Forest.Health

Responding to the growing scale of pests threatening forests

Trees in forests and urban areas are under attack at an unprecedented rate from diseases and pests. Changing climates, global trade, and forest fragmentation are accelerating pest devastation. In North America, all 14 ash species are vulnerable to the emerald ash borer and 5 are considered critically endangered[1]. Conifer stands of the west are being attacked by both non-native and native pests and diseases, and the fight is on to save the Eastern Hemlock of the Southern Appalachians. Dead trees left in these pests' wake are contributing to larger scale forest fires that have the potential to destroy homes and imperil communities. In addition, there are negative human health effects in areas where trees have been killed by pests[2].

Forest.Health is saving our forests by bringing experts together with advanced technologies to deploy innovative pest solutions.

Forest.Health[3] addresses the most critical forest health threats. Building on the work of the FHI, which focused on American chestnut, Forest.Health will address other threatened tree species and evaluate new technologies and approaches to fight catastrophic losses in our forests. It is a structured effort that has core aspects of being responsive to threats, collaborative in approach, and applicable across multiple sectors, while providing a coordinated voice for everyone who cares about the health of our forests.

Forest.Health aligns efforts and accelerates innovation to save other threatened tree species. It follows a stakeholder derived roadmap[4] that includes consideration of community input, policy regimes, ecological impacts, and scientific breakthroughs. This is all made possible by the trailblazing work of the Forest Health Initiative[5] (FHI).

Preventing $ Billions in Loss

The cost of treating, removing, and replacing the 38 million ash trees in U.S. communities is $25 billion, which doesn't include natural forest tree loss[6].

The value of standing Black Walnut in the U.S. exceeds $500 billion, yet there is no known natural resistance to Thousand Cankers Disease, which is spreading throughout its range[7].

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1 IUCNredlist.org

2 Donovan, Geoffrey H.; Butry, David T.; Michael, Yvonne L.; Prestemon, Jeffrey P.; Liebhold, Andrew M.; Gatziolis, Demetrios; Mao, Megan Y. 2013. The Relationship Between Trees And Human Health: Evidence From The Spread Of The Emerald Ash Borer.

3 https://Forest.Health

4 http://www.foresthealthinitiative.org/roadmap.html

5 https://foresthealthinitiative.org - The first FHI project was a directed research effort on American chestnut that integrated work across the spectrum of biotechnologies, including genome sequencing and bioinformatics, population genotyping for breeding, early screening for disease resistance, micropropagation of the best genetic materials, and transformation of native genotypes with resistance genes. The effort was supported by the USDA Forest Service, the U.S. Endowment for Forestry and Communities, and Duke Energy.

6 https://www.nrs.fs.fed.us/pubs/jrnl/2010/nrs_2010_kovacs_001.pdf

7 http://agriculture.mo.gov/plants/pdf/tc_pathwayanalysis.pdf

Operational Strategy

Forest.Health will operate as a public-private partnership with broad based support from industry, state and federal agencies, foundations, and citizens. It will leverage and build on existing efforts to accelerate the pace of achieving on the ground results. It is responsive, multi-sectored, open and inclusive, and sustainable.

Responsive

Forest.Health incorporates inputs from experts, models, and sensors, rapidly incorporating new information dynamically and nimbly. A continuous review of progress will evaluate new information and technologies, and provide a path for integration of new collaborators.

Multi Sectored

Forest.Health considers social, economic, ecological, and regulatory requirements alongside scientific research. It addresses multiple avenues of intervention across technologies, genetics, policy, society, and scales.

Open and Inclusive

Forest.Health integrates public outreach and education as a core component of the program. It enables citizen science forest health monitoring by bringing new data gathering technologies into the hands of anyone with a penchant for helping the environment.

Stakeholder dialogue is a key component of Forest.Health because having a social license to operate is essential for any successful large-scale forestry endeavor. A collaborative and transparent process provides a path for a more directed message and voice.

> **Internet of Trees**
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> A new generation of smart devices allows citizen scientists to monitor forest conditions and capture real-time data. The Internet of Trees will build on existing efforts such as the Forest Service's Smart Forests while supporting STEM education. This information will be aggregated into a national network to support better decision-making.

Sustainable

A long-term strategy will assure financial stability, intellectual continuity, a productive research pipeline, coordinated planting efforts, and a platform of open information sharing and outreach. A broad spectrum of funding sources that include governmental, academic, forestry organizations, and commercial entities will be sought.

Accomplishments

Forest.Health is engaging experts on target species and with key stakeholders who can provide broad input on a scale needed to implement an intervention strategy. Initial work is identifying and prioritizing an imperiled species list.

Prioritization Tool

First round species selection was accomplished using the US Forest Service CAPTURE[8] model. This process created a strong, science-based indicator of the level of threat to individual tree species. CAPTURE identifies imperiled species based on exposure and susceptibility to pests and pathogens, expected climate change pressure, and low adaptive capacity. Other threatened tree species lists such as the IUCN Red List are incorporated in the selection process. A detailed synopsis of these results is provided in the appendix.

Committees Formed

A list of the committee members and their affiliations is provided in the appendix.

- A Planning Committee is guiding this process.
- The first round of threat prioritization was accomplished with input from 21 forest health professionals using CAPTURE.
- A smaller group of experts will incorporate criteria such as ecological and social importance, regional considerations, economic impacts, and the potential for significant progress to further narrow the number of species under consideration.

Proposed Partner Meeting

The next milestone is a North American meeting, in 2018, that will bring scientific experts, federal, state and municipal partners, forestry groups, and commercial entities together to develop research and funding agendas. The meeting will focus on 2-3 tree species at various stages of intervention, from active ongoing research programs to nascent in concept.

The meeting will include presentations on the current state of research, promising intervention options, and partner needs. This will be followed by group discussions and aggressive timeline setting for achieving agreed upon forest health goals. A compilation of papers and outcomes from the meeting will be published to guide subsequent work on forest health.

Funding Strategy

This effort must be financially sustainable to be successful. Both direct and cost-sharing contributions will be incorporated in the development plan via program grants, online donations, and sponsorships. Partners will benefit from outreach and communication opportunities, the ability to help guide cutting-edge research agendas, and cost savings to their sector.

Department of Transportation

The DOT agencies use trees to meet municipal and engineering requirements. Forest.Health will partner with DOT to identify the most cost effective intervention strategies to mitigate negative impacts from pests. Finding cost effective solutions for government agencies ultimately saves tax-payer dollars.

Proposal Goals

[8] Potter, K.M., B.S. Crane, and W.W. Hargrove. 2017. A United States national prioritization framework for tree species vulnerability to climate change. *New Forests.* 48(2):275-300.

A) Finalizing Target Species

The CAPTURE model has identified the top 14 most pest-imperiled species in the U.S. A one-day meeting of selected experts in areas such as forest ecology, forest economics, human health impacts, and conservation will review the CAPTURE results. The outcome of this meeting will be a ranked and ordered list of imperiled species, based on expert derived additional criteria, that will be published on the Forest.Health website and used as part of the background material for the Kickoff Meeting.

B) Partner Meeting

A 2-day meeting will be held in Washington, DC in 2018. Approximately 35 attendees will include researchers, agency personnel, and funding Partners in the U.S. and Canada. Experts in their field will be identified and recruited by the planning committee to give presentations and help guide the discussions. The agenda will be developed by the planning committee and funding partners and will likely include:

- Talks on state of the science, resources in place and those needed. Talks will be supported by facilitated discussions.
- Outlining research agendas.
- A discussion of strategies for unifying the forest health community's message and voice.
- A review of the draft development plan for Forest.Health.

A compilation of papers by presenters will be published after the meeting. Peer reviewed journals will be approached to offer this as a special issue.

C) Development Plan

A long-term plan that ensues stability and efficacy for this effort will be created. The plan will detail the structure of the effort, its governance/management, timeline, budget, scientific direction, and fundraising strategy. A key aspect will be identifying current resources in place to allow for leveraging additional support. For example, available intellectual and technology know-how, on-the-ground delivery mechanisms, and public outreach will be detailed. A strategy for building a multi-tiered coalition to champion Forest.Health will be incorporated into a marketing and communication plan for outreach. Forest.Health currently includes a web form for comments, a list of donors and partners, and other communication material.

A robust funding strategy, including in-kind contributions, will be sought from a broad base of supporters and partners that may include governing bodies at the federal, state and provincial levels; federal US & Canada Government agencies; state & provincial forest agencies, municipalities and organizations; forest groups affected by target tree species; and for-profit and commercial entities in the forest products, biotech and IT sectors.

D) Internet of Trees

A widely distributed network of real-time sensors will help researchers get ahead of the growing scale of pests threatening our forests. DIY sensors will allow citizen scientists and students to participate in creating an expansive, connected dataset – an Internet of Trees. The first steps to creating this network have been taken by the U.S. Forest Service and other government agencies. These efforts will be amplified and built upon by identifying new opportunities, organizing technology and educational partners, and testing IoT sensors. This initial work will pave the way for forest health to take advantage of instant information.

Management

Forest.Health is managed by the Institute of Forest Biosciences (IFB). The IFB is a 15-year-old 501c3 non-profit organization headquartered in the U.S. with a satellite office in Canada. Its mission is to advance technologies and research to create healthier and more productive forests for the betterment of the future. Learn more at forestbio.org.

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Appendix

Project CAPTURE Survey Results for Forest.Health

The focus of the Project CAPTURE (Conservation Assessment and Prioritization of Forest Trees Under Risk of Extirpation) assessment was to identify and categorize forest tree species on U.S. forested lands, within the conterminous 48 States and Alaska, expected to be most vulnerable to genetic degradation in the face of pest and pathogen threats. Genetic degradation is defined as a significant reduction in the ability of a species to persist for the next century while maintaining sufficient genetic variation to adapt to changing environmental conditions.

We included 419 native forest tree species in this assessment. Most of these (362) were from the list inventoried by the national Forest Inventory and Analysis (FIA) program of the U.S. Forest Service within the contiguous United States and Alaska (Woudenberg et al. 2010). This number encompasses nearly all of the native trees inventoried by FIA within this area, with native status defined by the USDA PLANTS database (U.S. Department of Agriculture Natural Resource Conservation Service 2015). (Some species of hybrid origin are included on the FIA list, but were excluded from this project.) The list also incorporates an additional 57 tree or tree-like species not inventoried by FIA that also occur in the continental United States, and generally are rare or limited in their distribution.

Conceptually (Foden et al. 2013), the objective of the assessment was to categorize and prioritize these species based on the relationship among three dimensions of vulnerability (Figure 1):

(1) ***Exposure to the threat***, defined as the extent to which a threat could diminish a species' adaptive genetic variation. This represents the intensity of the climate change threat that may be experienced by individual species.
(2) ***Sensitivity to the threat***, defined as the degree to which a species' total genetic resource base is susceptible to a threat. This represents the potential response of individual species to the climate change threat.
(3) ***Low adaptive capacity for the threat***, defined as the extent to which a species is unable to adapt, through micro-evolutionary change and phenotypic plasticity, to a specific threat.

In early 2017, 33 natural resource professionals from a variety of disciplinary backgrounds, including forest health, forest management, forest genetics and forest ecology, completed a survey to inform the application of the hierarchical and data-driven framework. Specifically, they assessed the proposed assignments of species traits to vulnerability attributes, and vulnerability attributes to vulnerability dimensions. The survey results were used in the current study to quantify expert agreement with these assignments.

Pest and pathogen threats were based on a list of up to the five most serious insect and disease threats for each of the 419 host tree species. The identities of these threats and a severity rating for each were based on a thorough review of the literature. The threats and severity ratings were reviewed by 22 forest entomologists and pathologists, and adjusted as necessary following the review. The severity ratings are as follows:

- Complete mortality of all mature trees, or inability to reproduce = 10
- Significant/complete mortality in related species = 9
- Significant mortality of mature trees = 8
- Moderate mortality of mature trees = 5
- Moderate mortality in association with other threats = 3
- Minor mortality, usually of already-stressed trees = 1

Each of these severity ratings were transformed using an exponential function to reflect the nonlinear increase in severity across the rating groups. The transformed values of each species' pest and pathogen agents were then summed, with the summed threat numbers across species then standardized across species so the species with the highest threat severity had a score of 100, and the species with the lowest threat severity had a score of 0.

Species were given a vulnerability rating based on the mean of their three vulnerability dimension scores. (The Pest and Pathogen Exposure score was weighted higher for species facing a threat with the potential to result in the complete mortality of all mature trees.) The rating was on a scale of 0 to 100, with higher values indicating higher external threat exposure and intrinsic threat vulnerability. The species were then ranked from most to least vulnerable within each of the vulnerability classes determined by the *K*-means clustering.

As supplemental information, a climate change vulnerability score was determined for the species included in Potter et al. (2017). This encompasses the scores (on a scale of 0 to 100, as with pests and pathogens) for each of the three vulnerability dimensions, as well as an overall score (the mean of the three) and a rank. The species were then ranked based on their overall scores.

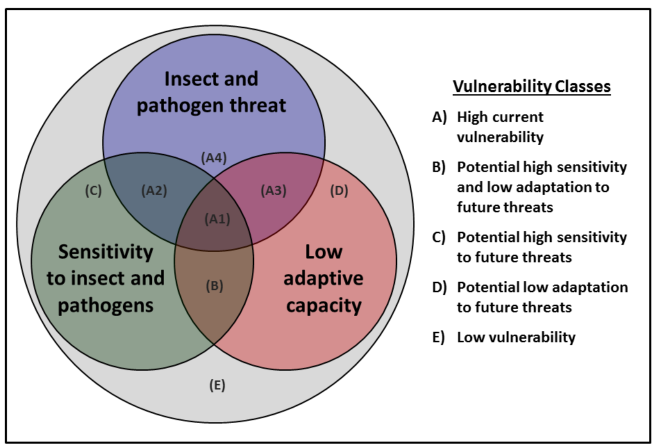
The species were clustered into seven groups (see also Table 1), with two groups (Cluster 7 and Cluster 2) having the highest degree of vulnerability, belonging to pest and pathogen classes A1 and A4. These groups encompassed 1 species:

Species Name	Common Name	Pest Class	Pest Cluster	Pest rank
Castanea dentata	American chestnut	A1	7	1
Torreya taxifolia	Florida torreya	A1	7	2
Castanea pumila var. *ozarkensis*	Ozark chinquapin	A1	7	3
Castanea pumila	Allegheny chinquapin	A1	7	4
Persea borbonia	redbay	A1	7	5
Lithocarpus densiflorus	tanoak	A1	7	9
Juglans cinerea	butternut	A4	2	6
Chamaecyparis lawsoniana	Port-Orford-cedar	A4	2	7
Tsuga caroliniana	Carolina hemlock	A4	2	8
Fraxinus americana	white ash	A4	2	10
Fraxinus nigra	black ash	A4	2	11
Tsuga canadensis	eastern hemlock	A4	2	12
Fraxinus pennsylvanica	green ash	A4	2	13

Table 1 Cluster mean and rank for vulnerability dimension scores and overall pest and pathogen vulnerability score, and assignment of each cluster to a vulnerability class (see Figure 1).

Cluster	Species (n)	Pest/Pathogen Exposure		Sensitivity		Low Adaptive Capacity		Overall		Vulnerability	
		mean	*rank*	*mean*	*rank*	*mean*	*rank*	*mean*	*rank*	*Description*	*Class*
1	81	2.75	4	30.29	7	36.91	5	23.32	7	Low vulnerability	**E**
2	7	88.64	2	46.46	6	31.04	6	80.32	2	High vulnerability	**A4**
3	89	1.16	7	85.77	1	47.06	3	44.67	3	Potential extreme sensivity and low adaptation to future threats	**B.1**
4	91	2.07	5	49.91	5	55.27	2	35.75	5	Potential low adaptation to future threats	**D**
5	101	1.31	6	63.07	3	30.32	7	31.56	6	Potential high sensitivity to future threats	**C**
6	44	21.24	3	57.2	4	42.87	4	38.56	4	Potential high sensivity and low adaptation to current, future threats	**B.2**
7	6	90.26	1	81.03	2	60.27	1	86.99	1	High vulnerability, esp. high sensitivity, low adaptive capacity	**A1**

Figure 1 Conceptual relationships among the three vulnerability dimensions (insect and pathogen threat, sensitivity to climate change, and low adaptive capacity), and the description of vulnerability classes defined by those vulnerability dimensions, based on Foden et al. (2013).



Forest.Health

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