NATIONAL ATMOSPHERIC DEPOSITION PROGRAM (NADP) CRITICAL LOADS OF ATMOSPHERIC DEPOSITION (CLAD) 2019-2020 ANNUAL REPORT

1.0 INTRODUCTION

Critical Loads of Atmospheric Deposition (CLAD) is a Science Committee of the National Atmospheric Deposition Program (NADP). The purpose of CLAD is to discuss current and emerging issues regarding the science and use of critical loads (CLs) for effects of atmospheric deposition on ecosystems in the United States (U.S.). This document serves as the 2020-2021 Annual Report of CLAD. The Annual Report contains sections that describe CLAD accomplishments, progress on CLAD Working Groups, CLAD products, the virtual Fall 2020 and the virtual Spring 2021 CLAD meetings, the United Nations Economic Commission for Europe (UNECE) International Cooperative Programme (ICP) Modelling and Mapping (M&M) Working Group on Effects (WGE) Coordination Centre for Effects (CCE) annual meeting, projects conducted by members of CLAD, and CL-related publications added to the CLAD website during the year.

The CLAD Executive Team for 2020-2021

Co-Chairs: Emmi Felker-Quinn (NPS), Jeff Herrick (EPA)
Secretary: Justin Coughlin (EPA)
National Critical Load Database (NCLD) Manager: Jason Lynch (EPA)

Additionally, CLAD has an Advisory Board made up of past-chairs, working group leads, and federal agency representatives who help guide CLAD activities and maintain cohesion across working groups.

CLAD Advisory Board: Julian Aherne, Mike Bell, Chris Clark, Linda Geiser, Richard Haeuber, Todd McDonnell, Linda Pardo, Jen Phelan, Ginger Tennant, Shaun Watmough, Jennifer Wilkening

This 2020-2021 Annual Report was produced by the CLAD Executive Team, reviewed by CLAD members, and accepted on December 6, 2021.

2.0 CLAD SUMMARY OF ACCOMPLISHMENTS

The CLAD Summary of Accomplishments document was updated with CLAD accomplishments that occurred during this year. These accomplishments included:

1. In celebration of the 50th anniversary of the Clean Air Act, CLAD sponsored a seminar series consisting of seven seminars detailing critical loads for individual ecosystem components and how agencies use critical loads for management decisions. Monthly seminars were recorded and are available here: https://nadp.slh.wisc.edu/critical-load-seminar-series/
2. Attendance at CLAD meetings during the Fall 2020 and Spring 2021 NADP meetings was between 42 and 45 participants.
3. Several CLAD members represented NADP/CLAD as the U.S. non-official National Focal Centre (NFC) at the April 2021 virtual meeting of the UNECE International Cooperative Programme on Modelling and Mapping of Critical Levels & Loads and Air Pollution Effects, Risks and Trends (ICP M&M).
4. Continued the efforts of the five Working Groups (WGs) within CLAD.

5. Working Group 6, to focus on ozone effects on ecosystems, research collaborations, and ozone critical levels, was formally approved during the Spring 2021 CLAD meeting.
6. CLAD and TDep held a joint session at the Spring 2021 meeting for a first look at how planned changes to TDep would affect CL exceedances.
7. Critical Load videos were finished and are now available on YouTube (links in 4.2 Critical Load Videos).

3.0 CLAD WORKING GROUPS

Working Groups (WGs) have been a component of CLAD since 2011. The objectives of the CLAD WGs are to increase our understanding and ability to estimate, represent, and communicate CLs of deposition in the U.S. There is a total of five CLAD WGs.

3.1 WG-1 ADDING NEW DATA AND CRITICAL LOADS TO THE NADP-CLAD NCLD

Objective: *The objective of this WG is to produce, adopt, and practice a standardized method for review and incorporation of new published data and CLs into the NADP-CLAD NCLD.*

During the past year, WG-1 has worked to release Version 3.2 of the NADP-CLAD NCLD and supporting documents. This database version will include new critical loads for aquatic acidification and lichens. The aquatic acidification section of the database is being reworked to include an uncertainty estimate for the critical loads determined by the Steady-State Water Chemistry (SSWC) model. In addition, critical load estimates will include a qualitative rating from 1-5 with 5 being the most certain value. New target critical loads from McDonnell et al. 2021 and newly calculated steady-state values from USFS water quality data from the southern Appalachia Mountains and south will be added to the database. New lichen community and individual critical load values will also be included in version 3.2 based on Geiser et al. 2019. The new version of the database is expected to be completed early 2022. Along with the release of the new data, WG-1 will also be submitting the database to Scientific Data (https://www.nature.com/sdata/), which is a peer-reviewed, open-access journal for descriptions of scientifically valuable datasets. All who have contributed to the NCLD database will be included as an author. The goal is to submit the database paper in early 2021.

Geiser, L.H.; Nelson, P.R.; Jovan, S.E.; Root, H.T.; Clark, C.M. Assessing Ecological Risks from Atmospheric Deposition of Nitrogen and Sulfur to US Forests Using Epiphytic Macrolichens. Diversity 2019, 11, 87. https://doi.org/10.3390/d11060087

McDonnell, T.C., C.T. Driscoll, T.J. Sullivan, D.A. Burns, B.P. Baldigo C, S. Shao and G.B. Lawrence. 2021. Regional target loads of atmospheric nitrogen and sulfur deposition for the protection of stream and watershed soil resources of the Adirondack Mountains, USA. Environmental Pollution 281. https://doi.org/10.1016/j.envpol.2021.117110.

3.2 WG-2 CHARACTERIZING UNCERTAINTY IN CRITICAL LOAD ESTIMATES

Objective: *The objective of this WG is to provide estimates of uncertainty for CLs in a standardized way to support the comparison of the strength of critical loads between critical load types and datasets.*

WG-2 continues to make progress working on the 5-point scale uncertainty rating for critical loads. The approaches have been defined and ratings have been made for lichen critical loads, preliminary ratings have been made for tree species critical loads, and ratings are being calculated for aquatic acidification. Chris Clark is planning to take a more active role in leading WG-2 in 2022. Goals for 2021/22 include completing uncertainty ratings, mapping them and drafting a manuscript about how they were developed.

3.3 WG-3 CRITICAL LOAD SYNTHESIS

Objective: *The objective of this WG is to develop a methodology/process for combining and representing multiple CLs in a rigorous, reproducible, and defensible manner to provide guidance in synthesizing and mapping CLs and in interpreting CL outputs. Different methodologies will be developed to meet the needs of the different federal agencies: EPA, NPS, USFS, BLM, and FWS.*

The focus of WG-3 in the past year has been on making products easily accessible to users. To that end, several tools are in development. A CL Hub is being developed which would serve as a means of accessing different information on CL and also provide a roadmap for users of CLs to guide them to the appropriate sources for their applications. A new version of N-CLAS, CLAS is being developed to provide access to CL and exceedance maps, as well as maps showing the current condition of different resources in response to current deposition levels. The goal is the development of figures and tables in a standardized way that can be applied to all federal lands. The CL Mapper continues to be updated, and the code was re-written and simplified to enable cheaper and faster updates in the future.

In addition, WG-3 has had several stakeholders give presentations about how they use CLs and what outputs or analyses are most useful to them. The objective of these presentations and discussions was to ensure that the necessary outputs are included amongst the products and that the Hub provides the appropriate level of guidance for users.

The goals of WG-3 for next year will be to: (1) finalize the preliminary report for the Bridger Teton national Forest, (2) create summary figures and table for critical loads of all federal lands, (3) complete development of CLAS to provide access to CL and EXC maps as well as the figures and table, (4) update the CL Mapper to include trees and lichen, (5) expand on the methods appendix to provide documentation on how to apply critical loads when different species level datasets are available, (6) summarize data from chosen case study parks and forests to guide future synthesis work, (7) draft several synthesis manuscripts for journals, and (8) update and create additional slideshow presentations to introduce managers to these applications of CLs.

3.4 WG-4 UNCERTAINTY IN DEPOSITION MODELS AND ESTIMATES

Objective: *The objectives of this WG are to understand the uncertainty that exists in measurements and models used to estimate the deposition of nitrogen (N) and sulfur (S) to the ecosystem and how it impacts critical load development and critical load exceedance.*

WG-4 had limited meetings during the last year but continued working on deposition uncertainty issues in small groups via email and during TDep Steering Committee meetings.

Mark Fenn (USFS) and Leora Nanus (SFSU) are leading an effort to compare IER throughfall and bulk deposition collector data with CMAQ and TDep data. Data from collectors along the west coast are being assessed for total N deposition to determine if there is consistent alignment between measurements and models across collectors or if it is regionally constrained. Where available they are also evaluating the impact of species on data correlation.

Meaghan Petix (WSU) and Mike Bell (NPS) are using lichen tissue concentration to assess TDep and CMAQ deposition patterns within Washington and Oregon. The assessment is comparing data from lichen FIA plots in the study area to the model grid cells that they fall within. The correlation will be refined based on elevation, slope, aspect, land cover, precipitation, and temperature to better understand which environmental variables are impacting the modeled output.

Jess Bash (EPA) and Mike Bell (NPS) are evaluating how CMAQ modeled N deposition data downscaled to 240m alters critical load exceedances in Shenandoah National Park. The rescaled data allows for more accurate deposition calculation to forest canopies due to less variation within a grid-cell. The outputs of this analysis will be used to help determine if we are over- or underestimating critical load exceedances due to the scale of modeled values.

John Walker (EPA) is working with researchers from the United Kingdom to better understand deposition to complex terrain. They are currently reviewing literature and comparing measurements and models to assess how relationships change in areas with significant elevation change. There may be an opportunity for us to provide data and analysis in the future.

3.5 WG-5 CRITICAL LOADS OUTREACH AND COMMUNICATION

Objective: *The goal of this WG is to develop an outreach and communication strategy to communicate the concept and use of CLs to stakeholder groups.*

Videos Introducing Critical Loads. This year, WG-5 has continued to work in collaboration with the US Forest Service, USFS Missoula Technology Development Center, and USDA media center to complete the creation of a set of videos that provide visually appealing, information rich, easily accessible introductions to critical loads and air pollution sensitive components of ecosystems for managers, regulatory agencies, and interested publics. There are seven critical loads video and a 'bonus' air quality tour of a national forest video:

- Introduction.
- Lichens
- Herbs
- Trees
- Aquatic ecosystems: Acidification
- Aquatic ecosystems: Eutrophication
- Synthesis
- Columbia River Gorge National Scenic Area Tour: Reading air quality and climate from lichens on trees

The Introduction video will be premiered at the NADP Business Meeting in the Joint Session. Video links will be shared after they have gone live.

Air Quality Awareness Week. WG-5 has also joined forces with NADP's Education Outreach Services committee to prepare for Air Quality Awareness week in May 2022. The team, comprised of NADP, NPS, FS, FWS, and EPA representatives will be developing materials along a management theme as follows:

- Monday: Acid Rain and the history of NADP
- Tuesday: Visibility and PM, Smoke
- Wednesday: Criteria Pollutants, especially nitrogen, sulfur, and ozone
- Thursday: Mercury, Toxics, Microplastics
- Friday: Air Quality and Climate Change

Critical Loads Nomenclature publication. Lastly, members of WG-5 continued to work on a journal article that presents and tests a standard naming convention and classification for critical loads. The system was applied to the CLs in the NADP-CLAD NCLD and Bridger Teton National Forest as a case study. The goal is to publish this manuscript in 2022.

4.0 CLAD PRODUCTS

CLAD produces documents, maps, datasets, and other materials to support advancing the estimation and representation of CLs in the U.S. A summary of CLAD products from 2020-2021 are detailed below.

4.1 CRITICAL LOAD SEMINAR SERIES

In celebration of the 50th anniversary of the Clean Air Act, CLAD sponsored a seminar series about how critical load data is collected, how different ecosystem components are responding to acidic deposition, and how this information is being used in policy and land management decisions. Over 200 people signed up for notifications about the seminar series. Seven seminars were held monthly from January 2021 through July 2021 with roughly 50 attendees on each seminar. The seminar series is intended to be used for a wide range of individuals with a broad understanding of critical loads. The webinars from the seminar series were uploaded to the NADP-CLAD website in 2021 and are now available for viewing at: https://nadp.slh.wisc.edu/critical-load-seminar-series/. The schedules of presentations and corresponding speakers were:

January 27 - Introduction to critical loads of N and S and deposition models

Speakers: Emmi Felker-Quinn (National Park Service); Mike Bell (National Park Service)

February 24 - Critical loads of N and S for epiphytic microlichen

Speakers: Linda Geiser (U.S. Forest Service); Rob Smith (U.S. Forest Service)

March 24 - Critical loads of N and S for tree growth and survival

Speakers: Linda Pardo (U.S. Forest Service); Justin Coughlin (Environmental Protection Agency)

April 28 - Critical loads of N and S for herbaceous species and herbaceous richness

Speakers: Chris Clark (Environmental Protection Agency); Todd McDonnell (E&S Environmental Chemistry)

May 26 - Critical loads of N and S for aquatic resources

Speakers: Jason Lynch (Environmental Protection Agency, Todd McDonnell (E&S Environmental Chemistry); Leora Nanus (San Francisco State University)

June 30 - Critical loads of N and S for soil, mycorrhizae, and microbes

Speakers: Erik Lilleskov (U.S. Forest Service); Michala Phillips (U.S. Geological Survey)

July 28 - A synthesis of the current state of critical load science and how data are used by federal agencies

Speakers: Tara Greaver (Environmental Protection Agency); David Gay (National Atmospheric Deposition Program)

4.2 CRITICAL LOAD VIDEOS

The Forest Service, in conjunction with CLAD, has developed informational critical load videos to highlight various ecosystem components and their respective responses to acidic deposition. These videos are envisioned to be introductory videos for individuals without prior critical load knowledge. The videos will be promoted in 2022 in coordination with the Education and Outreach Subcommittee (EOS) and are now publicly available at the links below:

Air Pollution Introduction: https://www.youtube.com/watch?v=SD05Q2tSzbY
Lichens: https://www.youtube.com/watch?v=6AR693kYYPE
Herbaceous Plants: https://www.youtube.com/watch?v=MNGHj3oj4q0
Trees: https://www.youtube.com/watch?v=BbdncQIX69I
Surface Waters Part 1: https://www.youtube.com/watch?v=x1iVngREMzc
Surface Waters Part 2: https://www.youtube.com/watch?v=98crQ7Jox4Y
Applying Critical Loads: https://www.youtube.com/watch?v=-gQ-GONJRhM

4.3 UPDATES TO CLAD WEBSITE

NADP has redesigned its website, which will change in appearance and page organization late in 2021. The landing page for CLAD will have the same URL: https://nadp.slh.wisc.edu/committees/clad/, and the information posted on the CLAD website will remain the same. The order in which pages are nested will change, and the URLs for documents posted on the website will change.

4.4 CRITICAL LOAD MAPPER

For 2021, the CL Mapper was overhauled to make the code more efficient and easier to update in the future. Other additions included the addition of Tribal Lands into the CL Mapper, updating several security patches, removal of the cumbersome Profile Reports, streamlining the deposition and exceedance datasets, and various smaller updates. This version (v.3.0) is currently available only on the Contractor's staging server, but soon will be migrated to the EPA server and will be publicly available.

5.0 CLAD MEETINGS

The Fall CLAD Meeting was conducted on October 27th during the virtual 2020 NADP Fall Meeting and Science Symposium held October 26th through the 28th. The Spring CLAD meeting was held virtually during the 2021 NADP Spring meeting conducted May 10th through the 14th. The minutes from the Fall Conference and Spring Meetings are available on the NADP-CLAD website at: (https://nadp.slh.wisc.edu/committees/clad/#clad-minutes).

5.1 FALL 2020 MEETING

The 2020 Fall NADP-CLAD Science Sub-Committee Meeting was held on Tuesday, October 27th virtually due to the SARS-CoV-2 global pandemic. A total of 42 people attended the meeting. The main topics discussed during the meeting included updates from the five CLAD Scientific WGs, updates on the Federal Land Managers' Air Quality Related Values Work Group (FLAG), CL Mapper, and NO_x/SO_x/PM Secondary National Ambient Air Quality Standard (NAAQS) Review, discussion of future CLAD activities, business, announcement of CL papers and posters that would be presented at the NADP science symposium, and CLAD members sharing updates on their current work.

CLAD WG Updates: WG1 presented planned updates to the National Critical Load Database (NCLD). WG2 gave an update on developing rubric systems for certainty metrics for each ecosystem component. WG3 gave an update on the finalization of the Bridger Teton National Forest report. WG4 provided updates on various projects occurring to better characterize uncertainty in deposition models. WG5 gave an update on the CL videos being developed by the Forest Service.

Mike Bell gave a detailed presentation on the history of FLAG, dating back to 2000, as agencies recognized a need to establish a consistent and transparent process by which federal agencies could review new permits as they relate to the Prevention of Significant Deterioration (PSD) determinations for Class I areas. The current FLAG subgroup began meeting in October 2020 and intends to incorporate appropriate CLs in its work. FLAG also intends to ask CLAD members for input from their respective area of expertise as the workgroup begins formalizing its guidance.

Additionally, Jen Phelan and Mike Bell provided an update on the CL Mapper (https://clmapper.epa.gov/). Research Triangle International (RTI) began its work on CL Mapper v3.0 which was going to add the lichen CLs from Geiser et al. (2019) and also update the software. Lastly, Tara Greaver presented on EPA's Review of the NO_x/SO_x/PM Secondary NAAQS. The final report of the Integrated Science Assessment (ISA) can be found here: https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=349473

In discussions about planning for CLAD's future, the CLAD Executive team is planning to renew the committee as a science committee within NADP by presenting a report of accomplishments and goals to the NADP Executive Team. The question of wrapping up the working groups was raised without resolution. Mike Bell raised the organization of a CLAD Seminar Series taking place in 2021.

CLAD business included approving the minutes from the Spring 2020 CLAD meeting and filling the CLAD Executive Team positions. Linda Geiser intended to continue co-chairing CLAD but was unable due to her role within NADP, so Jeff Herrick continued as CLAD co-chair, Emmi Felker-Quinn became the incoming chair, and Justin Coughlin was elected as the new secretary.

In addition to the CLAD business meeting, the NADP Science Symposium included two sessions dedicated to Atmospheric Deposition Effects in Aquatic and Terrestrial Ecosystems and Critical Loads of Atmospheric Deposition, as well as talks and posters in other sessions by CLAD Members. Talk titles and abstracts are posted at http://nadp.slh.wisc.edu/conf/2020/ .

5.2 SPRING 2021 MEETING

The CLAD Science Sub-Committee Meeting held two events during the virtual Spring 2021 NADP Meeting: a business meeting forum on Monday, May 10th and a science meeting on Wednesday, May 12th.

BUSINESS MEETING

The CLAD business meeting was held virtually on May 10th with 45 attendees. CLAD co-chair Emmi Felker-Quinn (NPS) called the meeting order and facilitated introductions. The main topics discussed during the meeting included CLAD's committee renewal, updates from the CLAD Seminar Series, changes to TDep outputs, CL Mapper updates, an update from the recent UNECE ICP M&M meeting (see section 6.0 for this update), working group updates, and a CLAD Round Robin report out. In addition, a proposal for a WG6 (Ozone Critical Levels) was put forth and approved with a majority of attendees.

WG1: Jason Lynch announced that NCLD v 3.2 was being worked on; its updates included additions of lichen CLs (Geiser et al., 2019), aquatic enrichments (Williams et al., 2017), aquatic acidification (USFS surface water data), other aquatic acidification (McDonnell et al., 2021), and herb papers (Clark et al. papers). WG2: Linda Pardo reported that WG2 began meeting regularly and was drafting a summary table to explain certainty metrics. WG2 intended to finalize a report by the Fall 2021 Meeting. WG3: Linda Pardo and Mike Bell reported that the Bridger-Teton National Forest report was about to be finalized and that automated reports for different Class I areas was being developed. Rob Smith (USFS) also reported on the Air Quality (AQ) Hub which will be a tool designed to find other air quality tools. WG4: Mike Bell reported on a throughfall deposition analysis and a downsizing of deposition analysis that will help refine deposition uncertainty. WG5: Jen Phelan (RTI) and Linda Geiser (USFS) reported on the CL videos and announced that they will be ready to share at the Fall 2021 Meeting. Another project, led by Jen Phelan, will focus on CL nomenclature and will resume in Fall 2021. WG6: Jeff Herrick (EPA) put forth a vote to approve the establishment of WG6 which will focus on ozone critical levels. The proposal was formally approved by a majority of CLAD attendees (18/34).

The CLAD Round Robin, in which members tell the committee about our ongoing projects, was conducted in multiple formats: members shared written updates in an online document and also spoke during the webinar about their projects. The full written updates are in the meeting minutes.

SCIENCE FORUM: TDEP CHANGES AND EFFECTS ON CRITICAL LOADS

In a virtual meeting on May 12th, staff from different federal agencies provided presentations on how TDep outputs were going to change as EPA modernized its methodology from using an AML script to an Arcpy script. Additionally, as CMAQ was revised (v5.3), EPA would rerun the TDep script to include additional changes. Greg Beachley (EPA) provided an overview of the TDep changes during the TDep Science Committee Meeting on Tuesday, May 11th.

Additional presentations were given by Mike Bell, Jason Lynch, and Justin Coughlin on how variations in total nitrogen and sulfur deposition in the TDep model runs affected CL results. Jason Lynch provided an overview of aquatic CLs, Mike Bell provided results from lichen community CLs, and Justin Coughlin gave an update on how tree CLs were affected.

Both sessions were recorded and included questions and discussion from the audience. The CLAD Executive Committee will post the session videos and slideshows on the NADP website.

5.3 CLAD MEMBERSHIP AWARDS

Starting in Spring 2019, CLAD began to acknowledge the long-term participation of its members. CLAD started in 2006. *This section will be updated with membership awards after the Fall 2021 CLAD meeting.*

6.0 UNECE ICP M&M WGE-CCE MEETING

The United Nations Economic Commission for Europe (UNECE) International Cooperative Program (ICP) Modeling and Mapping of Critical Levels & Loads and Air Pollution Effects, Risks and Trends meeting in April 2021 was conducted virtually. Many CLAD members attended the remote meeting, with Chris Clark presenting on new critical load data for the United States, and Mike Bell presenting on how this data was being integrated for use in management decisions. During the meeting, a representative from each European country presented on new critical load or deposition data that has been developed in the past year.

There was a session on developing a report to update the official empirical Critical Loads for Nitrogen (CLempN) for Europe based on the information developed in the past 10 years. This data from this report will also be integrated into a summary manuscript and will be used to guide decision making processes across Europe. An interesting aspect of the report is that most of the group was hesitant in creating a chapter about how to use and implement critical loads in decision making, as participants felt this guidance would be outside of the purview of the group. As of Fall 2021, the CLempN is in preliminary draft form, which will be revised in a late October workshop, with a final CLempN report to be officially published by the German Federal Environmental Agency and CCE in summer 2022.

Additionally, there was a special focus on the on-going Gothenburg Protocol review process, with two dedicated sessions dealing with the review of progress made towards achieving the environmental and health objectives of the Protocol.

7.0 NEW AND ON-GOING CL WORK CONDUCTED BY CLAD MEMBERS

This section reports on projects in progress related to critical loads which may be of interest to fellow CLAD members.

Greg Beachley (US EPA) is working on TDep maps for 2020 using the EQUATES time-series, planning to make them available in November. Years 2010, 2017-2019 will soon follow. More information is available from the TDep Meeting.

Mike Bell (NPS) is co-leading CLAD Working Group 3 synthesizing CLs for federal areas. Mike organized NADP-CLAD Seminar series which contained 7 talks on the state of critical load science focused on a different ecosystem component each time. They had an average attendance of around 50 people. Mike organized a session with Jason Lynch (EPA) for the NADP Fall Meeting on "30 Years after the Clean Air Act Amendments: The Past, Present, and Future of Acid Deposition Effects". He updated NPS Critical Load Exceedance tables and added new critical load data and worked with NPS staff to establish benchmarks for using critical loads in conditions and trends pages. Mike developed structure and prepared data for an automated critical load reporting tool to output critical load data for all NPS, USFS, and FWS areas. He is a co-author on two peer-reviewed natural resource reports applying critical loads within national parks:

McClung et al 2021. https://doi.org/10.36967/nrr-2284914

McCoy K et al 2021. https://doi.org/10.36967/nrr-2287254

Theresa Crimmins (USA National Phenology Network/University of Arizona) has started a data exploration of phenology data and deposition and is very interested in digging into relationships between deposition and critical loads and plant phenology.

Jeff Herrick (EPA) is working on several Ozone Critical Level projects.

Todd McDonnell (E&S Environmental) has completed and continues to work on a variety of projects related to critical loads, including:

1) Published regional target loads for low-order streams and watershed soils in the Adirondack Park (Cooperators: Syracuse University, USGS, NYSERDA).

2) Completed a regional assessment of critical loads of nitrogen deposition for understory vegetation in Great Smoky Mountains NP (Manuscript in review; Cooperators: USEPA and Wageningen UR).

3) Comparing modeling approaches (Clark et al. 2019, McDonnell et al. 2020, Wilkins et al. 2016) and critical loads for herbaceous vegetation species (Cooperators: USEPA and Trent University).

4) Developing a manuscript to compare CLs/TLs for soil acidification criterion derived from steady-state vs. dynamic mass balance models (Cooperators: RTI and USEPA)

5) Exploring methods for establishing critical loads associated with potentially harmful algal blooms (HABs)

6) Establishing regional critical loads for characteristic understory vegetation species in 8 National Parks including: Acadia NP, Glacier NP, Grand Teton NP, Joshua Tree NP, Rocky Mountain NP, Sleeping Bear Dunes NL, Theodore Roosevelt NP, and Yosemite NP. (Cooperators: NPS and Wageningen UR).

7)Published McDonnell et al, 2021. https://doi.org/10.1016/j.envpol.2021.117110

Rob Smith (US Forest Service - Biological and Physical Resources - Air Resource Management Program) is working on tree- and lichen-based CLs, in interaction with climate and disturbances on US forestlands, with a paper published (Geiser et al 2021, doi:10.1016/j.envpol.2021.118187) and another in review:

Smith, R.J., T.Ohlert, and L.H. Geiser. 2022. Embracing uncertainty and probabilistic outcomes for ecological critical loads. Ecosystems: in review.

Trent Wickman (USFS) collected lake water quality data in about 20 lakes with good historic records across MN/WI/MI. Trent also helped fund a project to look at ozone exposure of tribally important herbs at the previous site of the Aspen FACE experiment in N WI.

8.0 PUBLICATIONS

CL-related publications that will be added to the CLAD website this year include the following:

2021

Clark, C.M.; Sabo, R.; Geiser, L.; Perakis, S.S.; Schaberg, P.G., eds. 2021. *Air pollution effects on forests: A guide to species ecology, responses to nitrogen and sulfur deposition, and associated ecosystem services.* Vol I. Trees. FS-1156. Washington, DC: U.S. Department of Agriculture, Forest Service. 206 p. https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/15364%20FS_GuideToSpeciesEcology_v7%20508.pdf

Geiser, L.H., H.T. Root, R.J. Smith, S. Jovan, L. St. Clair, and K.L. Dillman. 2021. Lichen-based critical loads for deposition of nitrogen and sulfur in US forests. Environmental Pollution 291: 118187. https://doi.org/10.1016/j.envpol.2021.118187

S. Jovan, M.E. Fenn, M. Buhler, A. Bytnerowicz, A. Kovasi, M. Hutten, E. DiMeglio, D. Schweizer. Challenges characterizing N deposition to high elevation protected areas: A case study integrating instrument, simulated, and lichen inventory datasets for the Devils Postpile National Monument and surrounding region, USA. Ecol. Indic., 122 (2021). https://doi.org/10.1016/j.ecolind.2020.107311

Koplitz, SN, Nolte, CG, Sabo, RD, Clark, CM, Horn, KJ, Thomas, RQ, Newcomer-Johnson, TA. (2021) The contribution of wildland fire emissions to deposition in the US: implications for tree growth and survival in the Northwest. Environ, Res. Lett., 16. https://doi.org/10.1088/1748-9326/abd26e

Christopher E. Looney, Anthony W. D'Amato, Sarah Jovan. Investigating linkages between the size-growth relationship and drought, nitrogen deposition, and structural complexity in western U.S. Forests. Forest Ecology and Management, Volume 497, 2021. https://doi.org/10.1016/j.foreco.2021.119494

McClung, J. J., M. D. Bell, and E. Felker-Quinn. 2021. Extrapolating critical loads of nitrogen for alpine vegetation and assessing exceedance in national parks based on TDep Total N from 2002–2016. Natural Resource Report NPS/NRSS/ARD/NRR—2021/2240. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2284914

McCoy K., M. D. Bell, and E. Felker-Quinn. 2021. Risk to epiphytic lichen communities in NPS units from atmospheric nitrogen and sulfur pollution: Changes in critical load exceedances from 2001–2016. Natural Resource Report NPS/NRSS/ARD/NRR—2021/2299. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2287254

T.C. McDonnell, C.T. Driscoll, T.J. Sullivan, D.A. Burns, B.P. Baldigo, S. Shao, G.B. Lawrence. (2021) Regional target loads of atmospheric nitrogen and sulfur deposition for the protection of stream and

watershed soil resources of the Adirondack Mountains, USA. Environmental Pollution, 281. https://doi.org/10.1016/j.envpol.2021.117110

Newcomer, M. E., Bouskill, N. J., Wainwright, H., Maavara, T., Arora, B., Siirila-Woodburn, E. R., et al. (2021). Hysteresis patterns of watershed nitrogen retention and loss over the past 50 years in United States hydrological basins. Global Biogeochemical Cycles, 35. https://doi.org/10.1029/2020GB006777

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