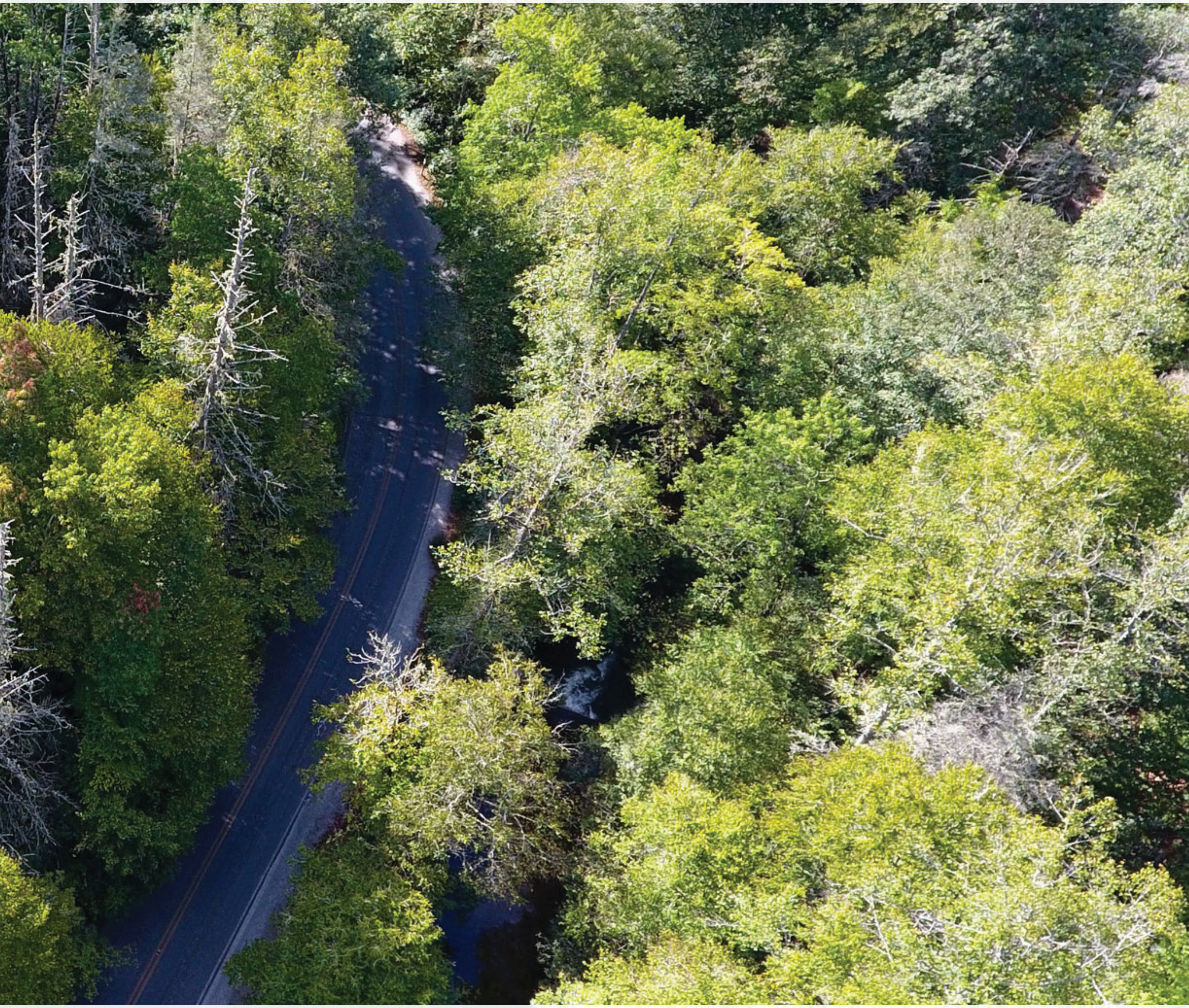
Tree Genes Initiative
REPORT 2018

Securing our Future Forests by Enhancing Technology, Capacity, and Speed



Institute of Forest Biosciences

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Cover image: Drone picture taken by Adam Costanza and Susan McCord in the Pisgah National Forest, North Carolina.

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Securing our Future Forests by Enhancing Technology, Capacity, and Speed

To meet the food, fiber, and fuel demands of a growing world population, sustainable plantation forestry will need to expand in productivity and scale[1]. At the same time, changing climates, severe weather events, shifting ecological growing zones, and invasive pests and diseases increasingly pressure commercial[2], urban[3], and natural forests[4]. Enhanced technologies, increased capacities, and meeting the challenges with greater speed will be necessary to sustainably meet demands while combatting forest threats.

Taking the pulse of forest practitioners and the state of our forests and communicating the needs to decision makers is the job of the Tree Genes Initiative (TGI).

The TGI[5] is a North American effort to accelerate the use of stress-adapted trees. It is comprised of over 60 Consortium members in the US and Canada with expertise in forest biotechnology, tree breeding, sustainable forest management, and production forestry. The TGI fosters communication among partner organizations and outside stakeholders. It includes all points along the research-stewardship chain. Its goal is to help enable on-the-ground changes by identifying current efforts, needs, and obstacles to using stress-adapted trees.

The first TGI report, published in 2015[6], identified eight critical gaps slowing the transfer of stress-adapted trees from upstream research to forest owners and managers. The gaps fell into three categories: Innovation, Policy, and Markets. TGI members identified tree breeding, communication, and fiber security as the most critical areas within these categories needing more in-depth investigation. This report is the summary of that work and delves into these issues in more detail, provides recommendations, and considers how emerging technologies might help overcoming these obstacles. An integrated approach to address these issues is needed to be fully successful.

The Institute of Forest Biosciences[7] (IFB) manages the work of the TGI. It is a non-profit 501-c that fosters the use of science and technologies that create healthier and more productive forests now and for the future.

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[1] World Bank Group Forest Action Plan FY16-20 *http://documents.worldbank.org/curated/en/240231467291388831/pdf/106467-REVISED-v1-PUBLIC.pdf*

[2] Morag F. Macpherson, Adam Kleczkowski, et al. The effects of invasive pests and pathogens on strategies for forest diversification, Ecological Modelling, Volume 350, 2017, *https://doi.org/10.1016/j.ecolmodel.2017.02.003*.

[3] Dale AG, Frank SD (2017) Warming and drought combine to increase pest insect fitness on urban trees. PLoS ONE 12(3): e0173844. *https://doi.org/10.1371/journal.pone.0173844*

[4] Krist, Frank J.; Ellenwood, James R.; et al. 2014. 2013-2027 national insect and disease forest risk assessment. Fort Collins, CO: US Forest Service, Forest Health Technology and Enterprise Team. *http://www.fs.fed.us/foresthealth/technology/pdfs/2012_RiskMap_Report_web.pdf*

[5] *https://treegenes.org*

[6] *https://treegenes.org/docs/TGI_2015_1.1C.pdf*

[7] *https://forestbio.org*

NEW TECHNOLOGIES IN CONTEXT

With any forest, pests are a concern, and more so with global trade and transportation providing an easy means of distributing pests around the world in a 24-hour cycle. Climate extremes can exacerbate pest problems giving rise to multiple life cycles of destruction[8]. The cost to society of forest pests is tens of billions of dollars. This has given rise to an intense technological focus on the prevention and eradication of invasive pests[9]. Yet, a perennial problem in forestry, whether commercial, urban, or conservation, is the extent and pace at which information is distributed and put to use. It would be shortsighted to report the findings of the TGI without providing context for how the recommendations can fit into a framework of innovation that frequently starts with agriculture. Forestry is often not a first adopter because of the long timeframes involved in growing and harvesting a 'crop' of trees, or in restoring a threatened forest tree species. However, forestry is starting to adopt cutting edge work pioneered in agriculture such as advanced genomic technologies, predictive modeling, and remote sensing at various resolutions with drones and satellites. Efforts that identify those tools most useful for foresters, that make the technology or information abundantly available, and that enable large-scale implementation, should be expanded. The TGI Consortium has identified technologies that increase speed, connectivity, and precision as useful and critical to implement for all types of forestry. These technological areas are each detailed within the associated gap issue that it could most benefit. The TGI firmly believes that incorporating aspects of these new technologies will help bridge the gaps outlined below.

TREE BREEDING AND IMPROVEMENT

Trees have been intentionally produced, moved to new locations, and planted since the 3rd century BC[10]. Breeding trees for ornamental, urban, commercial production, and pest resistance has been a cornerstone of the successful forest products industry in North America. However, over the last few decades the loss of public tree breeding programs and structural changes in the timber, pulp, and paper industry have resulted in diminished tree breeding efforts, particularly for minor or abandoned species that are of little commercial value. While some new information continues to be generated through public/private tree breeding programs, historic information including trial location and duration, tree species, germplasm ownership, test results, investigators, and relevant metadata, is now difficult or impossible to access because it is stranded or not digitized. With many of the leaders in tree breeding and improvement retiring, and the overall low numbers of tree breeders and forest geneticists in North America, this discontinuity is widening the knowledge gap while increasing the probability that we will be 'reinventing the wheel' with future breeding efforts. While new and innovative breeding technologies such as genomic selection and gene editing could draw the interest of young scientists to the field, they cannot be assumed to be a permanent solution. Capacity issues must be resolved to ensure tree breeding as a science and tool for forest health increases in efficiency and efficacy.

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[8] *https://web.archive.org/web/20170126004300/https:/www.epa.gov/climate-impacts/climate-impacts-forests*

[9] *https://phys.org/news/2015-07-nasa-goddard-technology-forest-pests.html*

[10] *https://sites.google.com/site/forestryencyclopedia/Home/Tree%20Improvement*

Gap Detail

Today there are critical gaps in tree breeding information curation, uptake, and dissemination that limit the broad use of data already generated in previous breeding efforts, particularly regarding "at risk" low commercial value and abandoned species[11]. While similar information gaps persist with some public tree breeding cooperatives at universities and government agencies, the lack of technical and human capacity, low interest from young researchers, and a focus on a relatively small number of commercial species pose a long-term problem.

Systems for gathering information from the field, organizing it, and making it available to a wide audience have changed dramatically in the last decade. What was once accomplished with pencil and notebooks is being replaced by digital smart-forms and cloud databases. Identifying and organizing information gathered in the past and making it available via the web for tree growers will benefit entities both large and small.

"Many of the current programs addressing genetic improvement of our hardwood and non-commercial softwood species are isolated, under-staffed and under-funded, resulting in limited success in achieving and deploying improved trees."[11]

Forest dependent communities are particularly vulnerable to catastrophic stand failure caused by weather extremes, pests, and uninformed management decisions. Having accessible information and extension resources that provide direction in what species to plant where, as well as best practices to follow, would be of high value to these communities.

Points to consider

- Some of this information is 'stranded' in hard-copy format and needs to be digitized.
- Newly generated information is not widely disseminated outside of the geographic region or group doing the research.
- Trial and error, failures, and unclear results are rarely reported yet highly valuable to others to reduce effort and resource use by not having to 'reinvent the wheel'.
- There is currently no unified format or comparable system for organizing field trial data.
- New models for communicating the information need to be investigated as forestry extension functions continue to be reduced, particularly for non-commercial and abandoned species.
- Overall breeding capacity is lower than needed to deliver stress-adapted trees to growers in the timeframe needed to combat current and impending threats.

Emerging technologies: Speed

Breakthrough technologies such as CRISPR-Cas9 (CRISPR), are creating new opportunities for forestry to combat these stresses more rapidly while also increasing growth and productivity. CRISPR enables rapid and precise genome editing without adding genes from outside the plant. CRISPR techniques have proven effective in trees[12], with modification of lignin and tannin production as

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[11] Nelson, C. Dana; Koch, Jennifer L. 2017. Institute of forest tree breeding: Improvement and gene conservation of iconic tree species in the 21st Century. In: Sniezko, Richard A.; Man, Gary; Hipkins, Valerie; Woeste, Keith; Gwaze, David; Kliejunas, John T.; McTeague, Brianna A., tech. cords. 2017. Gene conservation of tree species—banking on the future. Proceedings of a workshop. Gen. Tech. Rep. PNW-GTR-963. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 24-27. *https://www.fs.usda.gov/treesearch/pubs/55239*

[12] *http://www.tandfonline.com/doi/full/10.1080/21645698.2015.1091553*

proof of the technology[13]. Researchers are exploring ways to use this technology that can stably confer genetic changes within a single generation. Efforts are underway to use these techniques in trees to increase their resistance to pests, increase nutrient use efficiency so less fertilization is required, and increase their growth rate so that less land and fewer inputs are required to grow a given amount of wood. Essentially, this technology has the potential to enhance trees that can more rapidly combat stresses while also increasing growth and productivity.

CRISPR is rapidly moving GM from a Ph.D.-level lab-only environment to simple and inexpensive, i.e. science fair projects a high school student can make[14]. Not only can genome editing accelerate tree breeding, it may also inspire a new generation of researchers to enter the field, increasing the human capacity and interest in next generation tree breeding.

Solutions

The following can help bridge gaps in tree breeding while increasing capacity in the field:

- Institute an online tree breeding information system that is open and freely available.
- Organize and normalize breeding data.
- Capture stranded, non-digitized tree breeding information and make it human and machine readable for ML/AI.
- Update users as new information is available through human (extension) and electronic communications.
- Expand opportunities to train tree breeders and forest geneticists.
- Accelerate next generation tree breeding technologies such as CRISPR.
- Evaluate Permanent Sample Plots (PSPs) in Canada and Long Term Ecological Research sites (LTERs) in the US, to assess growth patterns of natural forest under changing climates.
- Work with large organizations that cruise commercial stands to collect information on various characteristics. This information can be pooled and relevant data for stress resiliency can be captured.

Resources available

Efforts are underway that address some of these issues. The tools tend to be regionally or species specific. Building on the progress of the following resources can help fill this gap most efficiently:

- *USDA Forest Service National Forest Genetics Laboratory (NFGEL)* provides genetic testing and information for integrated solutions to on-the-ground problems faced by natural resource managers and policy makers.
- *USFS Research Data Archive* publishes and preserves short and long-term research data collected from studies funded by a select group of research programs.
- *PINEMAP Decision Support System (DSS)* is a set of tools designed to help southeastern US foresters make better planting and management decisions by using climate data and regional productivity models to explore relationships between pine trees and climate.

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[13] *http://news.uga.edu/releases/article/researchers-edit-plant-dna-using-mechanism-evolved-in-bacteria-0615*

[14] $150 desktop CRISPR kit: *http://www.the-odin.com*

COMMUNICATION

As great swaths of forest trees are killed by pests and pathogens, many of which are invasive, there are left behind tree stands that are susceptible to fire, wind, and other hazards that impact local municipalities. How to manage these threats and determine what should be planted in the wake of forest loss is critical to long-term forest health. Policies play a critical role in the selection of stress-adapted trees and their widespread use. Sound forest policy is critically dependent on communication channels that clearly and efficiently bring new scientific discoveries to the attention of policy makers.

Gap Detail

Communication barriers or a lack of process to regularly update policies based on current scientific information restricts innovation and slows progress. Thinking, planning, and acting require more forethought today because of the speed and scale of change affecting our forests. Confounding factors include:

- Changing climates that are moving ecoregions and altering species compositions.
- Increased pest pressure, both native and invasive.
- Land use change that increasingly places people in wildland urban interfaces.
- Wildfires that have increased in intensity and destructive effect, including loss of life, because of these factors.

Improved communication within the scientific community, forest managers, and policy makers is needed to ensure the best science-based decisions regarding the use of stress-adapted trees to help mitigate and remediate these negative effects. Public communications strategies and outreach need to be a part of this model as these policies affect an ever growing numbers of municipalities.

Points to consider

- Stakeholders in science and policy do not always understand one another due to subject matter disparities.
- There are very few organized meetings or conferences that bring the science and policy communities together.
- Tree species and seed zone information is not always readily available to municipalities seeking to meet multiple needs.

Emerging technologies: Connectivity

Information sharing and the 'open' movement are providing innovative ways to work on complex problems from human health to climate change. Problems become easier to solve with more minds and hands developing creative approaches and solutions. Moving from traditional linear and centralized command and control systems of information management to distributed, open, and highly interactive models has accelerated innovation in organizations seeking to embrace technology[15].

Open movements have evolved to harness the power of decentralized innovation while establishing connections with a core system that curates the generated knowledge. These models are becoming the norm in many sectors of society.

Connectivity is key in crowd-sourcing data collection through citizen science. Anyone with a smartphone can gather useful forest related data. For example, TreeTaggr[16] uses a smartphone's GPS, camera, and metadata collection capabilities. Information gathered by citizens can be used by researchers to expand their reach. Technology available to the public is of such high quality, power[17], and availability that every opportunity to take advantage of this connectivity should be made.

[15] Bry, Nicolas. Rapid Innovation in Digital Time. *https://nbry.wordpress.com/rapid-innovation*

[16] *https://treetaggr.org*

[17] *https://www.popularmechanics.com/space/moon-mars/a25655/nasa-computer-iphone-comparison/*

An open forestry model is ideal to meet global demands asked of forests from a burgeoning population.

Open Forestry[18] is a global movement connecting people and resources through human and digital networks in innovative ways. It allows knowledge sharing across socio-economic, geographic, and expertise boundaries for the betterment of society and the environment.

Often information generated by large companies or research organizations fails to make its way downstream to ordinary users and conservation workers. This limits access to useful information in both directions: from researchers to end users, and back.

Solutions

Support avenues for collaboration that intentionally bring these communities together, such as the following:

- Promote efforts that enhance information sharing all along the research-use value chain.
- Engage citizens to help gather useful forest and pest information, provide feedback on activities that affect them, and raise awareness of issues affecting our forests.
- Continue to support Canada/US Forest Health Summits that examine ways to enhance cross-border collaborations and improve responses to forest health crises.
- Expand communication within the US and Canada between various landowners and government agencies.
- Establish workshop and exchange programs between policy analysts and researchers to involve scientists in policy-making and keep analysts up to date on current science.

Resources available

- Some examples of climate change workshops are available from the Northern Institute of Applied Climate Science. *https://www.nrs.fs.fed.us/niacs/climate*
- More information about the Canada/US Forest Health Summit is available online at *http://www.usendowment.org/uscanadaforestsummits.html*
- The Open Forestry movement is online at *https://openforestry.org*

[18] *https://openforestry.org* is a joint collaboration of the World Wildlife Fund's New Generation Plantations and the Institute of Forest Biosciences

FIBER SECURITY

Changing climates and increased pest pressure, if unchecked, could reduce the supply of cost-competitive wood fiber in coming years. Globally, forest area is projected to decrease over the next decade[19], while global demand for wood is projected, to triple by 2050[20]. While North America has a robust forest products industry, it is not isolated from the global market. Production in the U.S. and Canada could be impacted if pine species in the U.S and Canada continue to be felled by expanding pest pressure resulting from warmer conditions, or a new invasive pest. Stress-adapted trees can be bred specifically to better withstand pest and climate pressures. By investing in improved trees, forest products companies and tree farmers can enhance fiber security through a healthy and sustainable wood supply. [21]

7% of total forest cover is planted, yet it can provide nearly two-thirds of global roundwood demand. Plantations would need to be established at a rate of 10 million acres per year to meet growing population demand and stop deforestation[21].

Gap Detail

The changing landscape of forest ownership and R&D has made it more difficult to rapidly integrate solutions in working forests[22]. In addition to these capacity limitations, fiber security risks are compounded by these stressors:

- Ecoregion shifts that could impact local wood baskets in the future if the properly adapted species are not planted.
- Extreme weather events that could increase tree mortality on a large scale.
- The introduction of invasive pests and the range expansion of native pests that could accelerate forest decline.

Points to consider

- Non-vertically integrated forest products companies must rely on others to plant trees that are stress-adapted.
- Forest management practices need to be able to address future pest outbreaks and climate stresses.
- Better genetics provides an economic advantage that is critical in forestry where planting scales and rotation lengths are very large relative to row crops. Tools are available to accelerate the improvement cycle by a decade or more compared to conventional tree breeding efforts.

Emerging technologies: Precision

Good forest practices have always benefitted from increased precision. Whether it is identifying the minimum effective amount of fertilizer to apply, or optimizing rotation times, technology is at the heart of these optimizations. New precision-at-a-distance technologies are allowing tree growers to optimize their operations on a scale:efficiency ratio unimaginable just a few years ago.

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[19] Rémi d'Annunzio, Marieke Sandker, et al. Projecting global forest area towards 2030, Forest Ecology and Management, Volume 352, 2015. *https://doi.org/10.1016/j.foreco.2015.03.014*

[20] World Wildlife Fund *http://wwf.panda.org/wwf_news/?uNewsID=207367*

[21] World Wildlife Fund. Living Forests Report 2015. *http://awsassets.panda.org/downloads/living_forests_report_chapter_5_1.pdf*

[22] *http://www.usendowment.org/images/blue_ribbon_commission_report-web.pdf*

The rapid transition of military drone technology to consumer small Unmanned Aircraft Systems[23] (sUAS) has opened up a wealth of opportunities for tree growers. Aerial imagery such as Light Detection and Ranging (LiDAR) and hyperspectral 3D imaging was once only available to large companies and government agencies. Today, these technologies are in reach for smaller operators[24]. For example, a single operator can generate georeferenced 3D maps to estimate tree health, height, and standing volume using a relatively inexpensive drone and the power of distributed cloud processing power. These tools will empower tree growers with actionable insights about rotation planning, weed and pest incursion, and Best Management Practices (BMP) monitoring applied over a large area of forest land, within a matter of hours[25].

Even without owning dedicated remote sensing machinery, tree growers can assess aspects of their forests with satellite remote sensing. It is becoming easier for small scale users to access moderate-resolution imaging spectroradiometer[26] (MODIS) surface reflectance data imagery from satellites to estimate the large-scale health of their forests[27]. As this technology becomes increasingly more accessible and user friendly, it can be used for evaluating stands affected by specific events, such as post-disaster, or used for landscape-level decision-making in ongoing operations.

This trend will continue to grow in scale and breadth, becoming available to ever smaller landholders, and in breadth, as technological advances in this area are far from peaking. For example, sub-meter satellite imagery is available to consumers, and drones can be used to deliver seed capsules to replant in remote locations or challenging terrains[28].

Solutions

- Support programs and projects that identify the value to tree growers derived by better genetics and genomics in tree breeding.
- More forest rotation options, including decreasing rotation times to limit risks associated with changing climates and increased pest pressures.
- Coordinate with tree improvement co-ops to develop a standard set of practices for breeders/producers to ensure that their programs are technically robust and that they have adequately tested the materials they are selling.
- More comprehensive resource inventory information that includes forest health projections and market data. For example, more frequent Forest Inventory and Analysis (FIA) data gathering.
- Incorporate citizen science and remote technologies to enable small and medium scale operations to identify threats early and make course corrections more often.

Resources Available

- Genome Canada projects on value-added genomics in forestry *https://www.genomecanada.ca/en/why-genomics/genomics-sector/forestry*
- PineMap Decision Support System for tree growers in the U.S. South *http://climate.ncsu.edu/pinemap*
- i-Tree software suite for urban forestry *https://www.itreetools.org*
- TreeTaggr citizen science tool for all forests *https://treetaggr.org*

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[23] *http://fortune.com/2014/10/09/a-brief-history-of-drones*

[24] *http://www.precisionhawk.com/agriculture*

[25] *https://pix4d.com/industry/agriculture*

[26] *https://modis.gsfc.nasa.gov/about*

[27] *http://www.tandfonline.com/doi/full/10.1080/14498596.2015.1084247*

[28] *https://droneseed.co*

NEXT STEPS

The IFB is starting to tackle specific problems identified by the Consortium. To help speed open exchanges of breeding information in North America, the IFB will:

- Identify organizations, personnel, and sources of information from tree breeding academic co-ops, government agencies, forest products companies, and commercial tree nurseries.
- Determine what tree breeding information is available that could be publicly shared. Of particular interest is information on "at risk," low commercial value, and abandoned species.
- Aggregate and communicate results of the survey information identification on Open Forestry.
- Gaps identified in communication and tree breeding will also be a focus of *Forest.Health*[29] – an effort to rapidly advance technologies to save threatened tree species in North America.

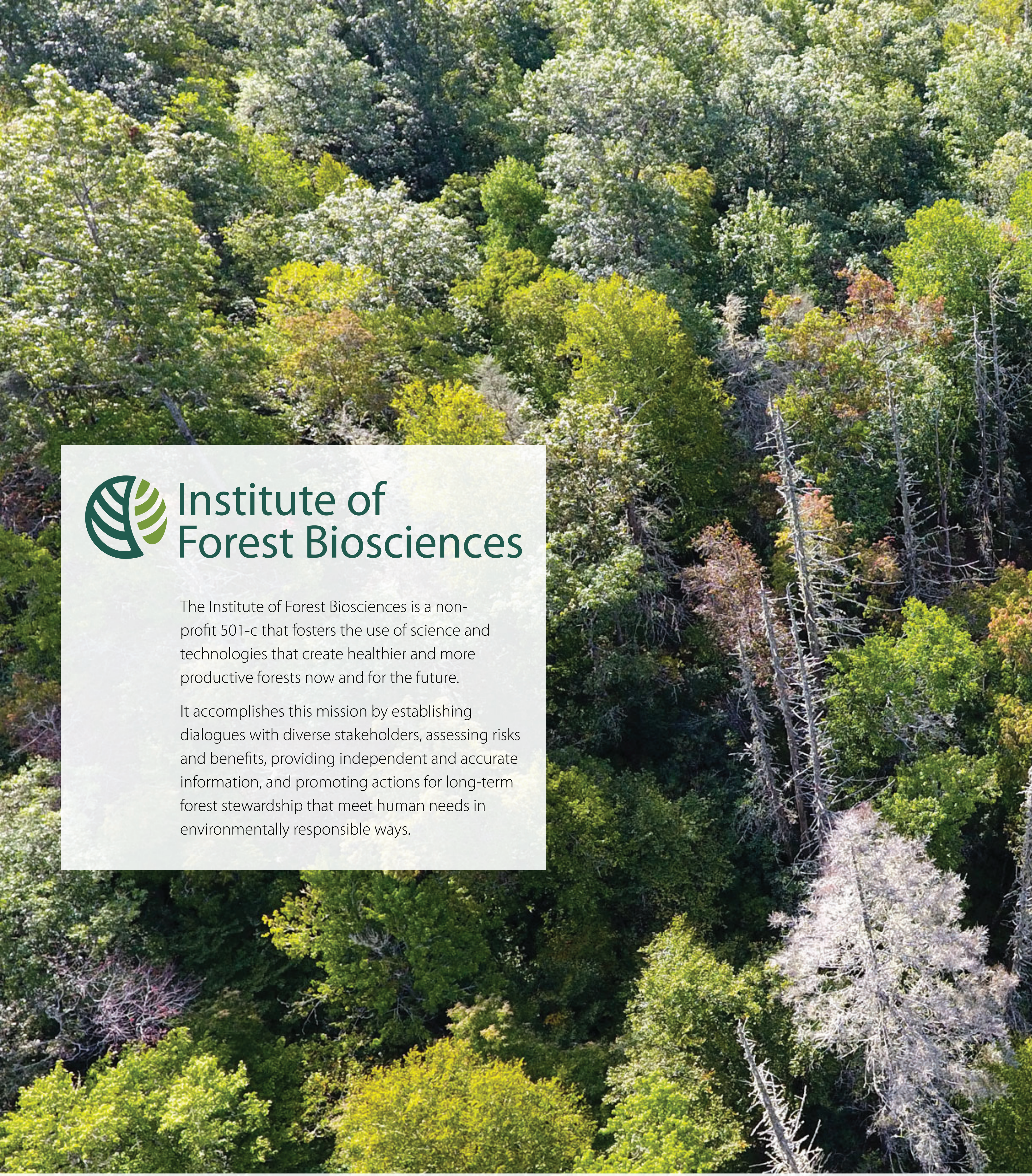
CONCLUSION

These three areas of need are tightly interconnected. Robust and integrated tree breeding programs are needed to ensure the development and use of stress-adapted trees. To ensure this, policies to foster use of stress-adapted trees must be informed by the most current scientific information. Doing so will safeguard the health of forests and urban trees for ecological and recreational services, create a more secure fiber supply.

The TGI, its consortium members, and steering committee, are taking positive steps to identify and close gaps that are slowing the development and use of stress-adapted trees. Learn more about the work we do at *treegenes.org*.

Support for this project was provided by a grant from the USDA Forest Service.

[29] *https://forest.health*



Institute of Forest Biosciences

The Institute of Forest Biosciences is a non-profit 501-c that fosters the use of science and technologies that create healthier and more productive forests now and for the future.

It accomplishes this mission by establishing dialogues with diverse stakeholders, assessing risks and benefits, providing independent and accurate information, and promoting actions for long-term forest stewardship that meet human needs in environmentally responsible ways.

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