Final Abstract

Final Report Approved on December 12, 2025

M.L. 2022 Project Abstract

For the Period Ending June 30, 2025

Project Title: Protecting Minnesota's Spruce-Fir Forests from Tree-Killing Budworm

Project Manager: Brian Aukema

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 03i

Appropriation Amount: $189,000

Amount Spent: $189,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

This project leveraged federal partners to jointly investigate eastern spruce budworm in Minnesota. We characterized the insect's natural enemies and weather patterns that foster moth dispersal, seeding new outbreaks. Understanding mortality and inciting factors of outbreaks will help manage budworm populations attacking balsam fir and white spruce in the future.

Overall Project Outcome and Results

The eastern spruce budworm is a native insect whose caterpillars feed on the needles of balsam fir and white spruce. Outbreaks in eastern North America commonly occur every 30-40 years, although Minnesota has had outbreaking populations annually since the 1950s. Repeated defoliation kills trees. Budworm management has historically focused on managing the trees. In this project, we focused on studying two aspects of budworm ecology: the natural enemies and dispersal. We collected more than 1,400 spruce budworm caterpillars and pupae and screened them for natural enemies. We found between 10% and 17% parasitism rates from 18 species of parasitoid wasps and flies reared from the immature budworms returned to the laboratory. All species had been previously noted elsewhere in North America and confirmed that natural enemies are prolific within Minnesota's forests. To study dispersal, we deployed baited

“autotraps” to collect moths during the eleven-week flight period in summer 2024. These traps lure budworm moths into a chamber where a camera records their time of arrival. We found that moth populations across the state rise and fall synchronously at scales of just over 200 miles. Dispersal of adult moths between forests likely seeds outbreaks by increasing mate-finding success, maintaining populations and providing a plausible explanation why Minnesota notes outbreaking populations annually. We integrated the moth capture data with atmospheric trajectory models (“Hysplit”) in which we found several temperature and precipitation signals associated with moth flight and dispersal. Understanding dispersal is key to knowing where early intervention strategies may or may not be appropriate; in some jurisdictions in eastern North America, treating emerging hotspots with biorational products can suppress populations. Understanding moth flight and mortality sources will continue to help understanding how outbreaks begin and continue in Minnesota’s spruce-fir forests.

Project Results Use and Dissemination

We gave presentations at local, regional, and national workshops and conferences, in person and online. This work trained two graduate students and six undergraduate students and technicians. Outreach presentations throughout the state were given to foresters, community groups, researchers, state and federal agency personnel and others over the three yeas. The PhD student is now submitting the dissertation chapters for consideration to scientific journals; these will be posted to the project page if/when accepted.

Environment and Natural Resources Trust Fund

M.L. 2022 Approved Final Report

General Information

Date: December 15, 2025

ID Number: 2022-185

Staff Lead: Tom Dietrich

Project Title: Protecting Minnesota's Spruce-Fir Forests from Tree-Killing Budworm

Project Budget: $189,000

Project Manager Information

Name: Brian Aukema

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Project Reporting

Final Report Approved: December 12, 2025

Reporting Status: Project Completed

Date of Last Action: December 12, 2025

Project Completion: June 30, 2025

Legal Information

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 03i

Appropriation Language: $189,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate conditions contributing to Minnesota's uniquely high population of the native and lethal spruce budworm to provide better management options for protecting the state's spruce-balsam fir forests.

Appropriation End Date: June 30, 2025

Narrative

Project Summary: Spruce budworm is native to Minnesota and the most significant tree killer in spruce-balsam fir forests. This project studies why populations increase to improve management opportunities in affected forests/regions.

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Spruce budworm is the most significant tree killer in spruce and balsam fir forests in North America. It is a native moth, and thus ineligible for project consideration by the Minnesota Invasive Terrestrial Plant and Pests Center. Caterpillars devour buds and needles on balsam firs and white spruce. Sustained feeding causes extensive tree mortality, especially to balsam firs. Budworm hotspots affect forest structure, wildlife, fire risk, and timber production.

Aerial surveys of northeastern Minnesota have noted budworm activity for 68 consecutive years. Budworm is always present. In contrast, other forests in eastern North America document regular outbreaks every 35 years with peaks lasting 5-6 years. Records of budworm outbreaks in eastern North America date back to the 1700s.

We do not know why budworms are so active and prominent in northern Minnesota, or how spruce budworm impacts cascade through spruce-fir forests. There are multiple possible factors: warm weather, dispersal of mating adults, forest structure and tree condition, and more. Insights from forests in eastern North America suggest that changes in the natural enemy (i.e., biological control) complex and greater ability to find mates as populations increase are likely responsible at least in part for increasing budworm numbers.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

To understand why Minnesota's populations are so high, we seek funding to:

1. Survey beneficial natural enemies in budworm populations within the state. It is hypothesized that buildup of generalist natural enemies in outbreaking populations, in concert with a decline in foliage abundance and quality, contribute to outbreak collapse. Surprisingly, the natural biological control agents in spruce budworm-affected forests have never been studied in Minnesota.

2. Characterize dispersal of female budworms within mainland Minnesota sites undergoing population phase transitions. Mate-finding failure may contribute to "Allee effects" and slow population phase transitions from endemic to epidemic levels. Although spruce budworm can disperse great distances, it is thought that localized mixing from dispersal from surrounding forests enhances mating success and encourages population phase transitions to outbreak levels.

3. LEVERAGED FUNDING OPPORTUNITY (FYI; NO FUNDS REQUESTED). We will integrate this work with a new federal National Park Service / US Forest Service project on Isle Royale (with introduced Minnesota wolves!)

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The current state of knowledge is how many trees will be killed when budworm populations are high, but not root causes of why populations fluctuate. Determining the prevalence, abundance, and type of natural enemies present in increasing or decreasing budworm populations, and how mating success contributes to outbreaks, moves us toward population forecasting tools with short- and long-term benefits. For example, St. Louis County, the DNR, and the USDA Forest Service currently incorporate aerial survey data of spruce budworm defoliation and mortality into Community Wildfire Protection Plans (standing dead conifers with needles increases wildfire risk).

Project Location

What is the best scale for describing where your work will take place?

Region(s): NE, Central,

What is the best scale to describe the area impacted by your work?

Region(s): Central, NE,

When will the work impact occur?

During the Project and In the Future

Activities and Milestones

Activity 1: Screen budworms for biological control agents

Activity Budget: $96,000

Activity Description:
We will work with DNR Forest Health Team partners to select sites in northern Minnesota. Exact number will be determined by annual budworm activity, site access, and statistical power. We will used published methods from other states and provinces to collect budworms, rear them on diet within the laboratory, and collect emerging natural enemies. Parasitoids will be identified to species and we will compare 1) number, 2) diversity, and 3) feeding breadth (i.e., generalists that can prey on other insects vs. specialists that only feed upon budworms) in increasing vs. decreasing populations. We will also analyze hyperparasitoids (i.e., parasites of parasitoids) if any, which are hypothesized to interfere with primary control in budworm-affected forests and may be associated with sustained outbreak behavior.

The activity will be conducted by a graduate student. Data will be analyzed by standard statistical techniques such as analysis of variance and regression, and results will be shared in oral and written form at appropriate venues (workshops, scientific journals, etc.).

Activity Milestones:

Description	Approximate Completion Date
Recruit graduate student to project, find suitable sites in northern MN	June 30, 2023
Collect and rear out parasitoids from high vs. low budworm sites (two years)	June 30, 2024
Identify and analyze diversity, numbers, and feeding guild differences, including hyperparasitoids if any	June 30, 2025

Activity 2: Characterize dispersal of female budworms within mainland Minnesota sites undergoing population phase transitions

Activity Budget: $93,000

Activity Description:
We will select between three and eight isolated sites depending on budworm abundance and deploy “autotraps” at each site. These traps are baited with a pheromone and collect flying female moths. A camera monitors trap contents – especially useful in remote locations – and changes a roll of internal sticky trapping paper 4X per day. This allows monitoring of dusk vs. dawn capture events and can help suggest immigration events.

The wings of collected moths will be removed in the lab and analyzed for various isotopes. Larval budworm incorporate the chemical signatures of local foliage into their bodies as they feed and grow. Because adult budworms do not feed, the signatures of the regions from which they occur are maintained after capture. With the help of colleagues at the Canadian Forest Service (leveraged funding), we will analyze these signatures and use ANOVA statistical tests to determine if the signatures in moths captured through time at a specific site are similar (i.e., thus all local) or varied (i.e., indicating immigration at specific times).

We will do similar on Isle Royale (separate project) to determine connectedness between Minnesota and Isle Royale. The activity will be conducted by a graduate student.

Activity Milestones:

Description	Approximate Completion Date

Recruit graduate student and identify sources of female moths to test	June 30, 2023
Sample female flying moths using pheromone autotraps	September 30, 2024
Determine the proportion that are resident vs. immigrant using isotope analysis	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
St. Paul Field Office	US Forest Service	Collaborators who will help secure aerial survey data for tree mortality	No
Forest Health Team	Minnesota Department of Natural Resources	Collaborators will help find field sites in areas of highest budworm activity	No

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
We will disseminate research results at regional, national, and international conferences; some participation of which is made possible by funds from other agencies leveraged by this grant. Candidate venues include the North Central Forest Pest Workshop, the Northern Silviculture Workshop, Western Forest Insect Work Conference, Entomological Society of America, IUFRO division workshops, Sustainable Forest Education Cooperative webinars, Cloquet Forest Research Review, and more. Work published in scientific journals or highlighted by mass or social media will acknowledge the partnership and support of the ENRTF.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
Despite being Minnesota's top native tree-killer of balsam fir and white spruce, LCCMR has not invested in a study of spruce budworm to date. We are requesting a three-year appropriation in the small project category ($189K). The investment will be integrated with a related but distinct project with the National Park Service and the US Forest Service. That work ($90K; exclusive of LCCMR funds) will take place on neighboring Isle Royale in Lake Superior but has direct relevance to Minnesota spruce-fir forests and moose-wolf ecology.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
MITPPC #2: Mountain Pine Beetle, Phase II: Protecting Minnesota	M.L. 2015, Chp. 76, Sec. 2, Subd. 06a	-
MITPPC #5: Optimizing Tree Injections Against Emerald Ash Borer	M.L. 2015, Chp. 76, Sec. 2, Subd. 06a	-
MITPPC #9: Dispersal Characteristics of Gypsy Moth Larvae to Improve the Effectiveness of Quarantines	M.L. 2015, Chp. 76, Sec. 2, Subd. 06a	-
Emerald Ash Borer Biocontrol - Phase III	M.L. 2017, Chp. 96, Sec. 2, Subd. 06b	$729,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Graduate student		Conduct the parasitoid surveys and mating success studies (3 yrs), either as university "research assistant" or "fellow." Latter UMN personnel code facilitates coverage of tuition from external partner as available.			19.9%	1.2		$125,583	-	-
Faculty member		Oversee project experiments and analyses (partial time in summer)			36.5%	0.3		$45,456	-	-
Undergraduate student helper		Help in rearing biological control agents from field samples			0%	1		$3,307	-	-
							Sub Total	**$174,346**	**$174,346**	**-**
Contracts and Services										
							Sub Total	**-**	**-**	**-**
Equipment, Tools, and Supplies										
	Tools and Supplies	Vials, insect rearing diet, identification guides, misc. field supplies including pheromone lures for autosampler traps	Executing the biological control agent sampling and identification					$628	$628	-
	Equipment	Lease of autosampler budworm traps ($750 each)	Paired with a lure, these traps have a camera and sticky paper to catch moths. A solar panel and SIM card sends images to cloud, allowing real time monitoring of trap contents in remote regions. User can log in and trigger new sticky paper deployment for capture remotely. Absolutely amazing new invention that budworm colleagues now use in Canada, saves immense time and effort.					$6,649	$6,649	-

			May be repurposed for upcoming LCCMR/MITPPC spongy moth project at end of this project.							
							Sub Total	**$7,277**	**$7,277**	**-**
Capital Expenditures										
							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Workshop travel to disseminate results; est. 2 people, 2 days: $300 hotel, $150 vehicle rental, $200 per diems, $100 registration = $750 total x 3 years but local travel may be much less and sometimes covered from other sources	Sharing results with Minnesota's forest resource community					$507	$507	-
	Miles/ Meals/ Lodging	Eight trips (2 people, three trips of 4 days; mileage varies depending on outbreak location, lodging at university research station in Ely, with per diem food at UMN rates, often subsidized with DNR vehicle), plus autotrap deployment and recollections	Field travel for sampling of spruce budworms and natural enemies, and autotrap deployment and recollections					$6,870	$6,870	-
							Sub Total	**$7,377**	**$7,377**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										

	Printing	Printing outreach materials	Dissemination of results on research poster at workshop/conference					-	-	-
							Sub Total	**-**	**-**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$189,000**	**$189,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
In-Kind	Waived UMN overhead	35% for non-federal agencies	Secured	$139,300	-	$139,300
			State Sub Total	**$139,300**	**-**	**$139,300**
Non-State						
Cash	Federal funds	Three year grant from US Forest Service / National Park Service staff to cover field travel and expenses on integrated project on tree mortality and forest recovery from spruce budworm at Isle Royale National Park. This project complements LCCMR objectives and pays for field work in Minnesota.	Secured	$90,000	$90,000	-
			Non State Sub Total	**$90,000**	**$90,000**	**-**
			Funds Total	**$229,300**	**$90,000**	**$139,300**

Attachments

Required Attachments

Visual Component

File: 16b20e13-12a.pdf

Alternate Text for Visual Component

Photo of spruce budworm and spruce-fir forests, overlaid by smaller photos of aspects of proposal leveraged with other funding agencies (e.g., moose and wolves at Isle Royale National Park with National Park Service)...

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
Letter of support from Sustainable Forests Education Cooperative	2b93f5a8-359.pdf
Letter of support from National Park Service / Isle Royale	6d937773-fd7.pdf
Authorization to submit - University of Minnesota	db618ab3-af1.pdf
Approved research addendum, post-review	49a93d1c-c50.pdf
Background Check Certification Form	f5b36ff6-cd0.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

Activity 2 has changed from "climatic analysis" to "mating success." This change takes advantage of funds leveraged since the proposal was submitted, is closely tied to testable theory, and was reviewed favorably in this project's research addendum.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

N/A

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Other • Budget - Personnel	Request: Please allow UMN to hire PhD student during academic year on an internal "fellowship" code. Rationale: This mechanism severs tuition from student stipend, allowing an external sponsor such as Veterans Administration to cover the tuition benefit. In this instance, "fellowship" code is NOT used as a merit award. Tuition savings ($16K/year) would be retained on project in personnel category and offset higher wage guidelines from UMN, as well as hiring more summer help.	March 29, 2023	Yes	April 4, 2023
2	Amendment Request	• Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences	Our project was primarily budgeted for personnel (98.4%) as our partner agencies (e.g., US Forest Service, National Park Service) are funding research, travel, and supplies. Due in part to wildfire priorities, delivery of some partner funds is delayed (but still secure). Kindly requesting permission to move $10K in personnel costs to equipment/supplies/travel to keep project intact and moving, as the critical summer window to capture these insects approaches.	June 13, 2023	Yes	June 15, 2023
3	Amendment Request	• Budget - Personnel • Budget - Travel and Conferences	Kindly requesting to move $1,000 from personnel to field travel. Field travel was rebudgeted on an emergency basis this past summer due to delays in delivery of partner funds (US Forest Service, National Park Service). The original guess of $2600 needed for field travel was $153 short; unfortunately, we never know in advance where the best field sites will be. The rebudget retains small travel buffer for	September 22, 2023	Yes	January 17, 2024

			2024 while anticipating delivery of federal funds.			
4	Amendment Request	• Narrative • Other • Activities and Milestones	Request to adjust Activity 2 to state "study of dispersal of budworm moths" rather than "study of mating success of budworm moths." The sharpened focus on dispersal that seeds new areas and supports outbreaks (with concomitant enhanced mating success due to numbers) originates with recent advice from expert colleagues is supported by partner agencies, and thus has no impact to LCCMR budget.	March 29, 2024	Yes	May 1, 2024
5	Amendment Request	• Budget - Capital, Equipment, Tools, and Supplies	Amendment ID 5: Update procurement info on Amendment 2. Delays in delivery of leveraged federal partner funding had led to proposed minor swap between grants of personnel (student) & equipment (traps) to keep project moving (Amendment 2, approved). This amendment request updates procurement of autosampler traps needed for Activity 2: 2024 rates and academic not commercial rates (discount). No change to budget categories or deliverables.	May 2, 2024	Yes	May 8, 2024
6	Amendment Request	• Budget - Capital, Equipment, Tools, and Supplies • Budget - Personnel • Budget - Travel and Conferences	Minor realignments after field season in which we had small overages in field travel, as delivery of federal partner funds was delayed and it is impossible to predict in advance where sampling will occur. Hence, shifting $1625 from personnel, $400 from supplies, $1250 from workshop travel, totaling $3275, to field travel to bring categories into better alignment. No change to scope or deliverables.	October 3, 2024	Yes	October 15, 2024
7	Amendment Request	• Other • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies	Amendment 7: Minor budget realignments (<$500 each) between categories reflecting actual costs incurred, anticipated costs through end of project, and unforeseen	April 22, 2025	Yes	May 6, 2025

		• Budget - Travel and Conferences • Budget - Printing and Publication	savings in select categories as we approach project completion. No change to scope or deliverables.			
8	Amendment Request	• Budget • Other • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Non-ENRTF Funds Contributed	Final amendment: Minor budget realignments to reflect final costs and correct a previous reporting error (trap lease was $28 less expensive than reported). All budget changes were less than $675. No changes to scope or deliverables, and the project is complete.	September 5, 2025	Yes	November 10, 2025

Status Update Reporting

Final Status Update August 14, 2025

Date Submitted: September 5, 2025

Date Approved: November 10, 2025

Overall Update

We have completed the project, and are pleased to share that the graduate student supported by this project will be defending her PhD on September 24. Activity 1 went well; we have collected budworms, reared their natural enemies, identified them, and catalogued the diversity present in Minnesota's spruce-fir forests. A synopsis of results is shared below. Activity 2, which sought to characterize dispersal of female budworms among sites in Minnesota using a novel radioisotope analysis where we compare moths with foliage on which they fed, suffered a small challenge in that we did not receive the final analysis of radioisotope data before project completion. The lab conducting this work (funded by federal partners) received some questionable readings so decided to re-analyze several samples, a move that we supported. We were still able to accomplish the goal of Activity 2 by switching to a spatial synchrony analysis of moth populations with the original data collected by autotraps. Because this LCCMR partnership was one of several for this regional budworm project (e.g., USDA Forest Service, National Park Service), we will still complete the radioisotope analysis in the year ahead.

Activity 1

In the summers of 2023 and 2024, we collected just over 1,400 spruce budworms at late larval and pupal stages, the life stages that typically yield the highest numbers and diversity of natural enemies. These were returned to the laboratory, placed on artificial diet, and reared until either a parasitoid emerged or an adult budworm emerged from the pupae. Parasitism rates ranged between 10 and 17%, depending on the site. In total, we identified 18 species of parasitoid wasps and flies that emerged from immature budworms. All of the species that we identified, such as Glypta fumiferanae Viereck (Hymenoptera: Ichneumonidae) and Itoplectis conquisitor (Say) (Hymenoptera: Ichneumonidae), are known parasitoids of eastern spruce budworm in other regions of North America. As such, we did not find any new or unexpected species. Spruce budworms in Minnesota have a thriving complex of biological control agents that are helping regulate populations, despite the large current outbreak. The full list of parasitoids and further comparative analyses will be available in the student's dissertation after her defense later this month. We expect to submit this data chapter for publication to a scientific journal shortly after defense.
(This activity marked as complete as of this status update)

Activity 2

Our original intent, as part of the larger project of which LCCMR was one partner, was to conduct isotope analysis on foliage and moths collected from disparate sites. Because budworms convert foliage into their bodily tissues as they grow, comparing moths among regions can differentiate local vs. immigrant moths. While specimen collections occurred on schedule and project partners (US Forest Service, National Park Service) sponsored the radioisotope analyses and student training, we have not received final results from the specialized radioisotope lab in South Africa where samples were sent. While awaiting results, we pivoted to working directly with the moth trap data from the sites across Minnesota where we trapped moths using the autotraps, daily over the 77 days flight period, in summer 2024. A spatial synchrony analysis revealed that populations are synchronous out to distances of at least 215 miles. Dispersal between subpopulations acts to synchronize their rising and falling together and ensures sufficient mate-finding success to initiate and sustain outbreaks. We further created atmospheric trajectory models using "HYSPLIT" modeling and found several temperature and precipitation signals associated with putative moth flights, which may enable better predictions in the future.
(This activity marked as complete as of this status update)

Dissemination

The PhD student, Jessica Rootes, will be holding a public PhD defense seminar on September 24, after which time the work in Aims 1 and 2 will be submitted to peer-reviewed scientific journals.

Status Update Reporting

Status Update March 1, 2025

Date Submitted: April 22, 2025

Date Approved: May 6, 2025

Overall Update

The graduate student supported by this project is expected to defend her PhD at the end of the summer, concomitant with the June conclusion of this project. Over the last six months, we have focused on identification of remaining parasitoids from two years of field collections. Many have needed confirmation from taxonomic specialists. Final analyses are now underway. In Activity 2, the graduate student has processed all of the foliage and moths for isotope analysis. This activity involved painstaking chemical washes and cleanings of individual moths to avoid any foreign debris from the traps contaminating the samples, which could obscure the geographic signature. The moths were then brought to the Jan Viser Isotope Analysis laboratory at the University of Ottawa where they were ground and weighed for processing – extremely delicate steps taken in a "clean lab." This preparatory work and travel was funded by a University of Minnesota Graduate School travel grant. We now await the results from the isotope analysis at the lab so we can determine the dispersal distances of moths in northern Minnesota and begin to understand the distances at which continuing outbreaks are continually seeded.

Activity 1

All collected parasitoids were reared out by this past fall, completing milestone 2. The graduate student has spent the last several months identifying specimens. Due to training in spring 2023 courtesy of a USFS-funded trip to visit budworm experts at the Laurentian Forestry Centre, Canadian Forest Service, identifications have gone well but there have been several for which we have sought additional confirmation working with a specialist in the University of Minnesota Insect Collection. We have not found any specimens that appear to be unknown or new to budworm ecology thus far, which in itself is an interesting finding. We are now beginning the diversity analyses and are on track to complete the project on time and on budget.

Activity 2

There have been two components to the isotope analysis. First, recall that foliage has been collected from all sites where the autotraps were placed in Minnesota forests in summer of 2024. The foliage was processed and sent to a colleague at the Canadian Forest Service who has sent the material off to a specialized radioisotope lab in South Africa. We await results. Second, the moths captured over the summer were painstakingly processed with individual cleanings before weighing and grinding into a powder that will be similarly analyzed. The graduate student just finished these remaining steps at the University of Ottawa on a research trip funded by the University of Minnesota Graduate School, at no cost to this project. These budworm moth specimens await entry into the analytical machines to determine chemical composition. When we receive the data, we will be able to compare which moths in a given trap might be local (i.e., matching local foliage signatures, as they incorporate the chemical signature of the foliage as they eat) vs. non-resident immigrants (i.e., matching signatures from a different forest).

Dissemination

I mentioned this work during a presentation on dispersal of mountain pine beetle:
USDA Annapolis Interagency Forum on Invasive Species Feb 25-28, Annapolis, MD. Aukema, B.H. and A.C. Kramer. Dispersal of pioneering mountain pine beetles from active infestations: implications to range expansion for this domestic invasive.

Status Update Reporting

Status Update September 1, 2024

Date Submitted: October 3, 2024

Date Approved: October 15, 2024

Overall Update

The project continues to go well as we expanded the amended second objective to dispersal using autotraps. These traps use a solar battery to power cell band communication that uploads real-time trap captures to the vendor, who uses AI to identify spruce budworm moths. We did have some technical challenges to overcome, such as weak signal on shady days in northern forests, and occasional problems from very curious bears. We completed sampling for Activity 1 and have reared out natural enemies of spruce budworm, from both Minnesota (this project) and on Isle Royale in partnership with the US Forest Service and National Park Service who offer benefits to this project. The MN DNR Forest Health Team also contributed a $5,000 travel grant, which helped greatly as we underbudgeted travel (we never know where the budworm populations might be best sampled until we get out in the field). This update requests a minor rebudget to realign travel and personnel categories accordingly. The DNR contribution facilitated presentation of project results to date to stakeholders at the most recent North Central Forest Pest Workshop in Sault Ste. Marie, Ontario; an annual gathering of forest health professionals from seven states and two provinces.

Activity 1

Like last summer, graduate student Jessica Rootes collected hundreds of budworms focusing on life stages that would yield the greatest diversity of natural enemies: late larvae, and pupae. These insects were returned to the lab where we placed them on artificial diets where they grew until they either turned into adults or natural enemies emerged. This fall, we have reared everything out, completing milestone 2, and now begins the process of identifications and diversity analyses over the next year. We again see many species of wasps and flies and are optimistic that identifications will move more quickly than last year now that we have (a) had some training in spring 2023 courtesy of a USFS-funded trip to visit budworm experts at the Laurentian Forestry Centre, Canadian Forest Service, and (b) have some experience from last year's specimens.

Activity 2

This summer, we leased Autotraps from TrapVue that were deployed in forests throughout Minnesota. The traps contain a battery that sends cell band communications to a central server that both pushes software updates in real time and gathers trap content data for immediate identification with a camera. We had some challenges early on as two of the traps did not communicate well with the central server until the vendor determined the cause of a software problem. Nonetheless, we were able to capture the budworm flight from the beginning to the end across much of Minnesota – including some surprise moths in Lake of the Woods. Over the next few months, we will be partnering with colleagues at the Canadian Forest Service to use isotope analysis to determine which moths in a given trap (based on time of day captured) might be local residents vs. long-distance immigrants. Local vs. immigrant captured moths can be distinguished by analyzing isotopes within trap captures and local foliage, as budworms incorporate local isotopes of chemicals in their bodies as they feed. Stay tuned!

Dissemination

We gave one presentation to regional stakeholders, paid for a student travel scholarship from the University of Minnesota Natural Resources Science and Management graduate program, a DNR-funded vehicle for travel to the workshop, and the US Forest Service.

Rootes, J.M. and B.H. Aukema. Emerging technology for emerging moths. North Central Forest Pest Workshop, Sault Ste. Marie, Ontario Sept 9-12, 2024.

Status Update Reporting

Status Update March 1, 2024

Date Submitted: March 29, 2024

Date Approved: May 1, 2024

Overall Update

The project continues to go well: we continue to benefit from investment of the US Forest Service, who have pledged a third year of funding. We also received news that the National Park Service will be partnering this upcoming summer as well! In Activity 1, we spent the winter identifying natural enemies of budworms as planned. Identifications were helped by the generous expertise of colleagues at the Laurentian Forestry Centre in Quebec City, Canada (a trip paid for last spring by the US Forest Service). We feel a great deal of confidence repeating sampling this summer and are excited to see what we find. For Activity 2 (mating success), further discussions with our colleagues – in tandem with mixed results in summer 2022 – prompt a request to modify the objective. Rather than study mating success as moths move to new regions, our colleagues have suggested we first focus on movement across regions themselves to identify the scope of the phenomenon. They have developed new ways to study dispersal not possible when this project was proposed. The US Forest Service has supported this change in objective with their funding, so an amendment is included with this update. No change to budget.

Activity 1

Last summer, the graduate student collected hundreds of budworms focusing on life stages that would yield the greatest diversity of natural enemies: late larvae, and pupae. These insects were returned to the lab where we placed them on artificial diets where they grew until they either turned into adults or natural enemies emerged. On US Forest Service funding, we also sampled other defoliating insects present at the same time to see if they had been acting as reservoirs for natural enemies that may cross over. We have been cataloging and identifying several species of wasps and flies important in biological control. We have used resources from our colleagues at the Canadian Forest Service to create an in-house guide tailored to what we're finding that we hope will speed identifications next year. The graduate student working on this Activity, Jessica Rootes, presented preliminary data this fall/winter at two workshops: the North Central Forest Pest Workshop in Waussau, WI (a gathering of forest health professionals from the 7 state / 2 province region), and the Grand Rapids Northern Silviculture Workshop in Grand Rapids, MN. Both presentations were well received, and she received First Place in the graduate student presentation competition at NCFPW!

Activity 2

As mentioned in the last progress report, meeting with our colleagues in Canada last spring left us feeling validated in finding our first mating success experiments were "learning experiences" rather than "resounding successes." In further conversations this past fall, we have coalesced on a revised objective to study dispersal using radioisotope methods. In brief, we think that budworm populations increase and outbreaks happen when an influx of moths blow in from elsewhere. These immigrants swamp the local population and increase mating success. There are now methods to distinguish if captured moths are local vs. immigrant by analyzing isotopes within trap captures and local foliage, as budworms incorporate local isotopes of chemicals in their bodies as they feed. Drs. Jean-Noel Candau and Phiippe Dargent-Bocanegra of the Canadian Forest Service have offered to collaborate, and the US Forest Service supports this objective. As such, we plan to deploy autotraps to do moth collections and detect immigrants this summer before analyzing the data this fall. Because LCCMR is primarily funding personnel vs. additional research expenses (partner funding of $30K/year), this suggested change does not change the budget but we feel will yield better insight to determine how outbreaks occur.

Dissemination

We gave two presentations, both of which were well-received:

Rootes, J.M. and B.H. Aukema. Natural enemy complexes of the eastern spruce budworm in Minnesota. Annual DNR/USFS Forest Health Workshop, 6 Feb 2024, Grand Rapids, MN.

Rootes, J.M. and B.H. Aukema. Preliminary comparison of insect natural enemies of eastern spruce budworm from Isle Royale National Park and mainland Minnesota. North Central Forest Pest Workshop, 11-14 Sep 2023, Wausau, WI [Jessica won first place in student presentation competition].

Status Update Reporting

Status Update September 1, 2023

Date Submitted: September 22, 2023

Date Approved: January 17, 2024

Overall Update

Budworm numbers were extremely high this summer in northern Minnesota, which was not so good for our spruce-fir forests but very good for the project. The project also continued to benefit from strong partnership with and investment from the US Forest Service that has helped fund travel and training. Given some challenges in executing mating success assays last summer, for example, the US Forest Service funded the graduate student and project lead to travel to the Laurentian Forestry Centre in Quebec City, Canada, for a few days in April to visit with global experts who have decades of experience dealing with spruce budworm. We visited with Drs. Jacques Regniere, Veronique Martel, Johanne Delisle, Kishan Sambaraju, and others and shared the project objectives and our proposed methods. Our colleagues were incredibly gracious with their time and expertise and we returned to Minnesota with better ideas of how to sample budworms, rear natural enemies, and measure dispersal. We decided to prioritize Activity 1 this summer (which went very well, see below), and are continuing to work toward an improved Activity 2 next summer, given our colleagues' valuable advice.

Activity 1

In May, the graduate student scouted areas of northern Minnesota for high populations of budworm that were accessible. Sites were suggested by our colleagues with the Minnesota DNR and we found all indications were pointing to a banner summer for budworms. We focused on areas around Ely as well as along the North Shore. We switched to a new sampling method suggested by our colleagues in Quebec using a custom-manufactured pole pruner basket 18" wide. We found it much easier to measure the foliage up high and scoop any budworms that often drop out of foliage when disturbed; it worked brilliantly. Budworms pass through six larval stages; we heeded our colleagues' recommendation to intensively sample later instars and pupae rather than all six larval instars as they felt that earlier instar sampling effort would not yield the abundance of natural enemies that make the greatest impact on budworm populations. We thus collected hundreds of late instar and pupal budworms. Budworms were returned to the laboratory and placed on artificial diet in rearing cups. We successfully reared out dozens of natural enemies, and are now beginning the long task of managing, cataloging, and identifying specimens.

Activity 2

With outcomes related to mating success scheduled for August of 2024, we did not focus on mating assays this summer. Meeting with our colleagues in Canada did leave us feeling validated in finding our first experiments last summer "learning experiences" rather than "successes," as our colleagues shared several lessons that didn't necessarily make it into finalized peer-reviewed publications that we were referencing. We discussed "lobster traps" that allow a male to fly into the trap but not out, as well as the necessity to sample at an appropriate height in the tree canopy, time flight appropriately given both local dispersal and immigration, and keeping samples in good condition suitable for dissection to determine mating success. In the winter, we will return to this Activity with plans to conduct experiments in summer 2024.

Dissemination

We highlighted this work in a presentation at the 2023 Great Lakes Science for Parks Symposium March 21-23 in Ashland, Wisconsin: Rootes, J.M., and B.H. Aukema. Forest regeneration is negatively impacted by ungulates, post spruce budworm outbreaks. This travel was paid for by the US Forest Service.

Status Update Reporting

Status Update March 1, 2023

Date Submitted: March 29, 2023

Date Approved: April 4, 2023

Overall Update
We have gotten off to a strong start with this project. We have recruited a PhD student who is a military veteran with substantial experience in project management. We were also able to combine LCCMR investment with investment from the US Forest Service that facilitates additional opportunities project-wide, such as travel and training. This past summer, for example, we were able to do some initial data collection to begin work on Activities 1 and 2 (collecting parastioids, deploying mating success experiments) that were not otherwise scheduled to begin on this project until next summer. We have valued the initial experience, as we have faced some challenges with the Methods in Activity 2 that we are currently troubleshooting with colleagues who have worked with mating success assays (see below).

Activity 1
We have recruited a graduate student, and she has spent the initial six months learning about working with spruce budworm. She collected data this past summer on forest recovery following outbreaks of spruce budworm. That activity is not part of this LCCMR project per se, but the research infrastructure developed in partnership with the US Forest Service allowed us to get started on this project's objective of studying parasitoids. We had located good populations of spruce budworm in northern Minnesota, and collected more than 100 late instar larvae and brought them back to the lab. We were excited to see some parasitoids emerge over the next several weeks under controlled conditions in the laboratory. The graduate student is now assembling identification resources to begin identifications. She has recently formed her PhD advisory committee that includes Prof. George Heimpel, a world expert in biological control., and we look forward to launching further sampling this summer.

Activity 2
As mentioned above, the graduate student has been leveraging the Forest Service funded work on forest recovery following outbreaks of spruce budworm to begin work on these objectives. The student collected several hundred pupae of spruce budworm this past summer and then identified them to sex using morphological characters under magnification. As the females emerged, our plan was to tether the females using dental floss before deploying them to the field. After a few days of exposure to flying males, our plan was to recollect them and return the insects to the lab. Dissections would indicate which females had mated and how frequently mating occurred. We experience several problems, however. First, although the tethering technique has been used successfully with other Lepidoptera, we found it did not work well with spruce budworm. We tried both tying and gluing techniques. The second problem was that birds would frequently prey on the budworms and ruin the experiments. We have consulted with colleagues in Canada who have tried similar experiments and have new ideas to secure the budworms with "lobster traps" that allow a male to fly into the trap but not out. The female remains protected from birds. Stay tuned!

Dissemination
We are excited to share that we have advertised this work in two presentations already:

Rootes, J.M., and B.H. Aukema. Ungulate browsing affects recovery of forests impacted by eastern spruce budworm. Entomological Society of America Annual Meeting Nov 12-16, 2022, Vancouver, BC

Rootes, J.M. and B.H. Aukema. How does ungulate herbivory impact forest regeneration in areas previously affected by the eastern spruce budworm? North Central Forest Pest Workshop Sept 12-15, 2022, Grand Rapids, MN