75-5856965a00d9/content

Elkinton, J.S., J.A. Lombardo, A.D. Roehrig, T.J. McAvoy, A. Mayfield and M. Whitmore. 2017. Induction of cold hardiness in an invasive herbivore: The case of hemlock woolly adelgid (Hemiptera: Adelgidae). Environ. Entomol. 46(1): 118-124. https://doi.org/10.1093/ee/nvw143

Ewing, C.J., C.E. Hausman, J. Pogacnik, J. Slot and P. Bonello. 2019. Beech leaf disease: An emerging forest epidemic. For. Pathol. 49(2): e12488. https://doi.org/10.1111/efp.12488

Fisichelli, N.A., S.R. Abella, M. Peters and F.J. Krist Jr. 2014. Climate, trees, pests, and weeds: Change, uncertainty, and biotic stressors in eastern US national park forests. For. Ecol. Manage. 327: 31-39. https://doi.org/10.1016/j.foreco.2014.04.033

Fitza, K.N., J. Allison, B. Slippers, N. Chingandu and S.E. Reed. 2024. Diversity and potential sources of introduction of the beech leaf nematode (*Litylenchus crenatae mccannii*) to Ontario, Canada. Can. J. Plant Path. (4): 356-366. https://doi.org/10.1080/07060661.2024.2312150

Frelich, L.E. and P.B. Reich, 2010. Will environmental changes reinforce the impact of global warming on the prairie–forest border of central North America? Front. Ecol. Environ. 8(7): 371–378. https://doi.org/10.1890/080191

Galbraith-Kent, S.L. and S.N. Handel. 2008. Invasive *Acer platanoides* inhibits native sapling growth in forest understorey communities. J. Ecol. 96: 293–302. https://doi:10.1111/j.1365-2745.2007.01337.x

Gauthier, M.K., É. Bourgault, A. Potvin, G.J. Bilodeau, S. Gustavsson, S. Reed, P. Therrien, E. Barrette and P. Tanguay. 2024. Biosurveillance of oak wilt disease in Canadian areas at risk. Can. J. Plant Pathol. 46(1): 27-38. https://doi.org/10.1080/07060661.2023.2261890

Gougherty, A.V. 2023. Emerging tree diseases are accumulating rapidly in the native and non-native ranges of Holarctic trees. NeoBiota 87: 143–160. https://doi.org/10.3897/neobiota.87.103525

Gougherty, A.V., A.D. Walters, A. Prasad, M.P. Peters, S.N. Matthews and I. DeMerchant. 2024. Climate, host abundance and spread: Unravelling the drivers of forest pest distributions in North America. J. Biogeogr. 51(12): 2498-2511. https://doi.org/10.1111/jbi.15004

Grondin, J., D. Rioux, L. Innes, B. Boulet and J. Bérubé. 2013. L'encre des chênes rouges. *In:* Ministère des Ressources naturelles (ed.), Le guide sylvicole du Québec, Tome 1 — Les fondements biologiques de sylviculture. Collective work under the supervision of B. Boulet and M. Huot. Les Publications du Québec, Québec. 678-681.

Grünwald, N.J., E.M. Goss and C.M. Press. 2008. *Phytophthora ramorum*: A pathogen with a remarkably wide host range causing sudden oak death on oaks and ramorum blight on woody ornamentals. Mole. Plant Pathol. 9(6) : 729-740. https://doi.org/10.1111/j.1364-3703.2008.00500.x

Guèvremont, H.C. and F.W. Quednau. 1977. Introduction de parasites ichneumonides pour la lutte biologique contre *Fenusa pusilla* (Hymenoptera: Tenthredinidae) au Québec. Can. Entomol. 109: 1545-1548.

Guo, Q., K.M. Potter, H. Ren and P. Zhang. 2023. Impacts of exotic pests on forest ecosystems: An update. Forests 14(3): 605. https://doi.org/10.3390/f14030605

Havill, N.P., S. Shiyake, A.L. Galloway, R.G. Foottit, G. Yu, A. Paradis, J. Elkinton, M.E. Montgomery, M. Sano and A. Caccone. 2016. Ancient and modern colonization of North America by hemlock woolly adelgid, *Adelges tsugae* (Hemiptera: Adelgidae), an invasive insect from East Asia. Mole. Ecol. 25(9): 2065-2080. https://doi.org/10.1111/mec.13589

Hudgins, E.J., B. Leung, C.J.K. MacQuarrie, D.G. McCullough, A. Francis, G.M. Lovett, Q. Guo, K.M. Potter, C.I. Cullingham *et al.* 2024. Five organizing themes for invasive forest insect and disease management in Canada and the United States. For. Ecol. Manage. 566: 122046. https://doi.org/10.1016/j.foreco.2024.122046

Innes, L. and A. Rainville. 1996. Distribution et détection du *Sirococcus clavigignenti-juglandacearum* au Québec. Phytoprotec. 77(2) : 75–78. https://doi.org/10.7202/706102ar

Jacobs, D.F., R.K. Dumroese, A.N. Brennan, F.T. Campbell, A.O. Conrad, J.A. Delborne, S. Fitzsimmons, D. Flores, C.P. Giardina *et al.* 2023. Reintroduction of at-risk forest tree species using biotechnology depends on regulatory policy, informed by science and with public support. New For. 54: 587–604. https://doi.org/10.1007/s11056-023-09980-y

Johns, R.C., N. Kirichenko, S. Edwards, S. Grauby, C. Hughes, K. Beltrando, B. Morin, E. Owens, J. Sweeney *et al.* 2024. *Orchestes fagi* (L.), Beech Leaf-Mining Weevil/Charançon du hêtre (Coleoptera: Curculionidae). *In:* M.A. Vankosky and V. Martel (eds). Biological Control Programmes in Canada, 2013-2023. pp. 292-296. CABI, Boston (MA). https://doi.org/10.1079/9781800623279.0032

Johnson, A., S. Hermann and K. Hoover. 2025. Predation of spotted lanternfly (*Lycorma delicatula*) by generalist arthropod predators in North America. Arthropod-Plant Interactions 19: 31. https://doi.org/10.1007/s11829-025-10138-0

Jones, C.C. and M.H. Yamamoto. 2024. Long-term patterns and mechanisms of plant invasions in forests: The role of forest age and land-use history. Biol. Invasions 26(9): 3125-3145. https://doi.org/10.1007/s10530-024-03365-8

Juzwik, J., T.C. Harrington, W.L. MacDonald and D.N. Appel. 2008. The origin of Ceratocystis fagacearum, the oak wilt fungus. Ann. Rev. Phytopathol. 46(1): 13-26. https://doi.org/10.1146/annurev.phyto.45.062806.094406

Juzwik, J., M.E. McDermott-Kubeczko, M.J. Moore and M. Ginzel. 2022. Evaluation of thousand cankers disease-symptomatic juglans nigra in Southwestern Ohio following population collapse of Pityophthorus juglandis. Plant Health Progress 23(4): 415-423. https://doi.org/10.1094/PHP-03-22-0032-RS

Kanaskie, C.R., T.C. Schmeelk, J.A. Cancelliere and J.R. Garnas. 2023. New records of southern pine beetle (Dendroctonus frontalis Zimmermann; Coleoptera: Curculionidae) in New York, New Hampshire, and Maine, USA indicate northward range expansion. The Coleopterists Bulletin 77(2): 248-251. https://doi.org/10.1649/0010-065X-77.2.248

Klymko, J. and K. Anderson. 2022. First records of the invasive beech leaf-mining weevil (Orchestes fagi) in New Brunswick and Prince Edward Island, Canada. J. Acad. Entomol. Soc. 18: 23-25.

Koch, J.L. D.W. Carey, K.S. Knight, T. Poland, D.A. Herms and M.E. Mason. 2012. Breeding strategies for the development of emerald ash borer - resistant North American ash. *In* R.A. Sniezko, A.D. Yanchuk, J.T. Kliejunas, K.M. Palmieri, J.M. Alexander and S.J. Frankel. Proceedings of the Fourth International Workshop on the Genetics of Host-Parasite Interactions in Forestry: Disease and Insect Resistance in Forest Trees. Albany, NY. pp. 235-239. Pac. Southwest Res. Stn.,

For. Serv., US Dept. Agric. https://www.fs.usda.gov/psw/publications/documents/psw_gtr240/psw_gtr240_235.pdf
Langmaier, M. and K. Lapin. 2020. A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. Front. Plant Sci. 11: 524969. https://doi.org/10.3389/fpls.2020.524969
Langor, D.W., E.K. Cameron, C.J.K. MacQuarrie, A. McBeath, A. McClay, B. Peter, M. Pybus, T. Ramsfield, K. Ryall *et al*. 2014. Non-native species in Canada's boreal zone: Diversity, impacts, and risk. Environ. Rev. 22(4): 372-420. https://doi.org/10.1139/er-2013-0083
Laushman, K.M., S.C. Hotchkiss and B.M. Herrick. 2018. Tracking an invasion: community changes in hardwood forests following the arrival of *Amynthas agrestis* and *Amynthas tokioensis* in Wisconsin. Biol. Invasions 20: 1671–1685. https://doi.org/10.1007/s10530-017-1653-4
Lavoie, C. 2019. 50 plantes envahissantes — Protéger la nature et l'agriculture. Les Publications du Québec, Québec (Qc). 415 p.
Lavely, E., L. Lavorivska, O. Uyi, D.M. Eissenstat, B. Walsh, E.J. Primka IV, J. Harper and K. Hoover. 2022. Impacts of short-term feeding by spotted lanternfly (*Lycorma delicatula*) on ecophysiology of young hardwood trees in a common garden. Front. Insect. Sci. 2: 1080124. https://doi.org/10.3389/finsc.2022.1080124
Leach, H. 2023. Spotted lanternfly frequently asked questions. Penn State University Extension, University Park (PA). https://extension.psu.edu spotted-lanternfly-frequently-asked-questions
Lebel, F. (ed.). 2016. Plan de gestion du dindon sauvage au Québec 2016-2023. Gouvernement du Québec, ministère des Forêts, de la Faune et des Parcs, Direction de l'expertise sur la faune terrestre, l'herpétofaune et l'avifaune. 122 p. https://cdn-contenu.quebec.ca/cdn-contenu/faune/documents/gestion-especes/Plans-gestion/PL_gestion-dindon-complet.pdf
Lesk, C., E. Coffel, A.W. D'Amato, K. Dodds and R. Horton. 2017. Threats to North American forests from southern pine beetle with warming winters. Nat. Clim. Chan. 7(10): 713-717. https://doi.org/10.1038/nclimate3375
Li, D.-W., N.P. Schultes, J.A. LaMondia and R.S. Cowles. 2019. *Phytophthora abietivora*, a new species isolated from diseased Christmas trees in Connecticut, U.S.A. Plant Disease 103: 3057-3064. https://doi.org/10.1094/PDIS-03-19-0583-RE
Liebhold, A.M., W.I. MacDonald, D. Bergdahl and V.C. Mastro. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. For. Sci. 41(suppl_1): a0001-z0001. https://doi.org/10.1093/forestscience/41.s1.a0001
Liebhold, A.M., E.G. Brockerhoff, L.J. Garrett, J.L. Parke and K.O. Britton. 2012. Live plant imports: The major pathway for forest insect and pathogen invasions of the US. Front. Ecol. Environ. 10(3): 135–143. https://doi.org/10.1890/110198
Lovett, G., M. Weiss, A.M. Liebhold, T.P. Holmes, B. Leung, K.F. Lambert, D.A. Orwig, F.T. Campbell, J. Rosenthal *et al*. 2016. Nonnative forest insects and pathogens in the United States: Impacts and policy options. Ecol. Appl. 26(5): 1437-1455. https://doi.org/10.1890/15-1176
MacQuarrie, C.J.K., K. Ryall, G. Jones, V. Martel, J. Sweeney, J.M. Gaudon and S.M. Smith. 2024. *Agrilus planipennis* Fairmaire, Emerald Ash Borer / Agrile du frêne (Coleoptera: Buprestidae). *In* M.A. Vankosky and V. Martel (eds). Biological Control Programmes in Canada, 2013-2023. pp. 88-102. CABI, Boston (MA). https://doi.org/10.1079/9781800623279.000988
MacQuarrie, C.J.K., M. Gray, E. Bullas-Appleton, T. Kimoto, N. Mielewczyk, R. Neville, J.B. Ogden, J.G. Fidgen and J.J. Turgeon. 2025. The distribution of the hemlock woolly adelgid (Hemiptera: Adelgidae) in Canada. Can. Entomol. 157: e11. https://doi.org/10.4039/tce.2025.2
Martel, M.-J. 2021. Guide de gestion du nerprun bourdaine pour les propriétaires forestiers. Agence de mise en valeur de la forêt privée de l'Estrie. Cookshire-Eaton (Qc). 52 p. https://afm.qc.ca/docs/Guide%20de%20gestion%20du%20nerprun%20bourdaine%20pour%20les%20proprietaires%20forestiers%20AMVFE%202021.pdf
Martel, V., O. Morin, S.K. Monckton, C.S. Eiseman, C. Béliveau, M. Cusson and S.M. Blank. 2021. Elm zigzag sawfly, *Aproceros leucopoda* (Hymenoptera: Argidae), recorded for the first time in North America through community science. Can. Entomol. 154(1): e1. https://doi.org/10.4039/tce.2021.44
Martin, D. and D. Volk. 2021. Pest alert: Beech leaf disease. U.S. Department of Agriculture, Forest Service, Eastern Reg. State and Private For. Milwaukee, WI. 2 p. https://www.dontmovefirewood.org/wp-content/uploads/2019/02/Beech-Leaf-Disease-Pest-Alert.pdf
Martín, J.A., J. Domínguez, A. Solla, C.M. Brasier, J.F. Webber, A. Santini, C.Martínez-Arias, L. Bernier and L. Gil. 2021. Complexities underlying the breeding and deployment of Dutch elm disease resistant elms. New Forests 54: 661-696. https://doi.org/10.1007/s11056-021-09865-y
Mayfield, A.E., III, S.M. Salom, K. Sumpter, T. McAvoy, N.F. Schneeberger and R. Rhea. 2020. Integrating chemical and biological control of the hemlock woolly adelgid: A resource manager's guide. FHAAST-2018-04. U.S. Department of Agriculture, Forest Service, Forest Health Assessment and Applied Sciences Team, Morgantown, WV (États-Unis). FHAAST-2018-04. 34 p. https://www.srs.fs.usda.gov/pubs/misc/misc_2020_mayfield_001.pdf
McClure, M.S. 1983. Temperature and host availability affect the distribution of *Matsucoccus matsumurae* (Kuwana)(Homoptera: Margarodidae) in Asia and North America. Ann. Entomol. Soc. Am. 76(4): 761-765. https://doi.org/10.1093/aesa/76.4.761
Mech, A.M., K.A. Thomas, T.D. Marsico, D.A. Herms, C.R. Allen, M.P. Ayres, K.J.K. Gandhi, J. Gurevitch, N.P. Havill *et al*. 2019. Evolutionary history predicts high-impact invasions by herbivorous insects. Ecol. Evol. 9(21):12216–12230. https://doi.org/doi:10.1002/ece3.5709
Moore, J.-D. and J.W. Reynolds. 2024. First record of the invasive Asian earthworm *Amynthas tokioensis* (Beddard, 1892) in the province of Québec, Canada. BioInvasions Records 13(1): 1–8. https://doi.org/10.3391/bir.2024.13.1.01
Moore, J.-D., Ouimet, R., Long, R.P. and P.A. Bukaveckas. 2015. Ecological benefits and risks arising from liming sugar maple dominated forests in northeastern North America. Environ. Reviews 23(1): 66-77. https://doi.org/10.1139/er-2014-0048
Moore, M., J. Juzwik, F. Miller, L. Roberts and M.D. Ginzel. 2019. Detection of *Geosmithia morbida* on numerous insect species in four eastern states. Plant Health Progress 20(3) : 133-139. https://doi.org/10.1094/PHP-02-19-0016-RS
MRNF. 2009. [Ministère des Ressources naturelles et de la Faune]. Insectes, maladies et feux dans la forêt québécoise — 2008. Gouvernement du Québec, ministère des Ressources naturelles et de la Faune, Direction de la protection des forêts. 63 p. https://mffp.gouv.qc.ca/documents/forets/fimaq/bilan2008.pdf
MRNFP. 2014. [Ministry of Natural Resources Forest Protection]. Risk assessment of the threat of brown spruce longhorn beetle to Nova Scotia forests. Report sponsored by the Forest Pest Working Group of the Canadian Council of Forest Ministers. 85 p. https://publications.gc.ca/collections/collection_2015/rncan-nrcan/Fo4-50-2014-eng.pdf

Nair, V.M.G., C.J. Kostichka and J.E. Kuntz. 1979. *Sirococcus clavigignenti-juglandacearum*: an undescribed species causing canker on butternut. Mycologia 71(3): 641-646. https://doi.org/10.1080/00275514.1979.12021049

Nealis, V.G. 2024. Balsam woolly adelgid. *In* J.P. Brandt, B.I. Daigle, J.-L. St-Germain, A.C. Skinner, B.C. Callan and V.G. Nealis (eds). Trees, insects, mites, and diseases of Canada's forests. Natural Resources Canada, Canadian Forest Service, Ottawa, Ontario. https://tidcf.nrcan.gc.ca/en/insects/factsheet/5314

Nealis, V.G., I. DeMerchant, D. Langor, M.K. Noseworthy, G. Pohl, K. Porter, E. Shanks, R. Turnquist and V. Waring. 2016. Historical occurrence of alien arthropods and pathogens on trees in Canada. Can. J. For. Res. 46: 172–180. https://doi.org/10.1139/cjfr-2015-0273

Ostry, M.E., G. Laflamme and S.A. Katocich. 2010. Silvicultural approaches for management of eastern white pine to minimize impacts of damaging agents. Forest Pathol. 40: 332-346. doi: 10.1111/j.1439-0329.2010.00661.x

Pedlar, J.H., D.W. McKenney, E. Hope, S. Reed and J. Sweeney. 2020. Assessing the climate suitability and potential economic impacts of Oak wilt in Canada. Sci. Rep. 10(1): 19391. https://doi.org/10.1038/s41598-020-75549-w

Pike, C.C., P. Berrang, S. Rogers, A. David, C. Sweeney and J. Hendrickson. 2018. Improving the resistance of eastern white pine to white pine blister rust disease. For. Ecol. Manage. 423: 114-119. https://doi.org/10.1016/j.foreco.2018.03.001

Pimentel, D., R. Zuniga and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ. 52(3): 273-288. https://doi.org/10.1016/j.ecolecon.2004.10.002

Potter, K.M., M.E. Escanferla, R.M. Jetton and G. Man. 2019. Important insect and disease threats to United States tree species and geographic patterns of their potential impacts. Forests 10(4): 304. https://doi.org/10.3390/f10040304

Potter, K.M., K.H. Riitters, B.V. Iannone III, Q. Guo and S. Fei. 2024. Forest plant invasions in the eastern United States: Evidence of invasion debt in the wildland-urban interface. Landsc. Ecol. 39: 207. https://link.springer.com/article/10.1007/s10980-024-01985-y

Pureswaran, D.S. and J. Garnas. 2025. Threat of red pine scale, *Matsucoccus matsumurae* (Kuwana) to the Midwestern United States and Canada. Plant Health Cases: phcs20250005. https://doi.org/10.1079/planthealthcases.2025.0005

Quiring, D., Ostaff, D., Hartling, L., Lavigne, D., Moore, K., and DeMerchant, I. 2008. Temperature and plant hardiness zone influence distribution of balsam woolly adelgid damage in Atlantic Canada. For. Chron. 84(4): 558–562. https://doi.org/10.5558/tfc84558-4

Ramsfield, T.D., B.J. Bentz, M. Faccoli, H. Jactel and E.G. Brockerhoff. 2016. Forest health in a changing world: Effects of globalization and climate change on forest insect and pathogen impacts. Forestry 89(3): 245-252. https://doi.org/10.1093/forestry/cpw018

Reed, S.E., D. Volk, D.K.H. Martin, C.E. Hausman, T. Macy, T. Tomon and S. Cousins. 2022. The distribution of beech leaf disease and the causal agents of beech bark disease (*Cryptoccocus fagisuga*, *Neonectria faginata*, *N. ditissima*) in forests surrounding Lake Erie and future implications. For. Ecol. Manage. 503: 119753. https://doi.org/10.1016/j.foreco.2021.119753

Régnière, J., V. Nealis and K. Porter. 2008. Climate suitability and management of the gypsy moth invasion into Canada. *In* Langor, D.W. and J. Sweeney (eds). Ecological impacts of non-native invertebrates and fungi on terrestrial ecosystems. pp 135-148. Springer, Dordrecht, NE. https://doi.org/10.1007/978-1-4020-9680-8_10

Rinkes, Z.L. 2004. Eastern wild turkey (*Meleagris gallopavo silvestris*) habitat preference and the impact of scratch foraging on hardwood regeneration in mixed oak forests. Master thesis. Ohio University. 34 p. http://rave.ohiolink.edu/etdc/view?acc_num=ohiou1088439746

Samarasinghe, S. and E.J. Leroux. 1966. The biology and dynamics of the oyster-shell scale, *Lepidosaphes ulmi* (L.) (Homoptera: Coccidae), on apple in Quebec. Annals of the Entom. Soc. of Québec 11(3). 206–292.

Sanderson, L.A., J.A. McLaughlin and P.M. Antunes. 2012. The last great forest: A review of the status of invasive species in the North American boreal forest. Forestry 85(3): 329–340. https://doi.org/10.1093/forestry/cps033

Seebens, H., T.M. Blackburn, E.E. Dyer, P. Genovesi, P.E. Hulme, J.M. Jeschke, S. Pagad, P. Pyšek, M. Winter *et al.* 2017. No saturation in the accumulation of alien species worldwide. Nat. Commun. 8(1): 14435. https://doi.org/10.1038/ncomms14435

Shamoun, S.F., D. Rioux, B. Callan, D. James, R.C. Hamelin, G.J. Bilodeau, M. Elliot, C.A. Lévesque, E. Becker *et al.* 2018. An overview of Canadian research activities on diseases caused by *Phytophthora ramorum*: results, progress, and challenges. Plant Disease 102(7): 1218-1233. https://doi.org/10.1094/PDIS-11-17-1730-FE

Sieg, C.H., J.S. Denslow, C.D. Huebner and J.H. Miller. 2010. The role of the Forest Service in nonnative invasive plant research. *In*: M.E. Dix and K. Britton (eds.), A dynamic invasive species research vision: Opportunities and priorities 2009–2029. Gen. Tech. Rep. WO-79/83. Washington, D.C.: U.S. Department of Agriculture, Forest Service, Research and Development: 55–66. https://www.fs.usda.gov/research/docs/invasive-species/wo_gtr79_83/wo_gtr79_83_035.pdf

Srivastava, V. and A.L. Carroll. 2023. Dynamic distribution modelling using a native invasive species, the mountain pine beetle. Ecol. Modell. 482: 110409. https://doi.org/10.1016/j.ecolmodel.2023.110409

Srivastava, D.S., L. Coristine,A.l. Angert, M. Bontrager, S.l. Amundrud, J.l. Williams, A.C.Y. Yeung, D.R. De Zwaan, P.l. Thompson *et al.* 2021. Wildcards in climate change biology. Ecol. Monogr. 91(4): e01471. https://doi.org/10.1002/ecm.1471

Streifel, M.A. P.C. Tobin, A.M. Kees and B.H. Aukema. 2019. Range expansion of *Lymantria dispar dispar* (L.) (Lepidoptera: Erebidae) along its north-western margin in North America despite low predicted climatic suitability. J. Biogeog. 46(1): 58-69. https://doi.org/10.1111/jbi.13474

Sun, J., T.M. Koski, J.D. Wickham, Y.N. Baranchikov and K.E. Bushley. 2024. Emerald ash borer management and research: decades of damage and still expanding. Annu. Rev. Entomol.69(1):239-258.https://doi.org/10.1146/annurev-ento-012323-032231

Sweeney, J.D., C. Hughes, H. Zhang, N.K. Hillier, A. Morrison and R. Johns. 2020. Impact of the invasive beech leaf-mining weevil, *Orchestes fagi*, on American beech in Nova Scotia, Canada. Front. For. Glob. Change 3: 46. https://doi.org/10.3389/ffgc.2020.00046

Trân, J.K., T. Ylioja, R. Billings, J. Régnière and M.P. Ayres. 2007. Impact of minimum winter temperatures on the population dynamics of *Dendroctonus frontalis*. Ecol. Appl. 17(3): 882–899. https://doi.org/10.1890/06-0512

Turgeon, J.J., B. Gasman, M.T. Smith, J.H. Pedlar, M. Orr, R.E. Fournier, J. Doyle, J. Ric and T. Scarr. 2022. Canada's response to invasion by Asian longhorned beetle (Coleoptera: Cerambycidae) in Ontario. Can. Entomol. 154(s1): e1. 87 p. https://doi.org/10.4039/tce.2021.60

Urban, J.M., 2019. Perspective: Shedding light on spotted lanternfly impacts in the USA. Pest Manage. Sci. 76(1): 10–17. https://doi.org/10.1002/ps.5619

Urban, J.M. and H. Leach. 2023. Biology and management of the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae), in the United States. Annu. Rev. Entomol. 68: 151–67. https://doi.org/10.1146/annurev-ento-120220-111140

Venette, R.C., A. Ambourn, B.H. Aukema, R.M. Jetton and T.R. Petrice. 2024. Hosts and impacts of elongate hemlock scale (Hemiptera: Diaspididae): A critical review. Front. Insect Sci. 4: 1356036. https://doi.org/10.3389/finsc.2024.1356036

Ward, S.F. and B.H. Aukema. 2019. Anomalous outbreaks of an invasive defoliator and native bark beetle facilitated by warm temperatures, changes in precipitation and interspecific interactions. Ecography 42(5): 1068-1078. https://doi.org/10.1111/ecog.04239

Williamson, T.B., M. Campagna and A.E. Ogden. 2012. Adapting sustainable forest management to climate change: a framework for assessing vulnerability and mainstreaming adaptation into decision making. Canadian Forest Service, Canadian Council of Forest Ministers, Climate Change Task Force. Fo79-3/2012E. 29 p. https://www.publications.gc.ca/collections/collection_2013/ccfm/Fo79-3-2012-eng.pdf

Winston, R.L., C.B. Randall, B. Blossey, P.W. Tipping, E.C. Lake and J. Hough-Goldstein. 2017. Field guide for the biological control of weeds in Eastern North America. U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia. FHTET-2016-04. 331 p. https://bugwoodcloud.org/resource/pdf/FHTET-2016-04_Biocontrol_Field_Guide.pdf

Winder, R., E. Nelson and T. Beardmore. 2011. Ecological implications for assisted migration in Canadian forests. For. Chron. 87(6): 731-744. https://doi.org/10.5558/tfc2011-090

Woodcock, P., Marzano, M. and C.P. Quine. 2019. Key lessons from resistant tree breeding programmes in the Northern Hemisphere. Ann. For. Sci. 76:51. https://doi.org/10.1007/s13595-019-0826-y

Zarfos, M.R., G.B. Lawrence, C.M. Beier, B.D. Page, T.C. McDonnell, T.J. Sullivan, M.T. Garrison-Johnston and M. Dovciak. 2024. Environmental change drivers reduce sapling layer diversity in sugar maple-beech forests of Eastern North America. Ecosystems 27:1021-1039. https://doi.org/10.1007/s10021-024-00930-z

Zhao, Y., P. Bonello and D. Liu. 2023. Mapping the environmental risk of beech leaf disease in the Northeastern United States. Plant Disease 107(11): 3575-3584. https://doi.org/10.1094/PDIS-12-22-2908-RE

Zhao, Z. L. Yang and X. Chen. 2024. Globally suitable areas for *Lycorma delicatula* based on an optimized Maxent model. Ecol. Evol. 14(9): e70252. https://doi.org/10.1002/ece3.70252