M.L. 2015 Project Abstract
For the Period Ending June 30, 2023

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WEBSITE: https://mitppc.umn.edu/
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp.76, Sec. 2, Subd. 6a

APPROPRIATION AMOUNT: $5,000,000
AMOUNT SPENT: $4,989,026
AMOUNT REMAINING: $10,974

Sound bite of Project Outcomes and Results

The Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC) funded 20 research sub-projects through this appropriation to better protect Minnesota lands from the harmful effects of 14 priority invasive species, such as garlic mustard, soybean aphid, and oak wilt. MITPPC discoveries improved TIS management across Minnesota.

Overall Project Outcome and Results

MITPPC funded 20 research sub-projects, in full or in part, through this appropriation, producing new techniques and technologies to protect Minnesota's lands from 14 high priority terrestrial invasive species (TIS). Four sub-projects are highlighted as examples:

- Garlic mustard biocontrol (Roger Becker, George Heimpel, and Jeanie Katovich, leads). This team completed host range testing and climatic assessments for two European weevils that feed on garlic mustard. Results supported petitions to the federal government to approve the release of *Ceutorhynchus scrobicolis*, a crown-feeding weevil, and *C. constrictus*, a seed-feeding weevil. If federal agencies decide that releases would be safe, these weevils will transform garlic mustard management across Minnesota.
- Soybean aphid detection and management (Robert Koch, Aaron Lorenz, and Demoz Gebre-Egziabher, leads). This team discovered an approach to accurately detect economically damaging infestations of soybean aphids from drone-based images and bred the first-ever aphid-resistant soybean lines that are also suitable for Minnesota growing conditions. These results should reduce insecticide use on Minnesota's 7 million acres of soybeans.
- Oak wilt detection and management (Jeannine Cavender-Bares, Rebecca Montgomery, and Jennifer Juzwik, leads). This team developed techniques to reliably detect oak wilt in images collected by drones or satellites. The team discovered robust methods to distinguish oak wilt from other oak stressors. This new detection technology will improve early detection efforts along the expanding invasion front for the disease in central Minnesota.
- Spotted wing drosophila economics and management (Mary Rogers, William Hutchison, and Gigi DiGiacomo). This team quantified a $2-7 million annual loss to Minnesota raspberry producers from spotted wing drosophila, determined that the pest likely overwinters locally in protected microhabitats, and demonstrated that exclusion netting provides a cost-effective management approach without the need for insecticides. Results are being readily adopted.

Discoveries from MITPPC researchers make TIS management more timely, effective, and reliable across Minnesota.

Project Results Use and Dissemination

MITPPC emphasized the dissemination of findings. MITPPC teams published results in 49 peer-reviewed articles in high-impact journals, such as the Journal of Integrated Pest Management, PLoS One, Ecology and the Environment, HortTechnology, and the Journal of Economic Entomology. Research teams brought their research directly to interested parties through over 170 presentations. Additionally, MITPPC, the College of Food, Agriculture, and Natural Resource Sciences and the University of Minnesota amplified communications through a variety of internal publications and social media (Twitter, website, YouTube channel) which also garnered significant interest in the local media.

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

Date of Report: August 8, 2020 [for work completed through June 30, 2023]

Date of Work Plan Approval: June 25, 2015

Project Completion Date: June 30, 2023

PROJECT TITLE: Minnesota Invasive Terrestrial Plants and Pests Center

Project Manager: Robert Venette

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Location: Statewide

Total Project Budget:	$5,000,000
Amount Spent:	$4,989,026
Balance:	$ 10,974

Legal Citation: M.L. 2015, Chp.76, Sec. 2, Subd. 6a

Appropriation Language:
$5,000,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the Invasive Terrestrial Plants and Pests Center established in Laws 2014, chapter 312, article 13, section 44, to conduct research to prevent, minimize, and mitigate the threats and impacts posed by invasive plants, pathogens, and pests to the state's prairies, forests, wetlands, and agricultural resources. This appropriation is available until June 30, 2023, by which time the project must be completed and final products delivered.

I. PROJECT STATEMENT:

The Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC) will serve a lead role in terrestrial invasive species research – coordinating initiatives on prevention of establishment; early detection and rapid response; development of new control methods and technology; integrated pest management; and minimizing non-target impacts of control. The MITPPC mission is to offer science-based solutions to pest invasions that ensure the protection of Minnesota's healthy prairies, forests, wetlands and agricultural resources. The goal is to eliminate, reduce, mitigate and prevent the introduction, expansion, or damage caused by terrestrial invasive species in Minnesota.

The array of terrestrial invasive species (TIS) of high concern for Minnesota are numerous and diverse, and include invasive grasses, trees, shrubs, insects, earthworms, mammals, fungal pathogens, and other microbes. TIS impact every citizen in the State: emerald ash borer damages our forests and urban landscapes; weeds diminish the biodiversity of our prairies and wetlands; and pests and pathogens destroy fruit and grain harvests resulting in significant economic costs. The annual, combined economic impact of plant, animal, and microbial invasives in the U.S. is estimated at $134 billion (Agricultural and Resource Economic Review, 2006). Minnesota's share of this loss is estimated at $3 billion annually, which is typical of the 50 states.

The MITPPC will support priority research on TIS that pose the greatest threats to Minnesota and a take a comprehensive, planned, multi-disciplinary approach to addressing risk. The MITPPC research prioritization process and subsequent lines of research will involve researchers from multiple disciplines, and will address invasives affecting our prairies, forests, agricultural landscapes and wetlands in urban, developing and rural contexts. The Center will identify research priorities for TIS already established in Minnesota and for those that appear likely to arrive and do harm, and develop control methods, management strategies, and policy to achieve effective outcomes. The expert panel working group will establish priorities and present requests for proposals and work-plans to conduct research to address identified priority invasive species. Proposals will be sent out for peer review to ad hoc scientific reviewers in the field of research, which will allow for rapid turnaround of proposals to expedite work to be completed. The ad hoc scientific reviewers will make award recommendations. These specific initiatives selected and their budgets will be provided to LCCMR for review as the selections are made and the work progresses.

The Center will prioritize and support multiple projects by research teams comprised of faculty, students, and staff from one of 10 participating departments. UMN faculty will work with both graduate students and post-doctoral associates on any given project. The scope of each research project will likely vary by species addressed. With this funding, it is expected that over a six-year period the Center will conduct an estimated seven projects and train roughly 14 graduate students and postdocs.

The Center is administratively located in the College of Food, Agricultural and Natural Resource Sciences (CFANS) in coordination with the College of Biological Sciences (CBS). Participating departments within CFANS include Entomology, Plant Pathology, Forest Resources, Agronomy & Plant Genetics, Horticultural Science, Applied Economics, Fisheries, Wildlife and Conservation Biology, and Bioproducts and Biosystems Engineering. Participating departments within CBS include Plant Biology and Ecology, Evolution and Behavior. Additionally, research will be possible on CFANS' eight research and outreach centers located in diverse agro-ecological areas of the State.

II. OVERALL PROJECT STATUS UPDATE:

Amendment Request 1/31/16
Changes have been made to this document to align with amendments adopted into the ML 2014 workplan, including language regarding sub-project approval process, the prioritization process, and the document's internal budget table.
Amendment Approved: February 15, 2016

Project Status as of *January 31, 2016:*
There has been no activity yet under this appropriation. Details on the MITPPC's work to-date, including details of the prioritization process, may be found in the ML 2014 ENRTF workplan and sub-workplans.

Project Status as of *July 31, 2016:*
There has been no activity yet under this appropriation. Details on MITPPC's work to-date, including details of the prioritization process, may be found in the ML 2014 ENRTF workplan and sub-workplans. Funds in this account will be allocated to research projects in response to the Center's next request for proposals (to be issued in August 2016).

Amendment Request (1/30/2017)
We are requesting slight changes to the timeline under Activity 1. The change in dates is to accommodate a later than anticipated start date for the FY 17 RFP. Outcomes remain the same.
Amendment Approved February 6, 2017

Project Status as of *January 31, 2017*:

At its July 12-13, 2016 meeting, the LCCMR directed the MITPPC to fund two projects: "*Alliaria petiolata* biocontrol: ecological host range of biocontrol agents," by Dr. Roger Becker and "Mountain pine beetle, ph. II: protecting Minnesota," by Drs. Kevin Chase and Brian Aukema. Both garlic mustard (*Alliaria petiolata*) and mountain pine beetle were identified as priority species by MITPPC and the research addressed at least one critical theme. The MITPPC and LCCMR agreed that the proposals would undergo external review before final approval. External reviewers raised a number of substantive questions that led to improvements in the scope of work and research protocols for both projects. The review/revision process is complete for Dr. Becker's proposal on garlic mustard. A sub-project work plan is being developed as an amendment to this work plan for review and approval by LCCMR staff. Drs. Chase and Aukema's proposal received several comments; they are currently addressing those comments and modifying the scope of work accordingly. We anticipate that process to be complete within the next several weeks. Both of these projects will be funded from the ML 2015, Ch. 76, Sec. 2, Subd. 6a appropriation.

The FY 17 MITPPC's Request for Proposals was issued on August 4, 2016 and closed on September 30, 2016. The RFP was based upon the document, "Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research." The RFP directed applicants to frame their research in one of four research themes and at least one of the top 15 species from each taxa.

MITPPC received 19 pre-proposals with $7.5 million in requests. In addition, the two LCCMR-directed projects cited above requested $1.085 million in funding, for a total of approximately $8.6 million. The 19 proposals underwent internal review by a panel of University researchers, with an invitation to 12 principal investigators to submit full proposals. Those 12 proposals are currently under external review, with an expected decision being made by the middle of February, 2017.

Other details on MITPPC's work to-date may be found in the updates to the ML 2014 ENRTF workplan and sub-workplans.

Project Status as of *July 31, 2017:*
Eleven projects were funded from the ML 2015 appropriation, totaling $4.65 million. The projects' workplans were approved by LCCMR staff and sub-accounts are currently being established at the University of Minnesota. The projects are preparing their labs and hiring the necessary staff to accomplish their research goals. The funded research projects are listed under Activity 1 below.

Amendment Request 10/27/17
The MITPPC requests the addition of a research project to this appropriation's portfolio, "MITPPC #12: Developing robust identification assays for *Amaranthus palmeri* in seed mixtures." In response to the identification of Palmer amaranth in the state, the MITPPC was approached by the Minnesota Department of Agriculture to assist in the development of a Palmer amaranth mixed seed identification process. Dr. Donald Wyse, an agronomist with the University of Minnesota, working collaboratively with researchers in other parts of the country, have developed a research design that has the potential to be important safeguard for conservation seed mixes used for land restoration coming into Minnesota. The seed identification method will help to safeguard Minnesota's agricultural and natural resources from this dangerous terrestrial invasive plant.

Amendment approved November 9, 2017

Project Status as of January 31, 2018:
Research projects made progress over the last six months and have submitted individual workplan and budget updates, all of which have been approved. This suite of research projects reflect the legislative directive to address the state's most pressing terrestrial invasive species. The MITPPC continues to engage research project staff and land managers in meaningful discussion about the efficacy of the applied research and its ultimate application.

Project Status as of July 31, 2018:
MITPPC staff met with each subproject team. Research projects made progress over the last six months and have submitted individual workplan and budget updates, all of which have been approved by LCCMR. A synopsis of those projects follows in this document. Projects funded under this appropriation have a range of start dates, so the extent of progress varies considerably, as expected. Two accomplishments are particularly noteworthy. First, Mr. Jake Whitman is nearing the completion of his Master's degree with Dr. Brian Aukema (Subproject #9, Characterizing Dispersal of Larval Gypsy Moth to Improve Quarantine Regulations). Preliminary results indicate that larvae may crawl more than 100 m over bare soil. This distance is substantially farther than previous studies had suggested was likely. Second, Dr. Gigi DiGiacomo (applied economist working on Subproject #10, Management Strategies for Spotted Wing Drosophila) has completed a grower survey and preliminary results indicate that this invasive insect is causing annual losses of $2-6 million annually for Minnesota raspberry producers. Pressures have increased substantially to use insecticides or risk going out of business.

Amendment Request 12/21/2018
The MITPPC has one minor adjustment to make to the dates of reporting, under this appropriation, as agreed to with LCCMR staff. The current dates, July 31 and January 31; the new dates are August 30 and February 28.

We request amendments to this overall work plan to reflect previously approved amendments to subproject work plans that were made since the last progress report. Here we summarize the date the amendment request was made, the nature of the amendment(s), and the official date of approval by LCCMR staff. Amendments are also reflected in the M.L. 2015 Project Budget – Overall Budget of Minnesota Invasive Terrestrial Plants and Pests Center. Modifications to that document are given the current date as projects were amended at various times through July 31, 2018. No amendments are requested beyond what has previously been approved by LCCMR staff. None of the modifications affect the Budget Reserve. Additional details about the amendments may be found in subproject reports.

Activity 1, Sub-project #1 Garlic Mustard Biocontrol: Ecological Host Range of Biocontrol Agents (Becker, project manager). Amendment request submitted (10/30/2018)- The Equipment/Tools/Supplies line item is increased by $428 (from $1,272 to $1,700) with a commensurate decrease in the travel line item (from $8,192 to $7,764). The reduction in travel is achieved through greater ride share to research sites with project cooperators or a one-day reduction in travel to meet with the Technical Advisory Group (preferred option). This request does not impact outcomes nor timeline of the research. Amendment request approved (11/9/2018).

Activity 1, Sub-project #3 Biological Control of the Soybean Aphid by *Aphelinus certus* (Heimpel, project manager). Amendment request submitted (11/3/2018)- Undergraduate labor is reduced in the personnel budget by $250 to compensate for a previously unnoticed typographical error that resulted in an underestimation of the travel budget by $250. This change lowered the Personnel budget from $479,096 to $478,846. Over the life of the project, the impact of this adjustment is negligible and will not affect timelines or outcomes. Amendment request approved (11/16/2018).

Activity 1, Sub-project #5 Optimizing Tree Injections against Emerald Ash Borer (Aukema, project manager). Amendment request submitted (1/19/2018)- The contract line item for azadiracthin treatments is reduced by $9,000 due to a change in vendors, and the supplies line item increases by $9,000 to achieve the same work. These changes do not affect the total budget, activity, nor the research outcomes. Amendment request approved (1/23/2018). It appears to be an oversight that the amendment was not included with the previous overall report for this project.

Activity 1, Sub-project #7 Tools to Distinguish Native from Exotic Reed Canary Grass (Anderson, project manager). Amendment request submitted (10/31/2018)- The equipment/tools/supply (E/T/S) line item is reduced from $61,070 to $31,070, a total of $30,000. A new budget line item for "Professional Services" is established for $30,000. The research team will use the service of a private lab to collect DNA sequences from reed canary grass more quickly and cost-effectively. The postdoc is redirected to devote more of his time to data analysis than data collection (no budget impact). This amendment will not impact outcomes nor timeline for the research project. Amendment request approved (11/9/2018).

Activity 1, Sub-project #8 Accurate Detection and Integrated Treatment of Oak Wilt (*Ceratocystis fagacearum*) in Minnesota (Cavender Bares, project manager). Amendment request submitted (11-2-2018)- a total of $12,500 is transferred from the Equipment/Tools/Supplies line item to the Professional/Technical/Service Contracts line item to correct an error in how the rental of field equipment was budgeted. This amendment request does not impact outcomes nor timelines of the research. Amendment request approved (11/9/2018).

Activity 1, Sub-project #9 Characterizing Dispersal of Larval Gypsy Moth to Improve Quarantine Regulations (Aukema, project manager). Amendment request submitted (11/02/2018)- A total of $307 is moved from capital expenditures (a reduction from $33,500 to $33,193) to Professional/Technical/Service Contracts (an increase from $1,500 to $1,807.) The costs associated with the servosphere were slightly less than anticipated. However, slightly greater use of the quarantine lab space was needed than originally anticipated to complete the work. This amendment zeros out the budget for this sub-project. Amendment request approved (11/16/2018).

Activity 1, Sub-project #10 Management Strategies for Spotted Wing Drosophila (Rogers, project manager). Amendment request submitted (11/01/2018) Professional and technical services are increased by $3,500 (from $40,000 to $43,500) and to decrease equipment and supplies by $3,500 (from $16,410 to $12,910). The need to construct and maintain high tunnels is less than originally estimated as the tunnels are proving to be sturdy. The adjustment directs funds for technical services for rental of a growth chamber for the project to maintain a year-round supply of live spotted wing drosophila for experiments. The team had anticipated using another current

growth chamber, but it has become unavailable due to current heavy use by other research teams. Amendment request approved (11/09/2018).

Amendment Approved (1/24/19)

Project Status as of January 31, 2019:
The MITPPC research projects had an overall successful performance in the last six months. Prominent among the highlights was a strong showing of MITPPC research at the Joint Conference of the Upper Midwest Invasive Species Conference and the National Invasive Species Management Association held in Rochester, MN in October 2018. Twenty-one research project team members made oral or poster presentations at the conference. The UMISC is the largest gathering of applied researchers and land managers in the upper Midwest. All materials presented by MITPPC research teams were branded and included proper attribution to the ENRTF. Once again, our colleagues from other states are impressed with Minnesota's commitment to terrestrial invasive species research.

Amendment Request (4/26/2019)
The MITPPC is requesting to add two projects to this appropriation. The first adds "Sub-Project 13, Terrestrial invasive species prioritization," led by Dr. Amy Morey to the suite of projects under this appropriation. This project will review and update "*Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research*," which has provided guidance on funding MITPPC research projects. This is a six month project will be staffed by a post-doctoral associate with Dr. Robert Venette's lab and is budgeted at $36,125

The second project is to co-fund a new research project with ML 2016 funds ("MITPPC 2016 Sub-project 7 Improved Detection and Future Management of Leafy Spurge and Common Tansy using Remote Sensing, Mechanistic Species Distribution Models, and Landscape Genomics, " by Dr. David Moeller and Dr. Ryan Runquist.) Known as MITPPC 2015 Sub-Project 14 under this appropriation, $70,812 would be encumbered from the ML 2015 reserve. Research updates and results will be provided under both appropriations' workplans.

We are also requesting three minor budgetary amendments; the amendments alter allocations among sub-project budgetary line items but do not change the total amount allocated to each sub-project:
MITPPC #1. An amendment is requested due to unanticipated costs for getting and utilizing serpentine soil (respirators, trays, buckets, etc.); shipping containers for insects; additional field pots, trays, nursery modifications when moved to avoid viruses in stock; supplies to get growth chambers to meet project needs (lights, modifying data collectors, etc.).
Decreases salaries by $1200 from $509,971 to $508,771
Increases supplies by $1200 from $1,700 to $2,900.
MITPPC #10**.** An amendment is requested to cover higher than expected high tunnel expenses associated with the research project by decreasing salaries by $2,059 from $419,190 to $417,333 and increasing supplies and materials by $2,059 from $12,910 to $14,969. High tunnel experimentation is crucial to this research project.

MITPPC #12: An amendment is requested to cover slight overage in travel expenses associated with this research project.
Decreases professional services by $263 from $59,220 to $58,957
Increases travel by $263 from $2,230 to $2,493

We are also requesting minor modifications to the names of sub-projects 1 and 2. To each, we insert "MITPPC #1:" and "MITPPC #2:" where needed to maintain consistency with the naming of other sub-projects.

Lastly, pursuant to conversations with LCCMR staff, we are requesting revisions to the current and future reporting procedures to make the process as simple as possible and emphasize achievements of MITPPC-related projects while allowing LCCMR to ensure that the expenditures and outcomes described in the work plan for

appropriations funded by the environment and natural resources trust fund are met. Specifically, this document will become the primary vehicle to describe research plans and report significant accomplishments of all sub-projects funded under this appropriation. Here will be found a brief overview of relevant MITPPC-related activities and a table with the current status of each sub-project. Each sub-project will be described with outcomes and activities with corresponding completion dates with enough detail to adequately convey what work is being conducted, why, and the projected impact. A budget for each sub-project will be attached to the overall work plan, however budgets for sub-projects will not report on sub-activities. Separate sub-project work plans will not be required. MITPPC will maintain copies of research addenda for each sub-project and make them available to LCCMR staff upon request. Dissemination activity will be reported with each sub-project; and overall MITTPC dissemination will be reported in the overall dissemination section of the work plan. MITPPC and LCCMR staff tested these reporting procedures for one year (2018) with appropriation M.L. 2016, Chp. 186, Sec. 2, Subd. 06a. Both parties agreed that the new procedures were more efficient (approximately 85% reduction in administrative effort) and conveyed all necessary information.

Because this transition is occurring mid-way through the appropriation and individual work plans for subprojects #1-12 are already on hand, LCCMR and MITPPC have agreed that the very brief descriptions for these subprojects in this document suffice. However, as future subprojects are added, additional context and description will be provided in the project description sections.

Amendment Approved (4/29/19)

Project Status as of July 31, 2019:
All sub-projects continue to make good progress. MITPPC staff met with research teams throughout May 2019 to review progress and discuss proposed modifications to research plans or budget allocations, including justifications for any proposed changes. Most projects were on-track to achieve outcomes as originally proposed. Research highlights are reported in the general update for Activity 1. Five sub-projects have made amendment requests.

Amendment Request (7/31/2019)
The MITPPC is requesting five amendments to this appropriation's research projects. Each is described below.

Sub-project 1:
The sub-project requests a decrease in personnel by $32,000 (from $508,771 to $476,771) and increase equipment by $2,000 (from $2,900 to $4,900) and professional services by $30,000 (from $80,565 to $112,565.). The increase in professional services is for an increase in usage fees from the biocontainment facility to accommodate the expansion of *C. constrictus* host range testing and the need to relocate to a make-shift greenhouse space during a renovation of greenhouse space that had been used by the project. The make-shift space is needed for the propagation of plants for host range testing. Additional equipment costs are needed for materials (seeds, soil, pots, fertilizer, etc.) to grow the plants. The project has been able to secure other funding to cover necessary personnel costs. There is no impact to outcomes nor timeline.

Sub-project 3:
This sub-project requests a decrease in professional and technical services by $1,000 (from $66,938 to $65,938) and create a line item for postage for $1,000. This request is due to a change in the nature of work with the Minnesota Department of Agriculture in which UMN will now pay for mailing postage. The Minnesota Department of Agriculture collects samples of soybean leaves with soybean aphids as they scout fields for other agricultural pests. The aphids are inspected at the University of Minnesota to determine the proportion of aphids that have been parasitized by *Aphelinus certus* around the state. In the past, MDA had shipped samples at their own expense, but the cost proved to be prohibitive.

Sub-project 7:

A request is made to amend the rationale, objectives, hypotheses and outcomes of Activity 2. We propose changing Activity 2 to "Collect additional reed canary grass (RCG) specimens from the transportation (highway) corridors and lakes across MN to identify the native vs. exotic status of populations". There would be no change to the budget or timeline of outcomes in Activity 2. The rationale for this change is based on the conclusions from the genetic analysis of RCG sampled from the University of Minnesota herbarium, forage and ornamental cultivars, rivers in MN and the Czech Republic (Activity 1). These results indicated that all RCG from MN rivers and native herbarium samples were a single, genetically-similar population distinct from European types. A native field of RCG from Roseau, MN also clustered these samples (except RCG from Roseau River). In addition, the current Roseau production fields where RCG varieties ('Palaton', 'Venture') are grown commercially and RCG from the Roseau River are genetically distinct from the remaining MN river populations. Collectively, these results suggest that the vast majority of reed canary grass along MN rivers might qualify as native. At this point, the development of a hand-held device to distinguish between native and exotic RGC seems pointless for MN land managers. Consequently, our new objective for Activity 2 is to collect additional samples along transportation corridors (highways) and lakes to determine the genetic stature of these populations relative to the native MN river populations, using the same genetic markers from Activity 1. This additional work will demonstrate whether RCG populations along the major highways and major lakes are also native.

Sub-project 8:
A request is made to decrease professional and technical services $5,471 ($38,500 to $33,029) and increase equipment and supplies by $5,471(from $9,387 to $14,858). The contractor was able to remove infected trees as part of Activity 3 for less than originally estimated. Supplies (particular laboratory equipment to test for the presence of the oak wilt fungus and to prepare the fungus to inoculate trees) and equipment have proven more costly than originally estimated. Outcomes nor timelines are affected by this budgetary change.

Sub-project 11:
We request a minor budget amendment to decrease equipment/tools/materials line item by $2,600 (from $19,441 to $16,841) and create a new line item at $2,600 for "shipping, data services, plot use fee", to fund shipping services of supplies and samples for analysis; service fees to transmit data from continuous data sensors at remote field sites to central data storage and analysis facilities; and $275 research plot fee at U of M Rosemount Research and Outreach Center (ROC). These changes support the completion of work under Activity 1.

Amendment approved 8/9/2019

Project Status as of January 31, 2020:
This appropriation currently supports 14 sub-projects. All research teams continue to make excellent progress in accordance with the timelines described below. Progress to date has been fully satisfactory. Specific sub-project accomplishments are described below, but particularly notable accomplishments are described here (not necessarily for all sub-projects). *Sub-project 1*: Host range testing is complete for *Ceutorhynchus constrictus*, a new biological control agent from Europe for garlic mustard. A federal petition for release of the insect into the wild is being prepared for federal review to determine if a release is likely to be effective and safe for native plants. *Sub-project 4*: Additional soybean varieties with resistance to the soybean aphid continue to move through the breeding pipeline. A recent publication from the project demonstrates the effective use of drones to detect infestations of soybean aphid that are at damaging levels. *Sub-project 6*: This sub-project detected the pathogen that causes soybean sudden death syndrome in six counties in central and northern Minnesota beyond the previously confirmed northern range. *Sub-project 8*: Research continues to demonstrate the promise of using hyperspectral imaging to distinguish healthy from oak-wilt infected trees. *Sub-project 10*: Organic bio-pesticides proved the most cost-effective method to manage spotted wing drosophila compared to alternative strategies: 1) high tunnels with exclusion or 2) open field plots treated with conventional pesticides. *Sub-project 12*: A new genetic method to identify Palmer amaranth in seed mixes, demonstrated to be the most robust and reliable method available, has been developed. *Sub-project 13*: An additional 46 terrestrial invasive

species have been evaluated as part of MITPPC's ongoing species prioritization, bringing the total to 170 species. The new prioritized list will be used in the request for proposals to be issued in February 2020.

Amendment Request (1/31/2019)
We are requesting seven amendments under this appropriation:

Sub-project 3: Heimpel. MITPPC is requesting a budget amendment to decrease equipment and tools $1,458 from $24,215 to $22,757 and increase printing the commensurate amount from $5000 to $6458. This adjustment is necessary in light of higher than expected publication fees. The amendment will not affect the total budget nor the timeline to achieve project outcome.

Sub-project 4: Koch. MITPPC is requesting a budget amendment to decrease travel by $3,764 from $14,000 to $10,236 and increase other by the commensurate amount from $5,000 to $8,764 to cover higher than expected greenhouse fees. The amendment will not affect the total budget nor the timeline to achieve project outcome.

Sub-project 10: Rogers. MITPPC is requesting an amendment to Activity 2, outcome 1. The amendment extends the deadline for the outcome from December 31, 2019 to December 31, 2020 and expands the scope of work slightly to include botanical repellents. The activity was completed as originally described, and a publication with results is in progress. However, in course of this work, we found that certain botanical products (for example, lavender oil, Ecotrol Plus [containing rosemary and peppermint oil and geraniol], and Sporan [containing rosemary, clove, thyme, and peppermint oil]) may act as repellents to spotted wing drosophila with limited impacts on non-target species and lower risk to applicators. There is no additional cost to the project. A fellowship to the graduate research assistant in Horticultural Science (Matthew Gullickson) resulted in a cost savings of approx. $33k.
MITPPC is also requesting a modest budget adjustment by increasing equipment and tools by $3,213 from $12,910 to $16,123 and by decreasing the same amount in travel from $28,900 to $25,687. This amendment will not affect the completion of other activities, nor will it affect the time or cost to complete the sub-project.

Finally, an error was corrected in the total sub-project budget sheet submission for this project

Sub-project 11: Reich. MITPPC is requesting a budget amendment to decrease equipment and tools by $4,000 from $16,841 to $12,841 and decrease personnel by $20,402 from $387,759 to $367,357 and increase professional services by $20,402 from $104,825 to $129,227. This request is necessitated by larger electrical costs than originally budgeted. The amendment will not affect the total budget nor the timeline to achieve project outcome.

Sub-project 12: Wyse. MITPPC is requesting a budget amendment to increase equipment and tools by $3,184 from $15,338 to $18,522 and decrease professional services by the same amount from $58,957 to $55,773. Higher than anticipated lab costs and lesser use of outside contractors necessitate this request. The amendment will not affect the total budget nor the timeline to achieve project outcome.

Sub-project 13: MITPPC is requesting an extension until July 31, 2020 and commensurate expansion of the work being conducted in prioritizing terrestrial invasive species. This request for an additional $35,335 from this appropriation's reserve (increasing the personnel line from $36,126 to $71,461) would fund analysis on an additional 32 species through the end of July 2020. The MITPCC will then have completed assessments of over 200 terrestrial invasive threats. This information will be used to guide MITPPC future funding decisions. This project is within the timeframe of availability for this appropriation.

Finally, we are requesting an amendment to the reporting structure of this document. Specifically, we request to discontinue broad status report summaries for Activity 1. Major accomplishments under this appropriation are documented in Overall Project Status Updates. Broad summaries under Activity 1 are redundant with this

section. Accomplishments of each sub-project within Activity 1 will continue to be provided. This change is consistent with agreed reporting changes between MITPPC and LCCMR for the appropriation under M.L. 2016, Chp. 186, Sec. 2, Subd. 06a.

Amendment Approved (04/08/2020)

Amendment request (06/05/2020)
Sub-project #6 requests a no-cost extension from June 30, 2020 to December 31, 2020. This request was submitted by the PI Dean Malvick in January and was mistakenly not included in the January 2020 update. Outcomes are not affected by this extension to the timeline.

Amendment Approved (06/23/2020)

Project Status as of July 31, 2020 [re-submitted December 21, 2020]:
COVID-19 struck Minnesota in March 2020, with significant disruptions to the normal operations of the University of Minnesota and MITPPC. MITPPC staff met virtually with all sub-project managers in May and June 2020. Efforts by sub-project managers to keep TIS research on pace were impressive. In some cases, researchers brought materials to set up "at home" laboratories. Or, research plans were modified to collect field data while maintaining social distancing and other safety practices. Despite these admirable efforts, research progress has been slowed.

Several research projects are requesting timeline adjustments; outcomes will not be affected. The requested extensions are due to laboratory and field constraints resulting from COVID-19. Affected projects are listed below and individual changes are reflected in each sub-project description.

Four sub-projects 7, 8, 12, and 13 completed their work during the last six months. The final abstract and financial accounting for sub-projects 7 and 12 are provided with this report. Per previous discussions with LCCMR staff, final abstracts and financial accounting will be provided for sub-projects 8 (ended June 30, 2020) and 13 (ended July 31, 2020) on January 31, 2021, the date of the next regularly scheduled update. This administrative procedure is meant to prevent multiple interim filings of this lengthy, complex report, a decision that benefits MITPPC and LCCMR staff.

Despite these setbacks, some significant progress was made. Of particular note, from *Sub-project 1*, a protocol to raise *Ceutorhynchus scrobicollis*, a weevil for the biological control of garlic mustard, was published in a peer-reviewed journal, in anticipation of federal-approval for release. The protocol will be essential for mass rearing and distributing the insect broad areas. From *Sub-project 4*, multiple soybean lines with resistance to soybean aphid were advanced to regional testing. Some of the soybean lines have multiple genes (stacks) for aphid resistance. This strategy was fortunate because laboratory testing has demonstrated that biotypes of the aphids already occur that can overcome resistance offered by single genes, but not the stacks. From *Sub-project 5*, emerald ash borer remains a significant management challenge for communities, but the first signs of associational protection from injections with biorational insecticides have been detected. This result means that not only is the treated tree protected, but so are nearby untreated trees. From *Sub-project 8*, research to identify oak wilt from remotely sensed imagery has progressed to the early implementation stage. A light "signature" has been identified that reliably indicates the physiological changes when oaks first become infected with the oak wilt fungus. The utility of the signature is being tested at 20 oak wilt sites. From *Sub-project 12*, a test for Palmer amaranth seeds has been developed with >99% accuracy and is expected to be commercially available in 2020.

Activities and outcomes for all sub-projects are described under Activity 2 below.

Amendment request (12/21/2020)

Despite the best efforts to keep all research projects on pace to achieve outcomes when originally anticipated, COVID-19 has caused delays. Delays were a consequence of reduced operations throughout the University of Minnesota, restrictions on travel to field sites, dismissing undergraduate research assistants to complete studies from home, disruptions associated with working from a home environment. Sub-project managers have worked diligently to respond to this interference and keep research teams safe. We do not detail the circumstances that affected each sub-project. We believe that project extensions of approximately 6 months are fully appropriate to give teams an opportunity to achieve desired outcomes. Adjustments to project end dates are reported in the work plan and the associated budget spreadsheet. One sub-project request to discontinue an activity due to a lack of time.

An amendment to sub-project 7, described below, will return $19,152 to the reserve. The total reserve goes from $9,687 to $28,839.

<u>We request the following specific amendments:</u>

- Sub-project 1: timeline changes (extension of final outcome from December 21, 2020 to June 30, 2021; all remaining outcomes achieved on same date)
- Sub-project 2: timeline changes (extension of final outcomes from Activity 1 from November 30, 2020 to May 31, 2021 with corresponding changes to other outcomes)
- Sub-project 3: timeline and budget changes (extension of Activity 4, Outcome 1 from March 31, 2021 to June 30, 2021) These changes will accommodate greater costs in growth chamber spaces and the addition of experiments in Rosemount and St. Paul. The request is to reduce a contract with the Minnesota Department of Agriculture (MDA) by $27,000 (from $37,844 to $10,844) as field surveys will be conducted primarily by University personnel, not MDA staff. Fees for greenhouse, growth chambers, and plots (listed under Professional/Technical/Service Contracts) increase by $27,000 (from $16,734 to $43,734) for additional experiments in support of Activity 4. Publishing fees for open access increase by $31 from $5,458 to $5,489 to reflect real costs incurred with the publication of scientific articles with findings from this subproject. To adjust for the slight overage in this line item, funds for travel to and from field sites are reduced by $31 from $26,750 to $26,719.
- Sub-project 4: budget change. The request is to decrease laboratory supplies (i.e., reagents and supplies for molecular marker assays) by $3,807 from $8,000 to $4,193 as fewer molecular supplies were needed than first estimated. We also request an increase travel to and from field sites by $3,600 from $10,236 to $13,836 to account for the need to send small crews in multiple vehicles to maintain social distancing. We also request a slight increase for the rental of field plots, greenhouses, and growth chambers by $207 from $8,764 to $8,971 to accommodate slightly more time needed for experiments than originally estimated.
- Sub-project 5: timeline changes (extension of end date from April 30, 2021 to August 31, 2021; all remaining outcomes achieved on end date). Budget change to balance contract of emamectin benzoate by increasing the line item by $3,294 (from $31,000 to $34,294; allowing more trees to be treated for emerald ash borer) and decreasing the contract for chemical analysis equipment by the same amount ($6,000 to $2,706; as the original estimate for the analysis was higher than actual expenses).
- Sub-project 6: timeline changes (extension of end date from December 31, 2020 to April 30, 2021; all remaining outcomes are extended to this new date; Activity 5 is discontinued because it is now considered infeasible given results from earlier parts of the project).
- Sub-project 7: We request modifications to multiple line items to reflect actual expenses incurred for the research, not estimated amounts. All actual expenditures are less than or equal to original estimates. Individual line items will not be called out here. The proposed changes reduce the sub-project budget from $268,000 to $248,848 and return $19,152 to the reserve for reallocation to other appropriate research projects.
- Sub-project 8: budget changes. The request is to decrease professional services with Metro Tall Timbers by $533 (from $19,212 to $18,679) and increase equipment by an equal amount (from $4,734 to $5,267)

to adjust for the additional supplies needed for work by UMN staff. Slightly less contracting work was needed than first estimated.

- Sub-project 10: timeline changes and budget changes (extension of final outcomes from May 31, 2021 to August 31, 2021; most remaining outcomes changed to this date) The budget amendment request is to increase personnel by $25,000 from $419,690 to $444,690 to account for additional time required to complete project work. A contract for service with Dr. Demoz Gebre-Egziabher is reduced by $22,750 (from $25,000 to $2,250) as Dr. Gebre-Egziabher was able to complete the work with existing personnel and equipment without significant additional investment. A contract with Dr. Mark Asplen is reduced by $2,250 (from $15,000 to $12,750) because the flight mill was inaccessible for some time during laboratory shutdowns. Expenses for helium balloons and monitoring supplies increase slightly from $3,321 to $3,397 to adjust for real incurred costs for supplies to monitor insects in the field. Travel costs were reduced by $76 from $1,000 to $924 to account for complex changes to the conduct of field work (fewer trips, more vehicles). There is no net change in the overall allocation to this sub-project.
- Sub-project 11: timeline changes (extension of final outcome from June 30, 2021 to December 31, 2021; all remaining outcomes achieved on end date). Budget changes: decrease personnel by $9,062 from $367,357 to $358,295 and increase electrical costs by $4,189 (from $126,833 to $131,022) and data services by $955 (from $2,394 to $3,349) to reflect real costs incurred by the project that were slightly higher than estimated. In addition, travel to field sites (mileage and lodging) is increased from $16,300 to $20,218 to adjust for the need to send multiple vehicles to field research sites and maintain social distancing en route. There is no net change to the overall allocation to this sub-project.
- Sub-project 12: budget changes. The request is to increase personnel by $1,880 from $131,422 to $133,322; to increase equipment by $24,408 from $18,522 to $42,930; to increase travel by $1; and to decrease professional services by $26,289 from $55,773 to $29,484. All changes reflect real expenses incurred on the project over original estimates. More work was conducted by the post doc rather than by the UMN Genomics Center. The proposed modifications do not change the overall allocation to this sub-project.
- Sub-project 14: timeline changes (extension of final outcomes [Activity 4, Outcome 5] from December 31, 2021 to December 31, 2022; most intermediate objectives extended by six months). An additional amendment is requested to the accompanying budget spreadsheet to report the correct end date for the sub-project.

Final abstracts and accounting for sub-projects 8 and 13 will be provided on January 31, 2021.

Lastly, we ask to correct a typographical error in the table associated with the July 31, 2017 activity status report. Specifically, the entry for MITPPC #3 (Heimpel) incorrectly indicates that the project was funded for $600,000. The correct amount is $590,390 as indicated on the budget spreadsheet.

Amendment Approved (12/28/2020)

Project Status as of January 31, 2021:
Sub-projects continued to adapt to challenges of operating under COVID-19. Across the board research teams have made meaningful progress on these research projects despite numerous logistical and personal challenges.

Sub-projects #8 and #12 finished during the previous 6 months. Sub-project #8 addressed the need for better detection tools and management options for oak wilt, one of the most devastating diseases of hardwoods in the state. This team made substantial progress on the development of methods and approaches for accurate detection of oak wilt in Minnesota forest using remote sensing and the analysis of signature light waves reflected from infected and healthy oak trees. Experiments demonstrated that the oak wilt disease can be differentiated from other stress factors under controlled conditions. They have also documented best practices for management to prevent spread of the disease.

Sub-project #12 addressed the need for tools to detect and identify Palmer amaranth seeds in seed mixtures; this weed is generally not known to occur in MN and finds of the weed have been eradicated by the Minnesota Department of Agriculture. Results of this project will give the MDA and other seed testing laboratories a powerful tool to shut down pathways for the arrival of this plant. The final product is a highly reliable test (>99.7% accuracy) for detecting Palmer Amaranth, both for individual plants and pools of seed. This test will be an important tool for Palmer control for Minnesota growers, crop consultants, and other agronomic specialists.

Ongoing projects also made solid progress. A few particularly significant accomplishments are noted here. (Other accomplishments are noted in individual sub-project updates provided below.) Sub-project #1 has prepared a draft petition to the US Department of Agriculture, Animal and Plant Health Inspection Service for the release of a seed-feeding weevil for the biological control of garlic mustard. Sub-project #3 prepared maps that showed relatively low soybean aphid densities across the state during the 2020 growing season, although high aphid densities in excess of 500/plant were recorded in some central Minnesota counties. A small wasp that attacks soybean aphid was found in most soybean growing areas, including where soybean aphid densities were low. Sub-project #4 conducted regional testing of soybeans with multiple genes for soybean aphid resistance; these soybeans continue to yield well under Minnesota growing conditions and are promising for commercial releases. Sub-project #5 reported the first evidence of associational protection (a form of herd immunity) from the use of naturally-derived insecticides to control emerald ash borer. Sub-project #10 developed organically approved methods of pest control for spotted-wing drosophila and demonstrated that the approaches are economically beneficial for small-scale raspberry growers in Minnesota.

Amendment request (2/12/2021)

We correct the end date of the appropriation. Per ML 2015, Chp.76, Sec. 2, Subd. 6a, "This appropriation is available until June 30, 2023, by which time the project must be completed and final products delivered." Changes were made to the cover page of this report and the summary budget spreadsheet. Five sub-projects continue to adjust from the ramifications of COVID-19 on the course and conduct of research. A common issue was that social distancing requirements limited the number of people per vehicle to one for travel to field sites. As a result, in-state travel costs were often greater than expected. Out of state travel was not allowed.

An amendment to sub-project 8, described below, will return $4,811 to the reserve. The total reserve goes from $28,839 to $33,650.

- Sub-project 1: budget and timeline changes
  We seek a budget amendment to increase the subcontract with CABI by $12,000 from $33,469 to $45,469. The modification is to allow for additional testing of *C. constrictus* to ensure that it only feeds on garlic mustard. Host range testing was originally planned to be completed in Minnesota, but an accident killed the insects. The insects could not be replaced due to inability to receive the insects from Europe because of COVID-19 constraints. This testing will be conducted at CABI during the spring of 2021. Funds for the subcontract come from reducing personnel from $476,771 to $476,071 ($700), the rents for greenhouse fees from $77,096 to $71,052 ($6,044), equipment/tools/supplies from $4,900 to $4,658 ($242), and travel from $7,764 to $2,750 ($5,014). These reductions are all commensurate with the discontinuation of host range testing in Minnesota. Timeline change adjusts Outcome 1 Activity 1 to June 30, 2021

- Sub-project 3: timeline changes
  We request an extension of Activity 4-Outcome 1 from June 30, 2021 to September 30, 2021 to compensate for unexpected project delays from COVID-19.

- Sub-project 4: budget changes
  We request to decrease personnel by $1,295 from $539,506 to $538,211; decrease equipment/tools/supplies by $4,193 from $4,193 to $0 and increase travel by $5,488, due to greater

than expected travel costs from safety issues associated with COVID-19. COVID-19 also prevented hiring an undergraduate research assistant. The team was also able to repurpose existing supplies to support the projects.

- Sub-project 8: budget changes
  We request modifications to multiple line items to reflect actual expenses incurred for the research, not estimated amounts. The amount for personnel increases by $11,640 from $306,533 to $318,173 to account for more personnel time to complete the project than was originally estimated. All other expenditures are less than or equal to original estimates. Individual line items will not be called out here. The proposed changes reduce the total sub-project budget from $357,420 to $352,609 and return $4,811 to the reserve for reallocation to other appropriate research projects.

- Sub-project 10: budget changes
  We request to increase personnel by $9,504 from $444,960 to $454,194 and decrease professional services by the same from $12,750 to $3,246. This will allow the hiring of staff through the University of Minnesota to complete flight studies using the vertical flight chamber and flight mill at Metro State University. The original plan had been to hire these staff through Metro State University.

- Sub-project 11: budget changes
  We request to decrease Equipment/Tools/Supplies by $2,856 from $4,000 to $1,144 and increase travel by same from $20,218 to $23,074 due to increase in travel costs from safety issues associated with COVID-19. The project was able to repurpose existing supplies to complete the work.

- Sub-project 14: timeline change
  We request to alter the timeline for Activity 2,-Outcome 2 from December 31, 2020 to December 31, 2021. Due to COVID-19 protocols in the lab group, the researchers were not able to access seeds/growth chambers this season. The change to this outcome does not alter the final completion for the sub-project.

We also add additional reporting dates for sub-projects 1, 2, 5, 6, 10, 11 and 14 to account for additional time approved with the last amendment request and to II Overall Project Status Update and IV Dissemination to correspond with the end of the appropriation. Remaining reporting dates for III. Project Activities and Outcomes -Activity 1 are deleted as updates are no longer reported here, as per prior approval of LCCMR staff.

Amendment Approved by LCCMR 3/01/21

Amendment request, (04/22/2021)
We request an amendment to sub-project 6, Activity 4, to adjust the timeline for outcomes 3 and 4 and the overall sub-project end date from April 30, 2021 to June 30, 2021. COVID-19 delayed the completion of research needed to get essential data for this project. This in turn delayed the ability to analyze data and synthesize key findings from the project for sharing with stakeholders, crop specialists, and other scientists. An additional two months will allow the team to complete, submit, and revise one report for publication and to complete analysis and prepare a solid draft outline for a second manuscript. A detailed timeline for the analysis of data and drafting of the second paper has been provided to MITPPC staff. Preliminary analyses indicate the presence of distinct genetic groups of *F. virguliforme*, the invasive fungus that causes soybean sudden death, in the state, and these genetic groups may differ in their ability to cause disease in soybean. Better knowledge of the genetics and genetic diversity of *F. virguliforme* will greatly inform future management, perhaps helping to avoid unnecessary treatments. The amendment does not affect funding to the sub-project and is still within the timeline of the appropriation to MITPPC.

Amendment Approved by LCCMR 4/26/21

Project Status as of August 19, 2021:
All sub-projects continue to make good to excellent progress towards the completion of outcomes despite lingering effects of COVID-19. All teams have developed approaches to continue data collection, analysis, and synthesis. Lingering challenges include recruiting new graduate students and hiring undergraduate research assistants. Turnover in project personnel is normal (e.g., students graduate and leave), and finding replacements is typically straightforward. However, multiple uncertainties with the pandemic have complicated and slowed recruitment and onboarding efforts. Nevertheless, sub-projects made substantive progress over the past six months. Some of the most exciting results came from two sub-projects that completed their research: MITPPC #1: Garlic mustard biocontrol: Ecological host range of biocontrol agents and MITPPC #6: Distribution and traits of the fungal pathogen *Fusarium virguliforme* that influence current and future risk to soybean and other legumes in Minnesota.

Sub-project #1 (led by Dr. Roger Becker) made major progress towards demonstrating the ecological safety of *Ceutorhynchus scrobicollis*, a weevil that is a potential biological control agent of garlic mustard. The insect feeds on garlic mustard crowns, enough that it can kill the plant. Although the species was recommended for release by the Technical Advisory Group from the US Department of Agriculture, Animal and Plant Health Inspection Service, concerns were raised by the US Fish and Wildlife Service (USFWS) about the possibility of the insect feeding on three species of threatened or endangered crucifers. Feeding tests completed under this sub-project showed that the insect poses little threat to these non-target crucifers. Further testing on vernalization requirements of garlic mustard (i.e., time at cold temperatures required before the plant will flower) and temperature/moisture requirements for *C. scrobicollis* all suggested that either the weevil or garlic mustard is unlikely to occur where the three non-target crucifers occur. A report that summarizes these findings will be submitted to USFWS in August 2021. Significant progress on non-target feeding tests for a related insect, *Ceutorhynchus constrictus*, was also completed. This insect feeds on garlic mustard seeds and a petition for its release has been drafted for Canadian and US regulatory agencies.

Sub-project #6 (led by Drs. Dean Malvick and Kathryn Bushley) significantly advanced our understanding of the invasive fungal pathogen, *Fusarium virguliforme*, the causal agent of sudden death syndrome in soybean. Results from this sub-project demonstrated that this fungus is more widely distributed, has more hosts, and is more cold-tolerant in Minnesota than previously thought. The pathogen was detected for the first time in seven counties. Black beans, pinto beans, kidney beans, and peas are susceptible, and the fungus can survive exposure to -40F. Three genetically distinct forms of the pathogen were identified, a finding that suggests the pathogen has been introduced multiple times in Minnesota. Two of the forms appear to be responsible for most of the spread in the state. This information has been incorporated into extension presentations to soybean producers and is encouraging greater vigilance against the pathogen across the state. The team continues to identify genes that may allow the fungus to invade new environments or cause disease in plants. This information is an essential pre-cursor to managing the disease through host plant resistance.

Additional information about Sub-projects #1, #6, and the rest are provided below. Final abstracts for sub-projects #1 and #6 are provided as separate documents.

Amendment request (08/19/2021)
We are requesting amendments to five sub-projects. Re-budget requests are made for Sub-projects #1 and #6 to reconcile estimated expenses with actual expenditures; unspent funds are returned to the reserve for future re-allocation to research projects. The reserve increases by $58,246 (=$29,827 + $28,419) from $33,650 to $91,896. Timeline adjustments are requested for Sub-projects #2 (Aukema-mountain pine beetle), #5 (Aukema-emerald ash borer), and #14 (Moeller and Briscoe-Runquist); no budget adjustments are requested for Sub-projects #2 and #5. Details for all amendment requests are provided below and are arranged by project number:

- Sub-project #1 (Becker): budget changes

The budget line item for personnel is reduced from $476,071 to $458,844. Less was spent on salaries than estimated because it was difficult to employ student labor during the pandemic and because a graduate student on the project (Mary Marek Spartz) received a fellowship to support a portion of her PhD dissertation. The amount dedicated to General Operating Services and Short Term rents is reduced from $71,052 to $70,552. The biocontainment facility was needed less than first estimated. The sub-contract with CABI is reduced from $45,469 to $33,469 because COVID-19 complicated the ability to complete some host-range testing. The amount for supplies is reduced from $4,658 to $4,558 to reconcile estimated expenditures with actual expenditures. Thus, the total project budget is modified from $600,000 to $570,173. The difference, $29,827, is returned to the reserve.

- Sub-project #2 (Aukema): timeline changes
  A request is made to extend Activity 1, outcomes 4 and 5 from May 31, 2021 to December 31, 2021 and to extend Activity 2, outcome 2 from March 31, 2021 to December 31, 2021 The request is made because a new graduate student was hired to complete some of the insect dispersal and distribution studies and the fungal pathogenicity studies that were addressed but not completed by earlier employees on the project. COVID-19 made it extremely difficult to recruit a new graduate student. Adequate funding is available for the request. Timing of staffing changes and travel restrictions resulted in some of the budget not being spent.

- Sub-project #5 (Aukema): timeline changes
  A request is made to extend Activity 1, outcome 1, Activity 2, outcome 2, and Activity 3, outcome 2, from August 31, 2021 to December 31, 2021. The departure of a research scientist and the impact of COVID-restrictions on a graduate student has slowed progress on elements of the project. An inability to hire undergraduate research assistants and a forced slowing of the pace of the project have resulted in some of the project funds not being spent.

- Sub-project #6 (Malvick): budget changes
  The budget line item for personnel is reduced from $346,423 to $329.979. Less was spent on salaries than estimated because it was difficult to hire undergraduate research assistants and it was not possible to replace a graduate student who completed her degree mid-project. The amount dedicated to soil analysis and DNA sequencing is reduced from $25,000 to $21,863 because slightly fewer isolates of the fungus were sequenced than first estimated. The amount for supplies is reduced from $30,877 to $30,202 to reconcile estimated expenditures with actual expenditures. Thus, the total project budget is modified from $412,00 to $383,581. The difference, $28,419, is returned to the reserve.

- Sub-project #14 (Moeller and Briscoe-Runquist): timeline and budget changes
  This sub-project is partially funded by ML 2016, Chp. 186, Sec. 2, Subd 06a. So, this amendment request was submitted with the ML 2016 work plan update. LCCMR staff approved the amendment request for this sub-project on 8/18/2021. The request: “The sub-project manager asks to alter the timeline for three activities: Activity 2, outcomes 5 and 6 from 12/31/2021 to 11/30/22; Activity 3, outcome 6 from 6/30/2022 to 4/1/2023; and Activity 4 from 6/30/2022 to 4/1/2023 and 5 from 12/31/2022 to 4/1/2023. A placeholder for an additional project update has been inserted. The adjustment to the overall duration of the sub-project is also reflected in the budget summary spreadsheet. These requests are due to difficult growing seasons over the last two years and the desire to have sufficient field data to build the mechanistic model for common tansy. The amendment requests are within the duration of the appropriation. Adequate funding exists because fewer undergraduate assistants were hired than first estimated, and some staff time is being paid from other funds for work on unrelated projects. The PI also requests a modest budget adjustment to decrease travel by $156 (from $9,000 to $8,844) and increase supplies by $156 (from $2,287 to $2,443). The team has concentrated field research closer to the St. Paul campus to reduce travel expenses. Enclosures to adjust temperature and moisture levels in the field were slightly more expensive to build than first estimated. The sub-project managers also

request a modest budget adjustment to decrease travel by $156 and increase supplies by $156." (The sub-project budget summary -Excel spreadsheet- does not include the budget amendment request because only salaries are funded from the ML 2015 appropriation.)

Amendment Approved by LCCMR (08/31/2021)

Project Status as of February 15, 2022:
This appropriation has supported 14 sub-projects, seven of which had completed work previously. In the last 6 months, six of the remaining seven projects have also completed work, specifically, sub-projects # 2, 3, 4, 5, 10, and 11. Final reports are submitted with this update report.

All projects continued to make strong progress over the previous six months. Given the number of projects that are closing, only major accomplishments are described here. More details are available with the final project summaries included below or in the final project abstracts.

Sub-project #2 (led by Dr. Brian Aukema) confirmed that mountain pine beetle is not yet present in Minnesota. Tests in the Black Hills, SD, where mountain pine beetle is native, showed that a newer, more expensive chemical lure is no more effective than traditional baits for detecting mountain pine beetles in traps. Dispersal studies demonstrated that adult mountain pine beetles may move up to 30 miles from an outbreak, but even with such a significant dispersal capacity, these insects are unlikely to fly from South Dakota to Minnesota. The research also demonstrated that other bark beetles and predators of bark beetles that occur naturally in Minnesota are unlikely to provide much protection to the forests of the state. The only promising result was that a fungus vectored by mountain pine beetle did relatively little damage to Scots pine, the only pine species that is common in both areas. These studies continue to reaffirm that mountain pine beetle is a significant threat to pines of Minnesota.

Sub-project #3 (led by Dr. George Heimpel) demonstrated that a tiny, non-stinging wasp significantly reduces the need for insecticides to control the soybean aphid, a serious invasive pest in agriculture. The wasp, *Aphelinus certus*, is predicted to be effective in at least 10% of soybean fields. The study also provided new evidence that this insect overwinters in soybean fields. The challenges that come with surviving the soybean harvest, soil tillage, and winter temperatures limit where the insect has been effective, but agronomic practices might be adjusted to improve survivorship of the wasp.

Sub-project #4 (led by Drs. Bob Koch and Aaron Lorenz) developed new methods to prevent or mitigate the harmful effects of soybean aphids in soybean fields. This team advanced several resistant soybean lines in the soybean breeding pipeline, including commercial release of one line. Furthermore, numerous crosses were made to incorporate aphid-resistance genes into soybean lines with other desirable traits and to test and advance them through the pipeline. The effectiveness of these new soybeans against phenotypically different lines of soybean aphids was novel. The team also demonstrated that remote sensing techniques with drones can be used to detect damaging levels of soybean aphid. New drone flight control technology was developed to increase the precision of spatial images. Collectively, this research has given growers more options to manage soybean aphid without relying on insecticides and to avoid unnecessary insecticide applications.

Sub-project #5 (led by Dr. Brian Aukema) demonstrated great value in the protection of ash trees with the use of biorational insecticides. The studies involved 1200 trees in 8 cities where densities of emerald ash borer were initially low. The study found that injecting approximately one-half of the ash trees at a site gave good protection to all ash trees nearby. Potential effects on other, so-called non-target, insects are a concern, so this issue was investigated rigorously from multiple perspectives. Collectively, the studies showed that injecting trees with emamectin benzoate or azadirachtin, two compounds derived from other organisms, posed minimal risks to non-target insects, especially pollinators.

Sub-project #10 (led by Dr. Mary Rogers) showed that spotted wing drosophila, a pest of soft-skinned berries, caused $2 million in damages to raspberry producers in Minnesota. This project demonstrated that exclusion netting significantly reduces damage from spotted wing drosophila and is cost effective without the need for insecticides. Naturally-derived deterrent compounds, to keep flies off fruit, were promising but performed inconsistently in the field. A combination of studies provided indirect evidence that the insect may be overwintering locally, offering new perspectives on the importance of local insect management.

Sub-project #11 (led by Dr. Peter Reich) found that glossy buckthorn, common buckthorn, tatarian honeysuckle, and morrow's honeysuckle grow about as fast as native forest species in southern Minnesota but faster than forest species in northern Minnesota. Warmer and drier weather in the future would favor these non-native woody species or species that are native to southern Minnesota. Honeysuckles tend to invade sites more quickly than buckthorn species. This research has culminated in a program to detect current infestations at a fine resolution and predict future invasion.

Sub-project #14 (led by Drs. David Moeller and Ryan Briscoe-Runquist) continues to make excellent progress on the development of new tools to detect leafy spurge across the landscape and to understand the genetic structure of tansy populations to better understand how the species has spread in the state.

MITPPC is developing a plan to spend the remainder of the budget reserve on new research or to communicate (publish) findings.

Amendment request (02/15/2022)
We are requesting amendments to six sub-projects and the addition of a new sub-project. Re-budget requests are made for Sub-projects #2, #3, #5, #10, and #11 to reconcile estimated expenses with actual expenditures; unspent funds are returned to the reserve for future re-allocation to research projects. The reserve increases by $158,983 (=$10,653 from sub-project #2 + $110,531 from sub-project #3 + $26,124 from sub-project #10 + $11,675 from sub-project #11) from $91,896 to $250,879. This balance is due, in large part, to the impact of COVID 19 on travel budgets associated with the research; the move of a post-doc to state government who was not replaced; and slightly lower equipment/tools/supplies costs. Lastly, we request the addition of a new sub-project #15 for $92,141 to be taken from the reserve. The total left in the reserve is $158,738 (=$250,879-$92,141).

Details for all amendment requests are provided below and are arranged by project number:

- Sub-project #2: Aukema (MPB) budget changes
  The budget line item for personnel is increased by $14,035 from $387,936 to $401,971; a decrease in professional/technical services by $3,345 from $8,550 to $5,205; a decrease in equipment/tools/supplies by $5,044 from $20,549 to $15,505; increase in printing by $857 from $800 to $1,657; a decrease in travel fleet by $6,507 from $19,045 to $12,538; decrease in in state travel by $3,156 from $4,360 to $1,204; and a decrease in out of state travel by $7,156 from $8,360 to $1,204; and a decrease in shipping by $337 from $400 to $63.

- Sub-project #3: Heimpel budget changes
  The budget line item for personnel is decreased by $64,515 from $478,847 to $414,332; professional services is decreased contract with MDA by $94 from $10,844 to $10,750 and greenhouse charges by $21,709 from $43,734 to $22,025; decrease in equipment/tools/supplies by $10,563 from $22,757 to $12,194; and a decrease in travel fleet by $12,650 from $26,719 to $14,069 and instate travel by $1,00 from $1,000 to $0.

- Sub-project #5: Aukema (EAB) budget changes

The budget line item for personnel is increased by $11,434 from $246,536 to $257,970; a decrease in professional services from $2,706 to $0; decrease in equipment/tools/supplies by $1,401 from $15,000 to $13,599; decrease in computer equipment by $264 from $1,314 to $1,050; decrease in printing by $40 from $150 to $110; and a decrease in travel fleet by $7,023 from $20,000 to $12,977.

- Sub-project #10: Rogers budget changes
  The budget line item for personnel is increased by $9,064 from $454,194 to $445,130; professional services contract for Dr Asplen is decreased by $3,246 from $3,246 to $0 and a decrease in growth chamber fees by $671from $3,500 to $2,829; an increase in equipment/tools/supplies by $140 from $3,397 to $3,537; and a decrease in travel fleet by $9,934 from $17,887 to $7,953; a decrease in meals and lodging by $54 from $924 to $870 and a decrease in conference travel by $3,295 from $6,800 to $3,505.

- Sub-project #11: Reich budget changes
  The budget line item for personnel is increased by $10,900 from $358,295 to $369,195; decrease professional services for electrical costs by $23,253 from $131,022 to $107,769 and an increase in data services by $783 from $3,349 to $4,132; a decrease in equipment/tools/supplies by $949 from $8,841 to $7,892 and a decrease in foliar analysis by $1,144 from $1,144 to $0; and a increase in travel by $1,988 from $23,074 to $25,062.

- Sub-project #15: Morey new project
  We request the creation of a new sub-project, "MITPPC #15, Expansion of the terrestrial invasive species prioritization" to be led by Dr. Amy Morey. The project will continue to conduct literature reviews and species assessments for invasive terrestrial invasive species of concern to different communities within the state. The budget for the sub-project is $92,141, all devoted to personnel. Dr. Morey was recently classified as a Researcher 5 with an associated increase in salary. All work will be completed by June 30, 2023. Activities and outcomes from the project are described below.

Amendment Approved by LCCMR 3/4/2022

Project Status as of July 31, 2022:
Currently, this appropriation supports two sub-projects, #14 and #15. Both continue to make very good progress towards achieving stated outcomes. Sub-project #14 (led by Drs. David Moeller and Ryan Briscoe-Runquist) published findings in the peer-reviewed journal *Remote Sensing in Ecology and Conservation*. The paper reports an application of artificial intelligence to process open-access satellite imagery from Worldview-2 and Planetscope to detect populations of leafy spurge on the landscape. The approach was highly effective, with accuracy ranging from 89.9-96.3%. The results have immediate relevance to invasive species managers in the state and provide a clear method to develop similar map products for other invasive plant species of concern. Not only do these products and approaches provide a detailed picture of where leafy spurge occurs in portions of the state, over time the products can indicate how effective management has been across the state. This publication was the focus of a media-outreach campaign, and the story was featured by KARE 11 (Twin Cities), Red Lake Nation News, and several national outlets (EurekAlert.org, Phys.org, etc.).

Sub-project #15 (led by Dr. Amy Morey) continues to include new species in MITPPC's overall prioritization process. Research is focusing on comparisons of different analytical methods to determine whether the climate of Minnesota might be suitable for invasive insects.

MITPPC staff recently received an informal notification about expenses incurred by a sub-project for which a final report had been filed. It appears that legitimate expenses were incurred during the approved sub-project period but were inadvertently charged to other accounts. Reconciling these expenses may require amendment

of one or more previously submitted final sub-project reports in the next reporting period. Amendments may affect the amount in the reserve, but those funds have not yet been encumbered.

Project Status as of December 8, 2022 [Interim report with amendment request]:
This report follows guidance provided by Director Nash on September 22, 2022 after MITPPC learned that some completed sub-projects had not fully reconciled their budgets when our previous report was filed. The recommendation was to submit an interim report without a full project update but with an amendment request to correct expenditures for eight sub-projects. Corrections are made in this report, the accompanying budget spreadsheet, and the final sub-project abstracts.

We also take this opportunity to request the addition of five new sub-projects for partial funding under the remainder of this appropriation. Sub-projects were identified after a two-step peer review process. A call for pre-proposals for research on priority terrestrial invasive species was issued in January 2022. Pre-proposals were due April 29, 2022. Twenty-two pre-proposals were submitted. Each pre-proposal was reviewed by up to five independent researchers from the University of Minnesota. Pre-proposals were ranked based on scores received; twelve were invited to submit full proposals. Each full proposal was reviewed by 2-3 nationally- or internationally-recognized subject matter experts. Eleven of the twelve projects were judged worthy of funding, and ten are moving forward at this time. Full proposals were modified as needed in response to reviewer comments. Sub-projects will be funded primarily through M.L. 2021, Project 2020-043, "Minnesota Invasive Terrestrial Plants and Pests Center, Phase 5" if approved by LCCMR.

Lastly, we ask to discontinue one sub-project and return all funding associated with it to the reserve. Sub-project #15 provided support for Dr. Amy Morey to continue assessments of terrestrial invasive species in support of MITPPC's prioritization process. This sub-project has proven to be superfluous as sufficient prioritization support is being provided through M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 06a, sub-project "MITPPC sub-project 12: Expanding and strengthening the prioritization of terrestrial invasive species in Minnesota," also led by Dr. Morey. Dr. Morey is providing excellent service to MITPPC within the scope of that project.

Amendment Request (12/08/2022)

We request three sets of amendments. The first set corrects the budgets and final reports for eight sub-projects that were previously closed under this appropriation. These revisions are a result of a full financial reconciliation of pertinent "child" accounts. (Note: at the time of the previous submission, any funds that were apparently unspent were reverted to the reserve bringing the total to $158,738.) Here and in the accompanying budget spreadsheets, we report the amount originally allocated to each sub-project and the amount that had errantly been reported as final sub-project expenditures. We then describe legitimate project expenditures that had been incorrectly charged to other accounts or errant expenditures that had been incorrectly charged to this appropriation. Corrections to legitimate project expenses reduce the amount available in the reserve; corrections to errant expenditures increase the amount available in the reserve. Amendments to sub-project budget line items are requested to reflect actual expenditures, not the estimates that were used to establish the budgets. Eight revised final reports (abstracts) are filed with this request. Corrected final project costs are as follows:

- Sub-project # 1 (Dr Roger Becker): This sub-project was originally allocated $600,000. The budget on August 31, 2022 was $570,173. After reconciliation, the revised total expenditures were $600,000 (personnel increase of $17,797 from $458,844 to $476,641; professional services increase of $30 from $70,552 to $70,582; and sub-contract increase of $12,000 from $33,469 to $45,469). A total of $29,827 is taken from the reserve as correction.

- Sub-project # 2 (Dr Brian Aukema): This sub-project was originally allocated $456,000. The budget on August 31, 2022 was $445,347. After reconciliation, the revised total expenditures were $444,982 (personnel increased by $1,842 from $401,971 to $403,813; travel decreased by $2,207 from $12,538 to $10,331). A total of $365 was returned to the reserve as correction.

- Sub-project # 5 (Dr Brian Aukema): This sub-project was originally allocated $320,000 and this amount was reported on August 31, 2022. After reconciliation, the revised total expenditures were $318,927 (travel decreased by $1,073 from $12,977 to $11,904). A total of $1,073 was returned to the reserve.

- Sub-project # 6 (Dr Dean Malvick): This sub-project was originally allocated $412,000. The budget on August 31, 2022 was $383,581. After reconciliation, the revised total expenditures were $383,651 (equipment increase of $70 from $30,202 to $30,272). A total of $70 was taken from the reserve as correction.

- Sub-project # 7 (Dr Neil Anderson): This sub-project was originally allocated $268,000. The budget on August 31, 2022 was $248,848. After reconciliation, the revised total expenditures were $263,273 (personnel increase of $4,139 from $180,304 to $184,443; increase in equipment by $8,243 from $12,357 to $20,600; and increase in professional services by $2,043 from $39,484 to $41,527.) A total of $14,425 is taken from the reserve as correction.

- Sub-project # 8 (Dr Jeannine Cavender-Bares): This sub-project was originally allocated $357,420. The budget on August 31, 2022 was $352,609. After reconciliation, the revised total expenditures were $356,382 (personnel increase of $3,733 from $318,173 to $321,946). A total of $3,773 is taken from the reserve as correction.

- Sub-project # 10 (Dr Mary Rogers): This sub-project was originally allocated $505,000. The budget on August 31, 2022 was $478,876. After reconciliation, the revised total expenditures were $477,541 (travel decreased by $1,335 from $3,505 to $2,170). A total of $1,335 is returned to the reserve as correction.

- Sub-project # 11 (Dr Peter Reich): This project was originally allocated $526,000. The budget on August 31, 2022 was $514,325. After reconciliation, the revised total expenditures were $526,000 (personnel increased by $10,920 from $369,195 to $380,11; travel increased by $755 from $25,062 to $25,817). A total of $11,675 is taken from the reserve.

The reserve has a net reduction of $56,996 after making the amendments to these eight sub-projects. All sub-projects were completed at or under the budget originally approved for each.
The second set of amendments that we request are for the addition of four new research projects to this appropriation. These research projects will be partially funded by the Budget Reserve of this appropriation, with the balance funded by the ML 2021 appropriation. Expenditures under this appropriation will be incurred by June 30, 2023. The projects are:

- Sub-project #16: Effects of Puccinia species complex on common buckthorn (Rhamnus cathartica), Dr Pablo Olivera Firpo, $33,000
- Sub-project #17: Studies of entomopathogenic fungi for effective biocontrol of the emerald ash borer - Phase 2, Dr Robert Blanchette, $33,000
- Sub-project #18: Incorporating adaptations into forecasts of range shifts with climate change, Dr Ryan Brisco Runquist, $33,000
- Sub-project # 19: Genetic control of invasive species: Phase 3, Dr Michael Smanski, $50,000
- Sub-project #20: Making revegetation as part of buckthorn management feasible in Minnesota, Dr Michael Schuster, $40,000.

A more complete summary of each research sub-project may be found later in this document, and in the associated budget spreadsheets. The reserve has an additional net reduction of $189,000 after the addition of these sub-projects.

The last set of amendments involves the removal of sub-project #15 from this appropriation. This sub-project was intended to provide additional support for the invasive species prioritization that guides MITPPC. The scope of work overlapped with M.L. 2018, Ch. 214, Art. 4, Sec. 2, Subd. 6a, 'MITPPC Sub-project #12: Expanding and Strengthening the Prioritization of Terrestrial Invasive Species in Minnesota.' Previous expenditures assigned to this (M.L. 2015) sub-project have been transferred to M.L. 2018, Ch. 214, Art. 4, Sec. 2, Subd. 6a, Sub-project #12, as expenditures fully align with that (M.L. 2018) sub-project. Thus, $92,141 is returned to the reserve.

If all amendments are approved, the reserve will be $4,882.

Amendment Approved 12/20/2023

Project Status as of January 31, 2023:
We are reporting on one research project currently operating under this appropriation, Sub-project 14, which is also reported under ML 2016 appropriation.
The only other activity during this period has been the establishment of child accounts for the five new research projects to be co-funded with the ML 2020 appropriation.

Project Status as of June 30, 2023:
Sub-project 14 (led by Drs. Moeller and Briscoe-Runquist) has now closed; the associated reports can be found under that section below. In the last six months, the team completed the development of species distribution models for leafy spurge based on satellite imagery. Maps of local occurrences of leafy spurge were produced, paving the way to generate statewide maps for this important weed. Genetic research on common tansy demonstrated that there are two genetic clusters in Minnesota. Each cluster differs in its preferred soil type and land use feature. This project overall provides evidence that these two weeds are responding genetically and physiologically to growing conditions in Minnesota. Understanding these differences allows us to better map current and future occurrences of these weeds and for managers to plan better for suppression activities at local (i.e., ownership) and regional (i.e., county) scales.

The five sub-projects established in the last report (sub-projects #16-20) have spent funds assigned under this appropriation. All projects are still within the first six months since they were approved by LCCMR and have focused on initializing work. Reports on research accomplishments are not due at this time. Reporting on these projects will continue under ML 2021, Subd 6a; Project ID 2020-043.

Amendment Request (8/8/2023)
Sub-project # 16 requests that the budget amount of $33,000 be reduced by $6,092 to $26,908. This change reduces the overall funding for this sub-project by the same amount from $363,871 to $357,779. The reduction in personnel expenditures reflects actual expenses incurred by June 30, 2023 (not estimates) and resulted from a later start to the research project than was projected. The balance will be returned to the reserve, increasing from $4,882 to $10,974. The change does not affect the $330,871 dedicated to this sub-project in ML 2021, Subd 6a; Project ID 2020-043, Sub-Project 2.

Amendment approved by LCCMR 1/15/24

Overall Project Outcomes and Results:
MITPPC funded 20 research sub-projects, in full or in part, through this appropriation, producing new techniques and technologies to protect Minnesota's lands from 14 high priority terrestrial invasive species (TIS). Four sub-projects are highlighted as examples:

- Garlic mustard biocontrol (Roger Becker, George Heimpel, and Jeanie Katovich, leads). This team completed host range testing and climatic assessments for two European weevils that feed on garlic mustard. Results supported petitions to the federal government to approve the release of *Ceutorhynchus scrobicolis*, a crown-feeding weevil, and *C. constrictus*, a seed-feeding weevil. If federal agencies decide that releases would be safe, these weevils will transform garlic mustard management across Minnesota.
- Soybean aphid detection and management (Robert Koch, Aaron Lorenz, and Demoz Gebre-Egziabher, leads). This team discovered an approach to accurately detect economically damaging infestations of soybean aphids from drone-based images and bred the first-ever aphid-resistant soybean lines that are also suitable for Minnesota growing conditions. These results should reduce insecticide use on Minnesota's 7 million acres of soybeans.
- Oak wilt detection and management (Jeannine Cavender-Bares, Rebecca Montgomery, and Jennifer Juzwik, leads). This team developed techniques to reliably detect oak wilt in images collected by drones or satellites. The team discovered robust methods to distinguish oak wilt from other oak stressors. This new detection technology will improve early detection efforts along the expanding invasion front for the disease in central Minnesota.
- Spotted wing drosophila economics and management (Mary Rogers, William Hutchison, and Gigi DiGiacomo). This team quantified a $2-7 million annual loss to Minnesota raspberry producers from spotted wing drosophila, determined that the pest likely overwinters locally in protected microhabitats, and demonstrated that exclusion netting provides a cost-effective management approach without the need for insecticides. Results are being readily adopted.

Discoveries from MITPPC researchers make TIS management more timely, effective, and reliable across Minnesota.

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Launch research on high priority, established terrestrial invasive species and rapid response for the prevention of establishment of new threats.

Description: By using funds from the 2014 General Fund appropriation, the MITPPC conducted a rapid prioritization in the spring of 2015 to identify immediate research needs among state agencies with primary responsibility for the management of terrestrial invasive plants and pests on public and private lands. Initial priority plants are species on the eradicate list, the control list, or the restricted noxious weed list as designated under Minnesota's noxious weed law, and initial priority pests were the brown marmorated stink bug (*Halyomorpha halys*) and oak wilt (caused by the fungal pathogen *Ceratocystis fagacearum*). Initial priority themes for research are:

- invasive species detection and distribution;
- invasive species response to climate change; and
- new approaches to management of invasive species.

These priorities were identified through a consultative process with eight representatives from the Minnesota Board of Water and Soil Resources, Minnesota Department of Agriculture, Minnesota Department of Natural Resources, and Minnesota Department of Transportation. Each agency had generated a list of several dozen potential research themes and topics. From these lists each agency self-selected their top four research priorities. MITPPC advised that a research topic should be considered a priority if it (i) would help the agency achieve its mission more effectively, (ii) would be of benefit to another agency (iii) could be supported by the agency financially or through in-kind contributions, and (iv) could be completed with the capacity at the

University of Minnesota. Agency priorities were vetted during a joint meeting on March 26, 2015. The initial prioritization was complete by April 15, 2015. The prioritization provided the basis for MITPPC's first request for proposals (RFP). After review by LCCMR staff, the RFP was issued on April 30, 2015. The complete request for proposals, including descriptions of priorities and the process by which projects will be selected, is attached as Appendix A to this work plan. The rapid prioritization and associated request for proposals will be used to allocate up to $1.2 million awarded to MITPPC though the M.L. 2014 ENRTF appropriation.

Eight pre-proposals were received on May 22, 2015. Those pre-proposals are currently being reviewed by a five member panel of University faculty who do not have a conflict of interest with the proposals submitted. Their evaluations will be used to determine which research teams will be invited to submit full proposals with the proposed or a modified scope of work. Full proposals will be reviewed by three experts outside of the University for scientific novelty and rigor. Funding recommendations will be reviewed by the Center Advisory Board. The intent is for initial projects funded under the M.L. 2014 ENRTF appropriation to begin by August 15, 2015.

A more expansive research prioritization was initiated in May 2015 to systematically evaluate threats posed by a wider array of terrestrial invasive plants, pathogens, and insects/arthropods than could be completed during the rapid prioritization. The more expansive prioritization will be used to allocate the remaining research funds from the M.L. 2014 ENRTF appropriation and the M.L. 2015 ENRTF appropriation. Twelve panelists were identified, six from the faculty at the University of Minnesota and six program managers with advanced degrees from partner agencies (Minnesota Departments of Natural Resources and Agriculture). In total, these panelists will identify 120 significant invasive plants, pathogens, or insects/arthropods that threaten Minnesota's agriculture, forests, wetlands, or prairies. An Analytical Hierarchy Process (AHP) will be used to rank these threats. AHP is a form of multi-criteria decision analysis that makes the process of selecting the highest priority threats consistent and transparent. AHP has been used by many agencies and organizations to facilitate complex decision making. In brief, the twelve member panel will engage in a facilitated discussion about criteria by which terrestrial invasive plants and pests should be considered a high threat (e.g., spread rate, reproductive rate, and impact potential) and the relative importance of each criterion. Each of the criteria will be applied to the 120 plants, pathogens, and insects/arthropods through reviews of the literature and consultations with relevant experts. National experts will be consulted to identify the greatest research needs for these priority taxa.

Upon the completion of the expansive research prioritization, the expert panel working group will establish priorities and present requests for proposals and work-plans to conduct research to address identified priority invasive species. Proposals will be sent out for peer review to ad hoc scientific reviewers in the field of research, which will allow for rapid turnaround of proposals to expedite work to be completed. The ad hoc scientific reviewers will make final award recommendations.

The Center will initiate and/or accelerate coordinated, applied research according to the prioritized list of pest and plant species that threaten Minnesota's prairies, urban and rural forests, wetlands, and agricultural resources as identified through this assessment process. Depending on the net impacts associated with each species, research may include new control methods including bio-control and technology, development of integrated pest management tools that minimize non-target impacts of control, early detection of and/or rapid response to new threats, and establishment prevention. The Center infrastructure is vital to improving Minnesota's capacity and response time to preventing and limiting introduction of new terrestrial invasive species. All research projects will include an analysis of any consequences related to the management of prioritized species to the State's non-target flora, fauna or our soils, water and climate.

Workforce development and training experts in invasive species management is also critical. A core component of each project will be funding of graduate students and postdoctoral associates to work with existing faculty.

Since University faculty are expected to acquire grants that cover their research salary, existing faculty are accounted for in the budget at 25% time in their role as the project leader. Providing salary through these awards will secure faculty time and intellectual effort in the projects, assuring that we are attracting the resources to provide project design, effort, and mentoring of the graduate students and post-docs in their research development. We do not anticipate hiring any new faculty for the projects.

The Center will support multiple projects by research teams, each comprised of a UMN faculty member from one of the participating departments, one graduate student and one postdoctoral associate. Estimated funding per project will be $180,000-210,000 per year, for three to four years. We expect this to result approximately seven projects in two separate phases, depending upon the priority identified by the annual risk assessment planning. It is expected that per project expenses for established invasive species will be higher as compared to prevention strategies.

These selected proposals are to be considered sub-projects with respect to this work plan. Detailed sub-project work plans and budgets will be submitted to LCCMR for review and approval. The details about each sub-project work plan will be included as attachments to this document. Regular activity updates and budget updates will be provided by sub-project leaders and MITPPC to LCCMR. This overarching work plan and budget will be updated accordingly to include general progress of the Center and a synopsis of activities completed by each sub-project. The budget updates for this overall work plan will provide summaries of expenditures (by budget line item) for each sub-project. Detailed sub-project reports and associated budget updates will be prepared by investigators in cooperation with the MITPPC Director and Associate Director. MITPPC will provide LCCMR with updates to this overall work plan and each sub-project as a single packet.

Summary Budget Information for Activity 1:	**ENRTF Budget:**	**$5,000,000**

Activity Completion Date:

Outcome	**Completion Date**
1. RFP released for first phase of projects	August 4, 2016
2. First phase research projects selected and launched (est. 4 projects, ranging from 3-4 years each)	March 1, 2017
3. Second phase research projects selected and launched (est. 3 projects, ranging from 3-4 years each)	June 30, 2017
4. Research findings for first phase of projects	May 15, 2020
5. Research findings for second phase of projects	May 15, 2021

Activity Status as of *January 31, 2016:*
There has been no activity yet under this appropriation. Details on the MITPPC's work to-date may be found in the ML 2014 ENRTF workplan and sub-workplans.

Activity Status as of *July 31, 2016:*
There has been no activity yet under this appropriation. Details on MITPPC's work to-date, including details of the prioritization process, may be found in the ML 2015 ENRTF workplan and sub-workplans.

Activity Status as of *January 31, 2017*:

At its July 12-13, 2016 meeting, the LCCMR directed the MITPPC to fund two projects: "*Alliaria petiolata* biocontrol: ecological host range of biocontrol agents," by Dr. Roger Becker and "Mountain pine beetle, ph. II: protecting Minnesota," by Drs. Kevin Chase and Brian Aukema. Both garlic mustard (*Alliaria petiolata*) and mountain pine beetle were identified as priority species by MITPPC and the research addressed at least one critical theme. The MITPPC and LCCMR agreed that the proposals would undergo external review before final approval. External reviewers raised a number of substantive questions that led to improvements in the scope of work and research protocols for both projects. The review/revision process is complete for Dr. Becker's proposal on garlic mustard. A sub-project work plan is being developed as an amendment to this work plan for review and approval by LCCMR staff. Drs. Chase and Aukema's proposal received several comments; they are currently addressing those comments and modifying the scope of work accordingly. We anticipate that process to be complete within the next several weeks. Both of these projects will be funded from the ML 2015, Ch. 76, Sec. 2, Subd. 6a appropriation.

The FY 17 MITPPC's Request for Proposals was issued on August 4, 2016 and closed on September 30, 2016. The RFP was based upon the document, "Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research." The RFP directed applicants to frame their research in one of four research themes and at least one of the top 15 species from each taxa.

MITPPC received 19 pre-proposals with $7.5 million in requests. In addition, the two LCCMR-directed projects cited above requested $1.085 million in funding, for a total of approximately $8.6 million. The 19 proposals underwent internal review by a panel of University researchers, with an invitation to 12 principal investigators to submit full proposals. Those 12 proposals are currently under external review, with an expected decision being made by the middle of February, 2017.

Other details on MITPPC's work to-date may be found in the updates to the ML 2014 ENRTF workplan and sub-workplans.

Activity Status as of July 31, 2017:
The eleven funded research projects are summarized in the table below and in the following sub-project descriptions.

Lead PI	**Research Project**	**Amount Funded**	**Species Addressed**
Becker	MITPPC #1: Garlic mustard biocontrol: Ecological host range of biocontrol agents	$600,000	*Alliaria petiolata,* garlic mustard, priority plant #15
Aukema	MITPPC # 2: Mountain pine beetle, Phase II: Protecting Minnesota	$456,000	*Dendroctonus ponderosae,* mountain pine beetle, priority insect #1
Heimpel	MITPPC #3: Biological control of the soybean aphid by *Aphelinus certus*	$590,390	*Aphis glycines,* soybean aphid, priority insect #3
Koch	MITPPC #4: Decreasing environmental impacts of soybean aphid management	$570,000	*Aphis glycines,* soybean aphid, priority insect #3
Aukema	MITPPC #5 Optimizing tree injections against emerald ash borer	$320,000	*Agrilus planipennis,* emerald ash borer, priority insect #2

Lead PI	Research Project	Amount Funded	Species Addressed
Malvick	MITPPC #6: Distribution and traits of the fungal pathogen *Fusarium virguliforme* that influence current and future risk to soybean and other legumes in Minnesota	$412,000	*Fusarium virguliforme,* soybean sudden death, priority pathogen #13
Anderson	MITPPC # 7 Tools to distinguish native from exotic reed canary grass	$268,000	*Phalaris arundinacea*, reed canary grass, priority plant #12
Cavender-Bares	MITPCC #8: Accurate detection and integrated treatment of oak wilt (*Ceratocystis fagacearum)* in Minnesota	$357,420	*Ceratocystis fagacearum*, oak wilt, priority pathogen #2
Aukema	MITPPC #9 Characterizing dispersal of larval gypsy moth to improve quarantine regulations	$35,000	*Lymantria dispar,* European gypsy moth, priority insect #5
Rogers	MITPPC # 10: Management strategies for the invasive spotted wing drosophila	$505,000	*Drosophila suzukii,* Spotted Wing Drosophila, priority insect #13
Reich	MITPPC #11: Will future weather favor Minnesota's woody invaders?	$526,000	*Lonicera morrowii,* Morrow's honeysuckle, priority plant #3; *Frangula alnus,* glossy buckthorn, priority plant #4*; Lonicera tatarica,* Tatarian honeysuckle, priority plant #6*, Rhamnus cathartica,* European buckthorn, priority plant #7
	Total allocated	**$4,649,420**	

Activity Status as of January 31, 2018:
With the addition of sub-project 12, Developing Robust Identification Assays for Amaranthus palmeri in Seed Mixtures ($208,230), the portfolio of research projects under this appropriation is near completion. A small balance will be held for unforeseen contingencies and/or for funding of smaller research projects. All research projects are underway with staff hired and laboratories prepared. Individual research progress can be found in each sub-project workplan.

Activity Status as of July 31, 2018:
Each of the twelve research projects made significant progress over the reporting period. The activities and outcomes can be found within the individual project descriptions below.

Activity Status as of January 31, 2019:
Each of the twelve research projects made significant progress over the reporting period. Notable accomplishments include: 1) US Fish and Wildlife Service initiated formal review of petition to release biological

control agents for garlic mustard; 2) The parasitic wasp, *Aphelinus certus*, was found to be keeping soybean aphid below economically-damaging levels in 10% of soybean fields in Minnesota, and options to increase the number of fields that benefit have been identified; 3) the first soybean line adapted to Minnesota growing conditions with resistance to soybean aphid was made commercially available, more lines will soon follow; 4) the pathogen that causes soybean sudden death was found to be more widely distributed in Minnesota than previously known; 4) studies with a servosphere showed that gypsy moth larvae can walk more than 100 ft over bare ground, raising concerns over the effectiveness of some current safeguards to prevent gypsy moth movement; 5) an economic analysis showed that spotted wing drosophila is costing Minnesota raspberry producers more than $2 million annually and has dramatically increased insecticide use on this high-value commodity. Additional activities and outcomes can be found within the individual project descriptions below.

Activity Status as of July 31, 2019:
All projects have made good to excellent progress towards completing stated outcomes. Notable accomplishments include: [from sub-project 3; Heimpel (Project Manager); biological control of soybean aphid] Activity 2 is now complete. A publication from this project by James Miksanek and George Heimpel in the journal *PLoS One* reports that only 11% parasitism of soybean aphid by the parasitoid *Aphelinus certus* (no common name) is needed to keep populations of soybean aphid in check. *Aphelinus certus* must arrive within 1 month of the arrival of soybean aphid to be effective. Cool summer temperatures improve the performance of *A. certus*. [from sub-project 6; Malvick (Project Manager); distribution and activity of soybean sudden death]Analysis of soil samples collected in the fall of 2018 demonstrate that the fungus that causes soybean sudden death is more widely distributed in the state than previously thought. [from sub-project 7; Anderson (Project Manager); genetic testing to distinguish native from invasive reed canarygrass] Preliminary analysis of over 2,000 plant samples collected from herbaria, all major river systems in Minnesota, previously collected plants from the Czech Republic; and a production field near Roseau, MN reveal unexpectedly similar genetic profiles from most samples in the state. (Samples from the Czech Republic were different.) These surprising results raise the possibility that much of the reed canarygrass within the state might actually be native. Additional testing from lakes and roadsides (where mixing of seeds might be more limited than along rivers) is proposed to confirm this result. [from sub-project 12; Wyse (Project Manager); genetic test to identify Palmer amaranth seeds] A testing protocol has been developed that has proven more than 99% accurate. In several hundred test cases, the protocol always correctly identified Palmer amaranth and in <1% of cases, incorrectly classified other *Amaranth* species as Palmer.

Activity Status as of January 31, 2020: No longer provided (see above).
Activity Status as of July 31, 2020: No longer provided.
Activity Status as of January 31, 2021: No longer provided.

Activity 1 Sub-Projects

Sub-project 1: MITPPC #1: Garlic mustard biocontrol: Ecological host range of biocontrol agents
Project Manager: Roger Becker
Description: The project's goal is to implement a novel technique to achieve long-term sustainable management of *A. petiolata* by developing a biological control program.

Summary of budget information for sub-project 1 **ENRTF budget**: $600,000

Sub-Project 1

Outcomes, Activity 1	**Completion date**
1. Determine the impact of *C. scrobicollis* feeding, oviposition and larval development on key native plants, with specific studies on the interaction of serpentine soils with *S. glandulosus* spp. *niger* specificity and effects on garlic mustard.	June 30, 2021
2. Find upper and lower development and oviposition threshold for *C. scrobicollis,* the effect of temperature and photoperiod on *C. scrobicollis* diapause, and determine date of flowering and chill units, and vernalization requirements for garlic mustard across North America.	June 30, 2021
Outcomes, Activity 2	
1. Complete host range testing for seed-feeder, *C. constrictus.*	June 30, 2021.
2. Use a Species Distribution model to predict the potential distribution of *C. scrobicollis* and *C. constrictus* in North America and develop a composite model using development parameters from Activity 1.	June 30, 2021
Outcomes, Activity 3	
1. Develop and verify a new methodology for monitoring garlic mustard populations.	June 30, 2021

Sub-Project Status as of June 30, 2017:
Seeds have been obtained and plants grown in preparation for the initiation of experiments with *C. scrobicollis* in fall of 2017 and *C. constrictus* in the spring of 2018. Tests for each weevil require phenology of the insects and the unique phenology of each test plant species be in synchrony to permit valid tests. The test plant colonies had been reduced in size and scope due to lack of funding when the project was not funded in the initial MITPPC RFP, and work is underway to re-establish test plant materials. Initial *C. scrobicollis* release sites are being selected for subsequent garlic mustard monitoring. A permit to APHIS PPQ was submitted on April 1, 2017 requesting approval to release *C. scrobicollis*, which begins the process of review by USFWS. We have established contacts with key individuals in USFWS to begin the process to gain approval by USFWS.

Sub-Project Status as of January 30, 2018
The invasive garlic mustard (*Alliaria petiolata*) is present in 37 states and 6 Canadian provinces. The long-term goal of this project is to develop a biological control program with two weevils, *Ceutorhynchus scrobicollis* and *C. constrictus*. To date, we have rebuilt the test plant and insect agent capacities for testing, and have determined the steps necessary to synchronize the phenology of the insects with the unique phenology of each test plant species to be able to conduct valid tests. We received a recommendation for release of *C. scrobicollis* in February 2017 from APHIS PPQ TAG, and now have begun the next step to gain approval by USFWS. Towards that end, single-choice larval development, oviposition and impact tests with *C. scrobicollis* are in progress or have been completed for *Lepidium barnebyanum* and *Nasturtium gambelii.* To improve host range prediction for garlic mustard, we are determining the chill units required for vernalization. Seeds have been obtained and plants

grown in preparation for the continuation of host range experiments with *C. constrictus* in the spring of 2018. EDDMapS and ISM Track have been used to map five of the long-term monitoring sites as part of the effort to find alternatives to permanent transects to characterize garlic mustard populations on the landscape. Cooperators with CABI in Delémont Switzerland have shipped insects collected near Berlin Germany this fall for specificity testing and to rebuild colonies at our U of M containment facility.

Sub-project Status as of July 30, 2018
The project is on track to meet deadlines and achieve our goals. Budget expenditures are on target, with considerable expenditures through June 2018 still pending in the system. We are preparing a response to APHIS PPQ and USFWS in a preliminary round of questions and clarifications of non-target effects and potential impacts. APHIS will then prepare a Biological Assessment and send to USFWS to begin their review of the petition to release *Ceutorhynchus scrobicollis*. Trials to define impacts of *C. scrobicollis* on native *Nasturtium gambelii* and *Lepidium barnebyanum* were completed. Progress has been made to characterize the Henneke serpentine soil to determine the effect of heavy metals on *C. scrobicollis* herbivory. The vernalization study is being repeated due to viral contamination of the garlic mustard test plants. *C. constrictus* testing continues to complete the test plant list in preparation for submitting the 1st petition to APHIS PPQ TAG to release *C. constrictus* for biological control of garlic mustard. The oviposition temperature thresholds have been determined for *C. scrobicollis*. Tests to determine if weevils acclimate to lower temperatures to oviposit are underway. Progress has been made on collecting distribution data of *C. scrobicollis* and *C. constrictus* in Europe. A trial to determine the labor and sample design needed to characterize garlic mustard has been completed, populations of garlic mustard mapped at five long-term monitoring sites, and the June data collected on all 10 of the 12 original sites that remain to cap the multiple years of data collection. These sites will be left in place, but annual data collection on all will no longer occur.

Sub-project Status as of January 31, 2019
A key regulatory milestone was achieved in that we submitted a response to the USFWS pre-Biological Assessment questions to begin the official USFWS review of our petition. We presented information at The International Symposium on the Biological Control of Weeds. Engelberg, Switzerland, The Upper Midwest Invasive Species Conference, Rochester MN, and at the North Central Weed Science Society meeting, Milwaukee, WI. We had voucher specimens accepted at the Canadian National Collection of Insects, Arachnids and Nematodes; the Beaty Centre for Species Discovery, Canadian Museum of Nature; the Systematic Entomology Laboratory, Smithsonian Institution, Washington DC; and at the Instituto de Biología UNAM, Departamento de Zoologia, Ciudad Universitaria, México. The effect of heavy metals on herbivory and insect behavior on *Streptanthus glandulosus* subsp. *niger* grown on a Henneke serpentine soil is in progress. The first successful round of vernalization trials to improve understanding of garlic mustard biology and potential distribution is almost complete. Host specificity of *C. constrictus* has been completed on an additional 5 species with no eggs found in developing seeds of any species. The first version of a model under development for predicting temporal population interactions between garlic mustard and biocontrol agent(s) prior release was published through the Python Package Index (PyPI): https://pypi.org/project/generations/. Preliminary indications from a non-permanent belt transect sampling array at four sites characterized the difficulty in accurately characterizing garlic mustard populations on the landscape.

Status as of July 31, 2019:
Our permit request to release *C. scrobicollis* in the U.S. is no. 4 on the docket for the USDA APHIS Biological Assessment. Meanwhile, work continues on *Streptanthus glandulosus* subsp. *niger* and potential bridge species, unresolved questions underlying this assessment. Single-choice development tests with *S. glandulosus* subsp. *niger* are near completion and we will begin an impact study on this species grown in serpentine soil. We will determine the potential for multi-generational development on *T. arvense* and *R. sinuata,* considered potential bridge species by some in APHIS ending our efforts on *C. scrobicollis* specificity testing. Four months since initiation, F1 *C. scrobicollis* weevils are emerging from 15°C plants and 5°C plants in development tests, dissertation research to determine biological limits of *C. scrobicollis*. More weevil emergence is expected

throughout the summer. The repeat of the vernalization experiment continues to inform improved predicted host range of garlic mustard. We have propagated native Brassicaceae test plants and representative species from other families to continue *C. constrictus* host range testing. An interface for a climate matching algorithm was set up at url: https://alfalimajuliett.shinyapps.io/climatematchapp/ Currently this application runs on the Bioclim algorithm but will host proposed climate suitability models as they are being developed. Permits have been acquired for a second year belt-transect sampling to determine methodologies appropriate to characterize garlic mustard on the landscape. The first fail-safe system failure in Facility 113 devastated our *C. scrobicollis* colony, impacts of which are still being determined.

Status as of January 31, 2020:
We are concluding work on the effect of serpentine soil on *Ceutorhynchus scrobicollis* herbivory, oviposition and larval development on the endangered plant species, *Streptanthus glandulosus* subsp. *niger*. Behavior of *C. scrobicollis* was not affected compared to control silt loam soils. Garlic mustard accumulated less and *S.g. niger* more biomass grown in serpentine soil. The 3rd run of the garlic mustard vernalization trial is underway with flowering just initiating in some plants, encouraging considering the first two attempts failed due to virus infections preventing flowering yr. 1, and missing the temperature trigger with the window to begin bringing pots in yr. 2. Temperature development thresholds of *C. scrobicollis* is progressing. F1 weevils have emerged from 21 plants in containment: one newly-emerged weevil from 0°C (found dead), twenty-four weevils from 5°C, nine weevils from 10°C, twenty-two weevils from the 15°C control temperature, four weevils from 20°C, and zero weevils from 25 and 30°C. We completed host range testing of *Ceutorhynchus constrictus* host on an additional seven native Brassicaceae species. A TAG petition for *C. constrictus* is in preparation. Potential distribution of *C. scrobicollis* and *C.* constrictus with several presence-only species distribution models including BIOCLIM, DOMAIN and RAMP continues. Lori Knosalla with Montgomery's lab was able to collect stratified belt-transect data at the same four sites visited in 2018 with the addition of the Nerstrand Scientific and Natural Area in 2019. We are on target, no obstacles to report

Status as of July 31, 2020:
After two failures of trials that each took over a year to complete we were able to complete a garlic mustard vernalization trial, essential to defining the potential range for garlic mustard for APHIS modeling to inform the Biological Assessment with APHIS, and we will repeat the trial in fall/winter of 2020/2021. Data collection of *C. scrobicollis* larval development thresholds was completed, which will allow us to improve species distribution modeling in North America. We are done with *C. scrobicollis* testing, with only a small population maintained in our BSL-2. The inability to get a *C. constrictus* shipment this spring from Switzerland due to COVID-19, in conjunction with low adult spring emergence from overwintering pupae in our containment facility, has put our host range testing on hold until next spring. . We will then prioritize testing the endangered Brassicaceae, *Boechera perstellata* as well as three remaining key species. Shape files and data sets have been organized to pursue heat mapping of the 5 targeted monitoring sites, and simulate spatial pattern of populations to determine the most appropriate quick assessment for land managers, and to better inform researchers of sampling that captures the dynamic population fluxes of garlic mustard on the landscape. A *C. scrobicollis* rearing paper was published in the Great Lakes Entomologist, an online presentation was given on the petition process and risk assessment for biological control of *Alliaria petiolata* for the North Central Branch of the Entomological Society of America, and an updated response was submitted to USDA/APHIS on the petition for release of *C. scrobicollis*.

Status as of January 31, 2021:
Garlic mustard vernalization trials are in the final data collection phase from which to build GDD models (4th attempt to get repeated successful trials). An analysis of the effects of temperature on *C. scrobicollis* development is in the final stages with PhD Candidate Marek-Spartz. Completing host range testing for the seed-feeder, *C. constrictus* is proving difficult, and impacted by CV 19. Our colleagues at CABI, Delémont, Switzerland, were not able to send us a shipment of *C. constrictus* adults this spring because of disruptions in transportation. In addition, we were unable to collect a sufficient number of *C. constrictus* adults from our

colony to conduct host range testing and are requesting funding for our colleagues at CABI-Switzerland complete *C. constrictus* host range testing during the summer of 2021. We have completed a first draft of a TAG petition for *C. constrictus* and are coordinating with colleagues in Canada to co-submit petitions to USDA APHIS TAG and the Canadian regulatory authorities. Thermal units and development *C. scrobicollis* were completed. The data collected will be used to inform a process model for the potential distribution of the agent in North America. *C. scrobicollis* introduction was simulated in the *Generations* Python package with improved garlic mustard parameters informed from our monitoring data. We plan to incorporate *C. constrictus* population dynamics in the near future using the double_agent.py module in the next version release.

Status as of August 19, 2021:
Garlic mustard vernalization trials are complete, and data analysis underway. Data are being used to build GDD models. An analysis of the effects of temperature on *C. scrobicollis* development is in the final stages with PhD Candidate Marek-Spartz. Completing host range testing for the seed-feeding weevil, *C. constrictus*, another potential biological control agent for garlic mustard is proving difficult and is complicated by COVID-19. Our colleagues at CABI, Delémont, Switzerland, were not able to successfully complete tests spring of 2021 on all species due to insurmountable issues with asynchrony among test plants and *C. constrictus. C. constrictus* requires test plants to be in early seed development at the time *C. constrictus* is ovipositing, usually under artificial conditions for all. We are writing the Technical Advisor Group (TAG) petition for *C. constrictus* in coordination with colleagues in Canada to co-submit petitions to USDA APHIS TAG and the Canadian regulatory authorities, possibly fall of 2021. At that time, we will make a decision to delay or include additional species tests. Dissertation chapters are nearing completion by PhD candidate Mary Marek-Spartz. Thermal units and development of *C. scrobicollis* area being used to inform a process model for the potential distribution of the agent in North America. A model for the distribution of *C. constrictus* is also nearing completion. A dissertation chapter on *C. scrobicollis* introduction simulated in the *Generations* Python package with improved garlic mustard parameters informed from our monitoring data in near completion. Mary Marek-Spartz anticipates defending her dissertation and completing PhD requirements in fall semester, 2021.

Final Report Summary:
Garlic mustard poses significant threats to our forest ecosystem. Research supported by this grant develops effective biological control of garlic mustard in Minnesota, the United States, and Canada, offering the first viable control option for this troublesome invasive plant. We gained a recommendation that *Ceutorhynchus scrobicollis* be considered for a release in the U.S. from the APHIS PPQ Technical Advisory Group. In follow-up consultation between USDA-APHIS-PPQ and USFWS, questions were generated that were intended to expedite writing the Biological Assessment for *C. scrobicollis*. Funding from this grant enabled us to address those questions with specific research on three federally listed species. COVID-19 altered our timeline, yet we will be submitting the third edition of the response in August 2021. This funding supported Entomology PhD candidate Mary Marek-Spartz to determine the expected range of biological control insects introduced to a new region, define specific biological thresholds of *C. scrobicollis*, and develop a novel biennial stage-structured plant-herbivore population model. She improved the accuracy of this model through data generated in our monitoring efforts funded from this grant. Also supported on this grant, Project Scientist Dr. Katovich further defined the vernalization requirements for a garlic mustard which will greatly improve the accuracy of the projected range of garlic mustard in the US, a key factor in determining the risk of introducing specific biological control insects to North America. Additionally, she completed host specificity testing for *C. scrobicollis* and made significant progress towards completing the registration package for *C. constrictus*. We have a draft of the petition for the release of *C. constrictus* for biological control of garlic mustard. Due to technical difficulties in rearing threatened and endangered species out of their normal habitats, we will complete the few species needed at CABI, Delémont CH.

Sub-Project 2: MITPPC #2: Mountain pine beetle, phase II: Protecting Minnesota
Project Manager: Brian Aukema

Description: This research will focus on characterizing immigration risk of the mountain pine beetle to Minnesota from proximate pine refugia and determine the susceptibility of living pines in Minnesota to adult beetles and their fungal associates.

Summary of budget information for sub-project 2 **ENRTF budget:** $444,982

Outcomes, Activity 1	**Completion date**
1. Four years of mountain pine beetle detection survey completed in Minnesota	December 31, 2020
2. New recommendations available for chemical lure(s) to attract mountain pine beetle	December 31, 2020
3. Determine levels and identity of insect predators and competitors in Minnesota (and nearby states) that may (not) interfere with mountain pine beetle invasion	December 31, 2020
4. Determine distance mountain pine beetles might be carried by wind	December 31, 2021
5. Determine proximity of mountain pine beetle to Minnesota and identify new possible pathways for introduction	December 31, 2021
Outcomes, Activity 2	
1. Determine chemical response(s) of trees to infection and assess whether the identity and concentration of compounds might deter mountain pine beetle	April 31, 2021
2. Determine ability of live trees to survive attack by the fungus carried by mountain pine beetle	December 31, 2021
Outcomes, Activity 3	
1. Determine densities of *Ips gradicollis* needed to outcompete mountain pine beetle	March 31, 2021
2. Recommendations provided to increase biotic resistance against mountain pine beetle	May 31, 2021

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Mountain pine beetle is an aggressive bark beetle that remains the biggest threat to pines of Minnesota, as epidemic population levels can colonize and kill mature pines. In April of 2017, we installed bark beetle traps in six sites across Minnesota, South Dakota and Nebraska. Each site contained five traps. Traps were baited with a variety of bark beetle pheromones to survey the species present in each state. Characterizing the insect complex is important to understand how populations of mountain pine beetle rise and fall, as mountain pine beetles in western North America depend on trees colonized by other bark beetles to persist during non-epidemic periods. The trapping arrangements included twelve traps baited with pheromones of the mountain

pine beetle. In addition, we installed three traps around International Falls in concert with cooperators at APHIS, and installed seven traps between Grand Rapids, MN and Bemidji, MN in concert with cooperators at the DNR, to detect mountain pine beetle. The summer of 2017 was spent collecting insects from these traps every two weeks. In the fall, we began sorting and identifying the collections. To date, we have not detected mountain pine beetle in Minnesota, although populations continued to look robust in the Black Hills of South Dakota, the western most native range for this insect.

Sub-project Status as of July 30, 2018
Mountain pine beetle is an aggressive bark beetle that remains the biggest threat to pines of Minnesota, as epidemic population levels can colonize and kill mature pines. In April of 2017, we installed bark beetle traps in six sites across Minnesota, South Dakota and Nebraska. Each site contained five traps. Traps were baited with a variety of bark beetle pheromones to survey the species present in each state. Characterizing the insect complex is important to understand how populations of mountain pine beetle rise and fall, as mountain pine beetles in western North America depend on trees colonized by other bark beetles to persist during non-epidemic periods. The trapping arrangements included twelve traps baited with pheromones of the mountain pine beetle. Through the winter, we sorted and identified insects from the biweekly collections. Although we collected a robust suite of bark beetles as well as various competitors and natural enemies, we did not detect mountain pine beetle in Minnesota or Nebraska. Moreover, we did not capture mountain pine beetles in the sampling transects emanating from the Black Hills of South Dakota, even though we did detect localized pockets of outbreaking populations of mountain pine beetle in the Black Hills in the summer of 2017. We have begun repeating sampling for 2018.

Sub-project Status as of January 31, 2019
All activities of this project went well this past summer, despite a major obstacle. The postdoc recruited as the lead personnel was unexpectedly invited to apply for a national lead position with a well-known tree care company. Dr. Chase accepted the position and departed the University of Minnesota in August. We are always thrilled when project personnel are recognized for their expertise, but the departure created some challenges maintaining all experiments in three states in late summer. Nonetheless, we completed all tasks as planned. We are now sorting through trap captures from transects testing new lures and the likelihood of long-distance dispersal from the Black Hills of South Dakota. Although we are still identifying species, it appears that no mountain pine beetles were captured in Minnesota this summer. We recruited a graduate student to undertake experiments in Aim 3, examining the basis for competitive interactions between bark beetles native to Minnesota and mountain pine beetle. These experiments are now underway. Two posters/updates on this project were presented to resource managers at the Upper Midwest Invasive Species Conference in Rochester, MN in October.

Status as of July 31, 2019:
All activities of this project continue to go well although we continue to negotiate the unexpected transition of Dr. Kevin Chase to industry. We have finished sorting through the trap captures from summer 2018 experiments testing new lures for mountain pine beetle and examining long-distance dispersal from nearest sources of mountain pine beetle, the Black Hills of South Dakota, towards Minnesota. We did not capture mountain pine beetles in Minnesota in summer 2018, and numbers of mountain pine beetles in the Black Hills of South Dakota were down slightly from 2017 levels. The new graduate student recruited to lead Aim 3, examining the basis for competitive interactions between bark beetles native to Minnesota and mountain pine beetle, analyzed his first experiment examining how bark beetles native to Minnesota respond to pheromones of mountain pine beetle and presented the results at the spring Western Forest Insect Work Conference.

Status as of January 31, 2020:
This past summer we again surveyed for mountain pine beetle in Minnesota's forests using two different lures as well as two lures of our native bark beetles. We did similar surveys in mountain pine beetle's native range within the Black Hills of South Dakota to give us clues of what lures might work best, as well as what native

predators and competitors might respond to the bark beetle pheromones. Identification has progressed slower than expected due to the unusually wet year. Wet trap contents attracted high numbers of carrion beetles that fouled the trap contents and substantially increase processing time. We attempted to catch live native bark beetles and mountain pine beetle in Black Hills for an experiment to examine under-bark competition, but were unable to catch sufficient numbers even with extra help donated by the Wheaton College Science Station. Our inability to collect several hundred bark beetles can be attributed to rain, protracted flight periods, and uneven population levels. We completed an experiment that started last summer looking at the suite of insects that colonizes logs baited with aggregation pheromones of mountain pine beetle and a potential native competitor, Ips grandicollis. We peeled the logs 12 months after field exposure, and set up another replicate, of which half of the logs were again peeled to give insight into early colonization by native bark beetles. Our two biggest findings from this past summer are that it does not appear that mountain pine beetle is present in Minnesota – although trap identification continues – and that pheromones of mountain pine beetle repel the native potential competitor, Ips grandicollis. This work was presented at two conferences: the North Central Forest Pest Workshop and the national meeting of the Entomological Society of America. Graduate student Zach Smith won second place for his presentation at the first conference.

Status as of July 31, 2020:

In the past six months we have focused on data analysis of the volumes of trapping and survey data collected to date, as well as analyzing gallery data within jack pine logs baited with different types of lures and exposed to bark beetles in the Black Hills of South Dakota. Some highlights include:

- the addition of the host volatile terpinolene vs. myrcene does not improve attraction of mountain pine beetles in the Black Hills. Statistically, there is no difference between the standard bait and this alternative formulation.
- a native, common pine engraver *Ips grandicollis* is repelled by pheromones of mountain pine beetle, so would likely not act as a significant competitor should mountain pine beetle arrive in Minnesota.
- other potential competitors such as *Hylastes* spp. and the red turpentine beetle *Dendroctonus valens* do exhibit some cross attraction to mountain pine beetle pheromones, but their numbers are very low in Minnesota. Moreover, they colonize lower parts of the tree that mountain pine beetle rarely colonizes.
- predators of bark beetles in Minnesota such as the clerid beetles *Thanasimus dubius* or *Madoniella* spp. are highly abundant, but show no attraction to pheromones of mountain pine beetle.

We have been preparing this work, and the work on competition between Ips grandicollis and mountain pine beetle (Activity 3), for publication.

Status as of January 31, 2021:
In the past six months we have noted three major highlights. First, we completed 2020 field surveys for mountain pine beetle in Minnesota. No mountain pine beetles were found. Second, Masters student Zach Smith defended his thesis examining response of natural enemies to the pheromone lures of mountain pine beetle as well as examining how the native eastern five-spined *Ips* interacts with pheromones of mountain pine beetle in the Black Hills of South Dakota. Finally, we added a new Masters student August Kramer to the project to examine dispersal capabilities of mountain pine beetle using outbreaking populations in Montana and obtained the best results since trying this ambitious experiment four years ago.

Status as of August 19, 2021:
Good progress was made in all areas despite slowdowns related to COVID-19 and working off-campus. The MS thesis of Zach Smith was defended and both data chapters were sent to journals. The first, comparing attraction of bark beetles and natural enemies to lures of mountain pine beetle in South Dakota, within the historic range of the insect, and Minnesota was submitted to *Oecologia* in April and remains in review. That work showed that there appears to be no difference between lures of mountain pine beetle. The second paper examines the repulsion of *Ips grandicollis* to mountain pine beetle pheromone. We found clear aversion, indicating that this native pine engraver bark beetle is unlikely to be a significant competitor with mountain pine beetle at the tree-

colonizing stage if mountain pine beetle does arrive in Minnesota. This work is now in press at *Forest Ecology and Management* and should be published by the end of 2021. Graduate student August Kramer also gave a [well-received!] presentation on dispersal capabilities of mountain pine beetle at the North American Forest Insect Work Conference.

Project Status as of January 31, 2022:
In the final six months of the project the primary emphasis was on completing work to determine the dispersal capabilities of mountain pine beetle from active infestations. We successfully executed two ambitious experiments trapping beetles along transects in both Montana and the Black Hills from forestland into prairies and range. As a value-added step, we tried to determine the full metabolic profile of the captured insects but did not succeed. This shortcoming could have been due to poor conditions that the beetles were in once they finally landed in the funnel traps. Due to the investment of the AVR foundation, we will be re-testing many of the beetles for simple lipid analysis as we extend this project for another six months. Lipid analysis is an alternative method to determine the extent to which a bark beetle has flown. Work from Activity 3 on the avoidance behavior of native pine engravers *Ips grandicollis* to the pheromones of mountain pine beetle appeared in *Forest Ecology & Management* and we have been providing reprints to interested parties accordingly. Other work completed during the past six months included minor revisions to the manuscript describing the natural enemy responses to mountain pine beetle as well as the study examining the chemical responses of Scots pine to inoculation with small plugs of *Grosmannia clavigera*, the fungus associated with mountain pine beetle. These final two papers are still in the publication pipeline and will be completed in the next six months with the transfer of support for this work to the AVR Foundation. Two presentations were given and well received. The project lead delivered a global presentation on project results to the IUFRO conference on Biological Invasions in Forests in Prague, Czech Republic and a second workshop presentation on mountain pine beetle to 55 attendees of the Sustainable Forest Education Cooperative locally.

Final Report Summary:
Surveys over the course of this project did not detect any mountain pine beetle in Minnesota. Although absence data cannot rule out inappropriate lure choices, testing of a new lure within the Black Hills of South Dakota where mountain pine beetle is endemic found that the conventional lure worked well. No improvements were noted when testing a new formulation. Long distance dispersal transects revealed that mountain pine beetles can be captured up to 30 miles away from active tree-killing outbreaks, but these singletons represented a fraction of a fraction of the population. Dispersal pressure was much lower in the last year of the project when beetles returned to endemic levels, which is the norm in western forests for decades at a time. Thus, we expect that the risk of mountain pine beetle reaching Minnesota by blowing from infestations in the Black Hills of South Dakota, which is approximately 500 miles away from the nearest mature pine forests in Minnesota, is extremely low. If mountain pine beetle was to arrive in Minnesota, it would have to establish into an environment with new flora (species of pines) and fauna (other species of bark beetles as well as their predators) to which it had never been exposed. The only species of pine common to the Black Hills and Minnesota is Scots pine; exposures to the fungus that mountain pine beetle carries revealed strong localized responses of Scots pine to the inoculation sites with defensive chemicals known as monoterpenes. Surveys of Minnesota's community of bark beetles, competitors, and predators responding to lures of mountain pine beetle in comparison to similar in the Black Hills revealed nuanced, regional variations in responses, but overall strong fidelity to cures of predators associated with local prey. Thus, we expect that predators or competitors in Minnesota would not optimally recognize the aggregation pheromone of mountain pine beetle. In one case with direct comparative tests in the Black Hills, we noted that one of the most common bark beetles that would potentially compete with mountain pine beetle in Minnesota, *Ips grandicollis*, avoids the lure of mountain pine beetle. We did note a few mountain pine beetles in traps baited with the aggregation pheromone of *Ips grandicollis* when the traps were placed far from active infestations of mountain pine beetle. This finding suggests that mountain pine beetle could respond to such pheromones as a "last-ditch" effort to find habitat during endemic periods where there are insufficient numbers to mass-attack, colonize, and kill large trees. If true, mountain pine beetle could find an endemic niche in Minnesota's pine forests. Because we still lack knowledge about how mountain pine beetles persist in

endemic states, and whether colonization densities might actually be lower in other species of Minnesota's pines if they have lower defensive responses, continued vigilance against mountain pine beetle as a threat to Minnesota's pine forests is warranted.

Sub-Project 3: MITPPC #3: Biological control of the soybean aphid by *Aphelinus certus*
Project Manager: George Heimpel
Description: The goal of this research is to understand the extent to which *A. certus* is suppressing soybean aphid populations throughout the state and the extent to which it reduces pesticide use.

Summary of budget information for sub-project 3 **ENRTF budget:** $479,859
Sub-Project 3

Outcomes, Activity 1	**Completion date**
1. Determination of in-field efficacy of *A. certus* in suppressing soybean aphids	December 31, 2019
2. Estimation of reduction in insecticide use attributable to *A. certus*	December 31, 2019
Outcomes, Activity 2	
1. Detailed characterization of life-history of *A. certus* complete with an emphasis on characters that affect efficacy	December 31, 2018
2. Estimates of the level of parasitism needed to suppress soybean aphid by *A. certus*	December 31, 2018
Outcomes, Activity 3	
1. Maps of soybean aphid density and *A. certus* prevalence throughout the state	December 31, 2020
2. Determine the relationship between aphid abundance and *A. certus* parasitism rate	December 31,2020
Outcomes, Activity 4	
1. Site-specific information on overwintering success is available	September 30, 2021
2. Determine where soybean aphid parasitoids are overwintering	December 31, 2020

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018**:**
Aphelinus certus is an Asian parasitoid wasp that was discovered attacking soybean aphids in Pennsylvania in 2005 and was first found in Minnesota in 2011. This species was not intentionally introduced and indeed, had been previously been deemed ecologically risky due to its ability to attack numerous aphid species, including species native to North America. Despite this risk to native aphids however, *A. certus* has the potential to

deliver significant benefits by attacking the soybean aphid, which is also native to Asia. We have been monitoring this parasitoid since its arrival in Minnesota and have found that it is now widespread throughout the soybean-growing areas of the state, although it appears to be less prevalent in Southeastern Minnesota. It is now by far the dominant parasitoid of soybean aphid, having outpaced the native *Lysiphlebus testaceipes* and other introduced parasitoids that were sometimes found attacking soybean aphid.
Our main objective with the MITPPC award is to determine to what extent *Aphelinus certus* is suppressing soybean aphid populations and also whether farmers can utilize knowledge of the prevalence of this parasitoid in their fields to reduce foliar insecticide applications. We are addressing these questions with a combination of field experiments, laboratory studies and mathematical modeling. So far these studies show that *A. certus* is capable of suppressing soybean aphids but that this does not happen in every field. Indeed, soybean aphid outbreaks have occurred since the establishment of *A. certus*, including in North-western Minnesota in 2017. However, the levels of parasitism found in many parts of the state indicate that suppression is occurring and that a substantial acreage does not need to sprayed due to the arrival of this biological control agent.
As this project continues, we will be better able to identify under what conditions suppression is likely to occur and we hope to provide usable guidelines to farmers so that they can use information on this parasitoid to optimize their pest management practices. This should lead to increased profitability as well as increased environmental protection from reduced foliar insecticide applications. This latter benefit is particularly critical since prairie habitats adjacent to soybean fields support endangered species of butterflies that are at risk of being impacted by foliar insecticide applications. In an extension of this work we will also determine the actual risk that *A. certus* poses to native aphid species in prairies adjacent to soybean fields. Thus, our aim is to provide a relatively comprehensive picture of the beneficial and detrimental effects of the accidental invasion of this aphid parasitoid to agricultural and natural landscapes of Minnesota.

Sub-project Status as of July 30, 2018
We plan to establish cages at an additional 5 sites for the 2018 field season (Obj. 1) and we are also planning further statewide sampling of soybean aphid (Obj. 3). Further laboratory studies have been done that show that *A. certus* females can parasitize over 300 soybean aphid over their lifetime (Obj. 2). These studies also showed that of *A. certus* encounters less than one aphid per day they are not able to live more than a few days. The outcome of the 2017-2018 overwintering studies are now being analyzed – they show that *A. certus* are able to overwinter within soybean fields as well as within woodlots (Obj. 4). We also completed laboratory cold-tolerance studies on *A. certus* over this time period, obtaining data on both super cooling points and on lower lethal temperatures.

Sub-project Status as of January 31, 2019
We completed three field experiments evaluating the ability of the parasitoid *Aphelinus certus* to control soybean aphids during the summer of 2018 in various parts of Minnesota. Parasitism rates in these studies were relatively low and so the experiments did not reveal strong effects of *A. certus*. To complement these studies we have finalized analyses of a mathematical model of soybean aphid – *A. certus* interactions that incorporates information from our own studies and the scientific literature. This model suggests that *A. certus* is currently suppressing soybean aphids to below the economic (spray) threshold in about 10% of Minnesota fields, which is consistent with our aggregated field results. The model also suggests that improvements in overwintering survival of and/or increased lifespan of *A. certus* could greatly improve aphid suppression. We believe that of these two factors, improvement of overwintering survival is achievable based on previous results showing that survival of the parasitoids in the leaf litter of no-till soybean fields can be high. Overwintering survival in tilled fields may be lower and this could reduce parasitoid impact statewide since most soybeans fields in Minnesota are tilled. Our current and future studies on overwintering of *A. certus* will focus on conditions that favor survival including differences in tillage practice. The results of our studies were shared in a number of forums during the second half of 2018 including the Upper Midwest Invasive Species Conference, a workshop of the International Organization of Biological Control and a meeting of the Entomological Society of America.

Status as of July 31, 2019:

Although no empirical progress was made on objective 1 (field cage studies) over the winter months, the population model prepared by James Miksanek (Ph. D student) relating *A. certus* to soybean aphid has been completed and parameterized with laboratory data on host-stage preference, post-parasitism reproduction and other aspects of parasitoid biology. The model suggests that *A. certus* makes insecticide applications unnecessary on 10% of soybean aphid fields, given the recommended spray threshold of 250 aphids per plant. A paper describing this model and its outcome has now been published in the journal *PLoS One*, and these activities complete objective 2 of the proposal. A second study completed by J. Miksanek shows that *A. certus* has increased lifespan when aphid densities are higher and also develops a parasitoid age-grading technique. Statewide surveys for soybean aphid and parasitoids (Obj. 3) did not take place over the winter, but laboratory studies on a hyperparasitoids species that had been found during previous surveys were completed by Jonathan Dregni (technician) over this period. These studies showed that the *A. certus* hyperparasitoid *Alloxysta brevis* is unisexual (i.e., only females are produced) and that this unisexuality is caused by an endosymbiotic bacterium. Progress on our understanding of *A. certus* overwintering (Obj. 4) included determination of an insulating effect of snow cover in likely overwintering sites (soybean fields and buckthorn patches) and studies comparing developmental times and milestones of diapausing and non-diapausing *A. certus*. These and related studies are being done by Dr. Carl Stenoien (Post-doc).

Status as of January 31, 2020:
Over this last summer field season we conducted two more field-cage experiments, one at University of Minnesota Research and Outreach Center in Waseca, and the other at an on-farm site in western Minnesota. These studies did not show a clear pattern of soybean aphid suppression by the parasitoid *Aphelinus certus*, but definitive statistical analyses of these results are still underway. In laboratory work completed by Ph.D. student J. Miksanek, we showed that *A. certus* lives longer when aphid densities are higher and this work has now been submitted for publication. Statewide surveys indicated relatively low densities of soybean aphid statewide with *A. certus* parasitism the highest in central Minnesota with hyperparasitoids continuing to be found. Progress on our understanding of *A. certus* overwintering included continuation of laboratory studies that will help us to predict emergence patterns of *A. certus* coming out of overwintering and a manuscript is in preparation by Dr. Carl Stenoien reporting these and other results.

Status as of July 31, 2020:
Laboratory studies on *A. certus* overwintering continued actively through early March when COVID-19 restrictions were initiated. At this point, remaining *Aphelinus certus* pupae were taken into the home of Dr. C. Stenoien where emergence was monitored to complete the experiment. These and previous data were compiled into a manuscript with Dr. Stenoien as first author that is currently nearing completion. Beyond this, we received permission from our Department and College to do a tillage experiment at UMore Park in which the emergence rate of *A. certus* mummies in the presence and absence of tillage was monitored. Unfortunately this experiment failed in the sense that even mummies in control treatments did not emerge. We also have permission to sample fields throughout Minnesota and are currently conducting these surveys with the help of collaborators in various parts of the state. In April 2020, PhD student James Miksanek, defended his dissertation, and postdoctoral researcher Dr. Carl Stenoien took a position with the Minnesota Pollution Control Agency.

Status as of January 31, 2021:
Laboratory studies on *A. certus* overwintering were completed by Dr. C. Stenoien and analyses of the data and preparation for submission for publication are underway; we hope to submit by March 15, 2021 (see working title below). We were able to conduct summer sampling and research, and produced a MN-wide map of soybean aphid and *A. certus* incidence and conducted two studies of weekly aphid and parasitoid densities over the summer. Data analysis for these latter studies are in progress.

Stenoien C.M, L. Chistianson, K. Welch, J.S. Dregni, K.R. Hopper & G.E. Heimpel. Cold tolerance and overwintering survival of *Aphelinus certus* (Hymenoptera: Aphelinidae) a parasitoid the soybean aphid (*Hemiptera: Aphididae*) in North America. In preparation.

Status as of August 19, 2021:
While we have made significant progress on the publication stemming from Dr. Steinoien's *A. certus* overwintering studies, it is still not ready for submission; we hope to submit by August 31, 2021 (see working title below). We were able to complete a comparison of *A. certus* emergence under conditions of simulated tillage vs. non-tillage under both laboratory and field conditions. Further field sampling is in progress.

Stenoien C.M, L. Chistianson, K. Welch, J.S. Dregni, K.R. Hopper & G.E. Heimpel. Cold tolerance and overwintering survival of *Aphelinus certus* (Hymenoptera: Aphelinidae) a parasitoid the soybean aphid (Hemiptera: Aphididae) in North America. In preparation.

Project Status as of January 31, 2022:
We completed a comparison of *A. certus* emergence under conditions of simulated tillage vs. non-tillage under both laboratory and field conditions (see below for a summary of the results). We conducted sampling of soybean aphid densities as well as parasitism by *A. certus* at two field sites over the summer field season – one in St. Paul and one in Rosemount, Minnesota, and conducted and organized general sampling statewide. We also gathered data on soybean aphid parasitism by *A. certus* in Minnesota over the last 10 years from our own work and that done by collaborators. These data will be used to characterize the extent to which A. certus has controlled soybean aphid over this time period. Lastly, we made significant progress on the publication stemming from Dr. C. Stenoien's work on *A. certus* overwintering, though it is still not ready for submission; we hope to submit by January 31, 2021 (see working title below).

Final Report Summary:
Prior to the year 2000, the approximately seven million acres of soybeans in Minnesota suffered very little insect damage and were seldom subjected to insecticide applications. This changed with the arrival of the soybean aphid from Asia during that year. This aphid rapidly became the most important insect pest of soybeans due to its ability to substantially lower soybean yield when present at high densities on plants. This led to a 'new normal' that included widespread insecticide use in soybeans in Minnesota, with areas in excess of one million acres sprayed in bad aphid years. While predatory insects were capable of suppressing populations in some years, this level of control was not consistent. We noted the arrival of a new natural enemy of soybean aphid in Minnesota in 2011, however – the parasitoid *Aphelinus certus* – that appeared to have the potential to be a game changer. This insect lays its eggs into soybean aphids, and the developing larvae kill the aphids from within. Our main objective was to determine the extent to which this parasitoid could control populations of soybean aphids below the level that necessitates insecticide use. We also hoped to elucidate agronomic strategies that could lead to increased control by this parasitoid. Based upon a combination of laboratory, field and theoretical studies, we were able to show that *A. certus* is indeed capable for suppressing soybean aphid densities below the threshold levels that farmers use to initiate insecticide use. Our theoretical simulations suggested that such control occurs in approximately 10% of fields during a given year. These studies also pointed to overwintering success of the parasitoids as a critical factor determining the strength of aphid suppression. It therefore stands to reason that any agronomic factors that increase overwintering success improve the parasitoid's capability of suppressing soybean aphid.

Sub-Project 4: MITPPC #4: Decreasing environmental impacts of soybean aphid management
Project Manager: Robert Koch

Description: The goal of the research is to decrease insecticide use and ameliorate associated environmental impacts through development of aphid-resistant soybean varieties and avoid unnecessary insecticide use through remote sensing.

Summary of budget information for sub-project 4 **ENRTF budget:** $570,000

Sub-Project 4

Outcomes, Activity 1	**Completion date**
1. Seed for well-adapted aphid-resistant varieties carrying *Rag1* or *Rag2* is available to growers.	October 31, 2019
2. Ability to screen plants for *Rag3* and *Rag4* resistance using molecular markers.	January 31, 2019
3. Seed of breeding lines pyramided with *Rag1*, *Rag2*, *Rag3*, *Rag4* ready for yield testing.	August 31, 2021
4. Determination of variability of soybean aphid biotypes at different landscape levels in Minnesota.	July 31, 2021
Outcomes, Activity 2	
1. Identify spectral and/or thermal indices that are likely to be optimal for detection of soybean aphid	October 31, 2019
2. Develop remote scouting tools to estimate aphid densities from spectral and/or thermal indices and plant, field, and landscape factors	December 31, 2020
3. Validate remote scouting tools.	August 31, 2021
Outcomes, Activity 3	
1. Identify Real Time Kinematic GPS technologies that are suitable for ultra-high precision mapping with small UAS.	September 30, 2018
2. Develop hardware and software which gives small UAS the capability to perform aerial scouting for soybean aphids. Integrate hardware and software into prototype small UAS.	September 30, 2020
3. Hardware and software performance validated in field tests.	August 31, 2021

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
During this reporting period, we initiated efforts on all project activities by hiring qualified staff (i.e., post-docs and students) and beginning experiments. For development of aphid resistant soybean varieties, efforts are well underway to increase the availability to growers of well-adapted aphid resistant varieties, to develop

pyramided soybean lines with multiple resistance (Rag) genes, and to refine methodology for assessing the diversity of virulent aphid biotypes in Minnesota. For biological assessment of remote sensing for soybean aphid scouting, an experiment at three locations was successfully carried by creating gradients of soybean aphid pressure in research plots and collecting visible, near-infrared, and thermal-infrared spectral data from those plots. For technological assessment of remote sensing for soybean aphid, a test of the current state of art of RTK/GPS technology (precise GPS positioning systems) was performed, results indicate that off-the-shelf technology does not meet the accuracy requirements of sub-centimeter accuracy necessary for direct geo-referencing. Communication among project partners has been effective and generally carried out via email and in-person meetings.

Sub-Project Status as of July 30, 2018
During this reporting period, progress has been made on all activities. For Activity 1, soybean lines confirmed to carry aphid resistance genes continue to advance through the soybean breeding pipeline. One aphid-resistant soybean variety M10-218053 has been licensed to Albert Lea Seeds as an early-maturity variety for organic production. In addition, seed from thirteen populations of soybean that were developed to carry different combination of Rag/rag genes (Rag1, Rag2, Rag3/rag3, rag4) are being planted for further evaluation in Saint Paul. Furthermore, a pilot study to test six different soybean aphid isolates against a panel of indicator lines revealed at least three biotypes (out of four previously known biotypes). For Activity 2, a greenhouse experiment was performed to evaluate the potential use of thermal infrared remote sensing for detection of soybean aphid injury. In addition, a second year of remote sensing field experiments have been set up in Rosemount and Crookston, Minnesota and in Kanawha, Iowa. These include a caged experiments and open field experiments that will have different levels of aphid infestation on soybean. For Activity 3, the assessment of the current state of art of precise GPS positioning systems has been published. In addition, work is underway to test algorithms and integrate two candidate precise geo-positioning systems with the U of MN autopilot (Goldy 3.0).

Sub-project Status as of January 31, 2019
During this reporting period, the project team continued to make good progress on all activities. For Activity 1, the first outcome has been met with a U of MN-developed aphid-resistant line now being commercially available; however, additional resistant lines continue to be advanced in the breeding pipeline. The ENRTF is listed as one of the funders of this research with the UMN Office of Technology Commercialization and will be compensated according to MS 116P.10 Royalties, Copyrights, Patents, and Sale of Products and Assets. Development of molecular tools to screen plants for resistance genes is nearly complete and work continues on combining multiple resistance genes in soybean lines and assess susceptibility of aphid populations. For Activity 2, experiments were performed at multiple locations. Analyses of spectral and thermal data are underway for optimization of aphid detection. Challenges were encountered in development of proposed experiments to assess field and landscape factors; therefore, an adjustment to research protocols is requested to focus efforts on assessing impacts of plant feeding by other insect pests on detection of soybean aphid. The adjustment does not affect the budget or timeline for this project. For Activity 3, available high-precision GPS technologies alone were found to be inadequate, but algorithms are being developed for fusion of high-precision GPS capable receivers with inertial measurement units to potentially meet requirements of use. Overall, the project is progressing well and results are being shared with stakeholders.

Status as of July 31, 2019:
During this reporting period, the project team continued to make good progress on all activities. To advance the adoption and availability of aphid-resistant soybean, new soybean lines carrying soybean aphid resistance genes were entered into the regional testing program to determine how the agronomics of these lines compares to other lines across a broad geography. In addition, based on previous work to combine multiple aphid-resistance genes into individual soybean lines, over 1,000 soybean lines were selected for evaluation in the next phase of the breeding pipeline in plant rows. Furthermore, analysis is nearly complete of 16 different populations of soybean aphid collected in 2018 and suggests considerable variability in response of aphid populations to different aphid-resistance genes in soybean. To advance the use of unmanned aerial systems to scout for

soybean aphid, analyses have been completed of data collected from soybean fields in 2018 and suggest that soybean aphid infestations can be detected from aerial near-infrared sensors. However, preliminary analyses of data collected from a caged field experiment suggest that the potential for thermal-based remote sensing for soybean aphid may be limited. Finally, progress was made toward implementation of recently developed positioning algorithms. A tool chain is being developed to process images captured by unmanned aerial systems. Overall, the project is progressing well and results are being shared with stakeholders.

Status as of January 31, 2020:
During this reporting period, the project team continued to make good progress on all activities. To advance the adoption and availability of aphid-resistant soybean, multiple soybean lines continue to be advanced through the breeding pipeline. Ten soybean lines with aphid-resistance genes performed well in regional trials. Additional, less advanced, lines were shown to have resistance to aphids in the laboratory and performed well in earlier phases of the pipeline. The second summer of collecting and biotyping of aphid populations showed again that even within a field, aphid populations vary in their susceptibility (or ability to overcome) aphid-resistant soybean. To advance the use of unmanned aerial systems (UAS) to scout for soybean aphid, field experiments were conducted in St. Paul and Rochester, MN in summer 2019. Cages and insecticides used to manipulate aphids and defoliating insects. We then collected spectral data and data on the insect populations throughout the season. Data from these experiments continue to be analyzed. Finally, progress continues to be made toward implementation UAS technology for scouting. A flight controller was built and is nearly ready for flight testing. This will allow drones to map out and precisely follow a pre-programmed trajectory for scouting. The end goal is to make a flight controller which, when mated with a drone, is easy to use, reliable and safe. Team members participated in the Unmanned Aerial Vehicle Symposium to disseminate information to stakeholders. Overall, the project is progressing well.

Status as of July 31, 2020:

During this reporting period, the project team continued to make good progress on all activities. To advance the adoption and availability of aphid-resistant soybean, numerous soybean breeding lines carrying multiple genes for aphid resistance were advanced to regional testing, internal advanced yield trials, and preliminary yield trials. Some of these soybean lines contain up to three aphid-resistance genes. The study of variation of soybean aphid biotypes found variation in soybean aphid biotypes at the township and field levels. To advance the use of unmanned aerial systems (uas) to scout for soybean aphid, field experiments were established in St. Paul and Rochester, MN for the summer of 2020. Pest populations will be manipulated in the experiments with the use of cages and insecticides respectively, and insect and spectral data will be recorded on a regular basis. In addition, data collected in the field during the summer of 2019 are currently being analyzed. Finally, progress continues to be made toward implementation uas technology for scouting. To enhance accuracy, we integrated a precise form of gps (known as rtk-gps) to provide the position solution to an autopilot that has been developed by the University of Minnesota. To enhance safety, we designed algorithms for monitoring the proper operation of all sensors (gps, air speed, etc.) on the autopilot. The algorithms will raise an alarm when sensor failure that can lead to unsafe operation are detected.

Status as of January 31, 2021:
During this reporting period, the project team continued to make good progress on all activities. To advance the adoption and availability of aphid-resistant soybean, numerous soybean breeding lines carrying multiple genes for aphid resistance were evaluated in regional testing, internal advanced yield trials, and preliminary yield trials. Some of these soybean lines contain up to three aphid-resistance genes. The study of variation of soybean aphid biotypes was submitted to a scientific journal. To advance the use of unmanned aerial systems (UAS) to scout for soybean aphid, field experiments were conducted in St. Paul and Rochester, MN for the summer of 2020. Pest populations were manipulated in the experiments with the use of cages and insecticides, respectively, and insect and spectral data was recorded on a regular basis. Data from these field experiments in 2019 and 2020 are being analyzed. Finally, progress continues to be made toward implementation UAS technology for scouting.

To enhance accuracy, we integrated a precise form of GPS (known as RTK-GPS) to provide the position solution to an autopilot that has been developed by the University of Minnesota. To enhance safety, we designed algorithms for monitoring the proper operation of all sensors (GPS, air speed, etc.) on the autopilot. The algorithms will raise an alarm when sensor failure that can lead to unsafe operation are detected.

Status as of August 19, 2021:
During this reporting period, the project team continued to make good progress on all activities. To advance aphid-resistant soybean breeding activities, we planted a soybean crossing block that will produce soybean lines carrying different combinations of aphid-resistance genes combined with high yield, protein, oil, high oleic, disease resistance, and food type soybean traits. In addition, multiple f1, f2, f3 and f4 populations have been advanced with different combinations of resistance genes. Furthermore, we have forwarded multiple aphid-resistant lines to preliminary yield trials, advanced yield trials, statewide public and private testings and regional testings. The results describing variation in soybean aphid biotypes within fields and townships have been published in the Journal of Economic Entomology.
To advance our remote sensing efforts, data were processed and analyzed for pest abundance, yield and hyperspectral readings. Yield was affected by high levels of soybean aphid, but not by low levels of soybean aphid or Japanese beetle defoliation. In addition, Japanese beetle defoliation was found to increase red-edge, but not near infra-red reflectance of soybean plants, was previously identified as promising for the detection of soybean aphids. Furthermore, we built the hardware (a modified version of Goldy) to host the new drone flight controls and we tested flight precision in simulation and on data collected from flight tests.

Status as of January 31, 2022**:**
During this reporting period, the project team completed activities. In relation to aphid-resistant soybean varieties, we worked with aphid-resistant soybean lines throughout the breeding pipeline, ranging from small-scale evaluation of new materials to large regional evaluation of more advanced material. Seed of the best three lines in regional testing has been purified, and may be sent to a winter nursery in Puerto Rico for a foundation seed increase. The work on assessing biotypes of aphid populations withing soybean fields was published. In relation to remote sensing, caged field experiments were performed at two locations in Minnesota in 2021. At each location data on aphid abundance, defoliation, and hyperspectral readings were collected and analyzed. Results were similar to previous years, indicating that typical levels of Japanese beetle defoliation (≤ 5%) increased red-edge reflectance, but not near infra-red reflectance of soybean plants. Thus, typical levels of Japanese beetle defoliation in the field is unlikely to affect the detection of soybean aphids with remote sensing. However, intense defoliation (≥ 33%) decreased reflectance at near infra-red and therefore could affect remote sensing for aphids. In addition, we have built the hardware to host new algorithms for autopilots used to guide small unmanned aerial vehicles for accurate and safe pest management missions. We have tested the algorithm in simulation and by post-processing data collected from flight tests.

Final Report Summary:
The invasion of US soybean by the soybean aphid resulted in dramatic increases in insecticide use, which has increased production costs for farmers and environmental and human-health risks. This proposal takes a two-pronged approach (preventative and therapeutic) to improve management of the soybean aphid through decreased insecticide input, which will result in increased environmental and economic sustainability of soybean production. Integration of preventative and therapeutic pest management tactics is fundamental to integrated pest management (IPM). For preventative management, we advanced the development and availability of aphid-resistant soybean. This included advancement of numerous resistant soybean lines already in the soybean breeding pipeline, including commercial release of one line. Furthermore, numerous crosses were made to incorporate different combinations of aphid-resistance genes into soybean lines, and to test and advance them through the pipeline. Novel research was also performed to examine the variability in susceptibility of aphid populations to these aphid resistant lines. For therapeutic management, we advanced the ability to use remote sensing for soybean aphid through a series of field experiments and technological advancements. Through caged experiments and open-field experiments, we documented that aphid-induced stress to soybean can be detected

from drone-based sensors. In addition, through additional caged experiments we found that typical levels of defoliation (<5%) from another insect, the Japanese beetle, is unlikely to affect the ability to scout for soybean aphid; however, higher levels of defoliation (>33%) could impact scouting for soybean aphid. In addition, we built hardware to host new algorithms for autopilots used to guide small drones for accurate and safe pest management missions. We have tested the algorithm in simulation and by post-processing data collected from flight tests. These advancements will help farmers prevent soybean aphid outbreaks through the use of aphid-resistant soybean and to more effectively respond to outbreaks through efficient drone-based scouting.

Sub-Project 5: MITPPC #5: Optimizing tree injections against emerald ash borer
Project Manager: Brian Aukema
Description: This research will quantify the proportion of trees that must be treated to confer herd immunity to untreated trees for two different non-neonicitinoid compounds.

Summary of budget information for sub-project 5 **ENRTF budget:** $318,927
Sub-Project 5

Outcomes, Activity 1	**Completion date**
1. Determine proportion of trees that must be treated to achieve herd immunity against emerald ash borer	December 31, 2021
Outcomes, Activity 2	
1. Describe community of insects that utilize ash trees in Minnesota	August 31, 2021
2. Determine effects of emamectin benzoate and azadirachtin on non-target insects	December 31, 2021
Outcomes, Activity 3	
1. Determine degree of exposure to emamectin benzoate and azadirachtin among non-target insects	August 31, 2021
2. Determine relationship between tissue concentrations and changes in non-target insect densities in treated ash trees.	December 31, 2021

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Tree injections of insecticides against emerald ash borer remain one of the most effective strategies for canopy preservation of ash trees in urban environments. This project, which began in the summer of 2017, investigates whether injection of a proportion of trees – not necessarily on a rotational basis – will keep untreated trees alive indefinitely, due to a "sink" effect on emerald ash borers that are feeding on treated trees. Adult emerald ash borers typically live for up to six weeks, and females undergo maturation feeding in the canopy before commencing oviposition. We began working with eight communities in Minnesota and selected twelve sites of approximately 100 trees. Half of the trees at each site were injected with a non-neonicotinoid insecticide.

Injections occurred on a gradient, such that in some areas 100% of the trees were injected, but in other areas none of them were, with a mix of treated and untreated trees in between. We await leaf flush in spring 2018 to begin to study whether untreated trees are conferred benefits by being located proximate to treated trees. This fall, we collected phenological data such as rates of color change and leaf abscission. We found that there were no differences between treated trees and control trees. In other words, injections of insecticidal compounds to preserve ash canopies do not appear to cause any noticeable changes in autumnal ash tree phenologies.

Sub-project Status as of July 30, 2018
We have been tracking the phenology and condition of all study trees as well as responding to a high number of inquiries about the project. Sampling for Activity II was initiated this spring. All trees were monitored for fall leaf abscission rates and canopy condition as well as spring leaf out to determine whether treatment alters the phenology of trees. All trees in the azadirachtin treatment received the scheduled June treatment. We have spent a large amount of time responding to inquiries about the project from the public when collecting data. Sets of sticky cards were placed in trees and visited weekly to determine whether bees are found foraging in canopies of ash trees in the spring. Sampling lasted three weeks during the flowering phenology period of ash trees. Data is now being analyzed. As above, we answered a high number of questions from the public while conducting this activity. We met with collaborators at Bethel University who will be helping with this activity. A chemistry undergraduate student (paid by Bethel, no cost to project) will be gaining valuable summer research experience on this project.

Sub-project Status as of January 31, 2019
We collected the second year of data as scheduled from twelve sites in eight communities that agreed to participate in the study. Approximately 100 ash trees were visited at each site; this is quite possibly the largest study of associational protection or herd immunity in North America. We took detailed notes on crown conditions, completed the scheduled treatments of select sites with non-neonicitinoid compounds, and harvested plant material for plant issue analysis. We sampled for non-target insects such as pollinators in both treated and control trees, and also in the seeds. This summer was an exceptional mast year, so there was an abundance of seeds and seed weevils. We began germination trials to determine whether treatments affect the viability of the germ tissue. The PhD student on the project mentored an undergraduate research project (registered credit at UMN) due to the latter's interest in the research that carried over from summer help. Presentations on this work were given at the Upper Midwest Invasive Species Conference and the Entomological Society of America. Due to an unexpected equipment breakdown, work on the final activity of plant tissue analysis has not yet commenced apart from initial methods development.

Status as of July 31, 2019:
Activities continue on schedule. Much of the past six months was spent identifying the bycatch on the sticky cards deployed for to study non-target effects of the different treatments. Harvested plant material was stored for plant issue analysis. We conducted another germination trial to determine whether treatments affect the viability of the germ tissue. We began arrangements for scheduled retreatments of select trees in the 1200 enrolled in the study, and corresponded with municipalities that sought to remove trees in instances of extreme decline. An outreach presentation was given as part of the spring outstate EAB meetings coordinated by the MDA.

Status as of January 31, 2020:
In the past six months, the project retreated all scheduled trees at twelve sites around the state of Minnesota. This study on whether injecting a subset of trees can confer benefits to untreated trees is the largest of its kind in North America of which we are aware. In addition, studies took place over the summer on frequency of visitation of non-target organisms to the trees, whether certain non-target organisms were affected by the various injected products, and whether the trees' phenologies are affected by injections. Graduate student Dora Mwangola presented her work on whether injection of a subset of trees can confer benefits to untreated trees at two conferences. Although results to date have proven largely inconclusive, largely because ash canopies in

our research sites are still quite robust, Dora's work was recognized with a second-place prize in the student competition at the national meeting of the Entomological Society of America. We have had two challenges that we continue to negotiate. First, chemical analysis of plant tissue has gone slower than expected due to machine breakdowns and analytical optimization. We are optimistic about progress at this time. Second, a family concern necessitated a brief absence for the PhD student and postponement of a remaining graduate program-related milestone from fall to upcoming spring semester. This delayed advancement to one credit status results in full rather than reduced tuition for the upcoming Spring 2020 semester. This adjustment has no significance to the project's outcomes nor timeline.

Status as of July 31, 2020:

In the past six months, we have completed the final scheduled injections of select trees within twelve sites around Minnesota. We have completed spring canopy ratings reflecting last summer's injections and have completed initial analyses on both current crown conditions and changes in crown conditions. Although canopies overall remain in excellent condition, we are pleased to report that we are noting more widespread associational protection emerging as emerald ash borer populations increase!

Statistically, we are finding associational protection of untreated trees seems to occur when injected neighbors are within 25 meters of the injected tree. This signal is detected early in EAB invasion before we see either widespread canopy decline, or a significant treatment effect at the level of the site (i.e., all 100 trees). The effect is subtle, and may have limited operational value at this time, but it is a clear effect and the first such documented effect of early association protection of which we are aware.

In the last progress report we reported continued challenges with chemical analyses of plant tissues due to machine breakdowns and analytical optimization. We overcame these challenges only to have covid-19 close laboratories. Our collaborator has undergone phased reopening and samples are now being processed again.

Status as of January 31, 2021:
Overall progress continues to go well despite challenges from altered working conditions due to the pandemic. We completed the third year of crown health ratings this past summer. Tree canopies in many of our sites still looked remarkably good, overall, and we only lost one site to preemptive removals by partnering cities. Analysis took place into the fall, and we are pleased to announce that we have been seeing the first signs of associational protection in four of the twelve sites. Other activities included continued work to solve the backlog of chemical analyses of plant tissues, conducting a second germination assay of ash seeds selected from the various insecticide vs. control treatments, and non-target impact assays using two different species (a moth and a worm).

Status as of August 19, 2021:
We have two major accomplishments to report. First, we have completed the fourth and final year of crown health ratings. Second, our collaborators at Bethel University have completed the backlog of chemical analyses of plant tissues. With these two achievements, all field and laboratory data collection is complete. We are now analyzing the data and systematically writing articles for journal submission. One paper, investigating whether injections of insecticide alter phenological events (that could affect interactions with non-target organisms), is complete and has been sent to co authors for their comments before submission. A second paper, investigating dynamics of seed-feeding *Lygus* spp. weevils over three years of different insecticide treatments, has been fully drafted and is now in editing stages before circulation with co authors. We have three more papers planned: one on surveys of non-target insects across the different treatments, one on laboratory assays studying insecticide effects on a variety of non-target organisms, and a final one on herd immunity that we are saving for last.

Project Status as of January 31, 2022:
In the final six months, we have analyzed the fourth and final year of crown ratings as well as the chemistry data

of plant tissues. The latter have been integrated with the data from the non-target assays, providing us with a laboratory examination of non-target effects of these insecticides on two defoliators and earthworms as decomposers. Two papers have been submitted or resubmitted for publication (i.e., impact of insecticides on tree phenology, impact of insecticides on *Lygus* seed weevils), and two more are in final stages of review (i.e., non-target effects, associational protection). These four chapters comprise the dissertation of PhD student Dora Mwangola. Two presentations were given; one at the IUFRO Conference on Biological Invasions in Forests in Prague, CZ, and another at the national meeting of the Entomological Society of America in Denver, CO.

Final Report Summary:
Emerald ash borer is an invasive insect that kills mature ash trees and has been spreading within Minnesota since its detection in 2009. Ash is a major component of many of Minnesota's urban forests. Injections of insecticides into ash trees can preserve trees indefinitely, but raises concerns for non-target organisms in the environment such as bees and earthworms. For this study, we injected subsets of 1200 trees located in eight different cities in Minnesota with two different insecticides. We specifically tested products that were not neonicotinoids that have presented past risks to pollinators. Insecticides were injected into the trunks in summer of 2017, with periodic reapplications until 2020 while we measured crown health of each tree each summer until 2021. The original site selections were in cities with low pressure from emerald ash borer. We found over the four years of the study that injecting only half of the trees in a given site gave good protection to all trees. We were unable to determine, however, whether this associational protection (i.e., preservation of canopy in an untreated tree when proximate to a treated tree), winter mortality to EAB, or some combination of both was responsible for the site-wide excellent conditions that persisted five years after EAB was present in these communities. Measurements of tree phenology such as leaf out and leaf drop showed that insecticides did not alter the timing of such events. One of the insecticides, emamectin benzoate, showed excellent protection of ash seeds against seed weevils by the third year of the study, without affecting seed viability. We also canvassed the insect communities that visited the trees and harvested leaves for feeding trials with nontarget organisms, and measured chemical concentrations in the leaves. We found that insects communities were similar between treated versus untreated trees across seasons, that bees preferred visiting synchronously flowering plants such as flowering crab apples and rhododendrons versus ash trees, that trunk-injected chemicals were not reliably detected in all plant parts after injection, and that invertebrates such as worms showed no reduction in reproduction or feeding on treated leaves. As such, we concluded that detrimental effects of the insecticides tested on non-target organisms are not likely to be ubiquitous or widespread. In summary, when homeowners or communities are selecting a product to preserve urban ash trees, we recommend emamectin benzoate as a suitable and effective alternative to neonicitinoid-based products.

Sub-Project 6: MITPPC #6: Distribution and traits of the fungal pathogen *Fusarium virguliforme* that influence current and future risk to soybean and other legumes in Minnesota
Project Manager: Dean Malvick
Description: The research goals of this project is to fill in key gaps in knowledge of abiotic and biotic factors controlling *F. virguliforme*'s distribution and the diseases it causes, and to develop tools to accelerate breeding for resistant varieties.

Summary of budget information for sub-project 6 **ENRTF budget:** $383,651
Sub-Project 6

Outcomes, Activity 1	Completion date
1. Develop refined and validated molecular approaches to confirm *F. virguliforme*	June 30, 2018

Outcomes, Activity 1	**Completion date**
2. Determine utility of aerial and satellite imagery for detection and monitoring of sudden death syndrome and develop protocols for most effective use	April 30, 2021
3. Survey and map the current geographic distribution of *F. virguliforme* in Minnesota in agricultural and non-agricultural fields and ecosystems for use by farmers, plant breeders, and agribusiness to prioritize and inform disease management strategies and crop breeding priorities	June 15, 2020
4. Determine potential crop damage from *F. virguliforme* to edible dry bean, alfalfa, and clover	June 15, 2020
Outcomes, Activity 2	
1. Describe whether there is a consistent correlation between sudden death syndrome disease incidence and severity and soybean cyst nematode infestation levels in soybean production fields	April 30, 2021
2. Determine if *F. virguliforme* is a frequent inhabitant of soybean cyst nematode cysts and define whether soybean cyst nematode cysts represent a significant risk for survival and spread of *F. virguliforme*	April 30, 2021
Outcomes, Activity 3	
1. Describe whether there is a consistent correlation between sudden death syndrome disease incidence and severity and soybean cyst nematode infestation levels in soybean production fields	April 30, 2021
2. Determine if *F. virguliforme* is a frequent inhabitant of soybean cyst nematode cysts and define whether soybean cyst nematode cysts represent a significant risk for survival and spread of *F. virguliforme*	April 30,2021
Outcomes, Activity 4	
1. Describe competitiveness of *F. virguliforme* based on nutrient utilization, fungal competition assays, and survival of this pathogen in varied field soil types	April 30, 2021
2. Establish cold temperature limits for survival of *F. virguliforme* that may bound distribution and spread now and under climate change	June 30, 2019
3. Characterize virulence of different strains of *F. virguliforme* along a latitudinal gradient to	June 30, 2021

Outcomes, Activity 1	Completion date
determine if virulence and disease risk varies by regions	
4. Identify genetic regions in *F. virguliforme* and evidence for adaptation that are involved in temperature tolerance or traits that may control invasiveness and/or virulence.	June 30, 2021

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Fusarium virguliforme is the causal agent of the soybean disease sudden death syndrome as well as root rot of dry edible beans, clover, alfalfa, and some native legumes. There is a lack of knowledge of the distribution and damage done by this pathogen in soybean and non-soybean systems, as well as the abiotic and biotic factors influencing its ability to spread, survive, and become a significant pathogen in new areas. To date field and laboratory studies have been conducted and key project personnel have been hired. We completed a field study focused on the host range of *F. virguliforme*. Field pea, processing pea, edible bean (navy, kidney, pinto, black, green bean), alfalfa, red clover, and white clover were evaluated in an inoculated field study. Preliminary results suggest that edible beans may be more susceptible to this pathogen than the other species under the field conditions in this study. With the help of multiple cooperators, 31 samples of plants and soil from different crop production fields were collected to survey for the distribution of *F. virguliforme* in MN. We have also optimized a petri-plate competition assay and a spore-germination assay and tested two strains of *F. virguliforme* against soybean root endophytic fungi. One isolate that outcompetes *F. virguliforme* and two isolates that show antagonism were identified. In summary, we have made solid progress and anticipate that much more progress will be made in the next project period after new project personnel begin working on the project in January 2018.

Sub-project Status as of July 30, 2018
Fusarium virguliforme (FV) is the causal agent of the soybean disease sudden death syndrome (SDS) and can cause root rot on edible bean and other legumes. However, its potential to damage plant species other than soybean in field environments is unknown. Because FV is a relatively new and spreading invasive species in MN, there is a need to understand its distribution and the abiotic and biotic factors influencing its ability to spread, survive, and become a significant pathogen on soybean and other plants in new areas. We initiated a multifaceted project to address these concerns in 2017. To date we completed one field study focused on the host range of FV. Field pea, processing pea, five classes of edible bean, alfalfa (two varieties), red clover, and white clover were included in this study. Initial results suggest that edible bean has greater potential to be a host to FV than the other species under the environmental conditions in this study. Additional host range studies are underway. To understand the distribution of FV in Minnesota, plants and soil were collected from 31 crop production fields with a focus on NW Minnesota, and additional samples are being collected from many counties and fields in 2018. They are being analyzed with a species-specific PCR assays. We have also developed and started competition assays to determine how FV competes with other soil pathogens. Our studies of FV are revealing new information on the host range, distribution, and invasive capacity of this spreading fungal plant pathogen.

Sub-project Status as of January 31, 2019
Work toward the major goals of this project has proceeded well over the past 6 months. Our effort on activity #1 has focused on surveys to determine where *Fusarium virguliforme* (FV) occurs, host range studies of this pathogen, and on improvement of methods to detect FV in soil and plant samples. Initial results indicate that FV

is more widely distributed in Minnesota than previously known, edible bean has greater potential to be damaged by FV than many other legume crop species, and low levels of FV can be detected in soil and plant roots with improved laboratory methods. These methods improve our abilities to survey for this pathogen. Our work on activity #2 has focused on obtaining soil samples with SCN from many counties in Western Minnesota. These samples will be analyzed for the presence of FV in soil and in SCN cysts in early 2019. The outcomes from Activity #3 suggest that isolates of FV isolates from different areas differ genetically, and they differ in their abilities to cause severe root rot and foliar disease and to utilize nutrients. This helps to explain how this pathogen is adapting to new environments and plant hosts. Our efforts during this period toward activity #4 have focused on obtaining background information needed to conduct the modeling. In summary, our studies on FV are revealing new information on its distribution and the factors influencing its ability to spread, survive, and become a significant pathogen on different plant species in new areas.

Status as of July 31, 2019:
Work on activity 1 has continued to focus on surveys to determine where *Fusarium virguliforme* (FV) occurs in MN, host range of this pathogen, and on improving methods to detect FV in soil and plant samples. The results indicate that FV is more widely distributed in Minnesota than previously known, a range of crop and native plant species can be infected by FV in field environments, FV can infect soybean cyst nematode (SCN) cysts in laboratory experiments, and low levels of FV can be detected in soil and plant roots with improved laboratory methods. Our accomplishments have included analysis of associations between SCN and FV from 50 soil samples from multiple counties in western and northwestern Minnesota. Our work shows that isolates of FV from different areas in MN and from different states differ genetically, differ in their abilities to utilize nutrients, and differ in their aggressiveness on soybean. Combined, these results further clarify how FV adapts to new environments and plant hosts. Much of our work is focused on obtaining information needed to conduct ecological modeling for this pathogen. In summary, our research on FV is continuing to reveal new information on its distribution in MN and multiple factors influencing its ability to spread, survive, and become a significant pathogen on different crops in new areas of the state. Results have been presented to agricultural professionals and crop producers at extension education programs across Minnesota.

Status as of January 31, 2020:
Our team has continued to make progress on understanding the distribution and traits of the invasive fungal pathogen *Fusarium virguliforme (FV)*. FV was confirmed in six counties in central and northern Minnesota beyond the previously confirmed northern range. These results show that the distribution of the pathogen and the areas at risk for the disease it causes on a range of crop and prairie plants are increasing in MN, suggesting a need to increase breeding for disease resistant soybean and other disease management tactics. To understand how FV can invade a soil system and become established where many fungi are established, our studies have revealed that FV can preferentially use some nutrients and inhibit the growth of several common soil fungi, thus giving it a competitive advantage. Analysis of pathogenicity and genetic diversity of FV from MN and other states confirm that FV isolates vary in aggressiveness, suggesting disease risk varies depending on which isolates are present in a field. We also determined that FV survives in colder soil temperatures than predicted in a previous study, indicating that the cold winters in MN will not stop the pathogen from spreading north. Results have been presented to agricultural professionals and crop producers at extension education programs across Minnesota as well as at a national scientific conference. Our research on FV is revealing novel information on its distribution in MN and the factors that influence its ability to survive and become established in new areas as a significant pathogen on multiple crops.

Status as of July 31, 2020:

The work of our team has continued to expand understanding of the characteristics and traits of the invasive fungal pathogen *Fusarium virguliforme*. Although the COVID-19 pandemic has greatly limited our abilities to conduct research over much of this project period, we have made good progress. Here are some of the highlights. To understand how *F. virguliforme* can invade a soil system and become established where many

fungi are already established, additional research has been done with nutrient utilization and fungal competition. This work has shown that *F. virguliforme* can preferentially use certain nutrients and inhibit the growth of common soil fungi, which can give this fungus a competitive advantage and enhance its' abilities to invade and become established. Our work with pathogenicity and genetic diversity of *F. virguliforme* shows that isolates of this pathogen vary considerably in aggressiveness and indicates that disease risk can vary in response to the specific isolates that are present in an area. Additional studies were also completed to determine if *F. virguliforme* survives in colder soil temperatures than predicted in a previous study, and our studies suggest that cold winters in Minnesota will not limit spread and survival of this pathogen. Project results have been presented to agricultural professionals and crop producers at extension education programs across Minnesota. In summary, this project has revealed new information on *F. virguliforme* and shows a greater distribution in Minnesota than known, and indicates multiple factors that influence its ability to become established as a pathogen on multiple crops in new areas.

Status as of January 31, 2021:
Fusarium virguliforme, the causal agent of sudden death syndrome of soybean and root rot of other legumes, continues to be a problem for crop producers. Our research team has made more progress in understanding this pathogen's ability to spread and cause disease. Some key outcomes from our work are as follows. We confirmed *F. virguliforme* for the first time in Grant County, which represents a continued spread northwest in Minnesota. Analysis of nutrient utilization suggests that *F. virguliforme* grows on a larger number of carbon and nitrogen sources than many other fungi found in crop fields, which may give it a competitive advantage. In other studies, analysis of competition between *F. virguliforme* and other fungi from soil, soybean roots, and SCN cysts revealed multiple fungi that can inhibit growth of *F. virguliforme.* However, growth of several other common soil fungi was inhibited by *F. virguliforme*, suggesting that this pathogen is a good competitor against multiple fungi and thus has an advantage in becoming established in new areas. Our microsatellite data indicate that there are three genetically distinct clades (groups) of isolates distributed across AR, IA, IL, MO, and MN. Some isolates occurring in one clade across central Minnesota have slightly higher pathogenicity to soybean. In summary, this project has revealed multiple factors that influence the ability of *F. virguliforme* to become established as a destructive pathogen on crops in new areas, and results have been presented to key agricultural professionals and crop producers across Minnesota.

Status as of August 19, 2021:

The fungal pathogen *Fusarium virguliforme* causes sudden death syndrome of soybean and root rot of other legumes. This is an expanding problem for crop producers in Minnesota. Our research team has made more progress in understanding this invasive pathogen. The following are some key outcomes. First, we completed a study and a manuscript on genetic and pathogenic variation and characteristic of *F. virguliform*e populations in Minnesota and the Midwestern U.S. The isolates ranged in aggressiveness from low to high, and three genetically distinct clusters of *F. virguliforme* were identified, with two clusters likely contributing most to spread of this fungus across the Midwest. The manuscript has been reviewed and being revised for publication in the journal *Phytopathology*. Second, we completed initial analysis of genomes from 35 isolates. This has included aligning the genomes with our reference genome from an isolate from MN, and calling and filtering the single nucleotide polymorphisms (SNPs) for all isolates. These are being used for our genome-wide association study (GWAS) that is determining genes potentially involved in pathogenicity and abilities to become established in new environments. Training was completed for one M.S. level (Becca Hall) and one postdoctoral scientist (Rod Olarte), which expands the expertise for addressing issues with invasive plant pathogens. In conclusion, this project has advanced our fundamental and applied knowledge of the characteristics of *F. virguliforme* that contribute to disease management and risk analysis for scientists, agricultural professionals, and crop producers.

Final Report Summary:
The fungal pathogen *Fusarium virguliforme*, which causes sudden death syndrome (SDS) on soybean and root rot of other legumes, is an expanding problem for crop producers in Minnesota. Our research team has made

discoveries regarding the pathogen's ability to spread and cause disease. First, a survey has confirmed the spread of the pathogen for the first time into seven counties in central and western MN. Second, studies of nutrient use suggest that *F. virguliforme* grows on a larger number of carbon and nitrogen sources than many other fungi in crop fields, likely giving it a competitive advantage. Analysis of competition between *F. virguliforme* and other fungi from crop fields revealed that while several fungi can inhibit its growth, multiple others are overcome by the pathogen, indicating it is a good competitor in soil and roots. Third, we determined it can survive to -40°C and thus its spread is not likely limited by cold temperatures. Fourth, in field and greenhouse experiments investigating host range, multiple crop species (black bean, pinto bean, kidney bean, and pea) showed symptoms of disease, and multiple other plant species were infected asymptomatically. Fifth, we completed a study and a publication on genetic and pathogenic variation among *F. virguliforme* populations in Minnesota and the Midwest. While genetic groups did not correspond to aggressiveness, three genetic clusters were identified, with two clusters likely contributing most to spread of this fungus. Sixth, we completed initial analysis of genomes from 35 isolates to investigate genes involved in pathogenicity and abilities to invade new environments. The projected trained one M.S. level and one postdoctoral level scientist, expanding expertise for addressing invasive plant pathogens. This project significantly advances fundamental and applied knowledge of *F. virguliforme* that can be harnessed for disease management and risk analysis by scientists, agricultural professionals, and crop producers.

Sub-Project 7: MITPPC #7: Tools to distinguish native from exotic reed canary grass
Project Manager: Neil Anderson
Description: This project will identify the structural plant traits to distinguish native from exotic forms of reed canary grass and to develop a hand-held molecular testing tool to quickly identify the status of populations.

Summary of budget information for sub-project 7 **ENRTF budget**: $263,273
Sub-Project 7

Outcomes, Activity 1	**Completion date**
1. Determine the minimal genetic information (molecular markers) that is needed to distinguish native from exotic reed canarygrass	March 31, 2018
2. Develop a map of the distribution of native and exotic reed canarygrass in Minnesota	May 1, 2019
Outcomes, Activity 2	
1. Collect additional reed canarygrass specimens from the transportation (highway) corridors and lakes across MN to identify the native vs. exotic status of populations".	June 30, 2020

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
The goal of this project is to determine native vs. exotic reed canary grass locations within MN (Activity 1) and to develop hand-held molecular testing tools for native/exotic types to enable land managers to quickly identify the status of populations (Activity 2). To date, we have obtained high quality and quantities of DNA suitable for genetic marker analysis. In addition to our existing collection of frozen leaf samples, herbarium tissue samples of reed canarygrass (<1940, presumed native) were collected at the UM Herbarium and seeds samples from UW

Madison (Casler's research laboratory) were obtained and planted for DNA extraction. Remaining frozen and fresh tissue samples are being processed; to date DNA from ~1,400 genotypes (>50% of all samples) from leaves have been extracted. For genotyping of reed canarygrass we will use SBG (Sequencing by Genotyping) instead of SSRs (single sequence repeats). Technological improvements, robustness and cost effectiveness of SBG drove this decision. The SSR-based analysis would have consumed ~1 year of time setting up and running gels for each SSR primer, followed by lengthy scoring times. To ensure the SBG method effectively achieves our ultimate goal in Activity 2, a 2018 pilot project involving a sample set of diverse 25 individuals will be test the effectiveness of sequencing vs. SSR data. We anticipate that additional genomic markers (SNPs) could be found to distinguish between native and invasive reed canarygrass with higher precision then SSR markers. If this pilot project proves successful, the remaining samples will be submitted for GBS.

Sub-project Status as of July 30, 2018
Our goal is to determine native vs. exotic reed canary grass (RCG) locations within MN (genetic diversity and population structure) and to develop a hand-held molecular testing method for native vs. exotic genotypes. This will enable land managers to quickly identify the status of current RCG populations in MN. Our experiments are analyzing both living (extant) and preserved herbarium specimens (historic) which represent MN native and exotic RCG genotypes. To date, all (n=2,036) collected RCG tissue samples have been processed and high-quality DNA was purified. The next-generation sequencing (DArTseq) approach was used to generate multi-locus data to characterize RCG populations downstream along MN major rivers. Preliminary results from subsampling experiment (~188 individuals) produced 16,902 SNP markers. We analyzed a pilot set of samples (herbarium/native, MN rivers, forage cultivars, European rivers) with these DArTseq (SNPs) data for a preliminary assessment of the SNP data. Many herbarium specimens had low levels of SNPs due to high level of DNA degradation; a few were usable, however, resulting in separations between types of reed canarygrass. This, along with future analyses of all RCG samples will determine which SNPs will be the most useful for identifying native from exotic or hybrid types by land managers.

Sub-project Status as of January 31, 2019
Genetic variation among and within historic (herbaria) and extant (living) populations from Minnesota and the Czech Republic were assessed by Diversity Arrays Technology sequencing (DArTseqLD) analysis, a low-density DNA sequencing approach to detect clonality of individuals within each location and identify exotic vs. native SNP markers. Among all genotypes, 13,967 high quality SNP markers were found among all samples collected. Wild populations from Minnesota and the Czech Republic create relatively separate, genetically different populations. With the exception of Roseau River and its adjacent production fields, all wild Minnesota rivers are a mixed (panmictic) population without particular genetic structure, in contrast with the Czech populations where each river is genetically distinct. Future research will focus on the distribution of genotypes along each river. The Roseau genotypes along with some herbaria and cultivar samples will be analyzed in the next six months to select potentially native markers (in relation to the other wild MN populations) for use in Activity 2. Five abstracts were published in the past six months relating to our Activity 1 findings. Two of these publications were for poster presentations while the remaining three were for talks given at national and regional meetings.

Status as of July 31, 2019:
Activity 1. Our most recent results showed that reed canary grass (RCG) herbarium samples (<1940; native) and their extant collections as well as RCG from a native unplowed field (Roseau, MN) all group together with the wild RCG collections from five MN rivers. Whereas, MN cultivars and those collected along the Roseau River formed a separate group. The Czech populations were distinct from all MN groups. Thus, the MN RCG river collections most likely native to MN (with the possible exception of Roseau river). The Analysis of Molecular Variance (AMOVA) analysis showed that the majority of variation of RCG collected along MN rivers is within populations (98.8%), not among populations (1.2%). The F_{st} values among RCG MN rivers (0.003-0.037) suggest very little divergence between those populations and a high level of shared genetic markers among RCG populations. Activity 2. Due to the fact that MN rivers RCG populations are without particular genetic structure (a panmictic or interbreeding population), identification of separate populations (MN rivers vs. commercial field) would only be possible with

the use of a large number of single nucleotide polymorphism (SNP) markers. Overall, due to high genetic variation observed within RCG populations, differentiation of MN rivers RCG population vs. commercial field with use of single or few SNP markers (diagnostic marker) will be highly difficult. Thus, we propose modifying Activity 2 to collecting populations along highway corridors and lakes throughout MN to identify whether these are native as well.

Status as of January 31, 2020:
For Activity 2, samples of reed canarygrass (RCG) were collected along six major Minnesota highways (n = 1394) to determine whether they are native (as was found along MN rivers, Activity 1) or not. Similar to plant collections along rivers, roadside collections took place every ~18 miles (30 km), and at each site 15 leaf samples were collected at determined spacings. Genomic DNA from all collected RCG samples was successfully purified, quantified and its quality checked. Genomic DNA (dilutions) are ready for DArTseq submission (SNP genotyping) by the end of 2019. Expected results from the genotyping are expected to be in early April 2020. Additional genotyping results (SNPs) of additional herbaria collections from the Midwest (n=128), Lithuania (n=37) and across N. America from Nelson et al., 2016 were received and are currently being analyzed. A publication that describes major results from Activity 1, which describes RCG in Minnesota is being finalized and submission to the journal Wetlands will be in early January 2020. A minor obstacle was not being able to collect along select lakes (Activity 2) in 2019; this will be completed in April-May 2020.

Status as of July 31, 2020:
For Activity 2, samples of reed canarygrass (RCG) were collected at six Minnesota lakes: Bush, Cedar, Como, Phalen, Mille Lacs, Minnetonka, Square, White Bear and Central Park (n = 152) to determine whether they are native (as was found along MN rivers, Activity 1) or not. Due to limited public access, RCG sampling was performed only in selected and a relatively limited fashion. Due to Covid-19 travel restrictions, we were unable to get permission to collect at the original lakes of interest as such travel would have involved overnight stays. Only travel to local lakes or parks was allowed. Also, due to limited presence of RCG and limited lake shore access a specific collection pattern (similar to how roadways and rivers were collected) was not possible. In addition, on some lakes (e.g. Lake Como), RCG was not very abundant. This was most likely due to intensive management efforts. Genomic DNA from all collected RCG samples was successfully purified, quantified and quality checked. Genomic DNA (dilutions) were submitted for DArTseq (for SNP genotyping) in June, 2020. Genotyping results are expected to be back in early September, 2020. A publication that describes major results from Activity 1, which describes RCG genetic population in comparison to Czech, cultivars and herbarium collections in Minnesota was submitted to the journal Wetlands Ecology and Management in June, 2020.

Final Report Summary:
The goal of this project was to use molecular markers to determine native vs. exotic reed canary grass status in various locations across Minnesota growing along rivers (Des Moines, Minnesota, Mississippi, Red, Roseau, St. Croix), in fields, as commercially-grown cultivars (forage, ornamental), and preserved historic specimens in herbaria (<1940, presumed native) and a corollary set of samples from rivers in the Czech Republic as exotic comparisons (Activity 1); along MN transportation corridors (highways) existing during the 1920s-1930s (Dust Bowl era) and Minnesota lakes (Bush, Cedar, Como, Phalen, Mille Lacs, Minnetonka, Square, White Bear) and Central Park (Activity 2). Due to Covid-19 travel restrictions, we were unable to get permission to collect along additional lakes. The number of plants analyzed totaled 3,430 (Activities 1,2). Plant DNA was extracted from each sample to determine genomic markers of short DNA sequences (2,889 highly differentiated single nucleotide polymorphisms, SNPs, out of 16,902 total markers) to distinguish native vs. exotic status. Genetic analysis of reed canarygrass showed that river populations are native Minnesota or North American types. Herbarium samples as well those from a native, unplowed field (Roseau, MN) were genetically similar to wild collections from five MN rivers; forage cultivars in commercial fields (Roseau, MN) and along the Roseau River formed a separate group. The exotic central European populations were distinctly different from all native MN groups. Most variation is within (98.8%), rather than among (1.2%), populations, suggesting little divergence and a high level of shared genetic markers. Across the state, Minnesota rivers had 2-32 genetic variants present,

some of which were shared among rivers. Thus, the majority of MN reed canarygrass, while invasive, is native in origin and not exotic (European). Thus, based on this study, all of MN reed canarygrass is native; Tribal and State managers may choose to preserve this species.

Sub-Project 8: MITPPC #8: Accurate Detection and Integrated Treatment of Oak Wilt (*Ceratocystis fagacearum)* in Minnesota
Project Manager: Jeannine Cavender-Bares
Description: This project will develop tools for detection and monitoring of oak wilt in Minnesota and to develop new tools and guidelines to prevent the spread of the disease.

Summary of budget information for sub-project 8 **ENRTF budget:** $356,382
Sub-Project 8

Outcomes, Activity 1	**Completion date**
1. Spectral indices associated with oak wilt, bur oak blight and drought at the leaf level and canopy level developed for use in the field	January 31, 2020
2. Sampling protocol and graphical user interface developed and tested	May 31, 2020
Outcomes, Activity 2	
1. Spectral indices associated with oak wilt, bur oak blight, borer and drought developed from hyperspectral imagery from NASA and NEON	January 31, 2020
Outcomes, Activity 3	
1. Up to twenty oak wilt centers treated	November 30, 2017
2. Determine efficacy of double vibratory plow control method and its economic costs compared with a single plow line	June 30, 2020

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Oak wilt, caused by the invasive fungal pathogen, *Ceratocystis fagacearum*, threatens the health of oak forests in Minnesota and across North America. We are developing novel remote sensing methods for rapid and accurate diagnosis of oak wilt and testing the efficacy of management approaches through rigorous field experiments. Our team is using hyperspectral sensors to detect leaf and canopy reflectance in sapling experiments and in infected forest stands across a range of spatial scales. In 2017, we established a greenhouse experiment with bur oak and pin oak saplings in which we infected plants with oak wilt, bur oak blight or imposed drought, and compared them to well-watered control plants. From hyperspectral reflectance measurements of leaves over a two-month period, we successfully classified symptoms of disease progression throughout the experiment on all infected plants. We have processed hyperspectral imagery of Cedar Creek Ecosystem Science Reserve (CCESR) obtained from flights by NASA pilots and have found that known oak wilt disease centers can be detected with high accuracy, an ongoing focal area of our work. Ten oak wilt-infected study sites in Chisago, Anoka, Isanti, and Sherburne Counties were identified and treated using the single and

double vibratory plow line methods in October 2017. These sites will be monitored and used for remote sensing model development and analysis. Training was provided to a University of Minnesota graduate student, two undergraduate students and a technician preparing for a long-term science career.

Sub-project Status as of July 30, 2018
Using the 2017 geolocated healthy and oak wilt infected trees at Cedar Creek Ecosystem Science Reserve (CCESR) and 2016 airborne hyperspectral imagery, we have trained models to 1) differentiate tree species and 2) to differentiate healthy and oak wilt infected oaks (Activity 2). Current models allow us to classify oak species compared to non-oak species with a 94% accuracy, to classify *Q. ellipsoidalis* compared to *Q. macrocarpa* with a 91% accuracy, and to classify healthy compared to oak wilt infected *Q. ellipsoidalis* trees with a 87% accuracy. We also collaborated with NASA scientists and were able to fly CCESR and the 10 oak wilt field sites established in 2017 to obtain new AVIRIS imagery. The imagery has not yet been processed but will be used for ongoing model development for accurate detection of infected trees.

We began (inoculations on July 2, 2018) a follow-up greenhouse experiment investigating hyperspectral detection of oak wilt and differentiating oak wilt from bur oak blight and drought in seedlings of *Quercus macrocarpa* and *Q. ellipsoidalis* (partially funded by a UMN Provost's Office Grand Challenges Grant). In our previous experiment, oak wilt cases were diagnosed correctly in 42% of cases in *Q. ellipsoidalis*, before most leaves were exhibiting symptoms. In the current experiment, we are including both leaf-level and whole-canopy hyperspectral reflectance measurements of seedlings to connect leaf-level and whole plant models for more accurate oak wilt detection (Activity 1). We are also measuring field-collected branches from mature oak wilt-infected and healthy *Q. ellipsoidalis* trees.

We are continuing to monitor the effectiveness of the double vibratory plow line (VPL) method in halting the spread of oak wilt in infected stands (Activity 3). In July and August, we will reassess the ten site that we treated with the VPL method in 2017 for any disease spread. We are selecting an additional ten sites for VPL treatment in September 2018.

Sub-project Status as of January 31, 2019
Using airborne hyperspectral imagery, we were able to differentiate oak species from other common mixed hardwood forest species with 84% accuracy, differentiate northern pin oak from bur oak with 91% accuracy, and differentiate healthy red oaks and oak wilt infected northern pin oak with 96% accuracy. Importantly, we were able to detect oak wilt-infected trees from imagery collected the year prior to their death, demonstrating the potential to detect oak wilt disease in advance of visual symptoms. Using published health indices, we found significant differences between healthy and oak wilt infected trees at chlorophyll sensitive wavelengths (R683 nm and R694 nm/R760 nm), indicating a small number of wavelengths can be useful. We completed a second seedling experiment in which we infected oaks with oak wilt, bur oak blight, or subjected them to chronic drought and measured hyperspectral reflectance at the whole plant- and leaf-level. Oak wilt can be differentiated from other treatments with 50% accuracy at both the leaf and whole-plant level. Using only symptomatic leaves of any unhealthy plant, we can detect oak wilt with nearly 70% accuracy, showing efficient detection with simple leaf measurements once trees are found to be unhealthy. We identified field sites containing northern pin oak saplings to use for a field inoculation and detection experiment in 2019. We established and treated 10 additional oak wilt centers with vibratory plow lines and completed surveys of previously treated sites. We presented our research findings at multiple local, regional and national or international venues.

Status as of July 31, 2019:
We have continued to make progress on our efforts to accurately detect oak wilt at multiple scales and to document best practices in management efforts to prevent spread of the disease. We began analysis of the AVIRIS NG airborne imagery following analysis protocols developed for the AISA imagery. We find that both data types can detect and differentiate oak species from other common mixed hardwood forest species and

accurately classify oak wilt-diseased oak species from healthy species (Activities 1 & 2). In the last six months, we initiated an outdoor potted sapling experiment and a field experiment using naturally growing oak saplings at the Cedar Creek Ecosystem Science Reserve. In the potted experiment, large northern pin oak saplings were infected with oak wilt or drought-treated, or both. Hyperspectral reflectance at the whole plant- and leaf-level (Activity 1) and a suite of physiological changes are being measured. In the field experiment, naturally growing northern pin oak or red oak saplings were inoculated with oak wilt and will be compared to healthy saplings using spectroscopy at the leaf and whole plant level. Our team submitted a manuscript for publication based on the greenhouse seedling experiment, and an undergraduate submitted an honors thesis. We have collectively given five oral or poster presentations at state, federal or university venues summarizing the work from the MITPPC project. We have also educated undergraduates through a field trip and contributed to the career advancement of a former post doc, a former junior researcher, and an undergraduate researcher.

Status as of January 31, 2020:
Our team continues to make progress on accurate detection of oak wilt at multiple scales and documentation of best practices in management efforts to prevent spread of the disease. We have advanced analyses and ground-truthing of AVIRIS NG airborne imagery including model development and spectral index development for stress physiology in response to the oak wilt disease (Activity 2). We conducted an outdoor potted sapling experiment and a field experiment using naturally growing oak saplings at the Cedar Creek Ecosystem Science Reserve. Hyperspectral reflectance at the whole plant- and leaf-level (Activity 1 & 2) and a suite of physiological changes were measured in summer 2019. In the field experiment, oak saplings were inoculated with oak wilt and compared to healthy saplings using leaf and canopy spectroscopy. Results indicate that physiological disease symptoms can be readily detected using spectral sensors at both leaf and canopy scales using statistical models and simple indices from spectral features linked to physiological stress. Establishment and treatment of 20 oak wilt sites is now completed (Activity 3). A manuscript for publication based on the greenhouse seedling experiment is in revision for *Tree Physiology*. Our team has been active in outreach activities that disseminate knowledge of effective oak wilt management techniques and progress in remote sensing of oak wilt to local, regional, national and international audiences disseminating the work from the MITPPC project. In the last six months, we have trained a post doctoral scientist, a technical scientist, two undergraduate research assistants and a first-year graduate student.

Status as of July 31, 2020:

We continue to develop an information and analysis pipeline for accurate detection of oak wilt from aerial imagery. We have advanced analyses of AISA Kestrel and AVIRIS NG airborne imagery including model development and spectral index development for stress physiology in response to the oak wilt disease (Activity 2). The analysis procedure that is most accurate involves a phylogenetic detection procedure, in which we first distinguish oaks from all other lineages, and then we detect the tree canopies in the red oak lineage. This enables high accuracy in detecting oak trees with early stages of oak wilt. We have also continued to analyze data from an outdoor potted sapling experiment and a field experiment using naturally growing oak saplings at the Cedar Creek Ecosystem Science Reserve. In these experiments, hyperspectral reflectance at the whole plant- and leaf-level (Activity 1 & 2) and a suite of physiological changes were measured in summer 2019. We found that physiological disease symptoms can be readily detected using spectral sensors at both leaf and canopy scales using statistical models and that simple indices from spectral features are linked to physiological stress. These stress signals significantly distinguish healthy and diseased plants. Analysis is continuing for the application of hyperspectral models to our 20 oak wilt sites (Activity 3). A manuscript for publication based on the greenhouse seedling experiment is published in *Tree Physiology* and a second manuscript is in development for *Remote Sensing and Environment*. In the last six months, we have trained a post doctoral scientist and a technical scientist. Due to covid19 we have refrained from experimental work and undergraduate training. Several planned meetings were cancelled. Our team has been active in outreach activities that disseminate knowledge of effective oak wilt management techniques and progress in remote sensing of oak wilt to local,

regional, national and international audiences disseminating the work from the MITPPC project. However, in the last six months we have limited these activities.

Final Report Summary:
Our team has made substantial progress on the development of methods and approaches for accurate detection of oak wilt in Minnesota forest using spectroscopic technology. We have also documented best practices for management efforts to prevent spread of the disease. Specifically, we have completed physiological experiments demonstrating the disease can be differentiated from other stress factors under controlled conditions (Activity 1). A manuscript on the greenhouse seedling experiment using leaf and whole plant spectroscopic data to differentiate oak wilt from bur oak blight and drought has been published in Tree Physiology. We have advanced analyses and ground-truthing of AVIRIS NG airborne imagery including model development and spectral index development for stress physiology in response to the oak wilt disease (Activity 2). In an outdoor field experiment using naturally growing oak saplings at the Cedar Creek Ecosystem Science Reserve, oak saplings were inoculated with oak wilt and compared to healthy saplings using leaf and canopy spectroscopy. Results indicate that physiological disease symptoms can be readily detected using spectral sensors at both leaf and canopy scales using statistical models and simple indices from spectral features linked to physiological stress. Lastly, treatments were completed at 20 oak wilt sites with a new "double plow line" to prevent spread of the disease through root grafts. Initial assessments indicate the approach is highly effective, but a final determination will be made 5 years after treatment, beyond the life of this project (funding secured from USDA Forest Service). Two postdoctoral scientists, a technical scientist, a first-year graduate student and two undergraduate research assistants received training and mentoring during the project.

Sub-Project 9: MITPPC #9: Characterizing dispersal of larval gypsy moth to improve quarantine regulations
Project Manager: Brian Aukema
Description: This research will conduct laboratory and field-based behavioral and mark-resight studies to determine how feeding status and age affect dispersal and the costs and effectiveness of different barriers around woodpiles.

Summary of budget information for sub-project 9 **ENRTF budget:** $35,000
Sub-Project 9

Outcomes, Activity 1	**Completion date**
1. Determine effects of developmental stage, feeding status, and environmental stimuli on larval movement to determine "worst case" conditions	December 31, 2017
2. Determine the maximum and expected distances that gypsy moth larvae can move as a foundation for a new recommendation for isolation zones around commercial log decks	April 31, 2018

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Due to health issues at Syntech, manufacturing and shipping took longer than anticipated. We have spent the month of December setting up the base unit, configuring the software, and testing it with non-quarantine insects like Madagascar hissing cockroaches. We have built a custom enclosure that allows us to conduct more nuanced experiments. The first larvae of gypsy moth are scheduled to hatch in the last week of December in the quarantine facility, and we look forward to conducting our first experiments.

Sub-Project Status as of July 30, 2018
The European gypsy moth, *Lymantria dispar* L. (Lepidoptera: Erebidae) is an invasive insect in North America. Gypsy moth larvae are highly polyphagous and capable of extensive defoliation during population outbreaks. The United States maintains a quarantine across the established range of the gypsy moth to slow the spread of the moth. One component of the quarantine requires that entities that move wood products across quarantine boundaries stage those wood products within a buffer zone area devoid of any host vegetation. The purpose of the buffer zone is to reduce the likelihood that late instar gypsy moth larvae will pupate nearby, emerge as adults, mate, and lay eggs on the wood. In practice, this buffer zone is 100 feet in radius. It is difficult to evaluate the efficacy of the buffer zone practice, however, due to our limited understanding of the movement ecology of these larvae. In this project, we investigate how host type and food deprivation affects the movement capacity and behavior of larvae in the laboratory using a servosphere. Testing is complete and results are now being analyzed for the final report.

Final Report January 31, 2019
The European gypsy moth is an invasive insect that feeds on over 300 species of trees and shrubs. Management guidelines within a national quarantine recommend that wood products, such as timber being harvested and moved from the forest, are staged within a buffer zone area devoid of any host vegetation during harvesting operations. This buffer zone reduces the likelihood that late instar gypsy moth larvae will pupate nearby, emerge as adults, mate, and lay eggs on the wood. In practice, this buffer zone is 100 feet in radius, but this distance was established with limited understanding of the movement ecology of gypsy moth larvae. We conducted laboratory experiments at the University of Minnesota to determine how host type and food deprivation affected movement of gypsy moth caterpillars. During outbreaks, food can become scarce as larvae strip trees of foliage. Larvae were raised on one of five foods: oak, tamarack, Norway maple, sugar maple, or artificial diet. Subsets of larvae were also deprived of food for zero, 24, or 48 hours. After the food deprivation period, late instar larvae were placed on the servosphere. Larvae raised on oak, a preferred host, were unlikely to move unless starved. They moved farther and faster the longer they were starved. In contrast, when larvae were raised on less preferred hosts, they were more likely to move without prior starvation. These results suggest that feeding on optimal hosts provides gypsy moth larvae with the energy and nutritional requirements to move more quickly to more food when there is none immediately available. Thus, risks of larvae crossing a regulatory buffer zone may increase where an outbreak results in complete defoliation of preferred hosts. Results from this laboratory study were integrated with a federally-funded field study to inform best management practices of this invasive species in Minnesota.

Sub-Project 10: MITPPC #10: Management strategies for the invasive spotted wing drosophila
Project Manager: Mary Rogers
Description: This research will seek to understand the relative impacts of local movement, long-distance migration, and potential overwintering sources. Additionally, the research will investigate the efficacy of innovative and alternative management techniques, evaluate the cost effectiveness and economic impact of SWD management alternatives, and develop decision-making tools for growers.

Summary of budget information for sub-project 10 **ENRTF budget:** $477,541
Sub-Project 10

Outcomes, Activity 1	**Completion date**
1. Determine the possible extent of local overwintering by spotted wing drosophila in Minnesota	August 31, 2021
2. Determine the role of local movement in colonization of raspberry fields through laboratory-flight-chamber and in-field vertical trapping studies	August 31, 2021

Outcomes, Activity 1	Completion date
3. Determine the possible role of long-distance movement in colonization of raspberry fields through aerial observation	August 31, 2021
4. Develop new forecasting models for integrated pest management based on an improved understanding of the ecology of spotted wing drosophila, and source of populations	August 31, 2021
Outcomes, Activity 2	
1. Determine efficacy of novel biopesticide products (Erythritol, lufenuron, Spear-T, P, and C) and botanical repellents against spotted wing drosophila in laboratory bioassays and on raspberries in the field	December 31, 2020
2. Determine efficacy of physical exclusion using poly-covered high-tunnels and fine mesh netting on reducing spotted wing drosophila damage in raspberries	December 31, 2019
3. Determine interaction of novel biopesticide products and poly-covered high-tunnels for increased efficacy against spotted wing drosophila in raspberries	December 31, 2019
Outcomes, Activity 3	
1. Estimate the current economic impact of spotted wing drosophila infestation rates in the Minnesota raspberry industry.	December 31, 2019
2. Calculate the potential costs and benefits associated with alternative spotted wing drosophila management practices for conventional and organic raspberry growers.	December 31, 2020
3. Estimate the aggregate economic benefits, if any, of conventional and alternative spotted wing drosophila management practices.	December 31, 2020
4. Develop an estimation tool that can be used by growers to make informed financial decisions about spotted wing drosophila control for soft fruit production.	December 31, 2020

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:

Spotted wing drosophila (*Drosophila suzukii*, SWD) is an invasive, cosmopolitan fruit fly that has been present in MN since 2012. Female flies lay eggs in ripe, soft skinned fruit including raspberries, blueberries, and strawberries. Eggs hatch into larvae that feed inside the fruit, rendering fruit unmarketable. SWD is causing significant economic damage to the berry industry as a whole, but the economic impact in our state is not well documented. Worldwide, growers are increasing pesticide spray applications in attempts to manage this new pest. Repeat applications of broad-spectrum pesticide sprays can increase the risk to non-target insects and have negative environmental consequences. Additionally, insecticide sprays may fail to adequately protect fruit from damage due to high pest populations and low thresholds. Because SWD is a new pest in MN, it is not known whether or not adults survive through winter or migrate into the state from warmer regions, making it difficult to predict when SWD will first appear. In this project, we aim to minimize the threat of SWD to natural resources and the economy of our state in three ways: 1) improve our understanding of the relative impacts of local movement, long-distance migration, and potential overwintering sources of SWD; 2) investigate the efficacy of alternative management techniques including biological pest pesticides and exclusion; and 3) evaluate the cost effectiveness of SWD management alternatives and develop decision-making tools for Minnesota berry growers.

Sub-Project Status as of July 30, 2018
Spotted wing drosophila (*Drosophila suzukii*, SWD) is an invasive, cosmopolitan fruit fly that has been present in MN since 2012. Female flies lay eggs in ripe, soft skinned fruit including raspberries, blueberries, and strawberries. Eggs hatch into larvae that feed inside the fruit, rendering fruit unmarketable. SWD is causing significant economic damage to the berry industry as a whole, but the economic impact in our state is not well documented. A team of researchers at the University of Minnesota are working together to better understand the biology of this pest in our cold climate, determine effective management practices for this pest, and assess the economic impact of SWD in our state. Based on this last objective, our team has found that most raspberry growers in our state are small-scale producers, experiencing infestation rates of 2-100%. Most raspberry growers in MN use U-Pick operations, which makes chemical management difficult due to pesticide reentry intervals. Consequently, many growers are plowing under berries and/or refraining from harvesting fruit due to SWD infestation. Growers report that summer-bearing, floricane cultivars experience less infestation, whereas fall-bearing, primocane cultivars are more seriously impacted, due to increased pest population density. Our results indicate that growers in the south and south-central regions of the state report higher levels of infestation. Organic growers primarily practice sanitation for SWD control, whereas non-organic utilize pesticides, mass trapping, pruning, scouting and sanitation. This information helps inform and guide our management recommendations and improve outreach for fruit growers in Minnesota.

Sub-project Status as of January 31, 2019
The overall major accomplishments in the past 6 months include key developments on our SWD research in Minnesota. Specifically, we are building evidence to determine how this invasive pest moves to and within the state, which will help guide future pest management recommendations (i.e. field sanitation, monitoring). In addition, our research is uncovering which pest management products are practical for chemical control of this pest, and best management practices for using exclusion and controlled environment techniques to reduce infestation, increase marketability and profitability of fresh berries. In addition, our work has shown that the economic impact of SWD on raspberry production in MN is $2.2 million annually. Major accomplishments over the last 6 months include the submission of a manuscript on the economic impacts of SWD on Minnesota to the Journal of Integrated Pest Management; and graduate research assistant Anh Tran in the Hutchison lab won 2nd place for her oral presentation on determining SWD morphs based on body size at the annual Entomological Society of America conference. These efforts elevate our work to a national audience and may be used to leverage additional funding sources to continue research on this pest, to the benefit of small fruit growers in Minnesota. So far, our project has not experienced any major obstacles that influence our ability to meet our proposed deadlines. So far, we are on track to complete all outcomes by the end of our funding period in June, 2021.

Specifically, for Activity 1, additional Degree-day (DD) modeling analyses (base threshold of 10^{o} C) were completed and found to be in agreement with May and mid-June SWD adult catch dates, reflecting potential winter and summer morph activity. Given these results, and agreement with the DD model, we have secured two additional locations, with collaborating berry farmers known to have high SWD populations (Hastings, Forest Lake) to repeat the early spring/summer monitoring in 2019. This research is getting us closer to understanding how SWD moves to and within MN, which will help us refine pest management recommendations. This work will continue in 2019 and is currently on track to meet deadlines (ending in May, 2021). For activity 2, the team completed 20 unique laboratory bioassays, including measuring adult mortality, oviposition, larval development, pupal development, and emergence of 2nd generation of adults on fresh raspberry fruit. Data was analyzed and is being prepared for publication. In addition, we completed the first year of the semi-field assays at the Rosemount Research and Outreach Center using the eight most promising treatments from the lab assays. However, of the eight treatments, only Mustang Maxx (conventional restricted use pesticide) resulted in significantly higher mortality than the untreated control. We also completed the first year of research on exclusion netting plus insecticide treatments at the West Central Research and Outreach Center in Morris, MN. We found that total yield and marketable yields of raspberries were significantly higher in the full season mesh exclusion treatment. From a stakeholder perspective, this research will guide insecticide recommendations for management of SWD, and also determine best management practices for exclusion of SWD, while highlighting the benefits of controlled environment techniques. The work is on track for completion and a second year of field research will be completed in 2019. Finally, team member, Gigi DiGiacomo submitted a manuscript titled *Economic Impact of Spotted Wing Drosophila (Diptera: Drosophilidae) Yield Loss on Minnesota Raspberry Farms: A 2017 Grower Survey*, to the Journal of Integrated Pest Management for consideration. Additionally, a second round of telephone surveys was completed in November 2018 to obtain additional data in an effort to verify SWD infestation rates, SWD-related yield and labor expenditures for SWD control. This study will determine the cost of labor-related SWD management practices: scouting, pesticide/bio-pesticide applications, pruning, mass trapping, increased harvest frequency, field sanitation and installation of exclusion measures. The on-farm labor data eventually will be paired with material input costs for conventional and alternative SWD control measures studied by field researchers for this project. The labor and material input costs will be used to calculate on-farm costs and returns associated with conventional and organic SWD control strategies. The work is on-track to meet deadlines and work will be completed in Dec. 2020.

Status as of July 31, 2019:
Key accomplishments within the past 6 months (from Dec. 2018-May 2019) include publication of a manuscript, titled *Economic Impact of Spotted Wing Drosophila (Diptera: Drosophilidae) Yield Loss on Minnesota Raspberry Farms: A Grower Survey*, was accepted and published in April 2019 in the Journal of Integrated Pest Management 10(1): 11; 1-6. A press release was prepared by Dana D'Amico for the manuscript in April 2019. DiGiacomo and Rogers worked with D'Amico to provide quotes and data for the press release. A second manuscript, titled *Efficacy of Organic and Conventional Insecticides for* Drosophila suzukii *when Combined with Erythritol, a Non-nutritive Feeding Stimulant*, was accepted for publication with minor revision, to the journal Crop Protection in May 2019. A third manuscript is in preparation for the development of a quantitative scale to identify and distinguish winter and summer morphs of SWD. Additionally, multiple SWD traps (n = 90) across three sites have been deployed to increase the likelihood detecting an overwintering SWD earlier in the season. Additional lab assays on botanical products are showing promise for repelling SWD and preventing oviposition. A NC-SARE graduate student grant has been submitted to fund additional work in this area. Three talks on our project were given at the MN Fruit & Vegetable Growers Association meeting in St. Cloud, MN in January 2019. Additionally, three team members attended the MITPPC board meeting in February 2019 to share research findings. Our second season of field work is underway.

Status as of January 31, 2020:
Key accomplishments within the past six months include publication of a manuscript titled *Efficacy of organic and conventional insecticides for* Drosophila suzukii *when combined with Erythritol, a non-nutritive feeding stimulant* in the journal Crop Protection in November, 2019. In addition, another manuscript titled

Morphometric criteria to differentiate Drosophila suukii (Diptera: Drosophilidae) seasonal morphs was accepted with major revision to the open access journal Plos One. Two research presentations were given by graduate students Tran and Gullickson at the annual Entomological Society of America conference in St. Louis, MI in November. Gullickson was awarded an NC-SARE graduate student grant titled *Field implementation of botanical repellents for organic management of spotted-wing drosophila (Drosophila suzukii)* which will fund additional on-farm research in summer 2020 with grower stakeholders. Gullickson, Rogers, and DiGiacomo also submitted a grant to the Organic Farming Research Foundation titled *Yield and comparative economic analysis of organic management practices for spotted-wing drosophila in raspberries* to fund additional research on the economic benefits and trade-offs of field management practices for SWD. Lab flight assays to understand SWD flight behavior and continued early trapping to identify potential overwintering adult SWD in addition to economic analysis are on-going. A cost-benefit analysis has been completed using field trial data from the Morris and Rosemount sites to examine the financial efficacy of SWD control strategies studied. Data suggest that it pays to administer SWD controls under organic and non-organic management regardless of the treatment strategy used. Organic bio-pesticides proved the most cost-effective compared to alternative strategies: 1) high tunnels with exclusion; and 2) open field plots treated with conventional pesticides. Cost-benefit observations will be shared at winter conferences and further developed for publication.

Status as of July 31, 2020:
Key accomplishments within the past six months include publication of a manuscript titled Morphometric criteria to differentiate *Drosophila suzukii* (Diptera: Drosophilidae) seasonal morphs to the journal PLOS ONE in February 2020. This publication aids future SWD research by allowing scientists to objectively differentiate the morphs thereby improving our understanding of the biology and phenology of seasonal morph dynamics. A second manuscript titled Deterrent effects of essential oils on spotted-wing drosophila (Drosophila suzukii): Implications for organic management in berry crops was accepted for publication in a special issue on organic pest management in the journal Insects, and is significant because it addresses alternative management strategies using botanical oils which may reduce the risk of SWD pesticide resistance and lower the use of broad-spectrum insecticides used in SWD management. Our team is on track or have met the outcome deadlines for activities two (developing alternative management techniques) and three (economic impacts of SWD management), however progress related to activity one (local migration and overwintering) is delayed by three months due to laboratory shut-downs as a result of the Covid-19 pandemic. We have encountered no other obstacles to our research progress other than those posed by Covid-19. We have presented research results at three different grower forums and have submitted an abstract to present at the upcoming Upper Midwest Invasive Species Conference. We have submitted a pre-proposal for additional MITPPC funding to support research that would advance sustainable SWD management techniques in strawberries, a high value crop that has been under-studied and experiencing increased SWD-related yield losses.

Status as of January 31, 2021:
Key accomplishments within the past six months include publication of a manuscript titled *Deterrent effects of essential oils on spotted-wing drosophila (Drosophila suzukii): Implications for organic management in berry crops* was accepted for publication in a special issue on organic pest management in the journal Insects, and is significant because it addresses alternative management strategies using botanical oils which may reduce the risk of SWD pesticide resistance and lower the use of broad-spectrum insecticides used in SWD management. Another manuscript was submitted in December, 2020 related to our third activity on economic impacts of SWD, titled *Partial budget analysis of exclusion netting and insecticides for organic management of spotted-wing drosophila (*Drosophila suzukii *(Matsumura)) on small farms in the Upper Midwest* and is currently in review for the Journal of Economic Entomology. Results show that in almost all scenarios small-scale organic raspberry growers benefit economically from the application of exclusion netting on high tunnels and insecticides for open plots. The broader impact of this work is that these two organic management strategies for SWD can pay off for small-scale growers, preserving the production of locally grown raspberries. In addition, our team also shared results from our work at the Upper Midwest Invasive Species conference in November, reaching approx. 52

attendees. Our team is on track to complete all components of this project by the end of August, 2021 and have submitted new funding proposal to continue our work, including a pre-proposal to North Central SARE this fall.

Status as of August 19, 2021:
Key accomplishments within the past six months include publication of a peer-reviewed manuscript on the economic impacts of SWD has been published in the Journal of Economic Entomology. Results show that in almost all scenarios small-scale organic raspberry growers benefit economically from the application of exclusion netting on high tunnels and insecticides for open plots. The broader impact of this work is that these two organic management strategies for SWD can pay off for small-scale growers, preserving the production of locally grown raspberries. In addition, an interactive worksheet tool calculating returns of SWD control measures is available online. This will allow users (growers) to estimate costs and benefits of applying SWD management techniques based on our data. We continue our work on managing SWD in small fruit using non-insecticidal practices. To this end, we submitted three new grant proposals to continue funding our research. Our research on local and long-distance dispersal of SWD is in preparation for publication. Our data show that although SWD tends to stay closely to host fruit canopy, they can fly to vertical heights >6m which may indicate dispersal. In lab experiments, SWD winter morphs show poor flight performance, providing little evidence of long-distance dispersal capabilities. Six years of data on first catch of SWD in Minnesota align well with predictive degree-day models, providing indirect evidence of local overwintering in southern Minnesota (vs. long-distance migration). Lastly, we contributed to six new outreach activities (grower conferences, virtual publications) to convey results to stakeholders over the last six months.

Final Report Summary:
Spotted wing drosophila (*Drosophila suzukii*, SWD) is an invasive fly that lays eggs in intact, ripening fruit such as blueberries, strawberries, and raspberries. This pest has caused considerable economic losses for small fruit growers. First detected in MN in 2012, SWD threatens 750 acres of raspberries, strawberries, grapes, and blueberries, in addition to its 5,000 high tunnel operations statewide. At the start of our project, current control tactics were limited to repeat applications of broad-spectrum insecticides that failed to adequately protect fruit from infestation, in addition to posing risks to the environment. Additionally, we faced gaps in understanding the basic biology and behavior or SWD, such as migration and overwintering in Minnesota, which hindered our ability to recommend appropriate management strategies. To address this, we proposed three goals: 1) develop SWD forecasting tool using local migration and overwintering data; 2) investigate efficacy of alternative management techniques; and 3) research economic impact and develop decision making tools. As a result of our work, we have indirect evidence showing that SWD may be overwintering and little evidence that the SWD has the flight capabilities for long-distance movement. We learned that physical exclusion can effectively reduce SWD damage and is cost-effective for small farms and reduces the need for insecticide sprays. Our work on biopesticides and novel repellants shows promising results in the lab but is less consistent in the field, warranting new methods to increase field efficacy. Economically, we found that SWD is responsible for at least $2 million in losses annually to raspberry growers alone, establishing the need for management for the statewide fruit industry, and growers can benefit from adopting physical exclusion and biological based pesticides. Our science-based management recommendations for this best improves overall sustainability of small fruit production in Minnesota.

Sub-Project 11: MITPPC #11: Will future weather favor Minnesota's woody invaders?
Project Manager: Peter Reich
Description: This research will quantify and map how four woody invaders will compete with key native tree species in forest settings under current and future climate conditions.

Summary of budget information for sub-project 11 **ENRTF budget:** $526,000
Sub-Project 11

Outcomes, Activity 1	Completion date
1. Quantify sensitivity of woody invasives to recent climate and its statewide variation and determine competitive ability of these invasives versus native trees	December 31, 2021
2. Complete assessment of the potential for threat of woody invasive spread statewide	December 31, 2021
Outcomes, Activity 2	
1. Characterize capacity of woody invasives to colonize forest sites under potential future weather and climate in northern Minnesota	May 31, 2021
2. Complete assessment of the potential threat of spread of woody invasives in northern forests where these invasives are currently scarce	May 31, 2021
Outcomes, Activity 3	
1. Develop maps that show the current distribution of woody invaders, as well as uncertainty regarding their presence, to highlight the areas that will benefit most from more information.	December 31, 2021
2. Complete maps of shifts in encroachment vulnerability under a changing climate and therefore aid in prioritizing which areas require the most urgent management attention.	December 31, 2021
Outcomes, Activity 4	
1. Development of methods of creating effective local barriers to woody invasive spread.	December 31, 2021

Sub-Project Status as of June 30, 2017:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of January 30, 2018:
Minnesota's forests face unprecedented challenges, including from invasive species, climate change, and their joint impacts. Four non-native woody invasive species including two honeysuckle (*Lonicera morrowii, Lonicera tatarica*) and two buckthorn species (*Frangula alnus, Rhamnus cathartica*) are already abundant in many regions of the state, and could become major problems in the future in forest-dominated northern Minnesota; further, climate change could increase that possibility. These four species were the four highest priority woody invasives, according to "Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research". Among the reasons for such high concern are reductions in tree regeneration that can occur when the invasives colonize in high density. This is of particular concern in northern Minnesota, which supports the bulk of the state's forest industry and recreation, but is also of concern in other forested regions of the state, in many of which woody invasives are already present. In this project we will we address key knowledge gaps with the following activities. We will provide climate sensitivity assessments for the four key woody invasives based both on

retrospective analyses of growth performance of existing shrubs at sites that span the state's climate gradient and on a realistic field experiment in which the exotics and native trees will be grown at contrasting climate conditions. We will also produce maps of current distribution as well as projected future hotspots for invasion under climate change, and test new approaches to slow the spread of woody invaders at nascent invasion locations.

Sub-Project Status as of July 30, 2018
Two non-native honeysuckle (*Lonicera morrowii, Lonicera tatarica*) and buckthorn (*Frangula alnus, Rhamnus cathartica*) species are already abundant in many Minnesota forests, and have the potential to become major problems elsewhere; future climate could make them more competitive and more challenging to manage state-wide. We address knowledge gaps about their potential to become increasingly widely distributed, aggressive, and abundant, with four activities:

(i) Characterize growth sensitivity to past climate of these invaders, based on height and diameter growth analyses statewide. This work has not yet begun.

(ii) Assess whether the invasive species will out-compete native tree species with changing weather. Individuals of 11 native and the 4 invasive species were planted by spring 2018 in all 36 plots in an open-air experiment. Warming treatments began in April and rainfall manipulations in June. Shoot and leaf phenology were measured in all plots throughout spring and early summer. Measurements of net photosynthetic capacity began in June 2018.

(iii) Map the current distribution of these invaders and their likely distribution given both time to spread and a changing climate in which that spread will occur. This work has not yet begun.

(iv) Begin field tests of "buffer/barrier zone" techniques for slowing spread of woody invasives. No active research has begun, but preliminary scouting of field sites indicated our original design would likely be inefficient and cost-ineffective. We developed an alternative approach that should provide more meaningful information for less work and lower cost and are designing a specific field plan using that approach.

Sub-project Status as of January 31, 2019
Overall we made significant progress on activities two and four placing both on track to achieve planned goals. The main accomplishment(s) for activity two was successful establishment of the model plants cohort into research plots and application of the experimental treatment throughout the season. In addition, a number of physiological and growth performance measurements were taken on the model plants and collected data are currently being prepared for analysis. For activity four we successfully scouted potential locations for the experimental testing of the barrier strips and dendrochronological surveys. Currently, we are developing final protocols and overall plans for the upcoming season including preparation to scout for two remaining research sites for activity four.
In addition, during last season we hosted a number of visitors at the site of activity two that included;

- Five field classes for students from local Colleges and Universities (FDLTCC, UMD and UMN) with total attendance of approximately 80 students,
- A group of 12 international students including three faculty members from Nord University in Norway.
- A group of DNR area supervisors (around 60 individuals attended)
- A group of researchers from Finland including faculty members from Forest Resources department at the UMN

Currently, we are in the processes of post season organization and described lab work that includes processing of samples and data from 2018 and preparation for the next field season.

Status as of July 31, 2019:

Since conclusion of the field work late in 2018 we focused on winterizing the project and we shifted to the lab component of the work. This included post collection processing of samples and data (*e.g.* biomass weighing, data entry, cleaning and organization *etc.*). and necessary repairs, general cleanup and preparation for the next season. We also did preliminary data exploration in preparation for upcoming publications. Preliminary data exploration shows that woody invaders benefited from warmer growing conditions as their rate of carbon assimilation and overall biomass accumulation was enhanced while not all native species showed such favorable response to warming. The least favorable growth with warming were shown by native conifers and boreal species. In late winter and early spring we shifted to preparation of the research site for the growing season by reassembling warming and rainfall reduction treatments, planning treatments and measurements, fixing fences, wiring and other problems, hiring summer interns, and updating protocols for the upcoming season. In the first week of April we turned on warming treatment and begun 2019 field data collections. The project is on track to achieve its goals.

Status as of January 31, 2020:
Since June 2019 we conducted intense field work that focused on activity 2 and 4. The main accomplishments for each activity for the last 6 months are:
Activity one, we began final work on protocol development and site scouting in preparation for sampling in 2020.

Activity two, we focused on; i) implementing experimental treatments throughout the season, ii) planning and conducting sampling collections and ecophysiological surveys, iii) end of the season experiment winterization.

Activity four, over the course of the season we; i) established sugar maple barrier and control plots at Rice Creek and completed removal of buckthorn resprouts in target zones, ii) completed sampling of buckthorn and honeysuckle cookies from grids at UMore Park in Rosemount ROC and Tanglewood for estimates of historical spread rate of invasive species, iii) are currently processing collected buckthorn and honeysuckle cookies. In addition, due to high deer herbivory of sugar maple at Rice Creek we decided to fence the barrier and control plots to protect them from further damage.

In addition, during the season we have hosted two field classes and two groups of professionals at the site of activity two. All activities are on track to achieve their goals.

Status as of July 31, 2020:
This project is in the middle phases focused on data collection and analysis. No outcome deadlines transpired during this period, and no publications were produced. Data collection is proceeding as scheduled for all activities, aside from minor delays due to COVID-19. Activity 1 we have finalized sampling protocols and are in the processes of scouting for potential research sites that we plan to sample later this summer. Activity 2 we have started this season in April with implementation of the warming treatment and basic data collections (e.g. plant phenology, light conditions and soil processes). We also harvested individuals that had grown taller than the warming apparatus and replanted with new individuals to ensure they were subjected to the warming treatment. Currently we are on track with the activity goals with data analyses and write ups underway. In particular, a manuscript led by Artur Stefanski titled “Stomatal behavior moderates H2O cost of CO2 acquisition for boreal species under experimental climate change” is 80% complete. Activity 3 will begin in Fall 2020. Activity 4 is well underway: the first component, a field experiment, is established and experimental maintenance and data collection will continue through summer 2020 and 2021. The second component, a survey approach to assessing historical spread of buckthorn and honeysuckle in focal woodlots, is complete in terms of data collection and analyses are underway.

Status as of January 31, 2021:
Data collection is proceeding as scheduled for most activities, aside from some relatively substantial delays due to COVID-19. Activity 1, we have finalized sampling protocols and proceeded with sampling but of a more

limited scope than originally planned. We have established 20 research sites that were used for sampling in late summer. Sample processing is underway. Activity 2, we have conducted surveys and data collections such as plant gas exchange, yearly growth surveys, and plant phenology (scaled down due to COVID-19, but for additional season than originally planned, due to leveraged funding opportunities). In addition, we have also conducted root sampling of invasive species to estimate mycorrhizal root colonization. We also are about to submit a first manuscript. Activity 4 has two components. For the first, a field experiment started in 2018, we collected data in 2020 and will continue experimental maintenance and data collection through summer 2021. The second component, a survey approach to assessing historical spread of buckthorn and honeysuckle in focal woodlots, is complete in terms of data collection and analyses are underway. No outcome deadlines transpired during this period, and no publications were produced.

Status as of August 19, 2021:
Data collection is proceeding as scheduled for most activities, aside from some relatively substantial delays due to COVID-19. For Activity 1, 20 research sites were sampled in 2020 and processing of those samples is underway. For Activity 2, we have been working on data analysis, writing, and ongoing data collection (for additional season than originally planned, due to leveraged funding opportunities). The Activity-3 approach has been modified to allow a simpler, but more reliable output based on results of activities 1 and 2 than originally planned. Activity 4 has two components. For the first, a field experiment started in 2018, we are continuing experimental maintenance and data collection. The second component, a survey approach to assessing historical spread of buckthorn and honeysuckle, is complete in terms of data collection and analyses are underway.

Manuscripts in progress include “Stomatal behavior moderates water cost of CO_2 acquisition for 21 boreal-temperate and invasive species under experimental climate change” (95 % complete) and “Buckthorn seedling dispersal kernels from the edge of a buckthorn stand” (50% complete).

Status as of January 31, 2022:
Data collection is complete. Activity 1, we established 20 research sites that were used for sampling in 2020. We have processed the samples, except for soils. Activity 2, we have been working on data analysis and writing. Activity 3 has been modified and is underway. Activity 4 has two components. For the first, a field experiment started in 2018, we continued experimental maintenance and data collection, and made substantial progress on analysis and writing. The second component, a survey approach to assessing historical spread of buckthorn and honeysuckle, is complete in terms of data collection and analysis and writing is underway.

Final Report Summary:
Glossy buckthorn, common buckthorn, tatarian honeysuckle, and morrow’s honeysuckle are woody species that have been introduced to Minnesota forests from other continents. All four species frequently dominate forests and exclude native plant species. Warming temperatures and continued dispersal of these species are likely to significantly increase their abundance throughout Minnesota, especially in northern Minnesota. However, most effort by researchers and managers alike has been given to reactive measures against invasion instead of increased understanding of invasion processes and/or preventative measures. This project evaluated the climate sensitivity of these four invasive species in a way that provides for more accurate threat assessment of each throughout the state and provides tools for Minnesotans to potentially slow invasion into new areas and protect Minnesota’s forests. We analyzed growth rings of 274 trees to determine how quickly invasive species spread and characterize how native and invasive species have responded to past growing conditions. We found that growth rates of invasive buckthorn and honeysuckle are most similar to native cherries and ashes in southern Minnesota, but that the invasive species already are growing much faster than those native species in northern Minnesota. Within a forest, we found that buckthorn tended first to invade hilltops and subsequently spread to low-lying areas at a rate of 3-4m yr^{-1} (slower than honeysuckle, which spread at 6 m yr^{-1}). We experimentally assessed 10 native species in addition to the four invaders to determine which are favored by changing temperature and rainfall patterns (i.e. their responses to future climate). We found invasive and more southern

native species to be favored by warming conditions in terms of their growth and survival, whereas more northern native species were often strongly disfavored. We established programs to detect current invasion at fine-scale spatial resolution and predict future invasion based on the findings above, and set up long-term experiments to test the ability of tree plantings to slow invasion into new areas.

Sub-Project 12: MITPPC #12: Developing robust identification assays for *Amaranthus palmeri* in seed mixtures
Project Manager: Don Wyse
Description: A proactive certification process is needed to protect Minnesota's environment and agricultural industries from further Palmer amaranth introductions. To enable proactive certification and additional testing of seed lots as needed, a robust and fully validated molecular method is needed to differentiate among Palmer amaranth and visually-similar seed from other species.

Summary of budget information for sub-project 12 **ENRTF budget:** $208,230
Sub-project 12

Outcomes, activity 1	**Completion Date**
1. Develop high-throughput method for mechanical separation of *Amaranthus*-sized seed from mixed sampled	March 30, 2018
2. Optimize techniques for high throughput tissue disruption and DNA isolation procedure from filtered seed lots	September 30, 2018
Outcomes, activity 2	
1. Complete assessment of the specificity of molecular testing for distinguishing *A. palmeri* in *Amaranthus*-only seed mixes	January 30, 2019
2. Determine robustness of molecular tests to identify Palmer amaranth across a diverse panel of accessions	January 30, 2019
3. Optimize molecular tests to identify *A. palmeri* contamination in filtered subsamples from seed mixes	June 30, 2019
Outcomes, activity 3	
1. Complete genome sequencing to provide reliable and robust methods to identify Palmer amaranth from related species	June 30, 2019
2. Finish testing to with diverse Palmer amaranth lines to ensure the robustness of detection technologies	June 30, 2019

Sub-Project Status as of January 30, 2018:
Labs are being set up and the necessary personnel hired.

Sub-Project Status as of July 30, 2018
Palmer Amaranth (*Amaranthus palmeri*) is one of the largest emerging threats to agricultural systems in the upper Midwest. Traditional screening methods are unable to differentiate Palmer Amaranth from related non-invasive species of Amaranth, leading to introduction through contaminated seed mixes. In response we are

developing a species species-specific screening method to be implemented by the Minnesota Department of Agriculture. The end goal is to develop an assay with clear categorization for the presence/absence of Palmer Amaranth in a sample.

The development of mechanical separation protocol (Activity 1) is anticipated to begin in late October. This delay is to allow for more rapid progress on Activity 2, which will be presented in an oral session at the Upper Midwest Invasive Species Conference meeting this October.

Activity 2 is progressing well. *Amaranthus* seed has been acquired from multiple sources and is being grown in a greenhouse to provide DNA for this project. This step is expected to end in September. At that point high through-put DNA extraction will be performed through the use of Qiagen Biosprint kits. The resulting DNA will be used to validate the existing KASP marker developed by our Colorado team.
Development of new KASP markers (Activity 3) will be performed by submitting our DNA to UMGC for Genotype-by-Sequencing (GBS). GBS will allow us to identify species-specific single nucleotide polymorphisms (SNPs), which can then be used to design additional KASP markers. Submission to UMGC is anticipated to start in October/November.

Sub-project Status as of January 30, 2019
Our team has grown and extracted DNA from a large panel of Palmer Amaranth selected to cover the largest possible genetic diversity. We have coverage across a wide geographic range; from California to Georgia, and from Mexico to Minnesota. Additional samples from Senegal and Mali have been included to maximize genetic diversity of the panel. The extracted DNA is on hand, and ready to be deployed for later stages of the project. The initial Palmer marker, developed by our team members at Colorado State University, has been validated against this panel. The maker performed extremely well, with a 99.7% accuracy across 1,100 samples and a 0% failure to identify Palmer individuals. The marker performed well enough to overturn two species identifications from our seed suppliers. As a result of our testing we were able to halt distribution of Palmer seed through a national germplasm repository. These findings were disseminated at an oral session of the Upper Midwest Invasive Species Conference meeting on October 15th, 2018.The project is on track and has met its deadlines, with the exception of mechanical seed separation. This objective was deferred due to the higher priority and development time needed for the genetic part of the project. We will begin seed separation in January/February of 2019 and anticipate its completion by June 30th, 2019.

Sub-project Status as of July 31, 2019:
In the last six months we have made substantial progress in validating the first KASP marker for identifying Palmer Amaranth. The marker was validated against a panel of 1,100 individuals and demonstrated an overall accuracy of 99.73%. The assay showed a false negative rate of 0%, meaning that the assay was able to correctly detect all Palmer samples. The false positive rate for our assay was 0.44%, representing only 3 non-palmer individuals who were erroneously flagged as being Palmer. The low false positive rate is important because erroneous calls represent a waste of time and resources in unnecessary control efforts. The combination of low error rates indicate that our assay will be a reliable tool for identification of Palmer Amaranth.

Bulk seed testing of this marker has shown the ability to reliably flag contamination of Palmer Amaranth in a mixture of Waterhemp seeds at a rate of 1:20. Additional work is being conducted to increase the sensitivity of our bulk seed testing protocol.

DNA samples for additional marker development have been submitted to the University of Minnesota Genomics Center for sequencing. Development of these markers is on schedule and validation is expected to be performed this summer.

Preliminary results have been presented at the UMN Palmer Amaranth Summit on January 22nd, 2019 and as an invited speaker at Colorado State University on April 17th, 2019.

Sub-project status as of *January 30, 2020:*

GBS sequence data for our *Amaranthus* panel was obtained from the University of Minnesota Genomics Center and used to identify a set of candidate SNPs for species identification. 9 candidates were identified, with the two highest performing candidates approved for validation testing. These two candidate markers (along with a marker developed by our team members at Colorado State University) all passed validation with accuracies ranging from 99.7% to 99.9%. The two UMN developed markers were also used to assess performance for identifying Palmer contamination in seed mixes. Both markers were able to reliably identify contamination at a 1% level (1 Palmer seed mixed with 99 Waterhemp seeds), which matches the performance of current seed testing services. One marker has shown sensitivity at the 0.5% level (1 Palmer seed with 199 Waterhemp seeds), and collaborators at Colorado State University are currently working to confirm this performance in their labs. The result of this project is the most robust and reliable test for Palmer Amaranth currently available. Our detection thresholds match those available through testing services on the market, while our validation panel is the most robust and comprehensive to date. All assays have been tested on samples from across the United States, as well as two populations in South America (Brazil and Argentina) and two in Africa (Mali and Senegal). Additionally, we are the only assay to offer diagnostic statistics (e.g. false positive rates) for marker performance across a pool of 1,250 samples.

Final Report Summary (August 30, 2020):
Palmer Amaranth is an aggressive and prolific weed species that poses a major ecological and economic risk to growers in the state of Minnesota. Closely related to other pigweed species, Palmer has a far more severe impact on agricultural row cropping systems. Early identification of Palmer Amaranth is critical, as it has developed resistance to some of the most widely used herbicides; ALS-inhibitors, PPO-inhibitors, and glyphosate. Visual identification of Palmer Amaranth against other pigweed species is difficult, which has led to the use of genetic testing becoming the standard for identifying Palmer.

To address this emerging challenge we collected a team of weed science experts from the University of Minnesota, Colorado State University and the Minnesota Department of Agriculture. This team developed an improved genetic test to maximize the robustness and reliability of Palmer Amaranth identification for both individual plants and bulk seed screenings. To achieve this, our team collected Pigweed samples across the United States as well as Mexico, South America and Africa. We extracted DNA samples from a total of 24 populations of Palmer amaranth and 42 non-Palmer pigweeds, resulting in DNA from over 2,000 individual plants. We sequenced more than 800 of these samples through the University of Minnesota Genomic center to search for genetic differences between Palmer and the other species. These differences served as a target for developing a set of genetic markers that can be used for species identification. Once developed the genetic markers were tested against 1,250 pigweed samples to assess their performance.

The final result is a highly reliable test for (>99.7% accuracy) for detecting Palmer Amaranth, both for individual plants and pools of seed. This test will be an important tool for Palmer control for Minnesota growers, crop consultants, and other agronomic specialists. The test is expected to be commercially available in 2020.

Sub-Project 13: MITPPC #13: Terrestrial invasive species prioritization
Project Manager: Amy Morey
Description: The Minnesota Invasive Terrestrial Plants and Pests Center undertook an expansive research prioritization to systematically evaluate threats posed by a wide array of terrestrial invasive insects, plants, and plant pathogens in 2017 and created the document, "*Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research*," which has provided guidance on funding MITPPC research projects in subsequent years.

Since its publication, a number of plants and pests have been suggested for further review by stakeholders, including Palmer amaranth and jumping worms. The movement of TIS into Minnesota calls for a thorough review of suggested species. We will utilize the same methodology applied in the 2017 paper. An Analytical Hierarchy Process (AHP) was used to rank these threats. AHP is a form of multi-criteria decision analysis that

makes the process of selecting the highest priority threats consistent and transparent. AHP has been used by many agencies and organizations to facilitate complex decision making. This 14 month project will assess up to eighty species of plants, pests, and pathogens to update the prioritized lists used by MITPPC

Summary of budget information for sub-project 13 **ENRTF budget:** $71,461

Outcomes, Activity 1	**Completion Date**
1.10 TIS assessment completed	July 14, 2019
2. 11 additional TIS assessments (21 total)	August 12, 2019
3. 25 additional TIS assessments (46 total)	November 25, 2019
4. Updated prioritization of 170 species completed	December 1, 2019
5. 32 additional TIS assessments complete (200)	July 31, 2020
6. Updated prioritization of 200+ species completed	July 31, 2020

Status as of July 31, 2019:
The first outcome deadline of 10 completed TIS assessments has been met. The following species have been completed:
*Acer ginnala (*Amur maple)
Ailanthus altissima (tree of heaven)
Alium tuberosum (garlic chives*)*
Contarinia nasturtii (Swede midge)
Elaeagnus angustifolia (Russian olive tree)
Impatiens balfourii (Balfour's touch-me-not)
Lamium galeobdolon (yellow archangel)
Microstegium vimineum (Japanese stiltgrass)
Pyrenopeziza brassicae (no common name)
Resseliella maxima (soybean gall midge)

Status as of January 31, 20*20:*
All deadlines and goals in the past 6 months of the updated species prioritization project were met. No significant obstacles were encountered. The results of this work will provide an updated prioritization of species for the forthcoming 2020 funding cycle. This process allows the MITPPC to be dynamic and transparent in how it responds to emerging TIS threats and stakeholder concerns. An additional 20 species have been identified for future evaluations.

Status as of July 31, 2020:
Prioritization process was made more visible to the scientific and pest management communities. Presentations or publications have not resulted from this project during this time. All deadlines and goals expected of the updated species prioritization project from Jan – June 1, 2020 were met. No significant obstacles were encountered. The results of this work will provide an updated prioritization of species for an anticipated 2021 funding cycle. This process allows the MITPPC to be dynamic and transparent in how it responds to emerging TIS threats and stakeholder concerns. In addition, a draft of a technical description of the MITPPC prioritization process is in progress. This document will enable the MITPPC update period.

Final Report Summary
In 2017, the Minnesota Invasive Terrestrial Plants and Pests Center undertook an expansive research prioritization to systematically evaluate threats posed by a wide array of terrestrial invasive invertebrates, plants, and plant pathogens and created the document, "*Minnesota's Top 124 Terrestrial Invasive Plants and Pests: Priorities for Research*," which has provided guidance on funding MITPPC research projects in subsequent years. Since its publication, many terrestrial invasive species (TIS) have been suggested for further review by stakeholders. The movement of TIS into Minnesota and their potential harms calls for a thorough review of suggested species.

Following methodology developed in the 2017 document, this MITPPC project evaluated 77 plant, invertebrate, and plant pathogen species submitted for review by stakeholders. The results of each evaluation are incorporated into the Analytic Hierarchy Process (AHP) model used by MITPPC to rank and prioritize the TIS that threaten Minnesota's terrestrial ecosystems. AHP is a form of multi-criteria decision analysis that makes the process of selecting the highest priority threats consistent and transparent. AHP has been used by many agencies and organizations to facilitate complex decision making. This project provided an update to the research priorities for the MITPPC 2020 call for proposals, which included ~45 new or re-reviewed species.

Evaluations completed after the 2020 update will contribute to an anticipated 2022 prioritization update. The project also enhanced and updated the evaluation of species such that multi-page documents are produced for each species to clearly outline the information used for characterizing the potential threat posed to Minnesota. Evaluation documents will be made available for stakeholder feedback. These changes allow MITPPC to continue to be dynamic and transparent in how it responds to emerging TIS threats and stakeholder concerns.

Sub-project 14: MITPPC #14: Improved Detection and Future Management of Leafy Spurge and Common Tansy using Remote Sensing, Mechanistic Species Distribution Models, and Landscape Genomics

Sub-project managers: David Moller and Ryan Briscoe Runquist
Description: Species Distribution Models (SDMs) are developed to predict which geographic areas are under current risk of invasion and how distributions will expand or contract under climate change. Traditional SDMs are constructed only from environmental data and often underperform because they fail to account for how population demography and functional traits vary with environmental variables across geographic ranges. Here, we propose to develop mechanistic and process-based SDMs in order to provide fine-scale predictions of current and future distributions of two invasive species (leafy spurge and common tansy) that are widespread across much of the northern tier of the United States but considerably less common to the south. We will take a novel approach where we use remote sensing to gather demographic information on each species across MN. Publicly-available multi- and hyper-spectral satellite images will be analyzed to quantify abundance and population growth over the las 18 years. Those data will be used to develop process-based SDMs. We will also use manipulative controlled environmental experiments to assess population differentiation in ecologically-important traits across the region and determine critical thresholds that limit performance. Those data will be used to construct mechanistic SDMs. Finally, we will use landscape genomics to assess fine-scale population structure and patterns of dispersal across the region using low-cost, high resolution sequence data. Together, these integrative datasets will provide detailed predictions of habitat under current and future climates and inform near- and long-term management strategies.

This project is jointly funded by the M.L. 2016, Chp. 186, Sec. 2, Subd. 06a appropriation to MITPPC and will be split as follows:
ML 2015: $70,812
ML 2016: $352,000

Summary of budget information for sub-project 14 **ENRTF budget:** $70,812

Outcomes, Activity 1 Remote sensing and machine learning to gather environmental, population, and demographic data	
1. Gather remotely sensed environmental data from publicly-available sources	12/13/2019
2. Develop classifier using DL and remotely-sensed data to detect leafy spurge	12/31/2020
3. Gather demographic data on leafy spurge populations identified by classifier	12/30/2021
4. Develop classifier using DL and remotely-sensed data to detect common tansy	12/31/2021
5. Gather demographic data on common tansy populations identified by classifier	6/30/2022
6. Validate classification model and demographic data through field surveys	6/30/2022
Outcomes, Activity 2: Common garden experiments to assess niche thresholds and trait differentiation among populations	
1. Collect seeds for leafy spurge and common tansy from across range	12/31/2019
2. Conduct growth chamber experiments on leafy spurge seeds at varying temperatures to assess germination niche	12/31/2021
3. Conduct growth chamber experiments on leafy spurge juveniles at varying temperatures to assess first year emergence	12/31/2021
4. Conduct growth chamber experiments on common tansy seeds at varying temperatures to assess germination niche	11/30/2022
5. Conduct growth chamber experiments on common tansy juveniles at varying temperatures to assess first year emergence	11/30/2022
6. Conduct experiments on common tansy juveniles and adults at varying temperatures to assess relative growth rate, reproductive allocation, and biomass allocation (above- and below-ground)	11/30/2022
Outcomes, Activity 3 Build traditional mechanistic and process based distribution models	
1. Build traditional SDMs (Maxent and Boosted Regression Trees) of leafy spurge	12/31/2020
2. Build traditional SDMs (Maxent and Boosted Regression Trees) of common tansy	12/31/2020
3. Build process-based SDMs of leafy spurge	6/30/2022
4. Build process-based SDMs of common tansy	6/30/2022
5. Build mechanistic SDMs of leafy spurge	6/30/2022
6. Build mechanistic SDMs of common tansy	4/1/2023
Outcomes, Activity 4 Using landscape genomics to infer major dispersal pathways and sources of new infestations	

Outcomes, Activity 1 Remote sensing and machine learning to gather environmental, population, and demographic data	
1. Tissue collection and extraction	12/31/2020
2. Enzyme optimization for sequencing	6/30/2021
3. Sequencing and analysis of data within a spatial framework for leafy spurge	12/31/2021
4. Sequencing and analysis of data within a spatial framework for common tansy	4/1/2023
5. Final integrated report that summarizes current and future potential distributions of common tansy and leafy spurge complete	4/1/2023

Status as of July 31, 2019:
Sub-project is in early phases of organization. No update is required per LCCMR instruction.

Status as of January 31, 2020:
The main objective during the first phase of our project has been to identify populations of leafy spurge and common tansy that span the range of environmental conditions and land uses across the state of MN. Systematically identifying and collecting from these populations allows us to characterize how plant traits vary across the state. In future experiments, we will assess if there are particular traits that confer an advantage in different environments, such as in warmer or cooler temperatures. We will also be able to characterize how plant genomic DNA varies across the state and use this information to determine important pathways of dispersal and invasion. In total, we collected from 185 leafy spurge populations, of which 69% were new records and two were new county records, and 187 common tansy populations, of which 49% were new records and one was a new county record. Our intensive effort has put us ahead of schedule for our main collection effort. During this period, we also exhaustively surveyed a twelve square-mile area of Dakota Co. for new leafy spurge populations. In this area, we identified 1,840 leafy spurge sites, most of which were previously undiscovered. This dataset will be used to develop a computer algorithm that detect populations of invasive species using satellite images.

Status as of July 31, 2020:
To develop a computer algorithm that detects leafy spurge, last summer, we exhaustively surveyed a 12-mile square region in Dakota Co., MN for leafy spurge and georeferenced every population that we found. During the past six months we have digitized this ground-truth data and have used it to generate training, validation, and testing datasets for building a deep learning neural net classification model for leafy spurge. We have also, with help from our spring 2020 undergraduate student worker, Nolan Kerr, downloaded publicly- available satellite imagery from multiple sources to test in model training, including imagery from Landsat, Modis, Sentinel-2, and PlanetScope. We are also working to obtain Worldview 3 data. Currently, we are using the National Agriculture Imagery Program (NAIP) and an associated land classification mask generated by the Knight research group, which we have modified to include classifications for our leafy spurge ground-truth data. This winter, we have focused our early efforts on testing multiple deep-learning model architectures, namely pixel-based densely connected networks, image segmentation with 2D convolutional neural nets (CNN), and image segmentation with U-nets using Keras and TensorFlow in Python. We plan to continue testing additional architectures that fuse multiple model architectures and/or different satellite image data products. We have also started gathering additional ground-truth and testing data from other regions in MN. This is needed in order to train a robust model and test that the best performing models can correctly classify populations from different regions of the state.

Status as of January 31, 2021:

Our team has made progress on all of our project activities over the last six months. We built multiple promising computer algorithms to detect Leafy Spurge populations from satellite imagery, and we are currently evaluating our models. We continued to improve our remote sensing dataset by performing additional ground-truthing and conducting population size and density surveys in order to gather demographic data. We were limited by COVID from conducting large experiments, however, we were able to pilot methodologies to help ensure a successful 2021 season. Last, we completed sample DNA extractions for both species and submitted samples to the UMN Genomic Center. We will use these data to evaluate the genetic diversity of the species across MN and determine patterns of dispersal and gene flow.

We published an article in *Diversity and Distributions* that evaluated commonly-used methods for building and evaluating species distribution models, particularly those aimed at predicting range expansion. This paper included traditional species distribution models for Leafy Spurge and Common Tansy and provided a baseline prediction of invasion risk. We also have a manuscript in revision at the *Journal of Biogeography* that presents a new method for predicting range expansion for invasive species using information on the environmental affinities of co-occurring native species. This new method also leveraged a large MN DNR dataset of >10,000 plant communities across MN. R. Briscoe Runquist and T. Lake presented the results of both manuscripts at the UMISC conference in November. We wrote a small grant and were awarded $8000 of in-kind support of very high-resolution satellite imagery from the European Space Agency and T. Lake received two graduate student grants from the Bell Museum ($2500) and the Botanical Society of America ($1500) in support of our experiment to test for genetic differentiation and responses to climate change in Common Tansy.

Status as of August 19, 2021:
During the last six months, we have made progress on all three of our main objectives for this project. For our first research objective, we continued to focus on using satellite imagery and deep learning models to detect leafy spurge. We were able to build a deep learning model that can detect leafy spurge populations with 87% accuracy in Minnesota. For our second research objective, we have begun planting a large common garden experiment that will test for genetic differences in phenotypes between populations of common tansy collected from across Minnesota. In this experiment, we will also subject the plants to heating and drought stress treatments to test for adaptation to different environmental gradients that are present in Minnesota. For our third objective, we continued to guide our DNA extractions through the sequencing process at UMGC. Our leafy spurge genotyping-by-sequencing pilot experiment was successful and the full panel of samples is now with UMGC for sequencing. Our first common tansy pilot experiment was unsuccessful and our second pilot experiment was just completed (9 June 2021) with fewer loci than we anticipated; we are in the process of deciding next steps for this species. Last, we had a paper published in the Journal of Biogeography where we show that predictions of range expansion for invasive species are improved using information on co-occurring native plant species.

Status as of January 31, 2022:
In the past six months, we have focused on three main objectives: 1) validating our deep learning models for detecting leafy spurge from satellite imagery and preparing a manuscript with the models and results, 2) setting up and conducting a large common garden experiment on genetic differentiation in common tansy in MN, and 3) conducting bioinformatics and preliminary landscape and population genetic analysis of sequenced individuals. Our deep learning models leverage the use of publicly available satellite imagery to accurately predict areas of leafy spurge infestation. The most exciting development from our work has been the result that we can use a time series of satellite images over the growing season of leafy spurge to predict populations as accurately as models that use the more expensive and less widely available very high resolution satellite imagery. These results are currently under review at Remote Sensing of Ecology and Conservation. We have completed our first field season of our common garden, that will be used to determine niche thresholds and trait differentiation among MN populations of common tansy and leafy spurge. This data will be used to determine physiological limits and potential for future adaptation to climate in both species. Last, preliminary

bioinformatics and genomic analysis are ongoing. In leafy spurge, we are working to confidently call genotypes for its polyploid genome. In common tansy, preliminary population genetic analysis indicates that there is structured genetic variation in Northern MN, which reveals genetic differentiation and potential differences in geneflow in the landscape.

Status as of July 31, 2022:
Our team continues to make progress towards completing the goals for our outlined activities. During the last six months we have made progress on all four activities. For Activity 1, we published the paper, "Deep learning detects invasive plant species across complex landscapes using Worldview-2 and Planetscope satellite imagery" in the journal Remote Sensing in Ecology and Conservation. Our models had an >96% accuracy rate at detecting leafy spurge populations from publicly-available satellite images. We are developing large-scale temporal models for leafy spurge to detect demographic changes from remotely sensed data. For Activity 2, we have successfully overwintered and re-established our common tansy field experiment at the St. Paul Experimental Agricultural Station. Approximately 95% of the plants re-emerged this spring; we are currently imposing drought and heat treatments and gathering data on phenology and growth. For Activity 3, we have started to synthesize our multiple species distribution models on common tansy and leafy spurge. We previously built and published traditional SDMs and have now built mechanistic species distribution models based for both species using on data from growth chamber and field experiments conducted last summer. We are working towards demographic models based on the data gathered from our deep learning models for leafy spurge. For Activity 4, we have finished all of the bioinformatics and genetic analysis for common tansy and leafy spurge. We are currently finishing our final data analyses and are in the process of preparing two manuscripts on our landscape and population genetic results.

Status as of January 31, 2023:
In the past six months, our team has continued to work towards the completion of all of our project activity goals as we approach the conclusion of the project. We presented work at the meeting of the joint Ecological Society of America and Canadian Society for Ecology and Evolution this summer and the Upper Midwest Invasive Species Conference this fall. For Activity 1, we are building deep learning models that can use the 37 years of archival imagery from Landsat to detect leafy spurge demographic data. Once we have collected all of the data, we will use it to build process-based SDMs of leafy spurge. For Activity 2, we have successfully finished our large field experiment assessing adaptation to climate change in common tansy. This was a large and complicated experiment. It required a lot of dedicated time to harvest and deconstruct without inadvertently introducing common tansy to the study site. We are currently processing all of the data and conducting preliminary analyses for manuscript preparation. For Activity 3, we have completed many of the SDMs and are awaiting results from Activities 1 & 2 to complete the remaining SDMs. For Activity 4, we have completed all of the genetic sequencing work and are preparing two manuscripts on the landscape and population genetics of leafy spurge and common tansy. We plan to submit both manuscripts during winter 2022/23.

Status as of June 30, 2023:
Our team has achieved the majority of the stated goals and outcomes from our initial proposal using cutting-edge species distribution models and genetics to improve predictions of invasive range expansion in leafy spurge and common tansy. In both species, we found substantial genetic and phenotypic evolution that may impact their invasive risk and change future strategic decision making. In the leafy spurge system, we built highly accurate detection models that use publicly available satellite imagery and deep learning algorithms. These models allow for rapid field detection and monitoring as well as better predictive capacity because they 1) generate less biased occurrence records and 2) identify environmental factors that promote leafy spurge invasion. Population genomics and trait variation analysis of leafy spurge revealed that, despite relatively similar genetic variation across the expanding range, there was putatively adaptive evolution in germination dormancy in response to invasive expansion. In the common tansy system, we focused on understanding potentially adaptive genetic and trait variation. We conducted a large common garden experiment with climate manipulations. Data revealed important trait evolution that has occurred during range expansion that may

impact their response to climate change. Landscape genomic analysis of common tansy revealed that there are two distinct genetic clusters in Minnesota that are distinguished by changes in soil features and land usage. For the project, we have produced five major peer-reviewed publications. We are currently working on three additional publications on leafy spurge population genomics, common tansy landscape genomics, and trait evolution in common tansy across Minnesota.

Final Report Summary:
In our project, we used cutting-edge deep learning computer models, large scale field experiments, and genomic analyses to improve predictions of invasive range expansion for the two problematic weeds: leafy spurge and common tansy. In both species, we found substantial genetic and phenotypic evolution that may impact their invasive risk and change future strategic decision making. In the leafy spurge system, we built highly accurate detection models that leveraged publicly available satellite imagery, which allowed us to predict occurrences across large landscapes. Predictions of this magnitude allow for rapid field detection and monitoring as well as the identification of environmental factors that promote leafy spurge invasion. Population genomics and trait analysis of leafy spurge further revealed that, despite relatively similar genetic variation across the expanding range, populations from different regions of the state may have evolved differences in germination niche. In the common tansy system, we focused on understanding potentially adaptive genetic and trait variation using growth chamber experiments and a large common garden experiment with climate manipulations. Data reveal important trait evolution occurred during range expansion which has the potential to impact further invasion and that may influence the response to climate change. Landscape genomic analysis of common tansy revealed that there are two distinct genetic clusters in Minnesota that are distinguished by changes in soil features and land usage.

Sub-Project 16: MITPPC #16: Effects of Puccinia species complex on common buckthorn (*Rhamnus cathartica*)
Project Manager: Pablo Olivera Firpo
Description: Several crown rust fungi (*Puccinia* Series coronata) infect common buckthorn—sometimes severely—but the relative prevalence and their effects on this plant in Minnesota are poorly understood. Our investigation will identify the crown rust fungi that infect common buckthorn in Minnesota, associate disease symptoms and severity with the pathogens, and study their gramineous host range. We will generate the first distribution map of the crown rust species complex and their relative prevalence associated with buckthorn in Minnesota. Identified species will be evaluated for effect on common buckthorn growth suppression via measurements of biomass and mortality at the seedling stage in greenhouse experiments. The most virulent rust species impacting buckthorn, excluding the oat crown rust pathogen, will be evaluated in field conditions. In addition, we will evaluate the effect of crown rust infections on several weedy and invasive grass species in greenhouse conditions. Should our studies prove that rust infection is effective and practical for suppressing common buckthorn, it may find valuable use for land managers in eradication and ecological restoration efforts.

Summary of budget information for sub-project 16 **ENRTF budget:** $26,908 out of budget total of $357,779; expenditures under this appropriation will be completed by 6/30/2023 even though final project outcomes will be achieved at later dates.

Outcome	**Expected completion date**
Outcome 1: Survey of crown rust pathogen on common buckthorn	4/30/2025
Outcome 2: Effects of rust infection and mortality of common buckthorn seedlings	12/31/2025
Outcome 3. Effect *P. coronata* sp infection on quack grass, smooth brome, Ky bluegrass	12/31/2025

Status as of June 30, 2023: Pursuant to previous discussions with LCCMR staff about MITPPC sub-projects, a status report is not due now. The first six months after sub-project approval by LCCMR staff is routinely devoted to project initialization, for example, hiring staff, securing research space, purchasing equipment, etc. Progress will be documented in October 2023 under the ML 2021 appropriation to MITPPC (ML 2021, Subd 6a; Project ID 2020-043). A complete and final accounting of expenditures on this sub-project through 6/30/2023 is provided in the accompanying budget spreadsheet. Funding for the remainder of the sub-project will continue under the ML 2021 appropriation.

Sub-Project 17: MITPPC #17: Studies of entomopathogenic fungi for effective biocontrol of the emerald ash borer, Phase 2
Project Manager: Robert Blanchette
Description: This Phase II proposal will continue to obtain new strains of entomopathogens and further test already selected isolates in laboratory and field evaluations. Previous studies have found fungi that kill the egg stage of EAB and others that attack the larval and adult stages. Additional studies are needed to improve inoculum viability and methods of administering the biological control agents that will keep the entomopathogens alive under field conditions and help disseminate them. Field trials spraying the entomopathogens onto trees as well as using them in auto-contamination traps to deliver entomopathogens to adults will be tested. In addition, injecting trees with entomopathogenic fungi so that they become established as endophytes in ash trees will be tested. The use of fungi to help control EAB would add a new tool for managing this invasive pest. Results from this work will provide important new information and essential data on the interaction of fungi with EAB and ash trees and will help realize a new environmentally safe method of control.

Summary of budget information for sub-project 17 **ENRTF budget:** $33,000 out of total budget of $342,273; expenditures under this appropriation will be completed by 6/30/2023 even though final project outcomes will be achieved at later dates.

Outcome	**Expected completion date**
Outcome 1: Selection and testing of entomopathogens of EAB	6/30/2024
Outcome 2: Enhance field spore viability and field application methods	6/30/2024
Outcome 3: Field testing of entomopathogenic fungi for their biocontrol potential	12/31/2024
Outcome 4: Evaluation of the effect of selected strains on non-target organisms	6/30/2026

Status as of June 30, 2023: Pursuant to previous discussions with LCCMR staff about MITPPC sub-projects, a status report is not due now. The first six months after sub-project approval by LCCMR staff is routinely devoted to project initialization, for example, hiring staff, securing research space, purchasing equipment, etc. Progress will be documented in October 2023 under the ML 2021 appropriation to MITPPC (ML 2021, Subd 6a; Project ID 2020-043). A complete and final accounting of expenditures on this sub-project through 6/30/2023 is provided in the accompanying budget spreadsheet. Funding for the remainder of the sub-project will continue under the ML 2021 appropriation.

Sub-Project 18: MITPPC #18: Incorporating adaptation into forecasts of range shifts with climate change
Project Manager: Ryan Brisco Runquist
Description: Common tansy, *Tanacetum vulgare*, invaded the Upper Midwest in the late 1800s but has had substantially greater impacts on natural plant communities over the last few decades. In addition, land managers have observed recent westward and southward range expansion into warmer and drier habitats. One hypothesis is that adaptation has fueled increases in abundance and range expansion; however, no prior studies have assessed the role of adaptation on the current distribution or responses to climate change. Our ongoing research has shown that phenotypic and DNA sequence variation is geographically-structured across Minnesota, suggesting possible adaptive differentiation during invasion. Here, we propose to use a large reciprocal transplant experiment across Minnesota where temperature and precipitation have been manipulated to simulate future climate. Fitness variation over three years will be used to quantify the spatial scale of local adaptation, the traits that underlie it, and Genetic x Environment interactions in response to climate change. Our results will also be used to build species distribution models that explicitly account for adaptive trait differentiation in order to predict range shifts with climate change. Further, we will determine how genetics and environment, including climate change, contribute to the expression of ecologically-important traits that influence management practices.

Summary of budget information for sub-project 18 **ENRTF budget:** $33,000 out of total budget of $598,107; expenditures under this appropriation will be completed by 6/30/2023 even though final project outcomes will be achieved at later dates.

Outcome	**Expected completion date**
Outcome 1: Quantifying the spatial scale of local adaptation to current and future climate variation	6/30/2026
Outcome 2: Investigate functional traits that confer local adaptation	6/30/2026
Outcome 3: Develop evolutionarily-informed species distribution models to predict range shifts with climate change	6/30/2026

Status as of June 30, 2023: Pursuant to previous discussions with LCCMR staff about MITPPC sub-projects, a status report is not due now. The first six months after sub-project approval by LCCMR staff is routinely devoted to project initialization, for example, hiring staff, securing research space, purchasing equipment, etc. Progress will be documented in October 2023 under the ML 2021 appropriation to MITPPC (ML 2021, Subd 6a; Project ID 2020-043). A complete and final accounting of expenditures on this sub-project through 6/30/2023 is provided in the accompanying budget spreadsheet. Funding for the remainder of the sub-project will continue under the ML 2021 appropriation.

Sub-Project 19: MITPPC #19: Genetic control of invasive insect species: Phase 3
Project Manager: Michael Smanski
Description: Invasive insects place an incredible economic burden on the global economy and have the potential to irreparably damage natural ecosystems. There is a need for new control methods that are species-specific, broadly applicable to diverse invasive organisms, and cost-effective to allow scale-up for control of invasive species on a regional or national scale. With previous funding from MITPPC, we have developed a novel approach to biocontrol for the invasive fly, spotted wing drosophila (SWD, *Drosophila suzukii*), that leverages the latest genetic tools to engineer species-like barriers to reproduction. In this Phase 3 proposal, we will focus research efforts on learning how genetic and behavioral diversity in wild populations of SWD will impact the efficacy of genetic biocontrol. Specifically, we will (i) test for assortative mating behaviors in wild sub-

populations of SWD, (ii) measure the impact of mass-rearing environments on SWD fitness and fecundity, and (iii) perform a techno-economic analysis (TEA) of the genetic biocontrol applications at a regional and national level.

Summary of budget information for sub-project 19 **ENRTF budget:** $50,000 out of budget total of $599,362; expenditures under this appropriation will be completed by 6/30/2023 even though final project outcomes will be achieved at later dates.

Outcome	Expected completion date
Outcome 1: Quantification of assortative mating phenotypes in wild-caught and engineered SWD.	6/30/2026
Outcome 2: Measure the impact of mass-rearing on SWD male competition and female fecundity.	6/30/2026
Outcome 3. Technoeconomic analysis of SWD genetic biocontrol.	6/30/2026

Status as of June 30, 2023: Pursuant to previous discussions with LCCMR staff about MITPPC sub-projects, a status report is not due now. The first six months after sub-project approval by LCCMR staff is routinely devoted to project initialization, for example, hiring staff, securing research space, purchasing equipment, etc. Progress will be documented in October 2023 under the ML 2021 appropriation to MITPPC (ML 2021, Subd 6a; Project ID 2020-043). A complete and final accounting of expenditures on this sub-project through 6/30/2023 is provided in the accompanying budget spreadsheet. Funding for the remainder of the sub-project will continue under the ML 2021 appropriation.

Sub-project 20: MITPPC #20: Making revegetation as part of buckthorn management feasible in Minnesota
Project Manager: Michael Schuster
Description: Previous work funded by MITPPC ('Cover It Up!') has demonstrated that densely-planted native grasses, forbs, trees, and shrubs lower the survival and growth of buckthorn, *Rhamnus cathartica*. We propose three activities that leverage our existing experimental network and forge new partnerships to test ways to make effective revegetation as a part of buckthorn management feasible for many more Minnesota land managers. Activity 1 explores how to implement revegetation in a way that both dampens buckthorn success and meets managers' logistical constraints, by monitoring existing shrub seeding experiments, testing affordable and readily available state and commercial restoration seed mixes in collaboration with the Board of Water and Soil Resources, and identifying minimum effective planting densities of elderberry shrubs in partnership with the Shakopee Mdewakanton Sioux Community. Activity 2 identifies the optimal frequency, timing, and duration of buckthorn stem cutting to better facilitate revegetation and long- term buckthorn control without using herbicides. Activity 3 evaluates the consequences of revegetation for biodiversity of plants and pollinators using existing experiments in order to tailor seed mixes regionally within the state and allow managers to suppress buckthorn without sacrificing support or critical pollinator communities.

Summary of budget information for sub-project 20 **ENRTF budget:** $40,000 out of budget total of $525,000; expenditures under this appropriation will be completed by 6/30/2023 even though final project outcomes will be achieved at later dates.

Outcome	Expected completion date
Outcome 1: Seed mix experiment, site selection, and preparation	12/31/2024

Outcome	Expected completion date
Outcome 2: Revisit and monitor sites	12/31/2025
Outcome 3: Floral survey of Cover It Up! core plots	6/30/2026

Status as of June 30, 2023: Pursuant to previous discussions with LCCMR staff about MITPPC sub-projects, a status report is not due now. The first six months after sub-project approval by LCCMR staff is routinely devoted to project initialization, for example, hiring staff, securing research space, purchasing equipment, etc. Progress will be documented in October 2023 under the ML 2021 appropriation to MITPPC (ML 2021, Subd 6a; Project ID 2020-043). A complete and final accounting of expenditures on this sub-project through 6/30/2023 is provided in the accompanying budget spreadsheet. Funding for the remainder of the sub-project will continue under the ML 2021 appropriation.

IV. DISSEMINATION:

Description: Findings will be shared with agencies and citizen groups so that public information and decision making is based on the best available science. Updates on progress and research results will be disseminated through University of Minnesota, College of Food, Agricultural, and Natural Resource Sciences, and College of Biological Sciences via websites, social media, and publications. Media releases will also be used when warranted. Additionally, findings will be presented at local and national conferences and via peer-reviewed publication and student theses.

Status as of January 31, 2016:
There has been no activity yet under this appropriation. Details on the MITPPC's work may be found in the ML 2014 ENRTF workplan and sub-workplans.

Status as of July 31, 2016:
There has been no activity yet under this appropriation. Details on MITPPC's work to-date, including details of the prioritization process, may be found in the ML 2014 ENRTF workplan and sub-workplans.

Status as of January 31, 2017:
There has been no activity yet under this appropriation. Details on MITPPC's work to-date, including details of the prioritization process, may be found in the ML 2014 ENRTF workplan and sub-workplans.

Status as of July 31, 2017:
For a description of dissemination by the MITPPC on the ML 2014, 2015, and 2016 appropriations may be accessed in the ML 2014 workplan.

Status as of January 31, 2018:
Please note for all future updates under this section: For a description of dissemination by the MITPPC on the ML 2014, 2015, and 2016 appropriations may be accessed in the ML 2014 workplan.

Status as of July 30, 2018:
Please note for all future updates under this section: For a description of dissemination by the MITPPC on the ML 2014, 2015, and 2016 appropriations may be accessed in the ML 2014 workplan.

Status as of January 31, 2019:
Please note for all future updates under this section: For a description of dissemination by the MITPPC on the ML 2014, 2015, and 2016 appropriations may be accessed in the ML 2014 workplan.

Sub-project 1:

- Presentations:
  Katovich, E., R. Becker, M. Marek-Spartz, G. Cortat, H. Hinz, and L. Van Riper. 2018. Biological Control of Garlic Mustard with *Ceutorhynchus scrobicollis*, an Update. Poster at the XV International Symposium on Biological Control of Weeds. Engelberg, Switzerland. Session 1-P22-Target and agent selection. Aug. 26-31, 2018.

  Marek-Spartz, M., and K. Marek-Spartz, G. Heimpel, and R. Becker. 2018. Generations: understanding weed-herbivore interactions using Python. Poster at the XV International Symposium on Biological Control of Weeds. Engelberg, Switzerland. Session 4-P13-Novel methods to determine efficacy and environmental safety of agents. Aug. 26-31, 2018.

  Becker, R., L. Van Riper, R. Montgomery, L. Knosalla, M. Marek- Spartz, J. Katovich, and B. Kinkaid. 2018. Monitoring Garlic Mustard in Minnesota - Now You See Them, Now You Don't. Presentation at the Upper Midwest Invasive Species Conference. Rochester Convention Center, Rochester MN. Oct. 15-18, 2018

  E. Katovich, R. Becker, M. Marek-Spartz, G. Cortat, H. Hinz, and L. Van Riper. 2018. Biological Control of Garlic Mustard with *Ceutorhynchus scrobicollis*, an Update. Poster at the Upper Midwest Invasive Species Conference. Rochester Convention Center, Rochester MN. Oct. 15-18, 2018.

  Marek-Spartz, M., G. Heimpel, R. Becker, and K. Marek-Spartz. 2018. Generations: Understanding Weed-Herbivore Interactions Using Python. Poster at the Upper Midwest Invasive Species Conference. Rochester Convention Center, Rochester MN. Oct. 15-18, 2018.

  Becker, R., L. Van Riper, R. Montgomery, L. Knosalla, M. Marek- Spartz, J. Katovich, and B. Kinkaid. 2018. Monitoring Garlic Mustard in Minnesota - Now You See Them, Now You Don't. Presentation: North Central Weed Science Soc. Hyatt Regency, Milwaukee, WI. Dec. 3–6, 2018. (206)

  Poster: Katovich, E., R. Becker, M. Marek-Spartz, L. Van Riper, G. Cortat, and H. Hinz. Biological Control of Garlic Mustard: No Impact of *Ceutorhynchus scrobicollis* on Two Endangered Brassicaceae. Proc. North Central Weed Science Soc. Hyatt Regency, Milwaukee, WI. Dec. 3–6, 2018. (36)

  Poster: M. Marek-Spartz, K. Marek-Spartz, G. Heimpel, and R. Becker. *Generations*: Understanding Weed- Herbivore Interactions using Python. Proc. North Central Weed Science Soc. Hyatt Regency, Milwaukee, WI. Dec. 3–6, 2018. (34)

- Other dissemination:
  In preparation for regulatory approval to release in North America, voucher specimens for *C. constrictus* and *C. scrobicollis* were accepted to the Canadian National Collection of Insects, Arachnids and Nematodes, Agriculture and Agri-Food Canada, Ottawa, CANADA; the Beaty Centre for Species Discovery, Research and Collections Division, Canadian Museum of Nature, Ottawa, CANADA; the Systematic Entomology Laboratory- ARS, USDA, Smithsonian Institution – National Museum of Natural History, Washington DC, and the Instituto de Biología UNAM, Departamento de Zoologia, Ciudad Universitaria, México.

  Submitted a response to the USFWS on pre-Biological Assessment questions the agency had on our petition for release of C. scrobicollis in North America**:** Becker, R., E. Katovich, M. Marek-Spartz, G. Cortat, H. Hinz, and L. Van Riper. Response to USFSW re: An APHIS authored document derived from "A Petition for the Introduction, Experimental Release and Open-Field Release of the Root-Mining Weevil

Ceutorhynchus scrobicollis (Coleoptera: Curculionidae) for the Biological Control of *Alliaria petiolata* (Garlic Mustard) in North America." August 10, 2018. 16 pp.

Sub-project 2:

- Presentations:
  Smith, Z.M., Chase, K.D., and B.H. Aukema. Competition between mountain pine beetle *Dendroctonus ponderosae* and native Minnesota bark beetles *Ips grandicollis.* The Upper Midwest Invasive Species Conference, Rochester, MN

  Chase, K.D., Abrahamson, M.D., Ambourn, A.K., Vennette, R.C., and B.H. Aukema. Evaluating components of biotic resistance in Minnesota against mountain pine beetle. The Upper Midwest Invasive Species Conference, Rochester, MN

Sub-project 3:

- Publications:
  Kaser, J.M & G.E. Heimpel. 2018 Impact of the parasitoid *Aphelinus certus* on soybean aphid populations. Biological Control 127: 17-24.

  Christianson, L.D.E., C.M. Stenoien, G.E. Heimpel & K.R. Hopper. Laboratory measures as an initial assessment of *Aphelinus* spp. overwintering ability. Poster presentation. The Upper Midwest Invasive Species Conference, Rochester, MN

  Miksanek J.R. & G.E. Heimpel. Understanding the theoretical and ecological influence of the parasitoid *Aphelinus certus* on soybean aphid. The Upper Midwest Invasive Species Conference, Rochester, MN

  Miksanek J.R., G.E. Heimpel & J. Kaser. Infiltration of native prairie habitat by the Asian parasitoid *Aphelinus certus* (Hymenoptera: Aphelinidae). MN. Poster presentation. The Upper Midwest Invasive Species Conference, Rochester, MN

  Stenoien C, Christianson, L., Welch K, Hopper, K.R., & Heimpel G.E. The overwintering biology of *Aphelinus certus*, an adventive parasitoid of soybean aphid. The Upper Midwest Invasive Species Conference, Rochester, MN

  J. Kaser, J. Miksanek & G.E. Heimpel. Cessation of enemy release or continuation of invasion meltdown? The case of soybean aphid and its natural enemies. Invited symposium presentation at the Annual meeting of the Entomological Society of America, Vancouver, Canada.

  C. Stenoien, L. Christianson, K. Welch, K. Hopper & G.E. Heimpel. The overwintering biology of *Aphelinus certus*, an adventive parasitoid of soybean aphid. Oral presentation at the Annual meeting of the Entomological Society of America, Vancouver, Canada.

  Miksanek J.R. & G.E. Heimpel. Evaluating the risks and benefits of *Aphelinus certus*, an introduced enemy of soybean aphid, in North America: Integrating ecosystem-level effects into the decision-making process. IOBC-WPRS Working Group Meeting [Benefits and risks of exotic biological control agents]. Ponta Delgada, Açores, Portugal. September 2018

Sub-project 4:

- Presentations:
  Cira TM, Z Marston, I McRae, RL Koch. Oct 2018. Using drones to detect pests: A soybean aphid case study. Upper Midwest Invasive Species Conference, Rochester, MN

  Bhusal, S, R Koch, A Lorenz. Oct 2018. Advancing host-plant resistance for more sustainable management of soybean aphid. Upper Midwest Invasive Species Conference, Rochester, MN

  Cira TM, Z Marston, I McRae, E Hodgson, RL Koch. Nov 2018. Remote sensing for soybean aphid. Entomological Society of America Annual Meeting.

  Koch, R.L. 2018, December. Soybean aphid management: New challenges posed by insecticide resistance. Manitoba Agronomists Conference, Winnipeg, Manitoba, Canada (35-minute presentation with 380 attendees).

  Koch, R.L. 2018, September. Soybean aphid research and management. Advanced Ag Professional Insect and Disease Workshop. University of Minnesota, Extension. Rosemount, MN (60-minute presentation with 15 attendees).

  Naeve, S. and R.L. Koch. 2018, July. Managing the soybean environment and insect pests to maximize yield. Field School for Agricultural Professionals. Institute for Agricultural Professionals, University of Minnesota Extension. St. Paul, MN (two 120-minute presentations with 25 and 27 attendees).

  Koch, R.L. 2018, July. Soybean insects updates: Insecticide-resistant soybean aphid and Japanese beetles. Agronomy in Action Event, Golden Harvest/Syngenta. Stanton, MN. (45-minute talk with 20 attendees)

  Koch, R.L. 2018, June. Management of insecticide-resistant soybean aphids. Crops Field Day. Southern Research and Outreach Center. Waseca, MN. (30-minute talk with 85 attendees)

Sub-project 5:

- Presentations:
  Mwangola, D.M., Burrington, J.A., Ambourn, A.K., Abrahamson, M.D., and B.H. Aukema. Systemic insecticide treatment against Emerald ash borer: associative protection. Upper Midwest Invasive Species Conference, Rochester, MN
  Mwangola, D.M., and B.H. Aukema. Systemic insecticide treatments against emerald ash borer: Associational protection and potential non-target effects. ESA/ESC/ESBC Joint Annual Meeting Nov 11-14, 2018, Vancouver, BC

  The team met with a property management company and the executive board of a homeowner association at a local community involved with the project, to explain project design and answer questions about how they might expand involvement.

Sub-project 6:

- Presentations:
  Malvick, D. Distribution and Invasive Traits of the Fungal Plant Pathogen Fusarium virguliforme Upper Midwest Invasive Species Conference, Rochester, MN

Sub-project 7:

- Presentations:
  Noyszewski, A.K., N.O. Anderson, A.G. Smith, D. Dalbotten, E. Ito, M. Dockry, A. Timm, and H. Pellerin. 2018. Comparative DNA extraction of historic vs. extant reed canarygrass to determine native/exotic status. Upper Midwest Invasive Species Conference

  Anderson, N.O. 2018. Throwing out the bathwater but keeping the baby. Invasive Plants Research (INPR) Workshop "It's native. Wait! It's exotic…Oh no, It's a nuisance!", Proceedings of the Annual Conference of the American Society for Horticultural Science. Abstract, n.p. [presentation]

  Noyszewski, A.K., N.O. Anderson, A.G. Smith, D. Dalbotten, E. Ito, M. Dockry, A. Timm, and H. Pellerin. 2018. Challenges of establishing native vs. exotic status of reed canary grass herbarium specimens. Invasive Plants Research (INPR) Workshop "It's native. Wait! It's exotic…Oh no, It's a nuisance!", Proceedings of the Annual Conference of the American Society for Horticultural Science. Abstract, n.p. [presentation]

  Noyszewski, A.K., N.O. Anderson, A.G. Smith, D. Dalbotten, E. Ito, A. Timm, and H. Pellerin. 2018. Challenges of establishing native vs. exotic status of reed canary grass herbarium specimens. Floriculture Research Alliance, Annual Meeting, Minneapolis, MN, Oct. 16-17, 2018. Abstract, n.p. [poster]

  Smith, A.G., A.K. Noyszewski, A. Kilian, D. Dalbotten, E. Ito, M. Dockry, A. Timm, H. Pellerin and N.O. Anderson. 2018. Native and exotic reed canarygrass genetic structure and management. Plant Biology 2018, Annual Meeting of the American Society of Plant Biology, 14-18 August 2018, Montreal, Quebec. Abstract, Zone 300, n.p. [poster]

Sub-project 8:

- Presentations:
  "Tylose formation defies expectation: xylem anatomy and response to vascular wilts among temperate oaks". Isabella Armour (presenter), Beth Fallon, Jenny Juzwik, Rebecca Montgomery, Jeannine Cavender-Bares Botany Meeting, Rochester, MN. July 23, 2018.

  "Preserving forest biodiversity: Protection of biodiversity and ecosystem services through early detection of tree disease using hyperspectral remote sensing". Beth Fallon, Cathleen Nguyen, Anna Yang, Isabella Armour, Anna K. Schweiger, John A. Gamon, Hamed Gholizadeh, Jenny Juzwik, Rebecca Montgomery, Jeannine Cavender-Bares (presenter) International Oak Society Meeting, Davis, CA. October 22, 2018

  "Accurate detection of oak wilt (*Bretziella fagacearum*) using airborne imaging spectroscopy". Anna Schweiger (presenter), Cathleen Nguyen, Rebecca Montgomery, Jenny Juzwik, Phil Townsend, John Gamon, Hamed Gholizadeh, Jeannine Cavender-Bares**.** American Geophysical Union, Washington, D.C., December 13, 2018.

  Invited symposium talk, Ecological Society of America, New Orleans, LA. August 8, 2018
  "Detecting and differentiating fungal infection and drought stress in temperate oaks using leaf hyperspectral reflectance." Beth Fallon, Anna Yang, Cathleen Nguyen, Isabella Armour, Anna Schweiger, Jenny Juzwik, Rebecca Montgomery, John Gamon, Phil Townsend**, J**eannine Cavender-Bares (speaker)

  Public science outreach with Market Science (UMn CBS) at Midtown Farmer's Market, August 18. 2018.
  "Oak wilt and other tree killers: what are they and how can we find them?" Beth Fallon

  Minnesota Master Naturalists - West Metro Chapter meeting. September 2018.

Jeannine Cavender-Bares

University of Minnesota Plant Pathology Department, December 3, 2018."Advances in the detection of oak wilt (Bretziella fagacearum) using leaf-level, whole plant and remotely sensed spectroscopy". Beth Fallon, Anna Schweiger, Cathleen Nguyen, Anna Yang, Jenny Juzwik, Rebecca Montgomery, John Gamon, Hamed Gholizedeh, Jeannine Cavender-Bares (speaker)

"Detecting and differentiating fungal infection and drought stress in temperate oaks using leaf hyperspectral reflectance". Beth Fallon (speaker), Anna Yang, Cathleen Nguyen, Isabella Armour, Anna Schweiger, Jenny Juzwik, Rebecca Montgomery, John Gamon, Phil Townsend**,** Jeannine Cavender-Bares**.** Joint Conference of the Upper Midwest Invasive Species Conference and the North American Invasive Species Management Association, Rochester MN, October 16, 2018.

Sub-project 9:

- Presentations:
  Upper Midwest Invasive Species Conference Oct 15-18, 2018. Rochester, MN. Wittman, J.T., Kees, A.M., and B.H. Aukema. Characterizing the movement behavior of gypsy moth (*Lymantria dispar*) caterpillars using a servosphere.

  ESA/ESC/ESBC Joint Annual Meeting Nov 11-14, 2018. Vancouver, BC. Wittman, J.T. and B.H. Aukema. Effects of host foliage on the movement behavior of larvae of gypsy moth *Lymantria dispar.*

- Publications:
  Wittman, J.T. 2018. Effects of host type and food deprivation on the movement behavior of late-instar larvae of gypsy moth *Lymantria dispar* (Lepidoptera: Erebidae). Master's of Science thesis. Department of Entomology, University of Minnesota. Available on-line at: https://conservancy.umn.edu/bitstream/handle/11299/200988/Wittman_umn_0130M_19734.pdf?sequence=1&isAllowed=y (Accessed December 31, 2018).

  Wittman, J.T. and B.H. Aukema. (201x) Foliage type and availability alters the movement behavior of late instar European gypsy moth *Lymantria dispar* (Lepidoptera: Erebidae).*Journal of Insect Behavior* Submitted Nov 22, 2018.

Sub-project 10:

- Presentations
  Matthew Gullickson October 2018: Upper Midwest Invasive Species conference, Rochester, MN. Morphological and behavioral differences in spotted wing drosophila winter and summer morphs.

  University of Minnesota Organic Open House, St. Paul, MN. Integrated pest management for spotted wing drosophila. Presenter: Matthew Gullickson, September 2018: Defending berries against spotted-wing drosophila. (blog post) URL: http://fruit.umn.edu/content/defending-berries-swd

  Anh Tran, Mark Asplen, and Bill Hutchison, October 2018: Upper Midwest Invasive Species conference, Rochester, MN. Lethal and sub-lethal effects of novel insecticides on invasive spotted wing drosophila (*Drosophila suzukii*).

  Matthew Gullickson, Mary Rogers, Eric Burkness, Bill Hutchison, October 2018: Upper Midwest Invasive Species conference, Rochester, MN. Economic impacts of spotted wing drosophila SWD in MN.

  Gigi Digiacomo, November 2018: Entomological Society of America Annual Meeting, Vancouver, Canada. Does size matter? Using body measurements to differentiate *Drosophila suzukii* seasonal morphs. (Oral

presentation)

Anh Tran, Mark Asplen, and Bill Hutchison, November 2018: Entomological Society of America Annual Meeting, Vancouver, Canada. Lethal and sub-lethal effects of novel insecticides on spotted-wing drosophila (*Drosophila suzukii*). (Poster presentation)

Matthew Gullickson, Mary Rogers, Eric Burkness, Bill Hutchison, November 2018: Economic Impact of Spotted Wing Drosophila (Diptera: Drosophilidae)

- Publications:
  Yield Loss on Minnesota Raspberry Farms: A 2017 Grower Survey. *Submitted to*: Journal of Integrated Pest Management. Authors: Gigi Digiacomo, Joleen Hadrich, William Hutchison, Hikaru Peterson, Mary Rogers.

Sub-project 11:

- Presentations:
  Plant ecophysiology field class – Department of Biology – UMD
  Summer field session – Department of Forest Resources – UMN
  Ecology – FDL TCC
  NASP – National Advanced Silviculture Program
  DNR area supervisors meeting
  International students from Nord University – Norway
  University Zurich (September 2018). Oral presentation by Reich (approx. 100 attendees).
  University ETH Zurich (September 2018). Oral presentation by Reich (approx. 60 attendees).
  University of Utah (October 2018). Oral presentation by Reich (approx. 50 attendees).
  Marine Community Library (November 2018). Oral presentation by Reich (approx. 160 attendees).

- Other media
  Media mentions in the fall of 2018 include CFANS, Duluth News Tribune, Phys.org, Inforum.com, MN Daily

Sub-project 12:

- Presentations:
  "Developing robust identification assays for *Amaranthus palmeri* in seed mixtures " presented at an oral session of the Upper Midwest Invasive Species conference on October 15th, 2018

Status as of July 31, 2019:

Sub-project 1:

Findings of this research were presented in Biology, Ecology, and Management of Invasive Plants, AGRO 4505.

Sub-project 2:

Presentations:

Smith, Z.M. and B.H. Aukema. Field responses of mountain pine beetle and *Ips grandicollis* to pheromone baits in a novel sympatric range. Western Forest Insect Work Conference, April 17-20, Anchorage, AK

Sub-project 3:

Publication:

Miksanek, J.R. & G.E. Heimpel. 2019. A matrix model describing host-parasitoid population dynamics: the case of *Aphelinus certus* and soybean aphid. PLoS ONE 14(6): e0218217

Presentations:

6/2019. G.E. Heimpel**.** Biological Control as a Conservation Science. Plenary Address at the Foro BioProtección Vegetal, Valencia, Spain.

6/2019. G.E. Heimpel**.** Biological Control as a Conservation Science. Keynote Address at the International Symposium on Biocontrol and Integrated Pest Management for Crop Protection and Trade Facilitation, Taichung, Taiwan.

Sub-project 4:
Presentations:

- Siddhi J Bhusal presented a poster entitled "Variability of soybean aphid biotypes in Minnesota" at the Soybean Breeders' Workshop 2019 held in Saint Louis, MO on Feb 11-13th, 2019.

Publications:

- Bhusal, S., A. Hanson, A. Lorenz and R.L. Koch. 2019. Updated list of aphid-resistant soybean varieties available for Minnesota. Minnesota Crop News, University of Minnesota Extension. January 15, 2019. https://blog-crop-news.extension.umn.edu/2019/01/updated-list-of-aphid-resistant-soybean.html
- Hanson, A.A., S.J. Bhusal, A. Lorenz and R.L. Koch. 2019. Aphid-resistant soybean varieties for Minnesota. University of Minnesota Extension. https://extension.umn.edu/soybean-variety-selection/aphid-resistant-soybean-varieties-minnesota
- Marston ZPD, TM Cira, EW Hodgson, IV MacRae, RL Koch. [submitted] Detection of stress induced by soybean aphid (Hemiptera: Aphididae) using multispectral imagery from unmanned aerial vehicles. Environ Entomology.

Sub-project 5:
Presentations:

- Brian Aukema - Research update on EAB: The search for associational protection. MDA Regional Outreach Meeting in Detroit Lakes , MN 2/27/2019

Sub-project 6:
Presentations:

- Dean Malvick presented results from this work to agricultural professionals and crop producers at multiple extension education events across Minnesota to about 300 attendees.

Publications:

- An abstract on the distribution of FV was written and submitted to the American Phytopathological Society. It will be published on-line soon and the work will be presented at a conference in Ohio in August.

Sub-project 7*:*
Presentations:

- Noyszewski AK, Anderson NO, Smith AG, Kilian A, Dalboten D, Ito E, A. Timm, Pellerin H. 2019. Distinguishing Among Native vs. Exotic Reed Canarygrass (Phalaris arundinacea) using GBS (DArTseqLD). Plant Animal Genome Conference, 2019, San Diego, CA.

Publications:

- Noyszewski AK, Anderson NO, Smith AG, Kilian A, Dalboten D, Ito E, A. Timm, Pellerin H. 2019. Challenges of Establishing Native Vs. Exotic Status of Herbarium Specimens. *HortTechnology* (accepted).

Sub-project 9:
Project completed

Sub-project 10:
Presentations:

- April 2019. Matt Gullickson (Rogers lab) gave a spark-talk on his research on SWD at the Department of Horticultural Science day-long public outreach event, *Hort Sci Grows* (approx. 50 people in attendance)
- April 2019: Hutchison gave two outreach presentations, "IPM and Research Update for Spotted Wing Drosophila, and other Fruit Insects," to Fruit & Vegetable growers; Little Falls, and Alexandria MN, in collaboration with UMN Extension and Extension Educators at each location (~50 growers attending).
- January 2019: MN Fruit & Vegetable Association annual conference, St. Cloud, MN. Rogers & Gullickson delivered 3 talks in total covering exclusion strategies, holistic management strategies, and economic impacts of SWD on fruit crops (approx. 50 people in attendance)
- January 2019: MN Fruit & Vegetable Growers Assoc. annual conference, St. Cloud, MN. Hutchison's IPM Team participated with a Trade Show booth, for hands-on identification of SWD flies, use of traps for SWD, and free 10X hand lens' to assist growers with identification; specimens and live insects and brochures representing other invasive insect species were also available.

Publications:

- June 2019: Dana D'Amico and Gigi DiGiacomo collaborated to develop an info-graphic targeted at MN fruit growers thanking them for their participation in the electronic and telephone surveys (conducted in 2017 and 2018). Links to recent publications and key "take away" ideas from the surveys were included in the info-graphic. The info-graphic was emailed to the original survey population of 149 MN fruit growers. The open rate for growers was 42% (industry average for "Agriculture and Food Services" is 22%). < https://z.umn.edu/swd-survey>
- May 2019: peer-reviewed publication. DiGiacomo, G., Hadrich, J., Hutchison, W.D., Peterson, H., and Rogers, M. 2019. Economic impact of spotted-wing drosophila-related yield loss on MN raspberry farms: 2017 survey results and estimates. *Journal of Integrated Pest Management.* https://doi.org/10.1093/jipm/pmz006
- May 2019: Hutchison and IPM web coordinator, Suzanne Wold, updated the FruitEdge page, to include weekly SWD trap-catch data for the 2019 season, where growers can track the dates of 1st catch, and the annual build-up in infestations by berry crop group (https://www.fruitedge.umn.edu/swdtrap)
- May 2019: Dana D'Amico assisted the team with a press release related to the release of the DiGiacomo paper referenced above. Title: *New economic research reveals high cost of invasive species for Minnesota-grown raspberries* < https://mitppc.umn.edu/news/high-cost-invasive-species-mn-grown-raspberries>
- April 2019. Matt Gullickson wrote a blog post for the UMN Fruit & Vegetable newsletter. Title: Using high tunnels to protect raspberries from spotted-wing drosophila. < https://blog-fruit-vegetable-ipm.extension.umn.edu/2019/04/author-matthew-gullickson.html>

Sub-project 11:
Presentations:

- Two field classes for students from local Colleges and Universities (FDLTCC – Fond Du Lac Tribal Community College, UMD – University of Minnesota – Duluth) were hosted with total attendance of 21 students plus their instructors,
- A group of 9 international students including three faculty members from Nord University in Norway.
- We engaged in undergraduate research project that will look at the effect of warming and summer rainfall reduction on invasive species mycorrhizal associations.

Sub-project 12:

- Presentations:
  Developing robust identification assays for *Amaranthus palmeri* in seed mixtures. Poster presented at the UMN Palmer Summit, January 22nd 2019.

- Developing robust identification assays for the high impact invasive *Amaranthus palmeri*, seminar given as invited speaker at Colorado State University, April 17th 2019

Publications:

- Work mentioned in Star Tribune article "Invasive weed that threatens corn, soybean crops is spreading in Minnesota" on April 24th 2019

http://www.startribune.com/devastating-invasive-weed-is-spreading-in-minnesota/509009672/

- Created short video New Genetic Test for Palmer Amaranth for use by MITPPC communications. Video is available at: https://youtu.be/k3CinaswUCc

Sub-project 13:

No activity during this period.

Sub-project 14:

No activity during this period.

Status as of January 31, 2020:

Sub-project 1:

Guest Lecture: Findings of this research were presented in Biocontrol ESPM 3015.

Presentation: Mary Marek-Spartz. Making Parasitic Insects Our Friends. Strange Loop 2019, September 12-14, Stifel Theater, St. Louis, MO. Presented the *Generations* model as part of a broader discussion of functional programming and ecology.

Poster: Marek-Spartz, M., G. Heimpel, R. Becker. 2019. Climate match of two biological control agents (*Ceutorhynchus spp.*) prioritized for release to control garlic mustard (*Alliaria petiolata*) in North America. Poster. Entomological Society of America. St. Louis, MO. Nov. 17-20, 2019.

C. scrobicollis and *C. constrictus* voucher specimens accepted to:

Canadian National Collection of Insects, Arachnids and Nematodes
Agriculture and Agri-Food Canada
Ottawa, CANADA

Beaty Centre for Species Discovery
Research and Collections Division
Canadian Museum of Nature
Ottawa, CANADA

Systematic Entomology Laboratory- ARS, USDA
Smithsonian Institution – National Museum of Natural History
Washington DC 20560-0188

Sub-project 2:
Presentations:
Smith, Z.M., Takagi, E., Kees, A.M., Chase, K.D., and B.H. Aukema. Avoidance of *Ips grandicollis* to pheromones of a novel competitor, *Dendroctonus ponderosae.* Entomological Society of America Nov 17-20, St. Louis, MO

Smith, Z.M., Takagi, E., Kees, A.M., Chase, K.D., and B.H. Aukema. The scent of a stranger: semiochemical responses of mountain pine beetle and *Ips grandicollis* in a novel species interaction North Central Forest Pest Workshop Sept 24-27, Lisle, IL
(Zach received second place for this talk)

Sub-project 3:
Publication:
Miksanek, J.R. & G.E. Heimpel. 2019. A matrix model describing host-parasitoid population dynamics: the case of *Aphelinus certus* and soybean aphid. PLoS ONE 14(6): e0218217
Miksanek, J.R & G.E. Heimpel. Density-dependent lifespan and estimation of life expectancy for a parasitoid with implications for population dynamics. Submitted to Oecologia on 22 November, 2019.

Presentations:
6/2019. **G.E. Heimpel.** Biological Control as a Conservation Science. Plenary Address at the Foro BioProtección Vegetal, Valencia, Spain.
6/2019. **G.E. Heimpel.** Biological Control as a Conservation Science. Keynote Address at the International Symposium on Biocontrol and Integrated Pest Management for Crop Protection and Trade Facilitation, Taichung, Taiwan.
9/2019. **G.E. Heimpel**, C.E. Causton, J.R. Miksanek & K.A.G. Wyckhuys. Biological control of aphids (and allies) as a conservation science. Keynote address at Ecology of Aphidophaga 14, Montreal, Canada.
11/2019. **C. Stenoien**. Biological control agents in the off-season: Overwintering biology of Aphelinus spp., parasitoids of soybean aphid. Entomology Department Seminar, University of Minnesota.

11/2019. **C. Stenoien**, J. Miksanik & G.E. Heimpel. Weighing the good and the bad of uninvited biological control agents: A case study with the aphid parasitoid *Aphelinus certus*. Invited workshop presentation at the Annual Meeting of the Entomological Society of America, St. Louis, MO.
11/2019. **J. Dregni**, A. Casigraghi, M. Ferrer Suay & G.E. Heimpel. Hyperparasitoids on soybean aphids in North America: thelytoky in the hyperparasitoid *Alloxysta brevis* cured with antibiotics. Poster presentation at the Annual meeting of the Entomological Society of America, St. Louis, MO.

Sub-project 4:
Publications:
Marston, Z.P.D., T.M. Cira, E.W. Hodgson, J.F. Knight, I.V. MacRae and R.L. Koch. 2020. Detection of stress induced by soybean aphid (Hemiptera: Aphididae) using multispectral imagery from unmanned aerial vehicles. Journal of Economic Entomology 113(x): xx-xx https://doi.org/10.1093/jee/toz306

Presentations:
Koch, R.L. 2019, September. Moving soybean aphid scouting from the ground to the air. Unmanned Aerial Vehicle Symposium. Minnesota Invasive Terrestrial Plants and Pests Center. (30-minute talk with 55 attendees) https://www.youtube.com/watch?v=FBIJ0CPntVE

Koch, R.L.. 2019, July. Management options for insecticide-resistant soybean aphid. Field School for Agricultural Professionals. Institute for Agricultural Professionals, University of Minnesota Extension. St. Paul, MN (three 60-minute presentations with 15, 15 and 20 attendees.)

Sub-project 5:
Presentations:
North Central Forest Pest Workshop Sept 24-27, Lisle, IL. Mwangola, D.M., Burrington, J., Ambourn, A., Abrahamson, M.D., and B.H. Aukema. Show me your friends and I will show you your future: Urban ash trees and EAB.

Entomological Society of America Nov 17-20, St. Louis, MO. Mwangola, D.M., Burrington, J., Ambourn, A., Abrahamson, M.D., and B.H. Aukema. Protecting trees against emerald ash borer: what does it take to be a good neighbour?
(Dora's work was recognized with a 2nd place ranking in the President's Prize competition at the national meeting!)

Sub-project 6:
Presentations:
Poster was presented at the 2019 American Phytopathological Society's Meeting in Ohio titled: "Tracking the distribution and spread of the invasive pathogen Fusarium virguliforme in Minnesota".

Information from this project has been delivered to crop producers, crop consultants, and agribusiness to increase their understanding of risks of SDS and root diseases of other legume crops

Sub-project 7:
Publications:

Anderson, N. O. (2019). Throwing Out the Bathwater But Keeping the Baby: Lessons Learned from Lythrum and Phalaris. *HortTechnology*. [Online Publication Ahead of Print] doi: https://doi.org/10.21273/HORTTECH04307-19 Papers from the Proceedings of 2018 Workshop at the American Soc. for Horticultural Science, Washington DC (2018): Invasive Plants Research Professional Interest Group

Noyszewski, A. K., Anderson, N. O., Smith, A. G., Kilian, A., Dalbotten, D., Ito, E., . . . Pellerin, H. (2019). Challenges of Establishing Native Vs. Exotic Status of Herbarium Specimens. *HortTechnology*. [Online Publication Ahead of Print] doi: https://doi.org/10.21273/HORTTECH04313-19

Presentations:

Anderson, N. O., Noyszewski, A. K., Smith, A. G., Dalbotten, D., Ito, E., Timm, A., & Pellerin, H. (2019)., Modeling genetic structure of reed canarygrass (*Phalaris arundinacea*) along major Minnesota rivers as a guide to identify native and exotic spread. ASPB Conference Proceedings.

Sub-project 8:
Publications:
A manuscript was submitted to *Tree Physiology,* led by former post doc Beth Fallon:
Physiological mechanisms of decline integral to accurate spectroscopic differentiation of oak wilt infection from drought and leaf fungal infection by Fallon, Beth; Yang, Anna; Nguyen, Cathleen; Armour, Isabella; Juzwik, Jennifer; Montgomery, Rebecca; and Cavender-Bares, Jeannine. The manuscript has been reviewed and is currently in revision to be returned to the editor by December 31, 2019.

Presentations:
September 25, 2019, Jeannine Cavender-Bares delivered a presentation on "Prospects and challenges for detection of oak wilt (*Bretziella fagacearum*) using UAVs" at the public symposium on Drones in Invasive Species Management sponsored by the Minnesota Invasive Species Plants & Pests Center.

October 8, 2019, she presented the work “In defense of trees: accurate detection of oak wilt disease and drought in oak forest canopies and seedlings using spectroscopy” as a keynote speaker to an international audience in Finland at the *XI International workshop on sap flow* in Hyytiälä sponsored by the International Society of Horticulturalists (ISH) and the Institute for Atmospheric and Earth System Research and Forest Sciences in the Faculty of Agriculture and Forestry at the University of Helsinki. She will submit a paper for publication in the ISH journal *Acta Horticulturae* on the work.

October 15, 2019, she contributed a presentation from the research team on “Disease detection across scales” at the Smithsonian Environmental Research Center at the GEO BON meeting on Essential Biodiversity Variables and Nature Future Indications for 2020 and Beyond (EBVs 2020). GEO BON is the Group on Earth Observations Biodiversity Observation Network comprised of over 400 scientists, managers and practitioners from over 45 countries whose work is aimed at biodiversity conservation.

December 19, 2019 Cavender-Bares also presented the work “The Application of Satellite Data for Monitoring and Managing Oak Wilt Disease” to the NASA Surface Biology and Geology (SBG) Applications Working Group, a national team of remote sensing scientists working to contribute to the specifications and development of the forthcoming SBG hyperspectral satellite. NASA is developing some publicity for the work that will appear in 2020.

August 26-29, 2019 Juzwik and Paul Castillo provided a Vibratory Plow oak wilt treatment site as part of the Field Tour of Oak Wilt Management in the Upper Midwest, organized by U.S. Forest Service, Forest Health Protection for 30 natural resource professionals from the Midwest and Northeast USA.

Sub-project 10:
Publications:
Gullickson, M. G., Rogers, M. A., Burkness, E. C., & Hutchison, W. D. (2019). Efficacy of organic and conventional insecticides for *Drosophila suzukii* when combined with erythritol, a non-nutritive feeding stimulant. Crop Protection, 125, 104878.

Presentations:
June, 2019. Graduate student Matthew Gullickson presented: Spotted-wing drosophila management for small-scale fruit production and the home garden. Research and outreach presentation at Minnesota Master Gardeners Conference, Chanhassen, MN.

June, 2019. Graduate student Matthew Gullickson presented: Hands-on spotted-wing drosophila and beneficial insect demonstration at Ramsey County Fair. Outreach activity at Ramsey Country Fair, Maplewood, MN.

August, 2019. Graduate student Matthew Gullickson presented: Integrated pest management for spotted-wing drosophila. Research presented at University of Minnesota Organic Open House, St. Paul, MN.

September, 2019. Graduate student Matthew Gullickson presented: Organic research efforts at the University of Minnesota for spotted-wing drosophila management. Research presented at University of Minnesota Organic Open House, St. Paul, MN.

November, 2019. Graduate student Anh Tran presented: Investigating Drosophila suzukii flight behavior with vertical a flight chamber and tethered flight assays. Anh K. Tran, Mark Asplen, and William D. Hutchison. Entomological Society of America conference, St. Louis, MO.

November, 2019. Graduate student Matthew Gullickson presented: Deterrent effects of essential oils on spotted wing drosophila (Drosophila suzukii): Implications for organic management. Matthew Gullickson, Claire Hodge and Mary Rogers. Entomological Society of America conference, St. Louis, MO.

Sub-project 11:
Field presentations visits:

- Two field classes for students from local Colleges and Universities (FDLTCC – Fond Du Lac Tribal Community College, UMD – University of Minnesota – Duluth) were hosted with total attendance of 27 students plus their instructors
- NASP – National Advanced Silviculture Program was hosted with a total attendance of 42 professionals from across the country
- Forest Resource Association group was hosted with a total of 34 professionals attending

Undergraduate and graduate students' independent projects:
We engaged in undergraduate research project that will look at the effect of warming and summer rainfall reduction on invasive species mycorrhizal associations. Currently samples are being analyzed.

Sub-project 12:
Presentations:
*Palmer Amaranth in the Midwest: Herbicide resistance, dispersal vectors, and detection methods***.** Applied Plant Science Seminar at UMN, 12-2-2019

Active presence during regional Palmer Amaranth conference calls every 2 months. (Conference call consists of representatives from government, industry, and scientific researchers.)

Sub-project 13:
Publications:
"Minimizing risk and maximizing spatial transferability: challenges in constructing a useful model of potential suitability for an invasive insect", is in press with the Annals of the Entomological Society of America (Morey & Venette, *in press*. DOI: 10.1093/aesa/saz049). This paper was an invited submission and is part of a Special Issue on emerging technologies for addressing invasive insects.

Presentations:
67th Annual meeting of the Entomological Society of America in November 2019, "Threats to food security: Forecasting risk from invasive insects using MaxEnt". This invited presentation was part of a symposium entitled "Advocating for Entomological Solutions to the Grand Challenge of Global Food Security in the 21st Century".

Sub-project 14:
Presentations:
D. A. Moeller was interviewed by the Pioneer Press as a part of the article on the MITPPC

R. D. Briscoe Runquist met with Chris Klatt from Dakota County Parks about leafy spurge and common tansy populations in Dakota County Parks and in the County

T. M. Lake gave a guest lecture about invasive species and distribution modeling for the UMN class EEB 3001: Ecology and Society

D. A. Moeller and T. M. Lake taught three lab sections about species distribution models for the UMN class PMB3007W: Plant, Algal, and Fungal Diversity and Adaptation

Status as of July 31, 2020:
Sub-project 1:

Katovich EJ, Becker RL, Gerber E, Hinz HL, Cortat G, Reardon, RC. 2019. Lessons learned: rearing the crown-boring weevil, Ceutorhynchus scrobicollis (Coleoptera: Curculionidae), in containment for biological control of garlic mustard (Alliaria petiolata). J. Great Lakes Entomologist. 52 (3-4):78-93.

M. Marek-Spartz, R. Becker, G. Heimpel, E. Katovich. 2020. Petition process and risk assessment for a weed biological control agent of Alliaria petiolata in the United States. Presentation. North Central Branch of the Entomological Society of America. Online (Skirvin Hilton, Oklahoma City, OK March 15-20, 2020 to online April 20-24, 2020 due to CV 19)

Elizabeth Katovich, Roger Becker, Hariet Hinz, Ghislaine Cortat, Laura Van Riper, and Mary Marek-Spartz. Response to USFSW re: An APHIS authored document derived from "A Petition for the Introduction, Experimental Release and Open-Field Release of the Root-Mining Weevil *Ceutorhynchus scrobicollis* (Coleoptera: Curculionidae) for the Biological Control of *Alliaria petiolata* (Garlic Mustard) in North America." Updated February 7 2020 informed by *Streptanthus glandulosus* subsp. *niger* work since the response submitted in August 2018. 56 pp. Submitted Feb. 7, 2020. This was an updated response for USFWS questions on *Ceutorhynchus scrobicollis* for the Biological Control of *Alliaria petiolata* (Garlic Mustard) in North America was submitted to USDA APHIS PPQ with detailed responses to the three original USFWS comments and questions updated with information obtained since the August 2018 response, mainly *Streptanthus glandulosus* subsp. *niger* work conducted over the past year.

Sub-project 2:
No activity

Sub-project 3:
Miksanek, J.R & G.E. Heimpel. 2020 A field-based assessment of the parasitoid *Aphelinus certus* as a biological control agent of soybean aphid in North America. Biological Control 146 (in press but available online): https://doi.org/10.1016/j.biocontrol.2020.104284

Miksanek, J.R & G.E. Heimpel. Density-dependent lifespan and estimation of life expectancy for a parasitoid with implications for population dynamics. Accepted; *Oecologia*.

Sub-project 4:
Marston, Z.P., Cira, T.M., Hodgson, E.W., Knight, J.F., MacRae, I.V. and Koch, R.L., 2020. Detection of stress induced by soybean aphid (Hemiptera: Aphididae) using multispectral imagery from unmanned aerial vehicles. *Journal of Economic Entomology*, *113*(2), pp.779-786. HTTPS://DOI.ORG/10.1093/JEE/TOZ306

Sub-project 5:
The PhD student has been invited to participate in a special session of urban entomology at the upcoming national virtual meeting of the Entomological Society of America in November. We have also submitted an abstract for the Upper Midwest Invasive Species Conference the same month.

We have engaged in focused discussions as well with the cities of Maple Grove and Eagan to retain our study sites as they were inadvertently scheduled for removal. Removals have been delayed until 2021.

Sub-project 6:
No activity

Sub-project 7:
Anderson, N.O., Noyszewski, A. K., Smith, A. G., Dalbotten, D., Ito, E., Timm, A., & Pellerin, H. (2020). Reed Canarygrass: Implications for Control of an Invasive Species When It Is Native. UMISC Conference. Abstract submitted.

Noyszewski, A. K., Anderson, N. O., Smith, A. G., Dalbotten, D., Ito, E., Timm, A., & Pellerin, H. (2020). Regional patterns of reed canarygrass (*Phalaris arundinacea* L.) genetic structure along six major Minnesota rivers change management strategies. UMISC Conference. Abstract submitted.

Sub-project 8:
Publication:
Fallon, B., A. Yang, C. Lapadat, I. Armour, J. Juzwik, R. A. Montgomery, and J. Cavender-Bares. 2020. Spectral differentiation of oak wilt from foliar fungal disease and drought is correlated with physiological changes. *Tree Physiology* 40:377-390.

Presentation:
J. Juzwik, Overview and management of oak wilt. Oak Wilt and Bacterial Leaf Scorch Management Workshop, SEPAC, Purdue University, Butlerville, IN, February 27, 2020.

Sub-project 9:
No activity

Sub-project 10:
January 2020: Hutchison and Rogers co-presented "Managing a menace: SWD & IPM Updates" at the annual Northern Growers and Marketers conference hosted by the MN Fruit & Vegetable Growers Association in St. Cloud, MN.

January 2020: Gullickson (Rogers lab) presented on Spotted Wing Drosophila Management at the annual MN Dept. of Agriculture Organic conference in St. Cloud, MN.

DiGiacomo and Rogers were interviewed by Extension Educator Annie Klodd for a UMN FruitEdge podcast called "What's Killing My Kale?" The 25-minute interview is available as "Episode 5: the economic impact of SWD on the Minnesota berry industry" (https://www.fruitedge.umn.edu/kalepodcast).

Abstract submitted to participate in the 2020 Upper Midwest Invasive Species Conference. Title: Cost-effective organic controls for spotted-wing drosophila: bio-pesticides and high tunnel exclusion

Citation: Tran AK, Hutchison WD, Asplen MK (2020) Morphometric criteria to differentiate *Drosophila suzukii* (Diptera: Drosophilidae) seasonal morphs. PLoS ONE 15(2): e0228780. https://doi.org/10.1371/journal.pone.0228780.

Citation: Gullickson M, Hodge C, Hegeman A, Rogers MA (2020) Deterrent effects of essential oils on spotted-wing drosophila (*Drosophila suzukii*)*:* Implications for organic management in berry crops. Submitted to *Insects*.

Sub-project 11:

Washington Post – Climate Solution written by Brady Dennis "In fast-warming Minnesota, scientists are trying to plant the forests of the future"

Sub-project 12:

Ryan Briscoe Runquist, Scientist Spotlight on MITPPC website.
Uploading occurrence data taken during population surveys via EddMaps and GLEDN

Sub-project 13:

An abstract was submitted to the 2020 Upper Midwest Invasive Species Conference (fall 2020) for an oral presentation entitled, “Making better MaxEnt models for invasive species”, which will present previously MITPPC-funded research. In addition, the Project Lead (Morey) is a co-author on another abstract submitted to the 2020 UMISC, entitled “Prioritizing Minnesota’s Top Terrestrial Invasive Plants & Pests for Research”, which will present information on the MITPPC and its prioritization process.

Status as of January 31, 2021:

Sub-project 1:
Barth, K, R Becker, B Lockhart. 2020. Using Viruses as a Biocontrol on Garlic mustard (*Alliaria petiolata*). UROP Spring Symposium. University of Minnesota. (Poster).

Marek-Spartz ME. 2020. Phenology of *Alliaria petiolata* (garlic mustard) and proposed biological control agents *Ceutorhynchus scrobicollis* and *Ceutorhynchus constrictus* (Curculionidae). News from the Minnesota Invasive Plant and Pests Center, November 2020. Retrieved from < https://mailchi.mp/da2af6e93580/july2020-4582420?e=824f804246 > (Infographic Author)

Marek-Spartz M, RL Becker, GE Heimpel, Lori Knosalla, Mary Marek-Spartz, Rebecca Montgomery. 2020. Garlic mustard monitoring efforts inform a coupled weed-herbivore population model for simulating the release of potential biocontrol agents. Upper Midwest Invasive Species Conference. Rochester Convention Center, Virtual Mtg. due to CV19. (cancelled Duluth, MN). Nov. 2-6. 2020. (Poster).

Katovich ES, RL Becker, G Cortat, H Hinz, L Van Riper and M Marek-Spartz. 2020. An Update: Biological Control of Garlic Mustard with Crown-Boring and Seed-Feeding Weevils. Upper Midwest Invasive Species Conference. Rochester Convention Center, Virtual Mtg. due to CV19. (cancelled Duluth, MN). Nov. 2-6. 2020. (Poster).

Marek-Spartz M, RL Becker, GE Heimpel, Lori Knosalla, Rebecca Montgomery. and L VanRiper. 2020. Garlic mustard monitoring efforts inform a coupled weed-herbivore population model for simulating the release of potential biocontrol agents. Proc. N. Centr. Weed Sci. Soc., Vol. 74. Nov. 30-Dec. 1, 2020. (110). Virtual due to CV19. (cancelled Minneapolis, MN). (Poster).

Katovich ES, RL Becker, G Cortat, H Hinz, L Van Riper and M Marek-Spartz. An Update: Biological Control of Garlic Mustard with Crown-Boring and Seed-Feeding Weevils. Proc. N. Centr. Weed Sci. Soc., Vol. 74. Nov. 30-Dec. 1, 2020. (111). Virtual due to CV19. (cancelled Minneapolis, MN). (Poster).

Marek-Spartz ME, Becker RL, Heimpel GE. 2020. Using Functional Programming to model population interactions between herbivorous biocontrol agents and their target plant. Joint North Central Branch and Southwestern Branch of ESA Meeting. Symposium title: From Molecules to Ecosystems: A Survey of Data Management and Analytical Strategies in Entomological Research. (postponed due to COVID-19).

Sub-project 2:
Smith, Z.M., Chase, K.D., and B.H. Aukema. Assessing the response of the natural enemy complex in the Great Lakes region to pheromones of mountain pine beetle (*Dendroctonus ponderosae*). Entomological Society of America Nov 16-19, Virtual.

Kramer, A.C and B.H. Aukema. Mountain pine beetle dispersal and the predictors of spread. Entomological Society of America Nov 16-19, Virtual

Smith, Z.M. and B.H. Aukema. Native pine engravers avoid pheromones of mountain pine beetle. Upper Midwest Invasive Species Conference Nov 2-6, Virtual.

Sub-project 3:
Publications:
Miksanek, J.R & G.E. Heimpel 2020. Density-dependent lifespan and estimation of life expectancy for a parasitoid with implications for population dynamics. *Oecologia* 194: 311-320.
Monticelli, L., N. Desneux & G.E. Heimpel. Parasitoid-mediated indirect interactions between unsuitable and suitable hosts can generate apparent predation over both short and long time frames. *Ecology & Evolution* in press.
Presentation:
J.R. Miksanek & G.E. Heimpel. 11/2020. The parasitoid *Aphelinus certus* as a biological control agent of the soybean aphid. Upper Midwest Invasive Species Conference; Virtual.

Sub-project 4:

Bhusal, SJ, RL Koch, AJ Lorenz. 2021. Variation in soybean aphid biotypes within fields. Journal of Economic Entomology (accepted pending revisions).

K. Sun and D. Gebre-Egziabher, 2020, "A Two-Stage Affine Estimator for Nonlinear Static Parameter Estimation," AIAA Journal of Guidance, Dynamics and Control (https://doi.org/10.2514/1.G004713)

K. Sun and D. Gebre-Egziabher, 2019 "Observability and Performance Analysis of Model-Free Synthetic Air Data Estimator," AIAA Journal of Aircraft (doi.org/10.2514/1.C035290)

K. Sun and D. Gebre-Egziabher, "Air Data Fault Detection and Isolation for Small UAS using Integrity Monitoring Framework", 2020, in review the Journal of the Institute of Navigation (JION)

Sub-project 5:
Mwangola, D.M., Burrington, J., Ambourn, A., Abrahamson, M.D., and B.H. Aukema. The continued search for associational protection against emerald ash borer. Upper Midwest Invasive Species Conference Nov 2-6, Virtual

Mwangola, D.M., Burrington, J.A., Ambourn, A.K., Abrahamson, M.D., and B.H. Aukema. The search for associational protection in insecticide-treated urban ash in Minnesota (invited in Urban Forestry session organized by K.D. Chase). Entomological Society of America Nov 16-19, Virtual

In addition, we have been in discussion with several partner cities / homeowner associations on the study plans and interim results as they negotiate the continued encroachment of emerald ash borer.

Sub-project 8:
Ecological Society of America, , Aug. 3-6, 2020. Spectral reflectance models predict ecophysiological indicators of oak wilt and drought induced tree decline in red oaks.
Gerard Sapes (presenter), Lucy Schroeder, Jennifer Juzwik, Rebecca A. Montgomery and Jeannine Cavender-Bares.

Joint Conference of the Upper Midwest Invasive Species Conference and the North American Invasive Species Management Association, Rochester MN, November 2, 2020. "Spectral Reflectance Detects Oak Wilt Decline in Oaks at the Landscape Scale" **Gerard Sapes** (presenter), Cathleen Lapadat, Jennifer Juzwik, Rebecca Montgomery, Nanfeng Liu, Phillip Townsend, Jeannine Cavender-Bares

Sub-project 10:
Other outreach: Anh Tran, Skype-A-Scientist, June 22, 2020.
Letters to a Pre-Scientist, ongoing (Tran writes letters and talks about her research with SWD)

Presentation: Tran AK. Migration or Overwintering. CFANS Science in Seconds Competition. October 19, 2020

Presentation: Gullickson, M. G., DiGiacomo, G., Rogers, M. Cost-effective organic controls for spotted-wing drosophila: bio-pesticides and high tunnel exclusion. Upper Midwest Invasive Species Conference virtual research presentation, November 2-6th, 2020.

Presentation: Gullickson, M. G., Hodge, C. F., Riera Vila, I., Rogers, M. Spotted-wing drosophila (*Drosophila suzukii*) host suitability variation between half-high blueberry (*Vaccinium corymbosum*) cultivars. Entomological Society of America virtual graduate student presentation. November 11-31st, 2020.

Presentation: Tran AK., Burkness EC., Hutchison WD., Asplen MK., Rao S., and Rogers MA. Vertical and temporal distribution of *Drosophila suzukii*. 2020 Ten-minute talk, Annual Meeting Entomological Society of America, Virtual. November 11-31st, 2020.

Citation: Gullickson, M., Flavin Hodge, C., Hegeman, A., & Rogers, M. (2020). Deterrent Effects of Essential Oils on Spotted-Wing Drosophila (*Drosophila suzukii*): Implications for Organic Management in Berry Crops. Insects, 11(8), 536.

Citation: DiGiacomo, G., Gullickson, M. G., Rogers, M., Peterson, H., and Hutchison W. (2020). Partial budget analysis of exclusion netting and insecticides for organic management of spotted-wing drosophila (*Drosophila suzukii* (Matsumura)) on small farms in the Upper Midwest. Journal of Economic Entomology (in review).

Sub-project 13:

An oral presentation was given at the 2020 Upper Midwest Invasive Species Conference (Nov. 2020) entitled, "Making better MaxEnt models for invasive species", which presented MITPPC-funded research on species distribution modeling for the European Gypsy Moth. In addition, the Project Lead (Morey) was a co-author on another presentation given at the 2020 UMISC, entitled "Prioritizing Minnesota's Top Terrestrial Invasive Plants & Pests for Research", which presented information on MITPPC and its prioritization process.

Sub-project 14:

- Publication of paper on species distribution modeling (including models of Leafy Spurge and Common Tansy):
  Lake, T. A., Briscoe Runquist, R. D., & Moeller, D. A. (2020). Predicting range expansion of invasive species: Pitfalls and best practices for obtaining biologically realistic projections. *Diversity & Distributions*, *26*(12), 1767–1779.
- Publication of large meta-analysis on local adaptation:
  Briscoe Runquist, R. D., Gorton, A. J., Yoder, J. B., Deacon, N. J., Grossman, J. J., Kothari, S., Lyons, M. P., Sheth, S. N., Tiffin, P., & Moeller, D. A. (2020). Context Dependence of Local Adaptation to Abiotic and Biotic Environments: A Quantitative and Qualitative Synthesis. *American Naturalist*, *195*(3), 412–431.
- Local Adaptation meta-analysis featured in *Proceedings of the National Academy of Sciences: Front Matter Journal Club* (http://blog.pnas.org/2020/03/a-combination-of-living-and-nonliving-selective-forces-drive-local-adaptation-across-species/)
- Manuscript in revision at *Journal of Biogeography*:
  Briscoe Runquist, R. D., Lake, T. A, & Moeller, D. A., Improving predictions of range expansion for invasive species using joint species distribution models and surrogate co-occurring species

- Oral presentation at UMISC: Briscoe Runquist, R. D., “Improving predictions of range expansion for invasive species using joint species distribution models and surrogate co-occurring species”, 3 November 2020
- Poster presentation at UMISC: Lake, T. A. “Predicting range expansion of invasive species: Pitfalls and best practices for obtaining biologically realistic projections” 2-6 November 2020
- Dr. Briscoe Runquist was featured as an expert in an article written by *Popular Science* on the mysterious seed packets sent to people (https://www.popsci.com/story/environment/seeds-mail-advice/)

Status as of July 31, 2021:

Sub-project 1:
Ghislaine Cortat, Hariet L. Hinz, Esther Gerber, Elizabeth Katovich, Roger Becker and Laure Van Riper. 2021. *Ceutorhynchus scrobicollis*, as a potential biocontrol agent of garlic mustard (*Alliaria petiolata*). Presentation to APHIS PPQ TAG April 20, 2021. Virtual due to CV 19.

Mary Marek-Spartz, George Heimpel, Roger Becker. 2021. Using Functional Programming to model population interactions between herbivorous biocontrol agents and their target plant. Presentation at the ESA North Central Branch Meeting. Symposium title: “From Molecules to Ecosystems” June 22, 2021. Virtual due to CV 19.

Sub-project 2:

Publications (in review or submitted)

Smith, Z.M., Chase, K.D., Takagi, E., Kees, A.M., and B.H. Aukema. (202x) Colonization and reproduction of potential competitors with mountain pine beetle in batied logs of a new host for mountain pine beetle, jack pine. *Forest Ecology & Management* In press.

Smith, Z.M., Chase, K.D., and B.H. Aukema. Natural enemy and competitor responses to chemical cues associated with an eruptive herbivore expanding its range. *Oecologia* Submitted 04/08/21.

Presentations
North American Forest Insect Work Conference May 26-28, virtual. Kramer, A.C., and B.H. Aukema. Predictors of mountain pine beetle dispersal in western Montana (student oral presentation)

Sub-project 3:

Monticelli, L., N. Desneux & G.E. Heimpel. 2021. Parasitoid-mediated indirect interactions between unsuitable and suitable hosts can generate apparent predation over both short and long time frames. *Ecology & Evolution* 11:2449-2460.

Heimpel, G.E. and K.A.G. Wyckhuys. *In press*, Biological Control as a Conservation Science. In P. Mason, editor, Biological Control: A Global Endeavor, CSIRO Press.

Calvo-Agudo, M., Dregni, J.S., González-Cabrera, J., Dicke, M., Heimpel, G.E., Tena, A., Neonicotinoids from coated seeds toxic for honeydew-feeding biological control agents. *Environmental Pollution*; Accepted pending revisions.

Casiraghi, A., J.S. Dregni, N.P. Hidalgo, J. Kaser, G.E. Heimpel, J. Selfa & M. Ferrer-Suay. Brachyptery analysis in ALLOXYSTA (Hymenoptera: Figitidae): synonymy of A. CURTA as the brachypterous male of A. RAMULIFERA in the Nearctic. Submitted to *Proceedings of the Washington Entomological Society*.

Presentation

2/2021: G.E. Heimpel. Biological control of soybean aphid: the parasitoid *Aphelinus certus*. Invited Symposium Presentation: Soybean Breeders Conference (Feb. 22 – 24, 2021; virtual)

Sub-project 4:

Koch, R.L. 2021, January. Advancing remote sensing for soybean aphid. Research Updates for Agricultural Professionals, Institute for Agricultural Professionals, University of Minnesota Extension. (30-minute presentation for southern, northern and central Minnesota with 45, 52 and 57 attendees)

Koch, R.L. 2021, January. Remote sensing for soybean aphid. Minnesota Ag Expo. (8-minute video presentation)

Koch, R.L. 2020, December. Soybean aphid update: Can remote sensing improve scouting? Prairie Grains Conference. (20-minute presentation with 253 attendees). https://youtu.be/R5LtXBDwhj0

Sub-project 5:
North American Forest Insect Work Conference May 26-28, virtual. **Mwangola, D.M.**, and B.H. Aukema. The search for associational protection in urban forests treating for emerald ash borer (oral presentation).

Sub-project 6:

Presentations (7) were given to soybean growers and agricultural professionals around the state of Minnesota via a series of on-line webinars and other Extension educational events that highlighted key outcomes of this project.

Sub-project 10:
Viau, S. *Essential oils: exploring a health craze as a pesticide alternative for Minnesota berries.* News article on University of Minnesota College of Food, Agriculture, and Natural Resource Sciences website < https://cfans.umn.edu/news/pesticide-alternative-essential-oils-berries> May 18, 2021

Gullickson, M. G. Insect repellents for berries: Can spraying essential oils protect ripening berries from invasive spotted-wing drosophila? Fruit Extension blog article. https://fruit.umn.edu/news/insect-repellents-berries April 2021.

Gullickson, M. G. Chemical ecology of spotted-wing drosophila: Behavioral responses to olfactory stimuli and implications for organic pest management. Applied Plant Sciences Seminar Series, University of Minnesota. March 2021. Attendees: 28

Gullickson, M. G., Rogers, M. Field implementation of botanical deterrents for organic management of spotted-wing drosophila. Virtual poster presentation at Growing Stronger Virtual Conference. Awarded second place in the poster competition. Feb. 2021.

Shanovich, H., Gullickson, M. G., Toninato, A., Rogers, M. Invasive insects in organic fruit. Panel discussion at the Growing Stronger Virtual Conference. Feb. 2021. Attendees: 83

Rogers, M. Spotted-wing drosophila management: what works, what doesn't, and new things to try. Virtual presentation at MN Fruit and Vegetable Growers Association conference. Jan. 2021. Attendees: 43

Sub-project 14:
Publication of "Improving predictions of range expansion for invasive species using joint species distribution models and surrogate co-occurring species" in Journal of Biogeography

- Invited Seminar at Duke University, University Program in Ecology, Durham, NC by D. Moeller titled "The dynamics of species' geographic ranges: ecological and evolutionary perspectives" in January 2021.

Status as of January 31, 2022:

Sub-project 2:

- Presentations:
    - IUFRO 7.03.12, 7.03.07, 8.02.04 Biological Invasions of Forests Sept 20-24, 2021, Prague, CZ. Aukema, B.H., Smith, Z.M., and Chase, K.D. Invasion potential of mountain pine beetle to forests of the Great Lakes region
    - Sustainable Forestry Education Cooperative, Sept 14, 2021, Virtual. Webinar: Invasion potential of mountain pine beetle to forests of the Lake States. 55 attendees.
- Publication:
    - Smith, Z.M., Chase, K.D., Takagi, E., Kees, A.M., and B.H. Aukema. 2021. Colonization and reproduction of potential competitors with mountain pine beetle in batied logs of a new host for mountain pine beetle, jack pine. *Forest Ecology & Management* 497: 119455

Sub-project 3:

- Presentations planned for 2022:
    - Dregni, J.S., P. Cediel-Rueda, J.R. Miksanek, K. Welch, J. Kaser, R. Koch, G.E. Heimpel. 3/2022. Parasitism of soybean aphid by *Aphelinus certus* in Minnesota 2011 to 2021. Annual meeting of the North Central Branch, Entomological Society of America. Poster presentation.
    - Heimpel, G.E., J.S. Dregni. 3/2022. Biological control of soybean aphid using parasitoids. University of Minnesota Extension, webinar presentation.
- Publications related to the proposal but not directly addressing the objectives (MITTPC is acknowledged):
    - Calvo-Agudo, M., Dregni, J.S., González-Cabrera, J., Dicke, M., Heimpel, G.E., Tena, A., 2021. Neonicotinoids from coated seeds toxic for honeydew-feeding biological control agents. *Environmental Pollution* 289: 117813.
    - Casiraghi, A., J.S. Dregni, N.P. Hidalgo, J. Kaser, G.E. Heimpel, J. Selfa & M. Ferrer-Suay. Brachyptery analysis in *Aloxysta* (Hymenoptera: Figitidae): synonymy of A. CURTA as the brachypterous male of *A. ramulifera* in the Nearctic. *Proceedings of the Washington Entomological Society*; In press.
    - Stenoien C.M, L. Christianson, K. Welch, J.S. Dregni, J.R. Miksanek, K.R. Hopper & G.E. Heimpel. Cold tolerance and overwintering survival of *Aphelinus certus* (Hymenoptera: Aphelinidae) a parasitoid the soybean aphid (Hemiptera: Aphididae) in North America. In preparation for Environmental Entomology

Sub-project 4:

- Presentations
    - Ribeiro, A.V., R.L. Koch and B Potter. 2021, December. Soybean insect research update. Prairie Grains Conference. Grand Forks, ND

- Ribeiro, A.V., T. Cira, R. Miller, L. Benhken, I.V. MacRae and R.L. Koch. 2021, October. Impacts of soybean aphid and Japanese beetle or artificial defoliation on spectral reflectance of soybean canopies. 10-minute presentation. Meeting of the Entomological Society of America. Denver, CO.
- K Sun "Air Data Fault Detection and Isolation for Small UAS using Integrity Monitoring Framework", Webinar Presentation (https://www.ion.org/publications/abstract.cfm?articleID=102925)

- Publications
  - K. Sun and D. Gebre-Egziabher, "Air Data Fault Detection and Isolation for Small UAS using Integrity Monitoring Framework", (2021), *Journal of the Institute of Navigation (JION)* Volume 68(3), pp. 577 – 600 (https://doi.org/10.1002/navi.440*)*

Sub-project 5:

- Presentations
  - IUFRO 7.03.12, 7.03.07, 8.02.04 Biological Invasions of Forests Sept 20-24, 2021. Prague, CZ. Mwangola, D.M., Kees, A.M., Grosman, D.M., and B.H. Aukema. Preservation of urban canopies of ash trees using insecticide strategies to induce associational protection in Minnesota, USA [Note: project funds were not used for this presentation, as it involved international travel]
  - Entomological Society of America Oct 31 - Nov 3, 2021. Denver, CO. Mwangola, D.M. and B.H. Aukema. Injecting a subset of trees confers wider protection against increasing populations of emerald ash borer

Sub-project 11:

- Publications (submitted and in preparation)
  - "Stomatal behavior moderates water cost of CO_2 acquisition for 21 boreal- temperate and invasive species under experimental climate change"
  - "Spread rates of invasive common buckthorn and honeysuckle" (70% complete).
  - "Future climate favor nonnative species carbon assimilation rate and length of growing season over native boreal species" (drafting)
  - "Woody invader and native tree responses to climate - Growth & survival" (beginning drafting)

Status as of July 31, 2022:

Sub-project 14:
Publication: "Deep learning detects invasive plant species across complex landscapes using Worldview-2 and Planetscope satellite imagery" in the journal Remote Sensing in Ecology and Conservation

Google Cloud Research Credit program has granted us $1800 in research credits and another application has been elevated to consideration for their Climate Change Initiative Challenge program.

Sub-project 15:
Outreach related to the species prioritization process (Activity 2)
- Dr. Morey will present at the annual meeting of the North American Invasive Species Management Association in the fall 2022. The presentation will summarize MITPPC's species prioritization process.
- Dr. Morey was interviewed by the University of Minnesota regarding terrestrial invasive species and the species prioritization process used by MITPPC (https://twin-cities.umn.edu/news-events/talking-invasive-species-u-m)
- Dr. Morey continues individual conversations with stakeholders regarding the prioritized species and evaluation process

Outreach related to species distribution modelling and terrestrial invasive species (Activity 3).

- Dr. Morey gave a research presentation at the North Central Branch of the Entomological Society in the spring of 2022 showing preliminary modeling results for two insect species.
- An abstract was accepted for the 2022 Upper Midwest Invasive Species Conference that will highlight additional modelling progress for the invasive wasp, *Vespa mandarinia*, in fall 2022.

Status as of January 31, 2023:

Sub-project 14:
UMISC Presentations:
Landscape genetics of common tansy in Minnesota reveal two genetic clusters with distinct environmental tolerances (Ryan)
Deep learning detects invasive plant species across complex landscapes using Worldview-2 and Planetscope Satellite imagery (Tom)

Ecological Society of America - Montreal Presentation:
Deep learning detects invasive plant species across complex landscapes using Worldview-2 and Planetscope Satellite imagery (Tom)

UMN American Society of Photogrammetry and Remote Sensing Student Chapter Presentation:
Time series classification with convolutional neural networks (Tom)

Status as of June 30, 2023:

Sub-project 14:
New Collaborators:
- Lex Flagel, Gencove; Leafy spurge genomics
- Debalin Sarangi & Datta Chiruvelli, CFANS; Species distribution models
- Theresa Chen, Knowledge Computing Lab, CSE; Remote sensing of invasive species

- UMN Research and Outreach Centers (ROC):
  - St. Paul Experimental Station, St. Paul, MN
  - Southwest ROC, Lamberton, MN
- Cloquet Forestry Center in collaboration with the Fond Du Lac Band
- Minnesota State University, Moorhead, Science Outreach Center, Glyndon, MN

Final Report Summary:
MITPPC emphasized the dissemination of findings. MITPPC teams published results in 49 peer-reviewed articles in high-impact journals, such as the Journal of Integrated Pest Management, PLoS One, Ecology and the Environment, HortTechnology, and the Journal of Economic Entomology. Research teams brought their research directly to interested parties through over 170 presentations. Additionally, MITPPC, the College of Food, Agriculture, and Natural Resource Sciences, and the University of Minnesota amplified communications through a variety of internal publications and social media (Twitter, website, YouTube channel) which also garnered significant interest in the local media.

VI. PROJECT BUDGET SUMMARY:

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: More detail to be provided as specific research projects are proposed (if applicable)

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 42

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: None

B. Other Funds:

SOURCE OF AND USE OF OTHER FUNDS	Amount Proposed	Amount Spent	Status and Timeframe
Other Non-State $ To Be Applied To Project During Project Period:			
Minnesota Soybean Research and Promotion Council	$30,000	$30,000	Funds used to co-support MITPPC Sub-Project 4: Decreasing environmental impacts of soybean aphid management
Other State $ To Be Applied To Project During Project Period:			
General Fund Appropriation ML 2014, Chapter 312, Article 12, Section 8	$3,400,000	$572,876	Funds will be used to support the core operations and leadership of the Minnesota Invasive Terrestrial Plants and Pests Center by a Center Director and administrative support for the 8-year project period. This includes funding for est. 2 additional research projects, personnel costs (faculty, graduate students, postdoctoral associates), equipment, materials and supplies necessary for research. Each project is estimated at $180-210K/year for 3-4 years. 6/30/22
Past and Current ENRTF Appropriation:			
ML 2014, Chapter 312, Article 12, Section 8	$1,460,000	$678,743	Funds will be used to convene expert panel to create a framework and conduct initial assessment to establish highest priority species; convene expert panel annually in years 2 and 3 to assess net impacts of invasive species and control responses; and support 2-3 research projects (at $180-$210K/year for 3-5 years). 6/30/22
ML 2016, Chapter 186, Article Section 2, Subd. 6a	$3,750,000	$0	Funds will be used to conduct research to prevent, minimize, and mitigate the threats and impacts posed by terrestrial

SOURCE OF AND USE OF OTHER FUNDS	Amount Proposed	Amount Spent	Status and Timeframe
			invasive plants, pathogens, and pests to the state's prairies, forests, wetlands, and agricultural resources. 6/30/23
Institute on the Environment, UMN	$2,840	$2,840	Funds will be used to convene a panel to discuss to discuss the relationships between soybean aphids, an invasive species, soybean production, and the effects of pesticides on the Dakota skipper and other insect populations. 6/30/18
Other Funding History:			
	$	$	

VI. PROJECT PARTNERS:

A. Partners receiving ENRTF funding

Name	Title	Affiliation	Role
N/A			

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role

B. Project Partners (not receiving funds):

- USDA Forest Service Northern Research Station
- Minnesota Department of Agriculture
- Minnesota Department of Natural Resources
- Minnesota Forest Resource Council

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The Center's ultimate goal is to eliminate, reduce, mitigate or prevent the introduction, expansion or damage done by terrestrial invasive species in Minnesota. Metrics of success include: threat awareness, response efficiency, control effectiveness, non-target species protection, and mitigation strategies. Ancillary goals include: workforce development, citizen engagement, focused research strategies, improved response time to emerging threats, and improved coordination of efforts.

Success will depend on the ability to marshal multi-disciplinary teams in timely and prioritized ways to deliver results. While M.L. 2014 ENRTF and General Fund dollars will be used to conduct a risk assessment and launch initial research or prioritized species, funding is being sought through the M.L 2015 ENRTF request to support additional multi-disciplinary research teams. With adequate funding, the Center's efforts are expected to result in numerous, effective prevention and control methods within an eight year time frame for a significant portion of the 15-20 species upon which we will focus.

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 31 and July 31 of each year (every 6 months). A final report and associated products will be submitted between June 30 and August 15, 2023. Final summaries and abstracts for each subproject will be submitted roughly 45 days after project completion, however, may be submitted later in order to better synch with overall reporting dates.

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet
D. Acquisition, Easements, and Restoration Requirements
E. Research Addendum

X. RESEARCH ADDENDUM: A research addendum was developed after a panel of researchers from the University of Minnesota provided competitive reviews of the pre-proposals under this appropriation. The addendum was distributed to relevant experts outside the University of Minnesota and reviewed for scientific novelty, appropriateness of methods, qualifications of the research team, and potential impact on invasive species management. The research addendums were modified as necessary in response to comments received during the peer-review process. The final documents provide a technically detailed description of the research to be completed under this sub-project work plan. The research addendums are on file with the Minnesota Invasive Terrestrial Plant and Pest Center**.**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Pests and Plants Center-- Sub Project List FINAL
Legal Citation: ML 2015, Ch. 76, Art. 2, Sec. 6a
Project Manager: Robert Venette
Project Title: Minnesota Invasive Terrestrial Plants and Pests Center, Ph. 2
Organization: University of Minnesota
College/Department/Division: College of Food, Agriculture, and Natural Resource Sciences
Project Budget: $5,000,000
Project Length and Completion Date: 8 years, June 30, 2023
Current Date: August 8, 2023

Sub Project #	Species	Project Manager	Original budget^1	Revised Budget [08-08-2023]	Amount Spent	Balance	Status
reserve				$10,974	$0	$10,974	
1	Garlic mustard	Roger Becker	$600,000	$600,000	$600,000	$0	Complete
2	Mountain pine beetle	Brian Aukema	$456,000	$444,982	$444,982	$0	Complete
3	Soybean aphid	George Heimpel	$590,390	$479,859	$479,859	$0	Complete
4	Soybean aphid	Robert Koch	$570,000	$570,000	$570,000	$0	Complete
5	Emerald ash borer	Brian Aukema	$320,000	$318,927	$318,927	$0	Complete
6	Sudden soybean death	Dean Malvick	$412,000	$383,651	$383,651	$0	Complete
7	Reed canary grass	Neil O Anderson	$268,000	$263,273	$263,273	$0	Complete
8	Oak wilt	Jeannine Cavender-	$357,420	$356,382	$356,382	$0	Complete
9	Gypsy moth	Brian Aukema	$35,000	$35,000	$35,000	$0	Complete
10	Spotted wing drosophila	Mary Rogers	$505,000	$477,541	$477,541	$0	Complete
11	Common& glossy buckthorn, Morrow's &tatarian honeysuckle	Peter Reich	$526,000	$526,000	$526,000	$0	Complete
12	Palmer amaranth	Donald Wyse	$208,230	$208,230	$208,230	$0	Complete
13	46 TIS TBD	Amy Morey	$71,461	$71,461	$71,461	$0	Complete
14	Leafy spurge and common tansy	David Moeller & Ryan B. Runquist	$70,812	$70,812	$70,812	$0	Complete. See also M.L. 2016, Chp. 186, Sec. 2, Subd. 06a, Sub-project #7
15	TIS TBD	Amy Morey	$92,141	$0	$0	$0	Complete
16	Puccinia ssp, buckthorn	Pablo Olivera Firpo		$26,908	$26,908	$0	Complete under this appropriation. The remainder of the work continues under M.L. 2021, First Special Session, Ch 6, Art 5, Subd 6a, Sub-project #2
17	EAB	Robert Blanchette		$33,000	$33,000	$0	Complete under this appropriation. The remainder of the work continues under M.L. 2021, First Special Session, Ch 6, Art 5, Subd 6a, Sub-project #7
18	Common Tansy	Ryan Briscoe Runquist		$33,000	$33,000	$0	Complete under this appropriation. The remainder of the work continues under M.L. 2021, First Special Session, Ch 6, Art 5, Subd 6a, Sub-project #6
19	Spotted wing drosophila	Michael Smanski		$50,000	$50,000	$0	Complete under this appropriation. The remainder of the work continues under M.L. 2021, First Special Session, Ch 6, Art 5, Subd 6a, Sub-project #5
20	Buckthorn	Michael Schuster		$40,000	$40,000	$0	Complete under this appropriation. The remainder of the work continues under M.L. 2021, First Special Session, Ch 6, Art 5, Subd 6a, Sub-project #10
TOTAL			**$5,082,454**	**$5,000,000**	**$4,989,026**	**$10,974**	

^1, "Original budget" reflects the amount that was awarded to each sub-project when it was first established. Some sub-projects were established with savings from other sub-projects that had closed earlier. Thus, the total of this column will exceed $5,000,000

** Revised budget for previously submitted final report

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #1: Garlic Mustard Biocontrol: Ecological Host Range of Biocontrol Agents.
Legal Citation: ML 2015, Ch. 76. Art. 2, Sec. 6a
Sub-Project Manager: Roger Becker
Organization: University of Minnesota
Sub-Project Budget: **$**600,000
Sub-Project Length and Completion Date: 4.5 Years, June 30, 2021
Current Date: December 8, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits) Overall	$476,641	$476,641	$0
Salary - 1- PhD FTE/yr. for 3.5 yrs. (1 student stipend + $18,419/yr. Tuition/Benefits fringe + 3% inflation/yr.) = **$149,760 total.**			
Salary - Civil Service. 1.1 FTE/yr. for 4 yrs. (salary + fringe + 3% inflation for a composite of 3 personnel/yr.) = **$319,797 total.**			
Salary - Student Labor $11.50/hr. for 840 hr./yr. for 4 yrs. (full time summer, 1/4 time school year + 3% inflation adj./yr.) = **$40,414 total.**			
Professional/Technical/Service Contracts			
(General Operating Services and Short Term Rents). University of Minnesota watering charges and other service charges for greenhouse and field space (est. $600/yr.). Charges from a qualified carrier for insect APHIS permitted shipment, most recently OPTIMIZE Courier. Est. 5 shipments at $1500/per shipment - (ACTUAL COSTS TO COMPLY WITH REGULATORY REQUIREMENTS) from CABI Delémont Switzerland. Est. 2 scrobicollis and 3 constrictus over course of the grant. $300 ArcGIS annual license via U of MN. Together, plus anticipated $300 incidentals is $3700/yr. Totals $13,936. University of Minnesota greenhouse, containment facility and field space rental fees initially an est. $1200 per month. Yr. 3,4 decrease as C. scrobicollis need for quarantine space decreases. As budgeted, years 3 and 4 are not fully funded to meet $600,000 limit. Totals $33,160.	$70,582	$70,582	$0
Subcontract $8,000 per year plus 3% inflation for CABI, Delémont, Switzerland to conduct specificity testing we can not do in a quarantine facility such as choice tests outdoors, travel and labor to collect insects for shipment to quarantine in Minnesota. CABI conducts work that can not be conducted in Minnesota as we must be in a quarantine facility. CABI at Delémont has been involved from the beginning of this project and are capable, knowledgeable, experienced in biological control of garlic mustard.	$45,469	$45,469	$0
Equipment/Tools/Supplies			
Temperature probes, Garmin Monterra GPS navigator (est. $600), field supplies: flags, netting, stakes, pots, potting medium, etc.	$4,558	$4,558	$0
Travel expenses in Minnesota			
Covers 80% of est. travel to monitoring site research plots @ $0.54/ mile, 10 sites twice a year for	$2,750	$2,750	$0
COLUMN TOTAL	**$600,000**	**$600,000**	**$0**

~~$429,827 Returned to MITPPC reserve for ML 2015~~
$0 returned to MITPPC reserve for ML 2015

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #2: Mountain Pine Beetle Phase II: Protecting Minnesota
Legal Citation: M.L. 2015, Chp.76, Sec.2, Subd. 6a
Sub-Project Manager: Brian Aukema
Organization: University of Minnesota
Sub-Project Budget: $444,982
Sub-Project Length and Completion Date: 4.8 Years, December 31, 2021
Current Date: December 8, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits) - Total	$403,813	$403,813	$0
One postdoc, 4 years, $48,080 (22.4% fringe) indexed at 2.5% increase annually One 10% graduate summer student, Blanchette lab, to help with Activity 3 for 2 yrs ($1,342) Undergrad summer help, base $8,960 with 2.5% increases, 2 per year except year 4 (1) Faculty time, maximum of 3 pay periods each summer four years, total $58,480 + 33.4% benefits.			
Faculty time, maximum of 3 pay periods each summer four years, total $58,480 + 33.4% benefits.			
One postdoc, 4 years, $48,080 (22.4% benefits) indexed at 2.5% increase annually			
One 10% graduate summer student (17.6% benefits), Blanchette lab, to help with Activity 3 for 2 yrs ($1,342)			
Undergrad summer help (0% benefits) , base $8,960 with 2.5% increases, 2 per year except year 4 (1)			
Professional/Technical Services and Contracts - Total			
Wheaton College Science Station rental (similar to Phase I funded by LCCMR) - 4 yrs x $1500, Quarentine Lab Facility rental - 3yrs x $2850			
Wheaton College Science Station	$6,000	$6,000	$0
Quarentine Lab Facility at UMN	$5,205	$5,205	$0
Equipment/Tools/Supplies - Total			
Lures, traps, chemical standards, t-posts, insect rearing supplies, industrial cardboard tubes, safety equipment, scaffolding. Estimated between $5,340-$10,650 per year, with most expenses in Year 1 for Activities 1 and 2.			
Supplies- Lab and/or Field: [List out description/details]	$15,505	$15,505	$0
Printing - Total			
Printing of project reports and testing plans	$1,657	$1,657	$0
Travel - Total			
Rental of truck at Fleet rates each year, although lab truck will be assigned to project as possible to reduce expenses. Includes per diems and lodging along survey routes (Activities 1 & 2). Similar to phase I, much work on the insect will occur outside of the state to avoid introductions to MN.	$10,331	$10,331	$0
Travel in state	$1,204	$1,204	$0
Travel out of state	$1,204	$1,204	$0
Shipping - Total			
Shipping insects and lures between field sites	$63	$63	$0
COLUMN TOTAL	**$444,982**	**$444,982**	**$0**

$11,018 returned to ML 2015 reserve

Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC)
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #3: Biological control of the soybean aphid by *Aphelinus certus*
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: George Heimpel
Organization: University of Minnesota
Sub-Project Budget: $479,859
Sub-Project Length and Completion Date: 4 Years, September 30, 2021
Current Date: February 15, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$414,332	$414,332	$0
James Miksanek, PhD student: $145,300 (52% salary, 48% fringe); 50% FTE each year for 4 years.			
Kelton Welch & Carl Stenoien; Post-doctoral Associates: $253,109 (83% salary, 17% benefits); 100% FTE each year for 4 years.			
Undergraduate Research Assistants: $80,687 (96% salary, 4% benefits); 35% FTE each year for 4 years			
Civil Service salary, fringe: $11,891			
Professional/Technical/Service Contracts			
Contract with Minnesota Dept. of Ag. $12,000 in year 1 with 3% increases. Activity 3	$10,750	$10,750	$0
Greenhouse, growth chamber, plot fee charges;	$22,025	$22,025	$0
Equipment/Tools/Supplies			
Materials to construct field cages, vials and other storage supplies for laboratory work, insect traps. Total: $24,215 split evenly over activities 1, 2 and 4.	$12,194	$12,194	$0
Printing			
Printing extension materials; total $1,000 split evenly over all activities	$1,000	$1,000	$0
Publishing fees for open access; total $4,000 split evenly over all activities	$5,489	$5,489	$0
Travel			
Travel to and from field sites: vehicle rental and/or mileage, lodging: $6K per year for Activity 1.	$14,069	$14,069	$0
Travel to and from meetings and field days in Minnesota; $1K split evenly for all 4 activities.	$0	$0	$0
COLUMN TOTAL	**$479,859**	**$479,859**	**$0**

$110,431 returned to ML 2015 reserve

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC)
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #4: Decreasing environmental impacts of soybean aphid management
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Dr. Robert Koch
Organization: University of Minnesota
Sub-Project Budget: $570,000
Sub-Project Length and Completion Date: 4 Years, December 31, 2021
Current Date: February 15, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits) Total	$538,211	$538,211	$0
Robert Koch, Project Manager [summer salary]: $25,318 (75% salary, 25% fringe; calculation assumes 3% annual salary increase); 5% FTE each year for 4 years			
2 Graduate Research Assistants: $364,256 (57% salary, 43% tuition and fringe; calculation assumes 3% annual salary increase); 50% FTE each year for 4 years			
Post-Doctoral Research Associate: $149,932 (82% salary, 18% fringe; calculation assumes 3% annual salary increase); 62% FTE each year for 4 years			
Equipment/Tools/Supplies Total			
RTK capalbe OEM GPS receivers and associated peripherals to support installation	$3,494	$3,494	$0
reagents and supplies for molecular marker assays	$0	$0	$0
Travel expenses in Minnesota Total			
Travel to field research sites (vehicle rental/lease)	$19,324	$19,324	$0
Other Total			
rental of field plot, greenhouse, growth chamber space	$8,971	$8,971	$0
COLUMN TOTAL	**$570,000**	**$570,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #5: Optimizing tree injections against emerald ash borer
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Brian Aukema
Organization: University of Minnesota
Sub-Project Budget: $318,927
Sub-Project Length and Completion Date: 4.75 years, December 31, 2021
Current Date: December 8, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$257,970	$257,970	$0
Graduate Research Assistant: $161,556 (57% salary, 43% benefits and tuition); 50% FTE each year for 4 years			
Undergraduate research assistant: $37,207 (100% salary, 0% benefits); 35% FTE each year for 4 years			
Brian Aukema, Project Manager [summer salary]: $47,773 (75% salary, 25% benefits); 7.7% FTE each year for 4 years			
Professional/Technical/Service Contracts			
Administration of emamectin benzoate	$34,294	$34,294	$0
Administration of azadirachtin (moved to supplies)	$0	$0	$0
Contract for use of chemical analysis equipment	$0	$0	$0
Equipment/Tools/Supplies			
Supplies for crown ratings, insect collection and husbandry, and chemicals for tissue analysis, and ArborJet azadirachtin treatment.	$13,599	$13,599	$0
Computer for data management and analysis	$1,050	$1,050	$0
Printing			
Poster printing and/or page charges for dissemination of results	$110	$110	$0
Travel expenses in Minnesota			
Rental of university vehicle at fleet rates each summer, predominantly for Activities 1 and 2. As possible, laboratory truck will be assigned to project to reduce travel costs. Travel includes minimum of one meeting/workshop per year to present results to relevant audiences.	$11,904	$11,904	$0
COLUMN TOTAL	**$318,927**	**$318,927**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #6: Distribution and Traits of the Fungal Pathogen *Fusarium virguliforme* that Influence Current and Future Risk to Soybean and other Legumes in Minnesota
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Dean Malvick
Organization: University of Minnesota
Sub-Project Budget: $383,651
Sub-Project Length and Completion Date: 3.4 Years, June 30, 2021
Current Date: December 8, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$329,979	$329,979	$0
Post-doctoral Research Associate: $184,500 (80% salary; 20% benefits); 100% FTE each year for 3 years			
Post-doctoral Research Associate: $11,000 (80% salary, 20% benefits); 5% FTE each year for 3 years			
Graduate Research Asssistant: $135,223 (50% salary, 50% benefits and tuition); 50% FTE each year for 3 years			
Undergraduate research assistant: $15,700 (100% salary, 0% benefits); 35% FTE each year in years 1-2; 5% FTE each year in year 3			
Professional/Technical/Service Contracts			
Services for soil analysis and DNA sequencing at the University of Minnesota will comprise the bulk of this portion of the budget. In additon we will seek out qualified sources of aerial imagery that will comprise a minor part of this budget, and there will be shipping/mailing costs.	$21,863	$21,863	$0
Equipment/Tools/Supplies			
Laboratory supplies for fungal isolation and grown, equipment and supplies for phenotypic assays of fungi, qPCR analysis, greenhouse supplies, and soil temperature monitors.	$30,272	$30,272	$0
Travel expenses in Minnesota			
Funding for travel is requested because of extensive field survey and sampling work to cover mileage to collect samples, and registration and travel to three scientific meetings. (Approximatedly 65% is estimated for mileage, 15% for lodging, 5% for meals, and 15% for transportation costs to scientiric meetings).	$1,537	$1,537	$0
COLUMN TOTAL	**$383,651**	**$383,651**	**$0**

$28,349 returned to ML 2015 reserve

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #7: Tools to Distinguish Native from Exotic Reed Canary Grass
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Neil O. Anderson
Organization: University of Minnesota
Sub-Project Budget: $263,373
Sub-Project Length and Completion Date: 3 Years, June 30, 2020
Current Date: December 8, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$184,443	$184,443	$0
Andrzej Noyszewski, Postdoctoral Research Associate: $181,597 (82% salary, 18% benefits); 100% FTE each year for 3 years			
2 Undergraduate Research Asssistants: $25,333 (93% salary, 7% benefits); both positions 27% FTE each year for 2 years			
Equipment/Tools/Supplies			
Laboratory supplies for molecular genotyping of collected plant samples, molecular analyses of reed canarygrass plant DNA samples (chemicals, markers, DNA extraction kits, SSR primer development, pilot SNP chip development, SNP development; draft DNA seqencing of selected genotypes: native, invasive, hybrid)	$20,600	$20,600	$0
Laboratory supplies for development of hand-held tool for land managers and ABI fragment analysis to confirm effectiveness of hand-held device (chemicals, tools, markers)	$11,345	$11,345	$0
Professional Services			
Service fees for DArT genotyping	$41,527	$41,527	$0
Travel in state travel to collect rcg samples along major highway corridors. Total est mileage is $1,834 miles . Lodging and meals per UMN policy is included in total,	$5,358	$5,358	$0
COLUMN TOTAL	**$263,273**	**$263,273**	**$0**

$4,727 returned to ML 2015 reserve

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #8: Accurate Detection and Integrated Treatment of Oak Wilt (*Ceratocystis fagacearum*) in MN
Legal Citation: ML 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Jeannine Cavender-Bares
Organization: University of Minnesota
Sub-Project Budget: $356,382
Sub-Project Length and Completion Date: 4 Years, June 30, 2020
Current Date: December 8, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$321,946	$321,946	$0
Post doctoral Research Associate: $183,891 (66% salary, 34% benefits); 100% FTE each year for 3 years			
Civil Service			
Graduate Research Assistant: $62,822 (57% salary, 43% benefits and tuition); 50% FTE each year for 3 years			
Undergraduate research assistant: $18,720 (100% salary, 0% benefits); 35% FTE each year for 3 years			
Dr. Jeannine Cavender-Bares, Project Manager: $22,562 (66% salary, 34% benefits); 4% FTE each year for 3 years			
Dr. Rebecca Montgomery, Project Manager: $18,539 (66% salary, 34% benefits); 4% FTE each year for 3 years			
Professional/Technical/Service Contracts			
Metro Tall Timbers/Paul Kujawa and separate contract for tree removal via an RFP bid process. $26,000	$14,600	$14,600	$0
Rental of high precision GPS equipment $500	$500	$500	$0
Aerial lift rental $12,000	$138	$138	$0
Equipment/Tools/Supplies			
Field equipment: including but not limited to tree marking paint, nails, tags, flagging, binoculars, chainsaw and accessories, batteries, Spectralon panels that serve as white references, stepladders, coin envelopes and sample bags, and insect spray $3,444	$5,267	$5,267	$0
Laboratory supplies for PCR detection of oak wilt and bur oak blight, including agar, media, Petri plates, DNA extraction and PCR kits, pipette tips, and microcentrifuge tubes. $2,943	$6,389	$6,389	$0
Equipment maintenance (spectroscopy equipment, Scholander pressure chamber) $3,000	$5,052	$5,052	$0
Travel expenses in Minnesota			
Travel for field work to multiple field sites over four years, three workshops and one field demonstration; $0.54 per mile for ~5,555 miles $3,000	$2,490	$2,490	$0
COLUMN TOTAL	**$356,382**	**$356,382**	**$0**

$1,039 returned to ML 2015 reserve

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #9: Characterizing dispersal of larval gypsy moth to improve quarantine regulations
Legal Citation: ML 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Brian Aukema
Organization: University of Minnesota
Sub-Project Budget: $35,000
Sub-Project Length and Completion Date: 1.5 years, Aug 31, 2018
Date of Report: March 25, 2019 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM					
Capital Expenditures Over $5,000	**$33,193**	**$33,193**	**$0**	**$33,193**	**$0**
LC-770 servosphere and data acquisition system	$33,193	$33,193	$0	$33,193	$0
Other	**$1,807**	**$1,807**	**$0**	**$1,807**	**$0**
Quarantine lab rent	$1,715	$1,715	$0	$1,715	$0
Shipping fees to receive egg masses	$92	$92	$0	$92	$0
COLUMN TOTAL	**$35,000**	**$35,000**	**$0**	**$35,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #10: Management Strategies for the Invasive Spotted Wing Drosophila
Legal Citation: ML 2015, Ch. 76, Art. 2, Sec. 6a
Project Manager: Mary Rogers
Organization: UMN-Horticulture
M.L. 2014 ENRTF Appropriation: $477,541
Sub-Project Length and Completion Date: 4.5 Years, August 31, 2021
Current Date: December 8, 2022 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$445,130	$445,130	$0
Mary Rogers, Project Manager: $38,603 (66% salary, 33% benefits); 3.25 FTE for 4 years			
Graduate Research Assistant in Entomology: (50% salary, 17.6% benefits) plus tuition; 24 FTE for 4 years			
Graduate Research Assistant in Horticulture: (50% salary, 17.6% benefits) plus tuition; 18 FTE for 4 years			
Gigi DiGiacomo, Applied Economics Research Fellow: $90,931 (68% salary, 32% benefits); 15.6 FTE for 4 years			
Undergraduate research support: $10,560 (100% salary, 0% benefits); 5.54 FTE for 4 years			
Labor and project support for experimental plots of raspberries at the West Central Research & Outreach Center in Morris, MN, $6,000 per year for YR 1-2 & $3,000 for YR 3			
Professional/Technical/Service Contracts			
Contract for service fee by Dr. Demoz Gebre-Egziabher (Aerospace Engineering, UMN), for use of his UAV Technician/crew to conduct SWD dispersal sampling studies using Fixed-wing UAVs each year (Activity 1), with extra set up/validation costs in Year 1. Total: YR1 $10,000, YRS 2-4 @ $5,000 ea.	$2,250	$2,250	$0
Contract for service fee by Dr. Mark Asplen (Assist. Professor, Metro State University), for use of his flight chamber to conduct SWD dispersal studies, comparing the propensity and duration of flights between Winter and Summer morphs of SWD; study will use a flight chamber developed by Dr. Asplen, and multiple years of expertise; @ $5,000/year for Yrs 1-3; total, $15,000.	$0	$0	$0
Growth chamber fees	$2,829	$2,829	$0
Equipment/Tools/Supplies			
Helium balloons and monitoring supplies, traps and lures (YRs 1-4, $1,200/yr)	$3,537	$3,537	$0
Field equipment including tunnel construction (netting, PVC, wiggle wire, poly for exclusion) and irrigation, biopesticide products	$12,680	$12,680	$0
Microclimate sensor for ambient air temperature, RH (YR 1 only), sensor with remote monitoring sensing capabilities, weatherproof housing, solar panel and extension cablesMicroclimate sensor for ambient air temperature, RH (YR 1 only), sensor with remote monitoring sensing capabilities, weatherproof housing, solar panel and extension cables	$122	$122	$0
Travel			
Rental vehicle for travel to research sites in Minnesota. Estimated at $5,400 per year (YR 1-4)	$7,953	$7,953	$0
Mileage, lodging and meals requested to present at grower conferences in MN in YR 2-4, estimated at $250/event x 4 events.	$870	$870	$0
Travel requested for two Graduate Research Assistants and PIs to present research and learn about related SWD research at the annual Entomological Society of America conference. Estimated at $1,700 per attendee (x4) to cover registration, airfare, lodging and meals (YR 3 & 4)	$2,170	$2,170	$0
COLUMN TOTAL	**$477,541**	**$477,541**	**$0**

$27,459 returned to ML 2015 reserve

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #11: Will Future Weather Favor Minnesota's Woody Invaders?
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Peter Reich
Organization: University of Minnesota
Sub-Project Budget: $526,000
Sub-Project Length and Completion Date: 4.5 Years, December 31, 2021
Current Date: December 8, 2022 (complete)

$ BUDGET ITEM	Total budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$380,114	$380,114	$0
Four research professionals (post docs): $370,092 (81% salary, 19% benefits); 1 at 12 month/yr @ 0.70 FTE, 1 at 12 month/yr @ 0.3 FTE, and 2 at 12 month/yr @ 0.2 FTE			
One - four undergraduate students @ $11/hour: $17,667 (93% salary, 7% benefits)			
Professional/Technical/Service Contracts			
Electrical costs for B4WARMED experiment	$107,769	$107,769	$0
Data services; shipping	$4,132	$4,132	$0
Equipment/Tools/Supplies			
Lab supplies: Supplies, materials, maintenance, repair	$7,892	$7,892	$0
Foliar chemistry analysis	$0	$0	$0
Plot Rental	$275	$275	$0
Travel expenses in Minnesota			
Field site mileage & lodging	$25,818	$25,818	$0
COLUMN TOTAL	**$526,000**	**$526,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #12: Developing robust identification assays for *Amaranthus palmeri* in seed mixtures
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Don Wyse
Organization: University of Minnesota
Sub-Project Budget: $208,230
Sub-Project Length and Completion Date: 2 Years, January 31, 2020
Current Date: December 21, 2020 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$133,322	$133,322	$0
Postdoctoral Research Associate: $64,910 (82% salary, 18% benefits); 100% FTE each year for 2 years with a 2.5% increase in year 2			
Equipment/Tools/Supplies			
Lab supplies and reagents for Activity 2 (for example, DNA extraction kits, chemical reagents for PCR, eletrophoresis materials)	$42,930	$42,930	$0
Professional/Technical/Service Contracts			
DNA sequencing costs for Activity 3 to be completed at University of Minnesota Genomics Center.	$29,484	$29,484	$0
Travel			
$2,150 for out of state travel to Colorado State University. Trip 1: $1,190 for 5 days of travel for training in advanced DNA sequencing techniques. Trip 2: $960 for 4 days of travel for advanced training in informatics analysis of DNA sequences and protocols for information exchange (terrabytes of data)	$2,494	$2,494	$0
COLUMN TOTAL	**$208,230**	**$208,230**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #13: Terrestrial Invasive Species Prioritization
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Amy Morey
Organization: University of Minnesota
Sub-Project Budget: $36,126
Sub-Project Length and Completion Date: July 31, 2020
Current Date: December 21, 2020 (complete)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$71,461	$71,461	$0
Postdoctoral Research Associate: $36,126 (75.7% salary, 24.3% benefits); 100% for 7 months			
COLUMN TOTAL	**$71,461**	**$71,461**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget

Sub-Project Title: MITPPC #14: Building mechanistic and process based species distibution models for common tansy and leafy spurge: from landscapes to genomes

Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: David Moeller
Organization: University of Minnesota
Sub-Project Budget: $70,812
Sub-Project Length and Completion Date: 3.9 years, April 1, 2023
Current Date: August 31, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET BUDGET ITEM	TOTAL BUDGET	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$70,812	$70,812	$0
Researcher: $70,812 (55.8% salary, 34.2% fringe) 1 FTE			
COLUMN TOTAL	**$70,812**	**$70,812**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #15: Terrestrial Invasive Species Prioritization
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Amy Morey
Organization: University of Minnesota
Sub-Project Budget: $92,141
Sub-Project Length and Completion Date: June 30, 2023
Current Date: August 31, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET **BUDGET ITEM**	**Budget**	**AMOUNT SPENT**	**TOTAL BALANCE**
Personnel (Wages and Benefits)	$92,141	$43,082	$49,059
Researcher $92,141 (75.7% salary, 24.3% benefits); 75% for 16 months			
COLUMN TOTAL	**$92,141**	**$43,082**	**$49,059**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #16: Effects of *Puccinia* species complex on common buckthorn (*Rhamnus cathartica*)
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Pablo Olivera
Organization: University of Minnesota
Sub-Project Budget: $33,000
Sub-Project Length and Completion Date: 0.5 yrs (this portion), June 30, 2026
Current Date: August 8, 2023 (complete)

FUND BUDGET **BUDGET ITEM**	**Budget**	**Revised budget [8-8-2023]**	**AMOUNT SPENT**	**TOTAL BALANCE**
Personnel (Wages and Benefits)	~~$33,000~~	$26,908	$26,908	$0
Postdoctoral Research Associate: $213,690 (80% salery, 20% fringe) 1 FTE for .5 yr				
COLUMN TOTAL	**~~$33,000~~**	**$26,908**	**$26,908**	**$0**

	date	amount
returned to reserve	8/21/2023	$6,092

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #17: Studies of entomopathogenic fungi for effective biocontrol of the emerald ash borer, Phase 2
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Robert Blanchette
Organization: University of Minnesota
Sub-Project Budget: $33,000
Sub-Project Length and Completion Date: 0.5 yrs (this portion), June 30, 2026
Current Date: August 8, 2023 (complete)

TRUST FUND BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$33,000	$33,000	$0
Researcher $90,403 (73% salary, 27% fringe) 1 FTE for .5 yr			
COLUMN TOTAL	**$33,000**	**$33,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #18: Incorporating adaptations into forecasts of range shifts with climate change
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Ryan Brisco Runquist
Organization: University of Minnesota
Sub-Project Budget: $33,000
Sub-Project Length and Completion Date: 0.5 yrs (this portion), June 30, 2026
Current Date: August 8, 2023 (complete)

BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$33,000	$33,000	$0
Post-doctoral associate: $90,947 (73% salary, 27% fringe) 1 FTE for .5 yr			
COLUMN TOTAL	**$33,000**	**$33,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #19: Genetic control of invasive insects, Phase 3
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Michael Smanski
Organization: University of Minnesota
Sub-Project Budget: $50,000
Sub-Project Length and Completion Date: 0.5 yrs (this portion), June 30, 2026
Current Date: August 8, 2023 (complete)

FUND BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$50,000	$50,000	$0
Graduate Research Assistant: $229,868 (57% salary, 43% benefits and tuition); 1 FTE for .5 yr			
COLUMN TOTAL	**$50,000**	**$50,000**	**$0**

Environment and Natural Resources Trust Fund
Minnesota Invasive Terrestrial Plants and Pests Center
M.L. 2015 Sub-Project Budget
Sub-Project Title: MITPPC #20: Making revegetation for buckthorn management feasible in MN
Legal Citation: M.L. 2015, Ch. 76, Art. 2, Sec. 6a
Sub-Project Manager: Michael Schuster
Organization: University of Minnesota
Sub-Project Budget: $40,000
Sub-Project Length and Completion Date: 0.5 yrs (this portion), June 30, 2026
Current Date: August 8, 2023 (complete)

FUND BUDGET BUDGET ITEM	Budget	AMOUNT SPENT	TOTAL BALANCE
Personnel (Wages and Benefits)	$40,000	$40,000	$0
Post-doctoral associate: $378,165 (76% salary; 24% fringe) 1 FTE for .5 yr			
COLUMN TOTAL	**$40,000**	**$40,000**	**$0**