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Five organizing themes for invasive forest insect and disease management in Canada and the United States

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ABSTRACT

Forests provide crucial support for ecological communities and play a vital role in human well-being and livelihoods. Protecting forests from the impacts of invasive species is a challenge that spans epistemologies, governmental levels, and academic fields. Yet, sharing new information, existing practices, and challenges among relevant groups has often been limited in Canada and the United States. To address this challenge, we began with a review of all academic and Canadian and US grey literature to reveal major published themes in forest invader research and policy. We refined these through a survey and workshop with participants encompassing Indigenous knowledge holders, government scientists, non-government organization employees, and academic researchers based in Canada and the US. Our deliberations resulted in five organizing themes for research and practitioner action to address species invasions: 1) Overcoming barriers to knowledge sharing, for instance, through the employment of governmental liaisons, 2) Assessing risks and benefits of alternative forms

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of management, for instance through scenario models of spatial management decisions, 3) Making effective use of new technologies, such as advancements in genomics tools and sentinel plots, 4) Broadening the focus on invasion pathways, especially related to urban forests and the nursery trade, and 5) Considering equity and making space for differing epistemologies, for example through the improved engagement of Indigenous Peoples in forest invader management. We elicited semi-quantitative scores for the importance, uncertainty, feasibility, complexity, and time requirements of tactics aligned with these major themes. We also identified discrepancies in public attention and funding compared to forest experts' priorities, including in the role of the nursery trade as a pathway of secondary invader spread. We illustrate how these themes can inform priorities for management in three important areas of North American biosecurity: solid wood packaging, and emerald ash borer (*Agrilus planipennis*) and Asian longhorned beetle (*Anoplophora glabripennis*) management. This work provides organization to the growing set of tools and outlines priority management tactics for invasive forest pests.

1. Introduction

Forests in both Canada and the United States (US) are continually under threat from forest pests - a group of species responsible for the death of millions of trees and economic impacts amounting to billions of dollars annually (Aukema et al., 2011; Lovett et al., 2016). These impacts pose a major threat to the roles healthy forests play in both human and ecological wellbeing in Canada and the US. Pests put at risk numerous forestry-related industries in Canada and the US, which employ ~1.2 million people (Lippe et al., 2022). Simultaneously, urban forests provide habitat in heavily altered landscapes while delivering key ecosystem services (e.g. cooling, mental and physical health benefits) to city-dwellers (Roy et al., 2012; Norton et al., 2015). Forest lands enable Indigenous ways of life across Canada and the US, with forest access entrenched as a treaty right for many Indigenous Peoples in Canada (Smith, 1998; AFNCNB 2010; Wyatt et al., 2015). Given the benefits that forests provide, mitigating the effects of their pests remains a persistent but challenging problem.

Management of invasive forest pests is a complex process that occurs across many jurisdictional levels and can thus suffer from information loss and lack of coordination (Prinbeck et al., 2011). In the US, forest managers are obligated to respect treaties, Indigenous sovereignty, and self-governance on Treaty and Tribal lands (Lucero and Tamez, 2017). At the same time, North America is reckoning with its historical exclusion of racialized and Indigenous groups, including within the pursuit of conservation objectives (Kashwan et al., 2021; Morishima and Mason, 2017). Despite advances in our understanding of ecological processes affected by forest invaders, forging the relationships necessary to deliver solutions-oriented approaches across complex conservation problems remains difficult (Bodner et al., 2021). Strategies for improved communication and understanding of the viewpoints, knowledge, and challenges across the forest management network are needed to develop synergies and reconcile conflicts.

In this manuscript, we used a three-step process (Hemming et al., 2018), including 1) a literature review and topic modelling, 2) an expert elicitation survey, and 3) a 2-day workshop and in-depth discussions, to examine the problem of forest pests through the lens of Indigenous knowledge holders, government scientists, non-government organization employees, and academic researchers (Fig. 1). We summarized the state of management practices and potential ways forward, contextualizing options across these multiple perspectives. We derived provisional "themes" to help organize the main viewpoints expressed during this process. We identified tactics aligned with these major themes that our multidisciplinary group of experts selected as important. Finally, we used expert elicitation to also rank each tactic based on its importance, uncertainty, feasibility, complexity, and time requirements. This paper is the result of this collaborative exercise and aims to provide guidance for forest pest management that considers the knowledge, perspectives, and needs of multiple partners that are actively involved in this field.

2. Materials and methods

2.1. North American context: forest invader management in Canada and the US

Forest invader management requires coordination across local/municipal, provincial/state, federal, and international levels (Lovett et al., 2016; Allison et al., 2021; Table 1). Prevention of invasive pest entry into Canada and the US can occur at national borders and is the responsibility of the federal Canadian Border Services and US Customs and Border Protection agencies. At borders, agencies verify that importers of goods comply with international biosecurity standards. Surveillance and detection (and in some cases, eradication) of post-introduction invader spread through countries is primarily the responsibility of federal agencies, including the US Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) and the Canadian Food Inspection Agency (CFIA). APHIS also develops and enforces federal regulations pertaining to interstate or international movement of wood-related products. Federal agencies such as the Natural Resources Canada-Canadian Forest Service (NRCan-CFS) and the USDA Forest Service (USDA-FS), along with APHIS, focus on applied research into invasive forest pest dynamics and management. While

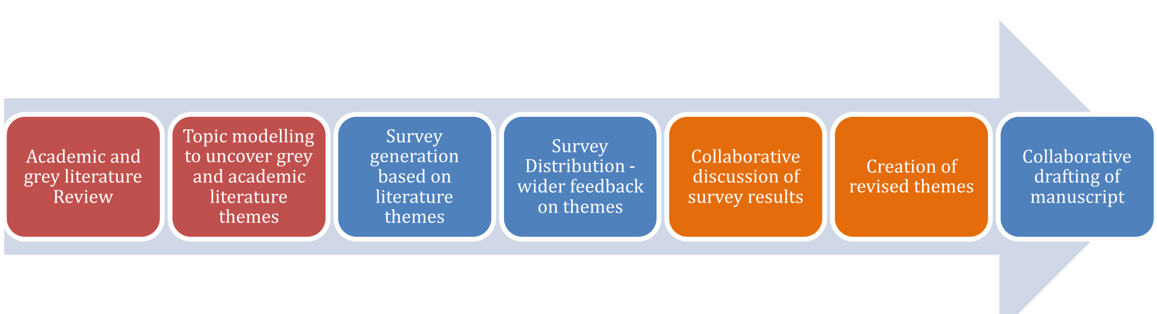

Fig. 1. The basic structure of this workshop follows the IDEA model for expert elicitation, which is an iterative process for understanding expert opinion that starts and ends with private components and has a middle public discussion component. The first two stages involved a literature review that was completed by a subset of co-authors (2), while the survey respondents represented the largest group of participants (20), with workshop participants (17) in the middle.

Table 1
Forest invader management partners in Canada and the United States, grouped by coauthor consensus according to the stage of invasion response they target, noting whether their focus is on direct management (M), research (R), or public outreach (O). Groups identified by participants to have limited formal interaction with the rest of the network are noted in *italics* with an asterisk (*).

Partner	Prevention/ Surveillance	Eradication	Spread Control	Host Removal/ Treatment
Canadian Government				
Canada Border Services Agency	M			
Canadian Food Inspection Agency	M, R, O	M, R, O	M, O	M, O
Canadian Forest Service	R	R	R	R
Provincial and Territorial Governments	M, R, O	M, R, O	M, R, O	M, R, O
United States Government				
Animal and Plant Health Inspection Service	M, R	M, R	R	R
State Governments		M, R	M, R	M, R
US Customs and Border Protection	M			
USDA Forest Service	R	R	M, R	M, R
Educational Institutions				
US Land Grant institutions, Forestry, Entomology, and Plant Pathology University departments	R, O	R, O	R, O	R, O
*Other academic departments**	*R*	*R*	*R*	*R*
Indigenous Partners				
*Indigenous Governments**		*M, R, O*	*M, R, O*	*M, R, O*
*Indigenous Rightsholders**	*M, R, O*	*M, R, O*	*M, R, O*	*M, R, O*
Local Government				
Municipal Governments			M, O	M, O
Other Groups				
Non-Governmental Organizations	M,R,O	M,R, O	M,R,O	M,R,O
'Other' conservation agencies, e.g. Conservation Districts, Invasive Species Management Areas, Forestry Assistance Program Foresters, etc.	M,R,O	M,R,O	M,R,O	M,R,O

NRCan-CFS is strictly research-based, USDA-FS provides some funding for invasive species management. Across countries, CFIA and APHIS cooperate and have joint initiatives, such as setting regulations around imported *Lymantria dispar var. asiatica* (Flighted Spongy Moth Complex) (CFIA, 2021). CFIA and APHIS have both hosted the North American Plant Protection Organization (NAPPO), which acts as a conduit for international communication. However, since they manage both imports and exports, CFIA and APHIS must consider pest issues and policies in the context of their impact on trade, including cross-border US-Canada trade, leading to competing interests and discretion in international communications. Regardless, there is a high degree of knowledge sharing among NRCan-CFS, USDA-FS, and academic departments of forestry and entomology across Canada and the US (MacDonald et al., 2023). There is also a long history of formal partnerships between NRCan-CFS and USDA-FS (Runyon et al., 1983).

While most invasive forest pest removal and/or treatment is led by local and municipal managers, larger-scale management programs are coordinated at the state and provincial/ territorial levels. In the US, funding for such activities is coordinated nationally by the Forest Health Protection program of the USDA-FS, in cooperation with individual states, and, in some cases, with USDA APHIS. Until 1997, Canada conducted an annual Forest Insect and Disease Survey. Since then, there has been no specific federally funded management program within Canada for forest insects and diseases. Canada's federal government typically contributes resources to pest management in response to major insect outbreaks (e.g., the native spruce budworm (*Choristoneura fumiferana* (Clemens); Runyon et al., 1983), which are largely managed at the provincial level. For invasive pests of quarantine significance (i.e., assumed to pose a significant risk to plant health), regulatory agencies in both countries (APHIS and CFIA) can coordinate federal responses based on the application of Canada and US Plant Protection Acts (APHIS 2014; CCFM 2012). Non-governmental organizations like Canada's Invasive Species Centre, and in some situations, the USDA's in-house National Invasive Species Information Center (https://www.invasivespeciesinfo.gov) can enable these groups to present their work to the public or to one another. These groups convene with academic and governmental researchers at national and international levels through annual conferences (e.g., Canada's Forest Pest Management Forum; USDA's Interagency Forum on Invasive Species).

While information is often shared across networks of forest managers and researchers (MacDonald et al., 2023), gaps remain in the current framework. In Canada, Indigenous Peoples make up a substantial portion of the forest workforce (CCFM 2022), but their input into forest management decisions has often been restricted (Wyatt et al., 2015) despite management actions that can have implications for both unceded and Treaty Indigenous lands. Further, while there are strong connections among forestry, entomology, and pathology-allied universities and departments (particularly at large/R1 [very high research activity] US Land Grant institutions), the engagement from the broader community of ecological and evolutionary biology researchers working on forest pest research varies widely, with some researchers having only brief contact with this network. Researchers with less association with the forest pest management community may not be as incentivized or aware of how to keep abreast of the latest (i.e., unpublished) information pertaining to forest pests. Finally, urban areas are epicentres of invasions (e.g., Poland and McCullough, 2006) but have not been historically examined within forestry research (Salomon Cavin, Kull, 2017), nor have they been historically well-funded by the existing management structure (but see the USDA-FS Community Forest Program, https://www.fs.usda.gov/managing-land/private-land/community-forest), which has implications for urban equity.

3. Adapted-IDEA protocol

Our approach for discerning priorities in forest invader management largely follows the IDEA ("Investigate," "Discuss," "Estimate," and "Aggregate") approach outlined in Hemming et al. (2017) (Fig. 1). This approach builds on other structured elicitation protocols such as the Delphi protocol, which has also been employed in conservation (Runge et al., 2011), but moves away from total consensus as a goal (Hemming et al., 2018). IDEA is made up of a pre-elicitation stage, where background information and consent for participation are gathered, followed by an elicitation stage focused on the "Investigate," "Discuss," and "Estimate" components, and ends with a post-elicitation stage where responses are aggregated. IDEA is also flexible enough to allow hybrid or remote participation (Hemming et al., 2018), which makes it well-suited for a workshop planned during a global pandemic.

To pre-elicit priorities in forest invader management in Canada and the US, we used topic modelling to extract major themes in the academic and government forest invader management literature (based on Binley et al., 2021, see **Appendix 1** for detailed methods). These themes formed the starting point for our survey, where we asked respondents to comment on the appropriateness of these themes and whether they thought any were missing. At the same time, we emailed a core group of 15 experts to elicit priority topics and management tactics to include in our survey via written and verbal discussion. We selected this group of experts with consideration for diversity in career stage, gender, career type, and geography, and included both Indigenous knowledge holders and Western science managers.

In the "Investigate" phase, we aggregated all identified priorities (including literature themes and expert priorities) into a survey and asked individuals to rank them by importance and feasibility (N=20). In the "Discuss" phase, we held a two-day workshop where a smaller group of participants (N=17) reviewed anonymous survey responses, which they then used in the "Estimate" phase to outline their revised priorities and feasibility estimates. We present the results of the "Aggregate" phase, where emergent themes are presented, and individual commentary on resultant rankings is synthesized into an overall view of the state of forest invader management.

There are two key differences between our approach and IDEA: first, we did not initially seek any quantitative estimates from experts – merely an understanding of the relative importance and feasibility of different approaches to forest invader management. In the aggregation phase, we converted these rankings into semi-quantitative scores, which all co-authors reviewed prior to publication. Second, our estimation phase was partly done publicly during our workshop, but participants were able to submit private feedback throughout the workshop and subsequent manuscript drafting process. Since all participants were invited to actively participate and co-author the resulting study, they are considered collaborators rather than research participants, and thus we did not require ethics clearance for this process.

3.1. Survey

We sent our online survey via email to 36 experts across domains, including federal and provincial practitioners, academic and government researchers, Indigenous forest managers, forest management NGO employees, and federal policymakers based on expert contacts known by project leads and their networks (**Appendix 2**). This sample size of experts was able to capture key members across all components of the management network in Table 1. The survey included questions on both the highest and lowest priority topics, topic feasibility, and uncertainty. There was space to add additional topics, and to comment on any of the questions. After finding that topic modelling results were more focused on individual species compared to expert-elicited themes, we also asked respondents whether they thought there should be more focus on single-species or multi-species approaches. Our survey received 20 individual responses. Survey respondents encompassed eight government scientists, four government policy researchers, four academic scientists, and four individuals in other fields, including an NGO employee, an entomologist, a government regulator, and a private science and policy researcher (**Appendix 2**). While we did not request country of origin information from respondents to preserve their anonymity, survey invitations were sent to ten Canadian and six US government employees, so we expect respondents to be more reflective of Canadian government perspectives. We drafted a report on the survey results that summarized the level of consensus in importance, feasibility, and uncertainty across topics, and removed topics deemed unimportant or problematic by all respondents. This summary document was used to organize a discussion in our two-day workshop.

3.2. Workshop and post-elicitation

The workshop was held virtually on 17–18 January 2022 and included nine invited participants, three hosts, and five graduate and/or postdoctoral rapporteurs. All rapporteurs have experience in invasion biology and/or forest ecology and were encouraged to participate actively in discussions. In-person workshop participation was not feasible due to lockdowns and restrictions associated with the BA.1 wave of the COVID-19 pandemic. During the workshop, we condensed the list to main priorities and extracted emerging themes, while discussing case studies that could be used as informative examples of how these themes play out in Canada and the US. We summarized the topics and associated management tactics within these themes according to their novelty, feasibility, complexity, time, and public acceptance. We re-coded responses such that higher scores across all dimensions could be interpreted as a tactic being evaluated more positively, where Simplicity=Max Score[5]-Complexity+1, and Speed=Max Score[5]-Time+1. As a group, we then chose three case studies that best reflected the need for advancement across these five themes and present them as a set of case studies (**Boxes 1–3**).

3.3. Positionality statement

We acknowledge the perspectives that dominate the framing and undertaking of this work (Holmes, 2020). Though our authorship team represents a diverse set of people engaged in the forest invader management sphere, the three organizers designed the survey and workshop from a Western academic perspective, framing the exercise through the lens of a traditional academic article. The participants in this study (20 survey respondents and 17 workshop attendees) have served as our main lens into the forest invader management network, and while the participants span a range of viewpoints, they are not an exhaustive set of forest invader management perspectives. Most notable given our workshop themes is the small number of Indigenous participants (two). We do not intend to represent the range of Indigenous ways of knowing about forest management within this work, but can speak to historical marginalisation that proceeded similarly across Indigenous communities in our study region. More generally, our participants do not capture the racial and income diversity present across forest management practitioners and researchers. Regardless, this work remains useful in its ability to bring together groups, including members that have not been historically part of the forest management network, for an open discussion that considers multiple priorities and perspectives.

Acknowledging these limitations, we aim to amplify marginalized perspectives in forest management in this publication and companion communication documents. Within the workshop, we asked participants to reflect on the concept of Two-eyed Seeing (Etuaptmumk) from Elder Dr. Albert Marshall (Mi'kmaq) to promote the equal positioning of multiple forms of knowledge. While this concept has analogues across many Indigenous knowledge systems (Reid et al., 2021), we wish to avoid only engaging with less controversial approaches in this work at the risk of appealing to a vague, pan-Indigenous perspective (âpihtawikosisân, 2012). Indigenous Science and Knowledge were further made central by devoting the first half day of the workshop to presentations by co-authors Bradley Young (President, National Aboriginal Forestry Association, Opâskwêyâhk [Cree]) and Abraham Francis (Environmental Services Manager, Mohawk Council of Akwesasne, Ahkwesáhsne Kanien'kehá:ka [Mohawk]) on Indigenous approaches and ideologies related to forest invader management. We see this work as an initial step in a long path to equitable engagement with non-Western perspectives.

4. Results and discussion

Roughly 75 % of respondents agreed that the themes elicited represented priorities in forest invader management. We found some

Table 2
Survey results presented in terms of attributes and provisional themes with the greatest level of agreement across respondents (N=20). We left the definition of the attributes up to the interpretation of the survey respondents (i.e., 'Promise' may have different definitions for different respondents). These results were compiled into a report presented to workshop participants. Only the top themes in each case are displayed here (full table in **Appendix 5**).

Attribute	Agreement Level	Theme(s)
Importance	60 %	Invasion lags make detection difficult
	60 %	A lack of data hinders progress
	60 %	We must understand how new trade routes and climate change impact our responses
	50 %	Developing better post-border sampling protocols, possibly informed by species distribution models
Promise to yield significant advances	45 %	Planning for resilience and planting diverse forests
	35 %	Use of continually-updated, publicly accessible databases, and/or use of community/citizen science data for monitoring
	35 %	We must understand how new trade routes and climate change impact our responses
Ease of implementation	60 %	Use of continually-updated, publicly accessible databases, and/or use of community/citizen science data for monitoring
	55 %	Pathway-level prevention of entry
	45 %	Increasing efforts for managing urban forests
Most-underused	55 %	Use of continually-updated, publicly accessible databases, and/or use of community/citizen science data for monitoring
	40 %	Engagement with Indigenous knowledge holders
	40 %	Planting diverse forests and promoting age, structure, and species diversity
Highest known levels of importance and effectiveness	70 %	Use of continually-updated, publicly accessible databases, and/or use of community/citizen science data for monitoring
	50 %	Pathway-level prevention of entry
	50 %	Planting diverse forests and promoting age, structure, and species diversity
High Uncertainty	40 %	Managing most non-native forest insects and fungi with biological control
	35 %	Devoting more focus to 'slow the spread' measures for more species rather than just focusing on limiting entry and initial establishment
	35 %	eDNA for species detection
Additional themes suggested by individual respondents	-	The role of decision-maker mistrust of management tools and regulatory fatigue
		The need for decision support tools to balance tradeoffs among the social, ecological, and economic consequences of invasions and their management
		The need to estimate the impacts (social/ecological/economic) of scenarios of inaction vs. action in the face of invasions, and more economic quantifications of the impacts incurred to date
		Increased understanding of the effects of climate change on invader survival and severity, shifting cold tolerance zones, and plant hardiness limits

consensus with priorities and underused strategies (Table 2), but also some stark disagreements (see **Appendix 4** for more information).

We drafted a two-dimensional figure to highlight prominent management themes and approaches of varying novelty and feasibility to guide further discussion (Fig. 2, full results in **Appendix 4**). After the workshop, using aggregated rapporteur notes, we created a table that assessed a larger suite of aspects associated with each priority on a five-point scale (**Table S1**). Major organizing themes that synthesize multiple priorities identified during the workshop were extracted from this table, and case studies were chosen to accompany each of these organizing themes.

Our workshop transformed the initial survey themes into five major organizing themes for the future of forest invader management in Canada and the US, including: 1) Overcoming barriers to knowledge sharing, 2) Assessing risks and benefits with alternative forms of management, 3) Making effective use of new technologies, 4) Broadening the focus to more pathways of invasion, and 5) Considering equity and making space for differing epistemologies (Fig. 2). While all themes are important, they vary in tractability. Some themes were not new, like "breaking down communication barriers," which scored low in novelty, but were time-consuming and complex. Alternately, some themes, like Indigenous sovereignty, may not have as much public support outside of Indigenous communities. Scores assigned to these topics and associated management tactics according to novelty, feasibility, complexity, time, and public acceptance are shown in Fig. 3 (full results in **Appendix 3**).

Below, we provide a description of each of our five main organising themes and relate them to three major issues in forest invader management in Canada and the US in **Boxes 1–3.**

4.1. Overcoming barriers to knowledge sharing

Within this theme, workshop discussions revolved around communication breakdowns that occur both within and among groups involved in forest invader management across Canada and the US (Table 1). While siloed information networks are a common multi-agency management problem (Cadman et al., 2020; Nunan et al., 2020), there are no easy solutions, and tackling these issues in forest invader management requires longer-term, complex approaches relative to other themes. Despite this, many proposed tactics were considered highly feasible.

As mentioned above, both Canada and the US have distributed networks of pest management responsibilities (Table 1). Some groups, including Indigenous governments, have very little exposure to the rest of the network. This may be because 1) many groups have a lower capacity for funding environmental or natural resource personnel, 2) they use different communication channels like social media platforms (e.g., Facebook) to share information with their members, and/or 3) even if the information is shared across these groups, they may have more pressing issues, such as a lack of clean water (Patrick, 2011, ISC 2022).

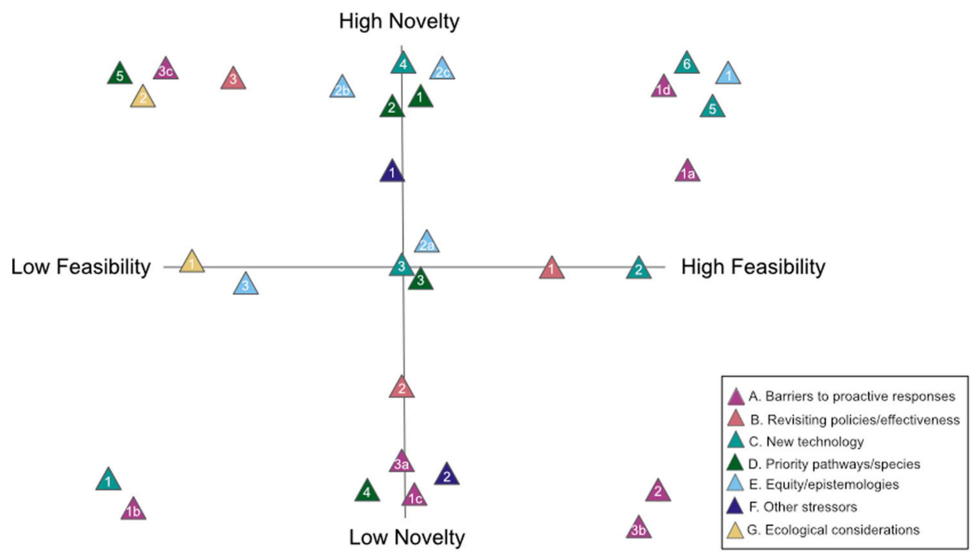

Fig. 2. Preliminary figure representing post-workshop consensus around survey provisional themes and associated tactics prior to condensing to five finalised themes. See **Appendix 4** for the full set of results.

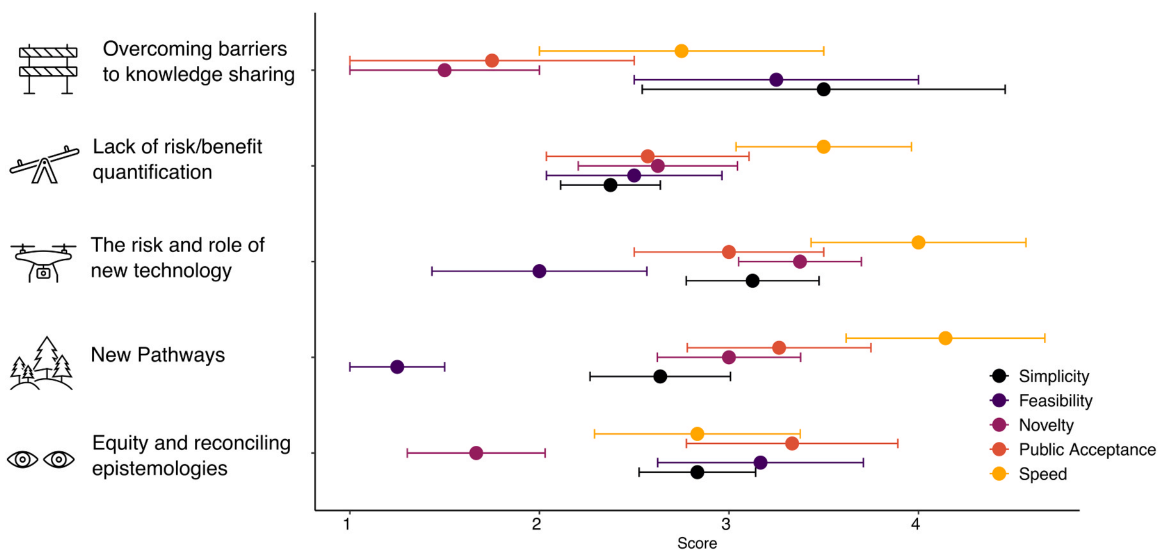

Fig. 3. Mean five-point scale scores (1=low, 5=high) of tactics employed to tackle the five major organizing themes from our survey and workshop, with standard error shown by error bars. Estimates represent the consensus of all workshop attendees (N=17) assigned to each tactic within a theme.

Further, without baseline data collection (e.g., of urban tree inventories, see theme 4) and limited budgets for technological advancement, it can be hard for communities to use information even when it is shared. Particularly in the eastern US and southern Canada, land tenure can complicate the ethics of forest management decisions since much forest is privately owned, but decisions relating to pest management have implications beyond individual forest stands and borders (i.e., the release of non-native biological control organisms).

To illustrate the importance of this theme, participants discussed the case of the Light Brown Apple Moth (*Epiphyas postvittana*) invasion in Northern California in 2007–2008. Managers decided to respond to the pest via aerial spraying of a non-toxic pheromone to disrupt mating without embarking on a public education campaign. Opposition to the pheromone application was triggered by concerns about aerial spraying along with the spread of misinformation about the toxicity of the pheromone (Linderman, 2013, Liebhold and Kean, 2019). Negative attitudes were further elevated when the pest was later deemed to be of lower risk than initially assessed (Carey et al., 2022).

Jurisdictional complexity further highlights the necessity of equitably engaging all people impacted by forest management decisions (see nursery pathway example in theme 4). To respond to the lack of proactive engagement with historically excluded groups such as Indigenous knowledge holders (Wyatt et al., 2015), members of the pest management network must focus on developing lasting relationships based on trust and consent. To solve these problems, workshop participants discussed employing liaisons to work at the interface among different groups, with a particular focus on employing members of this communication network with existing explicit roles and responsibilities relating to outreach such as academics and government employees.

In addition to outreach activities, some respondents (35 %) felt that community engagement could be boosted by continually updated, publicly-accessible databases and greater use of community science data for monitoring invasive species. This priority is reflected in initiatives focused more broadly on biodiversity conservation (e.g. GEO BON https://geobon.org). For example, from the policy side, one respondent stated that “the type of public database that is needed is the list of violations of wood packaging regulations, to help importers choose uninfested wood packaging". This approach could be promoted by including open science contributions as explicit promotional criteria for employees within agencies such as the Canadian Forest Service. Echoing this sentiment, one workshop participant called the Canadian Federal Government's nominal commitment to open science without providing incentives through promotion an "unfunded mandate". Contributions of forest pest detections to databases such as iNaturalist and EDDMapS, have, in some cases, resulted in important surveillance information (Epanchin-Niell et al., 2021, Box 2). While these data sources include identification errors and sometimes require expert validation, community science information can serve as a free source of additional surveillance effort (Binley and Bennett, 2023).

4.2. Lack of risk/benefit quantification

Our second theme surrounds the need for a better understanding and explicit usage of trade-offs in biosecurity decision-making. In particular, there is a need to quantify the cost of "doing nothing" in the face of an imminent invader (Ahmed et al., 2022). For example, one workshop participant said, "Our inability to quantify indirect impacts or impacts on less tangible resources may be why it looks like an invasion over time is not economically that big of a deal". Approaches to tackle this theme were rated moderate in their complexity and rated highly in terms of public acceptance, but political will was thought to be lacking. Indeed, it is rarely in a government's short-term best interest to spend money on proactive management (Leung et al., 2002; Cuthbert et al., 2022). Subsequent research related to this theme must be interdisciplinary to understand the biological components of risk, sociological components of effectiveness, and psychological components of decision-maker motivation (echoing analogous calls to treat conservation issues as social-ecological systems, *sensu* Bergman et al., 2022). Scenario modelling and decision theoretical approaches emerged as key methodologies to better understand management tradeoffs (Hauser and McCarthy, 2009; Epanchin-Niell and Liebhold, 2015; Hudgins et al., 2024).

Tackling this theme requires altered forms of data collection. The lack of collection and/or sharing of inspection effort data is a central barrier to understanding the costs and benefits of biosecurity practices. A formalized surveillance approach, known as "risk-based sampling" (Mastin et al., 2020) can allow for unbiased quantification of invasion risk. There have been movements within NAPPO to implement "risk-based inspection," which would provide a much-needed statistical basis for inspection (NAPPO 2020, Box 1), but there are no federal policies in place to require this in either Canada or the US. Despite the collection of interception data, it is currently impossible to disentangle the effect of detection effort, trade volumes, and/or compliance on border interceptions of pests.

Forest pathology is a major facet of forest invader management that is likely underrepresented by the academic and policy literature (based on topic modelling results, see **Appendix 1**). This bias was also reflected in our survey and workshop respondents' expertise. Many participants agreed that potentially invasive forest pathogens (fungi and disease complexes) are understudied and overlooked compared to insects due to lower detectability. Invasive pathogens are difficult to detect until they reach levels of impact high enough to generate concern. As such, windows of opportunity for proactive management are more readily missed. In addition, Canadian and US universities produce a relatively small number of trained forest pest managers, and among these, most are forest entomologists. Indeed, there have been declines in funding directed at academic forest pathology positions and departments since the 1980s across North America (Hadziabdic et al., 2021). This results in comparatively fewer forest pathologist positions available to address existing and emergent threats. We note that the number of dissertations in forest entomology and pathology together has remained relatively stable over the last 40 years (Wagner et al., 2022), suggesting a consistent pool of trainees, but with dwindling employment possibilities.

4.3. The risk and role of new technology

Thirdly, participants focused on the suite of technological tools available to manage invasions (e.g. gene editing, CCA, 2023) and on instances where these tools have succeeded and failed. Proactive communication and understanding the local context of any invasion are key for public acceptance and success of technologies. This involves understanding the political, cultural, and ecological history of a landscape and not applying a single approach to all problems. Individual technological advancements were highly variable in their scores of public acceptance, complexity, and time required. Participants noted that some approaches, such as breeding resistant stock, tend to be seen by the public as more "natural" and less controversial, while others are simple yet controversial, like the use of classical biological control or pesticides, and were described as requiring more care in their communication.

Despite public perception, pesticide treatment may be more cost-effective and involve lower risk than other tools in particular contexts. For example, Hemlock Woolly Adelgid (*Adelges tsugae*) is well controlled by systemic neonicotinoid insecticides (dinotefuran; imidacloprid) that are applied directly into trees or at the base of trees. While these products may have negative impacts (e.g. on pollinators) in agricultural settings or when applied to hardwood tree species that require insect pollinators, the non-target impacts of systemic insecticide applications in forested settings are low, particularly when wind-pollinated trees are treated (Benton et al., 2017; McCarty and Addesso, 2019).

Public and academic perception of classical biological control as 'potentially problematic' is partly grounded in early examples of high-profile catastrophic outcomes with little resemblance to contemporary biological control candidate species, such as the cane toad invasion in Australia (Simberloff and Stiling, 1996; Shine, 2010). More relevant examples of the unintended negative consequence of classical biological control can be cited, such as the introduction of *Compsilura concinnata*, a generalist lepidopteran parasitoid, for the control of *Lymantria dispar var. dispar* (Spongy Moth) and *Euproctis chrysorrhoea* (Brown-tail Moth) in the early 1900s (Boettner et al., 2000). *C. concinnata* has had substantial non-target effects on native insect populations without appreciably impacting *L. dispar* dynamics and has spread well beyond the current distribution of *L. dispar*. On the other hand, *C. concinnata* may have slowed the spread and reduced the distribution of *E. chrysorrhoea* (Elkinton & Boettner, 2012). While the risk of non-target effects is now better recognized, as recently as 1996, proposed introduction of the Coleopteran predator *Thanasimus formicarius* (Ant Beetle) in Canada and the US for control of *Tomicus piniperda* (Common Pine Shoot Beetle), an invasive Scolytinae bark beetle, was suspended indefinitely due to concerns about the displacement of the native bark beetle predator *Thanasimus dubius* (Dubious Checkered Beetle) (Kennedy and McCullough, 2002; NRCan 2015). Better public engagement would not have changed the risks of these introductions; proactive attention to direct and indirect non-target impacts is also needed.Box 2

Academic participants described novel tools that have created excitement (such as sentinel plots, Vettraino et al., 2017; Kenis et al., 2018) but are quite expensive, and that so far have little evidence of effectiveness. Participants noted that the management context will determine whether a technological tool is well-suited, where approaches must fit the local political, ecological, and cultural history of the management area being considered. One workshop participant stated, "Trust development is a two-way street and policy developers need to develop a trust [with communities]". The solution to these issues ties in heavily with Theme 1, where proactive discussions are required to understand the local context and engage all impacted people with the management decision. One intervention that is emblematic of these challenges is the US effort to develop genetic resistance to Emerald Ash Borer (*Agrilus planipennis*, see Box 3) in ash (*Fraxinus*) species.

Box 1
Emerald ash borer management.

Emerald Ash Borer (EAB) was detected in 2002, but an extensive dendrochronological study showed that it was established in southeast Michigan several years before that. Transport of infested ash nursery trees, logs, firewood, and related materials prior to EAB detection and subsequent imposition of quarantines resulted in numerous satellite populations that coalesced and increased spread rates (Siegert et al., 2014). Newly infested trees with low EAB densities exhibit no external signs of infestation. A lack of long-range pheromones for use in surveillance efforts, the difficulty of identifying new infestations, and challenges with regulating potentially infested firewood transported by private individuals contributed to the ongoing spread of EAB in the US and Canada (Herms and McCullough, 2014; McCullough, 2020; Liebhold and Kean, 2019). However, there have been promising developments in this species' management along with our organizing themes:

Effective Communication: The speed with which the EAB invasion spread made it difficult for states and provinces to keep up with the state of the infestation and with research related to management tactics (Sadof et al., 2023). In contrast to ALB, a small proportion of EAB adult females engage in relatively long-distance dispersal flights (Mercader et al., 2012; 2015), exacerbating challenges of effective detection and regulation. EAB scientists with a range of expertise in Canada and the US have collaborated to develop or improve detection capability (e.g., Tobin et al., 2021), to investigate options to protect trees in landscapes or forests with systemic insecticides (e.g., McCullough, 2020), and to implement integrated management strategies that may include biocontrol, systemic insecticides, tree removal/timber sales, and girdled trap trees (e.g., Mercader et al., 2015). Efforts to identify and propagate genetic resistance in some native ash species are also ongoing (but see **Technology Use**), although natural regeneration of *Fraxinus pennsylvanica* and *F. americana* is abundant in many post-invasion areas. Further, though the scientific and public acceptance of resistance breeding is increasing (but see Buggs, 2020), many Indigenous groups feel that the use of genomic tools to increase EAB resistance in ash species is inappropriate (Nathalie Isabel[21] (NRCan-CFS), *pers. comm.*).

Scenario Models: The cost of maintaining the US federal quarantine region for EAB combined with the broad distribution of EAB in the continental US (currently 36 states) led USDA APHIS to drop the federal quarantine in 2021. States can still impose their own external or internal quarantines on ash trees, wood, or related items. Much of the investment of USDA APHIS is currently directed at rearing, releasing, and evaluating non-native species of EAB parasitoids (APHIS, 2020). Scenario models have consistently demonstrated the benefits of using systemic insecticides to protect ash trees and associated ecological services in forests and urban forest settings in both countries (Kovacs et al., 2014, 2022; McCullough and Mercader, 2012; McKenney et al., 2012; Mercader et al., 2015; Sadof et al., 2023). Other models have projected EAB spread and the ecological, economic, and cultural impacts expected to be associated with this pest under different management tactics (Hudgins et al., 2024; Siegert et al., 2023). Across US management scenarios, EAB is projected to continue to spread, especially in the absence of federal spread controls (Hudgins et al., 2024).

Technology Use: The severity of the EAB invasion stimulated interest in classical biological control and served to incentivize the development of improved systemic insecticide chemistry and application technology. Parasitoid species native to China and Russia have been released and become established in many areas of Canada and the United States (Butler et al., 2022; Duan et al., 2023), but there is no evidence that these species can slow EAB population growth and the rate of ash decline and mortality in high density, epidemic populations (McCullough, 2020). Long term impacts of introduced parasitoids on EAB dynamics and ash recovery in post-invasion forests are yet to be fully determined. Duan et al. (2018) reported that non-native EAB parasitoids could limit the growth rate of endemic, low-density populations in regenerating ash stands. In a recent study in post-invasion forests, however, multiple releases of introduced parasitoids resulted in mortality of less than 15 % of EAB larvae in declining and presumably attractive ash trees while less than 5 % of EAB larvae in healthy trees were parasitized by these species (Wilson et al., 2024). In contrast, woodpeckers killed 22–38 % of larvae in declining ash and 6–13 % of larvae in healthy ash in these stands. Genetic tools were used to identify the source population of the EAB introduction into North America (Bray et al., 2011) and are used in the identification of EAB-resistant genotypes in some native ash species (e.g., Kelly et al., 2020). Operational deployment of resistant genotypes, however, could be challenging given abundant ash regeneration in some post-invasion forests, post-invasion competition with non-ash species, and hydrological changes following ash mortality that seem likely to preclude future ash establishment (e.g., Burr and McCullough, 2014; Engelken and McCullough, 2020; Palik et al., 2021; Krzemien et al., 2024). Other concerns include the long generation time of trees, potential for increasing vulnerability to native pests, and practical difficulties in scaling up nursery production. The persistent lack of trust by various stakeholders, including scientists and Indigenous peoples, could perhaps be improved through a more thorough examination of genetic trade-offs in resistance development and more honest communication of risks, possibly via engaging social scientists in decision-making processes (Blue & Davidson, 2021).

Novel pathways: The EAB invasion has demonstrated the vulnerability of many North American urban forests where low tree diversity reflects historical decisions on street tree species, as well as modern policies of homeowner associations that have sometimes limited which tree species can be planted in front of houses (see Paquette et al., 2021 for an examination of the 'true diversity' of urban forests). Biodiversity considerations and the impacts of EAB have focused efforts on diversifying new plantings and encouraging an array of trees for landscapes, parks, and roadsides (e.g. TreeCanada's 2 Billion Trees). Tree nurseries are responsible for propagating diverse species to increase resilience to an array of threats posed by pests, as well as changing climate. Policy incentives may be necessary for this large task.

Equity: Devastation of urban ash trees caused by EAB invasions has already resulted in often severe human health impacts (e.g., Donovan et al., 2013) and is likely to exacerbate urban health inequities, particularly in a changing climate (Smith et al., 2022). EAB has particularly negative impacts on Indigenous peoples for whom black ash (*Fraxinus nigra*) is culturally important for basket-making. Among other species, non-native Manchurian ash (*F. mandshurica*), and native white oak (*Quercus alba*) are being examined as alternatives to ash for basket-making. The response to the EAB invasion was an example of relationship building among US Tribal groups, academic researchers, and the US Forest Service (McCullough, 2013; Poland et al., 2015; Siegert et al., 2014; 2023). The US federal government consulted Tribal governments prior to the introduction of EAB biological control agents recorded in the associated US Environmental Protection Agency impact assessments (APHIS, 2007;; US DOE, 2015). After the decision for release was made, Tribal leaders were invited to comment on releases (APHIS, 2007). However, the removal of the federal EAB quarantine region was the source of many formal complaints by US Tribal groups. In contrast, the Saint Regis Mohawk Tribe approved the release of *Spathius galinae*, an EAB biocontrol agent, in 2014. Integrated efforts to slow EAB population growth and protect the ash resource on Akwesasne Tribal land in New York are underway, with substantial collaboration among natural resource specialists from the Saint Regis Mohawk Tribe, federal officials, and academic scientists (D'Amato et al., 2023).

4.4. New pathways

Participants focused on areas where invasions are spreading quickly but are receiving relatively little attention or funding. These strategies were largely considered feasible and with high public acceptance but require considerable time and complexity. One area is urban forests. Urban trees are important bridgeheads of forest pest invasions (Poland and McCullough, 2006; Hudgins et al., 2017), but funding for urban tree inventories is necessary for communities to plan for future threats. We note that the USDA-FS has developed tools to complete community inventories (https://www.itreetools.org/) and has an ongoing urban forest inventory program (https://www.fs.usda.gov/research/programs/urbanfia). In Canada, however, there is no consistent effort to establish urban tree inventory standards, though the US iTree software is used in some communities. One participant said, "When an invasive pest comes in [to a city], unless it is an unusual generalist, you need to know what its hosts are and what their distribution is. And unless you have an urban forest inventory, that becomes really difficult."

Another pathway is the nursery trade, which, as a domestic route of transmission (Liebhold et al., 2012), has been overlooked relative to pathways of entry across Canada and US borders. Nursery-related invasions can lead to complex ethical dynamics across states and provinces, especially since state and provincial regulatory agencies also bear the responsibility to protect local commodities and facilitate trade. One participant illustrated these jurisdictional issues, saying "I know from my state there have been numerous introductions of infested hemlocks, despite external quarantines imposed years ago to prevent such introductions on nursery stock from states with well-established hemlock woolly adelgid infestations. The state where the infested stock originated typically doesn't bear the costs of the introduced pest."

Participants also discussed the role of altered future trade patterns and climate change as interacting stressors in future invasions (Sardain et al., 2019). There is a need for interdisciplinary teams to tackle these interacting stressors in models that account for socioeconomic factors and altered recipient ecosystem projections (e.g., whether there will be an increase in usage of Arctic trade routes combined with improved suitability of Arctic ecosystems for pest establishment, Essl et al., 2019).

4.5. Equity and reconciling epistemologies

Our final theme – equitable management that amplifies historically-excluded voices and embraces multiple ways of knowing – is perhaps the most complex and long-term of all, requiring much more large-scale public buy-in to be feasible. Making space for marginalized voices is written into many existing funding calls and ministerial/agency mandates but allowing differing epistemologies into the practice of management itself is relatively novel and less well-accepted (but see Benedict and David, 2004). Indeed, it was absent from topic modelling (**Appendix 1**).

As in theme 1, developing and improving relationships with any community takes time and must be proactively initiated before rapid responses are needed. An important distinction when considering marginalized groups is accounting for their historical and current exclusion from forests and forest management. This history has eroded trust in Western science-oriented managers and, therefore, must be considered. Making space for Indigenous perspectives and knowledge within invasive insect management is important to correct the historical exclusion of Indigenous Peoples from their forested lands, as well as the lack of consent obtained from Indigenous Peoples during historical invader management interventions (Morishima and Mason, 2017). One Indigenous participant described the current context as "[The] pest issue is more of … land and territorial integrity for Indigenous people." … "You have deciding people descending on Indigenous communities."… "They make the decision without consulting the communities [pest management] touches." We note that this participant was describing the Canadian context, whereas some US participants are involved with or are aware of ongoing projects that include substantial Tribal involvement. Making space for new perspectives will be challenging, as this includes perspectives that differ substantially from Western management approaches – which do not explicitly discuss the value of all living things and having good relationships with them (Wehi et al., 2023). Approaching this task requires a commitment to theme 1 tactics, such as dedicated government and academic liaisons, who can build long-term partnerships that can respond to differing community priorities and capacities.

One of the major issues discussed with past management approaches was the reliance on generalized management strategies, which assume all communities are homogenous when it comes to an optimal management approach. Because of this, many communities are left to deal

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Box 2
Solid Wood Packaging Material interceptions of insects in Canada and the US.

Solid wood packaging material represents an immense volume of potentially-infested wood entering Canada and the US. However, the highest-risk source areas or shipment types cannot be determined from existing information, particularly in Canada, and temporal trends in successful detections of infested material are not easily tied to regulatory changes. Technological advances, if adopted alongside increased data transparency, would allow for the integration of this rich source of risk data into informative scenario models. Deficiencies related to our five themes are as follows:

Effective Communication. Federal inspection data are not shared openly in either the US or Canada. The agencies in charge of inspections (CBSA in Canada and CBP in the US) have very little association with the forest management network apart from sharing data with the CFIA and APHIS, which confirm some taxonomic identifications (Greenwood et al., 2023; Lovett, 2022). CBSA and CBP are both tasked with detecting more life-threatening shipments of drugs and weapons, and pest detection is often seen as a lower priority.

Scenario models: As mentioned in theme 2, CBSA does not record how many shipments it inspects, and instead only reports positive detections (Work et al., 2005; McCullough et al., 2006; Greenwood et al., 2023). This lack of baseline data collection means that mechanisms cannot be inferred from patterns in detections, as there is no control for shipment volumes or inspection effort. In contrast, the APHIS Agricultural Quarantine Inspection Monitoring Program conducts a random sampling approach to inspections and includes negative results in their data - thereby making it possible to control for search effort when examining detection data (Work et al., 2005; Jones, 2022; Greenwood et al., 2023). This is not the only US port inspection program and is limited in scope but has allowed for important estimates of invasion trends (Haack et al., 2022).

Technology Use: In Canada, CBSA employees have lower taxonomic expertise compared to CFIA employees, which can result in underreporting of more cryptic and/or difficult-to-detect species. CBSA employees receive only sporadic taxonomic training from CFIA. In the US, APHIS PPQ personnel are embedded at CBP offices for taxonomic identification and especially for pest detection in wood packaging and products. There are current trials for incorporating new technologies, such as DNA barcoding in inspection, but these have not been mainstreamed (Madden et al., 2019).

New Pathways: Wood dunnage (bracing materials) is often stored in the controlled portion of ports. It is difficult to ascertain the origin and to assign responsibility for non-compliant dunnage, which makes it challenging to combat its illegal deposition within ports (Greenwood et al., 2023). Until recently, wood dunnage was not required to be inspected in North American shipments, despite it constituting a large volume of wood (McCullough et al., 2006). In response to this risk in Canada, the CFIA developed a shipborne dunnage program effective July 2023 that will require dunnage import permits and fine non-compliant parties (CFIA, 2022). We note that enforcement of this program will still be subject to the lack of institutional prioritization of pest threats relative to other threats by CBSA and CBP.

Equity: Indigenous workshop participants noted that settler communities are disproportionately responsible for the risks associated with globalized trade, but Indigenous communities are less equipped to deal with its impacts, including culturally-important species declines. The greatest beneficiaries of imports are likely not those most heavily impacted by their associated invasions, such as working-class communities reliant on the forestry sector. On an international scale, the inability to produce compliant solid wood packaging materials can be a trade barrier for lower-income countries, and CBSA and CBP will target shipments for reasons unrelated to pests (such as weapons, drugs, and human trafficking), leading to biases in the countries whose shipments are inspected.

with the consequences of larger-scale invasion management decisions without direct involvement in management decisions. In Canada and the US, larger-scale management decisions may directly contravene the established treaty rights of many Indigenous Peoples when these decisions impact traditional hunting and fishing rights or the provision of clean water (CIRNAC, 2021; USDA-FS, 2023). Despite the risk of biological and chemical controls to these rights, such as pesticide contamination of water bodies or non-target impacts of introduced biological control agents on native wildlife, there has been little historical consent or consultation regarding their adoption. Keeping in mind our first theme, *Overcoming barriers to knowledge sharing*, the focus on smaller-scale, tailored approaches must be balanced with coordinated responses at larger scales, since invaders do not respect community boundaries (Hulme et al., 2009)

Our literature review of 490 articles, reviews, and reports identified only five documents (Siegert et al., 2014; Alexander et al., 2017; Costanza et al., 2017; Cobb, 2019; McCullough, 2020) mentioning the involvement of Indigenous Peoples in invasive species management. In contrast, when it has been sought out, Indigenous knowledge has been crucial for developing management plans for devastating invaders like Emerald Ash Borer, where historical distributional information was gathered for culturally important black ash trees (*Fraxinus nigra,* Benedict and David, 2004; Costanza et al., 2017; Siegert et al., 2023).

Box 3
Asian longhorned beetle eradication(s).

Asian longhorned beetle (ALB) (*Anoplophora glabripennis*) was initially discovered around the same time in both Canada (2003) and the US (1996) (Turgeon et al., 2022) . Eradication of ALB populations has been achieved in Canada and in some infestations within the US, but both countries have struggled to prevent re-introductions (Coyle et al., 2021). The large, conspicuous appearance of ALB adults and their behavior (e.g., reduced flight capacity) compared with other high-profile pests has facilitated ALB detection and eradication of localized infestations (US GAO, 2006a,b). Concern about ALB's impacts on economically-important maple syrup production provides a dual incentive for eradication. The developments for this species' management along our organizing themes has been mixed:

Effective Communication: The US ALB response was highly coordinated among APHIS, state and municipal managers, who co-produced a set of best practices (US GAO, 2006b). However, the US response was comparably more reactive than in Canada, given the lack of prior experience with the pest and the presumed sudden surge in infested wood packaging material following an ALB outbreak in China in the 1990s (Haack et al., 2010). In Canada, the ALB response has been considered a success due to the multi-agency cooperation used to quickly eradicate the pest (Allison et al., 2021; Turgeon et al., 2022), though it is not without its challenges. Eradication of ALB infestations in the US is still in progress in Ohio, South Carolina, and Massachusetts. International communication has been important for the transfer of lessons learned from US eradications to Canada (Haack et al., 2010).

Scenario models: There has been a great deal of research to understand the future climatic suitability of ALB (Zhou et al., 2021), as well as the optimal allocation of management resources for ALB eradication (Yemshanov et al., 2017). Such approaches can also inform our understanding of risk for related species, such as citrus longhorn beetle (*Anoplophora chinensis,* Haack, 2006).

Technology Use: Given that all ALB detections through 2008 were by the public (e.g. via tips to local management agencies), community science initiatives have been a crucial technological component of rapid response to this species (Haack et al., 2010). We note, however, that conspicuous signs of ALB infestation make this invader particularly well-suited for community science-based detection initiatives. Genetic data allowed Canada to determine that the source of the ALB introduction was from its native range in Asia, rather than via cross-border spread from the US (Carter et al., 2009). These data also indicated the two locations of infestations in the greater Toronto region were the result of the same introduction, and not multiple introductions. These data helped to reduce uncertainty around the effectiveness of new wood packaging standards (Turgeon et al., 2022). Continued genetic work on ALB is helping to identify genetic signatures of the native populations, which could be used to rapidly identify the source of new invasions should they occur (Cui et al., 2022).

Novel pathways: ALB's invasion and management history highlights a need for comprehensive monitoring in urban forests. In response to the threat of ALB, EAB, and *Phytophthora ramorum* in 2006, the US Government Accountability Office (GAO) recommended that "…the Secretary of Agriculture (1) expand efforts to monitor forest health conditions to include urban areas, particularly those deemed high risk for potential infestations" (US GAO, 2006b). In spite of this, urban forest inventories remain geographically biased to larger communities in the northeastern US (Koch et al., 2018).

Equity: There is no history of consultation with Indigenous communities in the eradication of ALB, likely due in part to the restricted nature of its historical distribution. However, there has been a great deal of public communication in municipalities impacted by tree removal programs, with mixed results. In both countries, urban residents have largely been supportive of the eradication program, barring a small number of dissidents (Turgeon et al., 2022). Particularly exemplary in win-win action was the response to the Worcester, Massachusetts, eradication in neighbourhoods heavily impacted by the tree removal program (Palmer et al., 2014). Many interviewees saw the inherent danger in monoculture-style urban plantings and took the replanting initiatives as an opportunity for community building (Palmer et al., 2014).

4.6. *Key messages and future directions*

Creative, collaborative solutions are needed to protect forests from the impacts of invasive species. Our research captures a diversity of views of some of the key groups involved in forest pest management, and highlights areas of similarity and differences. Other stakeholder groups and the full suite of their ideas may unveil other important possibilities. More work must be done to extend the discussions we initiated here. Our five themes help to organize the growing set of tools used to manage invasive forest pests. Our results highlight mismatches between funding and media attention and perceived risk expressed by forest experts, including in the role of urban forests and the nursery trade. Siloed communication across group types (Fig. 1) was a persistent theme; nonetheless, participants asserted that progress in effective communication was feasible with the use of liaisons. Other themes, such as technology adoption and equity, have open, multiway communication at their core. In this vein, new monitoring technology, such as eDNA, is the subject of proactive public education campaigns by NGOs. For example, Canada's Invasive Species Centre has partnered with NRCan-CFS and CFIA to create the Hemlock Woolly Adelgid Monitoring Network (https://www.invasivespeciescentre.ca/take-action/hemlock-woolly-adelgid-monitoring-network) to engage the public in surveillance efforts, including through eDNA tools. Another example of synergies among the themes is the management of hemlock woolly adelgid in Nova Scotia. Nova Scotian government agencies held consultations with local First Nations (via the Kwilmu'kw Maw-klusuaqn Negotiation Office) prior to submitting an application for emergency registration of two insecticides for control of hemlock woolly adelgid, and are engaging in consultations surrounding biological control with Mi'kmaq in one of the first examples of Indigenous engagement in a forest invader management decision process (D. Lavigne,[3] NRCan-CFS, *pers. comm*). Scenario-based approaches, ideally those co-developed with partners across the management network, provide a means to open lines of communication across paradigms of institutional values to make equitable tradeoffs when managing forest invaders.

CRediT authorship contribution statement

Emma J. Hudgins: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Brian Leung:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Chris J.K. MacQuarrie:** Writing – review & editing, Writing – original draft. **Deborah G. McCullough:** Writing – review & editing, Writing – original draft. **Abraham Francis:** Writing – review & editing, Writing – original draft, Methodology. **Gary M. Lovett:** Writing – review & editing, Writing – original draft. **Qinfeng Guo:** Writing – review & editing, Writing – original draft. **Kevin M. Potter:** Writing – review & editing, Writing – original draft. **Catherine I. Cullingham:** Writing – review & editing, Writing – original draft. **Frank H. Koch:** Writing – review & editing, Writing – original draft. **Jordanna N. Bergman:** Writing – review & editing, Writing – original draft, Project administration. **Allison D. Binley:** Writing – review & editing, Writing – original draft, Project administration. **Courtney Robichaud:** Writing – review & editing, Writing – original draft, Project administration. **Morgane Henry:** Writing – review & editing, Writing – original draft, Project administration. **Yuyan Chen:** Writing – review & editing, Writing – original draft, Formal analysis. **Joseph R. Bennett:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data and code associated with this manuscript are available at: https://doi.org/10.5281/zenodo.11464393

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.foreco.2024.122046.

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