National Science Foundation's Center for Advanced Forestry Systems (CAFS): A Comprehensive Overview

Executive Summary

The Center for Advanced Forestry Systems (CAFS) was established in 2007 as an Industry-University Cooperative Research Center (IUCRC) through the National Science Foundation (NSF) to address the research needs of the forest sector and led by Dr. Barry Goldfarb of North Carolina State University with the involvement of several universities across the US and numerous Industry Advisory Board (IAB) members. Since 2018, CAFS has been led by Dr. Aaron Weiskittel and the University of Maine with successful graduation from NSF IUCRC program expected in 2025.

Since its inception, CAFS has supported collaborative research at multiple spatial and temporal scales, including molecular, cellular, individual-tree, stand, and ecosystem levels. This has resulted in:

- Increased forest productivity through improved silvicultural and genetic practices.
- Enhanced competitiveness of the US forest products sector.
- Development of improved decision-support tools for forest managers, such as growth and yield models and remote sensing technologies.
- Fostered the development and implementation of new technologies in forestry.
- Promoted sustainable forestry practices across the US.
- Training for numerous graduate students.

Specific research highlights include:

- Estimating a regional nitrogen fertilization response (RRE) for Douglas-fir on late-rotation stands.
- Developing a consistent and biologically-meaningful metric of potential site productivity that can be related to a combination of environmental and edaphic factors and mapped across various regions.

- Synthesizing a nationwide forest measurements database, standardizing maximum carrying capacity modeling, and providing regionally relevant, national forest carrying capacity models.
- Examining drought-related physiological parameters and root morphological traits of various genotypes of western larch, black walnut, and coastal Douglas-fir.
- Minimizing both total and systematic error in satellite-derived maps for improved forest map accuracy.

These efforts have significantly impacted forest management practices and contributed to the sustainability and productivity of the nation's forests. This comprehensive report highlights the numerous outcomes, partnerships, and future potential of CAFS.

Founding & History

The Center for Advanced Forestry Systems (CAFS) was founded in 2007 to address forest management and decision-support research needs of the nation's forest products sector. It was established as an Industry-University Cooperative Research Center (IUCRC) through the National Science Foundation (NSF). The four founding university sites were North Carolina State University (NCSU), Oregon State University (OSU), Purdue University (PU), and Virginia Tech (VT). Since then, CAFS has expanded to nine university sites, including the University of Florida, University of Georgia (UGA), University of Idaho (UI), University of Maine (UM), and the University of Washington (UW). The UM site joined CAFS in 2009 and has served as the lead site since 2017 (Figure X).

Based on NSF expectations, CAFS CAFS was overseen and directed by NCSU's Dr. Barry Goldfarb

Research and Activities

CAFS research is need-driven and the IAB is instrumental in identifying key research priorities. CAFS has pursued a diverse portfolio of projects in the areas of genetics, forest health, growth and yield modeling, wood quality, forest management, and remote sensing. These projects have been mostly balanced across the focal areas, with a slightly higher emphasis on forest management, genetics, and growth and yield modeling.

Highlights

1. **Increased Forest Productivity**: CAFS research has led to increased forest productivity through the development of improved silvicultural and genetic practices.
2. **Enhanced Competitiveness**: CAFS research has enhanced the competitiveness of the U.S. forest products industry by providing solutions to industry challenges.
3. **Improved Decision-Support Tools**: CAFS research has led to the development of improved decision-support tools for forest managers, such as growth and yield models and remote sensing technologies.
4. **New Technologies**: CAFS research has fostered the development and implementation of new technologies in forestry, such as unmanned aerial vehicles (UAVs) and Light Detection and Ranging (LiDAR).

5. **Sustainable Forestry**: CAFS research has promoted sustainable forestry practices by providing a better understanding of the interactions between forest ecosystems and human activities.
6. **Graduate Student Training**: CAFS research and technology transfer activities have provided training for numerous graduate students, who have gained applied problem-solving skills using interdisciplinary techniques across multiple scales.
7. **Undergraduate Student Involvement**: CAFS has involved undergraduate students in research activities, exposing them to forest science and encouraging them to pursue graduate education.
8. **Technology Transfer**: CAFS facilitates technology transfer between scientists and member personnel, fostering the rapid implementation of new technologies.
9. **Diverse Workforce**: CAFS has helped increase the diversity of the forestry workforce through aggressive recruiting of graduate students from under-represented groups.
10. **Scientific Community**: CAFS research has benefited the broader scientific community through publications and presentations at scientific meetings.

Phase Accomplishments

Phase 1 (2008-2012)

- **Key Accomplishments**
    - Established CAFS as a collaborative research center with four founding university sites (NCSU, OSU, PU, VT).
    - Developed a diverse portfolio of projects across key research areas, including genetics, forest health, growth and yield modeling, wood quality, and forest management.
    - Successfully integrated regional research cooperatives under a consistent structure and function.
    - Initiated a multi-site collaborative fundamental research effort focused on better understanding tree nutrient uptake following fertilization.
- **Key Outcomes**
    - 27 research projects completed.
    - 47 MS and 49 PhD graduate students trained.
    - 13 post-doctorate researchers trained.
    - 378 peer-reviewed publications generated.

Phase 2 (2013-2017)

- **Key Accomplishments**
  - Expanded CAFS to nine university sites, adding regional depth and breadth.
  - Continued regional integration of research projects and completed a second multi-site collaborative fundamental research effort.
  - Maintained a balance across research focal areas, including forest management, genetics, and growth and yield modeling.
  - Added a wood quality component to the research agenda.
- **Key Outcomes**
  - 30 research projects initiated.
  - 84 MS and 50 PhD graduate students trained.
  - 6 post-doctorate researchers trained.
  - 309 peer-reviewed publications generated.

Phase 3 (2018-2023)

- **Key Accomplishments**
  - Greater focus on nationally-relevant research projects.
  - Reorganized research focal areas into three primary themes: forest management, forest genetics, and decision-support tools.
  - Added remote sensing as a fourth focal area.
  - Increased emphasis on emerging technologies and remote sensing applications.
  - Strengthened collaboration with national organizations, such as NCASI.
- **Key Outcomes**
  - 26 research projects in progress.
  - High level of multi-site collaboration (70% of projects).
  - Continued training of graduate students and post-doctoral researchers.
  - Development of a strategic plan and technology roadmap for CAFS.
  - Successful application for supplemental funding opportunities, including REU, INTERN, and START grants.

Overall Accomplishments

CAFS' research portfolio currently includes 26 projects, of which 70% are multi-site. This demonstrates the highly collaborative nature of CAFS, which is critical for its long-term

operation. Throughout its operation, CAFS has provided training for 47 MS and 49 PhD graduate students, as well as 13 post-doctorate researchers. CAFS research has resulted in 378 peer-reviewed publications, 65% of which were co-authored by graduate students.

Future Pathway

CAFS is currently in its third phase and is expected to graduate in 2024. The CAFS IAB is exploring options to sustain the program following its graduation. A multi-faceted approach has been proposed, which includes centralizing a portion of site resources, seeking new members with national interests, and pursuing Federal grants and contracts. Potential members include the National Council of Air & Stream Improvement (NCASI), American Forest Foundation, Sustainable Forestry Initiative (SFI), U.S. Endowment for Forestry & Communities, Inc., and the Climate Action Reserve (CAFS). Potential federal grants include USDA AFRI's Coordinated Agricultural Projects, NIFA's Integrated Research, Education, and Extension (IREE) Competitive Grants Program, NSF's National Socio-Environmental Synthesis Center (SESYNC), the Ecosystem Science Cluster, Accelerating Research through International Network-to-Network Collaborations (AccelNet), and the NSF EPSCoR Research Infrastructure Improvement Program.

Additional Impacts

Graduate student training: CAFS research and technology transfer activities have provided training for numerous graduate students, who have gained applied problem-solving skills using interdisciplinary techniques across multiple scales.
Undergraduate student involvement: CAFS has involved undergraduate students in research activities, exposing them to forest science and encouraging them to pursue graduate education.
Technology transfer: CAFS facilitates technology transfer between scientists and member personnel, fostering the rapid implementation of new technologies.
Diverse workforce: CAFS has helped increase the diversity of the forestry workforce through aggressive recruiting of graduate students from under-represented groups.
Scientific community: CAFS research has benefited the broader scientific community through publications and presentations at scientific meetings.
National economy: CAFS research has contributed to the economic health of the nation by supporting the forest products industry, which has a significant impact on the national economy.

Global health: CAFS research has contributed to the ecological health of the planet by supporting sustainable forestry practices, which are vital to the world's ecological health.

Key Outcomes and Impacts

Increased forest productivity: CAFS research has led to increased forest productivity through the development of improved silvicultural and genetic practices.
Enhanced competitiveness: CAFS research has enhanced the competitiveness of the U.S. forest products industry by providing solutions to industry challenges.
Improved decision-support tools: CAFS research has led to the development of improved decision-support tools for forest managers, such as growth and yield models and remote sensing technologies.
New technologies: CAFS research has fostered the development and implementation of new technologies in forestry, such as unmanned aerial vehicles (UAVs) and Light Detection and Ranging (LiDAR).
Sustainable forestry: CAFS research has promoted sustainable forestry practices by providing a better understanding of the interactions between forest ecosystems and human activities.

Conclusion

CAFS has made significant contributions to the advancement of forestry science and practice. The program has effectively leveraged the expertise of multiple university sites and industry partners to address national and regional forestry challenges. CAFS research has led to increased forest productivity, enhanced competitiveness of the U.S. forest products industry, and the development of improved decision-support tools for forest managers. The program has also fostered the development and implementation of new technologies in forestry and promoted sustainable forestry practices. CAFS is well-positioned to continue its important work in the years to come.

Key Phase 3 Projects

Project: Stand and Tree Responses to Late-Rotation Fertilization

- **Lead:** Eric Turnblom, Kim Littke, Jason Cross, Mason Patterson, and Rob Harrison (UW)
- **Objective:** To estimate a regional nitrogen fertilization response (RRE) for Douglas-fir on late-rotation stands.
- **Outcomes:**
    - Greatest tree and stand volume response in BC West and Oregon West and East regions.
    - Modeled volume response in Late-rotation and Paired-tree studies.
    - Predicted response regions contained significantly greater tree and stand response.
- **Impact:** This study has provided valuable data on the economics of late-rotation fertilization, helping forest managers make informed decisions about nutrient amendments.

Project: Assessing & Mapping Regional Variation in Site Productivity

- **Lead:** Rachel Cook (NCSU), Cristian Montes (UGA), Aaron Weiskittel (UM), Jeff Hatten (OSU), Mark Coleman (UI), Doug Jacobs (Purdue), Mark Kimsey (UI), Doug Maguire (OSU), Kim Littke (UW)
- **Objective:** To develop a consistent and biologically-meaningful metric of potential site productivity that can be related to a combination of environmental and edaphic factors and mapped across various regions.
- **Outcomes:**
    - Depth-to-water table linked to tree growth, basal area, foliar nitrogen, and needle length.
    - Site index improving 0.5 ft per year.
    - Site index fertilizer response shows geology matters within NRCS soil series.
    - Uncertainty in stand projections determined and modeled.
- **Impact:** This project has improved the assessment of site productivity, contributing to a simplified soil classification system and enhancing the confidence of response to silvicultural treatments.

Project: Assessing & Mapping Regional Variation in Site Carrying Capacity Across the Primary Forest Types in the US

- **Lead:** Mark Kimsey (UI), Aaron Weiskittel (UM), Rachel Cook (NCSU), Cristian Montes (UGA), Doug Mainwaring (OSU), Eric Turnblom (UW)
- **Objective:** To synthesize a nationwide forest measurements database, standardize maximum carrying capacity modeling, and provide regionally relevant, national forest carrying capacity models.
- **Outcomes:**
    - Northwest regional SDImax models are being shared (Web apps and rasters).
    - Data is prepared for SDImax modeling.
    - SDImax model built for loblolly pine in the southern United States, sensitive to site, stand, and silvicultural treatments, and validated by local experts.
- **Impact:** This project has contributed to a consistent methodology for identifying and managing forest density across multi-regional land holdings, improving forest management practices.

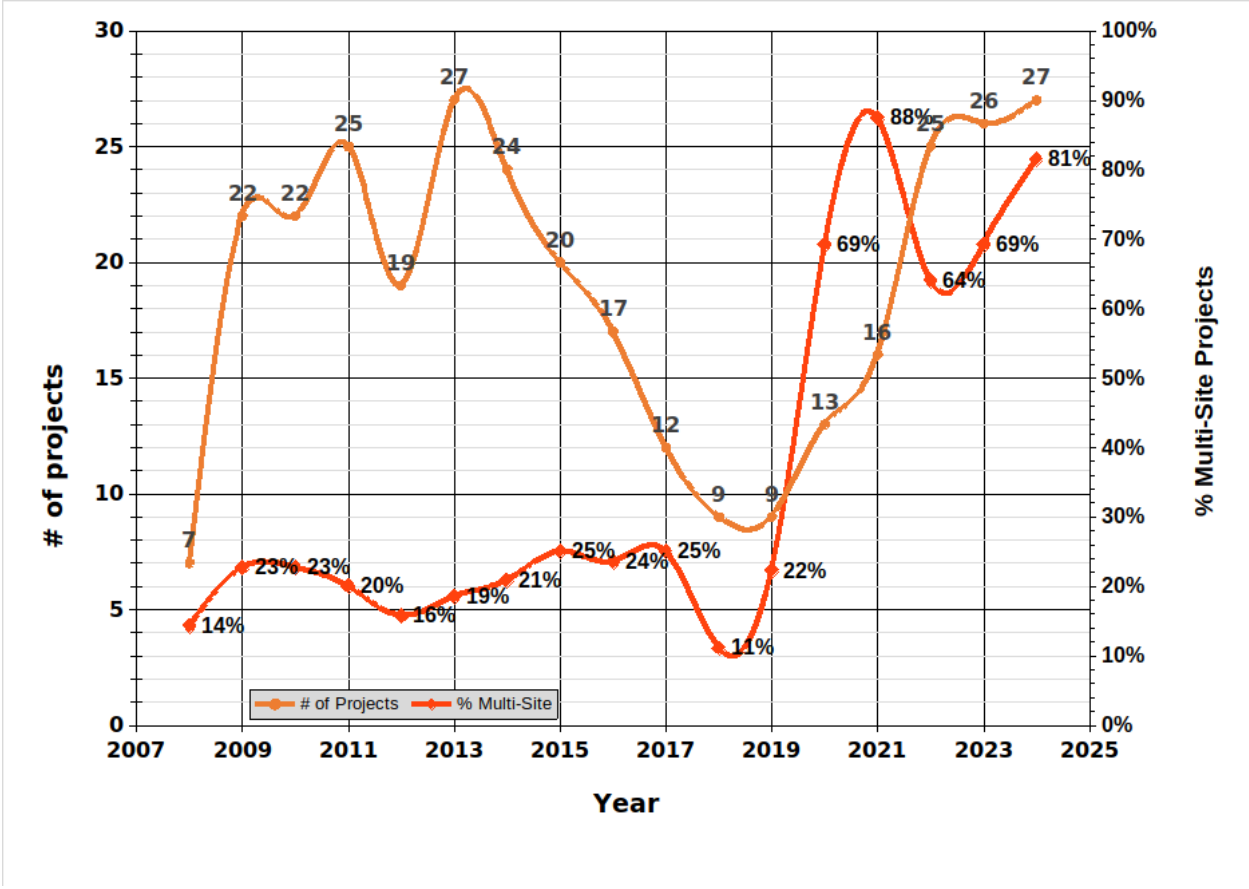
Project: Intraspecific Hydraulic Responses of Commercial Tree Seedlings to Nursery Drought Conditioning

- **Lead:** Andrew Nelson (UI), Douglass Jacobs (Purdue), Carlos Gonzalez-Benecke (OSU)
- **Objective:** To examine drought-related physiological parameters and root morphological traits of various genotypes of western larch, black walnut, and coastal Douglas-fir.
- **Outcomes:**
    - Estimating Black Walnut root diameters by sampling 3D point cloud.
    - Crop out most of the points in the root plug for architectural analysis.
    - Segments of the root skeleton are divided into slices.
    - Point cloud is sampled for each slice, and circle fitting is used to estimate radius/diameter.
    - Presence of a drought memory, in that early drought stress modified seedling responses to subsequent drought events.
- **Impact:** This project has provided new opportunities to generate data on dynamic responses of root systems to nursery treatments, improving seedling quality and reducing reforestation costs.

Project: Multi-Regional Evaluation of New Machine Learning Algorithms for Mapping Tree Species Distribution and Abundance

- **Lead:** Kasey Legaard, Aaron Weiskittel, Ken Bundy, Erin Simons-Legaard (UM)
- **Objective:** To minimize both total and systematic error in satellite-derived maps for improved forest map accuracy.
- **Outcomes:**
    - Species and forest type mapping workflows tested and finalized across approximately 5 million acres.
    - Currently processing data for statewide coverage.
    - Plan to integrate with NOAA C-CAP data and deliver final land cover products.
    - Preliminary aboveground live biomass from NAIP point cloud metrics and Sentinel-2 bands.
- **Impact:** This project has continued the development and proof of concept of low-cost forest mapping methods, improving the accuracy and efficiency of forest mapping.

These are just a few examples of the many successful projects undertaken by CAFS. The program has consistently demonstrated its ability to generate valuable research outcomes with a direct impact on forest management practices. By leveraging the expertise of multiple university sites and industry partners, CAFS has effectively addressed national and regional forestry challenges, contributing to the sustainability and productivity of the nation's forests.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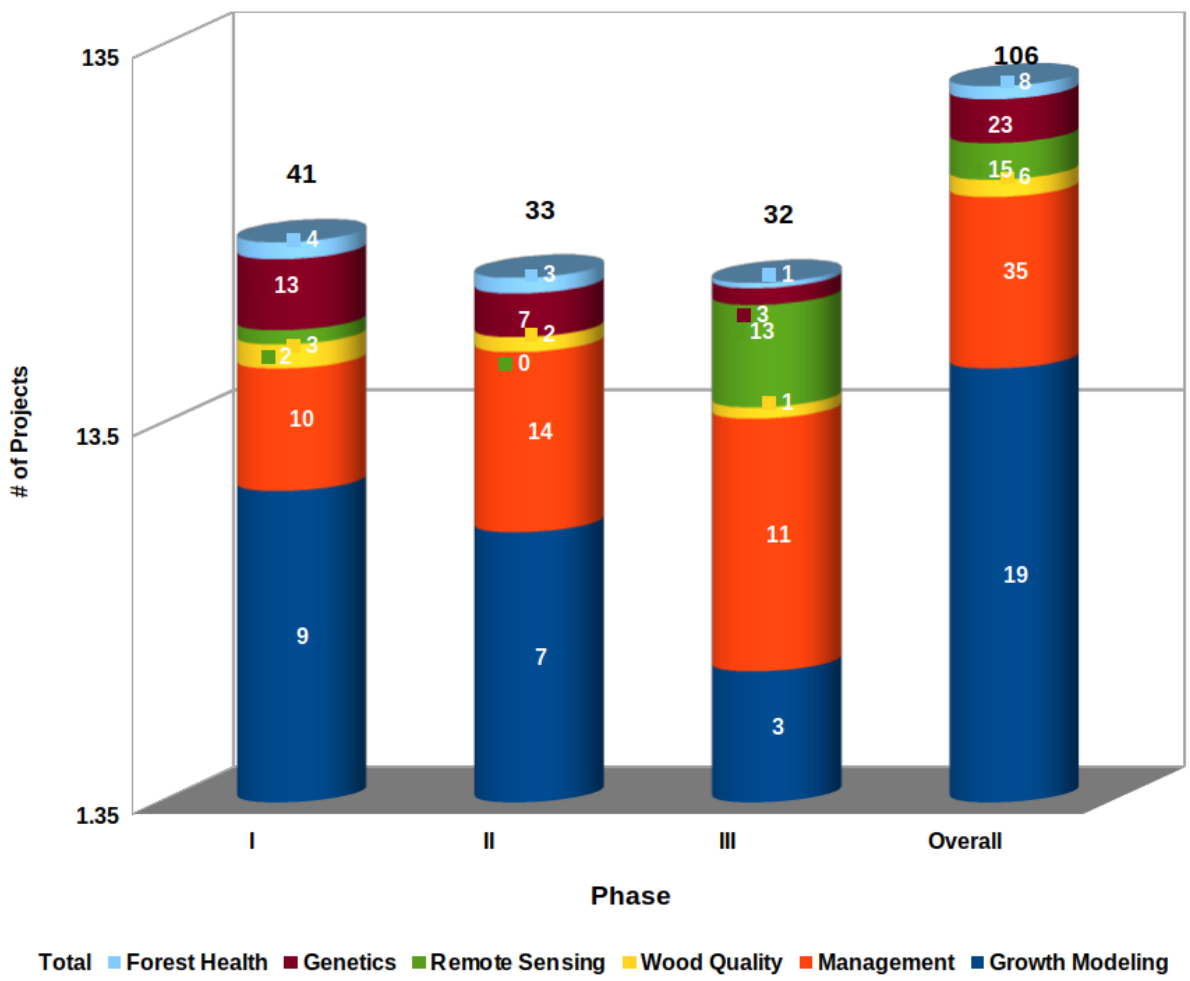
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