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Field Notes - forest threats

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Species Preservation in the Face of Novel Threats: Cultural, Ecological, and Operational Considerations for Preserving Tree Species in the Context of Non-Indigenous Insects and Pathogens

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Abstract

Non-Indigenous insects and pathogens (NIIP) have functionally eliminated numerous tree species of immeasurable cultural and ecological significance over the past century, with the number of species introductions and associated impacts growing each year. Foresters are often on the frontlines of these impacts, tasked with quickly adapting management plans to recover potential economic losses and maintain future silvicultural options following tree species loss. We highlight that the irreplaceable cultural and ecological values provided by many tree species argues for renewed focus on applying integrated pest management and adaptive strategies in novel ways to sustain these values for future generations. To guide these efforts, we describe a framework for adapting to NIIP centered on three interrelated components: preservation value, preservation approach, and preservation strategy. This framework and emerging species preservation efforts provide an alternative path forward to sustain threatened species and their associated values in an era of increasing change.

Study Implications: The impact of non-indigenous insects and pathogens (NIIP) is one of the greatest challenges facing the long-term stewardship of forests in North America. Species preservation efforts that apply integrated pest management and adaptive strategies to maintain species in the face of NIIP are increasingly needed in foresters' toolboxes to address these novel threats. Identifying the preservation values (ethical responsibility, cultural integrity, ecological function, genetic conservation) tied to a species preservation effort will help guide how preservation approaches and strategies are applied at stand and landscape scales to sustain species and associated cultural and ecological values into the future.

Keywords: non-indigenous insects and pathogens, integrated pest management, adaptive, management, cultural values, species preservation

For millennia, humans have had a close relationship with trees, holding sacred the food, shelter, transportation, medicine, and other values and products they provide (Costanza et al. 2017; Johnson et al. 2021; Östlund et al. 2020; Spry et al. 2020; Towner and Renteria 2022; Turner et al. 2009; Uprety and Asselin 2023; Uprety et al. 2013). This relationship is affected by the establishment of non-indigenous insects and pathogens (NIIP), which can lead to tree declines, mortality events or extirpation of species, threatening the important cultural values, traditional practices, and contemporary uses of trees across the globe (Pfeiffer and Voeks 2008). As global trade has expanded, the introduction and establishment of NIIP have increased over the last several decades (Aukema et al. 2010), potentially threatening more tree species and creating the need for increased protection efforts (Lovett et al. 2016). Although myriad forest management objectives exist, past, present, and future impacts of NIIP warrant greater consideration during the development of forest management plans (SAF 2022). Here, we present Indigenous and Western science perspectives to encourage the forestry community to

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make species preservation more of a priority in forested settings by outlining different goals and approaches to guide efforts to preserve threatened tree species across the landscape.

This call to action is motivated by the numerous examples of NIIP establishment in forests of North America over the past two centuries where subsequent tree damage and mortality have led to widespread decline or even functional extinction of a given tree species (figure 1 and Table 1; Ellison et al. 2005). Historically, the most devastating example is elimination of overstory chestnut (*Castanea dentata*) from forests extending from Georgia to Maine from the introduced chestnut blight (*Chryphonectria parasitica*) in the early 1900s (Liebhold et al. 1995). Across broad areas, chestnut was largely replaced by chestnut oak (*Quercus montana*) and red oak (*Q. rubra*) (Illick 1921; Korstian and Stickel 1927). In forested wetlands and riparian areas, similar losses of overstory American elm (*Ulmus americana*) occurred due to the introduced Dutch elm disease (*Ophiostoma ulmi*) and led to replacement by mesic species such as sugar maple (*Acer saccharum*), red maple *(Acer rubrum*), and black ash (*Fraxinus nigra*) (Barnes 1976; Boggess and Bailey 1964). Dramatic contemporary losses of overstory American beech (*Fagus grandifolia*), eastern hemlock (*Tsuga canadensis*), whitebark pine (*Pinus albicaulis*), and recently ash (*Fraxinus* spp.) to NIIP highlight the continued and increasing risk that NIIP pose to North American forests.

Tree losses from NIIP lead to a cascade of ecological impacts, including but not limited to functional and ecosystem service changes such as decomposition, nutrient cycling, carbon storage and sequestration, water purification, and regulation of hydrological processes (Boyd et al. 2013; Lovett et al. 2016). Biotic disturbances from NIIP often lead to reductions in productivity and in some cases, may lead to the net exchange of carbon in forests that switch from a sink to a source of carbon to the atmosphere (Hicke et al. 2012). When the impacts of NIIP are examined across the United States, the magnitude of impacts is enormous. Recent nationwide evaluations indicated that forests affected by insects and pathogens sequestered almost 70% and 28% less carbon, respectively, than plots without either for annual reductions ranging from 9.3 to 3.5 teragrams of carbon (Quirion et al. 2021). In addition, around 40% of the total live forest biomass in the United States is at risk for future loss from just the top 15 examples of NIIP (Fei et al. 2019).

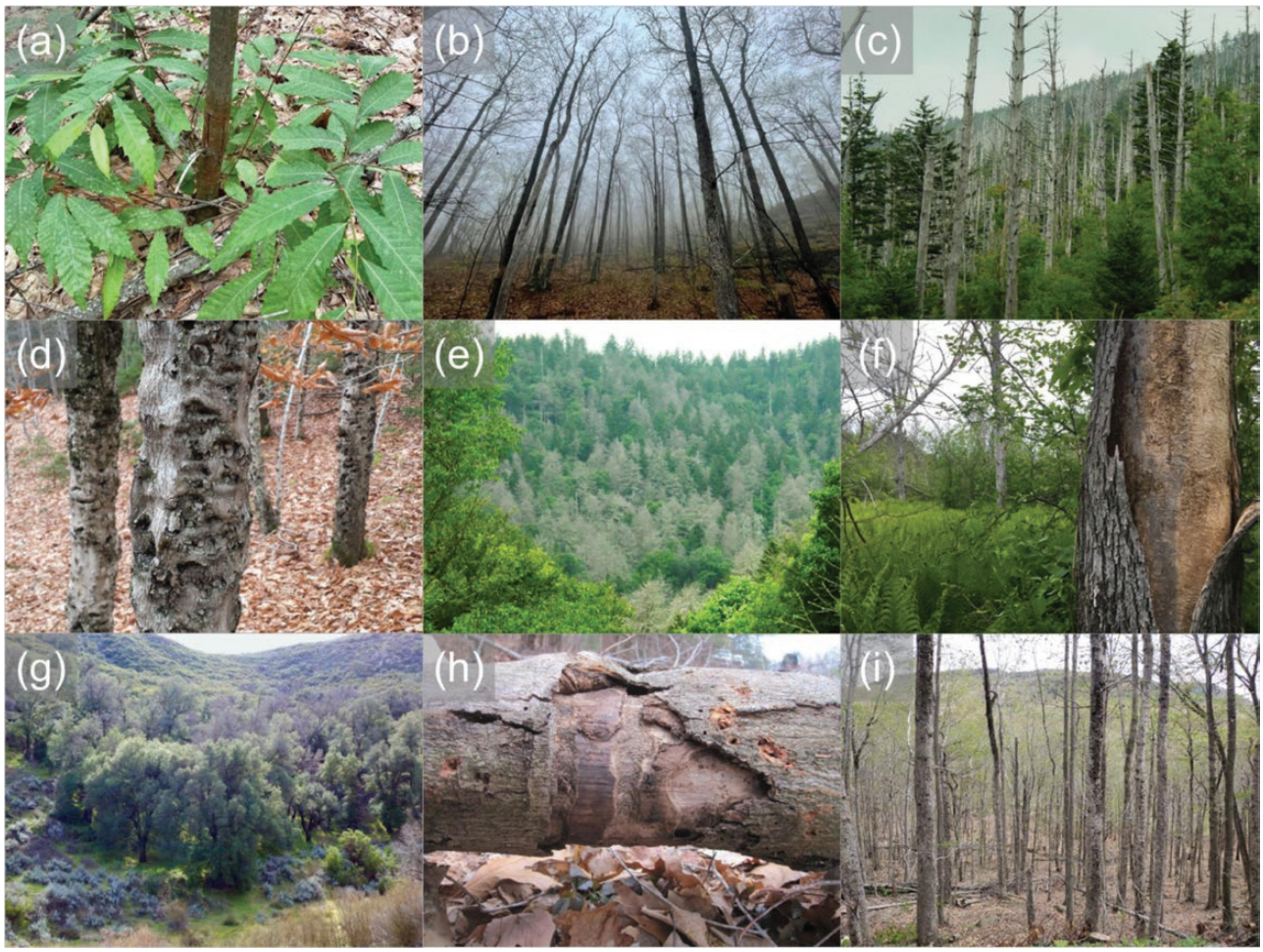

Figure 1. Examples of non-indigenous insect and pathogen impacts in US forests, including (a) chestnut blight, (b) spongy moth defoliation, (c) balsam woolly adelgid tree mortality, (d) beech bark diseased trees, (e) hemlock woolly adelgid tree mortality, (f) emerald ash borer tree mortality, (g) goldspotted oak borer tree mortality in California (outside of native range in North America), (h) Asian longhorned beetle feeding damage, and (i) beech leaf diseased trees with aborted buds. (Photo credits: a-h, N. Siegert; i, C. McIntire, USDA Forest Service).

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Table 1. Nineteen non-indigenous forest insects and pathogens in North America with current or potential future high impacts. Included are the common name, scientific name, host tree(s), observed or predicted ecological and cultural impacts, and geographic regions at risk. Adopted from Lovett et al. (2016).

Common name	Scientific name	Hosts	Impacts	Geographic region
Chestnut blight	*Cryphonectria parasitica* (Murrill) Barr.	American chestnut (*Castanea dentata*), chinkapin chestnut (*C. pumila*)	Virtually eliminated mature chestnuts; loss of culturally important food and wood source	Eastern deciduous forest
White pine blister rust	*Cronartium ribicola* J.C. Fisch	Five-needle pines (section Quinquefolia in genus *Pinus*)	Virtually eliminated several western pine species; loss of traditional source of medicine, component of legends	Continent-wide; greatest impacts in West
Phytophthora dieback	*Phytophthora cinnamomi* Rands	Many hosts including American chestnut, white oak (*Quercus alba*), shortleaf pine (*Pinus echinata*), and Fraser fir (*Abies fraseri*), fruit trees	High mortality of susceptible trees; loss of culturally important food and wood source	Continent-wide
Port-Orford-cedar root disease	*Phytophthora lateralis* Tucker & Milbrath	Port-Orford-cedar (*Chamaecyparis lawsoniana*)	Virtually eliminated host from lower elevation parts of its range; loss of traditional source of medicine and materials for sweat lodges, ceremonies, and lifeways	Klamath Mountains, CA and OR
Beech bark disease (scale insect + fungus)	*Cryptococcus fagisuga* Lindinger + *Nectria coccinea* var. *faginata* (Pers.) Fr.	American beech (*Fagus grandifolia*)	Severely reduces mature beech; often replaced by dense thickets of root sprouts; loss of traditional source of food, medicine, art, and legends	Deciduous forests of East and Midwest
Beech leaf disease	Associated with nematode *Litylenchus crenatae mccannii* ssp.	American beech	Premature leaf drop; branch dieback, tree mortality	Deciduous forests of Northeast and Midwest
European spongy moth	*Lymantria dispar dispar* L.	Many hosts include oaks, aspen (*Populus spp.*), willow (*Salix spp.*), and birch (*Betula spp.*)	Periodic outbreaks cause defoliations and can sometimes kill hosts; loss of culturally important food and wood source	Deciduous forests of East and Midwest
Hemlock woolly adelgid	*Adelges tsugae* Annand	Eastern (*Tsuga canadensis*) and Carolina hemlock (*Tsuga caroliniana*)	90% + mortality in most affected stands; traditional source of medicine and component of legends	Appalachians, Northeast and upper Midwest
Sudden oak death	*Phytophthora ramorum* S. Werres, A.W.A.M. de Cock	>100 species, especially tanoak (*Notholithocarpus densiflorus*) and several western oak species; some eastern oaks vulnerable	Vulnerable hosts often succumb whereas other hosts show minor impacts; loss of culturally important food and wood source	Coastal CA and OR; could potentially spread to eastern forests
Redbay ambrosia beetle + fungus (laurel wilt disease)	*Xyleborus glabratus* Eichhoff + *Raffaelea lauricola* Harrington and Fraedrich	Numerous probable hosts including redbay (*Persea borbonia*), pondberry (*Lindera melissifolia*), and pondspice (*Litsea* glutinosa) shrubs	Predicted > 90% reduction in redbay basal area within 15 years (25 years after first detected); loss of culturally important source of food and medicine	Eastern deciduous forests; greatest impacts in southeastern coastal plain
Emerald ash borer	*Agrilus planipennis* Fairmaire	All North American *Fraxinus* spp.	Most ash trees succumb. Some species of ash appear to have limited resistance; loss of medicine, material for cultural lifeways, and legends	Eastern deciduous forest; riparian areas in Great Plains and West, landscape plantings continent-wide
Dutch elm disease	*Ophiostoma ulmi (*Buisman) Nannf. *&* *O. novo-ulmi* Brasier; vectored by several insects including *Scolytus multistriatus* and *S. schevyrewi*	American elm (*Ulmus americana*); other native elms, e.g., red (*U. rubra*) or slippery elm (*U. glabra*), are more resistant	Severe impacts in urban areas; elms remain, although reduced in number and size, in riparian woodlands; loss of medicine, material for longhouses and cultural lifeways	Continent-wide

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Table 1. Continued

Common name	Scientific name	Hosts	Impacts	Geographic region
Butternut canker	*Sirococcus clavigignenti-juglandacearum* N.B Niar, Kostichka & Kuntz	Butternut (*Juglans cinerea*)	Severe mortality of butternut; over 80% mortality of butternut in the south; loss of culturally important food source	Deciduous forests of Northeast and Midwest
Balsam woolly adelgid	*Adelges piceae* Ratzeburg	Most true fir species (*Abies*) in N. America	Widespread impacts on firs; severe mortality of Fraser fir on S. Appalachian mountaintops and Christmas tree farms; loss of traditional source of medicine	Northeast; Southern Appalachians; Northwest
Oak wilt	*Bretziella fagacearum*	*Quercus* spp. esp. red oak group	Rapid oak mortality weeks to years; loss of culturally important food and wood source	Central, Midwest and Northeast deciduous forests
Asian long-horned beetle	*Anoplophora glabripennis* Motschulsky	Woody vegetation in fifteen families, especially maples, elms, and willows	Severe impacts possible in both urban and forest landscapes; eradication being attempted; loss of medicine and food, material for cultural lifeways, and legends	Continent-wide deciduous forests
Winter moth	*Operophtera brumata* L.	Many species including oaks, maples, cherries (*Prunus spp.*)	Severe impacts on hosts in southeastern New England; loss of culturally important food and wood source	Eastern deciduous forest
Polyphagous shot hole borer & Fusarium fungus	*Euwallacea (sp. unknown)* + *Fusarium euwallacea*	>200 species attacked by the insect; >100 support the fungus. Hosts killed include box elder (*Acer negundo*), bigleaf maple (*A. macrophyllum*), coast live oak (*Q. agrifolia*)	High mortality levels in vulnerable hosts; loss of medicine and food, material for cultural lifeways, and legends	Southern California hardwood forests, riparian and urban; potentially in Southeast
European woodwasp	*Sirex noctilio*	*Pinus* spp.	Most important killer of pines in Southern Hemisphere; modest impacts so far in the US; loss of traditional source of medicine, component of legends	All ecosystems with hard pines: Southeast, Great Lakes States, western US

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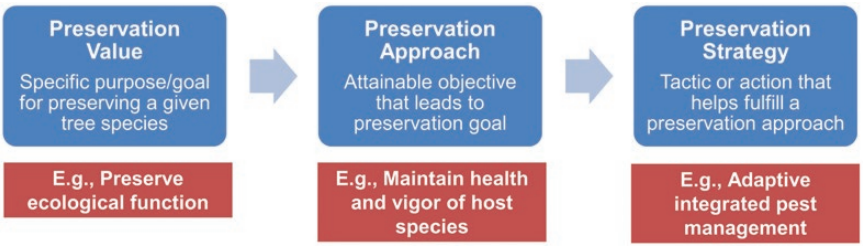

Figure 2. Framework for species preservation linking specific preservation values with associated approaches and strategies.

An aspect of NIIP that has historically received far less emphasis from Western scientists relative to their ecological impacts is the cultural ramifications of tree species loss, particularly in relation to traditional uses and values held by Indigenous peoples (Alexander et al. 2017). Many native tree species serve as the cornerstone of Indigenous cultures and livelihoods, supporting traditions, cultural lifeways, spirituality, and subsistence (Garibaldi and Turner 2004). For example, American chestnut was a key dietary staple, source of medicines and wood, and component of trade for many Tribal Nations in eastern North America, including the Haudenosaunee, Wampanoag, Siouan, Powhatan, Mohican, Wabanaki, and Cherokee (Baumflek et al. 2021; Tulowiecki and Larsen 2015). Similarly, black ash, a species now threatened by the introduced emerald ash borer (*Agrilus planipennis*), is of critical importance to traditions and lifeways of Tribal Nations in northeastern North America (Costanza et al. 2017; Siegert et al. 2023), whereas western red cedar (*Thuja plicata*) represents the cornerstone of Pacific Northwestern Indigenous culture (Zahn et al. 2018). Beyond material benefits, black ash and many other species threatened by NIIP are central to oral traditions, ceremonies, and legends, increasing the magnitude of species loss on cultural identities with impacts far exceeding those measured by ecological or economic criteria. With so much at stake, it is important to consider the value of incorporating some aspect of tree preservation in managing NIIP impacts. Foresters are a key component in implementing preservation practices to help sustain cultural and ecological health of our forests and those that depend on them.

A Case and Framework for Species Preservation

Given the scale, magnitude, and rate at which NIIP may affect a particular tree species, there is a tendency to lose hope for protecting species that have or are expected to experience widespread loss. Compounding this despair can be an inclination for foresters to adopt a "pre-salvage" approach to NIIP to buffer economic loss with the assumption that there is nothing else to be done. Nevertheless, we argue that efforts to protect imperiled species should remain at the forefront of adaptive forest management efforts. For instance, although the widespread decline and loss of species due to NIIP continue to grow, there is growing evidence from current NIIP outbreaks that some survival of affected species is occurring, even in the most heavily affected areas (Kinahan et al. 2020; Robinett and McCullough 2019; Townsend et al. 2005). Even low levels of survival attest to the possibility that some trees may exhibit varying levels of tolerance or genetic resistance, and therefore, efforts to protect populations of trees across the landscape may help conserve genetic diversity (Flower et al. 2018), maintain the species' evolutionary potential to cope with NIIP (Budde et al. 2016), and contribute to reference genome research (Huff et al. 2022). Moreover, the irreplaceable cultural and ecological values provided by many tree species argues for a renewed focus on applying integrated pest management and other adaptive strategies in novel ways to sustain these values and traditions for future generations. As foresters, we stand in a crucial position to harness our knowledge of forest ecology and management, as well as our relationships with those that own the land, to preserve these species and all that depend on them. If not us, then who? To guide these efforts, we describe a basic framework that centers on three interrelated components, preservation value, preservation approach, and preservation strategy (figure 2).

Preservation Values

Preservation value relates to the specific purpose or goal of species preservation. These values may vary according to many factors, including world view, cultural identity, forest management philosophy, management purpose, or ownership type; however, within our framework (figure 2), we suggest four primary values for species preservation (figure 3):

1. Ethical responsibility—preservation driven through ethical motivation and world view. For instance, from an Indigenous perspective, the entire natural world has a responsibility to maintain the dynamic relationships among beings. This responsibility is fulfilled by honoring the gifts we offer one another as beings within the natural world. Similarly, from a Western science perspective, ethical responsibility describes preservation of species motivated by a land ethic or an ethical obligation to conserve native species in the face of a human-induced stressor (i.e., NIIP).
2. Cultural integrity—the preservation of cultural values and relationships between species, both in the form of living individuals as well as culturally significant derived materials that support traditions and lifeways.
3. Ecological function—preservation of ecological functions provided by species (e.g., biota supported, role in trophic dynamics, influence on nutrient cycles and hydrological regimes) through maintenance of threatened species on site.
4. Genetic conservation—preservation of genotypes with potential for tolerance to NIIP and resilience for future conditions.

The relative importance of each of these values in guiding preservation efforts will likely vary by threatened species of interest and ownership. For example, cultural preservation

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may supersede other values for cultural keystone species (cf. Garibaldi and Turner 2004), like black ash or western red cedar, whereas genetic and ethical preservation may be common motivations for less abundant species. The more preservation values a strategy seeks to protect, the more likely it is to attract diverse partners interested in collaborating, which can increase support, resources, and opportunities. Each of these values is similar in sharing a common goal of generating resilience for future conditions of a given species.

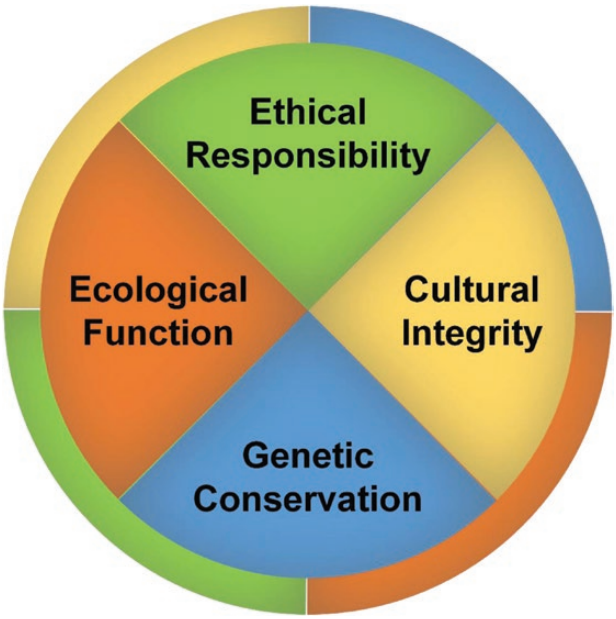

Figure 3. Values guiding species preservation efforts in the face of non-indigenous insects and pathogens. A given value may be the primary motivation for a preservation effort, but each value may be supported, depending on the preservation approach used (e.g., protection of a group of mature trees for cultural values may also preserve ecological functions, conserve genetics, and fulfill ethical responsibility tied to stewardship). Overlapping colors on the outer circle reflect the complementary relationship between values.

Preservation Approaches

Irrespective of preservation values, there are different approaches to species preservation that are available for maintaining a tree species in the landscape. Of primary importance, particularly during the early stages of invasion, are preventative approaches, largely centered on detection and monitoring surveys as well as quarantines and compliance with regulatory guidance for NIIP to both limit spread and guide the appropriateness of other strategies. This includes surveillance and trapping efforts led by forest health programs, citizen reporting and monitoring, and public outreach and engagement to convey best practices to limit species spread where possible. Maintaining live trees across the landscape is tantamount to being able to preserve values and function, with population-viability approaches correspondingly dedicated to maintaining the health and vigor of threatened trees (i.e., keeping trees alive) or maintaining future options for those trees on a site (e.g., encouraging regeneration, collecting seeds). These approaches may either concentrate preservation on isolated mature trees and small groups of trees or may extend preservation across landscapes and regions depending on preservation values being pursued (figure 4). Cultural adaptation approaches include preserving cultural materials (e.g., splints, bark, logs) and propagules (seed collection efforts) as well as oral traditions associated with the threatened species.

Preservation Strategies

Fortunately, for many species being affected by NIIP, there exist several strategies to protect and maintain their presence on the landscape. In particular, chemical and biological controls, silvicultural methods, and integrated approaches may

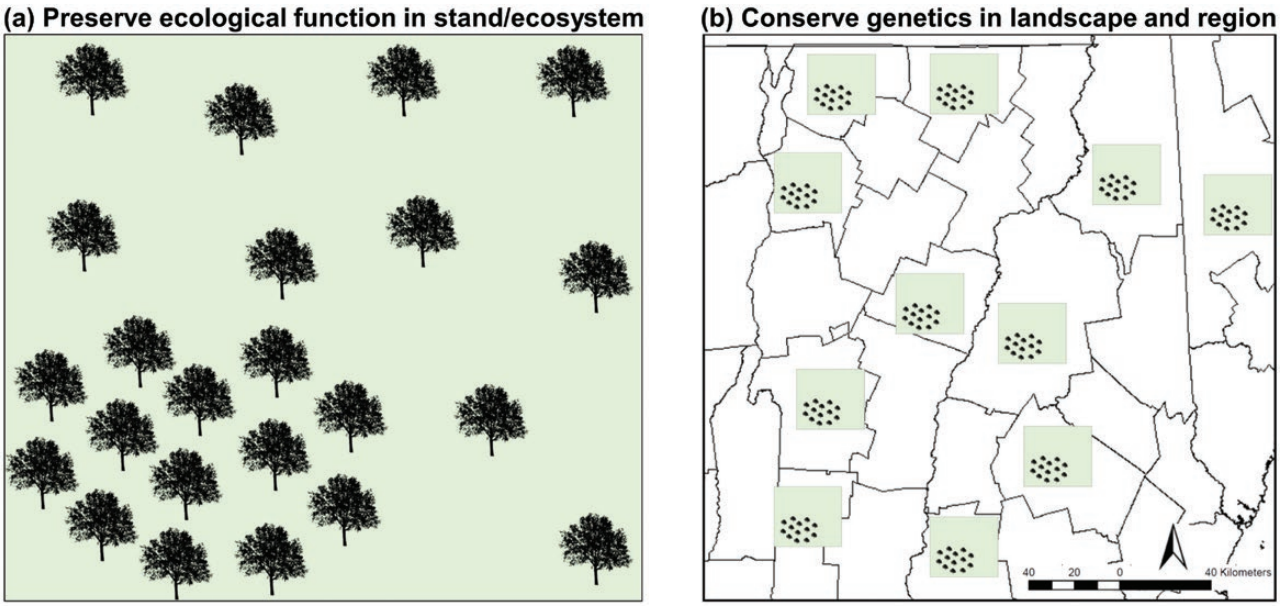

Figure 4. Different scales of species preservation depending on preservation values. (a) Protection of scattered individual trees across a stand or property to maintain ecological functions of threatened species. (b) Protection of groups or groves of threatened trees across a region (e.g., states of Maine, New Hampshire, and Vermont) to conserve genetic diversity of threatened species.

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be options to sustain trees and retain the important functional and cultural values associated with them (figure 5).

Chemical strategies apply insecticides, fungicides, or semiochemicals to limit NIIP impacts on host species. Much of the experience with this approach is in urban or residential settings to protect individual trees of high value to property owners or communities; however, these treatments have recently been viewed as key components of regional strategies for maintaining threatened species, such as hemlock, oak, and ash, in forested settings (Abella 2014; Flower et al. 2018). Therefore, we should expand these strategies into natural forest settings, making them a standard approach to managing NIIP. One advantage to this strategy is that it can be done on an individual property with only the permission and support of the landowner. Although it contributes to larger landscape preservation efforts, it does not necessitate waiting for the coordination of these efforts to be implemented immediately. Public and private foresters can identify prime properties within the land they steward (e.g., proximity to NIIP, presence of threatened species, relation to other populations of the species, support of the landowner) and begin implementing preservation strategies as soon as warranted.

Biological strategies that use biological control agents (biological organisms used to limit NIIP) have also been a commonly applied element of integrated pest management strategies (Duan et al. 2018; Onken and Reardon 2011). Organisms introduced as biocontrols include beetles, wasps, flies, bacterial and fungal agents, and viruses with varying levels of preservation and protection provided by any given biocontrol agent. These strategies are attempted at locations within a region and across landscapes in a long-term effort to establish sustainable suppression of NIIP.

Silvicultural strategies that maintain a threatened species on a site, either through deliberate retention of mature individuals or application of regeneration methods that encourage recruitment of new cohorts of the species at risk, may also serve as mode of preservation. These strategies contrast with other silvicultural treatments associated with forest protection (e.g., sanitation and pre-salvage harvests) in that silvicultural activities are deliberately trying to maintain populations

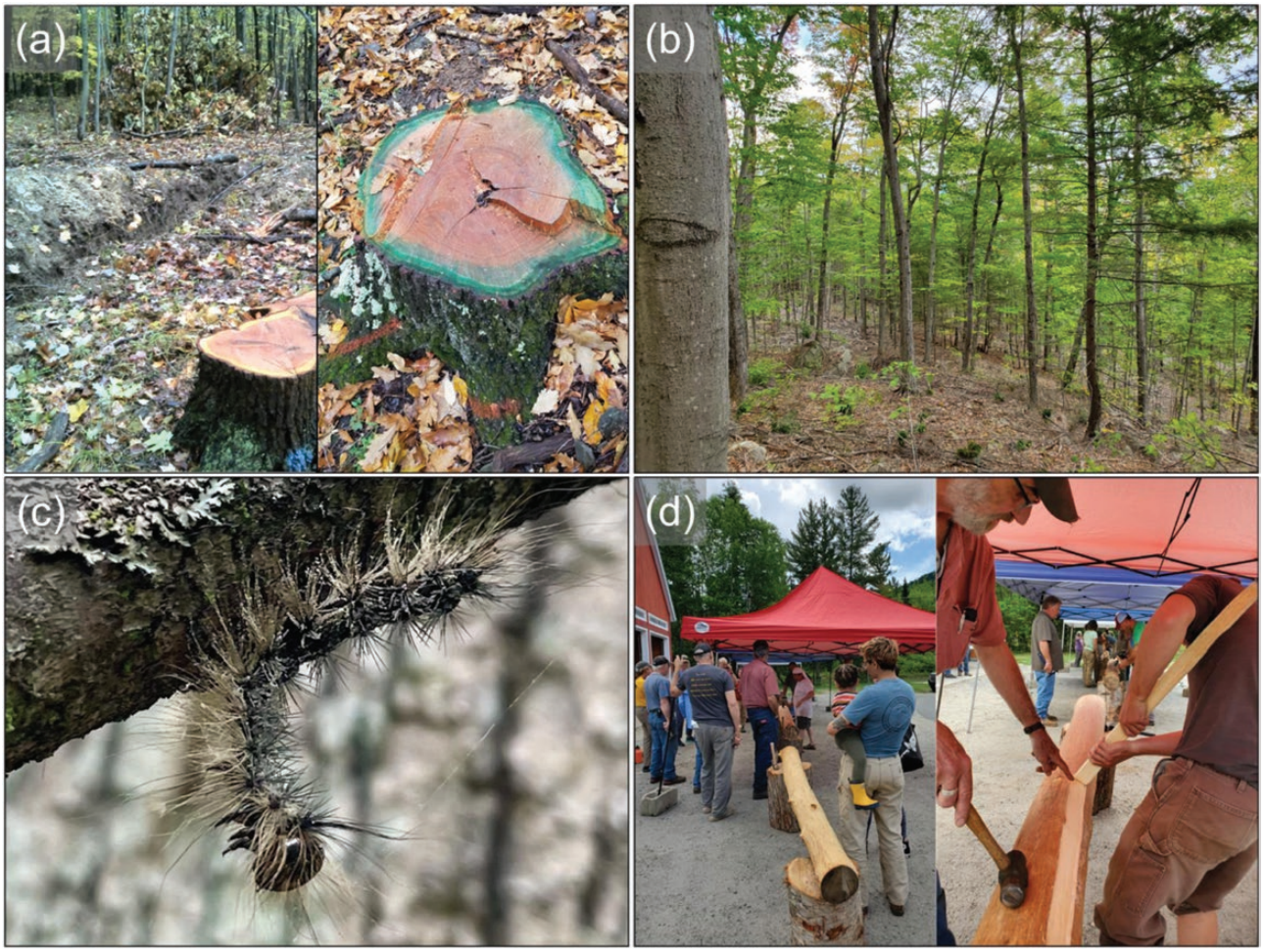

Figure 5. Examples of preservation strategies for tree species threatened by non-indigenous insects and pathogens. (a) Trenching to sever root grafting and a fungicide-treated stump in a mixed oak-hardwood forest as part of an integrated preservation strategy to protect oak species from the fungal disease oak wilt; (b) single-tree selection harvest in which American beech displaying resistance to beech bark disease (e.g., left foreground) have been deliberately retained as part of a silvicultural preservation strategy; (c) spongy moth larval cadaver killed by the fungal entomopathogen *Entomophaga maimaiga* used as part of a biological preservation strategy; (d) community black ash basket tree pounding event to produce splints as part of a cultural preservation strategy to support Indigenous cultural traditions around black ash following emerald ash borer invasion. (Photo credits: a, New York State DEC; b, A. D'Amato; c, N. Siegert; d, A. D'Amato).

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of the threatened species on site. For example, in the case of emerald ash borer, recommendations include encouraging a range of size classes of ash through silvicultural activities as well as retention of female individuals, given the dioecious nature of this species (D'Amato et al. 2020).

Cultural strategies used to protect the many cultural values of threatened tree species include initiatives that are often led by sovereign Nations' Natural Resource or Forestry Departments, Tribal Historic Preservation Departments, Basketmaker or other Tribal artisan alliances, and many more who recognize these threats to a species and the cultural lifeways they support. These collaborative efforts are built on the familial connections and sense of community that are fostered in Tribal communities as they exercise the cultural lifeways these trees provide. The strategies used by Tribal Nations are often integrated (D'Amato et al. second paper in this issue) and the suite of actions target all four of the values of preservation noted in this article. In some cases, artisans and harvesters have found ways to store materials derived from threatened species for long time periods to preserve the cultural lifeways tied so intimately to these species (e.g., Poland et al. 2015; Siegert et al. 2014). Strategies may also include exploration of alternative species to carry forward traditions if a given species is lost. Additionally, strategies include simply raising awareness among the public and specifically within the forestry sector about these cultural values and the potential impact their loss could have on Indigenous peoples. Cultural strategies demonstrate that beyond financial value and the ecological services associated with these trees, there may also be priceless values associated with them that are paramount for protecting and maintaining certain cultural lifeways. As such, there is a great need for local chapters of professional forestry organizations, such as SAF and state and federal agencies, to initiate and expand conversations with Tribal Nations about culturally important species, stewardship needs, and collaborative opportunities.

Integrative strategies combine multiple preservation strategies at a given site or across a region (e.g., McCullough et al. 2015) and, given the magnitude and novelty of NIIP, are often viewed as most effective. Nevertheless, not all strategies are acceptable or appropriate for a given preservation value or context. For example, chemical strategies may be undesirable when foodstuffs, such as acorns or inner bark, are derived from species being preserved (e.g., Alexander et al. 2017). Similarly, the introduction of biological control agents or modification or alteration of species genomes to enhance resistance may run counter to traditions around maintaining the balance of the natural world. Moreover, the financial and logistical constraints posed by treating trees with insecticides and fungicides may limit these practices to ecosystems and ownerships where financial costs of preservation are justified by the values being sustained. Identifying the appropriate strategies can and should be folded into current and future management planning.

Conclusions

The proliferation of NIIP will continue to be one of the greatest threats to the cultural, ecological, and economic values provided by trees around the globe. Although the scale and magnitude of NIIP impacts are considerable, our collective knowledge of the unique values provided by different tree species and associated preservation strategies for maintaining these values argues for needed integration of species preservation into the forester's toolbox. As with other management goals, examining species loss in a given woodlot or landscape through the lens of preservation values can serve to guide the foresters and landowners they work with in approaches and strategies used to lessen the cultural and ecological impacts of these threats. Foresters are often called on to serve as the caretakers of forests. Our specific knowledge, skills, and experience stewarding forests and working with landowners are critical to mitigating impacts and costs associated with NIIP invasions. Working to preserve species from NIIP will have impacts for generations to come.

This call to action has largely been motivated by the integrative and multicultural response to the establishment and continued spread of emerald ash borer across North America, particularly recent efforts over the past decade in the northeastern United States. The operationalization of preservation strategies historically reserved for landscape trees and urban forests and the centering of cultural values and perspectives to guide response to this threat represent an alternative model for addressing NIIP relative to historic Western strategies. On-the-ground applications of our framework for species preservation in the context of ash species are highlighted in the following article (D'Amato et al. second paper in this issue) and provide examples of an alternative path forward as we grapple with our responsibilities to the forest and the species therein in an era of increasing change.

Acknowledgements

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