Activities Related to the Cultivation and Utilization of Poplars, Willows, and Other Fast-Growing Trees in the United States, 2020-2023

UNITED STATES REPORT TO THE 27TH SESSION OF THE INTERNATIONAL COMMISSION ON POPLARS AND OTHER FAST-GROWING TREES SUSTAINING PEOPLE AND THE ENVIRONMENT (IPC) OF THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (UN FAO)

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United States Report to the
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TABLE OF CONTENTS

I. POLICY AND LEGAL FRAMEWORK

1. Introduction

Substantial investments in major economic, policy, and technological development affected activities related to the cultivation and utilization of poplars, willows, and eucalypts in the United States (US) from 2020-2023. Funding for research on the development and application of fast-growing trees came from private and public sectors, and significant shifts in funding priorities occurred across both sectors throughout the reporting period. The National Science Board (NSB), which governs the National Science Foundation (NSF), develops science and engineering indicators, and advises the President and Congress on science and engineering policy, research, and education issues. The NSB publishes a suite of reports related to Science and Engineering Indicators. In particular, the information presented in the following bullets is quoted verbatim from the 2024 report[1], Research and Development: U.S. Trends and International Comparisons.

- In 2022, the United States performed an estimated $885.6 billion in research and development (R&D) in current U.S. dollars. This is an increase from 2021 of 12% in current (nominal) dollars and a 5% increase in constant (inflation-adjusted) dollars.
- The business sector is by far the largest performer of U.S. R&D. In 2022, this sector performed an estimated $692.7 billion in domestic R&D (current U.S. dollars), or 78% of U.S. R&D, a 14% increase from the $608.6 billion performed in 2021 (6% increase in constant dollars).
- The second-largest performing sector in 2022 was higher education, with $91.4 billion (or 10% of the U.S. R&D total). This represented a 7% increase from 2021 in current dollars, but performance stagnated in constant dollars (-0.4% change). In 2022, the federal government performed $73.3 billion, for an 8% share of U.S. R&D, compared with $66.8 billion in 2021, for a 10% increase (3% in constant dollars).
- In addition to being the largest performer, the business sector is also the largest R&D funder in the United States. In 2022, the sector funded $672.9 billion, or 76% of total U.S. R&D, up from 69% in 2000 and 61% in 2010.
- The federal government funded 18% of U.S. R&D ($159.8 billion dollars) in 2022 as the second-largest source. The federal government funds the largest proportion of U.S. basic research performance (40%).
- Across all agencies in FY 2022, 24% of federal R&D obligations were devoted to basic research ($45.4 billion), 25% to applied research ($48.4 billion), and 51% to experimental development ($96.6 billion).

Three federal agencies exhibiting the greatest potential relevance to the cultivation of poplars, willows, and eucalypts in natural forests, planted forests, and agroforestry throughout the country had federal obligations for R&D that increased throughout the 2020, 2021, and 2022 fiscal years[1]. Specifically, federal R&D obligations for the US Department of Energy (DOE) increased nearly 13.9% from FY2020 to FY2022, while that for the US Department of the Interior (US DOI) and US Environmental Protection Agency (US EPA) increased 12.2% and 7.7%, respectively. Federal R&D obligations for the US Department of Agriculture (USDA), within which the USDA Forest Service resides, were 3.4% less in FY2022 than FY2020.

2. National Laws, Policies, and Regulations

In the US, there were substantial developments throughout the reporting period (2020-2023) for longstanding national policies, as well as new enactments that have or may affect the cultivation of poplars, willows, and eucalypts in natural forests, planted forests, and agroforestry throughout the country. These national policies focus on the production of renewable fuels, domestic energy security, resilience to climate change, restoration of degraded lands and waters, and rural economic development. Of particular note is the ***Energy Independence and Security Act (EISA) of 2007*** (Public Law 110-140; 19 December 2007). Enacted long before the reporting period, the EISA aimed to: 1) increase US energy security, 2) improve vehicle fuel economy, and 3) **develop renewable energy**. For the latter, EISA contained a National Renewable Fuel Standard (RFS) requiring fuel producers to use at least 36 billion gallons of biofuels by 2022, with 21 billion gallons being cellulosic biofuels. Estimates for this RFS were informed by an interdepartmental partnership between the US DOE and USDA that resulted in the release of a 2005 US Billion-Ton Report that demonstrated how agriculture and forest resources could potentially produce an annual sustainable output of one billion dry tons of biomass to displace approximately 30% of national petroleum consumption[1]. In 2011, the US DOE released a 2011 US Billion-Ton Update Report that provided more rigorous assessment of availability, prices, and resource sustainability in the context of implementation of the revised RFS and other policy initiatives[2]. The *2011 US Billion-Ton Update Report* greatly increased the potential of energy crops, including poplars, willows, and other fast-growing trees, for meeting projected feedstock demands necessary to support future supplies of renewable fuels. In 2016, the US DOE published the 2016 US Billion-Ton Report which supported earlier conclusions that the US could sustain production of sufficient renewable biomass to achieve the RFS target established for 2022, and the report included a more in-depth analysis of the role that poplars, willows, eucalypts, and other fast-growing trees could play in reaching renewable energy goals out to 2040[3]. Just after the current reporting period (2020-2023), in May 2024, the US DOE Bioenergy Technologies Office (BETO) released its fourth iteration of the billion-ton reports, the 2023 Billion-Ton Report. Among its key outcomes, the US can produce 1.1 to 1.5 billion tons of biomass annually in a future mature market, with the largest source of biomass being from purpose-grown energy crops[4].

Similarly, the ***Energy Act of 2020*** that was incorporated into the ***Consolidated Appropriations Act of 2021*** (Public Law 116-260; 27 December 2020) aims to modernize US energy policies to encourage innovation in technologies that are important for energy, national security, and environmental protection. In addition, the *Energy Act of 2020* authorizes spending on research and development for a wide variety of energy technologies, including growing and utilizing poplars, willows, eucalypts, and other fast-growing trees for biofuels.

The ***Agriculture Improvement Act of 2018*** (Public Law 115-334; 20 December 2018) (i.e., the 2018 Farm Bill) is also noteworthy with respect to the potential cultivation of poplars, willows, and eucalypts. The act reauthorized and modified many USDA programs, including those related to forestry, energy, and horticulture, as well as conservation, research, and extension activities. The 2018 Farm Bill was extended on 16 November 2023 through 30 September 2024, allowing programs to continue to the end of the 2024 fiscal year. Three such programs are pertinent to the production of fast-growing trees. First, the Conservation Reserve Program (CRP) pays a yearly rental payment in exchange for farmers removing environmentally sensitive land from agricultural production and planting species that will improve environmental quality. General CRP includes a Climate-Smart Practice Incentive to help increase carbon sequestration and reduce greenhouse gas emissions by helping producers and landowners establish trees and perennial grasses, enhance wildlife habitat, and restore wetlands. Second, the Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. Objectives of the CREP include: 1) protecting the Nation's ability to produce food and fiber, 2) reducing soil erosion and sedimentation, 3) improving water quality, and 4) creating or enhancing habitat for wildlife. Third, the Biomass Crop Assistance Program (BCAP) is a program that helps farmers grow crops for bioenergy production. The USDA's Farm Service Agency (FSA) administers the BCAP. Objectives of the BCAP include: 1) promoting energy-efficient bioenergy crops, 2) developing new crops and cropping systems that preserve natural resources, and 3) connecting farmers with energy companies that use the feedstocks.

The ***Inflation Reduction Act (IRA) of 2022*** (Public Law 117-169; 16 August 2022) also has implications for the cultivation of fast-growing trees in the US. The IRA is the largest investment in reducing carbon pollution in the history of the US. The IRA includes funding, incentives, and programs to help the country transition to a clean energy economy. Provisions of the IRA can help reduce climate damage and increase economic output in five ways, with the first three being directly relevant to growing poplar, willow, and eucalypt biomass feedstock production systems for biofuels, bioenergy, and bioproducts: 1) **mitigating greenhouse gases**, 2) **adapting to climate change**, 3) **reducing local pollution**, 4) supporting electric vehicle (EV) charging, and 5) supporting power infrastructure. The IRA has a section dedicated to the advancement of Sustainable Aviation Fuels (SAF), with those achieving a 50% or greater reduction in lifecycle greenhouse gas emissions under the most recent Carbon Offsetting and Reduction Scheme for International Aviation standards continuing to qualify for tax credits under US EPA and Internal Revenue Service (IRS) guidance. Similarly, these activities are a high priority for the US DOE that along with the USDA and other agencies recently released a SAF Grand Challenge, a government-wide approach to reduce the cost, enhance the sustainability, and expand the production of domestic SAF to meet 100% of the aviation fuel demand by 2050, which also advances the Biden Administration's goal to achieve carbon pollution-free electricity by 2035 (Executive Order 14008, Tackling the Climate Crisis at Home and Abroad; 27 January 2021). Funding announcements from the US DOE in spring 2024 supported high-impact R&D on mobilizing low carbon intensity, purpose-grown energy crops necessary to support the production goals of the SAF Grand Challenge.

It is worth noting that some provisions of the IRA dated back to the Biden Administration's American Jobs Plan that were redirected to the ***Infrastructure Investment and Jobs Act of 2021*** (IIJA) (a.k.a., Bipartisan Infrastructure Law, BIL) (Public Law 117-58; 15 November 2021). Key goals of the American Jobs Plan that carried forward to the enacted IIJA included: 1) **making infrastructure more resilient** through maximizing the resilience of land and water resources to protect communities and the environment, 2) **investing in R&D and future technologies** to establish the US as a leader in climate science, innovation, and R&D, 3) **reenergizing America's power infrastructure** to conserve public lands and waters, bolster community resilience, and advance environmental justice, and 4) **delivering the largest investment in tackling legacy pollution in American history** by cleaning up Superfund and brownfield sites, reclaiming abandoned mines, and capping orphaned oil and gas wells. For the latter, in 2023, the USDA Forest Service invested millions of dollars to remediate and restore mined lands, reducing the threat to human health and the environment [Provision 40804(b)(8) - Mitigate Environmental Hazards on Mined Lands]. These efforts involve nature-based solutions, such as utilizing poplars and willows for phytoremediation and associated phytotechnologies. Additional USDA programs supporting reforestation include: 1) USDA conservation programs such as the CRP (see above), Environmental Quality Incentives Program (EQIP), and Agricultural Conservation Easement Program

(ACEP), which can incentivize private landowners to plant trees and maintain forests, 2) USDA Forest Service, State and Private Forestry programs, including Urban and Community Forestry, Landscape Scale Restoration, and Forest Health Management, which can accelerate tree restoration on non-federal lands, and 3) USDA Forest Service National Forest programs such as Vegetation and Watershed Management and Collaborative Forest Landscape Restoration, which can help restore forest ecosystems while restocking federal forests affected by pests, diseases, or other disturbances.

[1] National Science Board, National Science Foundation. (2024). Research and Development: U.S. Trends and International Comparisons. Science and Engineering Indicators 2024. NSB-2024-6. Alexandria, VA. 51 p. https://ncses.nsf.gov/pubs/nsb20246/ | [2] Perlack, R.D., Wright, L.L., Turhollow, A.F., Graham, R.L., Stokes, B.J., & Erbach, D.C. (2005). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. DOE/GO-102995-112135, US Department of Energy; ORNL/TM-2005/66, Oak Ridge National Laboratory. Oak Ridge National Laboratory, Oak Ridge, TN. 59 p. https://doi.org/10.2172/885984 | [3] US Department of Energy. (2011). U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227 p. https://doi.org/10.2172/1023318 | [4] US Department of Energy. (2016). 2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks. M.H. Langholtz, B.J. Stokes, and L.M. Eaton (Leads), ORNL/TM-2016/160. Oak Ridge National Laboratory, Oak Ridge, TN. 448 p. https://doi.org/10.2172/1271651 | [5] US Department of Energy. (2024). 2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Resources. M.H. Langholtz (Lead), ORNL/SPR-2024/3103. Oak Ridge National Laboratory, Oak Ridge, TN. 268 p. https://doi.org/10.23720/BT2023/2316165

II. TECHNICAL INFORMATION

The information presented in this section is provided as a summary of 114 peer-reviewed manuscripts highlighting selected activities related to each area of work conducted in the US and/or involving coauthorship from US-based researchers, and, therefore, is not meant to represent a full synthesis of all 941 peer-reviewed manuscripts listed below (Section III.4. General Information: Literature).

1. Taxonomy, Nomenclature, and Registration

a) *Populus*

There was limited information published from 2020-2023 on the Taxonomy, Nomenclature, and Registration of poplars in the US. Please see the records below for recent advancements in the cultivation and utilization of poplars in the US. Previously, Isebrands and Richardson (2014) provided a comprehensive summary of the Taxonomy, Nomenclature, and Registration of poplars.

Isebrands, J.G., & Richardson, J. (eds). (2014). Poplars and Willows: Trees for Society and the Environment. Food and Agriculture Organization of the United Nations (UN FAO) and CAB International (CABI); Rome, Italy. ISBN 978-1-78064-108-9 (CABI); ISBN 978-92-5-107185-4 (FAO). 650 p. https://doi.org/10.1079/9781780641089.0000

b) *Salix*

Similarly, as for poplars, Isebrands and Richardson (2014) provided a comprehensive summary of the Taxonomy, Nomenclature, and Registration of willows.

Isebrands, J.G., & Richardson, J. (eds). (2014). Poplars and Willows: Trees for Society and the Environment. Food and Agriculture Organization of the United Nations (UN FAO) and CAB International (CABI); Rome, Italy. ISBN 978-1-78064-108-9 (CABI); ISBN 978-92-5-107185-4 (FAO). 650 p. https://doi.org/10.1079/9781780641089.0000

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on the taxonomic classification and identification of different willow species and hybrids[1-7]. From 2016-2020, with the IPC as the International Cultivar Registration Authority, a total of 854 cultivar epithets were included in the checklist for cultivars of *Salix*, providing a baseline for the formal registration of new cultivars[1]. Since 2016, 26 new cultivar epithets have been registered and included in the International

Register of Cultivars of *Salix*, providing detailed information about each registered cultivar, including traits such as foliage color, stem color, and growth habit[1]. Complementing this work, McGovern et al. (2021) discussed a proof-of-concept for an IPC *Salix* Cultivar Database that stores and manages information about *Salix* tree and shrub cultivars, including integrating information about epithets, families, and pedigrees[7].

In addition to classification, extensive efforts have been devoted to identification of willows, focusing on various morphological characteristics. For example, ovule number was studied to differentiate among willow species and hybrids[3-5]. Here, Marchenko and Kuzovkina (2021a, 2021b, 2023) verified the taxonomic designation of *Salix vitellina* L. using ovule number, comparing values with related *Salix* species[3-5]. They analyzed several specimens of *S. vitellina* from Europe and North America and revealed that *S. vitellina* specimens have an ovule index of 6-10, with most valves having four and five ovules. With this ovule distribution being similar to that of *Salix alba* L. specimens, their results suggested that *S. vitellina* belongs to *S. alba*. Based on their results, the number of ovules present in the ovaries of the willow flower can be a useful tool for species identification, with their data indicating that these differences in ovule number can be used as diagnostic characters to distinguish among species[3]. Furthermore, to aid in in species and hybrid verification, a method for calculating ovule number in the genus *Salix* was described[4], as well as data showing morphological comparisons to support identification and classification of species hybrids that distinguish them from their parent species[5]. Lastly, Marchenko and Kuzovkina (2022) evaluated the recent replacements of *Salix fragilis* L. with *Salix euxina* I.V. Belyaeva and *Salix* × *rubens* Schrank with *Salix* × *fragilis* L., proposing to continue the use of *S. fragilis* as the name for a glabrous crack willow and *S.* × *rubens* for its hybrid with *S. alba*[6].

In conclusion, these results provide valuable insights into the taxonomic classification, identification, and nomenclature of different species and hybrids within the genus *Salix*, as well as detailing the importance of databases for storing and managing cultivar information. Overall, these findings contribute to a better understanding of the taxonomy, classification, and archiving of willows.

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[1] Kuzovkina, Y. A., & Vietto, L. (2021). International registration of cultivar names for *Salix* L. (willow) in 2016–20. *HortScience*, *56*(1), 106–107. https://doi.org/10.21273/HORTSCI15356-20 | [2] Marchenko, A., & Kuzovkina, Y. (2023). Notes on the Taxonomy of *Salix vitellina* (Salicaceae). *Plants*, *12*(14), 2610. https://doi.org/10.3390/plants12142610 | [3] Marchenko, A. M., & Kuzovkina, Y. A. (2023). The ovule number variation provides new insights into taxa delimitation in willows (*Salix* subgen. *Salix*; salicaceae). *Plants*, *12*(3), Article 3. https://doi.org/10.3390/plants12030497 | [4] Marchenko, A. M., & Kuzovkina, Y. A. (2021a). Calculation of the ovule number in the genus *Salix*: A method for taxa differentiation. *Applications in Plant Sciences*, *9*(11–12), e11450. https://doi.org/10.1002/aps3.11450 | [5] Marchenko, A. M., & Kuzovkina, Y. A. (2021b). Identification of hybrid formulae of a few willows (*Salix*) using ovule numbers. *Silvae Genetica*, *70*(1), 75–83. https://doi.org/10.2478/sg-2021-0006 | [6] Marchenko, A. M., & Kuzovkina, Y. A. (2022). Notes on the nomenclature and taxonomy of *Salix fragilis* (Salicaceae). *TAXON*, *71*(4), 721–732. https://doi.org/10.1002/tax.12685 | [7] McGovern, P. N., Kuzovkina, Y. A., & Soolanayakanahally, R. Y. (2021). Short communication: IPC *Salix* cultivar database proof-of-concept. *Forests*, *12*(5), 631. https://doi.org/10.3390/f12050631

c) *Eucalyptus*

There was limited information published from 2020-2023 on the Taxonomy, Nomenclature, and Registration of eucalypts in the US. Please see the records below in Section III.4. (General Information: Literature) for recent advancements in the cultivation and utilization of eucalypts in the US.

2. Domestication, Breeding, and Selection of Genetic Resources

Sanderson et al. (2021) provided a comprehensive summary of the evolutionary history and diversification patterns of *Populus* (poplars, cottonwoods, and aspens) and *Salix* (willows). Their findings highlighted the role of hybridization and incomplete lineage sorting in generating phylogenetic conflict and shaping the diversity of these genera. They used targeted sequence capture and whole genome sequencing techniques to obtain genomic data from 165 samples representing various subgenera and sections within *Populus* and *Salix* for phylogenetic analysis using two approaches. First, they used the ASTRAL method to estimate gene trees for each gene and then inferred the best species tree by minimizing quartet distances among gene trees. Second, they concatenated all genes and used maximum likelihood analysis to estimate the most likely concatenated tree. In addition, they performed dating analyses to estimate the timing of diversification events. Their results revealed extensive phylogenetic conflict among genes, indicating the presence of hybridization and incomplete lineage sorting. Their results also highlighted the significant role of hybridization in the diversification and diversity of both genera. They discussed the challenges posed by hybridization in reconstructing phylogenetic histories of these genera. Overall, Sanderson et al. (2021) contributed to our knowledge of the factors influencing species diversity and phylogenetic relationships in willows, poplars, and their close relatives.

Sanderson, B. J., Gambhir, D., Feng, G., Hu, N., Cronk, Q. C., Percy, D. M., Freaner, F. M., Johnson, M. G., Smart, L. B., Keefover-Ring, K., Yin, T., Ma, T., DiFazio, S. P., Liu, J., & Olson, M. S. (2023). Phylogenomics reveals patterns of ancient hybridization and differential diversification that contribute to phylogenetic conflict in willows, poplars, and close relatives. *Systematic Biology*, *72*(6), 1220–1232. https://doi.org/10.1093/sysbio/syad042

a) *Populus*

i. Sections

Isebrands and Richardson (2014) provided a comprehensive summary of the Sections of poplars.

Isebrands, J.G., & Richardson, J. (eds). (2014). Poplars and Willows: Trees for Society and the Environment. Food and Agriculture Organization of the United Nations (UN FAO) and CAB International (CABI); Rome, Italy. ISBN 978-1-78064-108-9 (CABI); ISBN 978-92-5-107185-4 (FAO). 650 p. https://doi.org/10.1079/9781780641089.0000

ii. Breeding and Testing

Two selected studies provided contrasting yet valuable information on the cultural history of the Lombardy poplar[1] and the efficiency of genotype testing in hybrid poplar breeding[2]. Collectively, these findings can be useful for those interested in the cultural and historical aspects of poplar culture, as well as researchers, breeders, and horticulturists working with poplar trees. First, Beamish (2022) discussed how Lombardy poplar went from being greatly admired to reviled, facing hostility and negative labels such as odious and worthless. The shunning of Lombardy poplar was purported to be influenced by xenophobia, nativist movements, changes in horticultural fashion, and a growing sense of pride in native trees[1]. Second, Nelson et al. (2021) provided a detailed account of various ways to increase efficiency of hybrid poplar tree improvement, focusing on the testing process. They reported that early selection, elimination of certain nursery-based progeny trial measurements, and providing clone performance estimates through family field trials could potentially increase efficiency in genotype testing[2]. In addition, by examining age-age correlations, they found that selection for growth traits in hybrid poplars can be effective as early as one fourth of the rotation age. This is important given that previous studies have shown that age-age correlations can be predictive of performance at later ages, with the strength of such correlations dependent on factors such as site, clonal composition, region, and disease resistance[2].

[1] Beamish, A. (2022). A much-abused tree: The rise and fall of the Lombardy poplar. *Studies in the History of Gardens & Designed Landscapes*, *42*(2), 120–137. https://doi.org/10.1080/14601176.2022.2059287 | [2] Nelson, N. D., Berguson, W. E., McMahon, B. G., Cai, M., & Buchman, D. J. (2021). Vectors of efficiency in hybrid poplar genotype testing. *Silvae Genetica*, *70*(1), 39–56. https://doi.org/10.2478/sg-2021-0004

iii. Genomics

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on various aspects of poplar genomics, including gene dosage variation, lignin structure, wood anatomical and morphological traits, adventitious root development, and sex determination[1-8]. Bastiaanse et al. (2021) investigated the effect of gene dosage variation on leaf morphology in *Populus*[1]. They used a systems genetics approach and a large population of *Populus* lines and reported that gene dosage had significant impacts on leaf shape, size, stomatal patterning, and serration characteristics. In addition, they identified dosage-sensitive genomic regions that influenced specific morphological traits[1]. Brunner et al. (2021) provided a collection of abstracts showcasing current research and advancements in plant tissue culture, genetic engineering, and gene editing[2]. Bryant et al. (2023) focused on lignin structure in *Populus* and its genetic basis[3]. They conducted a genome-wide association study (GWAS) to identify candidate genes associated with lignin phenotypes and found several promising candidate genes involved in lignin biosynthesis[3]. Complementary work was also reported for transgenic poplar designed for biofuels[4]. Furthermore, Chhetri et al. (2020) conducted a GWAS using a large population of *Populus* genotypes and identified candidate genes associated with wood anatomical and morphological traits in *Populus trichocarpa* Torr. & Gray, thus providing insights into the genetic control of such traits[5]. Similarly, Nagle et al. (2023) conducted a GWAS to identify regulators of adventitious root development and found hundreds of candidate genes involved in various functions such as cell division and structure, hormone signaling, reactive oxygen species (ROS) signaling, and post-translational modifications (PTMs)[6]. Wang et al. (2020) examined the phylogenetic relationships and evolutionary diversification of the genus *Populus*, with results highlighting the complex patterns of gene flow and ancient polymorphisms within the genus. Their findings have important implications for understanding the evolutionary history and adaptive potential of poplars[7]. Lastly, Zhou et al. (2020) investigated the sex determination region (SDR) in *P. trichocarpa* and identified sex-associated markers and male-specific sequences within the SDR, confirming male heterogamety in the species[8]. Overall, these findings contributed to our understanding of the genetic basis of biologically- and economically-important traits in *Populus*, and the results have implications for genetic improvement and biofuel production in poplars. In particular, the studies highlighted the importance of considering multiple data types, such as gene dosage, gene expression, and co-expression networks, in understanding complex traits. Further research is needed to fully understand the genetic mechanisms underlying these traits and to optimize genetic modifications for desired outcomes in poplar breeding and biofuel production.

[1] Bastiaanse, H., Henry, I. M., Tsai, H., Lieberman, M., Canning, C., Comai, L., & Groover, A. (2021). A systems genetics approach to deciphering the effect of dosage variation on leaf morphology in *Populus*. *The Plant Cell*, *33*(4), 940–960. https://doi.org/10.1093/plcell/koaa016 | [2] Brunner, A. M., Beers, E. P., Sheng, X., Petzold, H. E., & Teixeira, R. (2021). From *Populus* molecular networks to transgenic field phenotypes. *In Vitro Cellular & Developmental Biology - Animal*, *57*(S1), 20–31. https://doi.org/10.1007/s11626-021-00576-4 | [3] Bryant, N., Zhang, J., Feng, K., Shu, M., Ployet, R., Chen, J.-G., Muchero, W., Yoo, C. G., Tschaplinski, T. J., Pu, Y., & Ragauskas, A. J. (2023). Novel candidate genes for lignin structure identified through genome-wide association study of naturally varying *Populus trichocarpa*. *Frontiers in Plant Science*, *14*, 1153113. https://doi.org/10.3389/fpls.2023.1153113 | [4] Bryant, N. D., Pu, Y., Tschaplinski, T. J., Tuskan, G. A., Muchero, W., Kalluri, U. C., Yoo, C. G., & Ragauskas, A. J. (2020). Transgenic poplar designed for biofuels. *Trends in Plant Science*, *25*(9), 881–896. https://doi.org/10.1016/j.tplants.2020.03.008 | [5] Chhetri, H. B., Furches, A., Macaya-Sanz, D., Walker, A. R., Kainer, D., Jones, P., Harman-Ware, A. E., Tschaplinski, T. J., Jacobson, D., Tuskan, G. A., & DiFazio, S. P. (2020). Genome-wide association study of wood anatomical and morphological traits in populus trichocarpa. *Frontiers in Plant Science*, *11*, 545748. https://doi.org/10.3389/fpls.2020.545748 | [6] Nagle, M. F., Yuan, J., Kaur, D., Ma, C., Peremyslova, E., Jiang, Y., Zahl, B., Niño de Rivera, A., Muchero, W., Fuxin, L., & Strauss, S. H. (2023). GWAS identifies candidate genes controlling adventitious rooting in *Populus trichocarpa*. *Horticulture Research*, *10*(8), uhad125. https://doi.org/10.1093/hr/uhad125 | [7] Wang, M., Zhang, L., Zhang, Z., Li, M., Wang, D., Zhang, X., Xi, Z., Keefover-Ring, K., Smart, L. B., DiFazio, S. P., Olson, M. S., Yin, T., Liu, J., & Ma, T. (2020). Phylogenomics of the genus *Populus* reveals extensive interspecific gene flow and balancing selection. *New Phytologist*, *225*(3), 1370–1382. https://doi.org/10.1111/nph.16215 | [8] Zhou, R., Macaya-Sanz, D., Schmutz, J., Jenkins, J. W., Tuskan, G. A., & DiFazio, S. P. (2020). Sequencing and analysis of the sex determination region of *Populus trichocarpa*. *Genes*, *11*(8), 843. https://doi.org/10.3390/genes11080843

b) *Salix*

i. Sections

Isebrands and Richardson (2014) provided a comprehensive summary of the Sections of willows.

Isebrands, J.G., & Richardson, J. (eds). (2014). Poplars and Willows: Trees for Society and the Environment. Food and Agriculture Organization of the United Nations (UN FAO) and CAB International (CABI); Rome, Italy. ISBN 978-1-78064-108-9 (CABI); ISBN 978-92-5-107185-4 (FAO). 650 p. https://doi.org/10.1079/9781780641089.0000

ii. Breeding and Testing

Carlson and Smart (2022) presented findings from a detailed study on biomass yield and growth traits in shrub willow hybrids and concluded that triploids produced greater levels of heterosis for biomass yield compared to diploids[1]. They focused on diploid, triploid, and tetraploid genotypes of willow and aimed to understand their performance, inheritance patterns, and heterosis effects on biomass yield. Their results showed that triploid genotypes exhibited significantly greater aboveground biomass (AGB) compared to diploid and tetraploid genotypes; however, biomass allocation ratios (i.e., ratios of leaf dry mass to stem dry mass, and root dry mass to stem dry mass) were significantly greater in tetraploid genotypes compared to triploids and diploids, and diploids had significantly lower biomass allocation ratios compared to both triploids and tetraploids[1]. In addition to biomass yield, Carlson et al. (2022) studied the inheritance patterns of gene expression on triploid F_1 progeny and their parents[2]. The results of their transcriptome analysis revealed that gene expression inheritance in the triploid F_1 progeny was mostly conserved and additive. However, a percentage of genes showed nonadditive inheritance patterns, ranging from 27% to 60% across the families. Transgressively expressed genes, which exhibited under- and over-dominant expression, accounted for a small percentage. The majority of the non-additive only genes showed dominance in the direction of the tetraploid parent[2]. Overall, findings from these studies contributed to our understanding of heterosis and can inform the development of improved willow bioenergy crops.

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[1] Carlson, C. H., & Smart, L. B. (2022). Heterosis for biomass-related traits in interspecific triploid hybrids of willow (*Salix* spp.). *BioEnergy Research*, *15*(2), 1042–1056. https://doi.org/10.1007/s12155-021-10305-0 | [2] Carlson, C. H., Choi, Y., Chan, A. P., Town, C. D., & Smart, L. B. (2022). Nonadditive gene expression is correlated with nonadditive phenotypic expression in interspecific triploid hybrids of willow (*Salix* spp.). *G3 Genes|Genomes|Genetics*, *12*(3), jkab436. https://doi.org/10.1093/g3journal/jkab436

iii. Genomics

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on the evolution, genetic basis, and pathways of sex determination in willows[1-6]. In particular, researchers identified candidate genes, explored genetic changes during sex chromosome transitions, and highlighted the importance of comparative studies in understanding sex determination mechanisms. In addition, studies were conducted investigating the impact of specific genes on protein abundance and identifying variations in gene copy numbers and expression between genotypes. Overall, the collective findings contributed to our understanding of the genetic pathways and gene expression patterns associated with sex determination in plants. Hu et al. (2023) investigated the transition from an XY system to a ZW system in willows and reported that the origins of sex chromosomes during homologous transitions may be more flexible than previously considered[1]. Feng et al. (2020) explored the pathways to sex determination in plants and the parallel evolution of molecular pathways underlying unisexual flowers. They reported that dioecy has independently evolved thousands of times in angiosperms, and that hormone response pathways, particularly cytokinin and ethylene response pathways, play a role in controlling unisexuality[2]. Hyden et al. (2021; 2023a; 2023b) investigated the role of specific genes in sex determination in willows[3-5]. They identified candidate genes involved in sex determination, such as AGO4, DRB1, GATA15, and ARR17. These genes showed differential expression between males and females and are expected to be present only in females. The expression of these genes results in differential abundance of proteins involved in floral development and sex determination processes[3-5]. Zhou et al. (2020) evaluated the gene content of palindromes in the female sex determination region of *Salix purpurea* L.[6]. Palindromes contain duplicated copies of genes involved in sex determination, such as the RR gene.

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[1] Hu, N., Sanderson, B. J., Guo, M., Feng, G., Gambhir, D., Hale, H., Wang, D., Hyden, B., Liu, J., Smart, L. B., DiFazio, S. P., Ma, T., & Olson, M. S. (2023). Evolution of a ZW sex chromosome system in willows. *Nature Communications*, *14*(1), 7144. https://doi.org/10.1038/s41467-023-42880-5 | [2] Feng, G., Sanderson, B. J., Keefover-Ring, K., Liu, J., Ma, T., Yin, T., Smart, L. B., DiFazio, S. P., & Olson, M. S. (2020). Pathways to sex determination in plants: How many roads lead to Rome? *Current Opinion in Plant Biology*, *54*, 61–68. https://doi.org/10.1016/j.pbi.2020.01.004 | [3] Hyden, B., Carper, D. L., Abraham, P. E., Yuan, G., Yao, T., Baumgart, L., Zhang, Y., Chen, C., O'Malley, R., Chen, J., Yang, X., Hettich, R. L., Tuskan, G. A., & Smart, L. B. (2023a). Functional analysis of *Salix purpurea* genes support roles for *ARR17* and *GATA15* as master regulators of sex determination. *Plant Direct*, *7*(11), e546. https://doi.org/10.1002/pld3.546 | [4] Hyden, B., Feng, K., Yates, T. B., Jawdy, S., Cereghino, C., Smart, L. B., & Muchero, W. (2023b). De Novo Assembly and annotation of 11 diverse shrub willow (*Salix*) genomes reveals novel gene organization in sex-linked regions. *International Journal of Molecular Sciences*, *24*(3), 2904. https://doi.org/10.3390/ijms24032904 | [5] Hyden, B., Carlson, C. H., Gouker, F. E., Schmutz, J., Barry, K., Lipzen, A., Sharma, A., Sandor, L., Tuskan, G. A., Feng, G., Olson, M. S., DiFazio, S. P., & Smart, L. B. (2021). Integrative genomics reveals paths to sex dimorphism in *Salix purpurea* L. *Horticulture Research*, *8*, 170. https://doi.org/10.1038/s41438-021-00606-y | [6] Zhou, R., Macaya-Sanz, D., Carlson, C. H., Schmutz, J., Jenkins, J. W., Kudrna, D., Sharma, A., Sandor, L., Shu, S., Barry, K., Tuskan, G. A., Ma, T., Liu, J., Olson, M., Smart, L. B., & DiFazio, S. P. (2020). A willow sex chromosome reveals convergent evolution of complex palindromic repeats. *Genome Biology*, *21*(1), 38. https://doi.org/10.1186/s13059-020-1952-4

c) *Eucalyptus*

i. Sections

Yost et al. (2021) aimed to determine the genetic variation and native origin of *Eucalyptus globulus* Labill. in California and to explore the factors influencing its naturalization in the region. They reported that *E. globulus* in California primarily originated from eastern Tasmania, with the genetic diversity of the Californian landrace being lower than that of the native Australian population. In addition, neither specific introduced genotype nor native origin influenced naturalization of *E. globulus* in California; instead, naturalization was influenced by local climate and disturbance factors. Overall, these findings contributed to our understanding of the naturalization patterns of *E. globulus* and highlight the importance of considering environmental factors along with genetics in invasion biology.

Yost, J. M., Wise, S. L., Love, N. L. R., Steane, D. A., Jones, R. C., Ritter, M. K., & Potts, B. M. (2021). Origins, diversity and naturalization of *Eucalyptus globulus* (Myrtaceae) in California. *Forests*, *12*(8), 1129. https://doi.org/10.3390/f12081129

ii. Breeding and Testing

Castro et al. (2021; 2022) highlighted the results of using top grafting as a technique to induce early flowering in Eucalyptus trees[1-2]. They conducted grafting experiments at different time periods before natural flowering and evaluated the survival rate, canopy area growth, and flowering capacity of the top grafts. In addition, the influence of paclobutrazol (PBZ), a growth regulator, on these traits was also examined. Overall, they concluded: 1) the top grafting technique was found to be viable for inducing early flowering in *Eucalyptus* trees, 2) the number of flower buds and fruits produced was satisfactory in both grafting periods (albeit higher for the grafts performed three months before natural flowering), and 3) the application of PBZ increased flowering but did not significantly affect survival or canopy area growth. Their information provided valuable insights into the use of top grafting as a technique for inducing early flowering in *Eucalyptus* trees. As such, their findings can be applied in tree improvement programs to obtain superior clones through self-pollination cycles[1-2]. Furthermore, Ibarra et al. (2023)

provided results from field tests comparing the growth and wood properties of a hybrid species (GloNi) derived from *Eucalyptus nitens* H. Deane & Maiden (NIT) and *E. globulus* (GLO) in two breeding zones, Arauco and Valdivia[3]. Their results provided valuable information for selecting suitable species for different breeding zones and understanding the performance of hybrid species in terms of growth and wood properties[3]. Rockwood et al. (2022) discussed the potential uses of *Eucalyptus amplifolia* Naudin and *Corymbia torelliana* (F. Muell.) K.D. Hill in Florida, USA, focusing on market opportunities for these woods that are currently limited but have potential for future expansion[4]. In particular, they highlighted specialty pulps, medium density fiberboard (MDF), wood-cement boards, plywood, oriented strand board, biochar feedstocks, biofuel and bioenergy production, windbreaks, dendroremediation, and weed suppression as potential opportunities[4].

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[1] Castro, C. A. D. O., Santos, G. A. D., Takahashi, E. K., Nunes, A. C. P., Souza, G. A. D., Resende, M. D. V. D., & Zanuncio, J. C. (2022). Top grafting to accelerate self-pollination in *Eucalyptus* breeding. *Revista Árvore*, *46*, e4630. https://doi.org/10.1590/1806-908820220000030 | [2] Castro, C. A. de O., dos Santos, G. A., Takahashi, E. K., Nunes, A. C. P., Souza, G. A., & de Resende, M. D. V. (2021). Accelerating *Eucalyptus* breeding strategies through top grafting applied to young seedlings. *Industrial Crops and Products*, *171*, 113906. https://doi.org/10.1016/j.indcrop.2021.113906 | [3] Ibarra, L., Hodge, G., & Acosta, J. J. (2023). Quantitative genetics of a hybrid population of *Eucalyptus nitens* × *Eucalyptus globulus*: Estimation of genetic parameters and implications for breeding strategies. *Forests*, *14*(2), 381. https://doi.org/10.3390/f14020381 | [4] Rockwood, D. L., Huber, D. A., Crawford, M. A., Rucks, P. C., Lamb, E., Fabbro, K. W., Minogue, P. J., Jump, R., & Hodge, G. R. (2022). *Eucalyptus amplifolia* and *Corymbia torelliana* in the southeastern USA: Genetic improvement and potential uses. *Forests*, *13*(1), 75. https://doi.org/10.3390/f13010075

iii. Genomics

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on the genomics of *Eucalyptus*, including population structure, genomic predictions, genetic containment, structural variation, adaptive introgression, and genomic selection[1-8]. Overall, this information contributed to our understanding of the genetic basis of important traits in *Eucalyptus* and has implications for breeding programs and the genetic improvement of *Eucalyptus* populations. Callister et al. (2022) explored the impact of accounting for population structure in genomic predictions of E. *globulus*[1]. They used the single-step genomic BLUP method to compare breeding value predictions from models that either excluded base population effects or included fixed genetic groups or marker-derived proxies called metafounders. They found that the inclusion of metafounders improved accuracy and stability in breeding value predictions[1]. Elorriaga et al. (2021) evaluated the use of CRISPR technology to disrupt the function of the LEAFY gene in *Eucalyptus* trees[2]. Their objective was to achieve genetic containment in *Eucalyptus* trees while retaining desirable vegetative growth traits, and they found that CRISPR disruption of the LEAFY gene resulted in sterile indeterminate inflorescences without significant adverse effects on juvenile vegetative growth or leaf morphology[2]. Similar results were reported by Nagle et al. (2023)[7]. Lötter et al. (2023) investigated the structural variation in *Eucalyptus* interspecific hybrids using long-read DNA sequencing data to assemble the haplogenomes of *Eucalyptus grandis* Hill & Maiden and *Eucalyptus urophylla* S.T. Blake hybrids, and they identified structural variants between the two haplogenomes, providing insights into genome structural rearrangement in these species[3]. Mostert-O'Neill et al. (2021) conducted a study on *E. grandis* to investigate the potential for adaptive genetic variation through hybridization with other species[4]. They reported that adaptive introgression may play a significant role in the ability of *E. grandis* to adapt to rapid climate change, identifying environmental factors that contributed to population differentiation patterns in *E. grandis*[4]. Mostert-O'Neill et al. (2022) studied the genomic consequences of artificial selection in *E. grandis* breeding and wild populations. Their aim was to understand the genetic differentiation between breeding and wild populations and identify the genomic changes that have occurred during domestication. They discovered that the breeding and wild populations were genetically distinct, indicating that artificial selection has led to genomic changes in *E. grandis*[5]. In addition to evaluating the efficiency of genomic selection compared to traditional breeding cycles, Mphahlele et al. (2020) conducted a study on genetic parameters, genomic selection accuracy, and genetic gains in *E. grandis*[6]. They reported that the use of a genomic relationship matrix improved breeding value prediction accuracy and genetic gains in *E. grandis*[6]. Rocha et al. (2022) conducted a GWAS to identify quantitative trait loci (QTLs) related to growth and wood quality traits in *E. grandis*, and they identified significant associations for both growth and wood quality traits and highlighted the importance of considering population structure and using multi-trait models in GWAS[8].

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[1] Callister, A. N., Bermann, M., Elms, S., Bradshaw, B. P., Lourenco, D., & Brawner, J. T. (2022). Accounting for population structure in genomic predictions of *Eucalyptus globulus*. *G3 Genes|Genomes|Genetics*, *12*(9), jkac180. https://doi.org/10.1093/g3journal/jkac180 | [2] Elorriaga, E., Klocko, A. L., Ma, C., Du Plessis, M., An, X., Myburg, A. A., & Strauss, S. H. (2021). Genetic containment in vegetatively propagated forest trees: CRISPR disruption of *LEAFY* function in *Eucalyptus* gives sterile indeterminate inflorescences and normal juvenile development. *Plant Biotechnology Journal*, *19*(9), 1743–1755. https://doi.org/10.1111/pbi.13588 | [3] Lötter, A., Duong, T. A., Candotti, J., Mizrachi, E., Wegrzyn, J. L., & Myburg, A. A. (2023). Haplogenome assembly reveals structural variation in *Eucalyptus* interspecific hybrids. *GigaScience*, *12*, giad064. https://doi.org/10.1093/gigascience/giad064 | [4] Mostert-O'Neill, M. M., Reynolds, S. M., Acosta, J. J., Lee, D. J., Borevitz, J. O., & Myburg, A. A. (2021). Genomic evidence of introgression and adaptation in a model subtropical tree species, *Eucalyptus grandis*. *Molecular Ecology*, *30*(3), 625–638. https://doi.org/10.1111/mec.15615 | [5] Mostert-O'Neill, M. M., Tate, H., Reynolds, S. M., Mphahlele, M. M., Van Den Berg, G., Verryn, S. D., Acosta, J. J., Borevitz, J. O., & Myburg, A. A. (2022). Genomic consequences of artificial selection during early domestication of a wood fibre crop. *New Phytologist*, *235*(5), 1944–1956. https://doi.org/10.1111/nph.18297 | [6] Mphahlele, M. M., Isik, F., Mostert-O'Neill, M. M., Reynolds, S. M., Hodge, G. R., & Myburg, A. A. (2020). Expected benefits of genomic selection for growth and wood quality traits in *Eucalyptus grandis*. *Tree Genetics & Genomes*, *16*(4), 49. https://doi.org/10.1007/s11295-020-01443-1 | [7] Nagle, M. F., Nahata, S. S., Zahl, B., de Rivera, A. N., Tacker, X. V., Elorriaga, E., Ma, C., Goralogia, G. S., Klocko, A. L., Gordon, M., Joshi, S., & Strauss, S. H. (2023). Knockout of floral and meiosis genes using CRISPR/Cas9 produces male-sterility in Eucalyptus without impacts on vegetative growth. *Plant Direct*, *7*(7), e507. https://doi.org/10.1002/pld3.507 | [8] Rocha, L. F., Benatti, T. R., de Siqueira, L., de Souza, I. C. G., Bianchin, I., de Souza, A. J., Fernandes, A. C. M., Oda, S., Stape, J. L., Yassue, R. M., Carvalho, H. F., Müller, N. A., Fladung, M., Acosta, J. J., Fritsche-Neto, R., & Tambarussi, E. V. (2022). Quantitative trait loci related to growth and wood quality traits in *Eucalyptus grandis* W. Hill identified through single- and multi-trait genome-wide association studies. *Tree Genetics & Genomes*, *18*(6), 38. https://doi.org/10.1007/s11295-022-01570-x

3. Plant Health, Resilience to Threats and Climate Change

a) Biotic Factors

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on various aspects of the interactions of poplars and willows with endophytes, pathogens, and environmental stressors[1-7]. Banan et al. (2024) contributed to the understanding of how endophytes can influence water use efficiency (WUE) in *P. trichocarpa* under water-deficit conditions[1]. They reported that endophyte inoculation can lead decreased stomatal conductance and increased intrinsic WUE (iWUE), but the impact on aboveground productivity may be limited. They highlighted the potential of endophytes as a tool for improving plant resilience and resource use efficiency in bioenergy feedstock systems[1]. Crowell et al. (2020a; 2020b; 2022) studied the susceptibility of different *Salix* species to two species of Melampsora rust, *Melampsora americana* and *Melampsora paradoxa*, and they identified *M. americana* as the most prevalent rust species in the northeastern United States[2-4]. They reported the presence of both vertical and horizontal resistance among willow genotypes, and they suggested that stomatal and trichome densities may contribute to rust resistance in *Salix*. Their findings have important implications for rust management in shrub willow cultivation and can guide future breeding efforts to develop resistant cultivars[2-4]. Doty et al. (2022) explored the potential of endophytes from wild *Populus* trees to act as biocontrol agents against plant pathogens[5]. They investigated the inhibitory mechanisms employed by these endophytes and their effectiveness against various plant pathogens. Their genomic analysis revealed the presence of gene clusters associated with antimicrobial activities in different endophyte strains, suggesting that the wild poplar tree microbiome could be a valuable source of beneficial endophyte strains for biocontrol applications against various pathogens[5]. Lenz et al. (2021) used metabolomics techniques to identify and quantify metabolites involved in signaling and cell wall remodeling in resistant and susceptible *P. trichocarpa* genotypes after inoculation with the fungal pathogen *Sphaerulina musiva*, the causal agent of Septoria canker disease[6]. They reported that resistant genotypes employed systemic acquired resistance, cell wall apposition, and lignin deposition as modes of resistance to *S. musiva*. In addition, susceptible genotypes lacked a robust defense response and showed depletion of metabolites involved in defense mechanisms. Their results provided useful information about the metabolic pathways and mechanisms associated with resistance and can inform breeding efforts to develop resistant poplar varieties[6]. Søndreli et al. (2020) identified *S. musiva* as the causal agent of an outbreak of Septoria canker on *P. trichocarpa* trees in Eastern Oregon, USA[7]. Their results demonstrated the varying susceptibility of different *P. trichocarpa* genotypes to *S. musiva*, as well as contributing to the importance of monitoring and managing this pathogen to protect tree health[7].

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[1] Banan, D., Sher, A., Doty, S. L., & Kim, S.-H. (2024). Endophyte mediated *Populus trichocarpa* water use efficiency is dependent on time of day and plant water status. *Phytobiomes Journal*, PBIOMES-11-22-0077-R. https://doi.org/10.1094/PBIOMES-11-22-0077-R | [2] Crowell, C. R., Bekauri, M. M., Cala, A. R., McMullen, P., Smart, L. B., & Smart, C. D. (2020a). Differential susceptibility of diverse *Salix* spp. To *Melampsora americana* and *Melampsora paradoxa*. *Plant Disease*, *104*(11), 2949–2957. https://doi.org/10.1094/PDIS-04-20-0718-RE | [3] Crowell, C. R., Wilkerson, D. G., Beckauri, M., Cala, A. R., McMullen, P. W., Mondo, S., Andreopoulos, W., Lipzen, A., Lail, K., Yan, M., Ng, V., Grigoriev, I. V., Smart, L. B., & Smart, C. D. (2022). The *Melampsora americana* population on *Salix purpurea* in the Great Lakes region is highly diverse with a contributory influence of clonality. *Phytopathology®*, *112*(4), 907–916. https://doi.org/10.1094/PHYTO-05-21-0201-R | [4] Crowell, C. R., Wilkerson, D. G., McMullen, P., Cala, A. R., Smart, L. B., & Smart, C. D. (2020b). Population biology of Melampsora americana and eQTL mapping for rust resistance in *Salix purpurea* shrub willow. *Plant Health 2020*. APS Annual Meeting. | [5] Doty, S. L., Joubert, P. M., Firrincieli, A., Sher, A. W., Tournay, R., Kill, C., Parikh, S. S., & Okubara, P. (2022). Potential biocontrol activities of *Populus* endophytes against several plant pathogens using different inhibitory mechanisms. *Pathogens*, *12*(1), 13. https://doi.org/10.3390/pathogens12010013 | [6] Lenz, R. R., Louie, K. B., Søndreli, K. L., Galanie, S. S., Chen, J.-G., Muchero, W., Bowen, B. P., Northen, T. R., & LeBoldus, J. M. (2021). Metabolomic patterns of Septoria canker resistant and susceptible *Populus trichocarpa* genotypes 24 hours postinoculation. *Phytopathology®*, *111*(11), 2052–2066. https://doi.org/10.1094/PHYTO-02-21-0053-R | [7] Søndreli, K. L., Keriö, S., Frost, K., Muchero, W., Chen, J.-G., Haiby, K., Gantz, C., Tuskan, G., & LeBoldus, J. M. (2020). Outbreak of Septoria canker caused by *Sphaerulina musiva* on *Populus trichocarpa* in eastern oregon. *Plant Disease*, *104*(12), 3266–3266. https://doi.org/10.1094/PDIS-03-20-0494-PDN

b) Abiotic Factors

There were several studies highlighting the importance of considering temperature, water stress, and genetic traits in forest management and bioengineering projects[1-4]. The results of these studies contributed to a better understanding of the physiological responses of different tree species to environmental stressors. Binkley et al. (2020) described the Tolerance of *Eucalyptus* Clones to Hydric, Thermal and Biotic Stresses (TECHS) project that focused on clonal plantations of *Eucalyptus* and examined the influence of temperature and water stress on tree growth across a 3,500 km gradient from the Amazon to Uruguay[1]. They reported that the mean annual increment (MAI) of stemwood production exhibited a humped pattern in relation to temperature, with the highest MAI observed at mean annual temperatures of 20 °C, and that whole-rotation MAI declined with increasing temperature and decreasing rainfall[1]. Chen et al. (2020) reported that drought resulted in a significant loss of stem xylem hydraulic conductance, leading to hydraulic failure and potential mortality in *E. urophylla* under drought stress[2]. In addition, decreased whole-plant hydraulic conductivity, sap flow density, and conversion of starch to soluble sugar were observed under drought conditions, thus highlighting the importance of considering both water and carbon dynamics in understanding drought-induced tree mortality[2]. Himes et al. (2021) identified hybrid poplar leaf traits that can serve as indicators of drought resistance[3]. They reported that carbon isotope discrimination ($\Delta^{13}C$) was not an effective indicator of drought resistance in hybrid poplar varieties, although abaxial stomatal density (ABAX) showed a significant correlation with varietal performance under drought stress. Overall, the best indicator of drought stress was a composite of multiple traits[3]. Keita et al. (2021) investigated the growth response of three willow species (*Salix discolor* Muhl., *Salix eriocephala* Michx., and *Salix interior* Rowlee) to different soil moisture treatments and its implications for riverbank soil bioengineering[4]. Their results highlighted the importance of considering species-specific responses to water stress when designing riverbank soil bioengineering projects. By selecting the appropriate willow species based on their tolerance to water stress, the success of these projects can be greatly improved[4].

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[1] Binkley, D., Campoe, O. C., Alvares, C. A., Carneiro, R. L., & Stape, J. L. (2020). Variation in whole-rotation yield among *Eucalyptus* genotypes in response to water and heat stresses: The TECHS project. *Forest Ecology and Management*, *462*, 117953. https://doi.org/10.1016/j.foreco.2020.117953 | [2] Chen, X., Zhao, P., Ouyang, L., Zhu, L., Ni, G., & Schäfer, K. V. R. (2020). Whole-plant water hydraulic integrity to predict drought-induced *Eucalyptus urophylla* mortality under drought stress. *Forest Ecology and Management*, *468*, 118179. https://doi.org/10.1016/j.foreco.2020.118179 | [3] Himes, A., Emerson, P., McClung, R., Renninger, H., Rosenstiel, T., & Stanton, B. (2021). Leaf traits indicative of drought resistance in hybrid poplar. *Agricultural Water Management*, *246*, 106676. https://doi.org/10.1016/j.agwat.2020.106676 | [4] Keita, N., Bourgeois, B., Evette, A., Tisserant, M., González, E., Breton, V., Goulet, C., & Poulin, M. (2021). Growth

response of cuttings to drought and intermittent flooding for three *Salix* species and implications for riverbank soil bioengineering. *Environmental Management*, *67*(6), 1137–1144. https://doi.org/10.1007/s00267-021-01444-3

c) Resilience to Threats and Climate Change

Many studies contributed to our understanding of plant adaptation, climate change mitigation, and sustainable land use practices. For example, several studies highlighted the importance of understanding the factors influencing leaf trait variation, the scale and sustainability of bioenergy expansion, the effects of eCO_2 on fine root dynamics, and the growth and response of *Eucalyptus* plantations to different treatments and environmental conditions[1-4]. Asao et al. (2020) tested the variation in leaf functional traits of *Eucalyptus camaldulensis* Dehnh. genotypes from different climates and reported that genotypic differences contributed significantly to the variation in aboveground biomass, indicating that some genotypes are better adapted to their specific environment in terms of growth[1]. There was no significant relationship between the climate of genotype provenance and leaf or performance traits, indicating that genotypes of *E. camaldulensis* are not specifically adapted to their climate of origin[1]. Calvin et al. (2021) discussed the importance of bioenergy for global climate change mitigation[2]. They described bioenergy with carbon capture and storage (BECCS), as well as integrated assessment models (IAMs) that link biophysical models of biosphere and atmosphere processes with socio-economic models to explore future scenarios of global energy, land, economy, and climate. Their key take home messages were that these IAMs provided valuable insights into the potential impacts of bioenergy deployment, but caution should be applied in interpreting their results due to uncertainties and limitations. In addition, alternative assessment methods can provide complementary insights and help inform sustainable bioenergy policies and practices[2]. Piñeiro et al (2020) studied the effects of elevated carbon dioxide (eCO_2) on fine root dynamics in a *Eucalyptus* woodland ecosystem and reported that the response of fine roots to eCO_2 was influenced by soil water availability and depth[3]. Under well-watered conditions, eCO_2 had limited effects on fine root biomass and production, while eCO_2 stimulated fine root growth and production under water-limited conditions[3]. Ryan et al. (2020) tested the growth and response of *Eucalyptus* plantations to different treatments and environmental conditions in southeastern Brazil[4]. They studied the effects of fertilization and water input on plantation growth and analyzed the relationships between growth and prior weather conditions, and the findings of this study were compared to the results of the TECHS Project described above[4].

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[1] Asao, S., Hayes, L., Aspinwall, M. J., Rymer, P. D., Blackman, C., Bryant, C. J., Cullerne, D., Egerton, J. J. G., Fan, Y., Innes, P., Millar, A. H., Tucker, J., Shah, S., Wright, I. J., Yvon-Durocher, G., Tissue, D., & Atkin, O. K. (2020). Leaf trait variation is similar among genotypes of *Eucalyptus camaldulensis* from differing climates and arises in plastic responses to the seasons rather than water availability. *New Phytologist*, *227*(3), 780–793. https://doi.org/10.1111/nph.16579 | [2] Calvin, K., Cowie, A., Berndes, G., Arneth, A., Cherubini, F., Portugal-Pereira, J., Grassi, G., House, J., Johnson, F. X., Popp, A., Rounsevell, M., Slade, R., & Smith, P. (2021). Bioenergy for climate change mitigation: Scale and sustainability. *GCB Bioenergy*, *13*(9), 1346–1371. https://doi.org/10.1111/gcbb.12863 | [3] Piñeiro, J., Ochoa-Hueso, R., Drake, J. E., Tjoelker, M. G., & Power, S. A. (2020). Water availability drives fine root dynamics in a *Eucalyptus* woodland under elevated atmospheric CO_2 concentration. *Functional Ecology*, *34*(11), 2389–2402. https://doi.org/10.1111/1365-2435.13660 | [4] Ryan, M. G., Stape, J. L., Binkley, D., & Alvares, C. A. (2020). Cross-site patterns in the response of *Eucalyptus* plantations to irrigation, climate and intra-annual weather variation. *Forest Ecology and Management*, *475*, 118444. https://doi.org/10.1016/j.foreco.2020.118444

4. Production Systems for the Bioeconomy

a) Nursery Practices and Propagation Techniques

Two studies provided insights into the growth and development of *Eucalyptus* seedlings[1-2]. Acevedo et al. (2021) highlighted the importance of optimal N concentration for promoting *E. globulus* seedling growth, as well as the use of a SPAD meter for monitoring N status[1]. They showed that 300 mg N L^{-1} was optimum, with seedlings exhibiting maximum growth, enhanced root growth, and higher tissue nutrient concentrations at this rate. In addition, they found the use of a SPAD meter, which measures chlorophyll content, could be an effective tool for monitoring N status in forest nurseries[1]. Chu et al. (2023) emphasized the potential benefits of using bagasse and zeolite in sewage sludge compost to reduce the concentration and bioavailability of potentially toxic elements (PTEs) in soil[2]. The addition of composts to the soil promoted growth of *Eucalyptus urophyllus* S.T. Blake seedlings, but the addition of sewage sludge compost increased concentrations of PTEs in the seedlings. Therefore, combined addition of bagasse and zeolite were shown to be an effective strategy for reducing the environmental risks associated with sewage sludge compost application[2]. Overall, these findings contributed to our understanding of seedling growth and provided practical recommendations for nutrient management in forest nurseries and the safe use of compost in soil.

[1] Acevedo, M., Rubilar, R., Dumroese, R. K., Ovalle, J. F., Sandoval, S., & Chassin-Trubert, R. (2021). Nitrogen loading of *Eucalyptus globulus* seedlings: Nutritional dynamics and influence on morphology and root growth potential. *New Forests*, *52*(1), 31–46. https://doi.org/10.1007/s11056-020-09778-2 | [2] Chu, S., Xian, L., Zhao, N., Lai, C., Yang, W., Wang, J., Long, M., Liao, D., Ouyang, J., Wang, Z., Jacobs, D. F., & Zeng, S. (2023). Combined addition of bagasse and zeolite stabilizes potentially toxic elements in sewage sludge compost and improves *Eucalyptus urophylla* seedling growth. *Forest Ecology and Management*, *539*, 121003. https://doi.org/10.1016/j.foreco.2023.121003

b) Planted Forests

i. *Populus*

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on the cultivation, productivity, and profitability of hybrid poplar trees for bioenergy, bioproducts, and biofuels[1-8]. Studies focused on factors that influence growth and performance of poplar trees, including pests and diseases, leaf area index (LAI), foliar nitrogen (N), stand density, fertilization, clone selection, and site suitability. Overall, the findings can be used to inform decision-making processes related to the development of poplar-based environmental systems and the sustainable production of feedstocks for the bioeconomy. Ghezehei et al. (2021) tested the early growth and productivity of poplar trees in North Carolina, USA[1]. Their study focused on the influence of pests and diseases, crown-related traits such as leaf area index (LAI), foliar nitrogen (N), and stand density, and silvicultural aspects such as fertilization, clone selection, and site suitability. Also, they highlighted the importance of considering real-world conditions when estimating the productivity of poplar plantations based on small-scale trials[1]. Ghezehei et al. (2020) examined the survival, growth, and biomass of 89 poplar clones in the coastal southeastern USA at four- and eight-year rotations[2]. They recommended selecting site-suitable clones for productivity-focused stands based on productivity first, then narrowing down the selection based on survival and rotation length. Changes were observed in the most site-suitable clones between longer and shorter rotations[2]. Pilipović et al. (2022) quantified water use efficiency (WUE) of hybrid poplar clones at three different sites in the Midwestern United States, with results showing significant variation in WUE and biomass production among different clones and sites[3]. As such, they highlighted the importance of considering site-specific factors when selecting poplar clones for biomass production. For example, there is a need to match poplar genotypes to site conditions for successful bioenergy deployment, particularly in water-limited environments[3]. Renninger et al. (2023) defined water use strategies of different genotypes of *Populus deltoides* and its hybrids grown for biomass production and ecosystem services in the Lower Mississippi Alluvial Valley, USA[4]. In particular, *P. deltoides* × *P. maximowiczii* 'DM' hybrids had lower WUE and higher leaf area loss compared to other genotypes, while *P. deltoides* × *P. deltoides* 'DD' genotypes had higher WUE and larger leaf areas. Their findings have implications for selecting genotypes with desirable water use strategies for sustainable tree growth and productivity, with 'DD' genotypes exhibiting more efficient water use strategies, while 'DM' hybrids being more susceptible to water stress[4]. Similarly, Renninger et al. (2022) compared the physiological functioning and productivity of *P.*

deltoides and three hybrid clones in the southeastern US[5]. Genotypes were tested under different site conditions and endophyte inoculations, and their results provided valuable insights into the performance and potential of these genotypes for biomass production and environmental remediation purposes[5]. Renninger et al. (2021) provided similar results, with genotype × environment interactions governing biomass, growth, and physiology traits[6]. Furthermore, Rogers et al. (2023) conducted a literature review detailing the methodologies used to measure poplar water use, as well as intrinsic and extrinsic factors influencing poplar water use[7]. They concluded that performance varied among different hybrid types and tree age classes, which can affect water use. Similarly, planting density also had a significant impact on hybrid poplar water use, with different densities leading to variations in growth, productivity, and morphology. Their findings are useful to guide decision-making in the design and management of poplar-based production systems[7]. Stanton et al. (2021) discussed the practice and economics of hybrid poplar biomass production for biofuels and bioproducts in the Pacific Northwest, USA[8]. In addition to the chemical composition of hybrid poplar biomass and production costs over a 20-year rotation, they evaluated management practices, yields, and harvesting methods. Their information can be used to inform decision-making processes related to the development of a biorefining industry in the region and the sustainable production of biofuels and bioproducts[8].

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[1] Ghezehei, S. B., Ewald, A. L., Hazel, D. W., Zalesny, R. S., & Nichols, E. G. (2021). Productivity and profitability of poplars on fertile and marginal sandy soils under different density and fertilization treatments. *Forests*, *12*(7), 869. https://doi.org/10.3390/f12070869 | [2] Ghezehei, S. B., Wright, J., Zalesny, R. S., Nichols, E. G., & Hazel, D. W. (2020). Matching site-suitable poplars to rotation length for optimized productivity. *Forest Ecology and Management*, *457*, 117670. https://doi.org/10.1016/j.foreco.2019.117670 | [3] Pilipović, A., Headlee, W. L., Zalesny Jr., R. S., Pekeč, S., & Bauer, E. O. (2022). Water use efficiency of poplars grown for biomass production in the Midwestern United States. *GCB Bioenergy*, *14*(3), 287–306. https://doi.org/10.1111/gcbb.12887 | [4] Renninger, H. J., Pitts, J. J., & Rousseau, R. J. (2023). Comparisons of biomass, water use efficiency and water use strategies across five genomic groups of *Populus* and its hybrids. *GCB Bioenergy*, *15*(1), 99–112. https://doi.org/10.1111/gcbb.13014 | [5] Renninger, H. J., Stewart, L. F., Freeman, J. L., & Rousseau, R. J. (2022). Physiological functioning and productivity in eastern cottonwood and hybrid poplars on contrasting sites in the Southeastern US. *BioEnergy Research*, *15*(2), 1057–1070. https://doi.org/10.1007/s12155-021-10377-y | [6] Renninger, H. J., Stewart, L. F., & Rousseau, R. J. (2021). Water use, efficiency, and stomatal sensitivity in eastern cottonwood and hybrid poplar varietals on contrasting sites in the southeastern United States. *Frontiers in Forests and Global Change*, *4*, 704799. https://doi.org/10.3389/ffgc.2021.704799 | [7] Rogers, E. R., Zalesny, R. S., Lin, C.-H., & Vinhal, R. A. (2023). Intrinsic and extrinsic factors influencing *Populus* water use: A literature review. *Journal of Environmental Management*, *348*, 119180. https://doi.org/10.1016/j.jenvman.2023.119180 | [8] Stanton, B. J., Bourque, A., Coleman, M., Eisenbies, M., Emerson, R. M., Espinoza, J., Gantz, C., Himes, A., Rodstrom, A., Shuren, R., Stonex, R., Volk, T., & Zerpa, J. (2021). The practice and economics of hybrid poplar biomass production for biofuels and bioproducts in the Pacific Northwest. *BioEnergy Research*, *14*(2), 543–560. https://doi.org/10.1007/s12155-020-10164-1

ii. *Salix*

Three studies provided insights into the sustainable production of willow[1-3]. Information obtained from these studies can be used to guide the selection, management, and optimization of willow genotypes and plantations for maximizing productivity and ecosystem services. Gouker et al. (2021) highlighted the importance of selecting appropriate genotypes and planting designs for maximizing biomass yield[1]. Conducted in Geneva, New York, USA, results included differences in budbreak rates, biomass traits, wood composition, and calorific value among genotypes and between two planting designs. Their information can be valuable for selecting and managing willow genotypes for biomass production[1]. Montes et al. (2021) estimated the potential and water-limited yield of six elite willow cultivars grown in a commercial-scale plantation in Centre County, Pennsylvania, USA[2]. They found that planting density had a significant impact on biomass yield, and the information obtained can be valuable for optimizing the cultivation of willow for biomass production[2]. Muklada et al. (2022) discussed favorable morphological characteristics and nutritional value of willow, making it a promising crop for forage production and bioenergy purposes[3]. Their results highlighted the potential of willow as a sustainable and productive crop for various agricultural applications[3].

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[1] Gouker, F. E., Fabio, E. S., Serapiglia, M. J., & Smart, L. B. (2021). Yield and biomass quality of shrub willow hybrids in differing rotation lengths and spacing designs. *Biomass and Bioenergy*, *146*, 105977. https://doi.org/10.1016/j.biombioe.2021.105977 | [2] Montes, F., Fabio, E. S., Smart, L. B., Richard, T. L., Añó, R. M., & Kemanian, A. R. (2021). A semi-commercial case study of willow biomass production in the northeastern United States. *Agronomy Journal*, *113*(2), 1287–1302. https://doi.org/10.1002/agj2.20603 | [3] Muklada, H., Fabio, E. S., & Smart, L. B. (2022). Growth, nitrogen uptake, and nutritional value of a diverse panel of shrub willow (*Salix* spp.) genotypes in response to nitrogen fertilization. *Agronomy*, *12*(11), 2678. https://doi.org/10.3390/agronomy12112678

iii. *Eucalyptus*

Research on *Eucalyptus* plantations has provided valuable insights into the factors influencing growth, including climate, genotype, and spacing. For example, several studies highlighted the importance of proper management practices for maximizing productivity, such as selecting appropriate genotypes, optimizing spacing, and managing competition[1-6]. Overall, these results contributed to the understanding of *Eucalyptus* growth and adaptation and can inform management practices and genotype selection for specific environments. In particular, Campoe and Binkley (2020) described the TECHS Project, a comprehensive research initiative that aims to understand the factors influencing the growth of *Eucalyptus* plantations[1]. Including intensive experimentation across diverse geography, their findings have provided valuable insights contributing to the development of improved management practices for *Eucalyptus* plantations[1]. Similarly, Campoe et al. (2020) studied the effects of climate and genotype on carbon fluxes and partitioning in *Eucalyptus* plantations[2]. They asserted that understanding how carbon budgets differ across sites and why clones can differ in wood production was crucial for improving productivity in stressful environments. In addition, they highlighted the need for further research on genotype × environment interactions to develop more process-based production methods and recommend genotypes with higher tolerance to different climatic regions[2]. Conti et al. (2020) investigated the climatic characterization and physiological parameters of *Eucalyptus* clones at three sites within the TECHS research platform[3]. Leaf turgor loss point and leaf water potential measurements showed variations among seasons and clones at each site, contributing to the conclusions that there were differences in drought tolerance among the *Eucalyptus* clones, but these differences were not solely determined by the leaf turgor loss point. Overall, the study provided valuable insights into the climatic characterization and physiological parameters of *Eucalyptus* clones, which can contribute to the understanding of their adaptation to different environmental conditions[3]. Rubilar et al. (2020) studied the effects of climate and water availability on the growth of different *Eucalyptus* genotypes and reported irrigation increased cumulative growth and leaf area index for most taxa[4]. They emphasized the need for strategic allocation of genotypes to contrasting drought risk environments and the importance of understanding genotype × environment interactions for predicting and maximizing plantation productivity in the face of climate change[4]. Hall et al. (2019) used various equations and models to analyze the growth and productivity data of *Eucalyptus benthamii* in the southeastern US and Brazil[5]. They developed the growth and yield models based on factors such as age, dominant height, and site index. Their conclusions provided valuable insights into the growth, productivity, and management of *Eucalyptus* plantations, including the impact on water resources, the potential for bioenergy production, and the development of modeling techniques to improve predictions[5]. Stape et al. (2022) reported that spacing and geometric layout had significant effects on the growth and productivity of *Eucalyptus grandis* × *Eucalyptus urophylla* clones in Brazil[6]. Square planting designs with high tree densities were found to be most productive, while wide spacing between rows may have cost-saving benefits or allow for intercropping. These findings provided valuable insights for forest managers and researchers in optimizing productivity of *Eucalyptus* plantations[6].

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[1] Campoe, O. C., & Binkley, D. (2020). Environmental and genetic influences on growth in *Eucalyptus* plantations: The TECHS special issue. *Forest Ecology and Management*, *476*, 118464. https://doi.org/10.1016/j.foreco.2020.118464 | [2] Campoe, O. C., Alvares, C. A., Carneiro, R. L., Binkley, D., Ryan, M. G., Hubbard, R. M., Stahl, J., Moreira, G., Moraes, L. F., & Stape, J. L. (2020). Climate and genotype influences on carbon fluxes and partitioning in *Eucalyptus* plantations. *Forest Ecology and Management*, *475*, 118445. https://doi.org/10.1016/j.foreco.2020.118445 | [3] Conti Junior, J. L. F., De Araujo, M. J., De Paula, R. C., Queiroz, T. B., Hakamada, R. E., & Hubbard, R. M. (2020). Quantifying turgor loss point and leaf water potential across contrasting *Eucalyptus* clones and sites within the TECHS research platform. *Forest Ecology and Management*, *475*, 118454. https://doi.org/10.1016/j.foreco.2020.118454 | [4] Rubilar, R., Hubbard, R., Emhart, V., Mardones, O., Quiroga, J. J., Medina, A., Valenzuela, H., Espinoza, J., Burgos, Y., & Bozo, D. (2020). Climate and water availability impacts on early growth and growth efficiency of Eucalyptus genotypes: The importance of GxE interactions. *Forest Ecology and Management*, *458*, 117763. https://doi.org/10.1016/j.foreco.2019.117763 | [5] Hall, K. B., Stape, J., Bullock, B. P., Frederick, D., Wright, J., Scolforo, H. F., & Cook, R. (2019). A growth and yield model for *Eucalyptus benthamii* in the southeastern United States. *Forest Science*, *66*(1), 25–37. https://doi.org/10.1093/forsci/fxz061 | [6] Stape, J. L., Silva, C. R., & Binkley, D. (2022). Spacing and geometric layout effects on the productivity of clonal *Eucalyptus* plantations. *Trees, Forests and People*, *8*, 100235. https://doi.org/10.1016/j.tfp.2022.100235

c) Naturally Regenerating Forest

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on naturally regenerating forests of *Populus tremuloides* Michx. (quaking aspen)[1-8]. These studies investigated various aspects of the species, including its genetic structure, population history, range dynamics, phenology, trait variation, ecological importance, and management strategies. The studies provided valuable insights into the evolutionary history, ecological dynamics, and conservation of quaking aspen. Bagley et al. (2020) explored the genetic structure, population history, and range dynamics of quaking aspen in North America[1]. They identified three distinct genetic clusters within the species range and provided evidence for stable-edge dynamics in the southwestern portions of the range[1]. Blonder et al. (2023) investigated the spatiotemporal patterns and drivers of canopy phenology in quaking aspen[2]. They reported that phenological traits vary across space and time and are influenced by genetic factors, such as cytotype and sex, as well as environmental factors, such as temperature, snowmelt date, and soil moisture. A primary emphasis of their results was the importance of considering lagged environmental effects and genetic factors in understanding phenological variation in quaking aspen[2]. Cole et al. (2021) examined the levels of trait variation, heritabilities, and ontogenetic trajectories of various traits in aspen trees[3]. They reported high levels of genotypic variation in growth, defense, and reproductive traits, and they identified trade-offs between growth and defense. They stressed the importance of considering ontogenetic patterns and genetic variability in understanding trait variation in aspen trees[3]. Crouch et al. (2023) provided a systematic review of aspen ecology and management in the southwest US[4]. They identified factors influencing aspen forest dynamics, such as climate, fire, ungulates, insects, and diseases, as well as management strategies to promote aspen ecosystem resilience and adaptive capacity. Their review emphasized the importance of considering fire, ungulate browse, and climate in shaping aspen populations[4]. DeRose et al. (2022) evaluated the relationship between polyploidy, growth, and defense mechanisms in natural populations of quaking aspen[5]. They found that polyploidy influences the allocation of resources and trade-offs between growth and chemical defense in aspen populations. Overall, their study provided insights into the genetic basis of trait variation in aspen trees and the ecological dynamics of plant populations[5]. Ding et al. (2020) tested the performance of aspen trees in different breeding regions and assessed the phenotypic traits of the offspring[6]. They reported high genetic variation in growth and adaptive traits among aspen genotypes and provided valuable information for tree improvement programs in a changing climate[6]. Kruger et al. (2020) quantified the costs of allocation to chemical defenses in aspen trees[7]. Allocation to chemical defenses is costly for aspen trees under conditions of intense intraspecific competition and resource limitation, and the study highlighted the importance of considering the independent roles of chemical defenses and other growth co-determinants in understanding the costs of allocation to defense[7]. Lindroth et al. (2023) tested the phytochemical variation in trembling aspen in the Intermountain West region of North America[8]. They reported high genetic variation in foliar chemistry among aspen genotypes and ontogenetic changes in chemical expression as ramets age. In addition, the phytochemical profiles of western and Great Lakes populations of aspen were compared, highlighting the ecological implications of phytochemical variation[8].

[1] Bagley, J. C., Heming, N. M., Gutiérrez, E. E., Devisetty, U. K., Mock, K. E., Eckert, A. J., & Strauss, S. H. (2020). Genotyping-by-sequencing and ecological niche modeling illuminate phylogeography, admixture, and pleistocene range dynamics in quaking aspen (*Populus tremuloides*). *Ecology and Evolution*, *10*(11), 4609–4629. https://doi.org/10.1002/ece3.6214 | [2] Blonder, B. W., Brodrick, P. G., Chadwick, K. D., Carroll, E., Cruz-de Hoyos, R. M., Expósito-Alonso, M., Hateley, S., Moon, M., Ray, C. A., Tran, H., & Walton, J. A. (2023). Climate lags and genetics determine phenology in quaking aspen (*Populus tremuloides*). *New Phytologist*, *238*(6), 2313–2328. https://doi.org/10.1111/nph.18850 | [3] Cole, C. T., Morrow, C. J., Barker, H. L., Rubert-Nason, K. F., Riehl, J. F. L., Köllner, T. G., Lackus, N. D., & Lindroth, R. L. (2021). Growing up aspen: Ontogeny and trade-offs shape growth, defence and reproduction in a foundation species. *Annals of Botany*, *127*(4), 505–517. https://doi.org/10.1093/aob/mcaa070 | [4] Crouch, C. D., Rogers, P. C., Moore, M. M., & Waring, K. M. (2023). Building ecosystem resilience and adaptive capacity: A systematic review of aspen ecology and management in the Southwest. *Forest Science*, *69*(3), 334–354. https://doi.org/10.1093/forsci/fxad004 | [5] DeRose, R. J., Gardner, R. S., Lindroth, R. L., & Mock, K. E. (2022). Polyploidy and growth—Defense tradeoffs in natural populations of western quaking aspen. *Journal of Chemical*

Ecology, *48*(4), 431–440. https://doi.org/10.1007/s10886-022-01355-5 | [6] Ding, C., Hamann, A., Yang, R.-C., & Brouard, J. S. (2020). Genetic parameters of growth and adaptive traits in aspen (*Populus tremuloides*): Implications for tree breeding in a warming world. *PLOS ONE*, *15*(3), e0229225. https://doi.org/10.1371/journal.pone.0229225 | [7] Kruger, E. L., Keefover-Ring, K., Holeski, L. M., & Lindroth, R. L. (2020). To compete or defend: Linking functional trait variation with life-history tradeoffs in a foundation tree species. *Oecologia*, *192*(4), 893–907. https://doi.org/10.1007/s00442-020-04622-y | [8] Lindroth, R. L., Wooley, S. C., Donaldson, J. R., Rubert-Nason, K. F., Morrow, C. J., & Mock, K. E. (2023). Phenotypic variation in phytochemical defense of trembling aspen in western North America: Genetics, development, and geography. *Journal of Chemical Ecology*, *49*(5–6), 235–250. https://doi.org/10.1007/s10886-023-01409-2

d) Agroforestry and Trees Outside Forest

There are many potential benefits of incorporating short rotation woody crops (SRWCs) into conventional agricultural practices and agroforestry systems. Although these purpose-grown trees have the potential to enhance biomass productivity, carbon sequestration, reduction of GHG, and nutrient accrual, the adoption of SRWCs for agroforestry requires support in terms of information, resources, and networking opportunities for farmers and growers. Several studies have addressed the biological, ecological, and social aspects of integrating SRWCs with agroforestry[1-5]. Gamble et al. (2020) described a study investigating the effects of different alley cropping systems on soil organic carbon (SOC) sequestration and nutrient accrual in Minnesota, USA[1]. Their results provided valuable insights into the potential of these systems for agroforestry and climate change mitigation[1]. Ile et al. (2022) reviewed the efficacy of producing SRWCs in the southeastern US to optimize biomass productivity, aboveground carbon sequestration, and belowground carbon sequestration in agroforestry systems[2]. They concluded that using SRWCs for bioenergy production can lead to more efficient use of forest resources, improved forest management, and the growth of a sustainable green economy, while the establishment of SRWCs on degraded agricultural lands can help restore soil health and enhance soil carbon storage[2]. Ile et al. (2023) documented a case study evaluating farmers' motivations and perceptions regarding the adoption of SRWCs in North Carolina[3]. They identified four key factors strongly influencing the adoption process: 1) market availability, 2) education awareness, 3) funding, and 4) social networking. Tailored information and support, including the establishment of farmers' cooperatives and online training courses for extension agents, were recommended to facilitate the adoption of SRWCs. Overall, farmers between the ages of 40 to 50 years old with larger land sizes were most likely to integrate SRWCs into their traditional agricultural systems[3]. Furthermore, from a biophysical perspective, Salceda et al. (2023) compared the removal efficiencies of total nitrogen (TN) and dissolved nitrogen (DN) in shallow groundwater by grass-only buffers and tree + grass buffers on grazing watersheds with deep loess soils[4]. They reported that both types of buffers were effective in reducing the concentrations of DN and TN in shallow groundwater, and that the establishment of sufficiently wide buffers can help mitigate groundwater contamination by nutrients and protect water quality[4]. Shults et al. (2020) measured the productivity and nutrient return of cover crops, plant-available soil nitrogen, and poplar leaf nutrients in different spacing treatments[5]. They reported that red clover cover crops can enhance nutrient availability and biomass production, but the effect on soil nitrogen and poplar leaf nutrients may vary depending on the spacing and vegetation treatments[5].

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[1] Gamble, J. D., Johnson, G. A., Current, D. A., Wyse, D. L., Zamora, D. S., & Sheaffer, C. C. (2020). Alley cropping affects perennial bioenergy crop root distribution, carbon, and nutrient stocks. *Agronomy Journal*, *112*(5), 3718–3732. https://doi.org/10.1002/agj2.20350 | [2] Ile, O. J., McCormick, H., Skrabacz, S., Bhattacharya, S., Aguilos, M., Carvalho, H. D. R., Idassi, J., Baker, J., Heitman, J. L., & King, J. S. (2022). Integrating short rotation woody crops into conventional agricultural practices in the southeastern United States: A review. *Land*, *12*(1), 10. https://doi.org/10.3390/land12010010 | [3] Ile, O., Typhina, E., Brannum, K., Parajuli, R., Bardon, R., & King, J. (2023). Toward the adoption of new farming systems among farmers: A case study of short rotation woody crops in North Carolina. *Journal of Extension*, *61*(1). https://doi.org/10.34068/joe.61.01.09 | [4] Salceda, M., Udawatta, R. P., Anderson, S. H., Mendis, S. S., & Liu, F. (2023). Agroforestry buffers on nitrogen reduction in groundwater on a grazed hillslope. *Agrosystems, Geosciences & Environment*, *6*(2), e20370. https://doi.org/10.1002/agg2.20370 | [5] Shults, P., Nzokou, P., & Koc, I. (2020). Nitrogen contributions of alley cropped *Trifolium pratense* may sustain short rotation woody crop yields on marginal lands. *Nutrient Cycling in Agroecosystems*, *117*(2), 261–272. https://doi.org/10.1007/s10705-020-10068-8

e) Harvesting

Several studies provided valuable insights into harvesting of poplars, willows, and eucalypts in the US, with key areas of study including understanding the impact of harvest timing, cultivar selection, field drying, and logistics optimization on biomass production, quality, and cost optimization[1-5]. Overall, the findings of these studies may inform decision-making and policy development in the bioenergy sector, contributing to the development of more efficient and sustainable biomass production and utilization practices. De Souza et al. (2022) investigated the effects of harvest timing on biomass production and nutrient removal in shrub willow crops[1]. They found that late-season harvests yielded more biomass compared to early-season harvests, and that second rotation yield was also higher than first rotation yield. Harvest timing affected nutrient removal, with nitrogen removal being highest in January and lowest in April[1]. Eisenbies et al. (2021) summarized the results of a study on the performance of a single-pass cut-and-chip harvester in commercial-scale short-rotation poplar crops[2]. Their objective was to understand the dynamics of material capacity and fuel consumption in poplar biomass crops, which can improve economic and environmental assessments of these systems. They showed that material capacity is influenced by standing biomass and field conditions, with material capacity increasing steadily with standing biomass, and that fuel consumption increases with tree height and is more pronounced in wetter weather conditions[2]. Eisenbies et al. (2020) provided information on a study for collecting harvester performance data from commercial-scale willow harvests on several sites in New York, USA[3]. Overall, they evaluated the performance of the harvesters based on material capacity and fuel consumption, and they analyzed the impact of independent variables such as standing biomass, rainfall, and season[3]. Rockwood et al. (2023) focused on field drying of *Eucalyptus* biomass in Florida, USA, and its potential to enhance biomass quality[4]. They concluded that field drying effectively reduced wood moisture content and enhanced biomass quality. The duration of field drying affected drying, but species, tree size, and tree form did not have a significant impact. Their findings have implications for the energy production industry, as reducing the moisture content of woody biomass can improve the efficiency of conversion processes and reduce energy costs[4]. Wang et al. (2020) discussed the optimization of biomass supply chains and the delivered cost of multiple biomass feedstocks in the northeastern US[5]. They identified the most cost-efficient logistics for biomass transportation and analyzed the factors that affect the delivered cost. Overall, supplying feedstocks to local and relatively small to medium-sized facilities may reduce transportation costs and make the overall economics feasible. These and other findings of the study may be used to inform decision-making and policy development in the bioenergy sector[5].

[1] De Souza, D. P., Eisenbies, M. H., & Volk, T. A. (2022). Growing season harvests of shrub willow (*Salix* spp.) have higher nutrient removals and lower yields compared to dormant-season harvests. *Forests*, *13*(11), 1936. https://doi.org/10.3390/f13111936 | [2] Eisenbies, M. H., Volk, T. A., DeSouza, D., Hallen, K., Stanton, B., Espinoza, J., Himes, A., Shuren, R., Stonex, R., Summers, B., & Zerpa, J. (2021). An assessment of the harvesting and fuel performance of a single-pass cut-and-chip harvester in commercial-scale short-rotation poplar crops as influenced by crop and weather conditions. *Biomass and Bioenergy*, *149*, 106075. https://doi.org/10.1016/j.biombioe.2021.106075 | [3] Eisenbies, M. H., Volk, T. A., De Souza, D. P. L., & Hallen, K. W. (2020). Cut-and-chip harvester material capacity and fuel performance on commercial-scale willow fields for varying ground and crop conditions. *GCB Bioenergy*, *12*(6), 380–395. https://doi.org/10.1111/gcbb.12679 | [4] Rockwood, D. L., Tamang, B., & Ellis, M. F. (2023). Field drying for enhancing biomass quality of *Eucalyptus* logs and trees in Florida, USA. *Forests*, *14*(5), 899. https://doi.org/10.3390/f14050899 | [5] Wang, Y., Wang, J., Schuler, J., Hartley, D., Volk, T., & Eisenbies, M. (2020). Optimization of harvest and logistics for multiple lignocellulosic biomass feedstocks in the northeastern United States. *Energy*, *197*, 117260. https://doi.org/10.1016/j.energy.2020.117260

f) Utilization for Wood Products

Several research studies contributed to the development of sustainable lignocellulosic fibers from renewable resources using green chemistry. The findings have implications for the production of pellets, medium density fiberboard (MDF), packaging, bioplastics, sanitary towels, wipes, and other products in the bio-based and circular economy[1-5]. Overall, these studies highlighted the importance of sustainable utilization of bioresources and the need for alternative pulping methods and raw materials to reduce ecological damage and promote efficient recycling of lignocellulosic fibers. Elniski et al. (2023) discussed the use of lignin as an additive to enhance the properties of willow pellets, which are used as a renewable energy source[1]. While lignin interacts with cellulose and hemicelluloses to promote bonding during pellet production, its effect on bulk density and ash content of pellets is inconsistent. For example, lignin generally increases the energy content of pellets, but its impurities can reduce energy content[1]. Ghezehei and Saloni (2023) evaluated the suitability of poplar stem-wood samples as feedstocks for pellet production, based on feedstock source location/region, age of stands, poplar clones, and tree stem sections[2]. They identified the best-performing poplar clones for each region and examined the effects of stem position on feedstock quality, comparing their results to pellet quality threshold values[2]. Himes et al. (2021) described the variation in wood properties [i.e., specific gravity, dimensional stability, hardness, screw withdrawal, and bending strength and stiffness {modulus of rupture (MOR) and modulus of elasticity (MOE), respectively}] of hybrid poplar grown in Boardman, Oregon, USA[3]. They assessed radial and vertical stem positions and determined wind influenced significant differences in some traits between different sides of the trees. In addition, boards milled closer to the bark had greater MOE and MOR than those from interior stem sections. Their results may be used to target specific stem positions for different applications[3]. Rockwood et al. (2022) highlighted the suitability of different poplar and eucalypt wood species and genotypes for MDF production in Florida, USA[4]. They analyzed the physical and mechanical properties of MDF panels, and tested effects from species, genotype, and log. Their results provided valuable insights for the selection of wood materials for MDF manufacturing[4]. Salem et al. (2021) explored the dynamics of fiber production from wood, non-wood, and agro-residues using carbonate hydrolysis and a mild kraft process without bleaching agents[5]. Their objective was to identify a sustainable alternative to synthetic polymer feedstocks for the production of packaging, bioplastics, sanitary towels, wipes, and related products. Based on their results, carbonate hydrolysis and mild kraft pulping can produce higher value fibers with sustainable properties[5].

[1] Elniski, A., Dongre, P., & Bujanovic, B. M. (2023). Lignin use in enhancing the properties of willow pellets. *Forests*, *14*(10), 2041. https://doi.org/10.3390/f14102041 | [2] Ghezehei, S. B., & Saloni, D. (2023). Assessment of feedstock quality of poplars (*Populus* L.) using selected pellet-quality parameters. *BioEnergy Research*, *17*(2), 993–1003. https://doi.org/10.1007/s12155-023-10711-6 | [3] Himes, A., Leavengood, S., & Polinko, A. (2021). Variation in wood properties of hybrid poplar lumber by radial and vertical position in stem: A case study from Boardman, Oregon. *Wood and Fiber Science*, *53*(3), 161–177. https://doi.org/10.22382/wfs-2021-17 | [4] Rockwood, D. L., Winandy, J. E., & Gribbins, N. R. (2022). Processing and wood factors influence medium density fiberboard production from young *Eucalyptus grandis*, *E. amplifolia*, *Corymbia torelliana,* and cottonwood grown in Florida USA. *Forests*, *13*(2), 266. https://doi.org/10.3390/f13020266 | [5] Salem, K. S., Naithani, V., Jameel, H., Lucia, L., & Pal, L. (2021). Lignocellulosic fibers from renewable resources using green chemistry for a circular economy. *Global Challenges*, *5*(2), 2000065. https://doi.org/10.1002/gch2.202000065

g) Utilization for Bioenergy

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on the potential of using feedstocks from SRWCs for bioenergy, including bio-jet fuel and bioethanol production[1-6]. For example, Budsberg et al. (2022) highlighted the environmental and economic benefits of switching to poplar-based biofuels, including reduced fuel use, lower greenhouse gas emissions, and potential economic viability[1]. Buell et al. (2023) summarized the potential of plant biology, genetics, and biotechnology in addressing various challenges in agriculture, renewable energy, and climate change – as they relate to feedstocks for renewable bioenergy sources[2]. In particular, their review focused on plant architecture, gene expression and regulation, lignin biosynthesis, trichome development, CRISPR-Cas9 technology, biofuel production, and climate change and plant growth[2]. Davis et al. (2020) modeled the economic potential for *Eucalyptus* as feedstocks for jet fuel additives in the US and found that the genus had potential to fulfill a portion of the demand for these additives[3]. They discussed production potential, distribution, market opportunities, and co-product utilization as they relate to challenges and uncertainties of producing *Eucalyptus*[3]. Jeong et al. (2020) evaluated the economic feasibility and environmental impact of using short rotation coppice (SRC) poplar as a feedstock for a biopower plant in Indiana, USA[4]. Based on a sensitivity analysis, they discussed different land types and the carbon effects of the biopower plant and concluded the plant operation is currently not economically feasible but could be viable with a higher carbon tax and stringent environmental policy targets[4]. Kim et al. (2021) assessed the tradeoffs between yield, disease incidence, and conversion efficiency of hybrid poplar genotypes used a bioenergy feedstocks[5]. They contributed information about wood chemistry (e.g., carbohydrate and lignin content) that may inform decisions for biomass utilization and bioenergy production[5]. Morales-Vera et al. (2022) emphasized the importance of conducting comprehensive life cycle assessments (LCA) to evaluate the environmental performance of biofuel production in the Pacific Northwest, USA[6]. Their results highlighted the environmental impacts of different stages of production and provided insights into areas for improvement. For example, future studies may focus on environmentally safe ways to produce ethanol in biorefineries and explore additional approaches to assess both the environmental and cost aspects of ethanol life cycles[6].

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[1] Budsberg, E., Parker, N., Bandaru, V., Bura, R., & Gustafson, R. (2022). Hydrocarbon bio-jet fuel from bioconversion of poplar biomass: Life cycle assessment of site-specific impacts. *Forests*, *13*(4), 549. https://doi.org/10.3390/f13040549 | [2] Buell, C. R., Dardick, C., Parrott, W., Schmitz, R. J., Shih, P. M., Tsai, C.-J., & Urbanowicz, B. (2023). Engineering custom morpho- and chemotypes of *Populus* for sustainable production of biofuels, bioproducts, and biomaterials. *Frontiers in Plant Science*, *14*, 1288826. https://doi.org/10.3389/fpls.2023.1288826 | [3] Davis, M. R., Kainer, D., Tuskan, G. A., Langholtz, M. H., Hellwinckel, C. M., Shedden, M., & Eaton, L. (2020). Modeled economic potential for *Eucalyptus* spp. Production for jet fuel additives in the United States. *Biomass and Bioenergy*, *143*, 105807. https://doi.org/10.1016/j.biombioe.2020.105807 | [4] Jeong, D., Tyner, W. E., Meilan, R., Brown, T. R., & Doering, O. C. (2020). Stochastic techno-economic analysis of electricity produced from poplar plantations in Indiana. *Renewable Energy*, *149*, 189–197. https://doi.org/10.1016/j.renene.2019.11.061 | [5] Kim, K., Voothuluru, P., Hamilton, C., McCord, J., Tamang, B., Cunningham, M., Eberhardt, T. L., Rials, T., & Labbé, N. (2021). Tradeoffs between yield, disease incidence and conversion efficiency for selection of hybrid poplar genotypes as bioenergy feedstocks. *Biomass and Bioenergy*, *154*, 106259. https://doi.org/10.1016/j.biombioe.2021.106259 | [6] Morales-Vera, R., Vásquez-Ibarra, L., Scott, F., Puettmann, M., & Gustafson, R. (2022). Life cycle assessment of bioethanol production: A case study from poplar biomass growth in the U.S. Pacific Northwest. *Fermentation*, *8*(12), 734. https://doi.org/10.3390/fermentation8120734

5. Environmental and Ecosystem Services

a) Site and Landscape Improvement

There were several studies highlighting the importance of using different materials such as biochar, sewage sludge, and fibercake residuals as soil amendments for unique restoration techniques[1-5]. These studies aimed to improve soil fertility, nutrient availability, and carbon sequestration in different types of soils and ecosystems across varying landscapes. Domingues et al. (2020) showed the addition of different biochars significantly increased soil pH and cation exchange capacity (CEC)[1]. They reported that high-ash biochars produced at low pyrolysis temperatures were effective in increasing CEC without improving soil fertility, while low-ash biochars increased carbon storage without causing alkalization. Their study provided valuable insights for tailoring and selecting biochars for specific agronomic and environmental applications, such as improving soil CEC[1]. Guerrini et al. (2021) investigated the potential of sewage sludge as a pedotechnomaterial (PTM) for soil recovery in degraded tropical soils[2]. Their results showed that applying sewage sludge led to improvements in soil fertility, nutrient availability, and plant growth, highlighting the potential of sewage sludge as a sustainable alternative for soil and ecosystem restoration[2]. Rockwood et al. (2022) discussed the carbon sequestration potential of *Eucalyptus* trees in Florida, USA using biochar as a soil amendment that enhanced carbon sequestration of the intensively managed short rotation woody crop systems[3]. In addition, they provided cost estimates for using biochar as a soil amendment, which are lower compared to previous estimates for carbon sequestration in forestry[3]. Rogers et al. (2021) tested the use of fibercake residuals from paper and containerboard production as soil amendments for hybrid poplar clones[4]. While specific effects varied depending on clone and type of fibercake used, their results showed the use of such residuals can positively impact the early growth and establishment of poplar trees[4]. Vinhal et al. (2022) described the design, implementation, and testing of specialized willow restoration mats using the DeValix technique at phytoremediation sites[5]. They identified generalist and specialist clones based on performance across sites in the Lake Superior and Lake Michigan watersheds of the US, and they showed DeValix mats can successfully establish willow clones and promote their growth for site and landscape improvement[5].

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[1] Domingues, R. R., Sánchez-Monedero, M. A., Spokas, K. A., Melo, L. C. A., Trugilho, P. F., Valenciano, M. N., & Silva, C. A. (2020). Enhancing cation exchange capacity of weathered soils using biochar: Feedstock, pyrolysis conditions and addition rate. *Agronomy*, *10*(6), 824. https://doi.org/10.3390/agronomy10060824 | [2] Guerrini, I. A., Sampaio, T. F., Bogiani, J. C., Backes, C., Harrison, R. B., Oliveira, F. C., Gava, J. L., Traballi, R. C., Garuba De Menezes Mota, R., Roder, L. R., Grilli, E., Ganga, A., James, J. N., & Capra, G. F. (2021). Sewage sludge as a pedotechnomaterial for the recovery of soils compacted by heavy machinery on *Eucalyptus* commercial plantation. *Journal of Cleaner Production*, *325*, 129320. https://doi.org/10.1016/j.jclepro.2021.129320 | [3] Rockwood, D. L., Ellis, M. F., & Fabbro, K. W. (2022). Economic potential for carbon sequestration by short rotation eucalypts using biochar in Florida, USA. *Trees, Forests and People*, *7*, 100187. https://doi.org/10.1016/j.tfp.2021.100187 | [4] Rogers, E. R., Zalesny, R. S., Benzel, T., & Wiese, A. H. (2021). Establishment of poplars in soils amended with fibercake residuals from paper and containerboard production. *Agroforestry Systems*, *95*(8), 1719–1733. https://doi.org/10.1007/s10457-021-00680-0 | [5] Vinhal, R. A., Zalesny, R. S., DeBauche, B. S., Rogers, E. R., Pilipović, A., Soolanayakanahally, R. Y., & Wiese, A. H. (2022). Establishment of willows using the novel DeValix technique: Ecological restoration mats designed for phytotechnologies. *International Journal of Phytoremediation*, *24*(7), 730–743. https://doi.org/10.1080/15226514.2021.1970102

b) Phytoremediation and Associated Phytotechnologies

Throughout the reporting period (2020-2023), there was an extensive amount of research focusing on phytoremediation and associated phytotechnologies as sustainable, nature-based approaches utilizing plants to remove and/or degrade pollutants from soil, water, and air[1-6]. Overall, the studies demonstrated the potential of poplars and other short rotation woody crops (SRWCs) for environmental solutions in various contaminated environments. The findings highlighted the importance of selecting appropriate clones based on specific contamination and environmental conditions. Overall, the studies contributed to our understanding of the long-term benefits and ecosystem services provided by SRWCs and emphasized the need for further research and the development of best management practices to maximize the potential of phytoremediation in ecological restoration efforts. For example, Landmeyer et al. (2020) tested salt-tolerant hybrid poplar trees for phytoremediation of slightly brackish groundwater contaminated with polycyclic aromatic hydrocarbons (PAHs) at a Superfund site in the Central Valley of California, USA[1]. They found that all salt-tolerant genotypes grew well and effectively removed naphthalene, a PAH compound, from the groundwater, highlighting the potential of using these trees for phytoremediation in these and other contaminated sites with deep groundwater[1]. Pilipović et al. (2020) investigated the growth and physiological responses of three poplar clones grown on soils artificially contaminated with heavy metals, diesel fuel, and herbicides[2]. They reported that growth and physiological responses were influenced by the interactions of clones with different contaminant types (i.e., genotype × environment interactions), as well as emphasizing the importance of physiological traits in poplar breeding and subsequent phytoremediation testing[2]. Zalesny et al. (2021) described the use of phyto-recurrent selection for the establishment of a regional phytotechnologies network consisting of sixteen phytoremediation buffer systems (i.e., phyto buffers) in the Great Lakes Basin, USA[3]. They examined genotype × environment interactions and evaluated the health, biomass, and growth of twelve poplar clones across the sixteen phyto buffers. Certain clones exhibited specialist or generalist responses in terms of biomass and growth, emphasizing the importance of considering genotype × environment interactions in phytoremediation projects and while developing phytotechnology best management practices[3]. Building on the work of Zalesny et al. (2021), Pilipović et al. (2020) compared the growth and physiology of three clone groups tested across the phyto buffers: 1) NRRI clones, 2) Experimental clones, and 3) Common clones[4]. The NRRI clones were new genotypes produced by the University of Minnesota Duluth, Natural Resources Research Institute. The Experimental clones had been tested broadly in the region but had not reached commercial status. The Common clones had been used in decades of testing and deployment in the Midwestern United States. Overall, they showed the NRRI clones exhibited the greatest potential for improving water quality and reducing nutrient runoff at landfills and similar liability sites in the region[4]. Salehi et al. (2023) tested the growth, biomass, nutrition, and heavy-metal accumulation of three poplar clones and one willow clone following irrigation with uncontaminated tap water versus wastewater[5]. They reported that eight months of irrigation with heavy-metal contaminated wastewater increased height, leaf area, tissue biomass, and phytoextraction and phytoaccumulation of macro-/micro-nutrients and heavy metals in tree tissues relative to the tap water control, demonstrating that these genotypes have potential for uses in systems with soils affected by similarly contaminated urban wastewaters[5]. Zalesny et al. (2020) evaluated the phytoremediation potential, biomass production, and biofuel recalcitrance of two hybrid poplar clones, 'DN34' and 'NM6', grown at a former landfill site in Rhinelander, Wisconsin, USA[6]. They highlighted that while both genotypes were effective in phytoaccumulation and phytoextraction of contaminants, 'NM6' outperformed 'DN34' for biomass and carbon-related traits while 'DN34' exhibited higher uptake levels for most elements despite 'NM6' having higher concentrations of certain elements in specific tissues[6]. Overall, their results contributed to the understanding of the long-term benefits and ecosystem services provided by poplar clones in landfill phytoremediation.

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[1] Landmeyer, J. E., Rock, S., Freeman, J. L., Nagle, G., Samolis, M., Levine, H., Cook, A., & O'Neill, H. (2020). Phytoremediation of slightly brackish, polycyclic aromatic hydrocarbon-contaminated groundwater from 250 ft below land surface: A pilot-scale study using salt-tolerant, endophyte-enhanced hybrid poplar trees at a superfund site in the central valley of California, April–November 2019. *Remediation Journal*, *31*(1), 73–89. https://doi.org/10.1002/rem.21664 | [2] Pilipović, A., Zalesny Jr., R. S., Orlović, S., Drekić, M., Pekeč, S., Katanić, M., & Poljaković-Pajnik, L. (2020). Growth and physiological responses of three poplar clones grown on soils artificially contaminated with heavy metals, diesel fuel, and herbicides. *International Journal of Phytoremediation*, *22*(4), 436–450. https://doi.org/10.1080/15226514.2019.1670616 | [3] Zalesny, R. S., Pilipović, A., Rogers, E. R., Burken, J. G., Hallett, R. A., Lin, C.-H., McMahon, B. G., Nelson, N. D., Wiese, A. H., Bauer, E. O., Buechel, L., DeBauche, B. S., Peterson, M., Seegers, R., & Vinhal, R. A. (2021). Establishment of regional phytoremediation buffer systems for ecological restoration in the Great Lakes Basin, USA. I. Genotype × Environment Interactions. *Forests*, *12*(4), 430. https://doi.org/10.3390/f12040430 | [4] Pilipović, A., Zalesny Jr., R. S., Rogers, E. R., McMahon, B. G., Nelson, N. D., Burken, J. G., Hallett, R. A., & Lin, C.-H. (2021). Establishment of regional phytoremediation buffer systems for ecological restoration in the Great Lakes Basin, USA. II. New clones show exceptional promise. *Forests*, *12*(4), 474. https://doi.org/10.3390/f12040474 | [5] Salehi, A., Zalesny, R. S., & Calagari, M. (2023). Effects of urban wastewater application on growth, biomass, nutrition, and heavy-metal accumulation of *Populus nigra* L. "62/154," *P. alba* L. "20/45," *P. euramericana* (Dode) Guinier "92/40," and *Salix excelsa* S.G. Gmel grown in heavy-metal contaminated soil. *International Journal of Phytoremediation*, *25*(10), 1371–1383. https://doi.org/10.1080/15226514.2022.2158783 | [6] Zalesny Jr., R. S., Zhu, J. Y., Headlee, W. L., Gleisner, R., Pilipović, A., Acker, J. V., Bauer, E. O., Birr, B. A., & Wiese, A. H. (2020). Ecosystem services, physiology, and biofuels recalcitrance of poplars grown for landfill phytoremediation. *Plants*, *9*(10), 1357. https://doi.org/10.3390/plants9101357

c) Environmental Applications for Ecosystem Services

Studies highlighting the potential benefits of using shrub willow buffers for bioenergy production and land management exemplify environmental applications for ecosystem services[1-5]. These buffers reduce greenhouse gas (GHG) emissions, provide ecosystem services, and improve soil health. Strategic placement of buffers and consideration of factors such as yield, fertilizer application rate, and transportation distance are important for optimizing the benefits and minimizing the impacts of shrub willow production. Overall, the findings contributed information on the potential development of a sustainable bioeconomy and provided insights for decision-making in the establishment of shrub willow biomass crops[1-5]. Canter et al. (2022) showcased the importance of strategic placement of shrub willow buffers to optimize GHG emissions and transportation distance[1]. They reported that shrub willow production on marginal land has the potential to contribute to a sustainable bioeconomy with reduced GHG emissions[1]. Englund et al. (2020) conducted a global assessment of the performance and progress of multifunctional perennial production systems for bioenergy and presented several case studies that illustrate the potential to meet bioenergy demands[2]. Also, they described the importance of identifying suitable locations for the strategic establishment of perennial crops. They emphasized the need to understand the specific landscape characteristics and environmental impacts in order to direct implementation efforts to areas where the benefits of perennialization could be maximized[2]. Jager et al. (2023) focused on the Mid-Atlantic region of the US and examined the potential value of ecosystem services provided by multi-zone riparian buffers consisting of native, perennial crops such as switchgrass and willow[3]. Their results suggested that strategic placement and choice of low-input perennial feedstocks are important for providing ecosystem services and reducing the carbon footprint of biofuels[3]. Yang et al. (2020) tested the production of willow biomass crops in upstate New York, USA and reported that willow crops were carbon-negative when grown on former cropland or pasture[4]. They highlighted the importance of considering multiple factors, such as land cover, transportation distance, and yield, in assessing GHG emissions and energy ratios. Their results may be used to inform policy-makers, land managers, and scientists in making informed decisions about the establishment of willow biomass crops and reducing GHG emissions in the bioenergy sector[4]. Zumpf et al. (2021) demonstrated that strategically integrated shrub willow buffers in an Illinois corn-soybean field had positive effects on soil health and microbial community composition[5]. Overall, their study contributed to the understanding of the relationship between crop management, soil health, and microbial communities, and provided insights into the potential benefits of perennial bioenergy crop production for sustainable land management[5].

[1] Canter, C. E., Zolton, K., Cacho, J. F., Negri, M. C., Zumpf, C. R., & Quinn, J. J. (2022). Impact of landscape design on the greenhouse gas emissions of shrub willow bioenergy buffers in a US midwest corn-production landscape. *Biofuels, Bioproducts and Biorefining*, *16*(3), 629–639. https://doi.org/10.1002/bbb.2345 | [2] Englund, O., Dimitriou, I., Dale, V. H., Kline, K. L., Mola-Yudego, B., Murphy, F., English, B., McGrath, J., Busch, G., Negri, M. C., Brown, M., Goss, K., Jackson, S., Parish, E. S., Cacho, J., Zumpf, C., Quinn, J., & Mishra, S. K. (2020). Multifunctional perennial production systems for bioenergy: Performance and progress. *WIREs Energy and Environment*, *9*(5), e375. https://doi.org/10.1002/wene.375 | [3] Jager, H. I., Nair, S. S., Efroymson, R. A., DeRolph, C. R., Parish, E. S., & Wang, G. (2023). Ecosystem services from partially harvested riparian buffers can offset biomass production costs. *Science of The Total Environment*, *889*, 164199. https://doi.org/10.1016/j.scitotenv.2023.164199 | [4] Yang, S., Volk, T., & Fortier, M.-O. (2020). Willow biomass crops are a carbon negative or low-carbon feedstock depending on prior land use and transportation distances to end users. *Energies*, *13*(16), 4251. https://doi.org/10.3390/en13164251 | [5] Zumpf, C., Cacho, J., Grasse, N., Quinn, J., Hampton-Marcell, J., Armstrong, A., Campbell, P., Negri, M. C., & Lee, D. K. (2021). Influence of shrub willow buffers strategically integrated in an illinois corn-soybean field on soil health and microbial community composition. *Science of The Total Environment*, *772*, 145674. https://doi.org/10.1016/j.scitotenv.2021.145674

III. GENERAL INFORMATION

1. Administration and Operation of the National Poplar Commission or Equivalent

a) USDA Forest Service as an "Other Suitable National Body"

The US Poplar Council, which was started in 1964, strongly advocated for the US to join the International Poplar Commission (IPC). Article IV of the original IPC Convention, which came into force in 1961, established that member countries had to designate a National Poplar Commission. As a private organization, the US Poplar Council could not be sanctioned by the US to act as the National Poplar Commission in fulfillment of the requirement to join the IPC Convention. Recognizing that the National Poplar Commission requirement was preventing the US (and other nations) from joining the IPC Convention, the IPC Executive Committee amended the Convention in 1967 with the adopted text "either for the establishment of a National Poplar Commission, or if not possible, for the designation of some other suitable National body".

In July of 1970, Secretary of State William P. Rogers wrote Secretary of Agriculture Clifford M. Hardin to inform him the Circular 175 procedure for the IPC had been completed. The Instrument of Acceptance of the Convention was transmitted to the FAO Director-General A.H. Boerma in August 1970, at which time he wrote the Secretary of State to confirm receipt. In October 1970, USDA Forest Service Chief Edward Cliff informed the Poplar Council of the acceptance of US membership into the IPC, and he thanked them for their support. In this letter, Chief Cliff noted that the USDA Forest Service had been designated as the US member agency — thus, **it was established that the USDA Forest Service fulfilled the IPC Convention requirement of "some other suitable National body"** in lieu of a National Poplar Commission. The USDA

Forest Service has maintained this role since 1970, and the national delegate to the IPC has been under the appointment of the USDA Forest Service Chief (or Deputy Chief for Research and Development).

Historically, there have been two IPC-affiliated organizations from the US. First, the US Poplar Council was active from 1964 to 2017. Second, the Short Rotation Woody Crops Operations Working Group (SRWCOWG) was formed in 1995 and remains active today. Given the substantially reduced number of US experts on poplars and other fast-growing trees throughout the 2000s, the US Poplar Council disbanded in 2017, with active members at that time joining the SRWCOWG. As a result, the SRWCOWG remains the sole organization dedicated to the cultivation and utilization of poplars, willows, eucalypts, and other fast-growing species in the US. Throughout time, USDA Forest Service researchers, including the US National Representative to the IPC, have held leadership roles in both groups, and this continues at present. The current connection between the IPC and SRWCOWG remains strong, and additional partnerships with the Poplar and Willow Council of Canada (PWCC) have resulted in substantial advancements in the development of short rotation woody crops throughout North America. These accomplishments are reflected in the activities, relations with other countries, innovations, and publications listed below.

b) Meetings, Congresses, and Study Tours Sponsored by IPC-Affiliated Organizations

- 2nd World Forum on Urban Forests: Greener, Healthier, and Happier Cities for All; 16-20 October 2023; Washington, District of Columbia, USA.
- 2023 International Phytoremediation Training Academy, USDA Forest Service International Programs; 14-18 August 2023; Menomonee Falls, Wisconsin, USA.
- 17th International Phytotechnologies Conference; 23-26 May 2023; Chicago, Illinois, USA.
- 8th International Poplar Symposium (IPS VIII): Poplars and willows in the era of global change: agroforestry, environmental improvement, and ecosystem services to enhance livelihoods; IUFRO Working Group 2.08.04 (Physiology and Genetics of Poplars and Willows); 4-6 October 2022; Novi Sad, Serbia (virtual).
- Joint Workshop of the Food and Agriculture Organization of the United Nations (UN FAO), International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC), and TreeDivNet: Management of Mixed and Pure Planted Forests – Stock-taking of Science and Practice; 30 September 2022; Rome, Italy.
- International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC) of the Food and Agriculture Organization of the United Nations (UN FAO); 29 September 2022; Rome, Italy.
- 9th Bioenergy Week of the Global Bioenergy Partnership (GBEP) of the Food and Agriculture Organization of the United Nations (UN FAO) (from Rhinelander, WI, USA); 26-29 September 2022; Asunción, Paraguay (virtual).
- Phyto Day: Enhancing Ecosystem Services Using Phytotechnologies for a Sustainable World; 14 June 2022; Mequon, Wisconsin, USA.
- 13th Biennial Short Rotation Woody Crops Operations Working Group Conference: 2022 International Short Rotation Woody Crops Conference; 2-4 May 2022; Mills River, North Carolina, USA.

- 26th Session of the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC), Food and Agriculture Organization (FAO) of the United Nations; 5-8 October 2021; Rome, Italy (virtual).
- Short Rotation Woody Crops Regional Updates Webinar Series (this is different than the webinar series listed below); hosted monthly by the University of Minnesota Duluth, Natural Resources Research Institute (NRRI); August-December 2020; Duluth, Minnesota, USA (virtual).
- Short Rotation Woody Crops Webinar Series (this took place in lieu of the 2020 Woody Crops International Conference due to the COVID-19 pandemic and is different than the regional updates webinar series listed above); hosted monthly by the University of Minnesota Duluth, Natural Resources Research Institute (NRRI); August-December 2020; Duluth, Minnesota, USA (virtual).

2. Relations with Other Countries

- Following all national phytosanitary requirements, there are active exchanges of poplar, willow, and eucalypt plant material from the US with many countries around the globe, including Brazil, Canada, China, India, Italy, Sweden, and the United Kingdom. US scientists that work with poplar, willow, and eucalypt collaborate all over the world through IPC and IUFRO activities in their area of expertise.
- Ron Zalesny of the USDA Forest Service in Rhinelander, Wisconsin USA hosted a former scientist from the University of Novi Sad, Institute of Lowland Forestry and Environment, in Novi Sad, Serbia (Andrej Pilipović, who is currently with the Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA) for a long-term (i.e., 20-month, 2020-2021) scientific exchange conducting phytotechnologies research at the USDA Forest Service, Northern Research Station. The overarching outcome was a set of phytotechnologies best management practices (i.e., Phyto BMPs) that are locally adapted within the Great Lakes Basin yet globally relevant. The scientific exchange was administratively supported by USDA Forest Service International Programs.
- Ron Zalesny, Liz Rogers, and Ryan Vinhal of the USDA Forest Service in Rhinelander, Wisconsin USA, along with Liza Paqueo of the USDA Forest Service International Programs office in Washington, District of Columbia, USA, developed and hosted the International Phytoremediation Training Academy (2023-current). The overarching objective of the academy is to bring together global researchers and practitioners to promote the successful planning, design, and establishment of phytoremediation systems through a combination of hands-on experiences, engagement with phytotechnologies professionals, and ready-to-use resources. Participants in 2023 were from the Democratic Republic of the Congo, Bangladesh, Lebanon, and India. Currently, participants for 2024 are being selected. The academy is funded by USDA Forest Service International Programs. Other instructors include Chung-Ho Lin (University of Missouri, Columbia, Missouri, USA) and Akshat Tyagi (Give Me Trees Trust, Delhi, India).
- From 2019-2020, Andrew Groover of the USDA Forest Service in Burlington, Vermont, USA hosted a Ph.D. student (Aleksandra Słupianek) from Poland in support of her developing laser capture methods in poplar wood (visit ended by pandemic).

- From 2018-2020, Andrew Groover of the USDA Forest Service in Burlington, Vermont, USA hosted an Associate Professor from the Chinese Academy of Forestry (Lijuan Wang) for training in genomics (visit ended by pandemic).
- Don Rockwood of Florida FGT, LLC in Orlando, Florida, USA provided eucalypt seed to North Carolina State University's Camcore program for evaluation by its members in several wet subtropic countries.
- The University of Minnesota Duluth, Natural Resources Research Institute (NRRI) (Duluth, Minnesota, USA) shipped hybrid poplar cuttings to a phytoremediation company in Canada to begin a trial in 2023.
- The University of Minnesota Duluth, Natural Resources Research Institute (NRRI) (Duluth, Minnesota, USA) collaborated with Euromediana in Lithuania that established a nursery bed of NRRI hybrid poplar clones. In 2023, Euromediana shared the NRRI cuttings with a wood products company in Europe and the Swedish University of Agricultural Sciences.

3. Innovations not Included in Other Sections

a) Notable Publications from Sources Outside Peer-Reviewed Journals

1. Buchman, D. Jackson, J., Berguson, W.E., McMahon, B.G., Nelson, N.D.; DuPlissis, J., & Host, G.E. (2020). Grower's Guide for Hybrid Poplar Plantations for Biomass Production. Natural Resources Research Institute, University of Minnesota Duluth. Retrieved from the University of Minnesota Digital Conservancy; Minneapolis, Minnesota, USA. 15 p. http://hdl.handle.net/11299/213759
2. Ghezehei, S., & Saloni, D. (2023). *Populus*-based Production of Solid Biofuel. Final Technical Report prepared for the North Carolina Department of Agriculture and Consumer Services Bioenergy Research Initiative. North Carolina State University; Raleigh, North Carolina, USA.
3. Ghezehei, S. (2023). The Silviculture of *Populus* for Veneer. Final Technical Report prepared for the North Carolina Department of Agriculture and Consumer Services New and Emerging Crops Program. North Carolina State University; Raleigh, North Carolina, USA.
4. Ghezehei, S., & Hazel, D. (2022). Intercropping *Populus* for Bioenergy and Veneer. Final Technical Report prepared for the North Carolina Department of Agriculture and Consumer Services Bioenergy Research Initiative. North Carolina State University; Raleigh, North Carolina, USA.
5. Ghezehei, S., Kurkalova, L.A., Hazel, D., & Nichols, E.G. (2021). Predicting SRWC Productivity and Economic Feasibility. Final Technical Report prepared for the North Carolina Department of Agriculture and Consumer Services Bioenergy Research Initiative. North Carolina State University; Raleigh, North Carolina, USA.
6. Ghezehei, S., & Hazel, D. (2020). Western North Carolina Bioenergy Forest Demonstration. Final Technical Report prepared for the North Carolina Department of Agriculture and Consumer Services Bioenergy Research Initiative. North Carolina State University; Raleigh, North Carolina, USA.
7. Hazel, D.W., Ghezehei, S.B., & Nichols, E.G. (2021). Growing Hardwood Veneer in 20 Years or Less on Your Land? National Woodlands, a Magazine for the National Woodland Owners Association. Autumn, 2021, 44(1). https://nationalwoodlands.com/publications/

8. Heppenstall, M., Himes, A., Haider, N., & Hart, N. (2023). Harvesting Hybrid Poplar for Bioenergy. In: Growing Hybrid Poplar for Bioenergy in the PNW. Zobrist, K., Haider, N., Stanton, B.J., & Stonex, R. (eds.). Washington State University Extension; Pullman, Washington, USA. 115 p. https://doi.org/10.7273/000005545

9. Jackson, J., & Reichenbach, M. (2023). A Collaborative Learning Process from a Distance. Natural Resources Research Institute, University of Minnesota Duluth. Retrieved from the University of Minnesota Digital Conservancy; Minneapolis, Minnesota, USA. 15 p. https://hdl.handle.net/11299/256906

10. Jackson, J., DuPlissis, J., & Meyer, N. (2022). Next-Gen Poplars Project: Extension Program Evaluation Report. University of Minnesota Extension and Natural Resources Research Institute University of Minnesota Duluth. Retrieved from the University of Minnesota Digital Conservancy; Minneapolis, Minnesota, USA. 5 p. https://hdl.handle.net/11299/241234

11. Kolka, R., Haight, R.G., Chun, C.L., Berens, M.J., Rogers, E.R., Vinhal, R.A., Zalesny, R.S. Jr., Nislow, K.H., Perry, C.H., & Connolly, S.J. (2022). Mercury Sulfur Initiative: Suggested Program of Research for the Upper Great Lakes States. General Technical Report, NRS-206. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 28 p. https://doi.org/10.2737/NRS-GTR-206

12. Lazarus, W.F., Nelson, N.D., Jackson, J., Berguson, W.E., McMahon, B.G., Buchman, D., & Cai, M. (2021). Comparison of Hybrid Poplar Wood Breakeven Prices as Affected by Current and Improved Genetics. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2021/16. Retrieved from the University of Minnesota Digital Conservancy; Duluth, Minnesota, USA. 20 p. https://hdl.handle.net/11299/219608

13. McGovern, P.N., Rogers, E.R., Vinhal, R.A., & Zalesny, R.S. Jr. (2023). Leveraging *Populus* Field Trials to Manage Environmental and Human-Induced Change. Technical Paper of the International Union of Forest Research Organizations (IUFRO) Working Party 2.08.04: Poplars and Willows; Vienna, Austria. 27 p. https://www.iufro.org/science/divisions/division-2/20000/20800/20804/publications/

14. Mitchell, D., & Jansen, A. (2024). Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop Summary Report. US Department of Energy, Office of Energy Efficiency and Renewable Energy, Technical Report DOE-EE 2808. 41 p. https://www.energy.gov/eere/bioenergy/articles/deploying-purpose-grown-energy-crops-sustainable-aviation-fuel-workshop

15. Nelson, N.D., Berguson, W.E., McMahon, B.G., Jackson, J., Buchman, D., DuPlissis, J., & White, T.W. (2021). Intellectual Property in the NRRI Hybrid Poplar Program – Inventory, Commercialization Plan, and Progress Report. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2021/07. Retrieved from the University of Minnesota Digital Conservancy; Minneapolis, Minnesota, USA. 13 p. https://hdl.handle.net/11299/218837

16. Nelson, N.D., Buchman, D., Cai, M., McMahon, B.G., & Berguson, W.E. (2022). Inter-Tree Competition Effects in Hybrid Poplar Genotype Testing. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/02. Retrieved from the University of Minnesota Digital Conservancy; Minneapolis, Minnesota, USA. 21 p. https://hdl.handle.net/11299/226513

17. Nichols, E.G., Hazel, D.W., Ghezehei, S.B., & Bowen, L. (2021). Opportunities and Guide for Short-Rotation Forestry in North Carolina. Online handbook. North Carolina State University; Raleigh, North Carolina, USA. 39 p. https://sites.google.com/view/shortrotationforestry/home/guide-to-s-r-forestry

18. Rockwood, D.L., Fabbro, K.W., Ellis, M.F., Ozores-Hampton, M., & Varshovi, A. (2022). Carbon Sequestration by Eucalypts in Florida, USA: Management Options Including Biochar and Associated Economics. In: Carbon Sequestration. Sarvajayakesavalu, S., & Karthikeyan. K. (eds.). IntechOpen. https://doi.org/10.5772/intechopen.104923

19. Rockwood, D.L., Ellis, M.F., Liu, R., Zhao, F., Fabbro, K.W., He, Z., & Derbowka, D.R. (2020). Forest Trees for Biochar and Carbon Sequestration: Production and Benefits. In: Applications of Biochar for Environmental Safety. Abdelhafez, A.A., & Abbas, M.H.H. (eds.). IntechOpen. https://doi.org/10.5772/intechopen.92377

20. Rogers, E.R., Zalesny, R.S. Jr., Vinhal, R.A., Weger, J., Van Acker, J., Soolanayakanahally, R.Y., Pajel, P., Springgay, E., Zoveda, R., Chauhan, S., McIvor, I., Paris, P., Singh, H., Thevs, N., & Worms, P. (2023). How Can Fast-Growing Trees Optimize Agroforestry Benefits? The role of the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment. Technical Brief of the Food and Agriculture Organization (FAO) of the United Nations. Rome, Italy. 6 p. https://www.fao.org/3/cc8646en/cc8646en.pdf

21. Zalesny, R.S. Jr., & Pilipović, A. (eds). (2022). Growth and Development of Short Rotation Woody Crops for Rural and Urban Applications. Printed edition of the special issue published in Forests. MDPI Publishers; Basel, Switzerland. ISBN 978-3-0365-4502-8. 390 p. https://doi.org/10.3390/books978-3-0365-4501-1

22. Zalesny, R.S. Jr., Casler, M.D., Hallett, R.A., Lin, C-H., & Pilipović, A. (2021). Bioremediation and Soils. Chapter 9, pages 237-273. In: Soils and Landscape Restoration. Stanturf, J.A., & Callaham, M.A. (eds). Elsevier Academic Press. 440 p. https://doi.org/10.1016/B978-0-12-813193-0.00009-6

23. Zalesny, R.S. Jr., Headlee, W.L., Soolanayakanahally, R.Y., & Richardson, J. (eds). (2020). Short Rotation Woody Crop Production Systems for Ecosystem Services and Phytotechnologies. Printed edition of the special issue published in Forests. MDPI Publishers; Basel, Switzerland. ISBN 978-3-03921-509-6. 303 p. https://doi.org/10.3390/books978-3-03921-510-2

24. Zobrist, K., Haider, N., Stanton, B.J., & Stonex, R. (2023). Growing Hybrid Poplar for Bioenergy in the PNW. Washington State University Extension; Pullman, Washington, USA. 115 p. https://doi.org/10.7273/000005545

b) Patents, Trademarks, Commercializations

- Doty, S. & Sher, A. (21 April 2022). Nitrogen fixing bacteria and an activity-enhancing microbial partner closely associated with wild poplar roots. University of Washington Record of Innovation Number 49511.
- Doty, S., & Tournay, R. (26 October 2021). Endophytes for improved phytoremediation of arsenic. University of Washington Record of Innovation Number 49368.

- University of Minnesota Duluth, Natural Resources Research Institute (NRRI) (Duluth, Minnesota, USA) commercialized their InnovaTree™ hybrid poplar (*Populus* × *euramericana*) which was registered by the IPC in 2021. In 2023, they have a US plant patent pending, as well as two commercial tree nurseries that are selling it and several other nurseries evaluating InnovaTree™ for sale.

c) Additional Innovations Not Listed Elsewhere

- **United Nations Endorsement of Phyto-Recurrent Selection**

  In 2003, USDA Forest Service researchers developed **phyto-recurrent selection** as a methodology to choose favorable tree varieties for phytoremediation and other phytotechnology applications. Since then, USDA Forest Service researchers and their partners have conducted extensive greenhouse, nursery, and field testing to refine and validate the method. As a result of these efforts, phyto-recurrent selection was endorsed as a "Good Practice" by the UN Decade on Ecosystem Restoration Task Force on Best Practices in 2023. Good Practices are evaluated by the Task Force according to their adaptability, scalability, and broad applicability for implementation in restoration efforts worldwide. Phyto-recurrent selection was determined to meet these criteria, and is now available online within the UN Framework for Ecosystem Restoration Monitoring (FERM) Registry: Phyto-Recurrent Selection to Enhance Ecosystem Services and Livelihoods in Rural and Urban Communities.

  Phyto-recurrent selection provides a sustainable solution to many diverse ecological challenges through the greening of degraded lands. As a selection practice, phyto-recurrent selection can be used to select the most appropriate trees for remediating contamination in soils, groundwater, and surface waters. Selected trees can then be used to reforest the contaminated or otherwise degraded lands, which in turn contributes to improving the quality of soils and waters. This technique can also be leveraged to address the effects of climate change through the selection of varieties with enhanced potential for carbon sequestration, climate adaptability, and climate change mitigation. Additionally, superior genotypes with optimal growth can be selected in order to maximize the production of bioenergy and bioproducts. For instance, varieties can be selected for the provisioning of fuelwood, thereby improving grower livelihoods. Finally, native species and genetically appropriate germplasm can serve as the base population for phyto-recurrent selection activities, which will help ensure the sustainability of restoration practices.

  For more information about phyto-recurrent selection, please contact: Ron Zalesny Jr. (ronald.zalesny@usda.gov), Liz Rogers (elizabeth.r.rogers@usda.gov), and/or Ryan Vinhal (ryan.vinhal@usda.gov).

- **Fast-Growing Trees Networks**

  A team at the University of Connecticut, led by Julia Kuzovkina, recently initiated a project to construct a network of researchers, practitioners, and institutions involved with 20 fast-growing tree genera to facilitate information exchange and collaborative projects. The first steps included the analyses of references and scientists who have published their work related to fast-growing species over the past 7 years. The following databases were analyzed: Google Scholar, Academic Search Premiere, BIOSIS Citation Index, Cab Abstracts, EBSCO, Scopus, JSTOR, CRIS. https://tinyurl.com/yp3f77ym

For more information about the fast-growing trees networks, please contact: Julia Kuzovkina (jkuzovkina@uconn.edu).

- Blumenfeld, S., Nichols, E.G., & Ghezehei, S.B. (2023) A productivity and economic assessment tool for poplar production for veneer in Western North Carolina. North Carolina State University.
- Groover, A. (2011-present). Developed poplar germplasm resource for dissecting complex traits based on gene dosage. USDA Forest Service. Burlington, Vermont, USA.
- Groover, A. (2014-present). Demonstrated gene copy number variation as a fundamental source of variation contributing to ecological and economically important traits in poplar. USDA Forest Service. Burlington, Vermont, USA.
- McGovern, P.N. (2023). Produced ten hybrid aspen families using established Open4st project parents. The families were comprised of three F_1 and five F_3 backcrosses with three females, four males and two wind pollinated families.
- North Carolina State University identified nine *Populus* clones suitable for veneer.
- North Carolina State University identified three *Populus* clones suitable for veneer and plywood.

d) Poplar, Willow, and Eucalypt Experts in the US

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e) Organizations and Programs Relevant to Poplars, Willows, and Eucalypts in the US

- **International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment, https://www.fao.org/ipc/en/**
- Advanced Hardwood Biofuels Northwest, https://hardwoodbiofuels.org/
- Argonne National Laboratory, Environmental Science Division, https://www.anl.gov/evs/departments
- American Farmland Trust, https://farmland.org/
- Association for Temperate Agroforestry, https://www.aftaweb.org/
- Beyond Trees Network, https://www.beyondtrees.global/
- Cornell University, Willowpedia, https://willow.cals.cornell.edu/

- Ecolotree, https://www.ecolotree.com/
- eXtension Farm Energy, https://farm-energy.extension.org/
- Florida FGT, LLC, https://www.floridafgt.com/
- Green Trees, https://www.green-trees.com/
- IEA Bioenergy Task 43: Biomass, https://task43.ieabioenergy.com/
- International Phytotechnology Society, https://phytosociety.org/
- Intrinsyx Environmental, https://www.intrinsyxenvironmental.com/
- IUFRO 1.03.00 Short Rotation Forestry, https://www.iufro.org/science/divisions/division-1/10000/10300/
- IUFRO 1.06.01 Phytotechnologies, https://www.iufro.org/science/divisions/division-1/10000/10600/10601/
- IUFRO 2.08.04 Poplars and Willows, https://www.iufro.org/science/divisions/division-2/20000/20800/20804/
- Leachate Management Specialists, https://www.leachate.us/
- Michigan State University, Forest Biomass Innovation Center, https://www.canr.msu.edu/fbic
- North Carolina State University, Camcore, https://camcore.cnr.ncsu.edu/
- North Carolina State University, Forest Productivity Cooperative, https://www.forestproductivity.org/
- Oak Ridge National Laboratory, Center for Bioenergy Innovation (CBI), https://cbi.ornl.gov/
- Oak Ridge National Laboratory, National Transportation Research Center, https://www.ornl.gov/facility/ntrc/research-areas/
- Oak Ridge National Laboratory, Plant Microbe Interfaces (PMI), https://pmiweb.ornl.gov/
- Poplar and Willow Council of Canada, http://www.poplar.ca/
- Sand County Environmental, https://www.sandcountyenv.com/
- Savanna Institute, https://www.savannainstitute.org/
- Short Rotation Woody Crops Operations Working Group, https://woodycrops.tennessee.edu/
- UN Decade on Ecosystem Restoration, Best Practices Task Force, https://www.decadeonrestoration.org/task-forces/best-practice
- University of Minnesota, CINRAM, https://cinram.umn.edu/
- University of Minnesota Duluth, Natural Resources Research Institute, https://nrri.umn.edu/
- University of Missouri, Center for Agroforestry, https://centerforagroforestry.org/
- University of Tennessee, Center for Renewable Carbon, https://crc.tennessee.edu/
- US DOE, Bioenergy Technologies Office, https://www.energy.gov/eere/bioenergy/bioenergy-technologies-office
- US DOE, Joint BioEnergy Institute, https://www.jbei.org/
- US DOE, National Renewable Energy Laboratory, https://www.nrel.gov/bioenergy/index.html
- USDA Forest Service, Forest Products Laboratory, https://www.fs.usda.gov/research/fpl

- USDA Forest Service, International Programs, https://www.fs.usda.gov/about-agency/international-programs/about-us
- USDA Forest Service, National Agroforestry Center, https://www.fs.usda.gov/nac/
- USDA Forest Service, Northern Research Station, https://www.fs.usda.gov/research/nrs
- USDA Forest Service, Pacific Northwest Research Station, https://www.fs.usda.gov/research/pnw
- USDA Forest Service, Pacific Southwest Research Station, https://www.fs.usda.gov/research/psw
- USDA Forest Service, Research and Development, https://www.fs.usda.gov/research/about
- USDA Forest Service, Rocky Mountain Research Station, https://www.fs.usda.gov/research/rmrs
- USDA Forest Service, Southern Research Station, https://www.fs.usda.gov/research/srs
- USDA Forest Service, Urban and Community Forestry, https://www.fs.usda.gov/managing-land/urban-forests/ucf
- Willow Biomass, State University of New York, https://www.esf.edu/willow/

4. Literature

In addition to receiving papers from experts, a comprehensive literature review was performed to identify records related to the cultivation and utilization of poplars, willows, eucalypts, and other fast-growing trees (a.k.a., short rotation woody crops, SRWC) in the United States from 2020-2023. Following the methods of Rogers at el. (2023), the literature review was conducted using the Web of Science database (https://clarivate.com/webofsciencegroup/-solutions/web-of-science/). Search logic included:

> *Populus*:
> (TS=(*Populus* OR poplar)) AND CU=(United States OR USA OR United States of America)
>
> *Salix*:
> (TS=(*Salix* OR willow)) AND CU=(United States OR USA OR United States of America)
>
> *Eucalyptus*:
> (TS=(*Eucalyptus* OR eucalypt)) AND CU=(United States OR USA OR United States of America)
>
> *SRWCs*:
> (TS=((SRWC AND rotation) OR (SRC AND rotation) OR (FGTs AND trees) OR ("short rotation" AND trees) OR "short rotation woody crops" OR "short rotation coppice" OR "fast growing trees")) AND CU=(United States OR USA OR United States of America)

where: TS = searches for topic terms in the following fields within a record: Title, Abstract, Author, Keywords, Keywords Plus®; and CU = searches for countries/regions in the Addresses field within a record. The timespan (i.e., publication date) for all searches ranged from 1 January 2020 to 31 December 2023. Only peer-reviewed manuscripts are included below. Notable publications from sources other than peer-reviewed journals are listed above [Section III.3.a)] Notable Publications from Sources Outside Peer-Reviewed Journals].

In total, 2,561 records were screened, with 199 papers received from experts (*Populus* = 156; *Salix* = 27; *Eucalyptus* = 9; SRWCs = 7) and 2,362 manuscripts identified from Web of Science (*Populus* = 1,174; *Salix* = 477; *Eucalyptus* = 618; SRWC = 93) (Figure 1). Each record was reviewed based on title, abstract, and content, and 1,679 records were excluded for lack of relevancy and/or redundancy among sources/searches. Therefore, there are 882 total unique records. Of these, 59 records are cross-listed among *Populus*, *Salix*, *Eucalyptus*, and/or SRWC, resulting in a total of 941 records reported below. Of those, 66% are for *Populus* (n = 621), followed by 20% for *Eucalyptus* (n = 185), 12% for *Salix* (n = 110), and 2% for SRWCs (n = 25) (Figure 1). The distribution of the five areas of work summarized in Section II above [Technical Information. 1) Taxonomy, Nomenclature, and Registration; 2) Domestication, Breeding, and Selection of Genetic Resources; 3) Plant Health, Resilience to Threats and Climate Change, 4) Production Systems for the Bioeconomy; 5) Environmental and Ecosystem Services] are illustrated in Figure 2. Across genera and SRWCs, the number of records was greatest for Production Systems for the Bioeconomy and least for Taxonomy, Nomenclature, and Registration. The number of records among the three remaining areas of work are dependent on specific category (i.e., *Populus*, *Salix*, *Eucalyptus*, SRWC) (Figure 2).

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Rogers, E. R., Zalesny, R. S., Lin, C.-H., & Vinhal, R. A. (2023). Intrinsic and extrinsic factors influencing *Populus* water use: A literature review. *Journal of Environmental Management*, *348*, 119180. https://doi.org/10.1016/j.jenvman.2023.119180

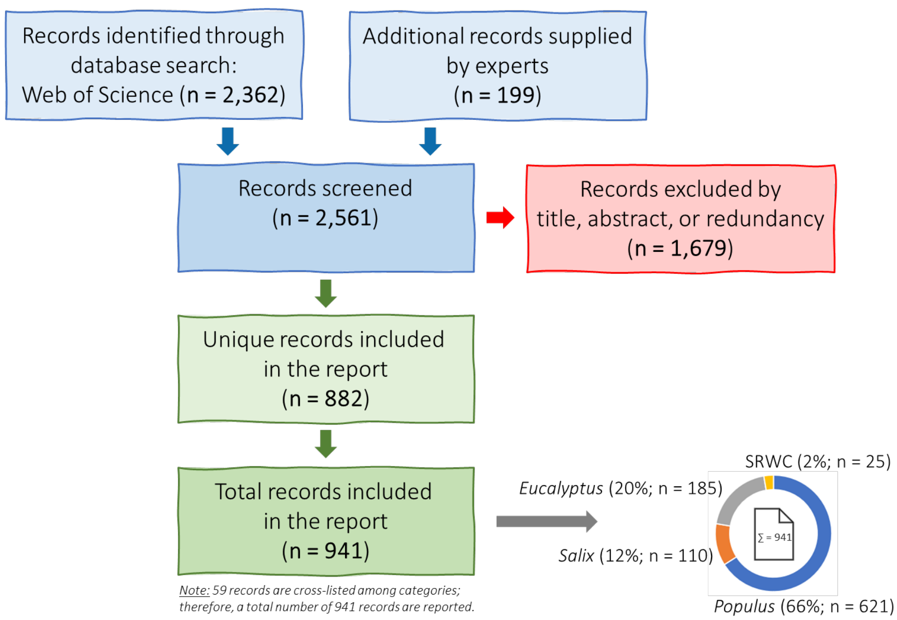

Figure 1. Flow chart of literature review process for selection of peer-reviewed manuscripts related to the cultivation and utilization of poplars, willows, eucalypts, and other fast-growing trees (a.k.a., short rotation woody crops, SRWCs) in the United States from 2020-2023. Methods were adapted from Rogers at el. (2023).

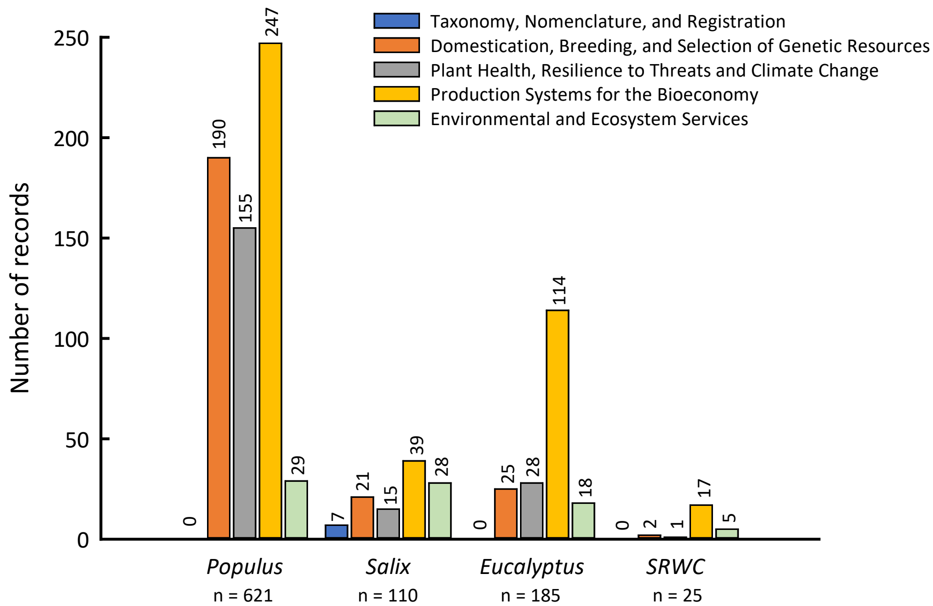

Figure 2. Number of records for each of five areas of work for *Populus*, *Salix*, *Eucalyptus*, and SRWC resulting from a literature review of peer-reviewed manuscripts related to the cultivation and utilization of poplars, willows, eucalypts, and other fast-growing trees (a.k.a., short rotation woody crops, SRWCs) in the United States from 2020-2023.

Populus

Taxonomy, Nomenclature, and Registration

None reported.

Domestication, Breeding, and Selection of Genetic Resources

1. Abbas, M., Peszlen, I., Shi, R., Kim, H., Katahira, R., Kafle, K., Xiang, Z., Huang, X., Min, D., Mohamadamin, M., Yang, C., Dai, X., Yan, X., Park, S., Li, Y., Kim, S. H., Davis, M., Ralph, J., Sederoff, R. R., … Li, Q. (2020). Involvement of *Cesa4*, *Cesa7-A/B* and *Cesa8-A/B* in secondary wall formation in *Populus trichocarpa* wood. *Tree Physiology*, *40*(1), 73–89. https://doi.org/10.1093/treephys/tpz020

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Production Systems for the Bioeconomy

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Eucalyptus

Taxonomy, Nomenclature, and Registration

None reported.

Domestication, Breeding, and Selection of Genetic Resources

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Taxonomy, Nomenclature, and Registration

None reported.

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IV. SUMMARY STATISTICS, 2020-2023

Questionnaire on Poplars and Other Fast-Growing Trees Sustaining People and the Environment

Contact Information	
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Terms and Definitions

The main FAO categories of land with a tree component are classified according to the terms and definitions of the Global Forest Resources Assessment (2020).

Naturally regenerating forest: Forest predominantly composed of trees established through natural regeneration. *Explanatory notes:* 1) Includes forests for which it is not possible to distinguish whether planted or naturally regenerated. 2) Includes forests with a mix of naturally regenerated tree species and planted/seeded trees, and where the naturally regenerated trees are expected to constitute the major part of the growing stock at stand maturity. 3) Includes coppice from trees originally established through natural regeneration. 4) Includes naturally regenerated trees of introduced species.

Planted forest: Forest predominantly composed of trees established through planting and/or deliberate seeding.

Explanatory notes: 1) In this context, predominantly means that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity. 2) Includes coppice from trees that were originally planted or seeded.

Plantation forest (subcategory of planted forest): Planted Forest that is intensively managed and meet ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing.

Explanatory notes: 1) Specifically includes: short rotation plantation for wood, fibre and energy. 2) Specifically excludes: forest planted for protection or ecosystem restoration. 3) Specifically excludes: forest established through planting or seeding which at stand maturity resembles or will resemble naturally regenerating forest.

Agroforestry: “Other land with tree cover” with temporary agricultural crops and/or pastures/animals. *Explanatory notes:* 1) Includes areas with bamboo and palms provided that land use, height and canopy cover criteria are met. 2) Includes agrisilvicultural, silvopastoral and agrosilvopastoral systems.

Trees in urban settings: “Other land with tree cover” such as: urban parks, alleys, and gardens.

<u>Forest</u>: Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use. *Explanatory notes:* 1) Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters *in situ*. 2) Includes areas with young trees that have not yet reached but which are expected to reach a canopy cover of 10 percent and tree height of 5 meters. It also includes areas that are temporarily unstocked due to clear-cutting as part of a forest management practice or natural disasters, and which are expected to be regenerated within 5 years. Local conditions may, in exceptional cases, justify that a longer time frame is used. 3) Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific environmental, scientific, historical, cultural or spiritual interest. 4) Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 meters. 5) Includes abandoned shifting cultivation land with a regeneration of trees that have, or are expected to reach, a canopy cover of 10 percent and tree height of 5 meters. 6) Includes areas with mangroves in tidal zones, regardless whether this area is classified as land area or not. 7) Includes rubber-wood, cork oak and Christmas tree plantations. 8) Includes areas with bamboo and palms provided that land use, height and canopy cover criteria are met. 9) Includes areas outside the legally designated forest land which meet the definition of “forest”. 10) Excludes tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards and agroforestry systems when crops are grown under tree cover. Note: Some agroforestry systems such as the “Taungya” system where crops are grown only during the first years of the forest rotation should be classified as forest.

<u>Other land with tree cover</u>: Land classified as “remaining land area”, spanning more than 0.5 hectares with a canopy cover of more than 10 percent of trees able to reach a height of 5 meters at maturity. *Explanatory notes:* 1) **Land use is the key criteria for distinguishing between forest and other land with tree cover.** 2) Specifically includes: palms (oil, coconut, dates, etc), tree orchards (fruit, nuts, olive, etc), agroforestry and trees in urban settings. 3) Includes groups of trees and scattered trees (e.g., trees outside forest) in agricultural landscapes, parks, gardens and around buildings, provided that area, height, and canopy cover criteria are met. 4) Includes tree stands in agricultural production systems, such as fruit tree plantations/orchards. In these cases, the height threshold can be lower than 5 meters. 5) Includes agroforestry systems when crops are grown under tree cover and tree plantations established mainly for other purposes than wood, such as oil palm plantations. 6) The different sub-categories of “other land with tree cover” are exclusive and area reported under one subcategory should not be reported for any other sub-categories. 7) Excludes scattered trees with a canopy cover less than 10 percent, small groups of trees covering less than 0.5 hectares and tree lines less than 20 meters wide.

Table 1. Total area (ha) of polars, willows, and eucalypts in 2023 in the US (see Country Notes), as well as area planted (ha) from 2020-2023.

Land use category / genus	Total area (2023; ha)	Total area by forest function (%)				Area planted from 2020 to 2023 (ha)
		Production		Protection (%)	Other (%)	
		Industrial roundwood (%)	Fuelwood biomass (%)			
Naturally Regenerating Forest						
Poplars	9,296,159			7.6	92.4	N/A
Willows	440,191			6.4	93.6	N/A
Mix of P&W	218,905			4.8	95.2	N/A
Eucalypts	Unavailable			Unavailable		N/A
Planted Forest						
Poplars	142,394			2.2	97.8	
Willows	5,658			32.0	68.0	
Mix of P&W	16,748			0.0	100.0	
Eucalypts	Unavailable			Unavailable		
Plantations						
Poplars						
Willows						
Mix of P&W						
Eucalypts						
Other Planted Forest						
Poplars						
Willows						
Mix of P&W						
Eucalypts						
Other Land with Tree Cover (Agroforestry)						
Poplars						
Willows						
Mix of P&W						
Eucalypts						
Other Land with Tree Cover (Trees in Urban Settings)						
Poplars						
Willows						
Mix of P&W						
Eucalypts						
Grand Total	**10,120,055**					

Country Notes: "Other" is forest land available for timber production but not necessarily intended for that purpose. In other words, it is not reserved nor protected, but the owner of the land may not plan to use the trees for industrial purposes. Citation: USDA Forest Service, Forest Inventory and Analysis Program, Wednesday, 29 May 2024 12:37:57 GMT. Forest Inventory EVALIDator web-application Version 2.1.2. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. [Available only on internet: https://apps.fs.usda.gov/fiadb-api/evalidator]. The state of Alaska, which has a considerable poplar and willow resource, is excluded from these statistics due to lack of data.

Table 2. Wood removals (m^3) of polars, willows, and eucalypts in 2023 in the US (see Country Notes).

Land use category / genus	Species	Total Removals	Industrial roundwood			Fuelwood / wood chips
			Veneer / Plywood	Pulpwood	Sawnwood	
Naturally Regenerating Forest						
Poplars[1]						
SPCD 741 – Balsam Poplar	*P. balsamifera*[2]	339,127.03				
SPCD 742 – Eastern Cottonwood	*P. deltoides*	523,811.15				
SPCD 743 – Bigtooth Aspen	*P. grandidentata*	2,166,649.83				
SPCD 744 – Swamp Cottonwood	*P. heterophylla*	72,708.44				
SPCD 745 – Plains Cottonwood	*P. deltoides*	9,305.70				
SPCD 746 – Quaking Aspen	*P. tremuloides*	7,517,427.18				
SPCD 747 – Black Cottonwood	*P. balsamifera*	61,867.66				
SPCD 748 – Fremont Cottonwood	*P. fremontii*	8,517.09				
Willows[3]						
SPCD 920 – Willow spp.	*S.* spp.	2,189.78				
SPCD 921 – Peachleaf Willow	*S. amygdaloides*	1,415.46				
SPCD 922 – Black Willow	*S. nigra*	78,879.04				
SPCD 927 – White Willow	*S. alba*	491.28				
Mix of P&W		Unavailable				
Eucalypts		Unavailable				
Planted Forest						
Poplars						
SPCD 741 – Balsam Poplar	*P. balsamifera*	8,521.79				
SPCD 742 – Eastern Cottonwood	*P. deltoides*	170,492.47				
SPCD 743 – Bigtooth Aspen	*P. grandidentata*	44,850.66				
SPCD 746 – Quaking Aspen	*P. tremuloides*	308,061.40				
SPCD 747 – Black Cottonwood	*P. balsamifera*	91,197.95				
Willows						
SPCD 922 – Black Willow	*S. nigra*	20,781.45				
SPCD 925 – Coastal Plain Willow	*S. caroliniana*	18,859.13				
Mix of P&W		Unavailable				
Eucalypts		Unavailable				
Other Land with Tree Cover (Agroforestry)						
Poplars						
Willows						
Mix of P&W						
Eucalypts						
	Grand Total	**11,445,154.49**				

[1] *Populus balsamifera* L.; *Populus deltoides* Bart. ex Marsh.; *Populus fremontii* S. Watson; *Populus grandidentata* Michx.; *Populus heterophylla* L.; *Populus tremuloides* Michx. | [2] The US Forest Inventory and Analysis categorizes *P. trichocarpa* as *P. balsamifera* ssp. *trichocarpa*, thus numbers for *P. balsamifera* are inclusive of *P. trichocarpa*. | [3] *Salix alba* L.; *Salix amygdaloides* Andersson; *S. caroliniana* Michx.; *Salix nigra* Marsh. | Country Notes: Data were obtained from the US Forest Inventory and Analysis (FIA) program and represent the most current inventory information from each state in the United States. Some states may be missing information (particularly Alaska) and removals should be viewed as approximate. Removals data include harvest removals only, not removals due to land conversion. Species with fewer than 10 observations were omitted because of high standard error values. Removals values are **AVERAGE ANNUAL REMOVALS**.

Table 3. Forest products in roundwood equivalents (1,000 m^3 r) in 2023 in the US (see Country Notes).

Land use category / genus	Wood fuel	Wood chips / particles	Sawnwood	Veneer sheets	Plywood	Particle board	Fibreboard	Wood pulp
Naturally Regenerating Forest								
	--------------------------------- *Roundwood equivalents (1,000 m^3 r)* ---------------------------------							
Poplars								
Willows								
Mix of P&W								
Eucalypts								
Planted Forest								
	--------------------------------- *Roundwood equivalents (1,000 m^3 r)* ---------------------------------							
Poplars								
Willows								
Mix of P&W								
Eucalypts								
Other Land with Tree Cover (Agroforestry)								
	--------------------------------- *Roundwood equivalents (1,000 m^3 r)* ---------------------------------							
Poplars								
Willows								
Mix of P&W								
Eucalypts								
Grand Total								

Country Note: These data are not available for the current reporting period.

Table 4. Prevailing trends until 2030 in the development of poplars, willows, and eucalypts in the United States.

	Increase	Decrease	Remain as is	No comment
1a. The conversion of naturally regenerating forests of poplar to other land uses will...	X			
1b. The conversion of naturally regenerating forests of willow to other land uses will...	X			
1c. The conversion of naturally regenerating forests of eucalypts to other land uses will...				X
2a. The conversion of planted forests of poplar to other land uses will...			X	
2b. The conversion of planted forests of willow to other land uses will...			X	
2c. The conversion of planted forests of eucalypts to other land uses will...			X	
3a. The conversion of planted forests of poplar to other species will...			X	
3b. The conversion of planted forests of willow to other species will...			X	
3C. The conversion of planted forests of eucalypts to other species will...				X
4a. The area of poplars for bioenergy plantations will ...			X	
4b. The area of willows for bioenergy plantations will ...	X			
4c. The area of eucalypts for bioenergy plantations will ...				X
5a. Government investments in poplars will ...				X
5b. Government investments in willows will ...				X
5c. Government investments in eucalypts will ...				X
6a. Private sector investments in poplars will ...				X
6b. Private sector investments in willows will ...				X
6c. Private sector investments in eucalypts will ...				x
7a. The significance of poplars for **productive** purposes will ...	X			
7b. The significance of willows for **productive** purposes will ...	X			
7c. The significance of eucalypts for **productive** purposes will ...			X	
8a. The significance of poplars for **environmental protection** purposes will ...	X			
8b. The significance of willows for **environmental protection** purposes will ...	X			

Table 4. Prevailing trends until 2030 in the development of poplars, willows, and eucalypts in the United States.

	Increase	Decrease	Remain as is	No comment
8c. The significance of eucalypts for **environmental protection** purposes will ...	X			
9a. The rejection by environmental groups of poplars will...				X
9b. The rejection by environmental groups of willows will...				X
9c. The rejection by environmental groups of eucalypts will...				X
10a. The **acceptance** by the general public of poplars as important natural resources will........				X
10b. The **acceptance** by the general public of willows as important natural resources will........				X
10c. The **acceptance** by the general public of eucalypts as important natural resources will........				X
11a. The introduction of poplars in **agroforestry systems** will........	X			
11b. The introduction of willows in **agroforestry systems** will........	X			
11c. The introduction of eucalypts in **agroforestry systems** will........				X

Country Note: The opinions expressed in this table are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.