

2018 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Assessing Natural Resource Benefits Provided by Lichens and Mosses

PROJECT MANAGER: Daniel Stanton

AFFILIATION: University of Minnesota - Twin Cities

MAILING ADDRESS: 140 Gortner Laboratory, 1479 Gortner Avenue

CITY/STATE/ZIP: Saint Paul, MN, 55108

PHONE: 612-626-3028

E-MAIL: stan0477@umn.edu

WEBSITE: www.dstantonlab.com

FUNDING SOURCE: Environment and Natural Resources Trust Fund

LEGAL CITATION: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03e as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

APPROPRIATION AMOUNT: \$213,000

AMOUNT SPENT: \$206,452

AMOUNT REMAINING: \$6,548

Sound bite of Project Outcomes and Results

We documented the potential impact of moss and lichen on the flow of water and pollutants through Minnesota forests. This impact varies across the state depending on the forest type but can reach more than 15% of each rain event. Pollutant filtering effects are smaller but not unimportant.

Overall Project Outcome and Results

Moss and lichen are common in forests, and yet they are often overlooked. But this does not mean unimportant: they retain water and heavy metals, and so a mossy forest may function quite differently from a barren one. This project aimed to quantify how much moss and lichen is in Minnesota forests and to estimate their impact on water flows and pollutant retention.

To reflect the diversity of Minnesota's landscape, we established 83 plots in 30 counties across the state to provide detailed and region-specific coverage of all of the major forest types recognized by the DNR. We recorded which species were present, their abundance (on forest floor, tree trunks and fallen branches), and collected the most abundant ones for lab analyses. 1650 unique specimens were collected.

The amounts vary greatly across the state, from less than one pound per acre to over 1,500 pounds per acre. These translate into sometimes considerable water storage capacity. With respect to heavy metals, contents were often quite low, at fractions of a pound per acre. We will follow up with future work on urban lichens to determine whether this is due to the lack of pollutants in forest sites. By combining our results with existing maps of forest coverage, we've been able to map these contributions across the state.

Another objective of the work aimed to test these estimates with experiments of how much water and elements are retained in the lab and field. Due to delays, these experiments were only installed in Spring 2022, and their continued monitoring and analysis will be funded from other sources.

Overall, our findings draw needed attention to an overlooked component of our forests, both in terms of diversity and impact on water cycles.

Project Results Use and Dissemination

The activities and findings in this project have been shared with the general public through a number of venues, including public presentations through Minnesota Master Naturalists, Minnesota Mycological Society, and the

Bell Museum of Natural History; workshops attended by 30-50 people each at Minnesota Naturalists Association Annual Meeting (2019) and Cedar Creek Ecosystem Reserve (2019, 2022-115 participants!); a booth in the University of Minnesota pavilion at the MN State Fair and several other events. Scientific dissemination has so far included an undergraduate-led peer-reviewed publication and oral presentations at three international conferences. Further scientific publications are planned for late 2022.



Environment and Natural Resources Trust Fund (ENRTF) M.L. 2018 ENRTF Work Plan Final Report

Date of Submission: August 5, 2022

Final Report

Date of Work Plan Approval: 06/05/2018

Project Completion Date: June 30, 2022

PROJECT TITLE: Assessing Natural Resource Benefits Provided by Lichens and Mosses

Project Manager: Daniel Stanton

Organization: University of Minnesota-Twin Cities

College/Department/Division: College of Biological Sciences/Ecology, Evolution and Behavior

Mailing Address: 140 Gortner Laboratory, 1479 Gortner Avenue

City/State/Zip Code: Saint Paul, MN 55108

Telephone Number: 612-626-3028

Email Address: stan0477@umn.edu

Web Address: www.dstantonlab.com

Location: Statewide

Total Project Budget: \$213,000

Amount Spent: \$206,452

Balance: \$6,548

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03e as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

Appropriation Language: \$213,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to survey, map, and analyze mosses and lichens across the state, including their moisture-retention capacity, effects on hydrology, and ability to filter airborne pollutants. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18. ENVIRONMENT AND NATURAL RESOURCES TRUST FUND; EXTENSIONS. [to June 30, 2022]

I. PROJECT STATEMENT:

Although usually small and unassuming, lichens and mosses are among some of the most impressive organisms in our landscape: they easily withstand freezing and drying. This tolerance comes primarily from two characteristics: (1) the ability to take up water rapidly, sometimes even from moist air and (2) the ability to derive most or all of their nutrition from dust, rain and air. These characteristics also illustrate how lichens and moss are likely to affect their surroundings: by holding moisture in the canopy of trees and by retaining minerals and pollutants. This project will combine surveys and experiments to provide an accurate assessment of what the effects of mosses and lichens are on pollutant and water retention in Minnesota, and how these effects are distributed across the state. For this we will draw on resources that make Minnesota one of the best states in the country for this work, including extensive background knowledge established by the Minnesota Department of Natural Resources, world-class historical collections at the University of Minnesota and skilled experts.

II. OVERALL PROJECT STATUS UPDATES:

First Update January 31, 2019

Project is off to a promising start for Activities 1 and 2. The research technician managing the field and lab-work was hired and started mid-July 2018, and several undergraduate students (University of Minnesota, Saint Catherine's University) have been working on the project. Lichen and moss surveys have begun, with 14 plots in 3 counties surveyed to date. These surveys have already included more than 50 new county records in Anoka (11), Isanti (4), Carlton (30), and Lake (6) counties for lichens alone. Exact sites for 2019 fieldwork have been selected and collection permit requests are being processed. Students hired by the project are working processing the lichen and moss collected for identification, total mass, water holding capacity and drying rate, as well as analyzing photos to assess ground cover. Lichen and moss samples for pollutant and nutrient content have been cleaned, but not yet sent off for analysis. Mapping activities are expected to begin next fall, once more sites have been surveyed and samples analyzed.

The start of Activity 3 has been delayed by delays in getting sensor parts. We are still hoping to construct and deploy the sensors in late winter or early spring (March-April) of this year. If delays continue, we intend to switch to commercial sensors (that will be able to measure less aspects of microclimate for the same cost).

Since the start of the project we have participated in three activities talking about lichens and moss, including this project, to a general public.

Amendment Request (01/31/2019):

An amendment to modify personnel is requested. Funds for field-assistants to support the project researcher were initially requested for undergraduate students. However, undergraduates from outside of the University of Minnesota system (e.g. a student from Saint Catherine's University in Saint Paul who assisted with some work during summer 2018) cannot be hired at University of Minnesota under this category, and instead are considered temporary hires. The same applies to recent graduates, one of whom was hired to assist with field work once the school semester had started (when it would be difficult to find enrolled undergraduates able to spend 2-3 days a week off-campus). We would like to amend the budget to be able to direct some of the funds designated for undergraduate hires towards temporary hires when necessary.

Amendment Approved by LCCMR 3/11/2019

Second Update June 30, 2019

We are in the midst of our second season of fieldwork on Activities 1 and 2. Already the project technician (Abby Glauser) and her two assistants (both UMN students) have surveyed 12 plots, meaning that we are on track to more than triple the number of sites surveyed in the previous year. The geographic coverage is also much

greater.

Nearly all of the materials from 2018 have been fully processed, with all voucher specimens identified and ready for archiving in the Bell Museum. The material collected in summer of 2019 will be processed in the fall (once the semester starts and undergraduate workers are hired) and into 2020, and is expected to go faster than the previous year now that we are streamlined protocols for sample processing and are more familiar with the species.

Activity 3 continues to be delayed for the reasons above. The sensors were to be constructed in collaboration with a different lab at the University of Minnesota, and since they are in the process of updating their sensors to new models, it has seemed best to delay for a few months. If delays continue into September/October, we intend to switch to commercial sensors (that will be able to measure less aspects of microclimate for the same cost).

The preliminary results of from the first year of work on this project will be the subject of both an oral presentation ("Small and mighty: estimating contributions of lichens and bryophytes to ecosystem services in Minnesota's forests" given by Abby Glauser, with D Stanton as co-author) and poster presentation ("Epiphyte Cover Varies with Height and Forest Type Across a Temperate to Boreal Ecotone" given by Abigail Meyer, coauthors A Glauser and D Stanton) at the annual meeting of the Botanical Society of America in July 2019.

Third Update January 31, 2020

The second summer of fieldwork for Activities 1 and 2 was successful, and greatly expanded the coverage of the state. The total number of surveyed plots is now 47 plots in 20 counties (up from 14 plots in 3 counties a year ago), and nearly 2000 voucher specimens of moss, liverwort and lichen have been collected. The specimens and materials are now being processed, which is expected to take at least until the start of the final field season in May 2020. There has been one major staffing change, with the project technician (Abby Glauser) leaving the project in December 2019. However, a new project technician (Tana Route) with considerable relevant experience started in January 2020 and the impact of the turnover on project timelines for Activities 1 and 2 has been small.

Activity 3 continues to be delayed for the reasons above, and switching to commercial sensors has been delayed by the staffing change. Travel costs for Activities 1 and 2 have exceeded the initially planned budget, and that additional expense has been covered using other funds (which will also be used to cover costs in the coming fieldseason)

Amendment Request (05/28/2020)

We are requested funds be shifted from the Equipment/ budget line to Travel.

- Equipment budget would be reduced by \$9,000 to a revised budget of \$2,000
- Travel budget would increase by \$9,000 to a revised budget of \$13,000

An amendment is requested to reflect changing expenses arising from COVID-19 safety precautions, as well as delays in equipment development that interfered with Activity 3. University of Minnesota guidelines for fieldwork in summer of 2020 currently encourage separate vehicles and socially distanced accommodations for all field workers, which nearly triples travel expenses for Activity 1. At the same time, Activity 3 has been delayed (and any further developments will be constrained by strict restrictions on lab activity), leaving unspent funds currently designated for equipment purchases. We are proposing to decrease the number of sites in Activity 3 from 4 to 1 to reflect this shift. The number of sites visited in Activity 1 is greatly increased as well to reflect increased sampling coverage.

Amendment Approved by LCCMR 6/10/2020

Fourth Update June 30, 2020: The combination of University and child-care closures interfered with progress on the project and report preparation in the early months of the pandemic. In June 2020 much of the situation was

still in the process of being resolved, as guidelines for lab and fieldwork associated with the University of Minnesota were being issued. Staff also had to be reassigned into new roles to accommodate health concerns **LCCMR and project manager assessed project delays in March 2021 and updated reports and plans accordingly**

Fifth Update January 31, 2021

After a third summer of fieldwork, Activities 1 and 2 are on a good track towards completion. Pandemic related safety measures complicated costs for fieldwork, but the reallocation of funds authorized in summer 2020 made it possible to cover those and complete collecting activities. Eighty-three (83) plots from across MN have been surveyed, and the majority of the lichen and moss specimens from those collections are now identified (1650 specimens). The remaining identifications are expected to be completed by sometime in April. Specimen processing for pollutants (Activity 1) and water-holding capacity (Activity 2) has been a little slower than hoped due to the need to minimize schedule overlap in the lab to comply with COVID-19 safety protocols. However, both remain on track, and efforts are being made to hire additional undergraduate student workers to accelerate the pace of work.

Activity 3 continues to be a challenge, even in its reduced form, due to constraints on travel and labwork. Current plans are for the lichen/moss removal experiments involved to be installed in Spring 2021, and monitoring to be maintained past the completion date of the project using discretionary funds (Faculty Start-up) available to the Project Manager.

Specimen preparation for archiving has been on hold due to restrictions on space access, but is expected to resume in April 2021 and be completed by project end. Outreach and dissemination activities have been constrained, but not entirely canceled by the pandemic. Data analyses of results for scientific publications are currently underway, with the aim of having at least one full manuscript prepared and submitted by project end.

Following discussion with the project manager on 3/23/2021, LCCMR has added this project to the list of those eligible for a COVID-related extension, dependent on legislative action.

Project extended to June 30, 2022 by LCCMR 6/30/21 as a result of M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18, legislative extension criteria being met.

Sixth Update June 30, 2021:

Field and lab work for Activities 1 and 2 are completed, with a total of 83 plots across MN surveyed, covering 30 counties and all major forest types of the state. All specimens have been identified, and specimens have been processed for biomass, water-holding capacity and chemistry thanks to the efforts of the project technician and several undergraduate students/recent graduates. A subset of the results from Activity 2 (Hembre et al. 2021, adapted from a undergraduate work by UMN student Kate Hembre) was published in peer-reviewed scientific journal *Frontiers in Forests and Global Change* in June 2021. Analyses of the fuller dataset are on-going.

Seventh Update January 31, 2022:

All field and lab work on Aim 2 and all field and nearly all lab work on Aim 1 are now complete. The results are still being analyzed and modeled.

For Aim 3, field experiments planned for fall 2021 were unable to occur. However, a graduate student in the lab has developed lab and field experimental protocols to measure dust and nutrient capture by lichens and mosses that, combined with the modeling in Aims 1 and 2, will address Aim 3. This work is now started in the lab, with a field component to come in spring (once temperatures thaw) and is has support to be maintained beyond the completion date of the project.

Amendment Request (05/25/2022)

We are requesting that funds be shifted from the Other (Chemical analyses) budget line to Travel and Personnel.

- Other (chemical analyses) budget would be reduced by \$7,000 to a revised budget of \$8,000
- Travel budget would increase by \$1,000 to a revised budget of \$14,000
- Personnel budget (field/lab assistants) would increase by \$6,000 to a revised budget of \$51,000

An amendment is requested to reflect changing expenses in the final stages of the project and shifting protocols in Aim 3. Because of the shift in Aim 3 to delayed deployment, as well as reduced sample analysis costs in Aim 1, less funds are required for chemical analyses than initially envisioned. The request is for these funds to be transferred to support additional sample processing and the new field and lab work for Aim 3 by undergraduate students and recent graduates (Personnel budget) as well as additional travel costs in the collection of materials and deployment of experiments in Aim 3.

Amendment Approved by LCCMR 5/26/22

Overall Project Outcome and Results

Moss and lichen are common in forests, and yet they are often overlooked. But this does not mean unimportant: they retain water and heavy metals, and so a mossy forest may function quite differently from a barren one. This project aimed to quantify how much moss and lichen is in Minnesota forests, and estimate their impact on water flows and pollutant retention.

To reflect the diversity of Minnesota's landscape, we established 83 plots across the state (30 counties). This gives detailed and region-specific coverage of all of the major forest types recognized by the DNR. In each plot we recorded which species were present, their abundance (on forest floor, tree trunks and fallen branches), and collected the most abundant ones for lab analyses. 1650 unique specimens were collected, including 279 new county records and several new state records.

The amounts vary greatly across the state, from less than 1 lb/acre to over 1,500 lbs/acre. These translate into sometimes considerable water storage capacity (~1,200 gallons/acre), over one tenth of a typical rain event. With respect to heavy metals, contents were often quite low, at fractions of a pound/acre. Whether this is due to the lack of pollutants in forest sites will be followed up with future work with urban lichens. By combining our results with existing maps of forest coverage, we've been able to map these contributions across the state.

Another objective of the work aimed to test these estimates with experiments of how much water and elements are retained in the lab and field. Due to delays, these experiments were only installed in Spring 2022, and their continued monitoring and analysis will be funded from other sources. Overall our findings draw needed attention to an overlooked component of our forests, both in terms of diversity and impact on water cycles.

Amendment Request (11/02/2022):

An amendment is requested to reflect slightly higher than anticipated travel expenses (\$14,194 instead of \$14,000). These expenses are counter-balanced by under-spending on sample analyses, which have been reduced accordingly (\$7,806 instead of \$8,000). Since both of these expenses are from Activity 1, there are no changes to the activity-specific budgets.

Amendment approved by LCCMR 01/09/2023

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Pollution and nutrient retention by lichens and moss

Description: One of the notable characteristics of both lichens and mosses is their ability to derive most of their nutrition from the air and dust. This makes them particularly susceptible to accumulating pollutants, and the abundance and identities of lichens and mosses on trees have been used as low-cost indicators of airborne pollutants. But this property has a different relevance if the lichens and moss survive: they effectively become a filter selectively retaining airborne pollutants. The scale of this potential effect is unknown, and likely varies

across the state. This part of the project would fund a technician and 2 undergraduate students or short-term hires to collect common species of lichen and moss across the state, including estimates of their local abundance. Each summer at least 15 sites will be visited, with the aim of sampling representatives of all of the state's common forest types by the end of the project, as well as urban trees and apple orchards. During the fall and spring, these samples will be analyzed for common nutrients (e.g. nitrate and ammonia) and pollutants (e.g. sulfur, heavy metals) at the University of Minnesota. The results of the analysis will be combined with state vegetation maps to create maps of potential environmental filter effects of lichens and mosses, since the effects are likely to vary with climate and forest type. This data will be made publicly available through the Bell Museum of Natural History Online Atlas and contributed to national databases using lichens and bryophytes as low-cost indicators of air-quality.

ENRTF BUDGET: \$108,000

Outcome	Completion Date
1. Survey of lichen and moss cover at representative sites across state	October 2020
2. Analysis of lichen and moss samples for pollutant and nutrient content	April 2021
3. Mapping of environmental filter effects of lichens and mosses	June 2021

Activity Status as of January 31, 2019

The technician (Abby Glauser, MS Oregon State University) and assistants have been hired and were able to survey 14 plots at University of Minnesota owned sites in three counties (Anoka, Carlton and Lake) between August and October 2018, when it became impossible to continue surveys due to snow-cover and cold. Lichen and moss identification is often not possible on site, and so so voucher collections were made, and are being identified, with nearly all large lichens and more than half of mosses identified to date. We expect to complete identifications by the start of the next field season this spring, and for identifications to go much faster in coming years, now that we are familiar with the common species. The voucher specimens will be added to the research collections at the Bell Museum Herbarium, which will make those records publicly accessible. These surveys have already contributed new records for University field-stations where ecological research has been going on for decades (over >100 years at Cloquet Forestry Center), which shows just how overlooked these organisms have been! These surveys have already included more than 50 new county records in Anoka (11), Isanti (4), Carlton (30), and Lake (6) counties for lichens alone.

The surveys have also involved developing novel protocols for estimating the total amounts of moss and lichens in forests, combining the cover on trunks, on branches and on the ground. Students hired by the project are working weighing these materials, as well as analyzing photos to assess ground cover.

Lichen and moss samples for pollutant and nutrient content have been collected and cleaned, but not yet sent off for analysis, we expect to do that this spring before the start of the next field-season in May.

Mapping activities are expected to begin next fall, once more sites have been surveyed and samples analyzed.

Second Update June 30, 2019

The second season of field work is off to a good start. Already the project technician (Abby Glauser) and her two assistants (both UMN students) have surveyed 12 plots, meaning that we are on track to more than triple the number of sites surveyed in the previous year. The geographic coverage is also much greater, with plots in 6 counties (Beltrami, Clearwater, Hubbard, Koochiching, Lake of the Woods and Roseau). Sites in at least 7 more counties are planned for the continuation of the summer.

Nearly all of the materials from 2018 have been fully processed, with all voucher specimens identified and ready for archiving in the Bell Museum. Only the lichen and moss samples for pollutant and nutrient content have been collected and cleaned, but not yet sent off for analysis. Because of improved efficiency in the field as well

as greater familiarity with the species, we expect the processing of materials to be more efficient this fall, and so although the quantities of material are greatly increased, a majority should be able to be processed before the 2020 field season.

Third Update January 31, 2020

The second summer of fieldwork was successful, and greatly expanded the coverage of the state. The total number of surveyed plots is now 47 plots in 20 counties (up from 14 plots in 3 counties a year ago), and nearly 2000 voucher specimens of moss, liverwort and lichen have been collected. The specimens and materials are now being processed, which is expected to take at least until the start of the final field season in May 2020. There has been one major staffing change, with the project technician (Abby Glauser) leaving the project in December 2019. However, a new project technician (Tana Route) with considerable relevant experience started in January 2020 and the impact of the turnover on project timelines has been small. For Fall semester 2019 3 undergraduate students worked on processing material for measuring biomass, water-holding capacity and chemical analysis, putting in ~100 hours each. An additional student recently started curating voucher specimens to be added to the Bell Museum. In Spring 2020 one of these students will be leading an independent study project to develop GIS tools to perform the mapping for the sub-activity 3, and two student will continue with processing material. Because the volume of material collected was much larger in 2019, not all of it is likely to be processed before the start of the next field season. However, the 2020 field season will be less intensive, and so it should still be possible to finish processing all materials before the end of the project period. Travel costs have exceeded the initially planned budget, and that additional expense has been covered using other funds (which will also be used to cover costs in the coming field season)

Fourth Update June 30, 2020

Fifth Update January 31, 2021

After a third summer of fieldwork, Activities 1 and 2 are on a good track towards completion. Pandemic related safety measures complicated costs for fieldwork, but the reallocation of funds authorized in summer 2020 made it possible to cover those and complete collecting activities. Eighty-three (83) plots from across MN (30 counties) have been surveyed, and the majority of the lichen and moss specimens from those collections are now identified (1650 unique and named specimens, as previous estimates included duplicate material). This represents a large increase in coverage from a year ago and includes all MN DNR Ecological Sections and 25 different Native Plant Communities, resulting in near-complete coverage of Minnesota's forest types, and completing outcome 1.

A first batch of specimens has been sent off for elemental analysis (outcome 2), and the basework for converting that information into maps (Outcome 3) was carried out in Spring 2020 by a UMN undergraduate student researcher, keeping it on track for completion.

Despite the pandemic, 2 undergraduate students at UMN participated in fieldwork activity for the summer, and 2 additional students were employed to process specimens through the Fall semester.

Sixth Update June 30, 2021:

Field and lab work for Activity 1 is completed, with a total of 83 plots across MN surveyed, covering 30 counties and all major forest types of the state. All specimens have been identified, and specimens have been processed for biomass, and chemistry thanks to the efforts of the project technician and several undergraduate students/recent graduates. Some of the samples have been sent off, and we are awaiting the return of the results. A current undergraduate will be analyzing this data in the fall of 2021 to incorporate it with the mapping scripts developed in 2020.

Seventh Update as of January 31, 2022:

Chemistry analyses are complete for approximately half of the samples, with the remainder being prepared this spring for analysis. The current results provide enough coverage for analysis pipelines to be developed in spring of 2022, so that remaining data can be rapidly incorporated.

Final Project Summary:

To reflect the diversity of Minnesota’s landscape, we established 83 plots across the state (30 counties). This gives detailed and region-specific coverage of all MN DNR Ecological Sections and 25 different Native Plant Communities, resulting in near-complete coverage of Minnesota’s forest types, with an emphasis on covering the most common forest types in each ecological region, as well as replicating common forest types to account for variation between forest patches. In each plot we recorded which species were present, their abundance (on forest floor, tree trunks and fallen branches), and collected the most abundant ones for lab analyses. In all, 1650 unique specimens were collected, including 279 new county records and several new state records. The more significant of these specimens (new county and state records, high quality examples of under-collected species, etc) are being added to the permanent archival collections at the Bell Museum of Natural History Herbarium. Furthermore, all records are available on request.

The amounts of moss and lichen vary greatly across the state, from minimal presence (less than 1 lb/acre) to very abundant (more 1,500 lbs/acre). Not the largest component of the forest, but enough to be worth considering, especially since our techniques likely under-estimate what is in the canopy.

For chemical analysis, 150 specimens representing the most abundant material available at most sites were analyzed for the contents of 27 elements. With respect to heavy metals and other elements, the contents were often quite low, at fractions of a pound/acre. Whether this is due to limited capacity for retention, or just the lack of pollutants in most forest sites remains to be seen, and will be followed up with future work with urban lichens. By combining our results with existing maps of forest coverage, we’ve been able to map these contributions across the state. For the moment, contrary to our hopes, it seems that mosses and lichens may be playing a relatively small role in filtering pollutants from rain-water, mostly because although there is enough to affect hydrology (see Activity 2), it may not amount to that much removal of heavy metals. Nonetheless, their ecological roles as indicators of air quality, which is how they have more traditionally been used, remain valuable, and the data collected as part of this project will serve future monitoring efforts.

ACTIVITY 2: Water retention by lichens and moss in tree canopies

Description: The water content of lichens and mosses varies frequently and dramatically, and many species are able to hold many times their weight in water (up to 20 times for some mosses!). This water can be taken up from rain, but also often dew, fog and even moist air. All this water in the canopy can make the canopies of trees considerably cooler and moister, but the existing studies of the scale of this impact have so far been conducted in the Pacific Northwest and the tropics, and may be limited direct applicability to the Minnesota landscape. This part of the project would make use of the specimens and survey information collected in Activity 1 to measure the water-holding capacity of lichens and moss and calculate their potential tree-scale impact. The project will determine predictors of water-holding capacity and drying rates of common lichens and mosses of Minnesota. This information will be combined with the aforementioned abundance data to generate maps of potential hydrological effects of lichens and bryophytes in forests.

ENRTF BUDGET: \$55,000

Outcome	Completion Date
1. Measurements of water holding capacity of common lichens and mosses of MN	April 2021
2. Mapping of hydrological impacts of lichens and mosses	June 2021

Activity Status as of January 31, 2019

Material for measurement of water holding capacity of common lichens and mosses was collected during the field surveys described in Activity 1, from 14 sites in 3 counties. These samples have been sorted and cleaned, and measurements of the water-holding capacity and drying rates have been made for multiple individuals of 10 common species, with a total of nearly 100 samples measured. We find differences between species, but similar shaped species often have quite similar drying rates, which will make it easier to scale up from the individual measurements to whole forest estimates. Measurements are still ongoing using the material collected in 2018.

Mapping activities are expected to begin next fall, once more sites have been surveyed and samples analyzed.

Second Update June 30, 2019

Measurements using material collected in 2018 were completed by April 2019, including additional measurements of lichens and moss from the ground layer of forests, in addition of the canopy lichens and moss initially planned. We have now collected additional material from an additional 12 plots already, and expect to collect much more over the course of the summer. This material will be processed in the fall (once the semester starts and undergraduate workers are hired) and into 2020.

Third Update January 31, 2020

Measurements using material collected in 2019 advanced rapidly in Fall 2019, with a dedicated undergraduate student trained and processing specimens. This student will continue in spring 2020. A second undergraduate student will be developing computer scripts to transform the water-holding measurements and field survey data into maps of these attributes across the state (this activity is a research internship and not costing the grant). Travel costs have exceeded the initially planned budget, and that additional expense has been covered using other funds (which will also be used to cover costs in the coming fieldseason)

Fourth Update June 30, 2020

Fifth Update January 31, 2021

Measurements using material from 2018-2020 continued in Spring 2020, and now cover most of the abundant species of lichen and moss in our samples. The undergraduate who led much of this work turned into a directed research project in Fall 2020 (after a summer of assisting with fieldwork), developing the analyses and setting up a peer-reviewed publication currently in preparation. A few remaining measurements are expected to be made in March and April 2021, and the computer scripts for combining those results with survey data are already mostly developed, building on the work of the research intern described in the 3rd update.

Sixth Update June 30, 2021:

Field and lab work for Activity 2 is completed, with a total of 83 plots across MN surveyed, covering 30 counties and all major forest types of the state. All specimens have been identified, and specimens have been processed for biomass, water-holding capacity and chemistry thanks to the efforts of the project technician and several undergraduate students/recent graduates. A subset of the results from Activity 2 (Hembre et al. 2021, adapted from a undergraduate work by UMN student Kate Hembre) was published in peer-reviewed scientific journal *Frontiers in Forests and Global Change* in June 2021. Analyses of the fuller dataset are on-going, but are expected to be completed over the course of Fall 2021-Spring 2022.

Seventh Update as of January 31, 2022:

As above, specimen processing is complete, and we are in the phase of final analyses ahead of the project ending in June.

Final Project Summary:

The specimens and sites in Activity 1 were also studied to understand the impacts of mosses and lichens on water cycling, with a total of 83 plots across MN surveyed, covering 30 counties and all major forest types of the state. All specimens have been identified, and specimens have been processed for water-holding capacity thanks to the efforts of the project technician and several undergraduate students/recent graduates. We evaluated the potential for water retention in the upper canopy (based on fallen twigs and branches), on the main bole (trunk) of trees and on the ground. Since different growth-forms differ in their ability to retain water, we evaluated representative specimens of all common species of each growth-form, to account for variation within and across growth forms. This information was then combined with the abundances of each of those forms (see Activity 1), and then scaled-up to the whole forest scale.

A subset of the results from Activity 2 (Hembre et al. 2021, adapted from a undergraduate work by UMN student Kate Hembre) was published in peer-reviewed scientific journal *Frontiers in Forests and Global Change* in June 2021. There is huge variation in the amounts of moss and lichen across the state, from minimal presence (less than 1 lb/acre) to very abundant (more 1,500 lbs/acre). These translate into a large range of water-retention values. In some areas the impact on water storage is very minimal, especially in places with almost no lichen or moss ground cover, and only small individuals on trees. This was most often the case in younger, drier forests in southern and western Minnesota. In contrast, in older forests, especially in northern and eastern Minnesota, moss and lichen was estimated to provide considerable water storage capacity (~1,200 gallons/acre) in canopy alone, or over one tenth of a typical rain event. This may not sound like so much, but a 10% change in water flow is a large impact, which in this case will be retained and keep the forest environment moister (and typically cooler) as that water is slowly released through evaporation.

The impacts of moss and lichen on water cycles are therefore not always ecologically important, but they can be, and those impacts are particularly strong in older forests (where mosses and lichens have had longer time to establish lush growth) and in cooler and wetter regions of Minnesota. Within a region, there is also considerable variation between forest types, with more water retention in lowlands (where this a lot of moss cover on the ground), and in deciduous forests (where the lack of leaves in the winter allows moss and lichen on trunks to grow faster, while still being protected from excess drying in the summer). The values we calculated are generally lower than what has previously been reported for temperate and boreal forests, but this is because in the past studies have mostly focused on old-growth in the Pacific Northwest, which is hardly representative of much of the country. Our findings show that even outside of those extremely mossy old-growth conditions, moss and lichens can have important impacts on water cycles, but this role shouldn't be overstated and can't be assumed to always be significant.

ACTIVITY 3: Experimental removal of lichens and moss in trees

Description: The final component of this project is the experimental removal of mosses and lichens to directly measure the resulting impact on trees. This is too time-consuming an effort to be carried out at all of the survey sites, but will provide more detailed measurements of the effects of lichens and mosses on trees, including the seasonal and year-to-year variation in their importance. This portion of the project would establish experiments at 1 sites across the state (Itasca) representing a wide variety of Minnesota forested landscapes. We have conducted a pilot experiment in a black spruce bog at Marcell Experimental Forest near Grand Rapids in the spring of 2017, which will be maintained as well. The effects of removing lichens on tree microclimate (temperature, humidity, etc) will be measured with custom-made sensors developed at the U of MN and the effects on chemical composition measured with resin bags. Direct tests of the impacts of forest lichen and bryophytes will be conducted at four sites representing different forest types. The measured effects of lichens and bryophytes on microclimate and stem-flow chemistry will be written up and published in scientific journals, as well as communicated to the general public in signage at the experimental sites.

ENRTF BUDGET: \$50,000

Outcome	Completion Date
1. Set up of lichen and moss removal experiments	April 2019
2. Measurement of effects on tree water and chemistry	June 2021

Activity Status as of January 31, 2019

The start of this activity has been delayed by delays in getting sensor parts. The sensors were to be constructed in collaboration with a different lab at the University of Minnesota, and since they are in the process of updating their sensors to new models, it has seemed best to delay for a few months. Some funds have been spent on sensor parts that will be used later, as well as field supplies that are shared with Activities 1 and 2. We are still hoping to construct and deploy the sensors in late winter or early spring (March-April) of this year. If delays continue, we intend to switch to commercial sensors (that will be able to measure less aspects of microclimate for the same cost).

Second Update June 30, 2019

This activity continues to be delayed for the reasons above. The sensors were to be constructed in collaboration with a different lab at the University of Minnesota, and since they are in the process of updating their sensors to new models, it has seemed best to delay for a few months. If delays continue into September/October, we intend to switch to commercial sensors (that will be able to measure less aspects of microclimate for the same cost).

Third Update January 31, 2020

This activity continues to be delayed for the reasons above.

Fourth Update June 30, 2020

Fifth Update January 31, 2021

Activity 3 continues to be a challenge, even in its reduced form, due to constraints on travel and labwork. Current plans are for the lichen/moss removal experiments involved to be installed in Spring 2021, and monitoring to be maintained past the completion date of the project using discretionary funds (Faculty Start-up) available to the Project Manager.

Sixth Update June 30, 2021:

Activity 3 continues to be a challenge, even in its reduced form, due to constraints on travel and labwork. Despite plans, we were unable to install lichen/moss removal experiments in Spring 2021. Current plans are for the lichen/moss removal experiments involved to be installed by a current graduate student in Fall 2021 if possible, and monitoring to be maintained past the completion date of the project using discretionary funds (Faculty Start-up) available to the Project Manager.

Seventh Update as of January 31, 2022:

Due to COVID complications and unavailability of the custom-made sensors, the Stanton lab has worked to address an understanding of how mosses and lichens directly impact trees through the following adaptations:

- Continued maintenance of the pilot plot at Marcell Experiment Forest
- Modeling data collected in Activities 1 and 2
- Lab-based experiments on water retention and nutrient leakage with lichens and mosses collected in northern MN
- and installing field experiments to test dust and nutrient capture by lichens and mosses that will be continued beyond the end of the project period (using other funds)

Field experiments planned for fall 2021 were unable to occur. However, a graduate student in the lab has developed lab and field experimental protocols to measure dust and nutrient capture by lichens and mosses that, combined with the modeling in Aims 1 and 2, will address Aim 3. This work is now started in the lab, with a field component to come in spring (once temperatures thaw) and is has support to be maintained beyond the completion date of the project.

The aim of this activity was to assess the amount of water and nutrients that might be intercepted by moss and lichens under natural conditions (and not just the maximums estimated from Aims 1 and 2). To meet these same objectives For this, current graduate student M. Cardenas has developed an experimental design for use in the lab and field, using lichen and moss samples collected in 2021. This involves a PVC ring containing nutrient-binding resins, with the moss or lichen of interest placed over it. In the lab setting, where we are currently testing it, we can compare the volume of water that is retained, as well as the chemistry of what is leached/retained by the moss or lichen. These will then be placed in the field at University of Minnesota field stations in April-May 2022 (once conditions have thawed) to track changes over a 6 month period (the analyses will be paid for by other funds, since this extends beyond the project period).

The data from the lab measurements (and eventually the field measurements, after project end) will be combined with the survey data in Activities 1 and 2 to improve estimates of the impacts of moss and lichen on water and nutrient flows at forest stand scales.

Final Project Summary

The start of this activity was greatly delayed by delays in getting sensor parts, and then by complications linked to the COVID-19 pandemic. We were eventually able to work out a number of adaptations to achieve goals:

- Continued maintenance of the pilot plot at Marcell Experiment Forest
- Modeling data collected in Activities 1 and 2
- Lab-based experiments on water retention and nutrient leakage with lichens and mosses collected in northern MN
- and installing field experiments to test dust and nutrient capture by lichens and mosses that will be continued beyond the end of the project period (using other funds)

A graduate student in the lab developed lab and field experimental protocols to measure dust and nutrient capture by lichens and mosses that, combined with the modeling in Aims 1 and 2, will address Aim 3. This work is started in the lab, and was deployed in the field at Cedar Creek Ecosystem Reserve (Anoka and Isanti counties) in May 2022. This experiment has non-LCCMR support to be maintained beyond the completion date of the project. The data from the lab measurements (and eventually the field measurements, after project end, unfortunately both still pending) will be combined with the survey data in Activities 1 and 2 to improve estimates of the impacts of moss and lichen on water and nutrient flows at forest stand scales.

IV. DISSEMINATION:

Description: Research findings will be disseminated to both general and academic audiences using a variety of platforms:

Scientific Publications: The proposed research is expected to generate several scientific research publications

Data Availability: The majority of the data generated by this project will be made freely available. Voucher specimens for all lichen and bryophyte samples will be deposited at the Bell Museum of Natural History Herbarium (MIN), which will include adding the records to the publicly accessible Bell Atlas (<http://bellatlas.umn.edu>). The maps of lichen and bryophyte impacts on forests will also be made freely available through the Bell Museum webpage. The FIA protocol survey data and the measurements of chemical

composition of common lichens and bryophytes will be added to the National Lichens and Air Quality database (<http://gis.nacse.org/lichenair/>).

Public Outreach Activities: The findings from this project will be communicated to the general public through several venues in addition to simply making the data available. D. Stanton is a coordinator for “Market Science” outreach program at the University of Minnesota College of Biological Sciences, which helps scientists at the UMN bring their research to the public at farmer’s markets and county fairs. We will develop a module for the Market Science format, and present it at multiple venues in years 2 and 3 of the project. Additionally, we will develop outreach activities with Bell Museum of Natural History.

Activity Status as of January 31, 2019

The project is still in early stages of generating data. Voucher specimens have been collected and identified material is expected to be added to the Bell Museum of Natural History Herbarium (MIN) collections this spring.

Since the start of the project we have participated in three activities talking about lichens and moss, including this project, to a general public. In July 2018 we participated in the Grand Opening activities at the Bell Museum with an activities table on a day that saw >1700 visitors come through the museum. In September 2018 we represented the University of Minnesota “Market Science” outreach program at the Frogtown Farm Fall Harvest Festival, engaging with 125+ visitors (of which ~½ were children). In January 2019 D. Stanton gave an invited talk to the Minnesota Mycological Society on lichens, including preliminary results from this project, to an attendance of 50-60 people.

Second Update June 30, 2019

The project is still in early stages of generating data. All voucher specimens collected in 2018 have been identified and are now in the queue to be added to the Bell Museum of Natural History Herbarium (MIN) collections.

The preliminary results of from the first year of work on this project will be the subject of both an oral presentation (“Small and mighty: estimating contributions of lichens and bryophytes to ecosystem services in Minnesota’s forests” given by Abby Glauser, with D Stanton as co-author) and poster presentation (“Epiphyte Cover Varies with Height and Forest Type Across a Temperate to Boreal Ecotone” given by Abigail Meyer, coauthors A Glauser and D Stanton) at the annual meeting of the Botanical Society of America in July 2019.

Third Update January 31, 2020

A full set of voucher specimens from the field work in 2018 have been prepared, and a volunteer is mounting them for accession into the Bell Museum of Natural History Herbarium (MIN) collections.

Two scientific conference presentations were made on this project: an oral presentation (“Small and mighty: estimating contributions of lichens and bryophytes to ecosystem services in Minnesota’s forests” given by Abby Glauser, with D Stanton as co-author) and poster presentation (“Epiphyte Cover Varies with Height and Forest Type Across a Temperate to Boreal Ecotone” given by Abigail Meyer, coauthors A Glauser and D Stanton) at the annual meeting of the Botanical Society of America in July 2019.

Additionally, outreach activities presenting this project to a general public included 4 hours at a booth in the University of Minnesota pavilion at the MN State Fair, workshops at Cedar Creek Ecosystem Reserve and the Minnesota Naturalists Association Annual Meeting and a talk at the Minnesota Mycological Society Meeting.

Fourth Update June 30, 2020

Fifth Update January 31, 2021

Specimen preparation for herbarium accession and inclusion in the publicly searchable Bell Atlas has been on hold due to restrictions on space access, but is expected to resume in April 2021 and be completed by project end.

Results from this work were included in a public talk series organized by the Bell Museum in May 2020 (Water What-ifs <https://cbs.umn.edu/blogs/cbs-connect/probable-meets-possible-spring-2020>), and Project Manager D. Stanton was a featured science for the College of Biological Sciences Market Science outreach group (<https://marketsci.org/2020/08/28/daniel-stanton-plant-environment-interactions/>).

Research results were also presented at an invited seminar at the University of Minnesota-Duluth in October 2020. Data analyses of results for scientific publications are currently underway, with the aim of having at least one full manuscript prepared and submitted by project end.

Sixth Update June 30, 2021:

A subset of the results from Activity 2 (Hembre et al. 2021, adapted from a undergraduate work by UMN student Kate Hembre) was published in peer-reviewed scientific journal *Frontiers in Forests and Global Change* in June 2021, and is freely available at <https://www.frontiersin.org/articles/10.3389/ffgc.2021.704190/full>. Further publications are planned, using a fuller set of results.

Seventh Update as of January 31, 2022:

Preliminary results of this work were presented to 55+ attendees of the West Metro Master Naturalists Association monthly meeting in an hour-long talk by D. Stanton in November 2021. Results were also presented to a scientific audience at the International Association for Bryology meeting in July 2021 (hosted in Québec City, Canada, but virtual).

Final Project Summary>

The activities and findings in this project have been shared with the general public through a number of venues, including public presentations through Minnesota Master Naturalists, Minnesota Mycological Society, and the Bell Museum of Natural History; workshops attended by 30-50 people each at Minnesota Naturalists Association Annual Meeting (2019) and Cedar Creek Ecosystem Reserve (2019, 2022-115 participants!); a booth in the University of Minnesota pavilion at the MN State Fair and several other events.

Scientific dissemination has so far included an [undergraduate-led peer-reviewed publication](#) and oral presentations at 3 international conferences and talks at the University of Minnesota-Twin Cities, University of Minnesota-Duluth and Minnesota State-Mankato. Further scientific publications are planned for late 2022.

V. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview: See attached budget spreadsheet

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

Explanation of Use of Classified Staff: NA

Total Number of Full-time Equivalent (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours:	Divide by 2,080 = TOTAL FTE:
--	------------------------------

6240 (junior scientist) + 1248 (undergraduates) = 7488	3.6
--	-----

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

Enter Total Estimated Personnel Hours:	Divide by 2,080 = TOTAL FTE:
--	------------------------------

B. Other Funds:

SOURCE OF AND USE OF OTHER FUNDS	Amount Proposed	Amount Spent	Status and Timeframe
Other Non-State \$ To Be Applied To Project During Project Period:			
	\$	\$	N/A
Other State \$ To Be Applied To Project During Project Period:			
	\$	\$	N/A
Past and Current ENRTF Appropriation:			
	\$	\$	N/A
Other Funding History:			
Indirect costs associated with this proposal	\$ 115,000	\$ 60452	Secured July 1 2018 to June 30 2021

VI. PROJECT PARTNERS:

A. Partners receiving ENRTF funding

Name	Title	Affiliation	Role

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
Otto Gockman		Midwest Natural Resources	Assistance on specimen identification and mapping
Courtner Kerns		Itasca Community College	Advice on fieldwork planning, student recruitment and assistance on specimen identification
John Thayer		Minnesota Wildflowers	Assistance on specimen identification and mapping

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The majority of the data generated by this project will be made freely available. Voucher specimens for all lichen and bryophyte samples will be deposited at the Bell Museum of Natural History Herbarium (MIN), which will

include adding the records to the publicly accessible Bell Atlas (<http://bellatlas.umn.edu>). The maps of lichen and bryophyte impacts on forests will also be made freely available through the Bell Museum webpage. The FIA protocol survey data and the measurements of chemical composition of common lichens and bryophytes will be added to the National Lichens and Air Quality database (<http://gis.nacse.org/lichenair/>), which will enable re-sampling in the future to track changes through time.

VIII. REPORTING REQUIREMENTS:

- **The project is for 4 years, will begin on 07/01/2018, and end on 06/30/2022.**
- **Periodic project status update reports will be submitted 01/31 and 06/30 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2022.**

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

- A. Budget Spreadsheet - attached**
- B. Visual Component or Map - attached**
- C. Parcel List Spreadsheet - NA**
- D. Acquisition, Easements, and Restoration Requirements - NA**
- E. Research Addendum - Separate attachment**

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2018 Budget Spreadsheet



Project Title: Assessing Natural Resource Benefits Provided by Lichens and Mosses

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03e

Project Manager: Daniel Stanton

Organization: University of Minnesota

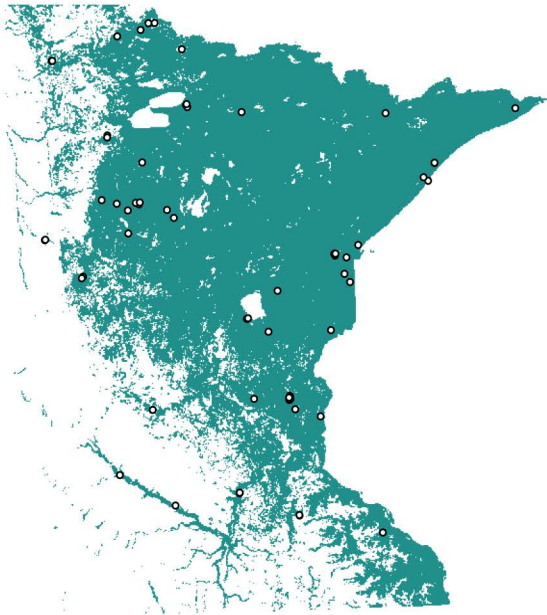
College/Department/Division: College of Biological Sciences/Ecology , Evolution and Behavior Department

M.L. 2018 ENRTF Appropriation: \$213,000

Project Length and Completion Date: 4 years, June 30 2022

Date of Report: May 25 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	REVISED BUDGET (11/02/2022)	AMOUNT SPENT	BALANCE
BUDGET ITEM			
Personnel (Wages and Benefits)			
Field/lab assistants. 2 for each summer and academic semester, to assist with collection and processing of samples. Salaries are calculated as \$1,500 per academic semester and \$4,500 for summers. Either U of MN undergraduates (100% Salary, 0% benefits) or undergraduates at other Minnesota universities and colleges and recent graduates (93% salary, 7% benefits). 20% FTE each year for 3 years	\$51,000	\$48,092	\$2,908
A junior scientist will lead the fieldwork teams of undergraduate students, as well as the sample processing and analyses. <i>Salary is calculated as \$35,000 annually plus 27.2% benefits, with 3% inflation for subsequent years. (79% salary, 21% benefits) 100% FTE each year for 3 years</i>	\$138,000	\$137,396	\$604
Equipment/Tools/Supplies	\$2,000	\$1,657	\$343
Custom-made sensors (~\$300 each) ~32 sensors			\$0
Resin Bags \$1,400			\$0
Travel expenses in Minnesota			\$0
Mileage for travel to sampling sites	\$14,194	\$14,194	\$0
Other			\$0
Chemical analyses of moss and lichens from across the state. Analyses will measure carbon, nitrogen content and 27 ions including heavy metals at \$33/sample with 150 samples analyzed each year.	\$7,806	\$5,113	\$2,693
COLUMN TOTAL	\$213,000	\$206,452	\$6,548

A**Study sites and forest cover****B****Predicted epiphytic lichen biomass density (kg/ha)**