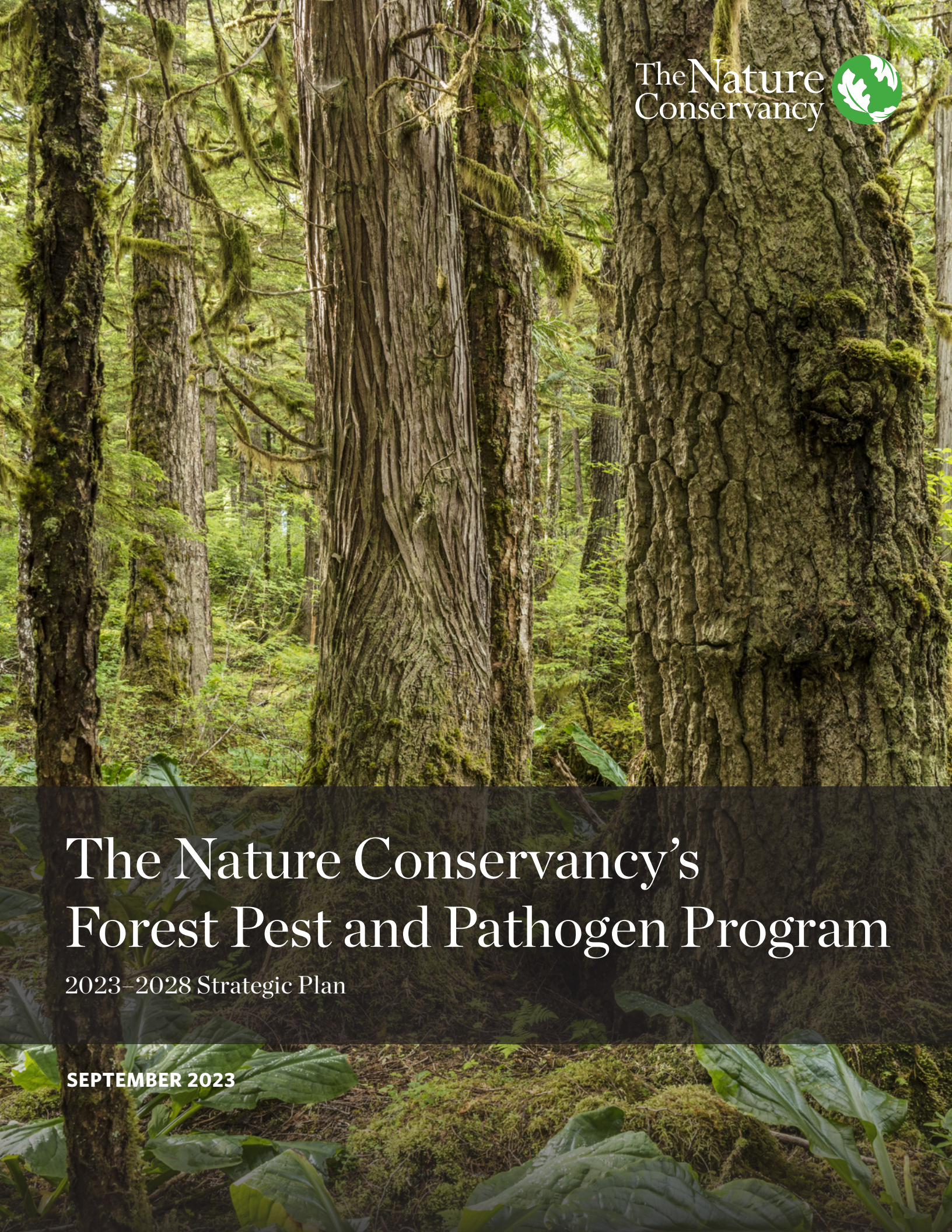

The Nature Conservancy

The Nature Conservancy's Forest Pest and Pathogen Program

2023–2028 Strategic Plan

SEPTEMBER 2023

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Dedication

Gary Lovett, for his lifelong dedication to advocating not only for action on forest pests and pathogens, but also for strong engagement by The Nature Conservancy.

Acknowledgments

See Acknowledgments for full list of subject matter experts and contributors. Special thanks to Resource Media and Hoffman Design Group for the report layout design and graphic design.

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Cover Photo

Mature longleaf pine and wiregrass in Fort Liberty, North Carolina. © Andrew Kornylak

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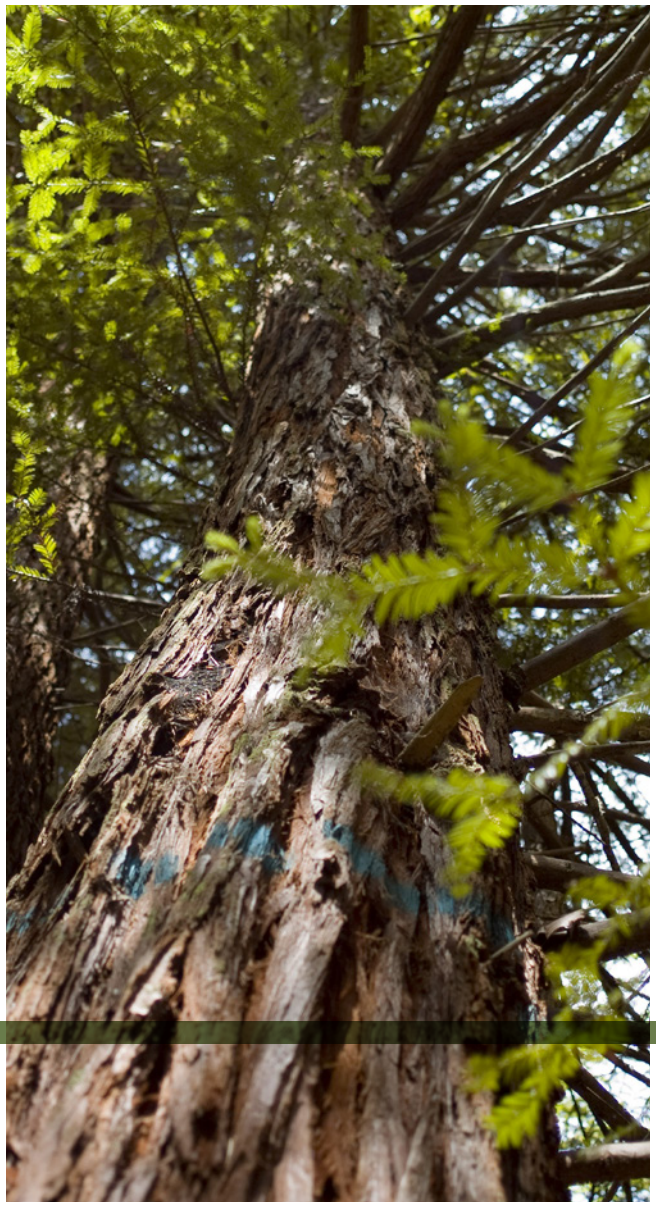
Mature longleaf pine and wiregrass in Fort Liberty, North Carolina. © *Andrew Kornylak*



Redwood tree at The Nature Conservancy's Garcia River Forest in California.
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Executive Summary

Executive Summary

Invasive forest pests and pathogens pose a direct threat to biodiversity, long-term ecosystem resilience, and carbon sequestration and storage across every landscape containing trees. Each of these three nature-based values are negatively impacted by the significant damage, decline, individual mortality, and species-wide functional extinctions that can result from invasive forest pests and pathogens. For nearly two decades, The Nature Conservancy (TNC), with its voice and direct influence, as well as the longstanding support of many partners across the globe, has been leading a variety of efforts to both mitigate the scope of damage from existing pests, and prevent additional pests from entering and establishing in North America.

Rising global trade combined with the ease of movement of people across biological boundaries, as well as the ever-growing influence of climate change, all work to increase the rate of introduction, rate of spread, and the overall severity of damage from invasive forest pests. Factor in the historical legacy of pest introductions that occurred before sufficient preventative measures (e.g., international trade regulations) were implemented, and the multilayered impacts to individual tree species as well as whole forested ecosystems are staggering in both scale and variety. As a result, the urgency and complexity of the challenges associated with limiting the effects of forest pests and pathogens is best addressed through a multifaceted approach with many complimentary strategies and partnerships.

This strategic plan outlines the most impactful and feasible opportunities for TNC to leverage both its own independent position, as well as the strengths of its public and private sector partners, to advance strategies protecting long term forest health.

These opportunities were identified through a series of external and internal interviews, working groups, and expert consultations; they represent different strategies for different points of intervention across the invasion continuum. The four broad opportunity areas identified are:

1. **Enhanced prevention along high-risk international pathways of entry**
2. **Strengthening the mechanisms that reduce domestic pathways of spread**
3. **Supporting urban forestry in the forest health context**
4. **Advancement of programs that breed and distribute pest- and pathogen- resilient trees**

The long-lasting and devastating impacts of invasive forest pests on the trees they infest or infect can permanently alter entire ecosystem functions, species composition, and landscape level resilience to other stressors such as drought, wildfire, habitat fragmentation, and climate change. TNC must leverage its strengths as a globally trusted, non-profit, science-based organization to address the threats to trees and forests within its own context; simply put, without healthy forests across North America, we will not fulfill our mission to take on the interconnected crises of climate change and biodiversity loss. Further, we must integrate our efforts at TNC with those of our many allied organizations and agencies. Working cooperatively within strong partnerships such as the Continental Dialogue on Non-native Forest Insects and Diseases remains a top priority to ensure the entire forest health community works both efficiently and holistically to address the problem of invasive forest pests. By using the prioritization presented within this strategic plan, the expertise and capacity of TNC staff and our many important partners will be leveraged to protect the values inherent in healthy trees and forests.

Emerald ash borer feeding damage. © *Steven Katovich, ForestryImages.org*

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Introduction

Introduction

Globally, and in North America, we are facing two interconnected crises — the loss of biodiversity and climate change. The protection and management of long-term ecosystem health, defined by the attributes of composition, condition, structure, and resilience is critical to addressing both crises. In forested landscapes the priority actions for many organizations and agencies, including The Nature Conservancy, are three core broad based conservation goals: protection of terrestrial biodiversity, management for long-term forest resilience, and an increase of nature-based carbon sequestration and storage. All three of these forest goals are directly threatened by the significant damage, decline, and mortality of trees caused by invasive pests and pathogens (Carerro et al 2022, Quirion et al 2021).

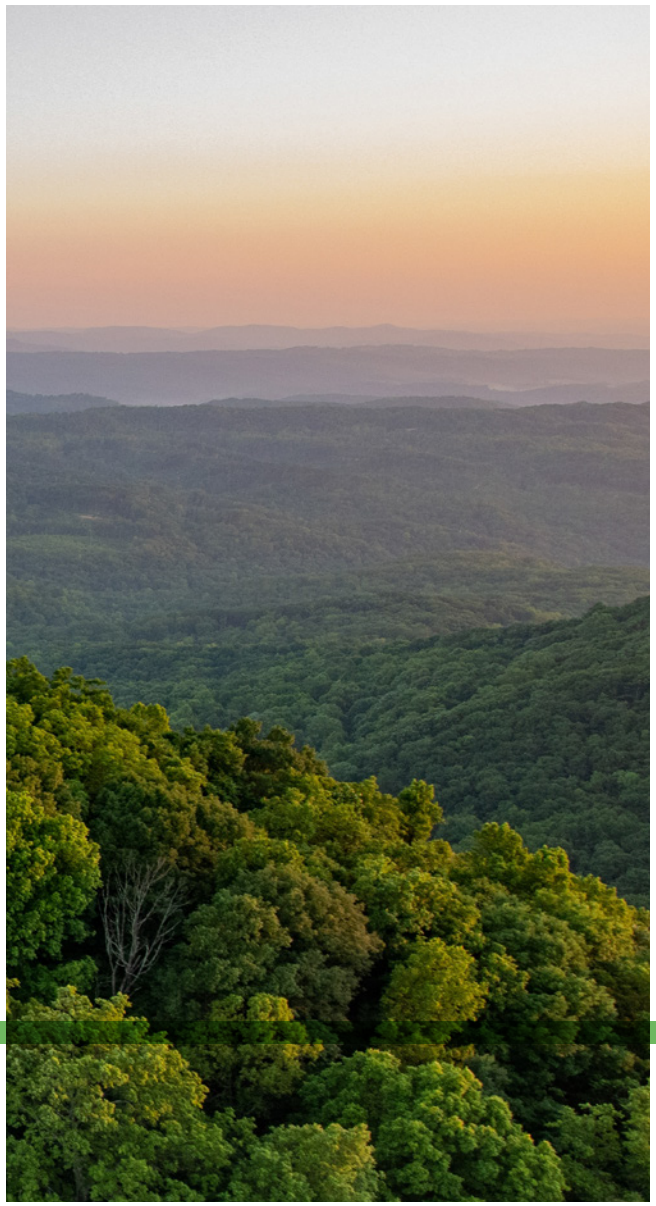
The seriousness of the invasive pest and pathogen threat to the biodiversity and function, and thereby resilience, of forested ecosystems cannot be overstated. North America has seen the functional extinction of two ecologically dominant tree species, American chestnut and American elm, in the last 150 years due to invasive forest pests and pathogens. The progressive elimination of other species and genera from entire regions and ecosystems is currently underway; more than fifteen species of North American forest trees are currently at risk of functional extinction from direct forest pest impacts in the next 50 years (Lombard et al 2021, Potter et al 2019).

In addition, the long-term stress, damage, and increased mortality seen in forests seriously affected by invasive forest pests and pathogens together create long lasting and significant net losses to carbon sequestration capacity. **A recent study estimates an annual reduction in live tree carbon sequestration capacity associated with severe forest insects and disease disturbance equal to 12.83 teragrams carbon/yr — or 9 percent of the total annual forest carbon in the contiguous US (Quirion 2021).**

The increase in trade across the world, the ease of movement of people across biological boundaries, and the constantly rising influence of climate change all combine to increase the rate of introduction, rate of spread, and the overall severity of damage from invasive forest pests. The urgency and complexity of the challenges associated with limiting the impact of forest pests and pathogens are best addressed through an approach that incorporates multiple complimentary strategies targeting various points along the invasion continuum. (see Appendix 1, Concept Map of Forest Pest and Pathogen Expanded Model).

The Nature Conservancy, in partnership with many others, has been involved in efforts to reduce the introduction and spread of forest pests and pathogens for over 15 years. The combination of our technical expertise and partnership building capacity along with our local to global presence has been leveraged to improve and accelerate what others are doing to address threats across the full forest pest and pathogen continuum. The USDA Forest Service's State, Private, and Tribal Forestry's Forest Health Program has supported this body of work for a decade, through a cooperative agreement which funds TNC's staff time in administering the direction and relationship building inherent to the Continental Dialogue on Non-native Forest Insects and Diseases (see Appendix 2, Continental Dialogue on Non-native Forest Insects and Diseases). This strategic plan was informed with significant input from the US and Canadian partners from both private and public sectors; many of these partners have had longstanding engagement in forest pest and pathogen work with TNC through their commitment to the Continental Dialogue (see Appendix 3, Strategic Planning Process).

The purpose of this strategic plan is to inform how The Nature Conservancy can best allocate direct efforts and prioritize meaningful partnership initiatives towards addressing the impacts of forest pests and pathogens in North American over the next five years. With TNC's current staff capacity and within its current funding structures, not all of the strategic actions listed within this plan are feasible in the near term- nor are all able to be addressed in the forum of the Continental Dialogue. In writing a comprehensive and concise assessment of those strategic opportunities that are feasible to address forest pests and pathogens across the full spectrum of the invasive species continuum, this plan also provides a clear focus for where TNC's current and future strategies and partnerships will have the greatest potential for success and impact- including those that represent a "stretch" goal for TNC's engagement in the five-year term. We are thankful for the many partners that contributed their time and expertise towards building this clear path forward for the successful protection of trees.



An aerial view of the Cumberland Forest Project, which protects 253,000 acres of Appalachian forest in Tennessee, Kentucky, and Virginia and is one of TNC's largest-ever conservation efforts in the eastern United States.
© Cameron Davidson

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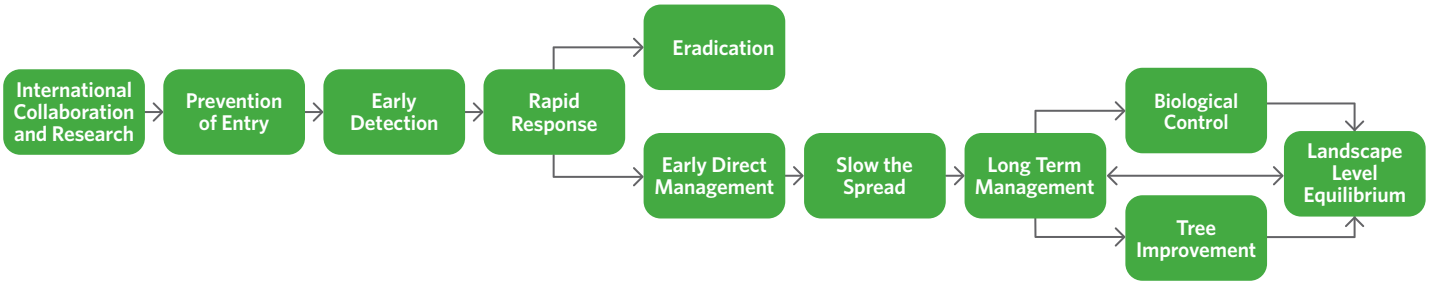
Planning Framework

Planning Framework

Traditional conceptual models for understanding the impacts and costs of invasive species and informing management interventions are often framed around the classic Invasion Curve. This model most often begins at the point of introduction and proceeds through the phases of-early detection, initial response, feasibility of eradication, public awareness, and long-term management strategies.

For this strategic plan, we use an expanded model, beginning with collaborative research and prevention actions that take place overseas and enroute to North America.

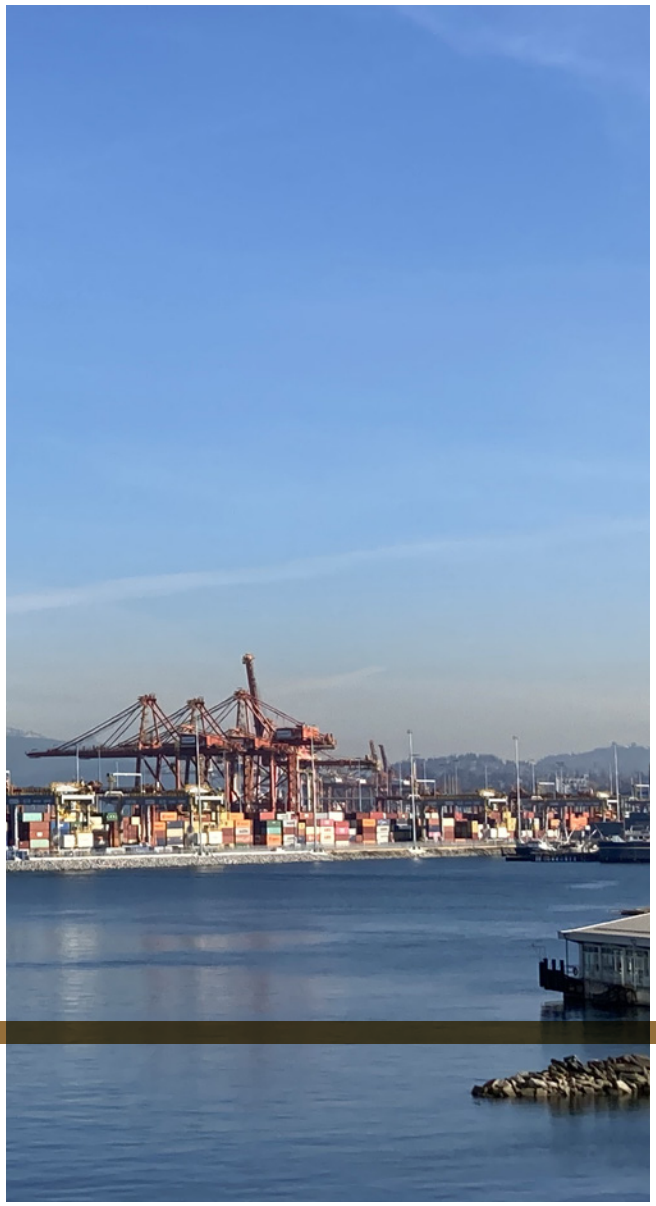
FIGURE 1: *Forest Pest and Pathogen Expanded Conceptual Model*



Using science and policy to not only identify organisms of potential concern, but also to actively prevent forest pests from gaining passage with travelers, goods, or conveyances into North America, is a critical first step that precedes early detection and it requires different strategies and partnerships. The importance of adding overseas prevention steps is shared by USDA APHIS' Safeguarding Continuum, as represented in the first of their three major groupings "Around the World, At the Border, Across the Nation." International research, partnership, and pathway-based prevention are also key components of the US Forest Service's International Programs Invasive Species program and the Society of American Foresters Position Statement on Invasive Species and Forests.

Invasive species prevention and management actions can generally be framed to focus on one of three conceptual groups: the specific resources to be protected (such as a tree species or a related industry), the individual pests, or the pathways and mechanisms of introduction and spread. Current legal and regulatory frameworks in North America often result in laws and regulations obligatorily written from the pest perspective; this can hinder proactive responses in areas where a pest is not yet known to be present. Comprehensive strategies for addressing invasive pests and pathogens that are not specifically required to adhere these regulatory mechanisms benefit by instead taking the third approach — focusing on the highest risk pathways and mechanisms of introduction and spread. This approach can better prevent, detect, and manage pests and pathogens that are unknown or poorly understood as well as those that are well known to scientists and regulators.

This strategic plan identifies four points along the forest pest and pathogen expanded conceptual model as having the greatest likelihood for TNC's effective and impactful engagement on reducing the near, middle, and long-term impacts of invasive forest pests and pathogens (hereafter termed "focal areas"); International Pathways of Entry, Domestic Pathways of Spread, Urban Forestry in the Forest Pest Context, and Pest and Pathogen Resilient Trees. Within each focal area, we assessed the most important strategies, who is best positioned to lead on different strategies; and then where TNC can have an outsized impact on the complex challenges within each.



The Port of Vancouver is the busiest port in Canada, handling 3.6 million shipping containers in 2022. © *Leigh Greenwood*

4

International Pathways of Entry

International Pathways of Entry

Preventing the entry of forest pests into North American ecosystems is the most scientifically sound, cost effective, and potentially successful strategy to protect trees and forests from new invasive species. Most invasive forest pests and pathogens are from a native range occurring outside North America, and here we discuss strategies to reduce the movement of forest pests on pathways associated with the international movement of goods and people.

The ever-increasing globalization of trade and speed of transit between continents has dramatically increased the threat from overseas origin forest pests in the past few decades. To meet this challenge, a wide variety of international partnerships between regions of the world, countries, trade partners, private entities, and non-profits are in place. As many of the issues within international trade that can lead to a reduction in the movement of forest pests into North America are best implemented via international bodies holding alliances and standards, the protective actions and strategies employed at this level can have a truly global impact to protect forest biodiversity and carbon sequestration worldwide.

The two trade-related pathways considered most significant in the international movement of forest pests are solid wood packaging material (crates, pallets, spools, dunnage, other) and plants for planting (seeds, seedlings, cuttings, and mature plants destined for planting or propagation at their destination). Other pathways are also important, including hitchhiker pest pathways (generalist contaminant pests that can be found on nearly anything- including in or on shipping containers, commodities, and ship or rail structures) and the emerging complexity of e-commerce enabled decentralized trade. Many other pathways play less prominent roles (whether due to lower volume, well enforced regulation, or other risk reducing conditions) in the spread of forest pests and are not described in this plan's narrative; these include commodities such as timber products, wooden handicrafts and furniture, plant materials imported for food, and cut flowers. The holistic reduction of risk within these pathways remain important to the overall prevention of entry of new pests — but due to various mitigating factors, these pathways do not rise to the level of top strategic importance within this plan.

INTRACONTINENTAL PATHWAYS PRESENT RISKS

Some forest pest species native to discrete regions of North America have become invasive due to human-assisted transport over previous biological divides which may or may not cross international boundaries. Most of the strategies to prevent the movement of intracontinental pests out of their native ranges fall within existing pathway-based mitigation approaches; this group of pests are generally addressed by either the international trade-related pathways (such as those that may be in solid wood packaging crossing the USA-Mexico border), or the domestic pathways of spread discussed later in this document (such as those that may be moved via the interstate transport of firewood).

The goldspotted oak borer was accidentally transported, likely via firewood movement, from its native range in north central Mexico and southern Arizona into the ecologically naive landscapes of southern California oak trees where it has become a devastating invasive species of mature oaks. Similarly, the mountain pine beetle, native to western North American forests, could become invasive if transported eastward through the movement of forestry products, or enabled to cross previous biological barriers by climate change, into Midwestern or eastern North American forested ecosystems. Other native forest insects and diseases may pose similar, yet not currently well understood, intracontinental risks.

This adult female mountain pine beetle is laying eggs within a lodgepole pine, one of its native range hosts in western North America.
© Brytten Steed, USDA Forest Service, ForestryImages.org

SOLID WOOD PACKAGING PATHWAY

Solid wood packaging material (including pallets, spools, crates, framing, dunnage, and other products) is a high-risk pathway for the transport of wood-borne and wood infesting forest pests. Two of the very highest impact forest pests were most likely introduced via infested solid wood packaging entering the US and Canada prior to the adoption of wood packaging mitigation measures — the Asian longhorned beetle and emerald ash borer. Emerald ash borer has killed over 100 million ash trees in North America since its introduction, and has the potential to cause the functional extinction of multiple ash tree species within less than a hundred years. The Asian longhorned beetles' biology renders it feasible to eradicate but at great expense; the cost to contain, manage, and eradicate the multiple discrete infestations of Asian longhorned beetles in North America and western Europe exceeded $1.9B from 1996 to 2017 (Cuthbert et al 2022).

The known risks of solid wood packaging are now mitigated primarily by an international regulation (International Standard for Phytosanitary Measure #15, known as ISPM 15) that applies to all international wood packaging movement (except between USA and Canada, by agreement) and requires an approved treatment to significantly reduce the risk of wood-borne organisms that may be present in solid wood packaging. Most solid wood packaging is treated via heat-treatment to a specification of 56°C for 30 minutes at the core of the thickest profile of the wood.

While ISPM 15 achieved widespread adoption by trade partners from 2002-2006, research has shown pest presence in solid wood remains problematic, and the modest reductions in pest presence that have been observed may not be adequately protective given the ever-increasing pressures of trade volume. Issues such as outright treatment fraud, accidental or negligent use of untreated material, insufficient — or incomplete — treatment, and post-treatment contamination still occur within this system and create substantial ongoing risk of forest pest transport. Further, ISPM 15 treatment is not designed to address post-treatment contamination risks, such as surface contaminating pests that may shelter in wood packaging or use it as a surface for egg-laying.

Five strategies were identified. Each strategy is followed by TNC's primary role.

1. **Research the current causal factors for the continued presence of pests in the international supply chain's solid wood packaging pathway.** This strategy, if implemented, would directly inform the priority order (through indicating likely level of effectiveness) of all other following strategies. TNC's role: Advocate and advise organizations with strong research capacity to advance this research rapidly, in concert with other environmental NGOs and professional societies.

2. **Increase the stringency of ISPM 15's requirements (i.e. changing the temperature and/or duration requirements, technical guidance, and treatment options) to reduce pest presence in solid wood packaging, if pest presence is due to a lack of rigor in the standard itself.** TNC's role: Work directly with regulatory bodies and policy makers to advance what the phytosanitary community believes will be the most impactful changes.

3. **Reduce fraud and other forms of intentional non- or under- treatment through increased inspection, greater trade data availability and collection, and focused intervention- if pest presence is due to these group of causal factors.** TNC's role: Lead advocacy for stronger compliance actions and data sharing by global and North American regulatory bodies.

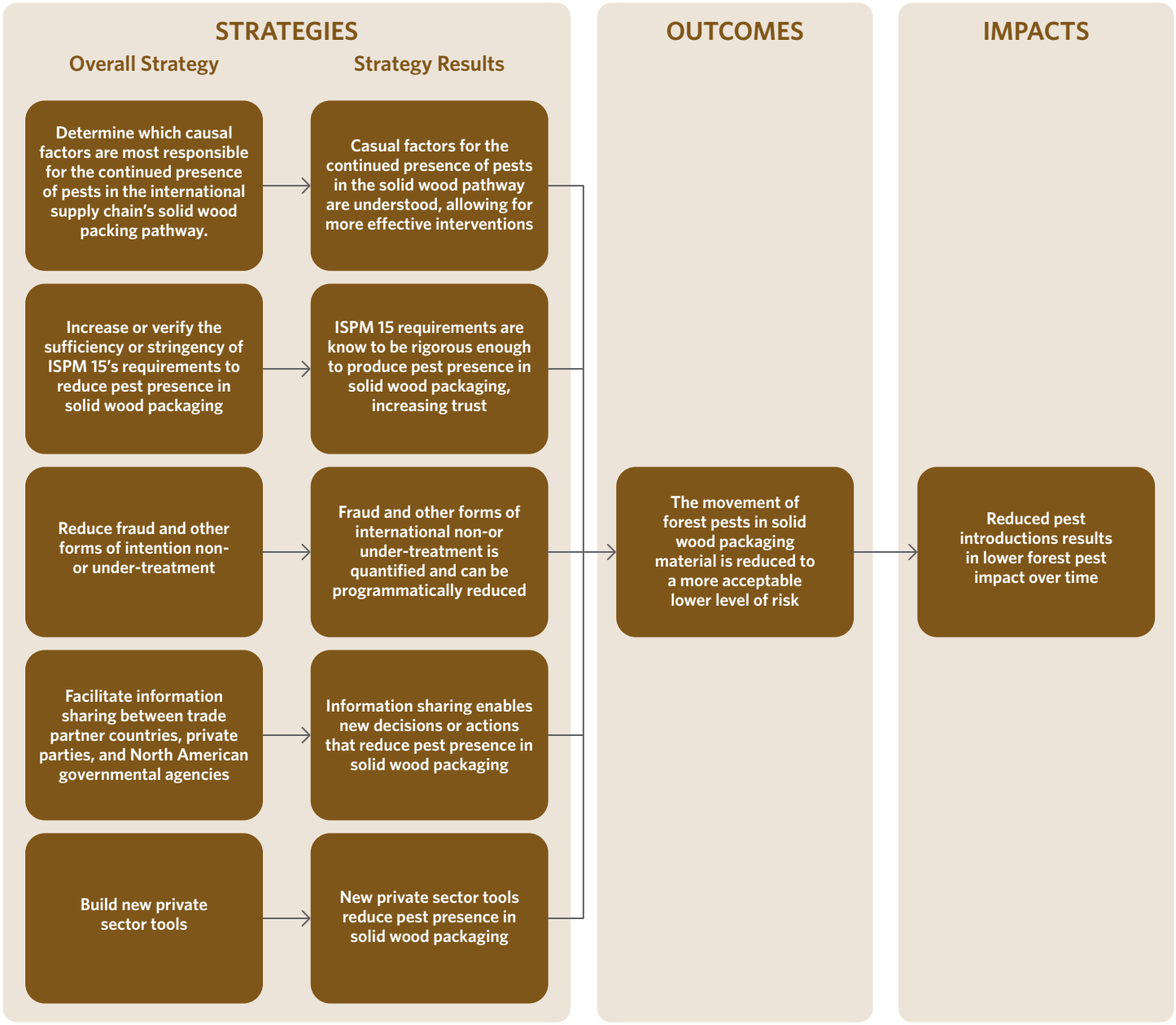
4. **Facilitate information sharing between trade partner countries, private parties, and North American governmental agencies to reduce pest presence, if current levels of non-compliance are due to a failure of mechanisms for auditors, manufacturers, and buyers to self-correct within the market.** TNC's role: Lead advocacy for transparency and trade partner collaboration by global and North American private and public entities.

5. **Build new private sector tools, such as taxes, insurance pools, or private port inspections that could reduce pest presence if application of these tools were wide enough, and logistically feasible, to create positive feedback loops within private solid wood packaging supply chains.** TNC's role: Support existing partner collaborations to advance aligned initiatives if and when they emerge.

Strategy Rationale within the Solid Wood Packaging Pathway

The Nature Conservancy has leveraged its strong knowledge base and institutional influence to incrementally improve the systems that reduce pest presence within solid wood packaging for nearly two decades. TNC's expertise in this area complements other non-profit and private sector efforts, allowing for both TNC-specific, and Continental Dialogue based, work to advance the science, policy, and implementation of solid wood packaging risk reduction. Ongoing research and global-scope international work will require different levels of engagement per each strategy. Overall, we will maintain and strengthen work through direct action (Strategies 1 and 2) or via leadership and partnership (Strategies 3, 4, and 5).

FIGURE 2: *Theory of Change for Solid Wood Packaging Pathway*



INTERNATIONAL PLANTS-FOR-PLANTING PATHWAY

The group of materials known as plants for planting includes seeds, seedlings, cuttings, and mature plants if they are destined for planting or propagation, rather than plant material for end uses such as consumption or manufactured products. Plants for planting have been well understood to present very high risk of transporting invasive forest pests and pathogens for well over 100 years (Liebhold et al 2012). As the seriousness of the plants for planting pathway was recognized early on by both the agricultural and forestry communities, a wide array of prohibitions, regulations, listing processes, risk analyses, certification programs, and best management practices now govern, and thereby systematically reduce the risks, the plants for planting pathway.

Due to this extensive protective framework, many of the most hazardous aspects of the plants for planting pathway are now prohibited entirely. For instance, it is against both US and Canadian law to import live plants in untreated natural soil from overseas, as soil can contain an enormous variety of invertebrates, microorganisms, and pathogens that would then be introduced along with the live plants. As a whole, the cumulative systems reducing risks for plants for planting; prohibits the entry of the types of materials that are deemed of most egregious risk (soil, certain taxa, etc), heavily favors low risk types of plant materials to enable continued international trade in some plant groups (certification and inspection of tissue culture, unrooted cuttings, bare-root plants), and takes a precautionary approach to allowing new stock types entry into the country given the reality that plant for planting have a novelty driven industry (USDA's programs such as; Post Entry Quarantine program for selected woody stock, creation of legal framework for Not Approved Pending Pest Risk Analysis status, the National Clean Plant Network for novel stock cleanliness and supply). Without these programs enabling risk-reduced trade, due to the industry norms, economic drivers, and horticultural history, it is likely the demand for novelty and supply of plants for planting would be filled via a much more extensive network of smuggled materials. A scenario of complete prohibition of plants for planting imports is widely considered to be of higher overall risk to plant health when compared to the current system, due to the high likelihood of illegal activity filling unmet demands.

Despite the long-term significant investment in a strong regulatory and management strategy to enable safe trade, invasive species are still entering via this pathway when existing systems are; inherently inadequate, not working as intended due to funding or functional issues, or, when illegal activity occurs undetected. For instance, microscopic or cryptic classes of potential invaders like viruses, bacteria, fungi, and nematodes may pass undetected through the protections within low-risk stock programs if DNA based detection programs are not consistently applied. Further, audits of the current systems are not comprehensive nor transparent, so the North American plant protection and research community as a whole do not have a clear view on what the failure rates are, nor their ultimate causes, across the spectrum of existing programs.

Five conceptual groupings of strategies were identified and deemed broadly feasible. The list that follows focuses on U.S. based interventions; additional research into parallel Canadian programs should be pursued in future plan updates:

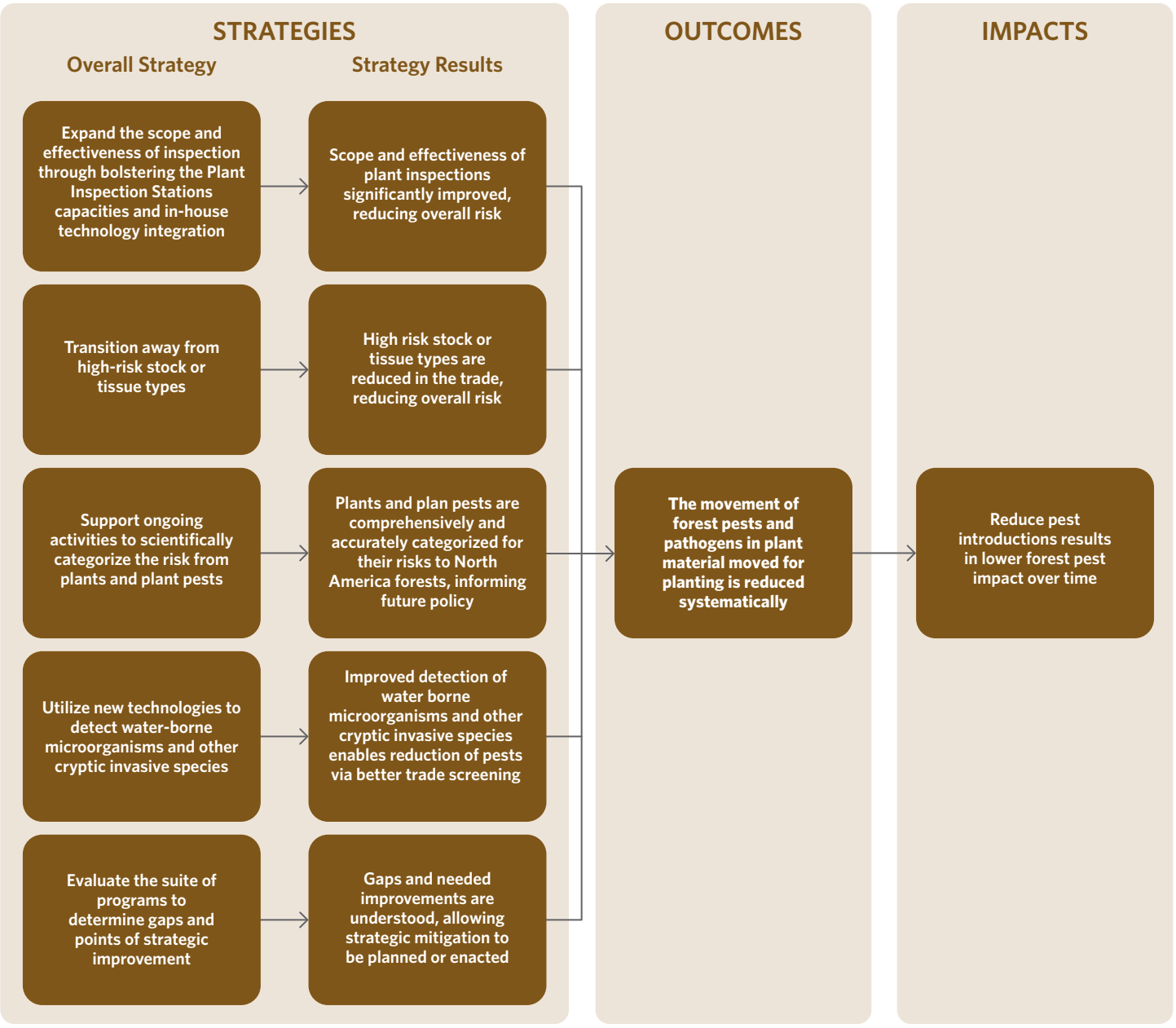
1. **Evaluate the suite of programs to determine gaps and points of strategic improvement.** Due to a lack of full-scale information on regulatory strengths and failures, the targeting of improvement measures is largely speculative, and thus current adaptive improvement actions may not be the most effective interventions. TNC's role: Advocate for increased attention and situational awareness through the work of the Continental Dialogue.
2. **Expand the scope and effectiveness of inspection through bolstering the Plant Inspection Stations capacities and in-house technology integration.** The Plant Inspection Stations inspect a vast quantity and variety of plants, largely visually. The current movement towards new facilities with modernized containment and DNA analysis labs needs to be accelerated. TNC's role: Leverage TNC's North American Policy and Government Relations capacity to bolster funding for these programs.
3. **Transition away from high-risk stock or tissue types for all woody genera.** Using lowest risk plant tissue types to bring in new varieties of plants via the National Clean Plant Network program enables trade while avoiding some of the higher risk profile and longer time frames of less preferable programs such as Post Entry Quarantine. TNC's role: Advocate when feasible.
4. **Support ongoing activities to thoroughly categorize risk from plants and plant pests scientifically and in a timely manner when they fall into the Not Approved Pending Pest Risk Analysis category.** TNC's role: Advocate when feasible.
5. **Utilize new technologies to detect potential water-borne microorganisms and otherwise cryptic invasive species threats within import enabling programs such as the Offshore Greenhouse Certification Program.** These commercial large volume imports are considered generally low risk, but there remains serious room for improvement in mitigating pest risks in the greenhouse environment. TNC's role: Advocate when feasible.

Strategy Rationale within the International Plants-for-Planting Pathway

The plants for planting pathway benefits from a long history of strong federal programs and actively interested private entities working together to minimize the inherent risks within this international trade activity. The Nature Conservancy's engagement in the plants for planting pathway would best lie within systems level incremental improvements through improving and aligning current policies for the USA and Canada, supporting scientific evaluation such as gaps analysis, and advocating for sufficient funding for USDA APHIS and US Customs and Border Protection programs to be sustained, strengthened, and/or expanded.

Through active engagement and work of the Continental Dialogue's participants and TNC's Forest Pest and Pathogen program, the existing portfolio of protections can be supported, modernized, systematically evaluated, and continuously improved. The trusted relationships, longstanding partnerships, bilateral engagement, and shared intrinsic goal of minimizing the import of plant pests should all be leveraged to effectively partner across professional spaces to reduce forest pest threats in the plants for planting pathway. Until such time that TNC is able to fund additional capacity in this work stream, the primary role for TNC is to maintain situational awareness via convening the Continental Dialogue and other partnership building.

FIGURE 3: *Theory of Change for International Plants for Planting Pathway*



INTERNATIONAL HITCHHIKER PEST PATHWAYS

Forest pests — and indeed many terrestrial invasive pests — can enter North American from overseas as incidental hitchhikers (or more formally, contaminating pests) on the commodities and conveyances of international trade and travel. In the case of forest pests, the hitchhiker pest pathways most commonly recognized as presenting high risk are shipping containers, ship and railcar structures, and heavy durable commodities such as raw metals, decorative stone, tile, heavy machinery, and vehicles. This last group generally represents commercial goods that may be stored outside and thereby exposed to potential contaminating pests in yards and facilities prior to packing and transit. The various hitchhiker pathways are well understood to present risks for forest pests including the Lymantrid moths (spongy and tussock moths) and spotted lanternfly, as well as terrestrial invasive pests not specific to forests, including a variety of taxa and species such as brown marmorated stink bug, eastern heath snail, Joro spider, northern giant hornet, and many species of invasive ants.

CONTAMINATING PESTS THREATEN MUCH MORE THAN TREES

The recent introductions of Joro spider, northern giant hornet, and yellow-legged hornet do not have precisely known causal events; scientific consensus is the likely pathway of introductions for these species is the hitchhiker pest pathway. Reducing the rate of arrival of all types of contaminant pests — including both tree pests and invasive pests not directly damaging to trees or forests — will protect the biodiversity and natural resilience of all terrestrial ecosystems across North America.

Solid wood pallets, plastic pallets, and metal framing can all potentially be contaminated with hitchhiking tree and forest pests- especially when stored outdoors. © *Leigh Greenwood*

The International Maritime Organization's Code of Practice for Packing Cargo Transport Units includes only non-mandatory best practices for the containers themselves. These international best practices are very broad general guidance with no regulatory component, and therefore have no enforcement mechanism nor metric of evaluation. Regional and taxa-specific programs and initiatives to systematically reduce the risk of contaminant pathways via regulation or more directed guidance do exist, including Australia's Sea Container Hygiene System, North American Plant Protection Organization's (NAPPO) North American Sea Container Initiative, and the longstanding multinational agreement (Mastro et al 2021) on the prevention of a group of high risk Lymantrid moths known as flighted spongy moths.

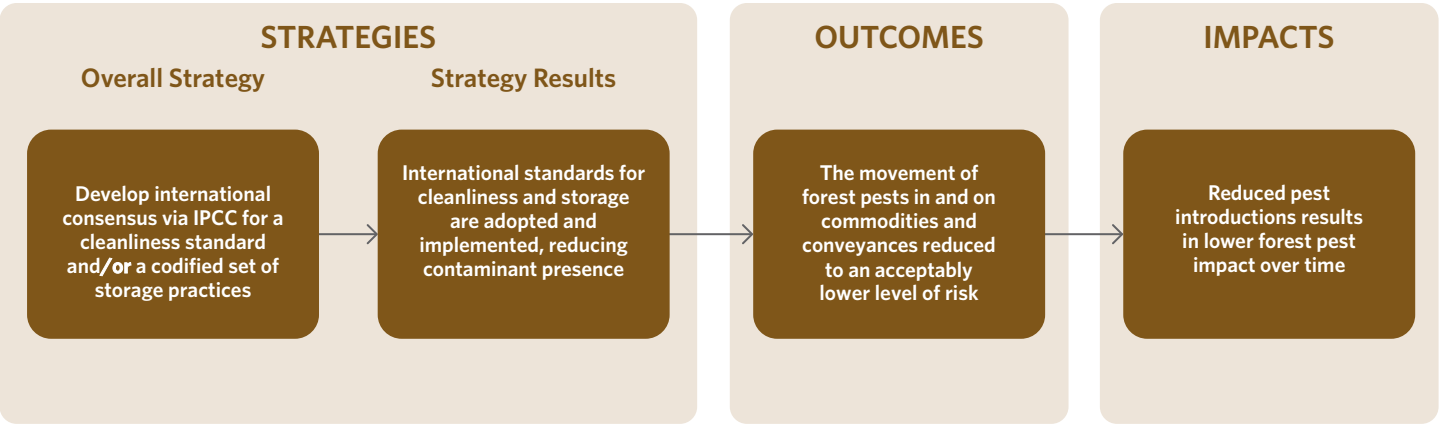
One priority strategy emerged as timely, feasible, and likely to be effective at reducing risk:

> **Advance international consensus via the International Plant Protection Convention (IPPC) Sea Container Task Force for a comprehensive cleanliness standard and a codified set of container packing and storage practices.** TNC's role: Advocate for prompt action at the IPPC level through both direct partnerships and the work of the Continental Dialogue.

Strategy Rationale within the International Hitchhiker Pest Pathways:

The hitchhiker pest pathways are a tremendously complex and under-regulated set of global pathways- and improving the safeguarding of these system is crucial from the perspective of limiting the movement of potentially invasive terrestrial organisms. The Nature Conservancy will directly encourage the integration and expansion of existing programs and initiatives to create a global framework (such as the creation of a new ISPM) of consistent and achievable hitchhiker pest reduction standards and programs. Through partnerships built via the Continental Dialogue and the parties closely related to our work on wood packaging materials, TNC will engage with entities such as NAPPO and the IPPC through their existing stakeholder engagement avenues (technical panels, calls for Topics, and others) to advance holistic approaches to meet the scale of this pathway's complexity.

FIGURE 4: *Theory of Change for International Hitchhiker Pest Pathways*



E-COMMERCE ENABLED PATHWAYS

International online peer to peer networks and decentralized marketplaces present an emerging and highly complex pathway for the movement of potentially invasive forest pests. In many cases, the sellers are unaware of or actively not compliant with the existence of regulations on the products they are selling. For instance, an independent artist of traditional carved wooden face masks may not know that the wood must be heat-treated before being shipped from its country of origin into the United States. On the other side of the transaction, buyers might purchase an item that violates one or more laws- without knowing such laws exist, and without a mechanism to be alerted by the commerce platform prior to completing the transaction.

The risk level of this pathway is under evaluation by the IPPC, multiple NPPOs, and others. The IPPC has e-commerce on its current framework for action, and increasing attention is being paid to this issue by agencies in the USA, Australia, New Zealand, and elsewhere. All parties addressing the e-commerce challenge will need to emphasize the importance of advanced technology approaches that meet the nature of the problem (i.e. A.I., machine learning, others) to tackle this pathway, rather than relying solely on legal, informational, or outreach based approaches that better suit traditional international business practices.

The current and much needed attention to the e-commerce pathway will likely create opportunities for productive engagement and risk reduction by private industry, public entities, and other interested parties. One overarching strategy was agreed upon given the current high level of interest in this issue:

> **Advance risk reduction programs to address e-commerce systematically through existing venues such as the IPPC or NAPPO.** TNC's role: Advocate for prompt action through both direct partnerships and the work of the Continental Dialogue.

Strategy Rationale within E-commerce Enabled Pathways

The Nature Conservancy's strength in this pathway's risk mitigation lies within collaborative advocacy at the domestic, continent-wide, and international level- and this is best accomplished via the Continental Dialogue. The Dialogue's interested individuals and groups can be leveraged to encourage the technology-based approaches that this emerging problem will require, with TNC's role being a convenor of concerted advocacy for integrated advances in risk reduction.

Forest pests like the invasive shot hole borers which infested the trees that became this pile of firewood often spread from their initial establishment point into new areas along multiple domestic pathways. © *Beatriz Nobua-Behrmann*

5

Domestic Pathways of Spread

Domestic Pathways of Spread

After initial establishment within North America, most invasive forest pests spread relatively slowly by natural biological processes such as active insect flight or passive wind- or water- based dispersal. In contrast, the accidental movement of forest pests through human activities can be quick and unpredictable; they are often spread far more rapidly, more often, and into more distant additional points of establishment. Human activities that spread pests often include recreation, direct commercial-associated transport, or indirect movement via transport conveyances. Specifically, commonly defined groups of domestic pathways for invasive forest pests include: firewood, plants for planting (generally speaking, nursery stock), other biological materials (soil, mulch, green waste, cut flowers, and holiday greenery), household moves, conveyances of commerce (rail, truck, pallets), high risk commodities (tiles, heavy machinery), wooden handicrafts, unconventional wood based products like pet chews, and the emerging complex pathway of items domestically sold and traded via person-to-person online marketplaces. While all of the domestic pathways contribute to the domestic spread of forest pests, it is widely agreed that the two pathways of greatest concern are firewood and plants for planting. The discussion on the latter includes soil both directly and indirectly associated with plants for planting. Firewood and plants for planting have historically been associated with repeated human-mediated dispersal events of high impact pests; thus, they are the two pathways that present the greatest opportunity for impactful intervention.

NOTE ON USA AND CANADA IN THIS SECTION

The Nature Conservancy's partners, strengths, and levels of involvement are very different in the USA and Canada. The differences drive some jurisdictional considerations within this strategic plan, especially in the Domestic Pathways of Spread chapter. Within the Firewood Pathway, issues regarding the US-Canada border, as well as domestic borders between individual US states and Canadian provinces, are all commonly part of TNC's work objectives- and were thus integrated into strategic planning efforts. In contrast, TNC has not worked on the International nor Domestic Plants for Planting Pathways in Canada in the past. Due to this difference in existing professional connections and knowledge, these focal areas of the strategic plan were explored at different geopolitical scales.

Untreated firewood cannot be brought across the U.S.-Canadian border in either direction- only certified heat-treated firewood is permitted to cross between nations. © *Leigh Greenwood*

FIREWOOD PATHWAY IN THE USA AND CANADA

Firewood as a domestic pathway for the spread of forest pests can be conceptually broken down into two groups: commercial firewood (firewood while being produced, bought, and sold — this includes sales in both informal settings and retail establishments), and individual firewood (firewood associated with its end user whether for recreational fires such as for camping or backyard fire pits, or for home and cabin heating as in wood stoves or boilers). While considerable real-world overlap exists between the two firewood categories, this division is useful as each group requires tailored strategies to reach the outcome of reduced forest pest spread via the firewood pathway.

Commercial Firewood:

As a broad generalization, firewood is not a high profit margin product. Changes in wood supply, transport costs, and labor costs cause firewood producers to face frequent business challenges and a highly competitive environment. Likely as a result, the commercial firewood industry is not represented by any industry specific group or association, which makes cohesive approaches to forest pest presence in the supply chain particularly challenging.

The availability of heat treatment certification is dependent on authorities granted (or not) within each state, or the presence of a domestic federally regulated pest. In 2023, 29 states had a heat treatment certification program that could be applied to firewood, and the most relevant pest, spongy moth *Lymantria dispar*, was present and regulated in over 20 states.

FIREWOOD RISK REDUCTION THROUGH HEAT TREATMENT

Certified heat-treated firewood, generally speaking, is firewood that was heated in a kiln to an approved temperature and duration by a private facility holding a compliance agreement with a state or federal entity. TNC worked with the U.S. National Plant Board to create the National Plant Board Firewood Guidelines, first published in 2020, which contain complete scientific and regulatory context for certified heat-treated firewood as well as other firewood types.

Certified heat-treated firewood is more widely available for sale in the eastern United States in large part due to the geography of the former federal domestic quarantine on emerald ash borer. © *Mark Rankin*

The current regulatory authorities over firewood in most state programs, and all federal programs, are not based on the commodity of firewood itself, but rather on the potential or actual presence of a forest pest of concern in or on the wood. This pest-based regulatory framework has resulted in an inconsistent state by state and pest by pest regulatory approach. The inconsistency of regulations coupled with a similarly inconsistent landscape of state-based certification programs results in a complex commercial firewood landscape that does not lend itself to simple solutions.

Addressing the root cause of the pest-based regulatory framework could provide long-term success at reducing the threat from commercial firewood; however, this potential strategy has a very low likelihood for success in a reasonable timeframe. Similar efforts to address this issue common to other invasive taxa (e.g., efforts to regulate potential invasive species within the pet trade) have been ongoing for decades with only incremental improvement.

Individual Firewood:

Effectively changing the behavior of millions of individual firewood user necessitates different, but complementary, strategies when compared to the previously mentioned commercial firewood best practices, regulations, and markets. Prior research by TNC shows that while firewood and forest pest information generally reaches the public, less than half of firewood users know of local laws, regulations, or recommendations. The action of traveling with personal firewood for the purposes of building a campfire elsewhere is not irrational; if a fire is part of the intended activities at one's destination, it makes sense on the individual level to bring firewood from home if it is freely available. The net result of many individual decisions to move firewood in this way translates to a high-risk activity for the dispersal of forest pests along the personal use firewood pathway, especially since it means the repeated event of people bringing firewood from largely urban and suburban areas where forest pest infestations are most often first established. The emotional attachment to campfires and the logistical reality of needing cordwood for home heating creates strong incentives to use firewood overall, making the key to risk mitigation of this pathway a systems-based approach of incrementally lowering risk along multiple points.

Three priority strategy groupings emerged from the discussion of commercial and personal firewood as both feasible and impactful:

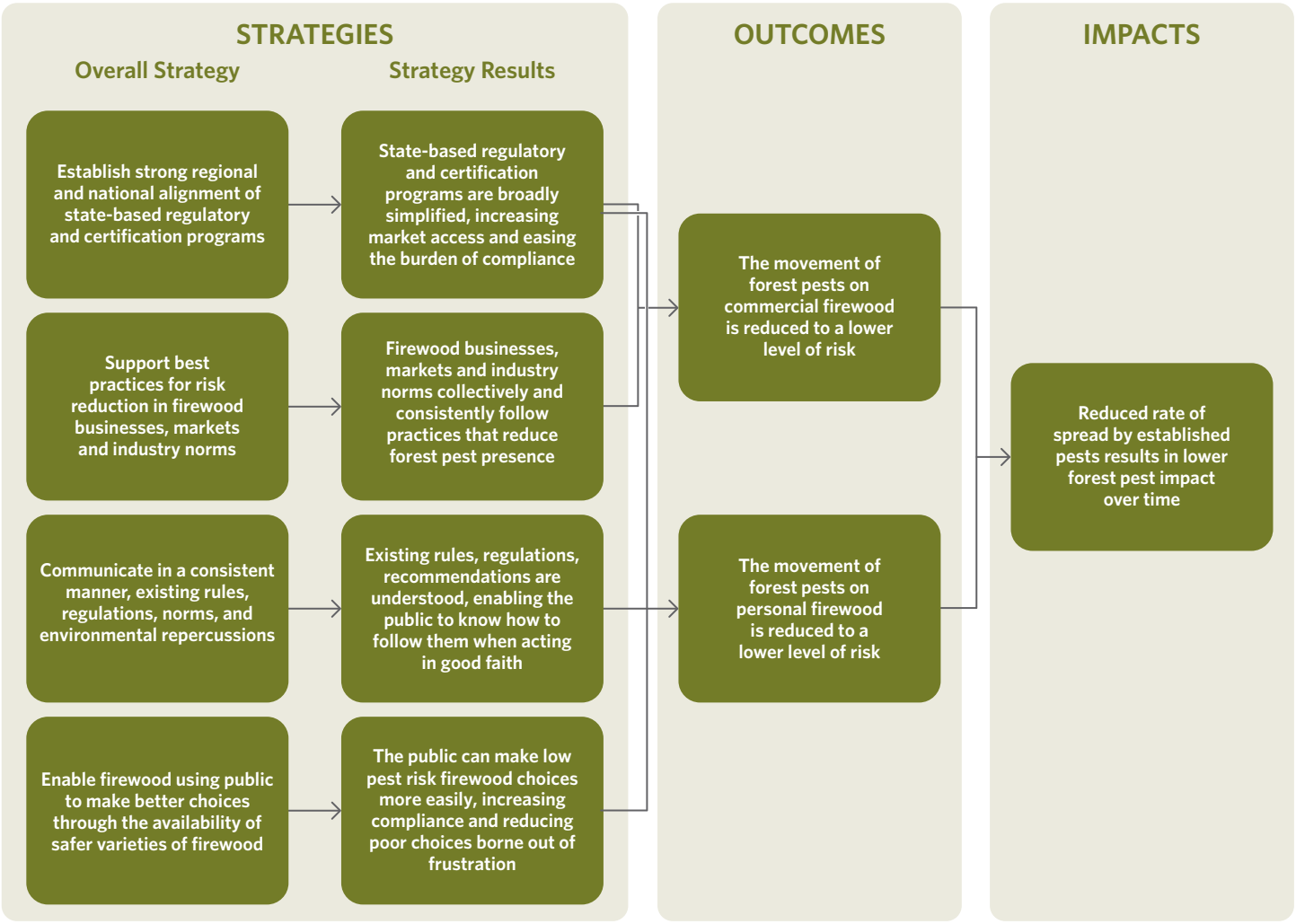
1. **Create strong regional and national alignment (commonly known as "harmonizing") of the various state based regulatory and certification environments to reduce pest presence in the commercial and personal firewood pathways through existing tools and authorities.** This would strengthen existing protections, allow for consistent and easily understood outreach messages, and incentivize the wider adoption of heat-treatment certification programs by state authorities. This is the firewood strategy most likely to see demonstrable success in a 5-year timespan. TNC's role: Advocate, convene, and leverage influence from longstanding partnerships to rapidly advance this strategy.
2. **Support best practices for risk reduction in commercial firewood businesses, markets, and industry norms through tools such as subsidies, technical support, or incentives.** This enables the firewood using public to make better choices via ease and availability of safer varieties of firewood (locally harvested, gathered on site, or certified heat treated- depending on pest and regional circumstances). TNC's role: Provide a supportive outreach environment to reinforce the actions by directly involved private entities and specialized educational partners, such as Extension agencies.

3. **Conduct outreach campaigns according to social science best practices to persuade firewood users to consistently adhere to existing rules, regulations, recommendations, and best practices.** The firewood using public must be actively encouraged towards better firewood using behaviors, and this encouragement needs to be consistently reinforced in order to effectively reduce the risk of forest pest movement along both the personal and commercial firewood pathways. TNC's role: TNC will continue to lead this effort at a North America- wide scale through the Don't Move Firewood campaign. The campaign's success comes in part from the diverse array of trusted partners and collaborative efforts across federal, state, tribal, and commercial entities with vested interest in a stable and effective firewood outreach program.

Strategy Rationale within the Firewood Pathway:

The Nature Conservancy has a long successful history of bringing dozens of stakeholders together to manage the Don't Move Firewood educational campaign, and continuing that campaign is a high priority that was underscored throughout the working groups and research conversations conducted for this strategic planning process. TNC's role in this space is similar to other non-profits that run behavior change campaigns specific to their areas of interest (e.g., PlayCleanGo and North America Invasive Species Management Association, Don't Let it Loose and Invasive Species Action Network); TNC is uniquely well positioned to run the Don't Move Firewood campaign by bringing together public and private interests to unite for the overarching goal of healthy trees. The overlap of needs for regulations to support both outreach and commercial firewood's risk reduction is nearly complete. TNC's expertise in this area also creates significant synergy in addressing the regulatory space via spheres of influence and professional relationship building.

FIGURE 5: *Theory of Change for the Movement of Forest Pests on Firewood*



The supply component of certified heat treated or local firewood at campground destinations and regularly available in the commercial market is less clearly aligned with TNC's strengths; much like the complimentary aspect of supporting best practices by businesses and markets listed in the aforementioned commercial firewood strategy group, this is a strategy better addressed via leveraging the capacity and new federal funding mechanisms through the Continental Dialogue on Non-Native Forest Insects and Diseases. Partners such as various USDA APHIS domestic programs staff and the US Forest Service Wood Innovations Program may have greater leverage and jurisdiction.

DOMESTIC PLANTS-FOR-PLANTING RELATED PATHWAYS IN THE UNITED STATES

The intracontinental movement of plants for planting and associated materials (such as the soil associated with potted plants) is a known pathway for a wide variety of pests and pathogens affecting trees and forests. Unlike the international movement of plants for planting, where legal frameworks for risk reduction are relatively well structured and comprehensive, the domestic regulations governing the interstate trade in plants for planting in the U.S. are fairly characterized as being highly fragmented, incomplete, and a source of frequent confusion and frustration for both industry and government agency staff.

SPECIAL CONCERNS ON THE USA-CANADA BORDER

The intracontinental movement of plants for planting, and the types of forest pests commonly associated with them, across the contiguous US-Canadian border is a special case due to both the ecological and political realities of this border. During the 2022 working group sessions on the movement of plants for planting, several concerns surfaced on the topic of US-Canadian regulations, materials movement, and inter-governmental cooperation, but no clearly defined strategic needs or actions were elevated. For this, and other pragmatic reasons, this strategic plan therefore focuses the scope of the intracontinental sections on interstate trade and movement within the USA only.

The box tree moth was first identified in Canada in 2018. Recent populations of box tree moth now found in New York, Michigan, and Ohio as of 2023 are likely from the Canadian infestation. © *Gregoire Dubois*

The authority for a federal regulation in the U.S. to regulate the movement of plants that may bear invasive pest threats is reliant on the presence of a federally regulated pest- and some very damaging pests that clearly cause serious economic and environmental harms are not deemed federally regulated pests. This sets up a system in which the federal entities do not or cannot engage to regulate the movement of potentially infested materials for established pests such as; emerald ash borer, spotted lanternfly, invasive shot hole borers, goldspotted oak borer, and many others. It thus becomes up to each state plant regulatory authority (typically, the state department of agriculture) to stand up its own suite of plant pest regulations, creating a patchwork of potentially non-aligned prohibitions or risk mitigation requirements- similar to the issues discussed in the firewood section above. Further complicating issues, some state and federal regulations that are well recognized to have outlived their usefulness create serious burdens within the interstate plant trade, which undermines trust and efficiency in the system.

With over fifty state and territorial regulating bodies and hundreds more industry and outreach interested parties, the interstate movement of potentially invasive species bearing plants, soil, and associated goods (such as empty reused pots) is a tremendously complex risk reduction environment. Given this complexity, the following overarching strategic actions were selected for having the greatest potential impact on the system as a whole:

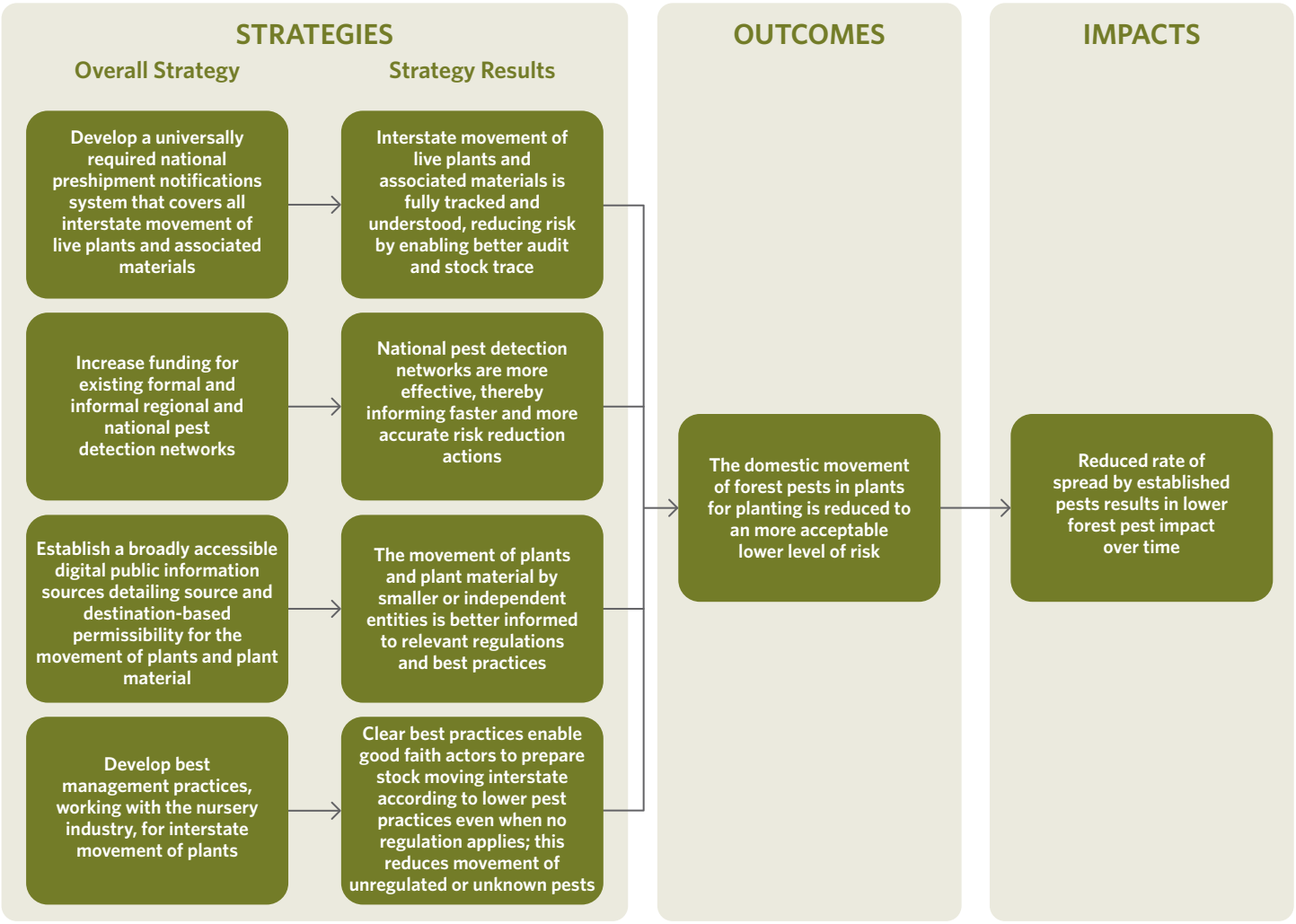
1. **Develop a universally required national pre-shipment notifications system that covers all interstate movement of live plants and associated materials.** Lack of adherence to existing regulations presents a serious hurdle to both business and plant health; a consistent system would enable improvements in information flow, business practices, and plant protection activities. TNC's role: Advocate when feasible. Leverage the partnerships of the Continental Dialogue to advance this strategy.

2. **Create a broadly accessible digital public information source detailing source and destination-based permissibility for the movement of any given type of plant or plant related materials.** This information is currently inaccessible to the layperson, making the regulatory landscape for interstate movement functionally opaque to smaller businesses. TNC's role: Lead efforts with partnering entities (such as the University of Georgia) to advance this strategy — seek funding to directly address this via a technology solution.
3. **Work with the nursery industry to develop their own best management practices for interstate movement of plants.** This may include actions such as making the existing Systems Approach to Nursery Certification program more financially and strategically valuable for nurseries to participate in, through incentives that could include recognition programs or value-added products. TNC's role: Advocate when feasible. Leverage the partnerships of the Continental Dialogue to advance this strategy.
4. **Increase funding for existing formal and informal regional and national pest detection networks (such as Cooperative Agricultural Pest Survey) to increase the effectiveness and validity of state and federal regulations based on pest presence or absence.** TNC's role: Utilize the North American Policy and Government Relations team to advise and pursue funding priorities and positions.

Strategy Rationale within the Domestic Plants-for-Planting Pathway:

The Nature Conservancy's expertise in partnership building provides an excellent basis for creating and facilitating working groups or public-private partnerships to actively plan, fund, and pursue the strategies listed above. The urgency of the information gathering and sharing needs in the first three strategies listed was very clear during the course of the strategic plan's working sessions making these three intertwined strategies a high priority for the Continental Dialogue in the immediate future.

FIGURE 6: *Theory of Change for Domestic Movement of Plants for Planting*



City trees in Seattle, Washington. © *Kevin Lee*

6

Urban Forestry in the Forest Pest Context

Urban Forestry in the Forest Pest Context

Most forest pest introductions to North America are associated spatially with major ports of entry receiving international trade, which themselves are typically found in urban areas. The longstanding association between first points of introduction of forest pests and urban areas is critical for understanding both the implications for early detection and rapid response, as well as the impacts of forest pests on the people and trees living in urban areas. Due to the patterns of trade and human activity, urban areas therefore become the frontline of detection, response, and management actions towards most forest pests during the introduction and establishment phases of the invasion model, and this important grouping of concepts and actions is defined by TNC's Cities Network forestry staff as "frontline forestry." Further, most of the world's population lives in cities, which are also on the frontlines of the impacts of climate change- urban areas are where extreme heat and weather disasters negatively affect billions of both people and trees.

The Nature Conservancy has engaged in urban forestry work since 2013 through a dedicated program created using investments from both the USDA Forest Service and private foundations committed to conservation of our nation's forests. This work aligns with the principles and objectives of preventing, mitigating, and minimizing the impacts of forest pests outlined elsewhere throughout this plan. Examples of national tree health initiatives include Healthy Trees, Healthy Cities — a partnership with the USDA Forest Service that engages a wide range of urban forest stakeholders in the long-term health monitoring of trees in cities, and Treesilience — a resilience and restoration initiative that prioritizes the establishment of the enabling conditions for healthy, resilient canopy in these frontline communities by focusing on mature tree pruning, removals, replacements, and site preparation on both public and private properties.

TNC's Cities Network Forestry program underwent its own strategic planning process in 2022-2023. TNC's Forest Pest and Pathogen Program served as a subject matter expert at multiple points during the team's process. Among the top issues that emerged are: urban forest and tree canopy loss, biodiversity loss and generalized ecosystem function decline in urban areas; and inequitable distribution of, and access to, healthy trees and greenspaces largely due to historic and present disinvestment in low-income communities and communities of color. Across the participating Business Units (BU) within TNC's Cities Network, the most commonly identified theme linking people and nature in urban areas (measured in Fall 2023 by over thirty letters of support from sixteen BU's and their community-based partners) was how tree and forest health in the urban environment is a unifying factor for the health of people and ecosystems.

Each of the recognized challenges for frontline forestry contain forest pest and pathogen components. Several of the current strategies employed by the Cities Network — such as "plant, manage, and monitor trees" — complement the strategies and actions outlined elsewhere in the Forest Pest and Pathogen strategic plan. It is therefore a key element of the Forest Pest and Pathogen Program Strategic Plan to maintain professional connections and an ongoing advisory role with TNC's Business Unit projects and staff working in urban forest contexts to ensure full integration of the forest pest and pathogen management elements necessary for long term forest health success.

These eastern hemlock seedlings are being grown in the research greenhouses at Holden Forests and Gardens as part of the hemlock wooly adelgid resistance breeding program. © *Rachel Kappler*

7

Pest and Pathogen Resilient Trees

Pest and Pathogen Resilient Trees

In the Invasive Pests and Pathogens chapter of "*Managing for Climate Resilience on The Nature Conservancy Preserves and Managed Lands in the Eastern United States*," the case for action and leadership by TNC to support the development of pest and pathogen resilient trees is clear.

> *"The most powerful on-the-ground TNC contributions to long term resilience to the threat of invasive forest pests may prove to be in actively managed recovery programs for affected tree species. With the knowledge, capacity, private ownership, and organizational infrastructure afforded to our land managers, TNC is outstandingly well suited to participate in regional, federal, or continent-wide multi-stakeholder species preservation and replanting efforts."*

While the prior sections of this strategic plan discuss researching, preventing, slowing, and mitigating the effects of forest pests and pathogens, this final section directly addresses the tree species themselves. Some invasive forest pests and pathogens that have, or will, enter North America, can then lead to the functional extinction of entire tree species. In these cases, when pest-based landscape level solutions such as biological control or mating disruption have failed, scientific intervention in the form of rapid selective breeding or genetic modification of affected tree species is necessary to protect long term biodiversity.

The challenges inherent to the success of this strategy at a landscape level scale are immense, and the time required to see these projects through is best measured by generations of scientists or trees — not by years of work. Individual trees or tree populations showing evidence of partial resistance to pests or pathogens must be identified, cultivated, and cross bred in nurseries at a scale that allows for seed or seedling distribution across entire natural landscapes — all while considering naturally occurring genetic diversity across tree species ranges and the anticipated effects of climate change on those ranges. In some cases, such as the white pine blister rust affected species of pine in the western U.S., this is already well underway through a combination of naturally occurring resistance, scientific capability of rapid screening of seedlings, and adequately supported programs. In other cases, such as for American beech and its two threats of beech bark disease and beech leaf disease, both historical efforts and a huge body of emerging science will need to be combined to create a path forward.

To directly address the tree species at the greatest peril of functional extinction due to invasive forest pests and pathogens, different strategies need to be employed according to the unique biology and science of each pest-and-tree ecological relationship.

The following five strategies were selected as the most critical for success in this challengingly complex conservation area:

1. **Protect breeding stocks and existing genetic diversity of imminently imperiled trees through silvicultural practices, strategic pesticide use, or other short-term strategies that support long-term successful retention of naturally occurring resistance or diversity.** TNC's Role: Support organizations with existing leadership and capacity in this strategy (US Forest Service, state-based forestry agencies) through national and regional advocacy.
2. **Evaluate, quantify, and bank genetic resources present naturally on the landscape (seed or leaf collection, genetic typing) to prepare for future programs.** TNC's Role: Directly conduct work for selected tree species, and convene partners in a leadership capacity, in collaboration with the US Forest Service and other key partners.
3. **When feasible, identify and traditionally breed resistant trees.** TNC's Role: Contribute organization and technical capacity for selected tree species, in collaboration with the US Forest Service and other key partners.
4. **When traditional partial or full resistance is not apparently present; define the use case and role of genetically engineered, edited, or modified resistant trees**. TNC's Role: Produce and amplify a position statement on biotechnology use in support of science-based solutions.
5. **Develop specific and effective complementary efforts, such as biological control organisms, to support the survival of partially resistant trees, when possible.** This is a scientific investment necessary for long term success in many pest and pathogen control programs, as a new ecological level equilibrium must be achieved to see success with programs. TNC's Role: Advocate for long-lasting funding, research, proactive research and development programs in these areas.

Strategy Rationale for Actions Supporting Pest and Pathogen Resilient Trees

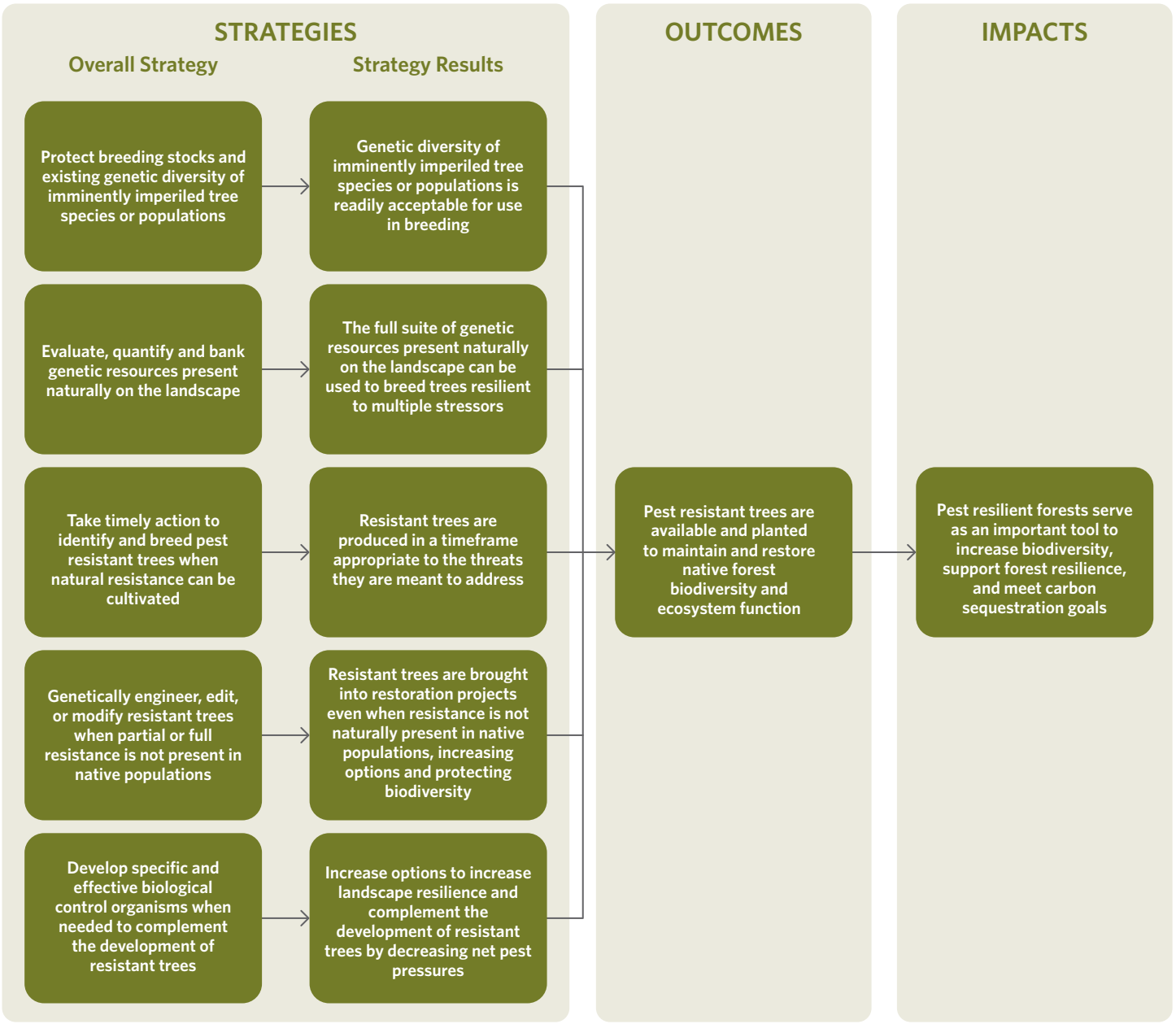
TNC's role in this space is not often as a direct research and development entity, but rather as a convenor of groups, complex projects, and ideas. Our unique effectiveness in supporting the improvement of tree species to meet this need comes from our capacity to support broad scale coordination of partners and entities. This capacity is evident in the calls to action within the Managing for Climate Resilience document; it will become even more relevant with TNC's Resilient Conservation Science team plan to expand this document's range to the Western states and thus becomes closer to continental-scale.

As a large and well-regarded environmental non-profit, TNC can leverage its strengths to serve in a coordinating and applied role for the funding of research, breeding, and test planting of resistant trees. This was first illustrated with TNC's longstanding American elm breeding program work in New England; in 2022 TNC's Forest Pest and Pathogen Program received a philanthropic gift enabling a new project with a much broader scope: three species of ash, eastern hemlock, and American beech.

In the case of a tree and pathogen where selective breeding has not yet demonstrated success (American chestnut and chestnut blight), TNC has engaged its voice as a thought leader and voice of scientific integrity in the support of research and development. Continuing the work of leading, supporting, and conducting critical tree breeding activities on the time and spatial scales required for success is the role that TNC should fill.

The Nature Conservancy's interest in protecting the native tree species of North America that are threatened by invasive pests and pathogens reflects this body of work's position as the natural, but unfortunate, final point on the forest pest conceptual continuum. In the cases where invasive forest pests rise to damage at the species viability level, these pests are therefore also threatening the biodiversity necessary to mitigate climate change via forest-based natural climate solutions (Fargione et al 2018).

FIGURE 7: *Theory of Change for Pest and Pathogen Resilient Trees*



Snow covered red spruce in a wintertime West Virginia wilderness forest at the Canaan Valley. © *Kent Mason*

8

Conclusion

Conclusion

The severe and ongoing impacts of invasive forest pests and pathogens extend across the continent — and the world — damaging biodiversity, long-term ecosystem resilience, and carbon sequestration. A failure to rise to the ongoing challenges inherent to forest health protection will bring only greater environmental and economic impacts. The reality that forest pests and pathogens are exceptionally difficult to eradicate once established means each additional introduction is likely to lead down a road of expensive and decades long mitigation programs necessary to protect forests' biodiversity and carbon sequestration potential. It is imperative to note that the selected pathway-based strategies within this strategic plan reflect the fact that with sufficient investments and adaptive management in the earliest parts of the forest pest continuum — research, prevention, and surveillance — future eradication programs will not need to be enacted, damage will be averted, and trees will be saved.

Reducing and managing the threats to biodiversity, ecosystem integrity, and carbon sequestration potential from invasive forest pests requires an exceptionally broad scope of strategies by many different of public and private partners across the globe. In this plan we present strategies that are most likely to be impactful, and most achievable, either through TNC's direct capacity and influence, or through the actions of affiliated coalitions like the Continental Dialogue on Non-native Forest Insects and Diseases, where TNC has a leadership role.

The Nature Conservancy and the participants in the Continental Dialogue are important parts of a large tree protection community that stretches across North America and the world. This community includes not only multiple leading federal agencies within each nation (i.e. US Department of Agriculture, Department of Homeland Security, and Department of the Interior; Canada Food Inspection Agency, Canada Border Services Agency, and Natural Resources Canada) but also a wide variety of associations (e.g. National Association of State Foresters, Society of American Foresters, Sustainable Urban Forests Coalition, National Wooden Pallet and Container Association, Canadian Wood Pallet and Container Association), research institutions, non-profit and non-governmental organizations (e.g. World Resources Institute, Arbor Day Foundation, Cary Institute for Ecosystem Studies), and more. The collective voices of each of these entities must be heard on the issues that matter to them- and these voices can then be leveraged to achieve those mutually aligned goals that protect trees.

There are many current standards, programs, and best practices in place across the realm of forest pest prevention that could provide greater protection if scaled to the size of the need, or if strong functional improvements in enforcement, targeting, auditing, or risk analysis were put into place. The Nature Conservancy's reach as an environmental advocacy group gives it a keystone position in the pattern of overlapping partnerships, parties, and geographies outlined above. Together with the myriad of partners that hold interests and expertise in forest health, TNC's work will result in healthier forests around the continent — and the world.

A hardwood forest stand in Michigan's Two Hearted River Forest Reserve.
© *Drew Kelly*

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Acknowledgments

Acknowledgments

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Forest floor of bracken fern and young balsam fir and white spruce trees among red pines in mixed coniferous forest in Itasca County Minnesota.

Appendix 1

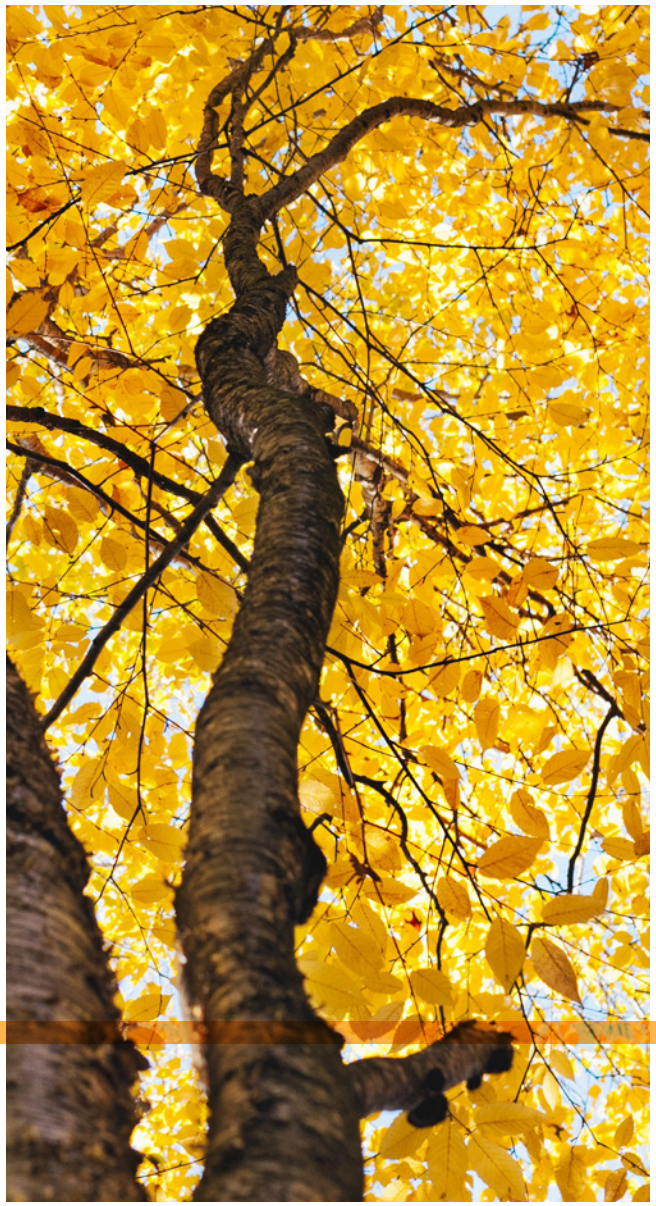
Concept Map of Forest Pest and Pathogen Expanded Model

Appendix 1: Concept Map of Forest Pest and Pathogen Expanded Model

PROTECTIVE MECHANISMS BEFORE OR EN ROUTE TO NORTH AMERICA	BROAD PATHWAYS OF ARRIVAL (PRIMARY SPREAD)	RISK REDUCTION MECHANISMS AT PORTS OF ENTRY	EARLY ESTABLISHMENT CONCEPTUAL SPACES	PROTECTIVE MECHANISMS DURING EARLY ESTABLISHMENT	BROAD PATHWAYS OF DOMESTIC MOVEMENT (SECONDARY SPREAD)	MITIGATION MECHANISMS FOR ESTABLISHED PESTS AND PATHOGENS	LONG TERM MANAGEMENT CONCEPTUAL SPACES	MANAGEMENT MECHANISMS AND PRACTICES FOR LONG TERM FOREST HEALTH
Presence of global, regional, and national regulations and measures (ISPMs, other)	Horticulture trade (plants for planting, seed, cut flowers, non-timber forest products, others)	Enforcement of existing measures and regulations	In or adjacent to traditional ports of entry (highway, rail, air, and sea)	Quarantines and other domestic policy	Nursery facilities, sales, distribution, and consumers	Quarantines and other domestic policy	Non-commercial private land (e.g. residential, small forested parcels)	Cultivation, production, replanting, and planting of resistant or resilient tree stock
Enforcement and audit of regulations and measures in source countries	Solid wood packaging (pallets, crates, dunnage, other)	Trade inspection and use of inspection data for improved targeting	Distribution and warehouse centers	Monitoring and trapping based detection	Containers, pallets, and commercial vehicles	Monitoring and trapping based detection	Commercial Forest Lands	Developing host resistance or tolerance via direct genetic manipulation (e.g. gene editing)
Private entity incentives and partnership	Non-solid wood packaging and conveyances (e.g. containers, ships, manufactured wood crating)	Data sharing between USA, Canada, and Mexico	Urban areas	Community science and first detector based detection	Railways and Highways	Community science and first detector based monitoring	Nursery and Landscaping Businesses	Science-informed tree planting programs (natural, restoration, production, and urban) for diversity and resilience
Pest, natural enemies, and tree risk analyses (in situ)	Passenger travel (e.g. fruit, seed)	Data sharing domestically across agencies and non-governmental entities	High risk commodity importers (e.g. nursery, tile, heavy machinery, steel)	Rapid response preparation, training, and deployment	Firewood, campgrounds, recreationists	Active pest management (e.g. pesticide, mating disruptors)	Federal, state, tribal, and private tree nurseries	Genetic host tree mapping research for breeding, climate information, future or contemporary planting
Horizon scanning and pathways analysis	Internet Commerce (e.g. micro pet trade, fall bulbs, entomophagy trade)	On site surveillience and detection systems		Data sharing on distribution and biology	Household moving	Data sharing on distribution and pathways	Research Facilities (e.g. academic, institute, botanical gardens)	Urban tree and forest management proactive practices
International scientific collaboration and documentation (e.g. peer reviewed journals, government reports, grey literature)	Imports for food use	Outreach and in-reach to travelers and port of entry workers		Pathway based slow the spread programs (e.g. Don't Move Firewood, PlayCleanGo, outreach to moving companies)	Green waste disposal	Pathway based slow the spread programs (e.g. Don't Move Firewood, PlayCleanGo, outreach to moving companies)	Urban and/or frontline forestry communities	Climate and pest resilience informed forest management
Sentinel and common gardens (in situ)	Timber and Lumber			Pest- or host- specific research programs	Biology of pest and host (e.g. flight, wind, soil, mutualisms, etc)	Research and monitor for host resistance or resilience	Public Lands (e.g. parks, open space, recreational, wildlife, wilderness)	Nursery stock certification, regulation, and incentive programs
Offshore certification of nurseries and living plant materials (e.g. cut flowers)	Small and new wood products (e.g. handicrafts, pet toys)			Sentinel, Common, and Research Gardens	Weather events (e.g. storm damage cleanup, flooding)	Systems Approach to Nursery Certification (SANC)	Orchards and agroforestry	Pest or pathogen control via gene editing, gene drive, or other novel means
Incentivizing or requiring lower risk live materials (e.g. tissue culture and micro-propagation)	Intracontinental movement across biological boundaries			Host resistance mechanism and screening research	Forest product harvest, storage, and movement	Host tree seed, stock, or gene banking	Utility and transportation right of way (e.g. gas lines, electric transmission, rail)	Biocontrol (implement, monitor, improve)
Biocontrol (preparatory research in home or invaded ranges, pre- or post- invasion)	Failed biological controls or other escapes			Biocontrol (research, initiation)	Forest management (e.g. thinning, harvest, prescribed fire, etc)	Biocontrol (develop, implement, monitor)		No-action, or acceptance (intentional decisions to not take action)
					Online sales (e.g. live plants, handicraft, foraged art and goods)			
					Informal plant and wood trade networks (e.g. iris societies)			

This concept map was developed as part of the strategic planning process, as a shared mechanism for participants to envision and define all the possible different mechanisms, pathways, and spaces of forest pest and pathogen relevance within North America. Each column is meant to capture a broad yet complete group of ideas- some of which were then used to define the strategic focal areas within the plan itself. **Omitted from this concept map are the overarching mechanisms of action and necessary enabling factors that impact most or all of the full continuum.** Those were also defined over time in discussions, and are summarized in brief as follows; **institutional and systematic change** through legislative work, policy building, and financial tools; **collaborative approaches** including public and private partnership; **climate informed actions** and planning; **human factors** including social science, enforcement, and accountability; **knowledge dissemination** of foundational science, best practices, and technical assistance; **outreach and education** across professional, in-reach, strategic, and mass media environments; and **institutional support** of long term scientific and technical expertise, capacity, and cross-boundary cooperation.

Mechanisms Pathways Spaces



A hardwood forest stand in Michigan's Two Hearted River Forest Reserve.
© *Drew Kelly*

Appendix 2

The Continental Dialogue on Non-Native Forest Insects and Diseases

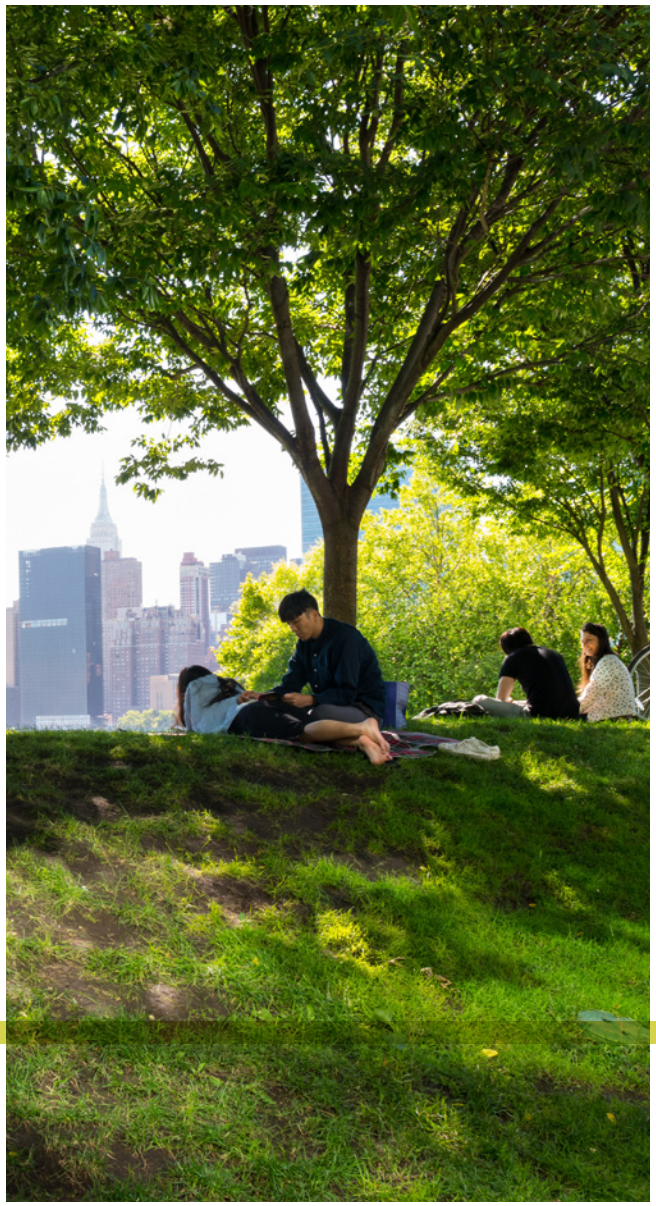
Appendix 2: The Continental Dialogue on Non-Native Forest Insects and Diseases

The Continental Dialogue on Non-Native Forest Insects and Diseases is a longstanding multi-organizational partnership that serves to protect and maintain healthy forest landscapes through collectively addressing the threat of invasive forest pests in North America. Through the years, the Dialogue has provided a central forum for its diverse attendees and participants to identify areas of mutual interest, discuss shared strengths and concerns, and build consensus around strategies and actions that will address those forest pest threats. The members of the Dialogue act together when they have shared interests, opportunities, leverage, and trust. The Nature Conservancy has convened the Dialogue since its inception, and in that time the outcomes of the Dialogue have proven to be an integral part of the success of TNC's Forest Pest and Pathogen Program.

The Dialogue's greatest strength, as repeatedly identified by many of the participants in the strategic planning interviews and discussions, is the opportunity for professionals across many different sectors and priority areas of invasive forest pests to create lasting and beneficial professional connections. These connections advance continent-wide forest health; the diversity of viewpoints, responsibilities, and approaches are crucial to identifying and accomplishing complex improvement strategies across the forest pest invasion continuum. Through in-person discussions, presentations, informal consultation, and the long-term development of shared approaches, the Dialogue serves as a key venue for conceptualizing cross-cutting efforts that would not otherwise have a dedicated time and place to begin.

The broadest goals of all the Continental Dialogue's participants are aligned with the goals of The Nature Conservancy; all entities act within their own values towards the long-term health of forests in North America. However, the Dialogue's participants are brought together not by the mission of The Nature Conservancy, but rather by their own interests, goals, and priorities. Therefore, while the Outcomes and Impacts outlined in TNC's strategic planning process are very likely to be aligned with Dialogue participants' desired outcomes and impacts, the Strategies that TNC has identified may be different from the strategies other entities would pursue. This is the strength of the Dialogue's structure- it's participants each bring unique institutional and professional strengths that may advance the community towards a particular desired outcome of forest health in ways that TNC or other partners would not anticipate. Together, the Dialogue's participants can connect, collaborate, and find ways to act together towards the shared best interests of forest health.

The Nature Conservancy's Forest Pest and Pathogen Program 2023-2028 Strategic Plan was directly informed, along every step of the way, by the viewpoints and expertise of Dialogue participants. However, the priority strategies as detailed within the strategic plan are not necessarily the preferred strategies or focus of any person or entity outside of TNC. It is the intent of the Forest Pest and Pathogen Program to maintain a broad focus – as detailed in **Appendix 1. Concept Map of Forest Pest and Pathogen Expanded Model** – on each step of the invasive continuum when convening the Continental Dialogue. This will allow the Dialogue's participants to set their own strategic priorities, as they always have, to collectively advance the protection of forest health across North America.



Gantry Plaza State Park along the East River in Long Island City, New York.

Appendix 3

Strategic Planning Process

Appendix 3: Strategic Planning Process

The assessment of strategies for forest pests and pathogens was addressed in two steps. The objective of the first step was to identify strategic focal areas — key sources of threats (such as the international horticulture trade) or management actions (such as active pest management) for which specific strategies could be developed. The strategic focal areas were informed by national and global models and frameworks of invasion management; our framework begins at research and prevention, moves into early detection and rapid response, and continues through to forest management and resilience (see both Figure 1 and Appendix 1, Concept Map of Forest Pest and Pathogen Expanded Model). Added to the model was an assessment of the probability of success and identification of cross-cutting strategic themes (e.g. climate change).

The strategic focal areas were first developed through a series of online (video-call) meetings with eight selected national-level professionals in forest pests and pathogens. Once a preliminary model of strategic focal areas was drafted, additional peer review was conducted by six more professionals from relevant fields and agencies to refine the model. The listings of all participants in all phases of this strategic planning process are included in the Acknowledgements.

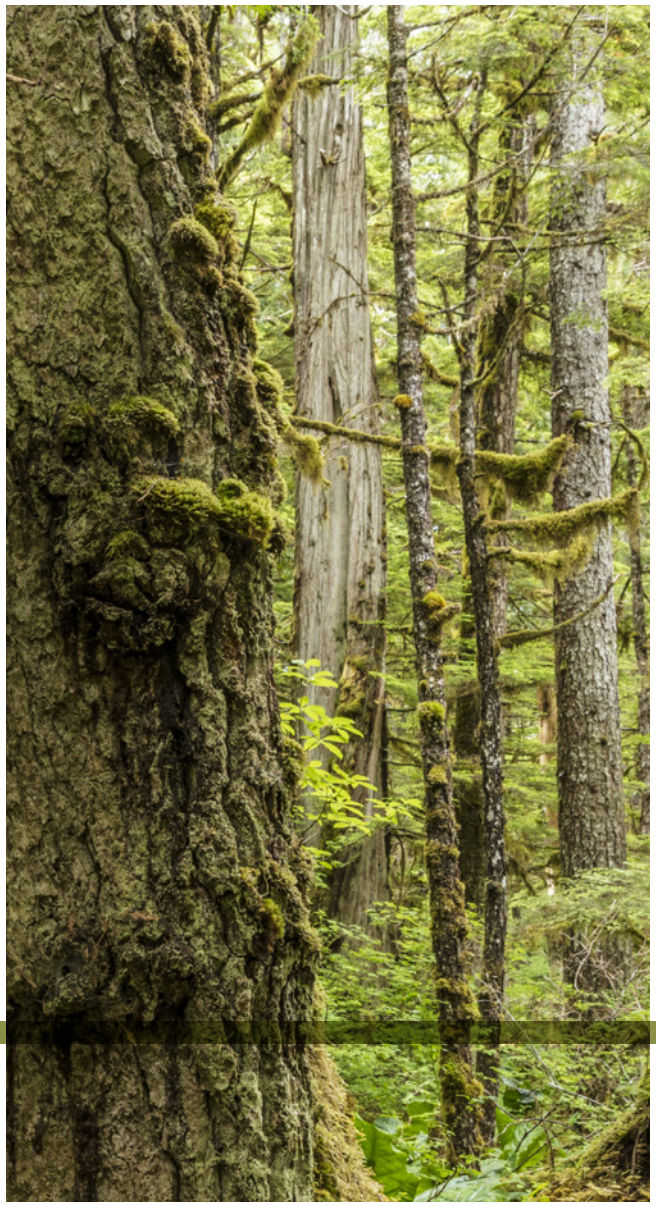
The second step of the process focused on understanding the context that influences the human-caused movement of pests and pathogens and the identification of potential strategic actions. Two teams worked on this assessment. The first team focused on the international movement of pests and pathogens, with membership consisting of US-based federal, state, academic and private industry representatives as well as Canadian federal agency staff. The second team focused on the domestic movement of pests and pathogens, with members from US-based federal, state, and private industry groups.

Both the international and domestic teams identified the primary pathways of movement within their area of expertise and used situation analysis to identify causal factors and potential strategies. Situation analysis, adapted from Conservation by Design and the Conservation Standards, assist in the identification of the social, cultural, institutional, political, and economic factors that influence the presence of pests within the pathways and the development of strategies to address these factors. All team members assisted in the development of the situation diagrams, visual constructs of the situation analysis, and were encouraged to comment on all diagrams. This allowed team members with multiple points of expertise to contribute throughout the process. Potential strategic actions were then prioritized by benefit and feasibility.

The output of the team's work first included the desired outcomes and goals for each pathway, the causal factors for the pathway, and potential strategies to reach the desired outcome. We used a Theory of Change analysis to summarize, illustrate, and test how the potential strategies link back to the desired outcomes.

A Theory of Change analysis is a process that explores and illustrates how a set of strategic actions lead to short-term results, long-term outcomes, and ultimate impacts. The analysis incorporates specific strategies, that in combination, are predicted to attain the desired outcomes and impacts. In addition, the analysis assists in identifying measures of progress and success and the assumptions and uncertainties inherent in programmatic planning. The diagram, as a visual tool, effectively communicates a program's shared vision and how the vision will be attained.

The Theory of Change diagrams illustrate, from left to right, the Strategy (a suite of actions that describe how a strategic result will be obtained), the Strategic Results (specific results when a strategy in successfully implemented), Outcomes (the desired change in the pathway attained through multiple strategies over longer time frames) and Impacts (the aspirational systemic change desired over a long-time frame, here being healthy North American forests). Each individual Theory of Change diagram is found embedded in its respective section within this document (Figures 2 through 7).



Old growth forest near Hatchery Creek Falls in Alaska's Tongass National Forest. © *Chris Crisman*

Appendix 4

Literature Cited

Appendix 4: Literature Cited

Carrero C, Beckman Bruns E, Frances A, Jerome D, Knapp W, Meyer A, Mims R, Pivorunas D, Speed D, Treher Eberly A, & Westwood M. 2022. Data sharing for conservation: A standardized checklist of US native tree species and threat assessments to prioritize and coordinate action. Plants, People, Planet, 1– 17. https://doi.org/10.1002/ppp3.10305

Cuthbert RN, Diagne C, Hudgins EJ, Turbelin A, Ahmed DA, Albert C, Bodey TW, Briski E, Essl F, Haubrock PJ, Gozlan RE, Kirichenko N, Kourantidou M, Kramer AM, Courchamp F. 2022. Biological invasion costs reveal insufficient proactive management worldwide. Science of The Total Environment, Volume 819, 2022, https://doi.org/10.1016/j.scitotenv.2022.153404.

Fargione JE et al. 2018. Natural climate solutions for the United States. Sci. Adv.4. DOI:10.1126/sciadv.aat1869

Liebhold AM, Brockeroff EG, Garrett LJ, Parke JL, Britton, KO. 2012. Live plant imports: the major pathway for forest insect and pathogen invasions of the US. 5 March 2012 https://doi.org/10.1890/110198

Lombard K, Anderson MG, Barlow K, Goodwin G, Serbesoff-King K, Sferra N, Wraithwall J (editors). 2021. Managing for Climate Resilience on The Nature Conservancy Preserves and Managed Lands in the eastern United States. The Nature Conservancy, Center for Resilient Conservation Science https://crcs.tnc.org/ , https://tnc.app.box.com/s/s42kiwxqz0wbx9qxk21xc8pvaqgg88hd Accessed August 18 2023

Mastro VC, Munson AS, Wang B, Freyman T, Humble LM. 2021. History of the Asian Lymantria species Program: A Unique Pathway Risk Mitigation Strategy. Journal of Integrated Pest Management, Volume 12, Issue 1 https://academic.oup.com/jipm/article/12/1/31/6359328

Potter KM, Escanferla ME, Jetton RM, Man G, Crane BS. 2019. Prioritizing the conservation needs of United States tree species: Evaluating vulnerability to forest insect and disease threats, Global Ecology and Conservation doi: https://doi.org/10.1016/ j.gecco. 2019.e00622 https://www.sciencedirect.com/science/article/pii/S2351989418304864

Quirion BR, Domke GM, Walters BF, Lovett GM, Fargione JE, Greenwood LF, Serbesoff-King K, Randall JM and Fei S. 2021. Insect and Disease Disturbances Correlate with Reduced Carbon Sequestration in Forests of the Contiguous United States. Front. For. Glob. Change 4:716582. doi: 10.3389/ffgc.2021.716582 https://www.frontiersin.org/articles/10.3389/ffgc.2021.716582

Solano A, Rodriguez SL, Greenwood LF, Rosopa PJ, and Coyle DR. 2022. Achieving effective outreach for invasive species: firewood case studies from 2005-2016. Biological Invasions. https://link.springer.com/article/10.1007/s10530-022-02848-w

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