Final Abstract

Final Report Approved on November 21, 2025

M.L. 2020 Project Abstract

For the Period Ending June 30, 2025

Project Title: Native Eastern Larch Beetle Decimating Minnesota's Tamarack Forests

Project Manager: Brian Aukema

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 08f

Appropriation Amount: $398,000

Amount Spent: $398,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

This project investigated the tree-kllling behavior of eastern larch beetle on tamarack as the unprecedented outbreak continues. We analyzed tree chemistry and defenses, identified how beetles communicate, cataloged natural enemies, and studied the life cycle of the beetle – laying the groundwork for pheromone-based management and population forecasting for resource managers.

Overall Project Outcome and Results

Eastern larch or tamarack is the fifth most abundant tree in Minnesota. An outbreak of eastern larch beetle began in 2001 and continues to the present, killing trees over 90% of Minnesota’s 1.26 million acres of tamarack forests. Our previous work showed that the unprecedented eruption coincided with expanding growing seasons that favor beetle reproduction. In this project, we investigated how eastern larch beetles coordinate attacks on trees and find mates using chemicals known as pheromones, how trees defend themselves, how rapidly the insects develop across a range of temperatures, and what other insects are present in these tamarack forests. Our project trained four graduate students and several undergraduate helpers. Working with collaborator Dr. Brian Sullivan (US Forest Service), we identified the chemicals that adult eastern larch beetles release when they colonize trees. Field testing of select blends revealed best

lures for detection and monitoring; other blends offer promising future avenues for tree protection. We catalogued more than 8,000 insects across 135 taxa in tamarack forests, yielding important insect biodiversity information in Minnesota's lowland conifer ecosystems. Further, we examined how trees respond to attacks by eastern larch beetles. We found that beetles preferentially colonize the largest trees in a stand. In fact, tree size is a better predictor of colonization and mortality than characteristics associated with tree defense such as the numbers of resin ducts. We showed that beetle larvae can enter a resting state as temperatures cool in the fall. Larvae then resume development to adults when favorable conditions return each spring, adding beetle numbers to waves of attack. Thus, seasonal outbreaks are exacerbated by expanding growing seasons: early, warmer springs and later, warmer falls. Our work underscores the continuing threat to Minnesota's tamarack resource, but also offers avenues for new management tactics to be developed ahead.

Project Results Use and Dissemination

We gave presentations at local, regional, national, and international workshops and conferences – in person and online – as audiences inside and outside of Minnesota wanted to learn how this otherwise benign insect became such a tree-killer. This work trained four graduate students, three of whom produced two theses and a dissertation as well as a number of scientific publications during the life of the project. Outreach presentations were given to foresters, community groups, researchers, state and federal agency personnel and others as we pieced together how expanded growing seasons facilitate more beetles and increased threats to tamarack.

Environment and Natural Resources Trust Fund

M.L. 2020 Approved Final Report

General Information

Date: December 2, 2025

ID Number: 2020-047

Staff Lead: Lisa Bigaouette

Project Title: Native Eastern Larch Beetle Decimating Minnesota's Tamarack Forests

Project Budget: $398,000

Project Manager Information

Name: Brian Aukema

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Project Reporting

Final Report Approved: November 21, 2025

Reporting Status: Project Completed

Date of Last Action: November 21, 2025

Project Completion: June 30, 2025

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 08f

Appropriation Language: $398,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to understand conditions triggering eastern larch beetle outbreaks and develop management techniques to protect tamarack forests from this native insect. This appropriation is available until June 30, 2025, by which time the project must be completed and final products delivered.

Appropriation End Date: June 30, 2025

Narrative

Project Summary: Eastern larch beetle, native to Minnesota, is suddenly decimating Minnesota's tamarack forests. This proposal develops insect management techniques and determines how bad this problem may remain in the future.

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

Tamarack (Larix laricina) is the fifth most abundant tree in Minnesota. Tamarack forests serve as habitat to several birds and mammals, including several on the DNR's list of Greatest Conservation Need, and provide critical ecosystem services such as water filtration. A key component of Minnesota's northern wetland ecosystems, tamarack's importance is increasing with the impending loss of black ash to emerald ash borer.

Eastern larch beetle is a native insect has killed trees over 40% of Minnesota's 1.26 million acres of tamarack forests since 2001. This insect is closely related to mountain pine beetle, and has been studied for more than 100 years. Outbreaks occasionally flare after other insects weaken the trees by eating their needles. In tamarack forests across North America over the past century, outbreaks have always subsided within three or four years. Hence, Minnesota's ongoing outbreak of 18 years and counting – spreading across almost half of the state's remaining tamarack – is highly unusual behavior for this insect.

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.

From 2012-2016, collaborative non-LCCMR research (UMN, DNR, US Forest Service) determined that extended growing seasons are responsible for this unprecedented outbreak. Previous research elsewhere in North America had shown that larch beetles can only reproduce once per year, because they putatively required a cold period (i.e., winter) before they become physiologically mature and reproduce in the spring. We discovered and published evidence that a proportion of insects in Minnesota can reproduce without a required cold phase (!). As such, we believe that the outbreak in Minnesota is occurring because a proportion of insects can develop a second generation each summer/fall as a consequence of slowly expanding growing seasons.

Because the insect has rarely been a problem historically, there is a paucity of management information for eastern larch beetle. In Minnesota, it remains critical to develop a better understanding of the insect for management plans (sampling, natural enemies, etc.

Activity 1: Characterize natural enemy complex, including what lures work best to attract them (e.g., foundational knowledge for biological control)
Activity 2: Determine what proportion of the insects can reproduce without overwintering and what cues affect those levels.

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?

Delineating the scope of the challenge will help understand management options and prioritize restoration efforts for tamarack on the landscape. For example, the US Forest Service publishes FIDL (Forest Insect and Disease Leaflet) guides for various insect challenges nationally. Currently, in the eastern larch beetle FIDL handbook, there is no section on management other than a note that management has not been required historically. This project will give us options to present to foresters and other natural resource managers throughout the upper Midwest.

Project Location

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

Region(s): NE, NW, Central,

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

Region(s): Central, NW, NE,

When will the work impact occur?

During the Project and In the Future

Activities and Milestones

Activity 1: Characterize the natural enemies and lures to attract them

Activity Budget: $194,630

Activity Description:
Bark beetles release airborne chemicals known as pheromones when they attack a tree in order to attract mates. The pheromone for eastern larch beetle has been discovered and is commercially available, but it is based on populations in western North America (think: different accent). The lure works well, but we hypothesize that further refinements will boost attraction (helpful for trapping pests) and/or selectively attract insects that feed on eastern larch beetle, such as checkered beetles and hister beetles. Preliminary surveys have shown that a variety of natural enemies are attracted to eastern larch beetle pheromones and could be useful in biological control, but a full survey has never been conducted.

Activity Milestones:

Description	Approximate Completion Date
Identification of accessible field sites with active populations	June 30, 2022
Characterization of tree chemicals that fend off beetles	September 30, 2024
List of predators and competitors associated with eastern larch beetle	June 30, 2025
Determination of optimal lure choice for trapping pest or augmenting natural enemies	June 30, 2025

Activity 2: Find the temperature threshold that governs generational development

Activity Budget: $203,370

Activity Description:
We now know that warm and/or elongated summers can result in two generations of eastern larch beetle in Minnesota instead of one. This activity will test development of the insect in the laboratory at a range of different temperatures to determine what life stage is receiving the developmental “stop sign” before winter, and elucidate whether the proportion of insects responsible for two generations each year instead of one changes through time. Once determined, we will be able to forecast the seasonal conditions under which tamarack will be under the greatest threat from this insect in the future.

Activity Milestones:

Description	Approximate Completion Date
Determination of diapause conditions and life stage	June 30, 2024
Determination of seasonal conditions that may trigger or maintain outbreaks	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Forest Health Team	MN Department of Natural Resources	Field and logistical support	No
Dr. Brian Sullivan	US Forest Service	International expert who will help with pheromone identification	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 share results at workshops, field days, and conferences as opportunities arise. Based on past research in the Aukema lab, example venues might be the annual Northern Silviculture Workshop in Walker, MN; the North Central Forest Pest Workshop; the January Cloquet Forestry Research Review, Western Forest Insect Work Conference, university seminars, Entomological Society of America, IUFRO, or others. This work will form the basis of a graduate thesis at the University of Minnesota, and we anticipate peer-reviewed publications for the scientific literature as well by or shortly after project completion. We will also send out notable achievements on social media. We will acknowledge the support of the ENRTF in all dissemination efforts.

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?
Past non-LCCMR research on eastern larch beetle was supported by a UMN McKnight Professorship award to Dr. Aukema ($142K; 2011-2013) and a US Forest Service Evaluation Monitoring grant ($176K; 2011-2016). Dr. Aukema is currently conducting complementary, ongoing work on tamarack in Minnesota on the failure of biological control in the resurgence of an invasive needle-feeding moth, larch casebearer (US Forest Service $101K; 2016-2020), and has secured an additional $50K from USDA McIntire Stennis (2018-2023) to complement these two projects.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Biosurveillance and Biocontrol of Emerald Ash Borer - Phase 2	M.L. 2014, Chp. 226, Sec. 2, Subd. 04d	$447,000
Mountain Pine Beetle Invasive Threat to Minnesota's Pines	M.L. 2014, Chp. 226, Sec. 2, Subd. 04e1	$175,000
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 research work in Activities 1 and 2			19.9%	2		$243,438	-	-
Faculty summer support		Advise and mentor research conducted by graduate student			36.5%	0.6		$60,611	-	-
Undergraduate		Undergraduate student worker during summers			0%	1		$26,100	-	-
Temporary student worker (recent university grad)		Summer research help			8%	0.75		$31,355	-	-
							Sub Total	**$361,504**	**$361,504**	**-**
Contracts and Services										
							Sub Total	**-**	**-**	**-**
Equipment, Tools, and Supplies										
	Tools and Supplies	$1,811 each of four years for research supplies such as funnel trap repair, pheromone lures for baiting traps, chemical standards, twine, and miscellaneous gear	Lindgren funnel traps specialized to catch larch beetles, pheromones attract them to traps, twine is used for period repairs (vs. buying new trap at $80 each), standards for chemical analysis, and hanging traps					$7,244	$7,244	-
	Equipment	Computer	Data collection, storage, analysis, and writing over life of project (4 years)	X				$1,176	$1,176	-
							Sub Total	**$8,420**	**$8,420**	**-**

Capital Expenditures										
		Insect rearing chambers (2)	Hold insects at constant temperatures for proposed research work	X				-	-	-
							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Spread over 48 months life of project, primarily in summers but winter travel checking conditions too; revised April 2025 to reflect savings due to more proximate ELB populations than anticipated (savings in mileage and lodging). Savings also occurred from generous DNR travel support summer 2024.	Trips for sampling eastern larch beetle and natural enemy complex, collecting tree resin, testing pheromone responses. Travel estimates derived from previous projects on larch beetle in northern Minnesota.					$10,336	$10,336	-
							Sub Total	**$10,336**	**$10,336**	**-**
Travel Outside Minnesota										
	Conference Registration Miles/ Meals/ Lodging	Revised April 2025 to reflect approx. $4K savings. Previous: Estimated 9 conference/workshops over 4 year life of project (adding 3rd grad student Aug 2023); Estimate for four day conference: $500 travel, $800 hotel, $250 food, $200 registration (student rate). Cost will likely continue to be reduced by competitive student travel grants; e.g., student on Activity 1 just received $1K travel award with DDF Fellowship!	Annual conference or workshop(s) to disseminate project results & confer with other experts	X				$11,932	$11,932	-
	Other	Revised Apr 2025 to reflect savings from canceled final trip. Previous: Three trips to Pineville, LA, 1 month duration each.	Expert Dr. Brian Sullivan recently offered a month of his time, expertise, and	X				$4,414	$4,414	-

		Trip description: student and project manager driving to Pineville with tree sections and insects (2 days), student staying for 3 weeks before driving back (2 days) while project manager rtn by air after 3 days. Est. $1250 fleet truck rental, $1000 mileage (2500 miles x 40c/mile), $1920 lodging next to research station (24 nights x $80), $350 per diems ($50/day; 4 travel days student, 3 project manager), $375 hotel en route ($125/night; 2 nights student, 1 night project manager), flight ($480, project manager return). Total budget is less than this due to cost savings staying in VA lodging in 2022, which will not be used in 2023. Amendment 8/23: instead of project lead going to Pineville, bringing Dr. Sullivan here to demonstrate new portable behavioral assay	specialized equipment, to train the student to identify pheromone directly from eastern larch beetle.							
							Sub Total	**$16,346**	**$16,346**	**-**
Printing and Publication										
	Printing	Publication charges and printing of research posters	Page charges for peer-reviewed journal articles; research posters for conferences					$1,394	$1,394	-
							Sub Total	**$1,394**	**$1,394**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$398,000**	**$398,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Insect rearing chambers (2)	No longer required; used unexpectedly inherited chambers (although they broke toward end of project) **Additional Explanation :** Requesting permission for two rearing chambers for lab assays in Activities 1 and 2. We currently have 5 old chambers; one wore out on previous LCCMR work (rearing biological control agents for EAB) and has been repaired without success and the other similarly needs replacement soon. Replacement chambers will last beyond life of project, but will continue to be used for forest insect work of benefit to the state (such as EAB).
Equipment, Tools, and Supplies		Computer	Requesting permission for a desktop computer $1176 for graduate student to store data, conduct analyses, and write results over life of project (4 years)
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	Revised April 2025 to reflect approx. $4K savings. Previous: Estimated 9 conference/workshops over 4 year life of project (adding 3rd grad student Aug 2023); Estimate for four day conference: $500 travel, $800 hotel, $250 food, $200 registration (student rate). Cost will likely continue to be reduced by competitive student travel grants; e.g., student on Activity 1 just received $1K travel award with DDF Fellowship!	Special request of $1750/conference for student(s), PI to share results/ receive advice at forest insect conference, which may be out of state (e.g., North Central Forest Pest Workshop where MN resource professionals attend rotate around midwest). Most experts are in other places with tamarack such as western North America and Canada.
Travel Outside Minnesota	Other	Revised Apr 2025 to reflect savings from canceled final trip. Previous: Three trips to Pineville, LA, 1 month duration each. Trip description: student and project manager driving to Pineville with tree sections and insects (2 days), student staying for 3 weeks before driving back (2 days) while project manager rtn by air after 3 days. Est. $1250 fleet truck rental, $1000 mileage (2500 miles x 40c/mile), $1920 lodging next to research station (24 nights x $80), $350 per diems ($50/day; 4 travel days student, 3 project manager),	Dr. Sullivan has offered to conduct pheromone identification and electroantennogram studies in his lab at no cost other than our expense sending the graduate student with beetles and clean tamarack for a month. We are thrilled with this unexpected opportunity as Dr. Sullivan is the expert in this field. While we have good guesses on attractive chemicals the beetles produce, this opportunity would pay for itself by eliminating the first few iterations of field experiments in initial proposal (testing best guesses) and moving to immediate identification and testing of the most behaviorally-active compounds identified by Dr. Sullivan and the student on this project.

		$375 hotel en route ($125/night; 2 nights student, 1 night project manager), flight ($480, project manager return). Total budget is less than this due to cost savings staying in VA lodging in 2022, which will not be used in 2023. Amendment 8/23: instead of project lead going to Pineville, bringing Dr. Sullivan here to demonstrate new portable behavioral assay	

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
			State Sub Total	**-**	**-**	**-**
Non-State						
In-Kind	US Forest Service MacIntire Stennis MN17-095 "Challenges to tamarack from native and invasive insects in Minnesota"	Augmenting travel funding, publication costs, vehicle repairs	Secured	$50,000	$50,000	-
			Non State Sub Total	**$50,000**	**$50,000**	**-**
			Funds Total	**$50,000**	**$50,000**	**-**

Attachments

Required Attachments

Visual Component

File: 26bb7af9-f44.pdf

Alternate Text for Visual Component

Picture of tamarack forest and eastern larch beetle...

Supplemental Attachments

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

Title	File
LCCMR 2019 Letters of support re-loaded (DNR, SFEC)	6e15188b-788.pdf
Background check waiver	c5701ebc-36f.pdf
Research paper on tree chemistry	7a95de3b-3c1.pdf
Research paper on eastern larch beetle pheromones	96ec46ae-746.pdf
Research paper on behavioral testing of compounds against eastern larch beetle	7363db0a-405.pdf
PhD dissertation of Emily Althoff	ffa72423-9fc.pdf
MS thesis of Rose Picklo	8f45004f-9da.pdf
MS thesis of Grace Graham	12a4eaef-164.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

We have made two changes:

1. Updated salary & benefits rates within personnel category to current.

2. Reallocated a portion of research travel from Minnesota to travel out of state, with accompanying permission request. Activity 1 originally proposed a series of iterative field experiments to develop a "better" lure for insect monitoring. Recently, Dr. Brian Sullivan of the US Forest Service (Pineville, Louisiana) offered to conduct pheromone identification and electroantennogram studies in his lab at no cost. He is an expert in this area. We propose to seize this opportunity and bring insects and tree material to Pineville shortly after the project begins. While we have good guesses on attractive chemicals the beetles produce, this opportunity would pay for itself by eliminating the first few iterations of field experiments (testing good guesses) and permit rapid field testing of the most active compounds (i.e., “best” lure) identified by Dr. Sullivan.

Neither change affects the scope, overall budget, expected outcomes or timeline of the project.

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?

Yes

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

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	• Budget - Travel and Conferences	Initial trip to identify pheromone compounds in Pineville, LA was delayed until August 2021 workplan approval. Using limited, late season beetles low in viability, the trip still facilitated identification of compounds to field test this spring, but no more (e.g. male- vs. female-produced compounds). This amendment budgets another trip to Pineville using expected savings from MN travel as we're unexpectedly finding beetles close to Twin Cities than ever before. Thank you for consideration.	May 6, 2022	Yes	May 6, 2022
2	Amendment Request	• Budget - Travel and Conferences	Three changes within travel (total travel does not change). 1) In Minnesota, request cost-saving use of lab truck ($114 insurance/month vs. $850 rental) as available, with savings retained in travel. 2) For conferences to present work/meet with experts, updated estimated costs due to inflation. 3) For collaborative trip to use specialized equipment in Pineville, LA, corrected typo clarifying three (not two) trips. Thank you for consideration and investment in project to date!	March 21, 2023	Yes	March 23, 2023
3	Amendment Request	• Budget • Activities and Milestones • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Printing and Publication	Two changes (no overall changes to scope or budgets): 1. Modified Activity 1 Milestone 3 to seize opportunity to add new student who has been characterizing resin through the year outside of LCCMR. 2. Minor changes in distribution across travel categories to reflect a) new accounting method at UMN for lab vehicle use b) additional workshop/conference travel	November 3, 2023	Yes	November 9, 2023

			given additional person c) Swap trip: Dr. Sullivan to MN instead of project lead to Louisiana. Thanks!			
4	Amendment Request	• Budget • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Printing and Publication	Approaching project completion, a reallocation of current and projected expenses across categories to align as necessary to complete project objectives. Three general changes: 1) Increase personnel $55K given opportunity to involve an additional grad student (amendment Fall 2023) 2) Decrease travel $30K given field sites thankfully (?) closer to Duluth than Red Lake (estimated from previous work) 3) Decrease of $25K equipment due to inheritance of growth chambers from a retiring colleague. Thank you.	April 22, 2025	Yes	May 7, 2025
5	Amendment Request	• Budget • Other • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Printing and Publication • Budget - Non-ENRTF Funds Contributed • Attachments	Minor budget realignments (all less than $1,000) to reflect final costs. I also made a correction to the printing amount from an earlier report. No changes to scope or deliverables, and the project is successfully complete.	September 5, 2025	Yes	October 14, 2025

Status Update Reporting

Final Status Update August 14, 2025

Date Submitted: October 7, 2025

Date Approved: October 14, 2025

Overall Update

The project is now complete and has gone well. We were able to train 1 PhD student (Emily Althoff), 3 Masters students (Rose Picklo, Grace Graham, and Ian Grossenbacher-McGlamery), and involve several undergraduates each summer. The list of predators and competitors of eastern larch beetle can be found in Emily's attached dissertation. We have identified a suite of chemicals that eastern larch beetles produce when they chew into a tree, and were able to field test synthetic versions of specific blends to determine the best lure for monitoring and detecting eastern larch beetles in a tamarack forest. (Other blends show promise for interrupting the attractive response and have potential for tree protection. These will be tested in project 2025-283). Graduate student Rose Picklo conducted an impressive array of developmental assays that showed that eastern larch beetle has a facultative (optional) subadult diapause – that is, if cooling fall temperatures preclude development to adulthood before winter, the insects can enter a physiological diapause and overwinter to resume development in the spring (rather than simply freeze and die). Thus, seasonal outbreaks are exacerbated by expanding growing seasons: early, warmer springs and later, warmer falls.

Activity 1

Overall, we catalogued more than 8,001 insects across 135 taxa in tamarack forests, providing an important biodiversity checklist into these lowland conifer ecosystems that continue to be heavily impacted by eastern larch beetle. During this project, we identified and published the tree monoterpene chemicals that tamaracks produce in their bark and phloem that may serve multiple functions in attracting/deterring larch beetles. This work was publishd in Forests; another paper on the defensive chemical responses of tamarack has been conditionally accepted at Ecological Applications. We were surprised to find that beetles select trees more based on size (bigger=better) than on the chemicals with which they have to contend in the bark. Manuscripts on what pheromone components the insects produce and respond to were published in Journal of Chemical Ecology and Environmental Entomology. In conjunction with our collaborator Dr. Brian Sullivan (US Forest Service), we validated seudenol as an attractive pheromone component of female eastern larch beetles (i.e., the host-selecting sex) and showed that frontalin, another compound, has mixed activity, being attractive at low doses but repellent at high doses. The best lures for monitoring eastern larch beetle appear to be seudenol with a low dose of frontalin.
(This activity marked as complete as of this status update)

Activity 2

Despite challenges with equipment (i.e., aging and cantankerous growth chambers), we completed diapause induction experiments and found evidence of a facultative, prepupal diapause in eastern larch beetle. Adult eastern larch beetles attack trees in the spring. The progeny develop into adults by mid to late summer. Historically, these brood adults prepare to overwinter before re-emerging to attack new trees the following spring. Prior field studies showed that some insects will attack new trees in the summer, trying to squeeze in a second generation before fall and winter. Development of this second generation has spurred the unprecedented outbreak since 2000. Our discovery and characterization of a developmental delay indicative of a facultative, pre-pupal diapause was identified within third and fourth instar larvae when exposed to temperatures below 14°C and 17°C, respectively. Thus, it appears that insects that do not successfully develop to adults by the onset of winter can enter a physiological diapause, survive the winter, and continue development the following spring. We now know the mechanism and temperatures that foster beetle reproduction throughout the growing season: extended growing seasons along the southern margin of tamarack (i.e.,

earlier and warmer springs / later and warmer falls) exacerbate outbreaks.
(This activity marked as complete as of this status update)

Dissemination
We have had two dissemination activities since the spring project report. First, graduate student Ian Grossenbacher-McGlamery gave a presentation on this work to the Friends of the Sax-Zim bog. The Sax-Zim bog contains a rich tamarack resource and we were pleased that the group generously allowed us to set up research sites there during the course of the project. Second, new postdoc Shealyn Malone gave a presentation at the North Central Forest Pest Workshop that incorporated some of the tree defense work of Masters student graduate Grace Graham. This presentation was given on 23 September 2026 at the John Wright Forestry Center of Purdue University. This annual meeting gathers forest health professionals from government, private, and academic sectors each year in the seven state and two province area. Shealyn (and Grace)'s talk was entitled "Chemical defense dynamics of Larix laricina during an unprecedented outbreak of Dendroctonus simplex."

I believe I have attached copies of previous scientific papers; I will forward the next (in Ecological Applications) as soon as it is available.

Status Update Reporting

Status Update April 1, 2025

Date Submitted: April 22, 2025

Date Approved: May 7, 2025

Overall Update

The past six months have been spent preparing, submitting, and publishing manuscripts to peer-reviewed journals after the successful defense of three graduate students on this project last July. Activity 1 is all but complete as we have finalized the list of predators and competitors of eastern larch beetle. This list will be included in the final project report. The final milestone, determination of optimal lure choices, is also on track for successful completion as we have become the first group to demonstrate production of seudenol by eastern larch beetle. In the past six months we have published two research papers in Journal of Chemical Ecology (i.e., what beetles produce) and Environmental Entomology (i.e., to what beetles respond). A third paper on tree defense chemistry has been accepted pending revision to a different journal. In Activity 2, one manuscript on diapause is still in preparation as breakdowns of growth chambers hampered completion and the grant has almost reached its end date, but otherwise all has gone well.

Activity 1

The checklist of insect species found in our tamarack sites was submitted to a peer-reviewed journal (Journal of Insect Science) but not accepted as the reviewers requested vegetation data that could potentially link biodiversity of the insects (8,001 insects across 135 taxa) with habitat types. We appreciated the invitation, but collection of vegetation data is beyond what we had proposed and not feasible in the timeline left. Manuscripts on what pheromone components the insects produce and respond to were published in Journal of Chemical Ecology and Environmental Entomology. We validated seudenol as a pheromone component of female eastern larch beetles (i.e., the host-selecting sex) and showed that frontalin has mixed activity, being attractive at low doses but repellent at high doses. We will test one more set of compounds suggested by our results this spring, but otherwise have the project complete. A third research paper on tamarack defensive chemistry was conditionally accepted at Ecological Applications.

Activity 2

As mentioned in the last project report, we completed diapause induction experiments and found evidence of a facultative, prepupal diapause in eastern larch beetle, a new discovery for this insect with major implications to beetle pressure in a warming climate. A manuscript submitted to Journal of Insect Physiology requested methodology not commonly used for bark beetles. Unfortunately at this stage, we are hampered with malfunctioning equipment. Two growth chambers approved in the original project budget were not purchased when the Project Lead inherited three growth chambers from a neighbouring laboratory after a colleague's retirement. Over the past 12 months, however, these chambers have each broken down and are too old to be repaired. Completion of additional experiments, even if new chambers could be procured, is likely time limited with a June completion date and weather now warming into spring that will affect beetle physiology. Instead, we have rebudgeted travel and equipment savings into personnel, as the involvement of a third graduate student on this project incurred higher costs in personnel. Despite the growth chamber breakdowns, overall, we are quite pleased with project results and the ability to involve more trainees.

Dissemination

Aukema, Brian H., Althoff, Emily R., and Brian T. Sullivan Unraveling the pheromone composition and behaviour of eastern larch beetle Dendroctonus simplex LeConte (Coleoptera: Curculionidae) in the Great Lakes region. Western Forest Insect Work Conference, April 14-17, 2025, Santa Fe, New Mexico.

Status Update Reporting

Status Update October 1, 2024

Date Submitted: October 3, 2024

Date Approved: October 25, 2024

Overall Update

The project continues to go well. This summer was incredibly busy as we had three students defend their graduate degrees (two Masters, one PhD). All three contributed to this project and made impactful discoveries that help us understand more of this system and how it is responding to a changing climate. In Activity 1, we are slightly ahead of expected schedule on Milestone 1 and 2 due in part to a tremendous push from Emily Althoff (PhD) who defended before accepting a faculty position at the University of Missouri. We have tree chemicals identified on Milestone 3 (including a publication last year), but are using the extra breathing room this fall to collaborate with Prof. Adrian Hegeman (Department of Horticulture, UMN) to identify some trace, challenging compounds that may have biotic relevance but have never been investigated. In Activity 2, departing MS graduate Rose Picklo determined that a facultative diapause likely occurs in the L3 and L4 stages and we are now submitting that work for publication as well.

Activity 1

The two students working on the arthropods associated with eastern larch beetle and optimal lure choices (Emily Althoff) and characterization of tamarack defensive chemicals (Grace Graham) defended their dissertations and theses in July 2024. Emily Althoff (PhD) finished identifications of insects in her funnel traps and rearing from infested logs of tamarack and identified 8,001 insects from 135 taxa, including five new state records for species not previously found in Minnesota (three species of wasps and two species of rove beetles). An additional species of wasp appears to be something that other researchers have found in Michigan and Newfoundland, but has never been formally described because only a few specimens have been found. This work has been submitted to the Journal of Insect Science and sets us on pace to complete Milestone 1 approximately six months early. Emily's other paper on determination of optimal lure choices has now been submitted to Environmental Entomology. We discovered that high doses of frontalin (a component of the insect's aggregation pheromone) can (nonintuitively) interrupt the aggregation response for eastern larch beetle, which reflects eastern larch beetle's attempt to deter additional colonizers from host trees when colonization densities become too high.

Activity 2

We completed all diapause induction experiments and found very clear evidence of a facultative, prepupal diapause in eastern larch beetle. That is, we have found evidence that if beetles develop to the L3 or L4 life stages in the fall and temperatures under the bark fall below 17 degrees C, a proportion of individuals will enter a metabolically suspended state until spring. This is a new discovery for eastern larch beetle. Larvae are the most cold hardy life stage, so this strategy helps overwintering success. Elucidating this diapause allows us to calculate seasonal conditions next that foster population success. We tried to determine mechanisms by which the insect exit the arrested state (do they need a longer cold period, or is simple warming enough to entice them to resume development?) but suffered a high degree of mortality that makes the data gathered to date unclear. We hope to try again this winter if we can secure enough insects and we suffer no equipment malfunctions.

Dissemination

Graham, Grace O. (2024) The resin defenses of eastern larch in response to eastern larch beetle: exploring insect-host dynamics under changing climatic conditions. MS Thesis defense, University of Minnesota, July 9.
Picklo, Rose M. (2024) . Influence of temperature on development of eastern larch beetle Dendroctonus simplex LeConte and reproductive success in two novel Larix hosts. MS Thesis defense, University of Minnesota, July 16.

Althoff, Emily R. (2024) The chemical ecology and insect associates of the eastern larch beetle (Dendroctonus simplex LeConte). PhD Dissertation defense, University of Minnesota, July 12.

Status Update Reporting

Status Update April 1, 2024

Date Submitted: May 2, 2024

Date Approved: May 31, 2024

Overall Update

The project continues to go well and we appreciate the approval of the amendment that has permitted additional training opportunities for personnel on this project. Over the winter, we focused the majority of our time on insect identification and data analysis. In Activity 1, characterization of volatile blends that attract both the eastern larch beetles and their natural enemies, we had identified two compounds being produced by the beetles and then deployed a field experiment testing release rates. We identified most of the insect catch from these experiments through the winter (some still pending). We obtained non-LCCMR funding to send the student to the Smithsonian of Natural History to work with an expert on identification of a species of parasitoid that appears to be a new discovery! Analysis of resin data produced by trees throughout the growing season yielded unexpected variation from spring to fall. In Activity 2, we continued analyzing data on studies of temperatures and eastern larch beetle development, finding that the lab results appear to be in good agreement with field observations – critical to eventual forecasting ability.

Activity 1

The student working on the field testing of lures and identification of natural enemies has been analyzing data from last summer's experiment testing different release rates of a compound known as frontalin that the beetles produce. We have been surprised that the highest level of attraction to this compound, when combined with seudenol (a compound known to attract eastern larch beetle) appears to come at an intermediate dose that we tested (0.1 mg/day). Lower doses are still attractive, and suggest that we have found the biological basis for mass aggregation of beetles on living trees as they come under attack. A few beetles attract other beetles (i.e., low levels of frontalin) until higher numbers arrive and eventually the signal becomes less attractive as the tree fills with insects and dies. We hope to exploit results such as these for tree protection strategies in a future LCCMR study. Resin studies showed the color and amount of resin is *highly* variable even within a single tree, and can change back and forth. Ongoing chemical analyses continue, as well as matching the resin produced with beetle attack periods.

Activity 2

As the latest batch of cold treatments terminate and we see which beetles resume development vs. stay in diapause (or have simply died), we will analyze these data. We are beginning to see clear patterns that any developmental arrest that allows beetles to stop development in the fall and resume the following spring appears to be restricted to late larval life stages. These responses appear to have some variation, however. In other words, there are frequently some insects in any developmental assay that behave in a manner we don't expect (e.g., continuing development at a temperature we think would 'shut them down'). These adaptations appear to allow them to persist in a changing environment – ensuring survival for the beetles but not necessarily our trees. We are working to integrate what we see in the lab with observations taken during resin collection in the field.

Dissemination

The graduate students gave three presentations of their work two over the winter as we continue to try to rapidly disseminate project results. The out-of-state presentation to the Entomological Society of America was funded entirely by external travel award to student, and coincided with her trip to the Smithsonian Museum of Natural History to work on identification of this insect that appears to be a new species.

Althoff, E.R., Sullivan, B.T., and B.H. Aukema. Not as "simplex" as that: understanding the ecological role of frontalin in relation to Dendroctonus simplex LeConte. Entomological Society of America Nov 5-8, National Harbor, MD.

Grace Graham, working on the resin chemistry objective, gave presentations to two gatherings of foresters and resource professionals in Minnesota:

Graham, C.G., Windmuller-Campione, M.A., and B.H. Aukema. Changes in induced defensive responses of Larix laricina in response to attacks by Dendroctonus simplex. Annual DNR/USFS Forest Health Workshop Feb 6, Grand Rapids, MN

Graham, C.G., Windmuller-Campione, M.A., and B.H. Aukema. Resin defenses of Larix laricina in response to Dendroctonus simplex. 2024 Forestry and Wildlife Research and Practice Review Feb 21, Cloquet Forestry Centre, MN

Status Update Reporting

Status Update October 1, 2023

Date Submitted: November 3, 2023

Date Approved: November 9, 2023

Overall Update

We have now returned indoors for the winter. In Activity 1, characterization of volatile blends that attract both the eastern larch beetles and their natural enemies, the PhD student spent more time with collaborator Dr. Brian Sullivan and his specialized equipment in the US Forest Service laboratory in Pineville, LA. They identified two compounds being produced by the beetles and then devised an ambitious field experiment testing release rates. Identifications of natural enemies from these experiments is ongoing (including an exciting discovery of what appears to be a new species to science!). The PhD student, Emily Althoff, received a prestigious Doctoral Dissertation Fellowship from the University of Minnesota for her work on Activity 1, and both Emily and Rose Picklo (Masters student on Activity 2) won competitive awards for their presentations at the North Central Forest Pest Workshop in Wausau, Wisconsin this fall! In Activity 2, studies of temperatures and eastern larch beetle development, Rose continued studies focusing on cold treatments and then warming the beetles up (a la winter then spring conditions) to see how they respond developmentally. The upcoming winter will involve a lot of data processing from experiments on both Activities.

Activity 1

Emily returned to the laboratory of collaborator Dr. Brian Sullivan and continued experiments identifying pheromone components produced by beetles tunneling in tamarack logs. In the last progress report, we mentioned that some components decrease rapidly after mating, which led us to hypothesize that at least one of these components was a key to mate attraction. Dr. Sullivan and Emily devised an intricate walking beetle bioassay in the laboratory that seemed to prove this conjecture. Dr. Sullivan is hoping to bring this portable assay to Minnesota in lieu of Dr. Aukema returning to Pineville with Emily, as had been in the original workplan (see Amendment request). A related field experiment in Minnesota captured thousands of beetles and natural enemies, including one species which appears to be new to science. We are continuing to work on insect identifications. Another graduate student, Grace Graham, has joined Activity 1 to characterize resin chemistry of the trees that affects both beetle attraction and tree defense. Her first year of data collection was funded by a University of Minnesota graduate fellowship, and we are excited to bring her onto this project for year 2.

Activity 2

In the spring we brought in some of the “phloem sandwiches” (i.e., bark and phloem sandwiched between sheets of plexiglass in which we have eastern larch beetles developing from egg to adults). These had been subjected to cold treatments after various lengths of development in an attempt to determine which life stage might have a developmental arrest that allows the insect to survive the winter (i.e., diapause), and, more importantly, when the insects might resume development after being rewarmed. These experiments give us some idea of how life cycles are paused and resumed under various climatic scenarios – our ultimate goal by the end of the project. We continue to analyze data from the many permutations in these experiments. We experienced two challenges (not insurmountable); first, we realized this past spring that more beetles than expected died from cold exposure last winter, perhaps because we did not cool them down at a sufficiently slow “autumnal” rate (we have no way of knowing for sure). Second, one of our growth chambers developed a hole where beetles could escape! Fortunately, the insects remained in the rearing room and were recovered, but we will be replacing the chamber soon.

Dissemination

North Central Forest Pest Workshop is an annual gathering of forest health professionals in the seven state two province area of the Midwest, this year in Wisconsin:

Picklo, R. and B.H. Aukema. Facultative pre-pupal diapause in the eastern larch beetle, Dendroctonus simplex. NCFPW Sep 11-14, Wausau, WI (2nd place)

Althoff, E.R., Sullivan, B.T., and B.H. Aukema. Forty years of cues and clues: what do we know about frontalin as an attractant for eastern larch beetle? 2023 NCFPW Sep 11-14, Wausau, WI (3rd place)

The work continues to get strong interest from outside of Minnesota as well:

Aukema, B.H. How insect response to a changing climate is decimating tamarack in the Great Lakes region. University of Alberta April 14, Edmonton, AB (travel paid by U of A)

Aukema, B.H. Half-hour presentation on extended growing seasons and outbreaks of eastern larch beetle to the Michigan-based interagency meeting. Fall Interagency Forest Invasives Committee Meeting Virtual (MI); Oct 17. 2023. Attendance: 23 state and federal personnel.

Research update from the forest entomology lab: one hour presentation at the USFS St. Paul Field Office Forest Health Cooperators meeting Roseville, MN, March 1 2023.

Status Update Reporting

Status Update April 1, 2023

Date Submitted: March 21, 2023

Date Approved: March 23, 2023

Overall Update

The project continues to go well, with several accomplishments this fall. We previously reported completion of Activity 1 Milestone 3, characterization of tree volatiles. We worked through the fall to prepare that data for publication and it just came out in Forests, an open-access peer-reviewed journal. The work was invited to be part of a special collection on insect and tree volatiles of interest in forest pest management. The information will be incorporated into future lure development as we continue testing behavioural responses of eastern larch beetle to different compounds in the field this summer. In Activity 3, we have been very pleased with the volumes of data collected on beetle development at different temperatures. We think we see early evidence of a diapause in some insects! This would be a new discovery for eastern larch beetle. We were pleased to share these collective results at two venues this past fall.

Activity 1

We have spent the fall and winter to date analyzing the trap catches from summer trapping experiments in which we deployed different chemical combinations. We have found that one particular tree chemical seems to retain attraction to eastern larch beetle, but, when paired with a pheromone component, tends to decrease attraction of natural enemies: a great result for reducing bycatch! The graduate student is now working on identifying the species of natural enemies. We have also been processing the data from working with collaborator Dr. Brian Sullivan at the US Forest Service station in Pineville, Louisiana last summer and making plans to return. Last summer the graduate student measured chemical signals produced by eastern larch beetles in the laboratory when they tunnel into tamarack logs. We have found that one particular compound remains very high after the beetles mate, while three other compounds tend to decrease rapidly. We are now making plans to test these components behaviorally in the next round of field assays and perhaps with a new arena assay in the laboratory.

Activity 2

The fall and winter to date have been spent checking development of individual beetles within extensive rearing experiments on a near daily basis. The graduate student had set up multiple “phloem sandwiches” (i.e., bark and phloem sandwiched between sheets of plexiglass in which we have eastern larch beetles developing from egg to adults). Many beetles progressed from egg through five larval stages to pupae and then adults at warmer temperatures and were complete by November. Colder temperatures, however, slow development such that a great deal of time was spent painstaking examining tiny larvae through the plexiglass for signs of molting on a near daily basis (i.e., measuring the head capsules of tiny larvae under the microscope). We have been finding in the L4 stage that some beetles seem to stop developing at colder temperatures of between 10C and 15C, which would be consistent with a diapause or developmental arrest until more appropriate climatic conditions return. In some of the warmer assays, the graduate student has been dissecting adult progeny to determine if they are reproductively mature. Some prior research has suggested that some adult beetles need a cold period to become reproductively mature, so we are testing that.

Dissemination

In addition to the publication, the two graduate students gave two presentations at the Joint Annual meeting of the Entomological Society of America and Canada in Vancouver in November. One also gave a presentation on the potential for finding a developmental arrest in eastern larch beetle to the Northern Silviculture Workshop in Walker, Minnesota in January. This annual workshop attracts close to 200 foresters and agency personnel from across Minnesota.

Publication

Althoff, E.R., O'Loughlin, T., Wakarchuk, D.A., Aukema, K.G., and B.H. Aukema. (2023) Terpenoid composition of phloem of Larix laricina in the Great Lakes Region: with what must eastern larch beetle Dendroctonus simplex contend? Forests 14(3), 566; https://doi.org/10.3390/f14030566

Presentations

Althoff, E.R., Sullivan, B.T., O'Loughlin, T., Wakarchuck, D., and B.H. Aukema. Larching on: Development in eastern larch beetle chemical ecology. Entomological Society of America Annual Meeting Nov 12-16, 2022, Vancouver, BC

Picklo, R., and B.H. Aukema. Developmental timing of eastern larch beetle, Dendroctonus simplex. Entomological Society of America Annual Meeting Nov 12-16, 2022, Vancouver, BC

Rose Picklo and Brian Aukema. Developmental arrest in eastern larch beetle. Northern Forest Health Workshop, February 1, 2023, Walker, MN.

Status Update Reporting

Status Update October 1, 2022

Date Submitted: October 14, 2022

Date Approved: October 17, 2022

Overall Update

The project continues to go well, with several accomplishments over the summer. First, we have completed milestones 3 and 4 under Activity 1 on schedule. That is, we have successfully analyzed tree chemicals present under the bark of eastern larch that we can now incorporate into future lure combinations (Milestone 3). We also were able to identify eight suitable trapping sites where we deployed lures to test behavioral activity of both eastern larch beetles and their predators in the field (Milestone 4). We successfully recruited a Masters student on Activity 2 to examine temperature thresholds that control development of each life stage of eastern larch beetle. We immediately set up an ambitious laboratory experiment that has gone very well in the first few months as we track insect developmental progression. We were pleased to present early methods and results from this work in a talk and poster at the North Central Forest Pest Workshop in Grand Rapids, MN in September.

Activity 1

This summer the PhD student spent a month at the US Forest Service station in Pineville, Louisiana working with Dr. Brian Sullivan to further measure chemical signals and responses to volatiles by eastern larch beetles in the laboratory. Female beetles initiate attacks on trees. Volatile profiles were taken from twenty female beetles tunneling in tamarack, twenty female beetles that had mated, twenty mated male beetles, and twenty females that had not fed at all, as we try to determine which beetle-produced compounds are responsible for mating signals. Back at the University of Minnesota, we selected sites for beetle trapping and natural enemy attraction experiments in central and northern Minnesota. Each of eight sites received five traps with different compounds based on work in Pineville and were checked weekly during the peak flight season of the first flight of beetles. We are currently analyzing the trap contents – some traps captured more than 7,000 beetles in one week! Finally, we received the results of tree chemistry back from collaborators in British Columbia, Canada, after we had sent samples of trees from various locations in Minnesota. We have just accepted an invitation to publish these data in an upcoming special journal issue.

Activity 2

We successfully onboarded a Masters student on Activity 2 to examine temperature thresholds that control development of each life stage of eastern larch beetle. Upon staffing the position, we immediately set up an ambitious experiment. With help from the DNR, we harvested a monster tamarack tree in central Minnesota and harvested its bark in large sheets once back in the lab. Pieces were cut into squares that were sandwiched between sheets of plexiglass to make “phloem sandwiches.” Into more than 80 sandwiches, mating beetles were introduced that then laid eggs. We have been checking these sandwiches daily to measure developmental times of eggs, larval life stages, pupae, and adults at a range of cold to warm temperatures in growth chambers. Some of the warm temperature plates have completed development; as expected, beetle development slows at colder temperatures. We continue to watch plates especially between 10-15C to determine if there is a spot where larval development is suspended in a temperature-induced diapause in a bid to understand what cues govern development of two generations of beetles in one year.

Dissemination

The two graduate students gave two presentations at the North Central Forest Pest Workshop in Grand Rapids, Minnesota (Sept 12-15). This annual workshop attracts state and federal agency personnel, foresters, and resource managers from seven states and two Canadian provinces in the Great Lakes region.

Althoff, E.R., Sullivan, B.T., O’Loughlin, T., Wakarchuck, D., and B.H. Aukema. Living larch: developments in eastern larch

beetle chemical ecology (presentation)

Picklo, R.M. and B.H. Aukema. How does temperature affect developmental timing of eastern larch beetle? (poster)

Status Update Reporting

Status Update April 1, 2022

Date Submitted: May 6, 2022

Date Approved: May 6, 2022

Overall Update
We began work on Activity 1 immediately after the workplan was approved in August of 2021 as a PhD student, Emily Althoff, was brought onto the project. The first (and most reliable) generation of eastern larch beetle flies in early-mid summer, but we were fortunate to collect stragglers flying in August and keep them alive long enough to bring them to our collaborator Dr. Brian Sullivan in Pineville, Louisiana. At the US Forest Service research station, we spent a week collecting volatiles produced by the beetles and studying electroantennogram responses with one of the world's foremost specialists in this area. Although we did not have a large number of viable beetles with which to work, we were able to collect some critical initial data that has positioned us to test compounds in the field this spring. A book chapter was published that highlighted the need for this work. Several research update/planning conference presentations were given and we gained valuable feedback from colleagues. A graduate student has been identified to work on Activity 2 beginning this summer.

Activity 1
Work on determining the responses to chemical lures focused on working with collaborator Dr. Brian Sullivan with the US Forest Service in Pineville, Louisiana to measure chemical signals and responses to volatiles in the laboratory. Immediately after the workplan was approved, we successfully collected two dozen beetles using flight traps at sites less than one hour from the Twin Cities, closer than we expected to find eastern larch beetle in tamarack. We drove two days to Pineville, and immediately placed the beetles onto clean tamarack logs. As the beetles tunneled, they produced "frass" that contains pheromones to attract conspecifics. These volatiles were collected onto adsorbent beads before the chemical compounds were extracted and identified using gas chromatography. Simultaneously, we took other beetles and carefully measured electroantennogram responses in their antennae to various mixtures of potential pheromones and host compounds wafted across them. Although we did not have high numbers of beetles, we found some very surprising responses to compounds that had never been previously recorded! The winter was spent analyzing these results. We have planned field experiments this summer to begin testing functions of these compounds and see how they compare to standard lures.

Activity 2
A graduate student was recruited this spring to work on determining thermal development requirements for eastern larch beetle. She will begin this summer.

Dissemination
In the fall, we published a book chapter on eastern larch beetle and tamarack that contained the state of knowledge for managing this beetle. The chapter contained contributions from people working on this project, the DNR, and Prof. Marcella Windmuller-Campione as we collectively work to better management of lowland conifer forests that are being decimated by eastern larch beetle. The full citation is:
McKee, F.R., Windmuller-Campione, M.A., Althoff, E.R., Reinikainen, M.R., Dubugue, P.A., and B.H. Aukema. (2021) Eastern larch beetle, a changing climate, and impacts to northern tamarack forests. In: Bark Beetle Managememt, Ecology, and Climate Change. Edited by K.J.K. Gandhi and R.W. Hofstetter. Elsevier.

The graduate student, Emily Althoff, also gave research presentations of her initial findings and/or discussed future plans at the following workshops and conferences:
North Central Branch of the Entomological Society of America (March 2022)

Entomological Society of America National Meeting (March 2022)
IUFRO Conference on Biological Invasions of Forests (Sept 2021)

We are pleased to report that these presentations were well received, and that the student was able to secure external travel funding for many of these conferences.