M.L. 2015, Chp. 76, Sec. 2, Subd. 06b Project Abstract
For the Period Ending June 30, 2020

PROJECT TITLE: Emerald Ash Borer Ecological and Hydrological Impacts – Phase II
PROJECT MANAGER: Anthony D'Amato
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp. 76, Sec. 2, Subd. 06b

APPROPRIATION AMOUNT: $400,000
AMOUNT SPENT: $400,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results
Project demonstrates great vulnerability of Minnesota's ash forests to emerald ash borer, including potential shifts from forested to marsh-like vegetation once ash trees have been killed. Promising strategies to mitigate these impacts through establishment of non-ash species using tree planting and other methods have been demonstrated through this project.

Overall Project Outcome and Results
The Emerald Ash Borer (EAB) has been decimating ash trees throughout the Lake States and is currently on the doorstep of the vast acreages of black ash in northern Minnesota. There are over one billion black ash trees in the state and loss of this species is expected to have significant cultural and ecological impacts across the region. This project was a continuation of the Ecological and Hydrological Impacts of Emerald Ash Borer project that received ENRTF funding in 2010 and was designed to increase our understanding of the vulnerability of northern Minnesota forests to EAB and develop appropriate strategies for increasing the resilience of these critical habitats to the impacts of this introduced insect. Results from this project indicate that loss of black ash will have significant impacts on the hydrology of these areas with overstory mortality resulting in an increased duration of flooding. These impacts are likely to be greatest in swamps occupying depressional or transitional hydrogeomorphic settings. Examination of 32 black ash wetlands across northern Minnesota indicated a region-wide lack of species capable of replacing black ash following EAB and point to an urgent need for active silvicultural intervention to establish non-host tree species in these wetlands. To this end, we monitoring survival of seedlings planted as potential replacement species over a nine-year period and found that the highest surviving species were American elm, swamp white oak, Manchurian ash, and hackberry. Another species showing promise is balsam poplar, which is readily planted from cuttings and may provide an operationally efficient strategy for establishing non-ash tree species in areas threatened by EAB. Collectively, this work has helped identify both the black ash wetlands most vulnerable to EAB impacts, as well as the forest conservation strategies most effective at mitigating these impacts.

Project Results Use and Dissemination
The results of this project have been shared on numerous occasions with resource professionals, policy makers, citizens, and scientists over the past five years in efforts to inform forest conservation decisions regarding the impacts of emerald ash borer on black ash forests in Minnesota. These dissemination activities have included the development of case studies within the Great Lakes Silviculture Prescription Library highlighting key outcomes of this work. In addition, we have shared the results from this project with private forest landowners, and county, state, tribal and federal natural resource managers on numerous occasions, including through two Sustainable Forestry Education Cooperative webinars (September 15, 2015 and October 17, 2017) and

presentations at the Upper Midwest Great Lakes Landscape Conservation Cooperative North Woods Work Group meeting at Sault St. Marie, MI June 28, 2016, and the Society of American Foresters National Convention in Madison, WI on November 3, 2016. The results of this work have also been shared directly with the Silviculture Program Coordinator for the Minnesota DNR to discuss ways in which the findings from this project can inform black ash management guidelines for the state of Minnesota (February 16, 2017). We co-organized the workshop, "Science and Management of Ash Forests after EAB" in Duluth, MN July 25-27, 2017 where results from this project related to hydrology and understory vegetation and associated management strategies were presented to over 200 resource managers, policy makers, and scientists from across MN, MI, WI and the northeastern US. Results of this project related to management strategies for minimizing emerald ash borer impacts were presented as part of the National Silviculture Workshop in Bemidji, MN May 21-23, 2019. This included a field tour for natural resource managers to the sites established under Phase I of this project with representation from the Minnesota DNR, several MN County Land Departments, Chippewa National Forest, Superior National Forest, Division of Resource Management for the Leech Lake Band of Ojibwe, as well as foresters and scientists from across the US. The results of this project related to potential replacement species for planting to sustain the functioning of black ash wetlands following EAB were shared as part of a webinar "Integrating Assisted Migration into Adaptation Strategies for Northeastern Forests." This webinar is part of the Northern Institute of Applied Climate Science Forest Webinar series, with over 120 forest managers viewing the webinar, which is now archived online on YouTube. Finally, the project PI has served on the Minnesota DNR black ash management guideline committee since the inception of this project and has shared project results to influence the current recommendations for managing MN black ash forests in the face of EAB.

Publications resulting from this work are available for download from the USFS Treesearch website. Additional publications from this work that are currently in development will also be posted on this site and shared with LCCMR staff for dissemination.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2015 Work Plan

Date of Report: November 13, 2020

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: June 11, 2015

Project Completion Date: June 30, 2020

Does this submission include an amendment request? _No_

PROJECT TITLE: Emerald Ash Borer Ecological and Hydrological Impacts – Phase II

Project Manager: Anthony D'Amato

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Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$400,000**
	Amount Spent:	**$400,000**
	Balance:	**$0**

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 06b

Appropriation Language:
$400,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to assess the potential impacts of emerald ash borer on Minnesota black ash forests and quantify potential impacts on native forest vegetation, invasive species spread, and hydrology. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Emerald Ash Borer Ecological and Hydrological Impacts – Phase II

II. PROJECT STATEMENT:

Black ash swamps cover over one million acres of northern Minnesota and provide critical habitat for wildlife and serve many important functions, including flood regulation and carbon storage. The ecology and functioning of these swamps is greatly threatened by the introduced Emerald Ash Borer (EAB), which has been decimating native populations of ash throughout the Lake States and is currently located in Superior, WI on the doorstep of the vast acreages of black ash in northern Minnesota. Although cold winter temperatures may kill some EAB, there is no evidence cold temperatures will stop the spread and survival of this introduced pest in northern Minnesota, an area with over 1 billion black ash trees. This project is a continuation of the Ecological and Hydrological Impacts of Emerald Ash Borer project that received ENRTF funding in 2010. This project has established a large-scale network of research sites in black ash swamps that is assessing potential EAB impacts and evaluating potential mitigation strategies, including establishing non-host tree species in these areas. The initial phase of this work has already identified significant potential impacts of EAB and pre-emptive harvesting on native plants and forest hydrology, including loss of native plant diversity and increased flooding, but continued funding is needed to ensure that additional progress can be made towards developing strategies for increasing the resilience of black ash swamps to EAB, as well as anticipating landscape-level impacts of this insect pest.

The goals of this project are:

1. To increase our understanding of the long-term impacts of EAB on the ecology and hydrology of black ash forests in Minnesota and to develop appropriate strategies for increasing the resilience of these critical habitats to the effects of EAB. The project will achieve this goal by examining the long-term hydrological and ecological response of black ash forests to treatments simulating EAB and evaluating the survival and growth of potential replacement species for black ash.
2. The second goal of this project is to generate an assessment of the vulnerability of northern Minnesota black ash forests and associated infrastructure (i.e., roads) and natural features (streams and lakes) to EAB impacts. The project will accomplish this by mapping the location and extent of black ash swamps throughout northern Minnesota and determining potential changes in hydrology and forest habitats that can be expected once EAB spreads through northern Minnesota.

The accomplishment of the above-listed goals will yield critical information for anticipating the regional impacts of EAB on wildlife habitat and ecosystem services, including flood regulation and carbon sequestration across northern Minnesota. By examining existing experiments and field trials aimed at developing strategies for increasing the resilience of black ash forests to EAB, this project will provide much-needed management guidance for resource managers to address this pressing forest health threat. This guidance will include recommendations on alternate tree species to favor/establish in these areas and appropriate management regimes. In addition, the maps and datalayers of black ash forest wetlands across northern Minnesota will be a critical tool for developing landscape-level plans and vulnerability assessments for these threatened forest types. These tools will be particularly useful in designating conservation and mitigation priorities based on the proximity of black ash habitats to infrastructure and aquatic systems that could be negatively impacted by changes in forest hydrology, as well as areas containing known populations of sensitive species.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 11, 2016: We completed the fourth year of post-harvest vegetation and hydrological measurements across 576 sampling plots covering over 200 acres of black ash swamps on the Chippewa National Forest (The first three years were supported under Phase I of this project). Analyses of four-year trends in survival of planted seedlings indicate that American elm, swamp white oak, and hackberry are the species with the greatest levels of survival out of the 11 non-ash species planted (> 80% survival for all three species in non-clearcut plots). Survival of all planted species is lowest in clearcut areas, suggesting this practice

may create challenging conditions for establishing non-ash species. The survival of swamp white oak and balsam poplar seedlings planted in the fall was significantly greater than spring plantings, suggesting fall timing for planting may be most effective for these species to enhance survival in black ash systems. The fourth season of post-harvest hydrological measurements was completed and water table dynamics were similar to the third growing season with clearcut and girdle (EAB mortality) treatments experiencing flooded conditions that persisted six to eight weeks longer than in no-harvest and group selection areas. The duration of these flooded conditions for four years after the loss of ash indicates EAB and preemptive clearcutting will cause significant, long-term shifts in water table conditions towards greater flooding and loss of tree cover in these areas. Thirty additional black ash study sites were identified in St. Louis, Lake, Carlton, and Aitkin County to conduct additional hydrologic monitoring and vegetation sampling.

Amendment request January 11, 2016: An amendment is requested to rebudget $122,855 from Personnel (Wages and Benefits) to Professional/Technical Contracts. This rebudget request ($122,855) would be used for a contract with the USDA Forest Service Northern Research Station and co-PI, Dr. Brian Palik to support salary and fringe for a research associate (0.75 FTE) to coordinate collection of ecological field data from black ash forests for four years. This research associate was originally budgeted to be based out of St. Paul at the University of Minnesota; however, being based out of the US Forest Service Research Station in Grand Rapids, MN represents the most cost-effective approach for completing this research given our need to have personnel dedicated to this study who are located close to the field sites. In addition, this technician would gain access to USFS vehicles for travel that would be provide as in-kind support towards the research project. This rebudget request is being made in anticipation of hiring a research technician to support the project.

Amendment approved by LCCMR 1-19-2016

Project Status as of July 5, 2016: We have established plots for documenting vegetation and hydrological conditions in 30 black ash swamps across St. Louis, Lake, Carlton, and Aitkin County. These sites represent the range of conditions and vulnerabilities of black ash swamps in the state and span the primary Native Plant Communities (NPCs) in which black ash constitutes a significant component (WFn55 and WFn64). Vegetation sampling has been completed at 5 of these sites, with the remainder being completed by the end of this field season. Piezometers for monitoring ground water tables during the growing season have also been installed in these areas. The fifth year of post-harvest vegetation and hydrological measurements on the 576 sampling plots established on the Chippewa National Forest under Phase I of this project is 25% complete and will be finished during the months of July and August. Measurements will include evaluations of the survival of potential replacement species for black ash five years after planting. Mapping algorithms for classifying and delineating the extent of black ash forests in regions dominated by broad depositional features (e.g., glacial lakes) have been completed. Mapping approaches for distinguishing ash swamps under other landscape conditions are ongoing this summer.

Project Status as of March 14, 2017: We have measured the vegetation conditions across 30 black ash swamps in St. Louis, Lake, Carlton, and Aitkin County and have installed monitoring wells for examining ground water dynamics in these systems. In addition, we have completed the fifth year of post-harvest measurements of vegetation and sixth year of growing season hydrological measurements across all of the study sites established during Phase I on this project on the Chippewa National Forest. The five-year survival and growth of potential replacement species for black ash were also measured and indicate that swamp white oak, American elm, and hackberry remain the most promising species to establish in these areas. Black ash remains the dominant species naturally regenerating across these sites with limited representation from other native tree species, highlighting the difficulty in increasing the diversity of these areas through harvesting alone. Geospatial modelling of back ash forest habitats was conducted by integrating forest inventory data (namely species composition) with a variety of geospatial data layers in a statistical prediction model. Specifically, plot-level species summaries depicting the presence or absence of black ash were integrated with several Landsat-derived vegetation indices and LiDAR to map the presence and absence of black ash across north central Minnesota. The

model had an overall accuracy of 84.3% and is now being evaluated with other areas of the state, including northeastern portions.

Project Status as of November 18, 2017: We have collected a second year of hydrological measurements across the 30 black ash swamp study areas established as part of Phase 2 of this project. Water table dynamics across these areas highlight strong coupling between black ash seasonal water use and patterns in water table depth. Based on these patterns, loss of black ash to emerald ash borer will have the most significant impacts on flooding duration on sites with greater organic soil depths. We also completed the sixth year of post-harvest measurements of vegetation and seventh year of growing season hydrological measurements across all of the study sites established during Phase I on this project on the Chippewa National Forest. Swamp white oak, American elm, and hackberry remain the most promising species to establish in these areas. Given the continued dominance of black ash in the regeneration layer, we have initiated a small-scale study in a portion of these sites examining the effectiveness of competition control that removes regenerating black ash from around planted, non-ash species. We continued refining our ability to map the abundance of black ash forests across Minnesota using geospatial modelling. Integration of remotely sensed indices of seasonal moisture conditions has allowed us to increase the accuracy of our models to 85.7% and we are now refining these models with variables that use phenological signatures to map black ash abundance.

Project Status as of April 5, 2018: We have measured and characterized two seasons of vegetation and hydrological conditions across the 30 black ash swamp study areas established as part of Phase 2 of this project. Although these ash swamps exhibit a wide range in hydrologic conditions and vegetation structure, daily and seasonal patterns in water table levels indicate a strong relationship between the abundance of black ash in the forest overstory and flooding duration. Sites exhibiting black ash decline had greater flooding duration throughout the growing season suggesting loss of canopy ash to emerald ash borer will likely generate similar or more significant effects. The importance of black ash in regulating hydrological function has been reinforced through analysis of the seventh year of growing season hydrological measurements across all of the study sites established during Phase I of this project on the Chippewa National Forest. The increased duration of flooding observed following clearcut harvests of black ash and girdling treatments (meant to emulate emerald ash borer infestations) have persisted for the past six years with little evidence for recovery. These patterns indicate a potential shift to an alternate hydrologic regime that favors the establishment of herbaceous and shrub communities; a condition that will make maintaining forested cover in these areas quite challenging. Analysis of seedling survival in areas where black ash competition control was applied will provide greater insights into restoration strategies that can enhance the survival of tree species, such as swamp white oak, American elm, and hackberry, which have continued to show promise as potential replacement species for black ash. Mapping efforts documenting the abundance of black ash forests were completed for north central Minnesota, with geospatial models now being refined for application to the remainder of northern Minnesota. Topographic indices and phenological signatures remain the most effective remote sensing and geospatial predictor variables for mapping black ash abundance.

Project Status as of August 8, 2018: We are currently collecting a third year of hydrological measurements across the 30 black ash swamp study areas established as part of Phase 2 of this project. We also completed vegetation assessments of these areas to determine the range of ecological characteristics associated with black ash-dominated forests and the potential for non-ash species to naturally replace ash following EAB. Black ash constitutes a disproportionate component of the regeneration layer of these forests with lesser amounts of American elm, red maple, balsam fir, American basswood, balsam poplar, and bur oak. Given these current conditions, it is unlikely that other species will naturally replace black ash forests in these areas following EAB, particularly given associated increases in elevated water tables observed in the study sites established during Phase I of this project on the Chippewa National Forest. Monitoring of seedling survival and growth in areas where we have simulated EAB impacts indicate that swamp white oak, American elm, and hackberry remain the most promising species to establish in these areas, particularly if browse protection and localized competition control are used to enhance seedling survival. We applied our mapping approach for black ash forests to a

14,000 square mile area in northern Minnesota and were able to generate fine-scale presence/absence maps of black ash stand dominance that could ultimately be used to support EAB risk and vulnerability assessments across large spatial extents. Similar maps are now being made for the remainder of the state.

Project Status as of April 11, 2019: We have measured and characterized three seasons of vegetation and hydrological conditions across the 30 black ash swamp study areas established as part of Phase 2 of this project. Daily and seasonal patterns in water table levels in these areas reinforce a strong relationship between the abundance of black ash in the forest overstory and flooding duration. The eighth growing season of hydrological measurements were completed across all of the study sites established during Phase I of this project on the Chippewa National Forest. The increased duration of flooding observed following clearcut harvests of black ash and girdling treatments (meant to emulate emerald ash borer infestations) continue to persist with little evidence for recovery in these areas. In particular, these treatments had shallower water tables and lower levels of evapotranspiration than control areas and group selection harvests after seven years after treatment application. In addition, there was a greater level of herbaceous cover on these sites indicating ecosystem state shifts driven by vegetation-water table interactions. The ability of group selection harvests to maintain water tables dynamics comparable to intact black ash wetlands suggests this partial harvesting approach may be able to preserve wetland functioning while serving as an opportunity for increasing the representation of non-ash species. Mapping efforts documenting the abundance of black ash forests were completed for north central Minnesota and published in the Canadian Journal of Forest Research.

Project Status as of August 21, 2019: We are currently finishing collecting a fourth year of hydrological measurements across the 30 black ash swamp study areas established as part of Phase 2 of this project. Evaluations of the seasonal hydrologic dynamics collected from these areas over the past three seasons indicates distinct water table dynamics depending on the hydrogeomorphic setting of black ash swamps. Swamps in either depressional (basin) or transitional settings are more tightly coupled with black ash phenology and water use than those in swales. The loss of black ash from all of these settings will result in an increased duration of flooding; however, impacts will be greatest for those swamps in depressional or transitional settings. Monitoring of seedling survival and growth in areas where we have simulated EAB impacts continue to indicate that swamp white oak, American elm, and hackberry remain the most promising species to establish in these areas, particularly if browse protection and competition control are applied. Other species also showing high levels of survival, depending on level of overstory mortality, are red maple and balsam poplar, with maple showing greatest survival in areas with an intact black ash canopy and balsam poplar performing best in clearcut areas. Across species examined, balsam poplar has shown the greatest levels of growth in areas it has survived, suggesting this species may be suitable for rapidly establishing canopy cover in places where black ash mortality is high. Finally, we published fine-scale presence/absence maps of black ash stand dominance for assisting with efforts focused on evaluating EAB risk and vulnerability in northern Minnesota.

Project Status as of February 19, 2020: We have measured and characterized four seasons of vegetation and hydrological conditions across the 30 black ash swamp study areas established as part of Phase 2 of this project. In addition, a ninth growing season of hydrological measurements and eighth year of measurements on planted seedlings were completed across all of the study sites established during Phase I of this project on the Chippewa National Forest. Potential replacement species with the highest levels of survival over this nine-year period include American elm, swamp white oak, Manchurian ash, and hackberry. Another species showing promise as potential replacement species is balsam poplar, which although showing lower levels of survival than the aforementioned species, has demonstrated the greatest levels of growth in the areas that it has persisted. This species is readily planted from cuttings, which may provide an operationally efficient strategy for establishing non-ash tree species in areas threatened by emerald ash borer. Results from these plantings were shared as part of the Forest Adaptation Webinar series in early January.

Overall Project Outcomes and Results: The Emerald Ash Borer (EAB) has been decimating ash trees throughout the Lake States and is currently on the doorstep of the vast acreages of black ash in northern Minnesota. There

are over one billion black ash trees in the state and loss of this species is expected to have significant cultural and ecological impacts across the region. This project was a continuation of the Ecological and Hydrological Impacts of Emerald Ash Borer project that received ENRTF funding in 2010 and was designed to increase our understanding of the vulnerability of northern Minnesota forests to EAB and develop appropriate strategies for increasing the resilience of these critical habitats to the impacts of this introduced insect. Results from this project indicate that loss of black ash will have significant impacts on the hydrology of these areas with overstory mortality resulting in an increased duration of flooding. These impacts are likely to be greatest in swamps occupying depressional or transitional hydrogeomorphic settings. Examination of 30 black ash wetlands across northern Minnesota indicated a region-wide lack of species capable of replacing black ash following EAB and point to an urgent need for active silvicultural intervention to establish non-host tree species in these wetlands. To this end, we monitoring survival of seedlings planted as potential replacement species over a nine-year period and found that the highest surviving species were American elm, swamp white oak, Manchurian ash, and hackberry. Another species showing promise is balsam poplar, which is readily planted from cuttings and may provide an operationally efficient strategy for establishing non-ash tree species in areas threatened by EAB. Collectively, this work has helped identify both the black ash wetlands most vulnerable to EAB impacts, as well as the forest conservation strategies most effective at mitigating these impacts.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: ***Determine the long-term impact of EAB on native plant communities, spread of invasive species, and hydrology***

Description: We will conduct continued monitoring of the research and demonstration sites established in Phase One to assess the long-term impacts of EAB on native plant communities, spread of invasive species, and hydrology. These sites are large-scale manipulations of black ash systems that allow for assessments of the ecological impacts of EAB on black ash forests, and for evaluations of potential adaptive management actions for sustaining the ecological functions of black ash systems after the loss of this species to EAB. Each site is over 25 acres in size and has the following treatments replicated using a split-plot, complete block design.

a) ***Ash mortality*****:** Four levels of ash mortality were implemented at each site in four acre areas (n=8 for each mortality treatment): 1) retain all ash (control), 2) simulated EAB mortality by girdling all ash, 3) group selection harvests (remove groups of ash in 0.1 acre acres covering 20% of unit), and 4) harvest of all ash (clearcutting). For girdling treatments, all trees within 4 acre patches were girded using draw knives. Harvests and girdling occurring in winter 2011. Each treatment is surrounded by a 5 acre, untreated buffer to minimize influence on adjacent treatments.

b) ***Planting*****:** Each ash mortality treatment is split with two levels of planting treatment: no planting and planting. For the planting treatments, we have planted a range of native species most likely to grow within the wet forest conditions, including northern white cedar, tamarack, American elm, swamp white oak, and red maple. Half of the seedlings were planted the growing season prior to the implementation of the mortality treatments and the other half at the beginning of the growing season following treatment implementation.

Across these treatments vegetation and hydrological measurements have occurred yearly on 576 sampling plots covering over 200 acres of black ash swamps. These measurements will be continued with Phase Two of the study. In particular, all vegetation, including trees, understory vascular plants, invasive species, and forest regeneration will be measured annually for five years within a series of nested plots. Hydrological impacts of ash mortality treatments will continued to be assessed with a series of piezometers (screened PVC tubing) installed in the central portion of each treatment area. Pressure transducers within each piezometer continuously measure ground water tables during the growing season to directly assess treatment effects on groundwater storage and transport. These measurements will be continued for five years. Meteorological data

(precipitation, temperature, wind speed, relative humidity, and solar radiation) will also be collected continuously at each treatment area to estimate surface and soil evaporation with the Penman equation. Estimates of evapotranspiration components (i.e., transpiration and evaporation) and precipitation will be used to estimate treatment effects on site water balance. Results from these collective measurements will be synthesized into a final report describing the long-term impacts of EAB on black ash wetlands in northern Minnesota.

Summary Budget Information for Activity 1:

ENRTF Budget: $157,783
Amount Spent: $157,783
Balance: $ 0

Outcome	Completion Date
1. Measure the long-term impacts of EAB on forest hydrology, including flooding impacts	*September 2019*
2. Measure the long-term impacts of EAB on native plant communities and spread of invasive plant species	*September 2019*
3. Final report of activity results submitted	*June 2020*

Activity Status as of January 11, 2016: We have completed the fourth year of post-harvest sampling of forest hydrology and vegetation across 576 sampling plots in the 8 research areas on the Chippewa National. We have also completed mapping known populations of invasive species adjacent to our study areas to allow for monitoring of their potential future spread into these areas. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of July 5, 2016:
We have completed the fifth year of post-harvest measurements of vegetation across 2 of the 8 study sites within black ash forests on the Chippewa National Forest in northern Minnesota and will complete measurements on the remaining 6 sites by September 2016. The sixth year of growing season hydrological measurements are also ongoing and will be completed in September. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of March 14, 2017: We have completed the fifth year of post-harvest measurements of vegetation and sixth year of growing season hydrological measurements across all of the study sites on the Chippewa National Forest. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of November 18, 2017: We have completed the sixth year of post-harvest measurements of vegetation and seventh year of growing season hydrological measurements across all of the study sites on the Chippewa National Forest. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of April 5, 2018: We have completed all vegetation and hydrological measurements for the sixth and seventh seasons, respectively. We will be sampling these ecosystem components in the coming field season and are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of August 8, 2018: We have completed the seventh year of post-harvest measurements of vegetation across 7 of the 8 study sites within black ash forests on the Chippewa National Forest in northern Minnesota and will complete measurements on the remaining site by September 2018. The eighth year of growing season hydrological measurements are also ongoing and will be completed in September. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of April 11, 2019: We have completed all vegetation and hydrological measurements for the seventh and eighth seasons, respectively. We will be sampling these ecosystem components in the coming field season and are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of August 20, 2019: We have completed the eighth year of post-harvest measurements of vegetation across all of the 8 study sites within black ash forests on the Chippewa National Forest in northern Minnesota. The ninth year of growing season hydrological measurements will be completed in September. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Activity Status as of February 19, 2020: We have completed all vegetation and hydrological measurements for the eighth and ninth seasons, respectively. We are on schedule to meet all proposed completion dates for deliverables under Activity 1.

Final Report Summary: We completed four years of sampling across 576 sampling plots covering over 200 acres of black ash swamps established on the Chippewa National under Phase I of this project. Collectively, between Phase I and II of the project, we have now documented nine total years of ecological and hydrological responses to ash mortality and harvesting in these areas. These measurements indicate that loss of overstory ash trees, either by clearcut harvests of black ash or girdling treatments (meant to emulate emerald ash borer infestations) will result in an increased duration of flooding during the growing season that persists for at least nine years with little evidence for recovery. In particular, these areas had shallower water tables and lower levels of evapotranspiration than control areas and group selection harvests for nine years after treatment application. Moreover, vegetation conditions in these areas shifted to a high level of herbaceous and graminoid cover with little evidence of new tree seedling recruitment indicating ecosystem state shifts driven by this prolonged flooding. Results regarding these potential changes in black ash forest hydrology and vegetation structure were summarized in a peer-reviewed publication (Diamond et al. 2018), as well as numerous field tours of these study sites as part of workshops and trainings related to sustaining black ash forests in the face of EAB.

ACTIVITY 2: ***Develop and implement recommendations for mitigating impacts of EAB on black ash forests, including planting suitable non-host tree species***

Description: The growth and survival of planted and natural seedlings representing non-host species for EAB, including American elm, northern white cedar, and tamarack, and established in Phase One will be monitored yearly to develop recommendations for species to plant to increase the resilience of black ash forests to EAB. Measurements include over 3,000 seedlings across a range of ash mortality and management conditions. Seedling survival and growth has been measured for four years and will continue for an additional five years under Phase Two to determine the suitability of different tree species as options for increasing the resilience of black ash wetlands. Planted seedlings will be measured for basal stem diameter and total height to determine rates of growth and vigor. In addition, the presence of deer browse damage will also be recorded. Volumetric moisture will be measured periodically within the seedling subplots throughout the next five growing seasons using TDR moisture probes. Light availability for each seedling will also be assessed at the center of each plot using a LAI-2000 plant canopy analyzer. Measurements collected under Activity 1 related to vegetation and hydrology will be used to develop predictive equations for determining the conditions most conducive for different tree species to survive within black ash wetlands. These models and findings from our long-term evaluations of seedling survival and growth will be summarized as part of a management guide for increasing the resilience of black ash wetlands to EAB.

Summary Budget Information for Activity 2:	**ENRTF Budget:**	**$85,180**
	Amount Spent:	**$85,180**
	Balance:	**$ 0**

Outcome	**Completion Date**

1. Measure the long-term survival and growth of potential replacement species for black ash	*September 2019*
2. Develop and implement recommendations for increasing the resilience of black ash forests to EAB	*January 2020*
3. Present recommendations to DNR, Minnesota Legislature, and National Forests	*May 2020*

Activity Status as of January 11, 2016: We completed the fourth year of measurements of the growth and survival of potential replacement species for black ash. A total of 134,168 seedlings representing 11 potential replacement species (384 reps per species per treatment) were planted across each treatment as part of Phase I of this study and include northern white cedar, yellow birch, tamarack, red maple, hackberry, swamp white oak, black spruce, quaking aspen, cottonwood, balsam poplar, American elm (resistant variety, local seed source crossed with Valley Forge cultivar), and Manchurian ash. Low survival of many of these species, particularly in the clearcuts resulted in 65,275 seedlings being measured and monitored in 2015. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of July 5, 2016:
We have completed an initial survey of seedling survival for the fifth year of measurements and the majority of seedlings present at the end of last growing season (~65,000) survived the winter. We will be measuring growth and survival of all seedlings in August to determine the level of vigor for those seedlings surviving five years post-planting in these environments. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of March 14, 2017: We have completed the fifth year of measurements on all planted seedlings, including assessments of height, diameter, and incidence of browse damage. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of November 18, 2017: We have completed the sixth year of measurements on all planted seedlings and are now also evaluating how competition from regenerating black ash influences survival and growth of these other species. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of April 5, 2018: We have completed the sixth year of measurements on all planted seedlings and have developed protocols for the seventh year of measurements, which will include additional focus on how competing vegetation is influencing survival of different tree species. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of August 8, 2018: We have completed the seventh year of measurements on 80% of the planted seedlings and have also quantified localized competitive conditions around each seedling. We will finish measurements on the remaining seedlings by September. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of April 11, 2019: We have completed the seventh year of measurements on all planted seedlings and have developed protocols for the eighth year of measurements. Measurements in the seventh year included the influence of competing vegetation on seedling survival and growth. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of August 21, 2019: We have completed the eighth year of measurements on 95% of the planted seedlings, including assessments of local competition and browse impacts. We will finish measurements on the remaining seedlings by September. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Activity Status as of February 19, 2020: We have completed the eighth year of measurements on all planted seedlings. We are on schedule to meet all proposed completion dates for deliverables under Activity 2.

Final Report Summary: A total of 65,275 seedlings representing 11 potential replacement species were measured for eight growing seasons in the experimental treatments established under Phase 1 (3 and 5 years of measurements under Phase I and II, respectively). The species of seedlings were northern white cedar, yellow birch, tamarack, red maple, hackberry, swamp white oak, black spruce, quaking aspen, cottonwood, balsam poplar, American elm (resistant variety, local seed source crossed with Valley Forge cultivar), and Manchurian ash. Seedlings were either containerized or bare-root planting stock. Species with consistently higher overall survival rates were swamp white oak, American elm, hackberry, and Manchurian ash, although the latter species died back annually to the root collar due to winter injury and subsequently resprouted. Another species with moderate levels of survival was balsam poplar, which demonstrated the highest levels of height growth across treatments. In response to trainings and communications from this work, managers in the areas adjacent to our study areas have begun deploying cuttings of balsam poplar as a potential strategy to diversify black ash forests threatened by EAB. The findings related to potential replacement species and adaptive strategies for increasing resilience of black ash forests has been shared at numerous workshops, webinars, and field tours and was also summarized in D'Amato et al. (2018).

ACTIVITY 3: ***Assess the vulnerability of black ash forests and associated resources and infrastructure for northern Minnesota***

Description: The distribution, extent, and configuration of black ash forests across northern Minnesota will be mapped based on multispectral and multitemporal satellite digital data and regional forest inventories. Landsat Thematic Mapper (TM) images from different points in the growing season will be used to identify black ash forest wetlands, given the unique phenology of this tree species in terms of leaf expansion relative to other deciduous species in northern Minnesota. Field validation will be conducted based on forest inventory data to determine the accuracy of classification schemes developed for identifying black ash forest habitats. ArcGIS 10.2 and ENVI+IDL will be used for processing Landsat imagery and generating maps of black ash forest wetlands. Forest composition maps depicting the extent and characteristics of black ash forest across northern Minnesota will be created to determine areas with the highest degree of vulnerability to EAB and to inform management and mitigation priorities.

Maps generated under this activity will be used to locate 30 other black ash swamp sites beyond Phase One sites to conduct additional hydrologic monitoring and vegetation sampling. These sites will be used to fully represent the range of conditions and vulnerabilities of black ash swamps in the state and will span the primary Native Plant Communities (NPCs) in which black ash constitutes a significant component (WFn55 and WFn64). We will establish a series of sampling plots and hydrological monitoring stations at each additional black ash site for examining vegetation and water table conditions in these areas. Vegetation will be sampled at one time during Phase Two to generate a description of the native plant communities characterizing black ash swamps and the potential for naturally-occurring tree seedlings to serve as replacement species for black ash. Hydrological measurements will follow similar protocols as those used for Phase One and will involve the installation of a piezometer in the central portion of each swamp and the use of pressure transducers to measure ground water tables during the growing season to assess patterns of groundwater storage and transport in these areas. Hydrological measurements will occur for four years to account for monthly and yearly variability in precipitation patterns. Water budget models will be developed from hydrological measurements occurring under Activity 1 and 3 and used to determine the relative magnitude of groundwater change that could be expected for a given black ash wetland following EAB infestation. These estimates will be paired with our maps of black ash wetlands to identify areas where EAB may have the greatest impacts on regional hydrology.

Summary Budget Information for Activity 3:

ENRTF Budget: $157,037
Amount Spent: $157,037
Balance: $ 0

Outcome	Completion Date
1. Develop statewide map of black ash forest wetlands using remote sensing and forest inventory data	*June 2018*
2. Measure hydrology and vegetation at black ash sites across northern Minnesota	*September 2018*
3. Assess statewide vulnerability of black ash forest wetlands	*September 2019*

Activity Status as of January 11, 2016: RapidEye Satellite imagery with 5 m spatial resolution was acquired and processed for the 1500 square mile area surrounding our main research sites to develop classification schemes for identifying and mapping black ash wetlands. Field validation is currently being conducted using forest inventory data from our research areas and surrounding forests. Once this validation is completed, we will be applying this approach to the remainder of northern Minnesota to generate a statewide map of black ash wetlands. We also were able to locate 30 additional research sites for measuring hydrology and vegetation of black ash forest wetlands in St. Louis, Lake, Carlton, and Aitkin County and will be establishing plots at these sites this upcoming field season (2016). We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of July 2016: Field validation of black ash wetland classification schemes was completed for the areas surrounding our main research sites. These wetlands occur primarily in broad, depositional features, including glacial lake basins, and we are currently acquiring imagery and field data for black ash wetlands in more topographically diverse regions of northern Minnesota, particularly the Arrowhead Region. We have established plots for sampling vegetation and hydrological conditions in 30 research sites in St. Louis, Lake, Carlton, and Aitkin County. Vegetation sampling has been completed at 5 of these sites, with the remainder being completed by the end of this field season. Piezometers for monitoring ground water tables during the growing season have also been installed in these areas and will be used for monitoring water table dynamics over the next four field seasons. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of March 14, 2017: We have measured the vegetation conditions across 30 black ash swamps in St. Louis, Lake, Carlton, and Aitkin County and have installed monitoring wells for examining ground water dynamics in these systems. Measurements in these areas included understory vegetation and assessments of the number of non-ash tree species in the regeneration layer. These sites will be monitored in subsequent field seasons primarily for quantifying hydrological regimes in these areas. A statistical prediction model for mapping black ash occurrence across the landscape was developed based on data from our sample plots and other regional inventories, Landsat-derived vegetation indices, and LiDAR data. This model was applied to north central Minnesota and was able to map the presence and absence of black ash with an overall accuracy of 84.3%. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of November 18, 2017: We have measured a second year of hydrologic conditions across the 30 black ash swamp study areas we established through Phase 2. Our mapping efforts for predicting the occurrence of black ash across Minnesota were also continued with a series of remotely sensed indices of site-level moisture and topographic conditions integrated into our prediction model. Based on the inclusion of these variables, we were able to map the presence and absence of black ash with an overall accuracy of 85.5% and plan on adding variables based on phenological cues to further refine our maps of black ash forests.

Activity Status as of April 5, 2018: We will be collecting the third year of hydrologic measurements from across the 30 black ash swamp study areas we established through Phase 2 in the upcoming field season (spring/summer 2018). We have completed mapping efforts documenting the abundance of black ash forests in

north central Minnesota and are now refining these geospatial models for application to the remainder of northern Minnesota. The integration of topographic indices with phenological signatures has resulted in a high level of accuracy in detecting black ash wetlands (85.7%), particularly in larger depressional settings. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of August 8, 2018: We are currently collecting the third year of hydrologic measurements from across the 30 black ash swamp study areas we established through Phase 2 of the project and will be completed with this measurements in September. We have generated a map of fine-scale presence/absence of black ash stand dominance across a 14,000 square mile area in northern Minnesota. Similar maps are now being made for the remainder of the state. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of April 11, 2019: We will be collecting the fourth year of hydrologic measurements from across the 30 black ash swamp study areas we established through Phase 2 in the upcoming field season (spring/summer 2019). We have completed mapping efforts documenting the abundance of black ash forests in north central Minnesota and have published these results in the Canadian Journal of Forest Research. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of August 21, 2019: We are currently finishing collecting the fourth year of hydrologic measurements from across the 30 black ash swamp study areas we established through Phase 2 of the project and will be completed with this measurements in September. We have finalized fine-scale presence/absence maps of black ash stand dominance across northern Minnesota. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Activity Status as of February 19, 2020: We completed the fourth year of hydrologic measurements from across the 30 black ash swamp study areas we established through Phase 2. We have completed mapping efforts documenting the abundance of black ash forests in northern Minnesota. We are on schedule to meet all proposed completion dates for deliverables under Activity 3.

Final Report Summary: We established 30 additional research sites for measuring hydrology and vegetation of black ash forest wetlands in St. Louis, Lake, Carlton, and Aitkin County. These forests were deliberately selected to represent the range of hydrogeomorphic settings black ash wetlands occur within to inform a more robust understanding of the vulnerability of these communities to EAB impacts. An initial vegetation survey was conducted at each of these sites to document the diversity of tree species in these areas, particularly in relation to potential for replacing black ash trees once they were killed by EAB. Our results indicate a region-wide lack of species capable of replacing black ash, including low existing potential for replacement of black ash from other trees currently in the overstory or through release in the understory. These results point to an urgent need for active silvicultural intervention to establish non-ash tree species in these wetlands, but this must be done in ways that prevent degradation of sites from loss of the foundational role of black ash in controlling ecosystem functions, particularly water table regulation.

Detailed hydrological data were collected from these new research areas from 2015-2019 allowing us to characterize potential impacts of ash mortality on water table dynamics, flooding, and soil moisture regimes. Three distinct water table dynamics were observed depending on the hydrogeomorphic setting of black ash swamps. Swamps in either depressional (basin) or transitional settings were more tightly coupled with black ash phenology and water use than those in swales with water tables highly responsive to black ash water use. The loss of black ash from all of these settings will result in an increased duration of flooding; however, impacts will be greatest for those swamps in depressional or transitional settings. Fine-scale measurements of site elevation created for these areas demonstrated that depressional sites had minimal variation in microtopography, which may create potential challenges to establishing new seedlings given the lack of elevated microsites above the water table.

The extent and distribution of black ash wetlands was estimated using remotely-sensed data, including Landsat and LiDAR, and extensive field data collections in black ash communities. Models for predicting black ash occurrence were constructed and applied to north central Minnesota, which contains the highest concentration of black ash wetlands in the state. From this work, we were able to map the presence and absence of black ash with an overall accuracy of 84.3% with results summarized in Engelstad et al. (2018).

V. DISSEMINATION:

Description: The final product of this project will be an interpretive report describing (a) the long-term impacts of emerald ash borer (EAB) on the hydrology and plant communities in black ash swamps in Minnesota, (b) management recommendations for increasing the resilience of black ash wetlands to EAB, and (c) assessments of the statewide vulnerability of black ash communities to this threat. This report will be made available on the internet as a Department of Forest Resources Staff Paper Report. In addition, several manuscripts will be written based on this research and submitted for publication in peer-reviewed journals. A fact sheet summarizing principal findings of this project will be distributed to LCCMR members and legislators at the state and federal level. Results will be presented at state and national forest management and forest health conferences, and notably to agency and individual participants in the Sustainable Forests Education Cooperative. Results will also be used to inform the development of a management guide for minimizing the impacts of EAB on black ash forests. All reports and publications from this project will be made available via the Department of Forest Resources (www.forestry.umn.edu) and Sustainable Forestry Education Cooperative (http://sfec.cfans.umn.edu/index.htm) websites.

Status as of January 11, 2016: The results of this project related to the impacts of EAB on forest hydrology were shared with resource managers via a webinar on September 15, 2015 that was part of the University of Minnesota Sustainable Forests Education Cooperative Fall Webinar Series. In addition, the impacts of forest management treatments and planting season on the survival of potential EAB replacement species were presented at the 2015 Society of American Foresters Convention in Baton Rouge, LA on November 5, 2015. Finally, a case study describing the initial findings and management recommendations for black ash wetlands in Minnesota was submitted and published on the Great Lakes Silviculture Library website maintained by the Sustainable Forests Education Cooperative. (http://silvlib.cfans.umn.edu/content/evaluating-ecological-impacts-eab-and-climate-change-black-ash-forests-chippewa-nf).

Status as of July 5, 2016: The results of this project related to potential management options for addressing the impacts of EAB on black ash forests were presented to resource managers and policy makers via a seminar at the Upper Midwest Great Lakes Landscape Conservation Cooperative North Woods Work Group meeting in Sault Ste. Marie, MI on June 28, 2016.

Status as of March 14, 2017: The results of this project related to the impacts of emerald ash borer on hydrology and understory vegetation and associated management strategies were presented to resource managers, policy makers, and scientists via three presentations at the 2016 Society of American Foresters National Convention in Madison, WI on November 3, 2016. In addition, the project manager met with the Silviculture Program Coordinator for the Minnesota DNR to discuss ways in which the findings from this project can inform black ash management guidelines for the state of Minnesota on February 16, 2017.

Status as of November 18, 2017: The results of this project related to the impacts of emerald ash borer on hydrology and understory vegetation and associated management strategies were presented to resource managers, policy makers, and scientists as part of the workshop, "Science and Management of Ash Forests after EAB" in Duluth, MN July 25-27, 2017 (https://ashworkshop.org/). This workshop was co-organized by the Project Manager and other scientists on this project and included four presentations based on the findings of this project. Over 200 participants attended this workshop, which included a panel discussion organized by the Project Manager that involved foresters and planners from the Minnesota and Wisconsin DNR and Chippewa

National Forest discussing potential management strategies for increasing the resilience of black ash forests to EAB. Results of this project were also shared via a webinar through the Sustainable Forests Education Cooperative on October 17, 2017 (https://sfec.cfans.umn.edu/2017-webinar-transitioning-black-ash). Finally, results of the mapping efforts were shared at the 2017 Society of American Foresters National Convention in Albuquerque, NM on November 16, 2017.

Status as of April 5, 2018: The results of this project related to management strategies for minimizing emerald ash borer impacts were presented as part of a field tour for natural resource managers from the Chippewa National Forest and Division of Resource Management for the Leech Lake Band of Ojibwe, as well as science leadership for the USDA Forest Service Northern Research Station on March 22, 2018.

Status as of August 8, 2018: The results of this project related to management strategies for minimizing emerald ash borer impacts were synthesized in an article, "Evaluating Adaptive Management Options for Black Ash Forests in the Face of Emerald Ash Borer Invasion," which was published in the peer-reviewed journal *Forests* (http://www.mdpi.com/1999-4907/9/6/348).

Status as of April 11, 2019: The results of this project related to mapping black ash forests in northern Minnesota were summarized in an article "Mapping black ash dominated stands using geospatial and forest inventory data in northern Minnesota, USA", which was published in the peer-reviewed journal *Canadian Journal of Forest Research* (https://www.nrcresearchpress.com/doi/10.1139/cjfr-2018-0481#.XK_bzNh7lEY).

Status as of August 21, 2019: The implications of this work for sustaining black ash as a cultural resource were shared as part of a workshop for tribes across the Lake States and northeastern states at the "Towards Preservation of a Cultural Keystone Species: Assessing the Future of Black Ash Following Emerald Ash Borer Invasion" workshop in Burlington, VT May 7-8, 2019. Results of this project related to management strategies for minimizing emerald ash borer impacts were presented as part of the National Silviculture Workshop in Bemidji, MN May 21-23. This included a field tour for natural resource managers to the sites established under Phase I of this project with representation from the Minnesota DNR, several MN County Land Departments, Chippewa National Forest, Superior National Forest, Division of Resource Management for the Leech Lake Band of Ojibwe, as well as foresters and scientists from across the US.

Status as of February 19, 2020: The results of this project related to potential replacement species for planting to sustain the functioning of black ash wetlands following EAB were shared as part of a webinar "Integrating Assisted Migration into Adaptation Strategies for Northeastern Forests". This webinar is part of the Northern Institute of Applied Climate Science Forest Webinar series, with over 120 forest managers viewing the webinar, which is now archived online at:
https://www.youtube.com/watch?time_continue=3&v=O1t9_vvgGNA&feature=emb_logo

Final Report Summary: The results of this project have been shared on numerous occasions with resource professionals, policy makers, citizens, and scientists over the past five years in efforts to inform forest conservation decisions regarding the impacts of emerald ash borer on black ash forests in Minnesota. These dissemination activities have included the development of case studies within the Great Lakes Silviculture Prescription Library highlighting key outcomes of this work. In addition, we have shared the results from this project with private forest landowners, and county, state, tribal and federal natural resource managers on numerous occasions, including through two Sustainable Forestry Education Cooperative webinars (September 15, 2015 and October 17, 2017) and presentations at the Upper Midwest Great Lakes Landscape Conservation Cooperative North Woods Work Group meeting at Sault St. Marie, MI June 28, 2016, and the Society of American Foresters National Convention in Madison, WI on November 3, 2016. The results of this work have also been shared directly with the Silviculture Program Coordinator for the Minnesota DNR to discuss ways in which the findings from this project can inform black ash management guidelines for the state of Minnesota (February 16, 2017). We co-organized the workshop, "Science and Management of Ash Forests after EAB" in

Duluth, MN July 25-27, 2017 where results from this project related to hydrology and understory vegetation and associated management strategies were presented to over 200 resource managers, policy makers, and scientists from across MN, MI, WI and the northeastern US. Results of this project related to management strategies for minimizing emerald ash borer impacts were presented as part of the National Silviculture Workshop in Bemidji, MN May 21-23, 2019. This included a field tour for natural resource managers to the sites established under Phase I of this project with representation from the Minnesota DNR, several MN County Land Departments, Chippewa National Forest, Superior National Forest, Division of Resource Management for the Leech Lake Band of Ojibwe, as well as foresters and scientists from across the US. The results of this project related to potential replacement species for planting to sustain the functioning of black ash wetlands following EAB were shared as part of a webinar "Integrating Assisted Migration into Adaptation Strategies for Northeastern Forests". This webinar is part of the Northern Institute of Applied Climate Science Forest Webinar series, with over 120 forest managers viewing the webinar, which is now archived online at this link. Finally, the project PI has served on the Minnesota DNR black ash management guideline committee since the inception of this project and has shared project results to influence the current recommendations for managing MN black ash forests in the face of EAB.

Publications resulting from this work are available for download from the USFS Treesearch website site (https://www.fs.usda.gov/treesearch) and include:

Toczydlowski, A. J. Z., R. A. Slesak, R. K. Kolka, R. T. Venterea, A. W. D'Amato, and B. J. Palik. 2020. Effect of simulated emerald ash borer infestation on nitrogen cycling in black ash (*Fraxinus nigra*) wetlands in northern Minnesota, USA. Forest Ecology and Management 458:117769

Engelstad, P. S., M. J. Falkowski, A. W. D'Amato, R. A. Slesak, B. J. Palik, G. M. Domke, and M. B. Russell. 2019. Mapping black ash dominated stands using geospatial and forest inventory data in northern Minnesota, USA. Canadian Journal of Forest Research 49:892-902

Diamond, J. S., D. L. McLaughlin, R. A. Slesak, A. W. D'Amato, and B. J. Palik. 2018. Forested versus herbaceous wetlands: Can management mitigate ecohydrologic regime shifts from invasive emerald ash borer? *Journal of Environmental Management* 222:436-446.

D'Amato, A. W., B. J. Palik, R. A. Slesak, G. Edge, C. Matula, and D. R. Bronson. 2018. Evaluating adaptive management options for black ash forests in the face of emerald ash borer invasion. Forests 9:348-365.

Kolka, R. K., A. W. D'Amato, J. W. Wagenbrenner, R. A. Slesak, T. G. Pypker, M. B. Youngquist, A. R. Grinde, and B. J. Palik. 2018. Review of ecosystem level impacts of emerald ash borer on black ash wetlands: what does the future hold? Forests 9:179-194.

Additional publications from this work that are currently in development will also be posted on this site and shared with LCCMR staff for dissemination.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$251,145	One month of faculty summer salary and fringe (0.36) for five years (PI-D'Amato; 0.1FTE); One month of faculty summer salary and fringe (0.36) for five years (Co-PI Falkowski; 0.1FTE); Post-doctoral researcher examining impacts of EAB on hydrology and native plant communities; salary and fringe (0.1812) for five

		years (0.5 FTE); Work-study undergraduate student to assist with data collection and processing; Salary and fringe (0.0743) for 5 years
Professional/Technical Contracts	$122,855	Contract with the USDA Forest Service Northern Research Station and co-PI, Dr. Brian Palik ($122,855) to support salary and fringe for a research associate (0.75 FTE) to coordinate collection of ecological field data from black ash forests for five years. This research associate is based out of the US Forest Service Research Station in Grand Rapids, MN and represents the most cost-effective approach for completing this research given our need to have personnel dedicated to this research study who are located close to the field sites and with access to USFS vehicles.
Equipment/Tools/Supplies:	$14,000	Supplies for constructing wells for monitoring hydrology at each site ($10500),Haglof distance measuring equipment ($700), stake whiskers for marking subplots ($110), calipers for measuring seedling growth ($320), supplies for constructing frames for measuring understory vegetation ($150), diameter tapes for measuring overstory trees ($150), and data loggers for micrometeorological measurements ($2070)
Travel Expenses in MN:	$12,000	Due to the high number of study sites and logistics associated with visiting and measuring black ash wetland sites $12,000 is budgeted for domestic travel within Minnesota. This money will be used to pay for mileage (75%) and lodging (25%) for researchers, the field technician, and graduate and undergraduate students. Mileage costs are associated with rental of a field vehicle through the University of Minnesota motorpool for four field seasons. Travel reimbursement will follow University of Minnesota protocols.
TOTAL ENRTF BUDGET:	**$400,000**	

Explanation of Use of Classified Staff: NA

Explanation of Capital Expenditures Greater Than $5,000: NA

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 8.54

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: NA

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
U.S. Department of Interior, Northeast Climate Science Center.	$ 165,000	$64,389	Funds from this source will be used to develop methodology for quantifying regional vulnerability of black ash swamps and will directly complement the research proposed in this LCCMR project. In addition, funds from this source will be used to develop outreach materials related to increasing resilience.
USDA FS Northern Research Station	$90,000	$27,741	In-kind salaries provided by U.S. Forest Service Researcher (0.5 FTE; B. Palik), as well as in-kind use of Forest Service ATV, vehicle, and trailer.
State			
University of Minnesota	$10,009	$10,009	In-kind salaries provided by UMN Researchers (0.01 FTE; L. Nagel)
TOTAL OTHER FUNDS:	**$265,009**	**$51,664**	

VII. PROJECT STRATEGY:

A. Project Partners: The project team largely includes the same partners as Phase One and will be led by scientists at the University of Minnesota, Dept. of Forest Resources, including Professors Anthony D'Amato, Michael Falkowski, and Linda Nagel, and a scientist with the USFS, namely Dr. Brian Palik, and Dr. Rob Slesak of the Minnesota Forest Resources Council. Cooperators will include DNR Ecological and Water Resources and Forestry and the Chippewa and Superior National Forests.

B. Project Impact and Long-term Strategy: This project is a continuation of the Ecological and Hydrological Impacts of Emerald Ash Borer project that received $636,000 of 2010 funding from the ENRTF. This work has identified the potential for significant, immediate alterations to native plant communities and the amount of flooding in forested wetlands in northern Minnesota due to EAB. We have begun developing and implementing mitigation strategies for these impacts, including planting non-host tree species; however, additional funding is critical for generating long-term assessments of the effectiveness of these strategies and the duration of EAB impacts. A key product that will be developed from Phase Two will be the development and implementation of recommendations for increasing the resilience of black ash forests to EAB and these will be formalized into statewide guidelines through consultation with the DNR.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
ENRTF: "Ecological and Hydrological Impacts of Emerald Ash Borer." M.L. 2010, Chp. 362, Sec. 2, Subd. 6b	June 2009-2015	$636,000

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT ACQUISITION/RESTORATION REQUIREMENTS: N/A

IX. VISUAL COMPONENT or MAP(S): N/A

X. RESEARCH ADDENDUM: Peer reviewed in Phase I

XI. REPORTING REQUIREMENTS:

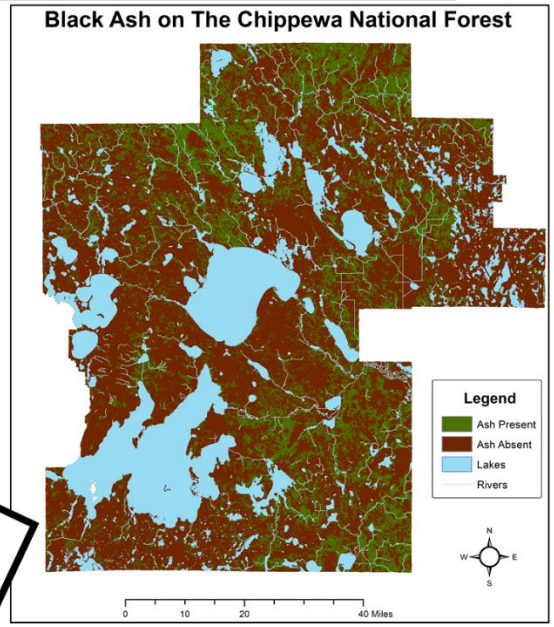
Periodic work plan status update reports will be submitted no later than January 2016, June 2016, January 2017, June 2017, January 2018, June 2018, January 2019, June 2019, and January 2020. A final report and associated products will be submitted between June 30 and August 15, 2020.

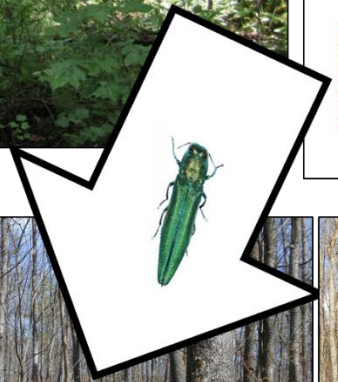
Environment and Natural Resources Trust Fund
M.L. 2015 Project Budget

Project Title: Emerald Ash Borer Ecological and Hydrological Impacts – Phase II
Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 06b
Project Manager: Anthony D'Amato
Organization: Department of Forest Resources, University of Minnesota
M.L. 2015 ENRTF Appropriation: **$** 400,000
Project Length and Completion Date: 5 Years, June 30, 2020
Date of Report: November 13, 2020

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Determine the long-term impact of EAB on native plant communities, spread of invasive species, and hydrology***			***Develop and implement recommendations for mitigating impacts of EAB on black ash forests, including planting suitable non-host tree species***			***Assess the vulnerability of black ash forests and associated resources and infrastructure for northern Minnesota***				
Personnel (Wages and Benefits)	$96,331	$96,331	$0	$40,129	$40,129	$0	$114,685	$114,685	$0	$251,145	$0
PI summer salary and fringe (0.36) for five years to lead project and develop project reports and publications (PI-D'Amato; one month per year=0.38 FTE over project period, $37,604)											
Co-PI summer salary and fringe (0.36) for five years to lead remote sensing analyses and mapping of black ash wetlands (Co-PI Falkowski; one month per year=0.38 FTE over project period, $23,958)											
Post-doctoral researcher examining impacts of EAB on hydrology and native plant communities; salary and fringe (0.1812) for five years (24 wks per year=2.5 FTE over project period, $140,650)											
Work-study undergraduate student to assist with data collection and processing; Salary and fringe (0.0743) for 5 years (16 wks per year=1.53 FTE over the project period, $26,689)											
Professional/Technical Contracts											
US Forest Service (Dr. Brian Palik): funds for hiring one full-time field technician for all five years of the study (0.75 FTE; $122,855)	$40,952	$40,952	$0	$40,951	$40,951	$0	$40,952	$40,952	$0	$122,855	$0
Equipment/Tools/Supplies											
Supplies for constructing wells for monitoring hydrology at each site ($10500),Haglof distance measuring equipment ($700), stake whiskers for marking subplots ($110), calipers for measuring seedling growth ($320), supplies for constructing frames for measuring understory vegetation ($150), diameter tapes for measuring overstory trees ($150), and data loggers for micrometeorological measurements ($2070)	$11,500	$11,500	$0	$2,100	$2,100	$0	$400	$400	$0	$14,000	$0
Travel expenses in Minnesota											
Due to the high number of study sites and logistics associated with visiting and measuring black ash wetland sites $12,000 is budgeted for domestic travel within Minnesota. This money will be used to pay for mileage (75%) and lodging (25%) for researchers, the field technician, and graduate and undergraduate students. Mileage costs are associated with rental of a field vehicle through the University of Minnesota motorpool for four field seasons. Travel reimbursement will follow University of Minnesota protocols.	$9,000	$9,000	$0	$2,000	$2,000	$0	$1,000	$1,000	$0	$12,000	$0
COLUMN TOTAL	**$157,783**	**$157,783**	**$0**	**$85,180**	**$85,180**	**$0**	**$157,037**	**$157,037**	**$0**	**$400,000**	**$0**

Minnesota's black ash forests cover over one million acres providing habitat for a diversity of species and regulating key processes, like forest hydrology





Loss of black ash due to Emerald Ash Borer or preemptive clearcutting can shift these forests to grass and sedge-dominated ecosystems and lead to greater amounts of flooding. Using planting efforts of non-ash species, like the swamp white oak and balsam poplar pictured above, will be critical to facilitate planting efforts aimed at increasing the resilience of these areas.