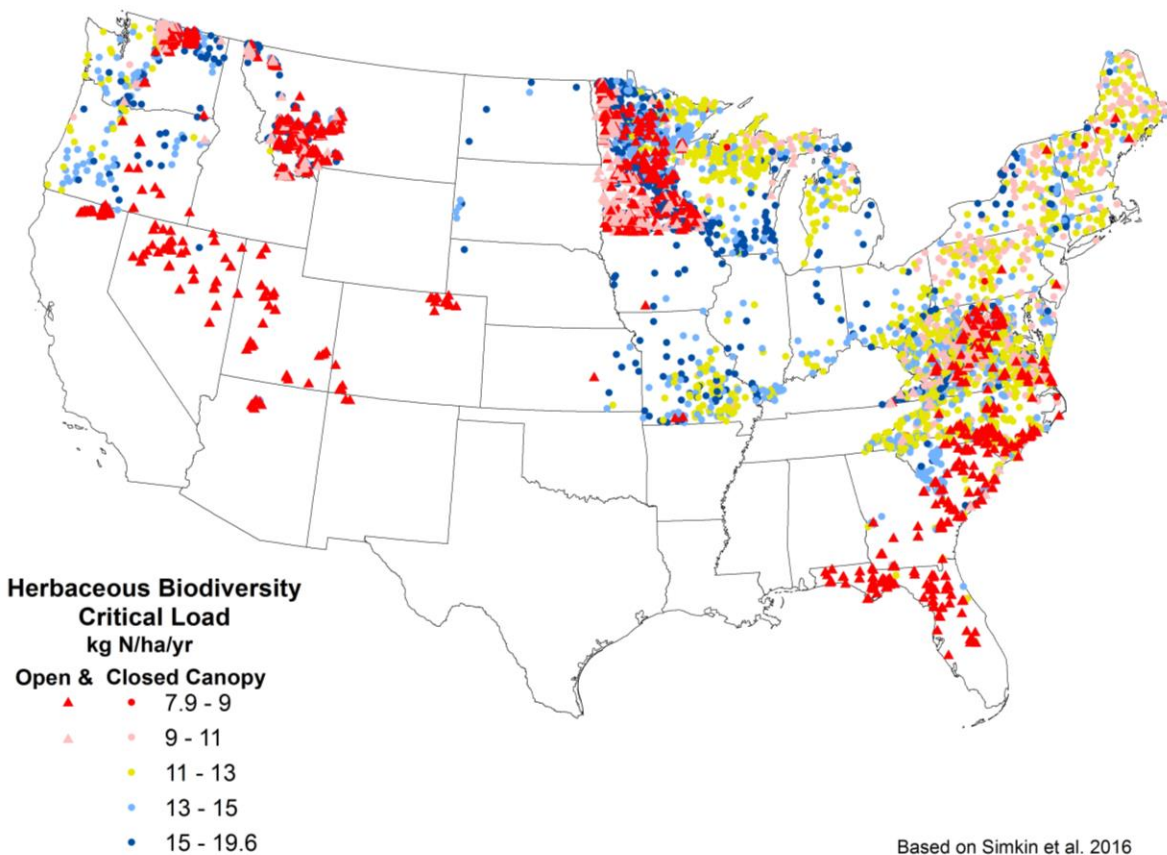




# 2020 Summary of Critical Load Maps



**On the cover:** Critical Loads for Herbaceous Biodiversity (Simkin et al. 2016).

**Use Condition and Citation;** please use the following: The intended use of this database is for scientific, policy-related, or educational purposes. Any published use of the CLAD database information must acknowledge the original sources for the data used. Each critical load value in the database can be linked to its origin using the RefID field. The proper citations for each RefID can be found in Table 7 of the database (Citation for all critical load values). In addition, whenever a data user presents and/or publishes research based on critical load values in the database, CLAD and NADP must be acknowledged. A suggested acknowledgement is:

*When referencing maps or information in this report, please use the citation: National Atmospheric Deposition Program, 2020. National Atmospheric Deposition Program 2019 Summary of Critical Load Maps. Wisconsin State Laboratory of Hygiene, University of Wisconsin-Madison, WI.*

# Contents

<b>Background</b> .....	4
<b>About the Maps and National Critical Load Database (NCLD)</b> .....	6
<b>Surface Water Critical Loads for Acidity and Exceedances</b> .....	8
<b>Forest Soil Critical Loads for Acidity</b> .....	18
<b>Empirical Critical Loads for Nitrogen</b> .....	22
<b>Critical Loads for Herbaceous Biodiversity and Exceedances</b> .....	27
<b>Cited References</b> .....	32

## Background

In April 2010, the National Atmospheric Deposition Program (NADP) Executive Committee formed the Critical Loads of Atmospheric Deposition Science Committee (CLAD). This committee evolved from an ad hoc group originally formed in 2006. The purpose of CLAD is to discuss current and emerging issues regarding the science and use of critical loads for effects of atmospheric deposition on ecosystems in the United States. The goals of CLAD are to:

- Facilitate technical information sharing on critical load topics within a broad multi-agency/entity audience;
- Fill gaps in critical loads development in the United States;
- Provide consistency in development and use of critical loads in the United States;
- Promote understanding of critical load approaches through development of outreach and communications materials.

For more information regarding CLAD, please visit the NADP-CLAD web page at <http://nadp.sws.uiuc.edu/committees/clad/db/>.

Starting in 2010, the “FOCUS Pilot Study” project gathered and synthesized both empirical and calculated critical loads data and information from dozens of regional- and national-scale projects (Blett et al. 2014). CLAD members submitted data to this cooperative effort as a productive and meaningful way to share information to improve methods for estimating, calculating, mapping, interpreting, and refining critical loads. The first round of

critical load data synthesis formed the foundation for an informal, unofficial submission to the UNECE Coordinating Center on Effects (CCE) in 2011. This unofficial submission to the European critical loads community represented a maturing of interest in the United States’ critical loads science community.

### What is a critical load?

Air pollution emitted from a variety of sources is deposited from the air into ecosystems. These pollutants may cause ecological changes, such as long-term acidification of soils or surface waters, soil nutrient imbalances affecting plant growth, and loss of biodiversity. The term “critical load” is used to describe the threshold of air pollution deposition that causes change to sensitive resources in an ecosystem. A critical load is technically defined as “the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not expected to occur according to present knowledge” (Nilsson and Grennfelt 1988). Critical loads are typically expressed in terms of kilograms per hectare per year (kg/ha/yr) or equivalents per hectare per year (eq/ha/yr) of wet or total (wet + dry) deposition. Critical loads can be developed for a variety of ecosystem responses, including shifts in microscopic aquatic species, increases in invasive grass species, changes in soil chemistry affecting tree growth, and lake and stream acidification to levels that can no longer support fish. When critical loads are exceeded, the environmental effects can extend over great

distances. For example, excess nitrogen can change soil and surface water chemistry, which in turn can cause eutrophication of downstream estuaries.

Critical loads describe the point at which a natural system is impacted by air pollution. For ecosystems that have already been damaged by air pollution, critical loads help determine how much improvement in air quality would be needed for ecosystem recovery to occur. In areas where critical loads have not been exceeded, critical loads can identify levels of air quality needed to protect ecosystems in the future. United States scientists, air regulators, and natural resource managers are currently developing critical loads for areas across the United States and collaborating with scientists developing critical loads in Europe and Canada. Once critical loads are established, they can then be used to assess ecosystem health, inform the public about natural resources at risk, evaluate the effectiveness of emission reduction strategies, and guide a wide range of management decisions.

This summary is a collection of critical load maps for the United States, developed by CLAD members using critical load data that are publicly available as part of the NADP CLAD National Critical Load Database v3.1 (NLCD). The full set of critical load maps can be downloaded at the following link: <http://nadp.sws.uiuc.edu/committees/clad/db>.

### **What are critical load exceedances?**

The critical load is exceeded if the deposition load of a pollutant is greater than or equal to the critical load of the pollutant for the same location. Exceedance of the critical load

indicates that an ecosystem is at risk for detrimental effects for atmospheric deposition. For example, when S and N deposition is above the surface water critical load for acidity, acidification of the waterbody is assumed to be taking place, potentially leading to impacts on the aquatic community. In mathematical terms, the exceedance is simply where the deposition is greater than the critical load.

Critical loads are uncertain, and that uncertainty is often considered when exceedances are determined. This is particularly important when deposition is at or near the critical load. For these cases, the critical load error is often used to group sites into their own separate class called “at or near” the critical load while those above and below the range of uncertainty “likely exceed” or “likely to not exceed”, respectively. For example, the margin of error for surface water critical loads for acidity for S is approximate  $\pm 0.5 \text{ kg S/ha/yr}$  ( $\pm 3.125 \text{ meq/m}^2\text{/yr}$ ). A waterbody is then “likely to exceed” its critical load when deposition is  $0.5 \text{ kg S/ha/yr}$  above the critical load estimate and “likely to not exceed” when deposition is at least  $-0.5 \text{ kg S/ha/yr}$  below the critical load estimate. If deposition to the watershed is between  $-0.5$  to  $0.5 \text{ kg S/ha/yr}$  around the critical load, the waterbody is “at or near” the critical load because both the deposition and the critical load are within the margin of error.

Critical load exceedances have been calculated for surface water critical loads for acidity for S only and the critical loads for herbaceous biodiversity based on Simkin et al. (2016).

## About the Maps and National Critical Load Database (NCLD)

The critical load maps provided here represent a compilation of empirical and calculated critical load values from a variety of regional- and national-scale projects. The intended uses of these maps are for scientific, policy-related, or educational purposes. These maps illustrate critical loads in the National Critical Load Database v3.1(NCLD) and help to identify spatial gaps in information, as well as additional research needs.

These maps focus on critical loads of sulfur and nitrogen deposition and the effects on terrestrial and aquatic environments:

- Surface Water Critical Loads for Acidity
- Forest Soil Critical Loads for Acidity
- Empirical Critical Loads for Nitrogen
- Critical Loads for Herbaceous Biodiversity.

The maps for surface water critical loads are updated with many new critical load values as well as a continue stream reach coverage for the southern Appalachian Mountains based on McDonnell et al. (2014). New to the map

summary are critical loads for Herbaceous Biodiversity based on Simkin et al. (2016). Both plot and Ecoregion level critical load estimates are mapped.

The critical load values and maps were developed cooperatively with individuals or groups sharing critical load information and are not intended to be comprehensive of all known critical load values and data for the United States While substantial efforts have been made to ensure the accuracy of data and documentation contained in the NCLD v3.1 database, complete accuracy of the information cannot be guaranteed. The qualities and accuracy of the critical load values are best described in the individual associated research publications. It is important to review material in the cited papers prior to using critical load information from these maps and the NCLD v3.1. In addition, any opinions, findings, conclusions, or recommendations drawn from these maps and datasets do not necessarily reflect the views of the National Atmospheric Deposition Program (NADP), the Critical Loads of Atmospheric Deposition Science Committee (CLAD), or its member affiliations.



Stoney Brook, North Central Pennsylvania. Photo courtesy of Jason Lynch.



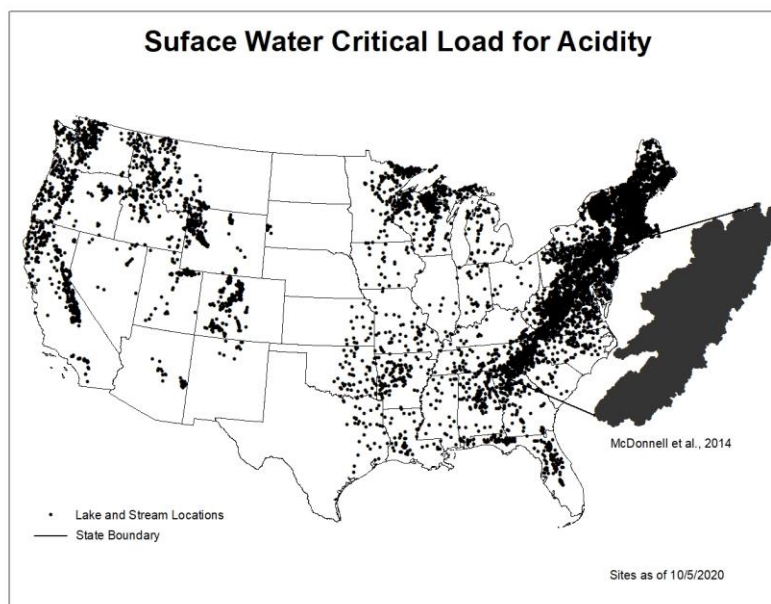
## Surface Water Critical Loads for Acidity and Exceedances

### Critical Load

For this series of maps, the critical loads represent the combined deposition load of sulfur and nitrogen, or the deposition load of sulfur only, to which a lake or stream could be subjected to and still maintain a healthy aquatic system and prevent significant harmful effects. These critical loads are calculated for specific waterbodies (e.g., an alpine lake) based on simple-mass balance models that incorporate present-day surface water chemistry data from monitoring locations. Mass balance approaches consider the net loss or accumulation of acids, nutrients, and base cations in soils and surface waters necessary to maintain the surface water acidity (e.g., Acid Neutralizing Capacity (ANC)) above a pre-selected level or “chemical threshold,” likely to prevent ecosystem harm. The steady-state approach does not estimate how long it will take for ecosystem response (improvement or decline) to occur; rather, it estimates the critical load of deposition that protects the aquatic ecosystem.

Data from over 13,700 individual streams and lakes (Lynch et al. 2020) were used to develop steady-state surface water critical loads for acidity. In addition, McDonnell et al. (2014) determined steady-state surface water critical loads for acidity using a regional regression model for over 154,000 continuous stream reaches for the southern Appalachian Mountain.

Multiple approaches were employed for estimating steady-state acid-base balance load (e.g., Sullivan et al. 2012; McDonnell et al. 2012; Scheffe et al. 2014; McDonnell et al. 2014). The chemical threshold for ANC was set at 20  $\mu\text{eq/L}$



for waterbodies in the western United States and 50  $\mu\text{eq/L}$  for waterbodies in the eastern United States, which best reflects the natural acidity conditions in these regions. The “Aquatic Ecosystem Concern Levels and Ecological Effects” table below generally describes the expected ecological effects for the eastern United States at given ranges of ANC. Critical loads for sulfur and nitrogen (S+N) and sulfur (S) deposition are expressed in terms of ionic charge balance as milliequivalents per square meter per year ( $\text{meq/m}^2/\text{yr}$ ). See NLCD metadata document for a more complete description of the methods (Lynch et al. 2020).

Critical loads are based on water quality data collected from a range of years from the 1980s to the present. Not all waterbodies with surface water data are suitable for calculating critical loads for acidity. The following were excluded from critical load calculations: (1) insufficient or unsound data such that the mass-balance



estimates were compromised (e.g., waterbodies with runoff rates > 0.15 mm/yr), (2) sulfate values exceeding 400 µeq/L, which suggest a non-atmospheric source of sulfur, such as mine drainage or sulfur-bearing bedrock, (3) imbalanced chloride and sodium concentrations, which suggest the water body was influenced by salt contamination, and/or (4) the size of the watershed at the sampling point was greater than 14,400 km<sup>2</sup>.

The maps on pages 11 through 13 show aggregated critical loads at the 12 x 12 km grid cells. Waterbodies where more than one calculated critical load value occurred were averaged to produce a single value for each waterbody. These single critical load values per waterbody were then aggregated into a summary value for each grid cell. Aggregations maps are shown for the “average” and 10<sup>th</sup> quantile critical load based on recommendation of CLAD. A 10<sup>th</sup> quantile critical load represents the most sensitive 10 percent data available for a grid cell.

The maps on page 14 show critical loads for Sulfur only based on McDonnell et al. (2014). Critical loads are defined for each stream reach for the entire Southern Appalachian Mountain study domain.

Uncertainty estimates for maps on pages 11 through 13 are not available at this time. Instead, the number of critical loads per grid cell gives a qualitative measure of reliability for the aggregated critical load: an aggregated critical load based on more values is assumed to be more reliable. The number of critical loads per 12 x 12 km grid (not including critical loads

from McDonnell et al. (2014)) is presented on page 15. The number of critical load values in each grid cell varies depending on the availability of data for a particular area (see the critical load values per grid map). The Mid-Atlantic and Appalachian Mountains have considerably more critical load values than other regions. In addition, the critical load values in the database are not necessarily a representative sample of all waterbodies found in each grid cell. Instead, this mapping exercise provides a representation of the availability of data in a particular grid cell.

Maps contain critical load data through 10/5/2020(NCLD v3.1); however, the NCLD is continuously being updated.

### **Critical Load Exceedance**

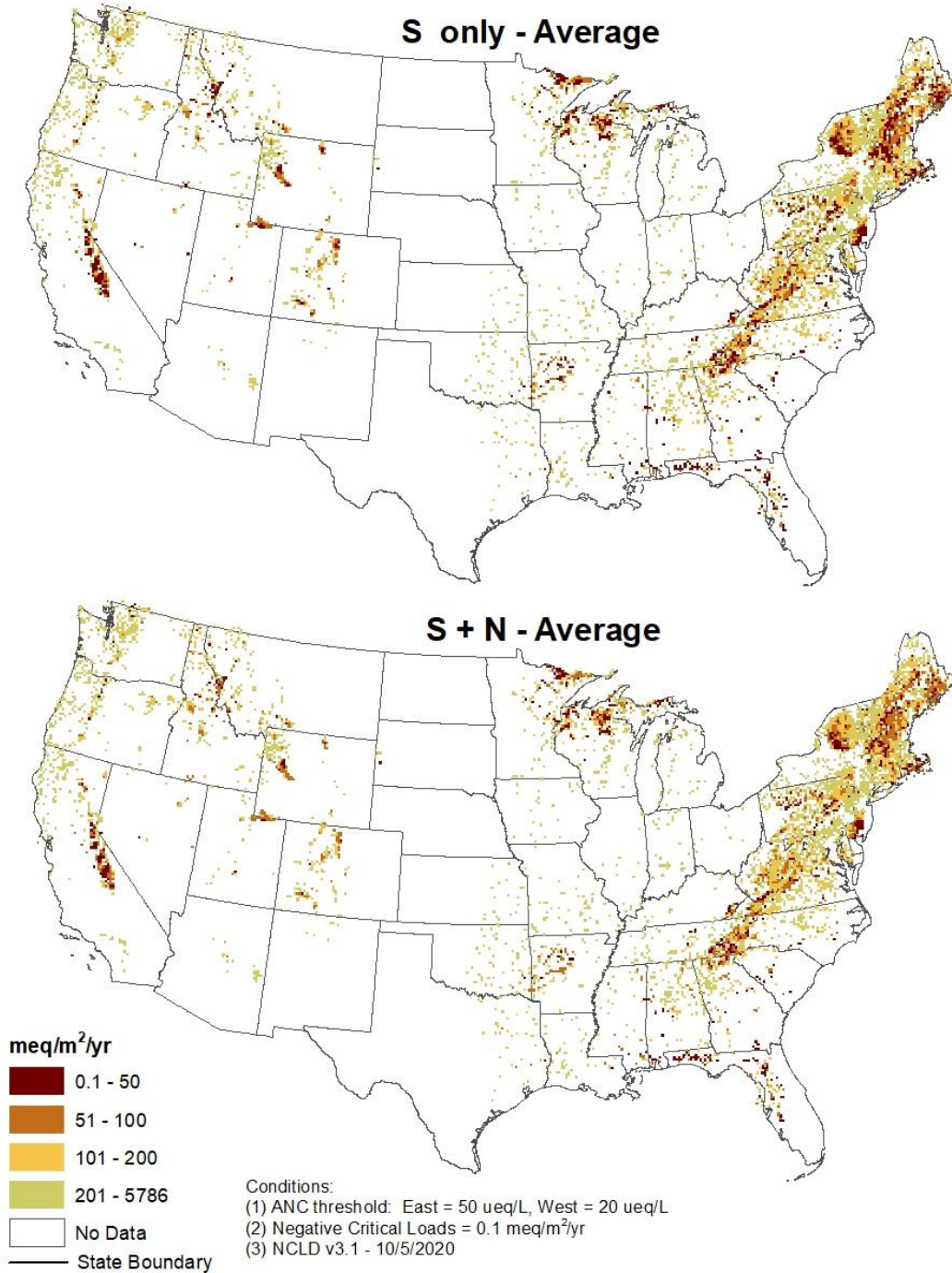
The maps on pages 16 and 17 show surface water critical load exceedances for acidity. Critical load exceedances are for S only based on average TDep deposition (<http://nadp.slh.wisc.edu/committees/tdep/tdepmaps/>) for the years 2015-2018. Waterbodies that are likely to exceed their critical load are where total S deposition is above the estimated error in the critical load. Nitrogen deposition for these maps were not considered. The estimated error is ± 0.5 kg S/ha/yr (± 3.125 meq/m<sup>2</sup>/yr). Waterbodies that likely do not exceed are those below the estimated error. Where deposition is within the range of uncertainty of the critical load, it may or may not exceed within the margin of error. Here the margin of error was between -0.5 to 0.5 kg S/ha/yr (-3.125 to 3.125 meq/m<sup>2</sup>/yr).

### Aquatic Ecosystem Concern Levels and Ecological Effects

Category Label	ANC Level ( $\mu\text{eq/L}$ )	Expected Ecological Effects
Acute Concern	Less than 0	Near-complete loss of fish populations is expected. Planktonic communities have extremely low diversity and are dominated by acid-tolerant forms. The numbers of individuals in plankton species that are present are greatly reduced.
Elevated Concern	0 to less than 50	Fish species richness is greatly reduced (e.g., more than half of expected species are missing). On average, brook trout populations experience sublethal effects, including loss of health and reproduction (fitness). During episodes of high acid deposition, brook trout populations may experience lethal effects. Diversity and distribution of zooplankton communities decline.
Moderate Concern	50 to less than 100	Fish species richness begins to decline (e.g., sensitive species are lost from lakes). Brook trout populations are sensitive and variable, with possible sublethal effects. Diversity and distribution of zooplankton communities begin to decline as species that are sensitive to acid deposition are affected.
Low Concern	Greater than or equal to 100	Fish species richness may be unaffected. Reproducing brook trout populations are expected where habitat is suitable. Zooplankton communities are unaffected and exhibit expected diversity and distribution.

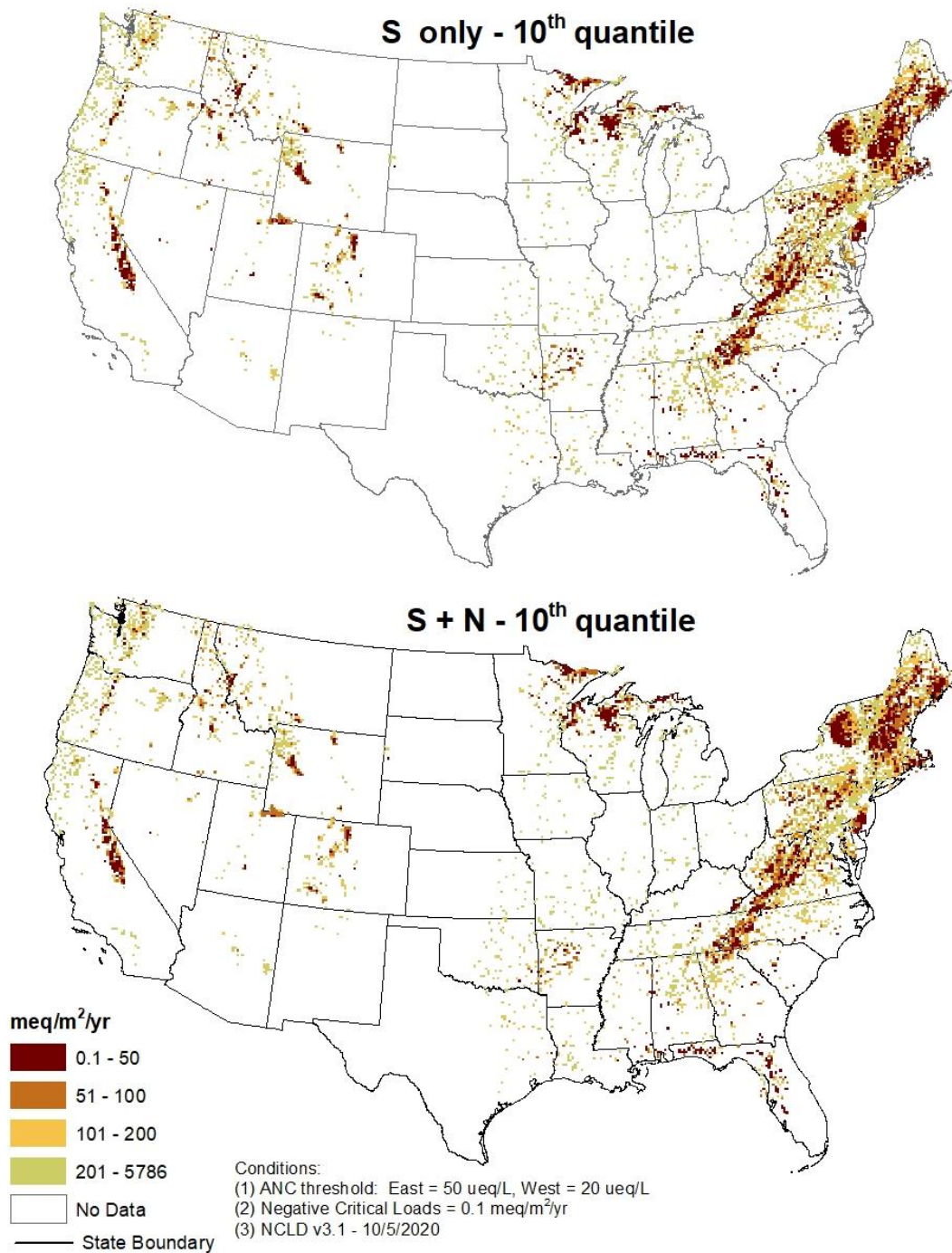
From Burns et al. (2011)

# Surface Water Critical Load for Acidity



Surface Water Critical Loads for Acidity. Average aggregation for 12 x 12 km grid cell with S only (top) and S + N only (bottom) (See Lynch et al. (2020) for data source information).

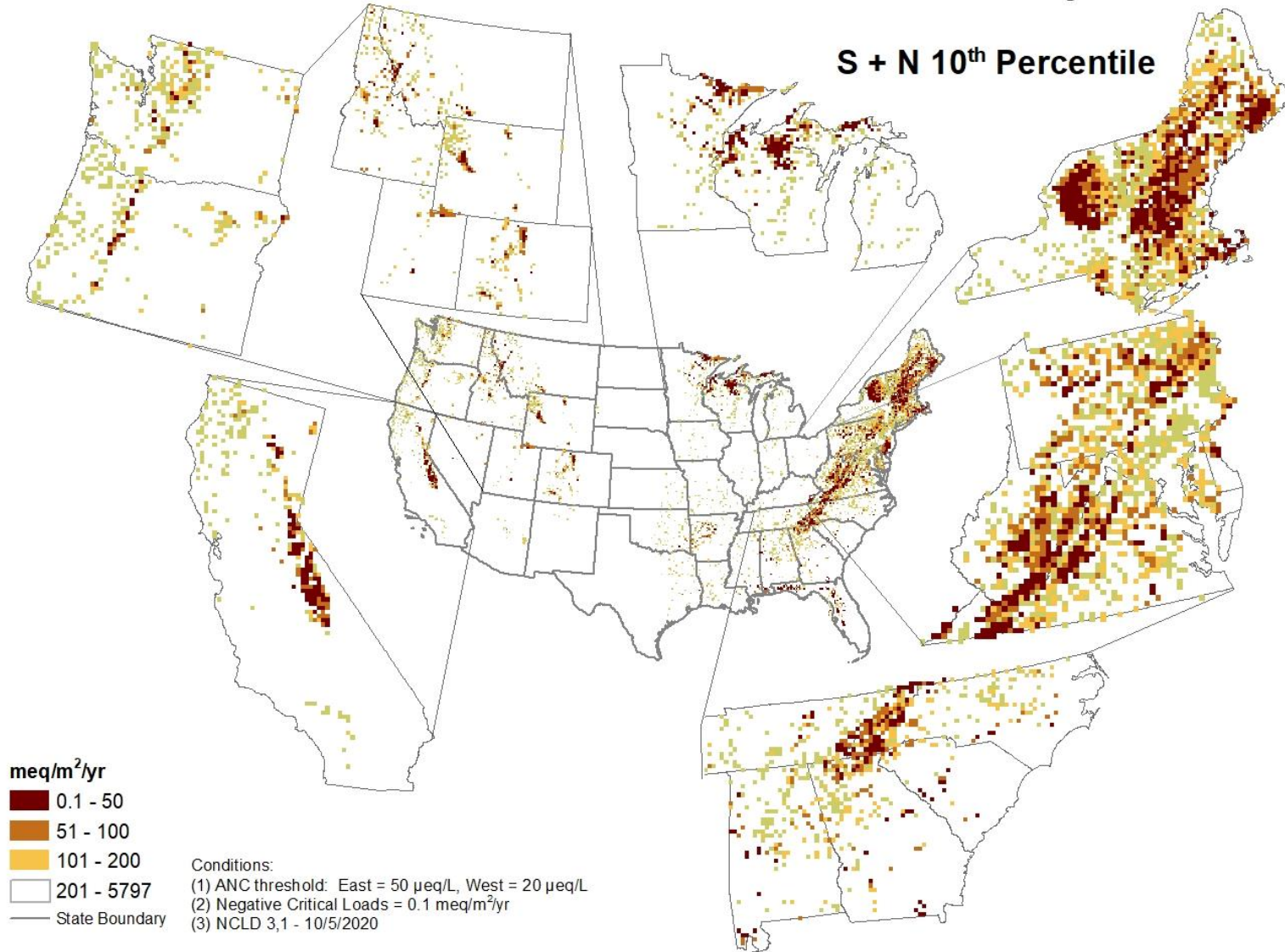
## Surface Water Critical Loads for Acidity



Surface Water Critical Loads for Acidity. 10<sup>th</sup> quantile aggregation for 12 x 12 km grid cell with S only (top) and S + N (bottom) (See Lynch et al. (2020) for data source information).

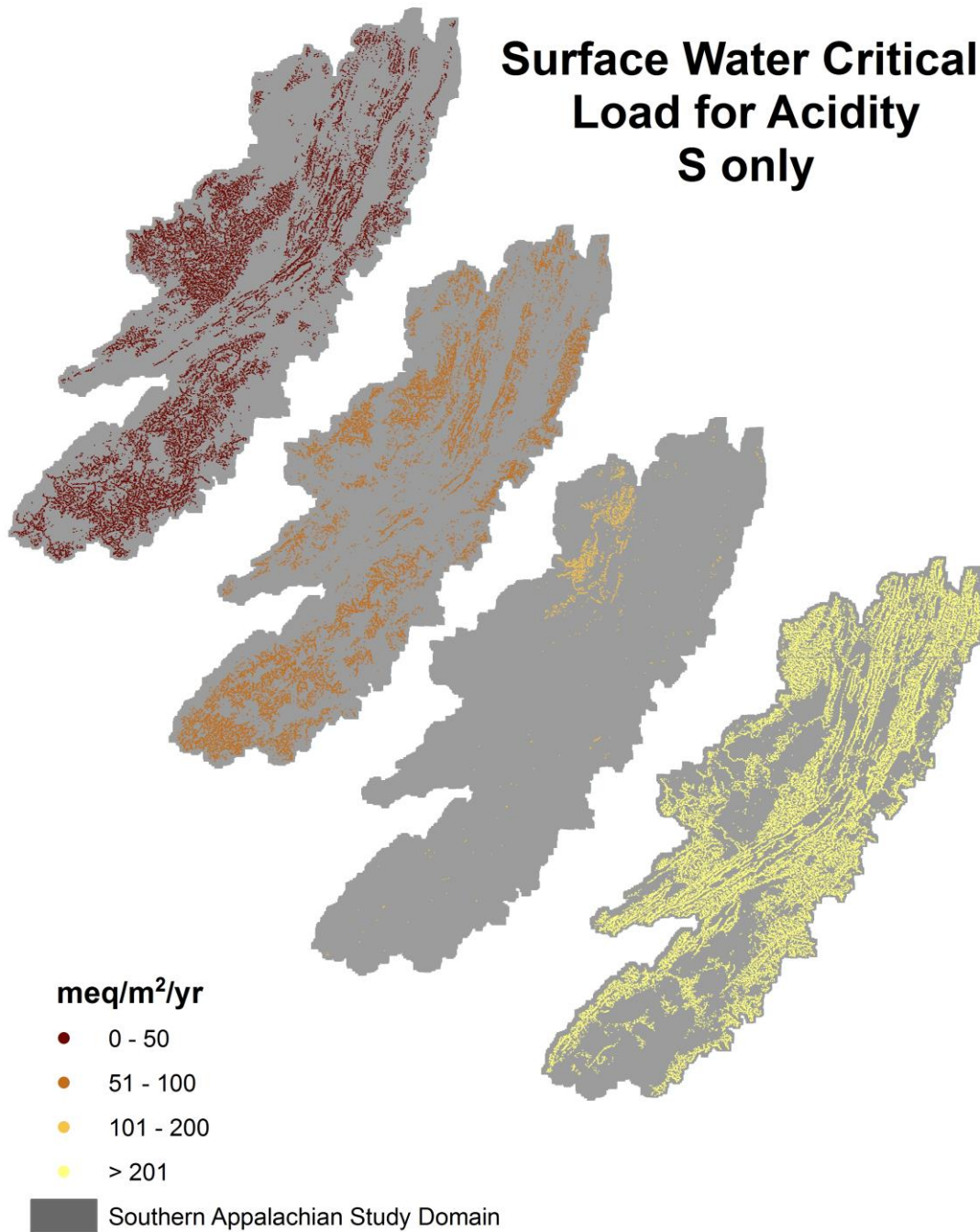


# Surface Water Critical Loads for Acidity



Surface Water Critical Loads for Acidity. 10<sup>th</sup> quantile aggregation for 12 x 12 km grid (See Lynch et al. (2020) for data source information).

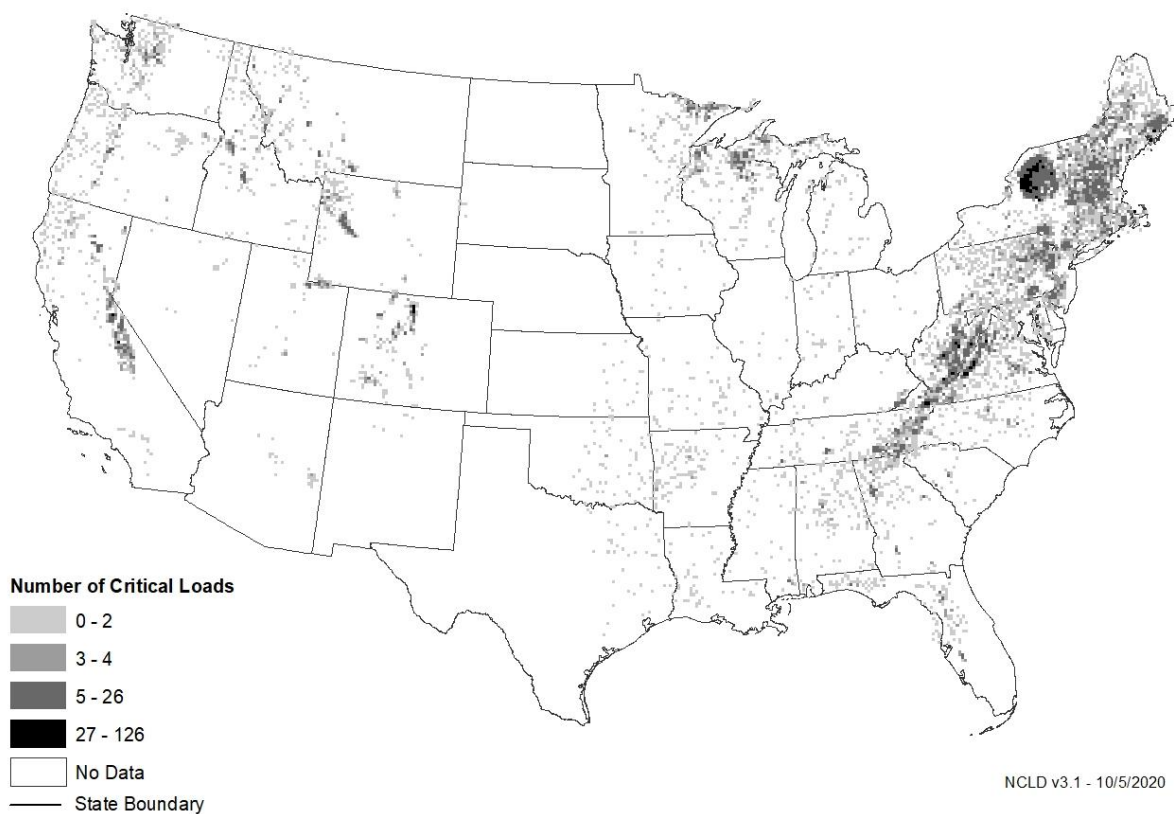
## Surface Water Critical Load for Acidity S only



Based on McDonnell et al., (2014)

Surface Water Critical Loads for Acidity. Critical load for S only based on McDonnell et al. (2014). Critical loads (locations) are defined for each stream reach for the entire Southern Appalachian Mountain study domain.

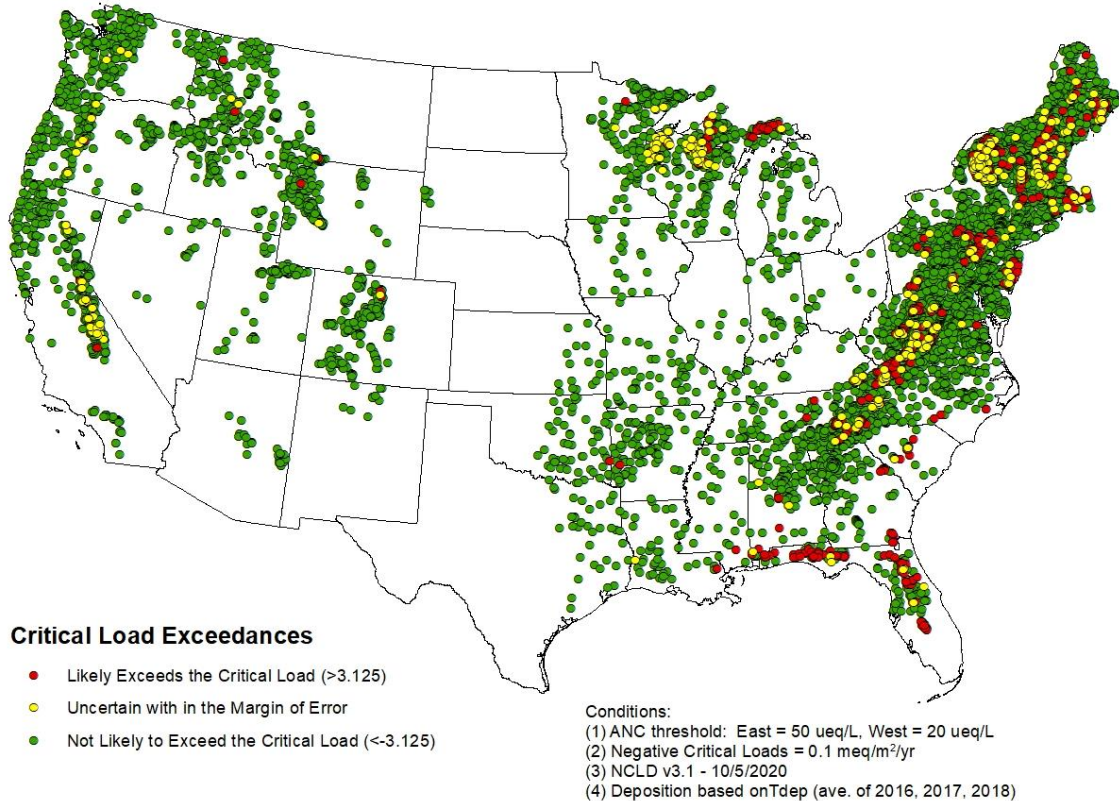
## Surface Water Critical Load for Acidity



Number of critical loads per 12 x 12 km grid cell.

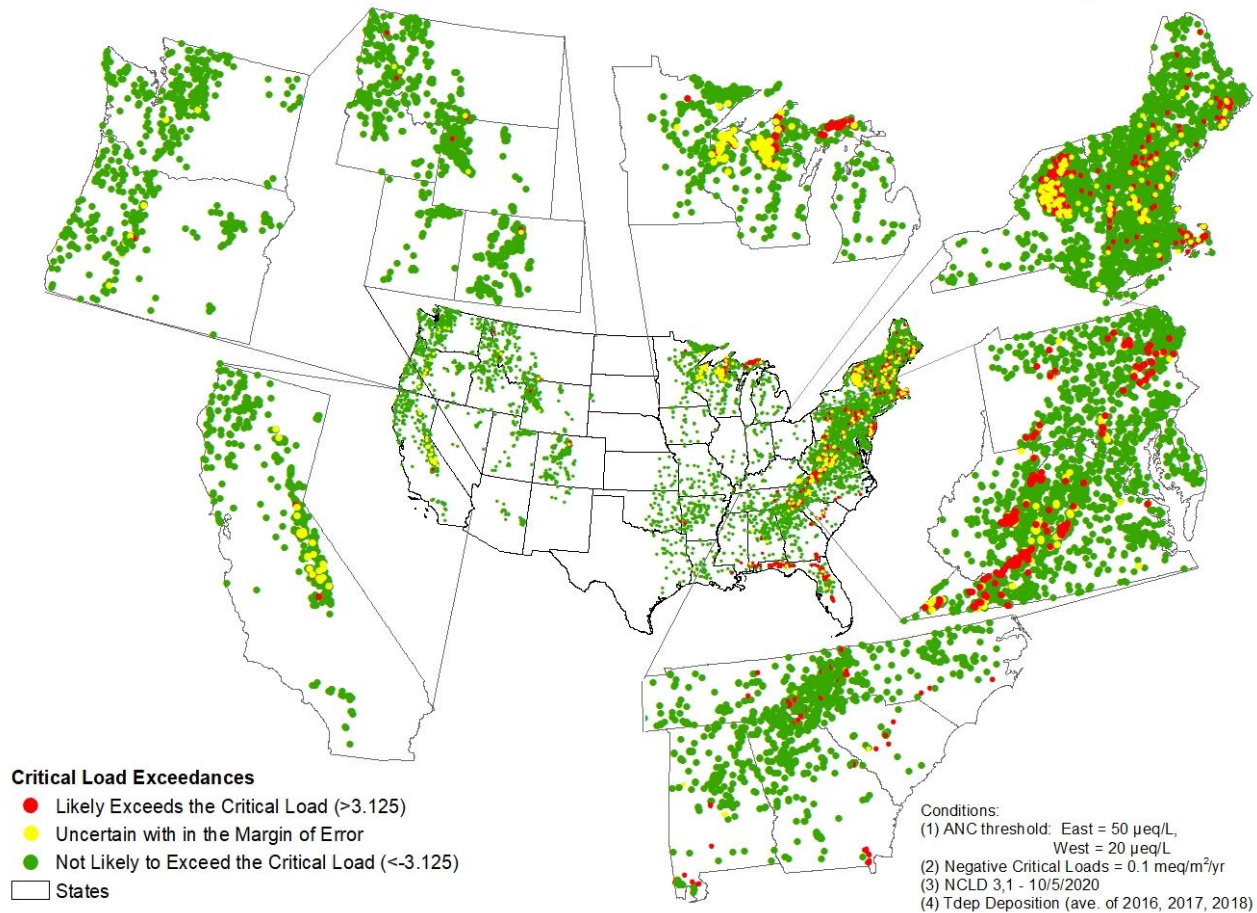


## Surface Water Critical Load Exceedances for Acidity



Surface Water Critical Load Exceedances for Acidity. Critical load exceedances are for S only based on average TDep deposition for the years 2015-2018. Waterbodies likely to exceed (red) the critical load are where total S deposition is 3.125 meq/m<sup>2</sup>/yr above the critical load, while those likely not to exceed (green) are where 3.125 meq/m<sup>2</sup>/yr below the critical load. Waterbodies that fell between -3.125 to 3.125 meq/m<sup>2</sup>/yr (yellow) are those with deposition near the critical load and may or may not exceed given the margin of error.

## Surface Water Critical Load Exceedances for Acidity



Surface Water Critical Load Exceedances for Acidity. Critical load exceedances are for S only based on average Tdep deposition for the years 2015-2018. Waterbodies likely to exceed (red) the critical load are where total S deposition is  $3.125 \text{ meq/m}^2/\text{yr}$  above the critical load, while those likely not to exceed (green) are where  $3.125 \text{ meq/m}^2/\text{yr}$  below the critical load. Waterbodies that fell between  $-3.125$  to  $3.125 \text{ meq/m}^2/\text{yr}$  (yellow) are those with deposition near the critical load and may or may not exceed given the margin of error.

# Forest Soil Critical Loads for Acidity

## Critical Loads

Mapped terrestrial forest soil ecosystem critical loads for acidity are from McNulty et al. (2007, 2013), Duarte et al. (2012, 2013), Sullivan et al. (2011a, 2011b), McDonnell et al. (2013), and Phelan et al. (2014, 2016). All of these studies calculated steady-state critical loads for forest ecosystems using the simple mass balance (SMB) approach (UBA 2004). Steady-state models are used to calculate critical loads that will allow ecosystem sustainability over the long term. Water and soil chemistry, mineral soil weathering rates, deposition data, and an understanding of ecosystem responses to chemical changes are all used in these models. The steady-state approach does not estimate how long it will take for ecosystem response (improvement or decline) to occur; rather, it estimates the critical load of deposition that protects the forest ecosystem.

Base cation weathering rates were estimated using various methods among the studies. McNulty et al. (2007, 2013) and Duarte et al. (2012, 2013) used the clay percent-substrate method. Sullivan et al. (2011a, 2011b) and McDonnell et al. (2013) used the Model of Acidification of Groundwater In Catchment (MAGIC) on a watershed bases, using an input-output mass balance approach. Phelan et al. (2014, 2016) used the PROFILE model, which integrates soil mineralogy and other environmental properties.

The base cation to aluminum [BC]: [Al] ratio was selected as the chemical criterion for McNulty et al. (2007, 2013), Duarte et al. (2011, 2013), and Phelan et al. (2014, 2016). McNulty et al.

(2007, 2013) used the following critical thresholds for the molar [BC]: [Al] ratio: 1 for conifer forests and 10 for deciduous forests. The critical threshold used by Duarte et al. (2012, 2013) and Phelan et al. (2014, 2016) was a [BC]: [Al] molar ratio of 10 for all forest types. Sullivan et al. (2011a, 2011b) and McDonnell et al. (2013) used various chemical criteria, which included [BC]: [Al] molar ratio of 1 and 10, calcium to aluminum [BC]: [Al] molar ratio of 1 and 10, and base saturation of 5 and 10 percent. A base saturation of 5 percent was used in the map on page 21.

See McNulty et al. (2007, 2013), Duarte et al. (2012, 2013), Sullivan et al. (2011a, 2011b), McDonnell et al. (2013), and Phelan et al., (2014, 2016), and NCLD metadata 2017 for more detail on methods used to calculate the critical loads of acidity (Lynch et al. 2020).

The maps on page 20 show critical loads mapped at 1 km<sup>2</sup> spatial resolution (McNulty et al. 2007, 2013), at 5 km<sup>2</sup> spatial resolution (Duarte et al. 2012, 2013), at the watershed scale (Sullivan et al. 2011a, 2011b and McDonnell et al. 2013), and at the sample site (Phelan et al. 2014, 2016). Critical loads are estimated for forest areas only and are expressed in terms of an ionic charge balance as equivalents per hectare per year (eq/ha/yr).

The strength of the SMB approach is that it provides a means for comparing forest soil susceptibility to acidification across the conterminous United States (McNulty et al. 2007, 2013). However, the McNulty et al. (2007, 2013) results should be considered preliminary due to the uncertainty in the underlying data,

which is related to data quality, spatial heterogeneity, natural variability, and model suitability (Li and McNulty 2007). The Li and McNulty (2007) analysis indicates that uncertainty in the SMB approach comes primarily from the components of base cation weathering and the estimate of acid-neutralizing leaching. Improvement in these two parameters would considerably improve these critical load estimates (Duarte et al. 2013). Base cation weathering rates used by McNulty et al. (2007, 2013) may be more uncertain in the south and west regions of the United States, given the suitability of the model used to estimate the base cation weathering for those regions. The maps on page 21 show critical loads calculated by (McNulty et al. 2007, 2013), but with a 20 and 40 percent increase in base cation weathering, indicating the relative sensitivity of these modeled estimates to base cation weathering rates.

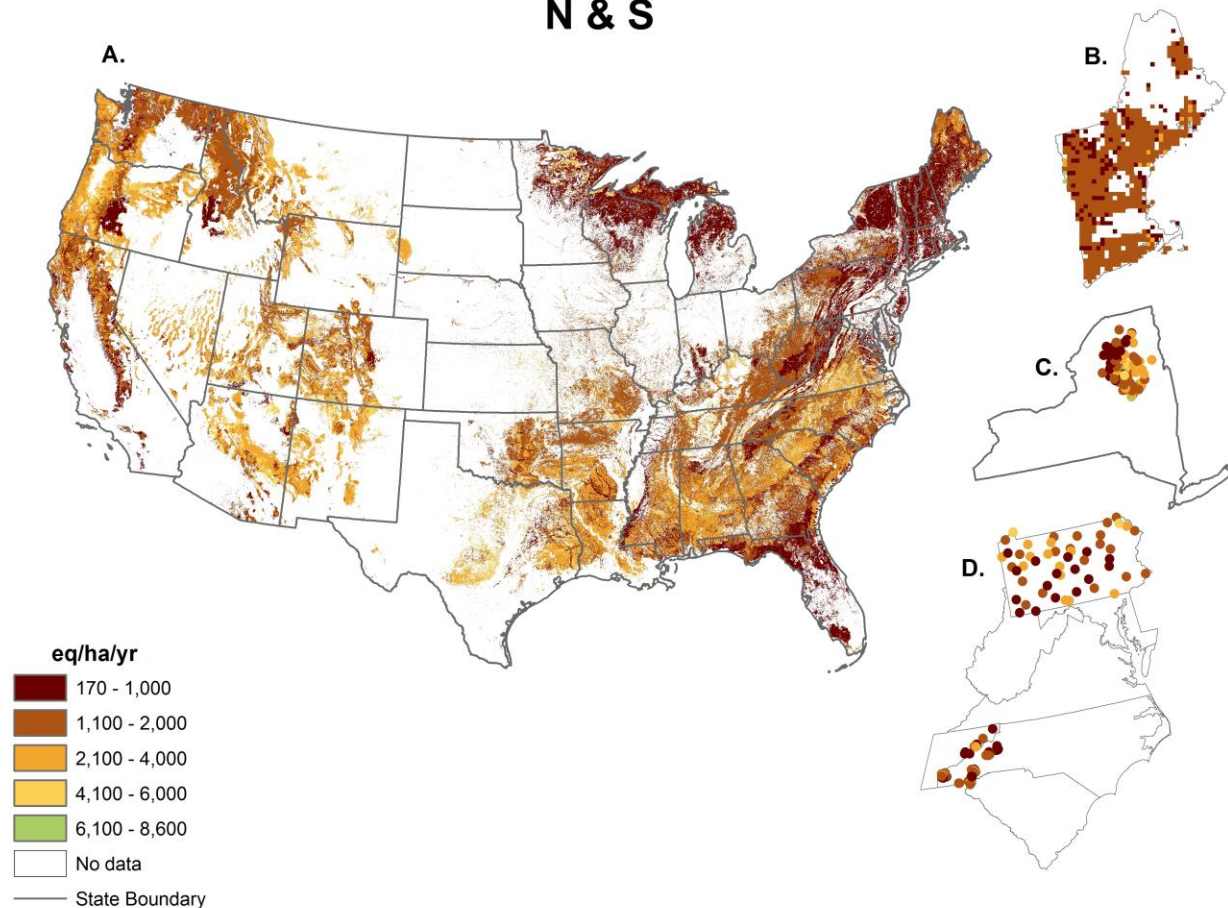
The Phelan et al. (2014, 2016) application of the PROFILE model was a preliminary test of the ability of this model to estimate base cation weathering rates in forested ecosystems in the United States, using the recently released USGS National Landscapes Project dataset (<http://minerals.cr.usgs.gov/projects>). While their application was successful, the critical load calculations were restricted to only 51 sampling sites in Pennsylvania.

Critical loads calculated by Sullivan et al. (2011a, 2011b) and McDonnell et al. (2013) are technically "target" loads because they specify a year by which to achieve the level of the chemical criterion; however, the year of 2300 (longest period of simulation) best approximates the steady-state "critical" load condition. In addition, the MAGIC model application was based on soil data from a single sampling site within each watershed. Each critical load represents the entire watershed area.

Lastly, the SMB model approach provides only point-in-time estimates of forest soil acidity, not

a prediction of how the soils may change over time. The relative coarse spatial scale provides a general pattern of soil acidity. A more systematic analysis of model inputs and measures is still needed in order to identify areas of forest health concerns.

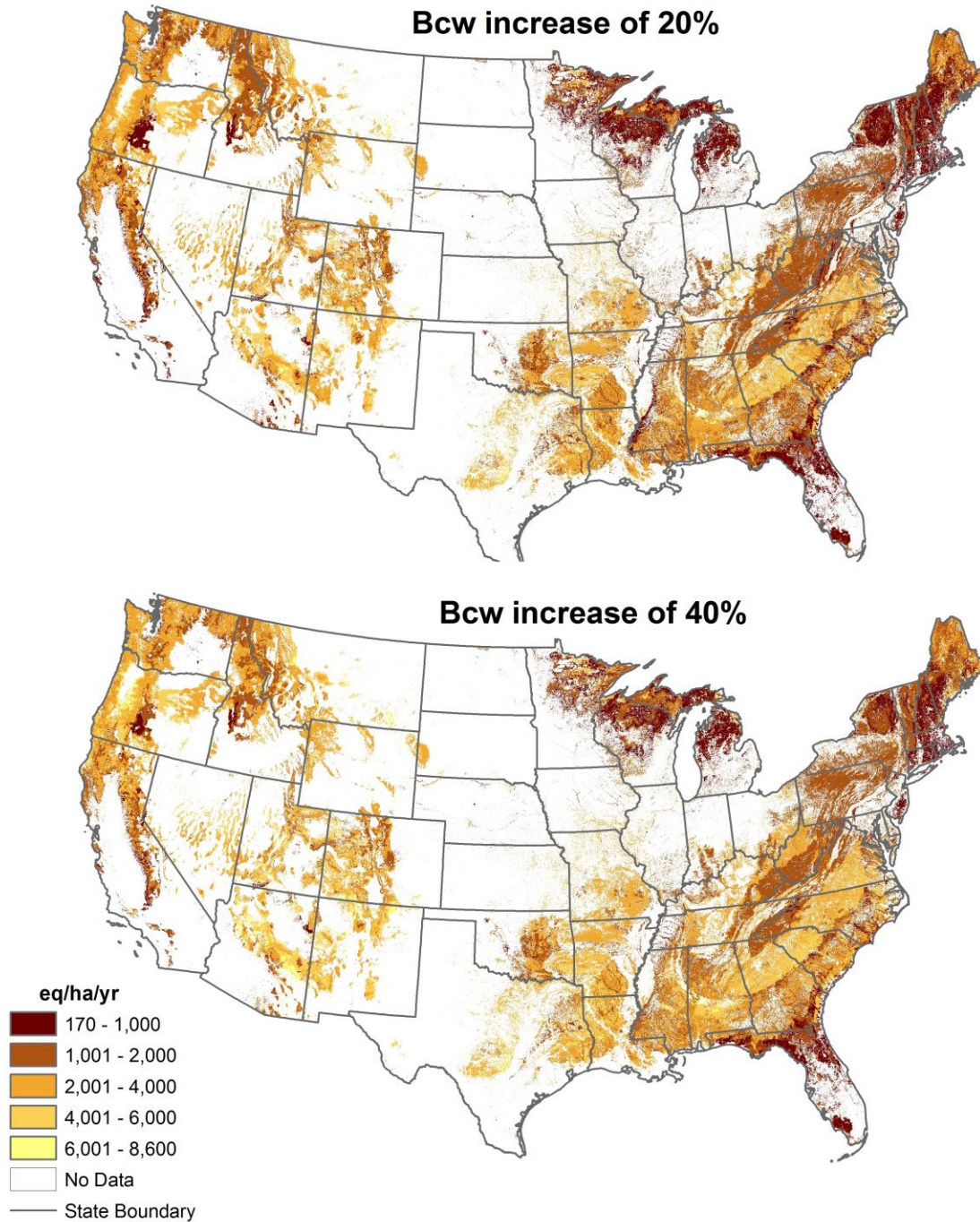
## Forest Soil Critical Loads for Acidity N & S



Forest Soil Critical Loads for Acidity. (A.) McNulty et al. (2007, 2013) critical loads are mapped at 1 km<sup>2</sup> spatial resolution (center map). The color scheme presented here is different from the original McNulty et al. (2007, 2013) publications. For uncertainty, see Li and McNulty (2007); (B.) Duarte et al. (2012, 2013) critical loads are mapped at 5 km<sup>2</sup> spatial resolution; (C. and D.) Phelan et al. (2014, 2016) critical loads are mapped for each sampling site (Pennsylvania). Sullivan et al. (2011a, 2011b) and McDonnell et al. (2013) critical loads are mapped as a single point at the center point of the watershed (New York and North Carolina).



## Forest Ecosystem Critical Loads for Acidity N & S



Forest Soil Critical Loads for Acidity with base cation weathering increased by 20% (top) and 40% (bottom) (McNulty et al. 2013). Color scheme presented here is different from the original McNulty et al. (2007, 2013) publications.

# Empirical Critical Loads for Nitrogen

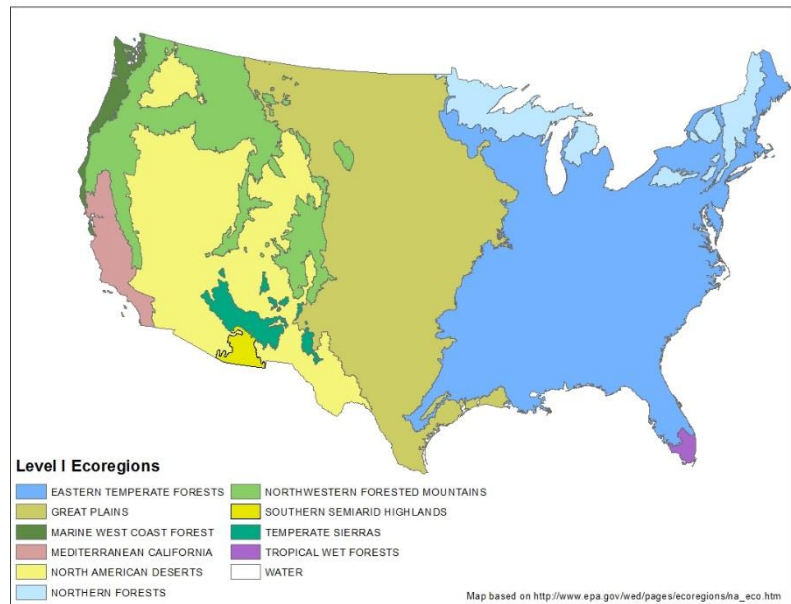
## Critical Loads

Empirical approaches are based on the observation of ecosystem responses (such as changes in plant diversity, soil nutrient levels, or fish health) to specific deposition levels at a given point in time. These relationships are developed using dose-response studies or by measuring ecosystem responses to increasing gradients of deposition over space or time. Empirical information can be used to develop site-specific critical loads or generalized to estimate critical loads over similar areas.

The maps on pages 22 and 23 show empirical critical loads developed by Pardo et al. (2011a, 2011b). These empirical critical loads are defined by ecoregion and include a range of values representing different responses by various receptors based on the best scientific information available at the time. Maps are for receptors, including mycorrhizal fungi, lichens, herbaceous species and shrubs, and forest ecosystems, and are mapped at the Level 1 Ecoregion scale ([http://www.epa.gov/wed/pages/ecoregions/na\\_eco.htm](http://www.epa.gov/wed/pages/ecoregions/na_eco.htm)). See Pardo et al., (2011a, 2011b) for more details about how these critical loads were determined.

The maps on page 24 show empirical critical loads for lichen using methods developed by Geiser et al. (2010) and Root et al. (2015) and aggregated at the 4 x 4 km grid. Root et al. (2015) estimated critical loads for the mountain regions in Washington, Oregon, Idaho, and Montana. Maps on page 24 represent a high and low critical load range, which is based on

the minimum and maximum critical load presented in Geiser et al. (2010) and Root et al.



(2015). Agriculture and urban areas, based on the 2011 National Landcover Database (NLCD), were removed from the maps below and depicted as white spaces. See Geiser et al. (2010) and Root et al. (2015) for more details about how critical loads were estimated.

These empirical critical loads represent nitrogen impacts (eutrophication and/or acidification) of total nitrogen deposition (wet and dry) expressed in terms of kilograms of nitrogen deposition per hectare per year (kg N/ha/yr).

Minimum and maximum critical load values are specified; however, these values may represent different impacts (for example, a minimum critical load for lichen may be based on changes in community composition, while a maximum critical load for lichen may be based on changes to lichen chemistry which impact an individual species). Because a range of responses was reported for each receptor, the low end of the



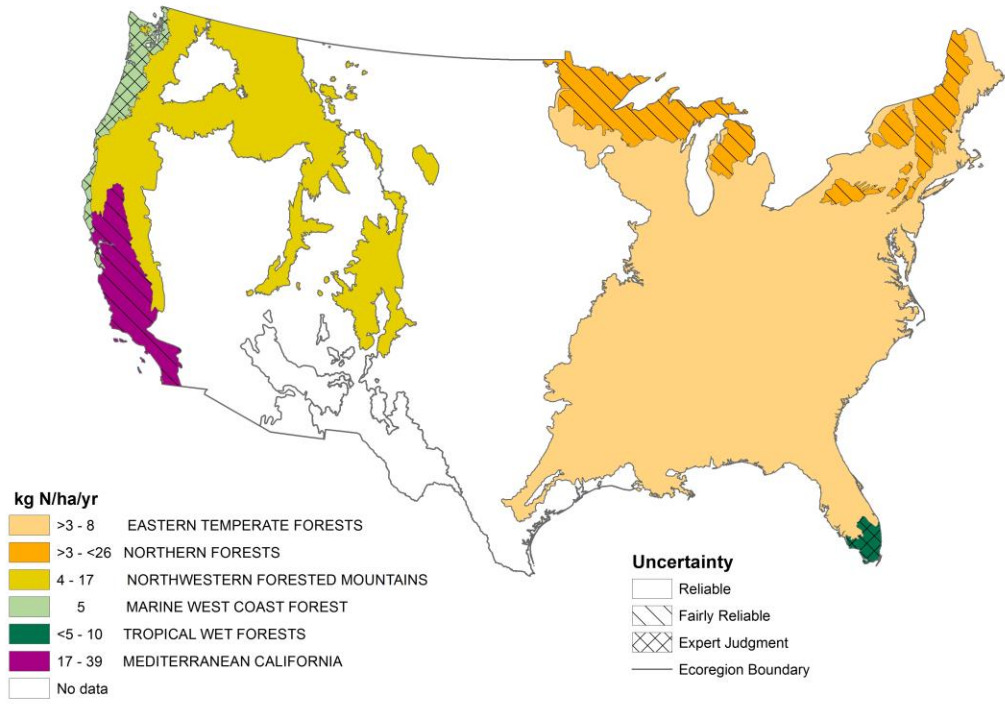
range provides a somewhat conservative critical load estimate.

These critical loads represent a specific point in time and are mapped at a coarse scale. Because of the mapping scale, a receptor for a given map may not actually be present locally; site-specific data are therefore needed to verify the presence of the receptor. For example, the forest ecosystem receptor applies only to areas where forests occur. In addition, other environmental and biological factors (soil pH, species composition, etc.) may affect the critical load range for a given area. Additional empirical

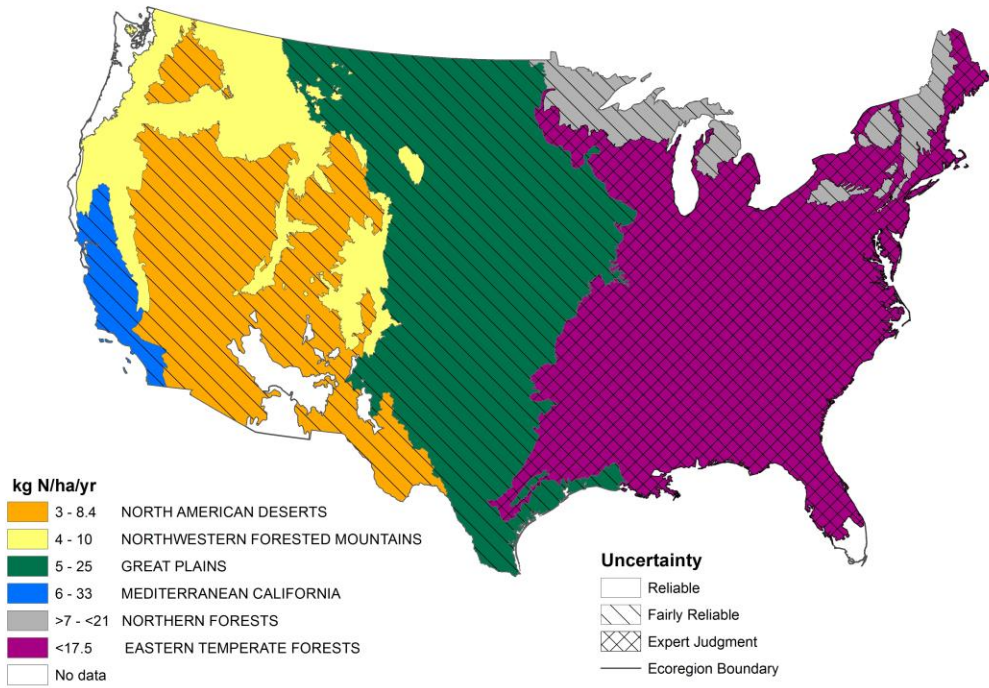
critical loads are being developed that account for more site-specific factors and will represent a much smaller geographic area.

Uncertainty of the empirical critical loads mapped on pages 24 and 26 are based on the strength of the scientific literature for each critical load receptor. Uncertainty is expressed as “reliable,” “fairly reliable,” and “expert judgment” (see Pardo et al. 2011a, 2011b for more details). Uncertainty of the empirical critical loads mapped on page 24 is currently not available.

### Empirical Critical Loads for Nitrogen - Forest Ecosystems

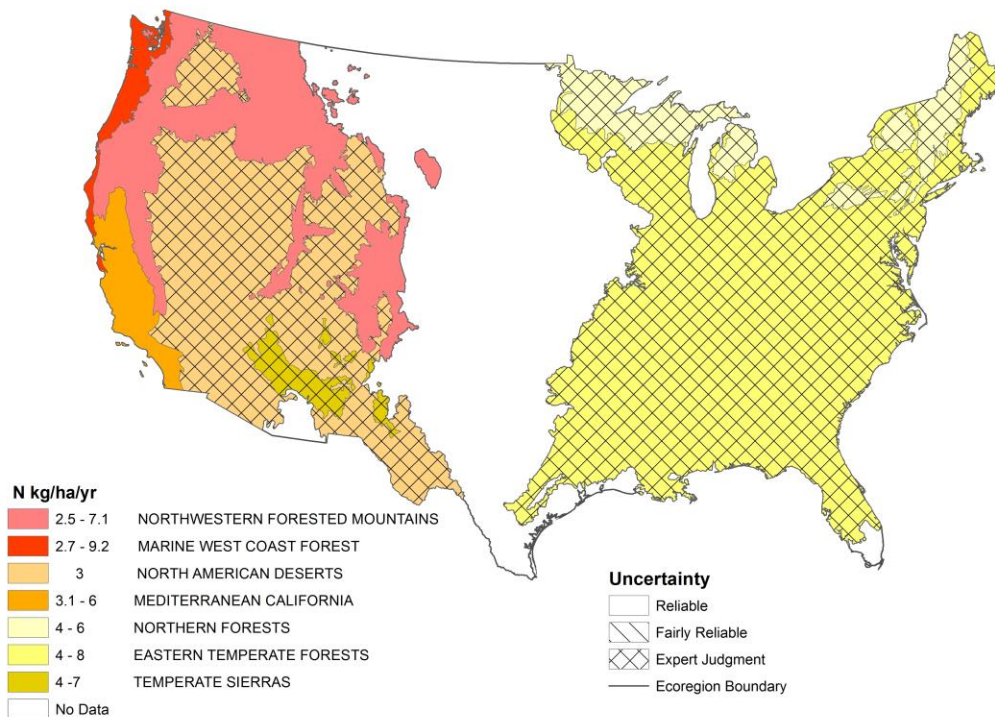


### Empirical Critical Loads for Nitrogen - Herbaceous Plants & Shrubs

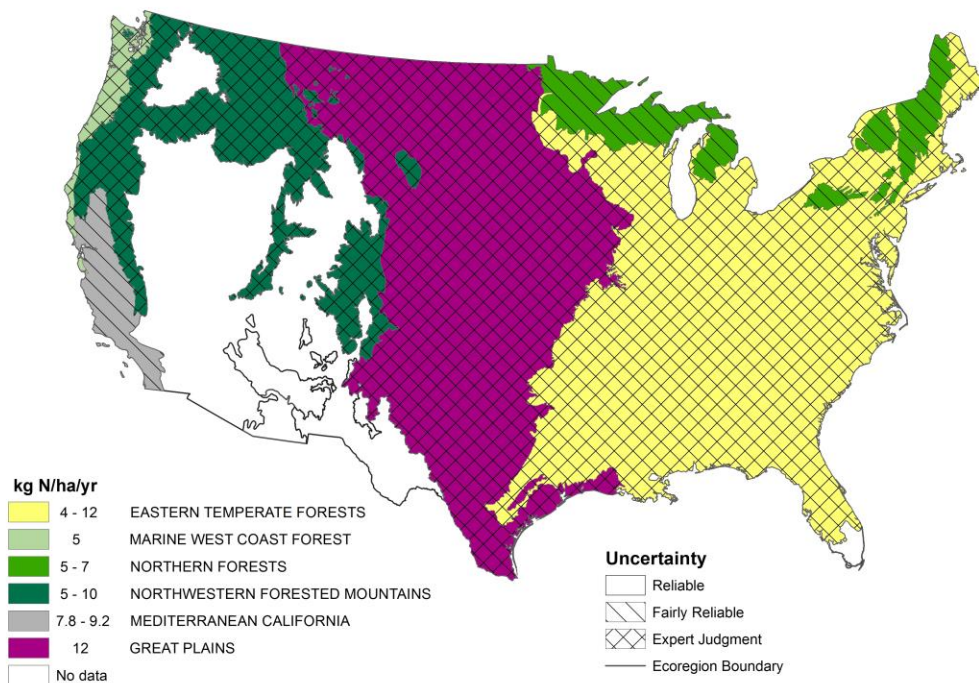


Empirical Critical Loads for Nitrogen for Forest Ecosystems (top) and Herbaceous Plants and Shrubs (bottom) (Pardo et al. 2011a, 2011b). The color schemes presented here are different from the original (Pardo et al. 2011a, 2011b) publication.

### Empirical Critical Loads for Nitrogen - Lichens



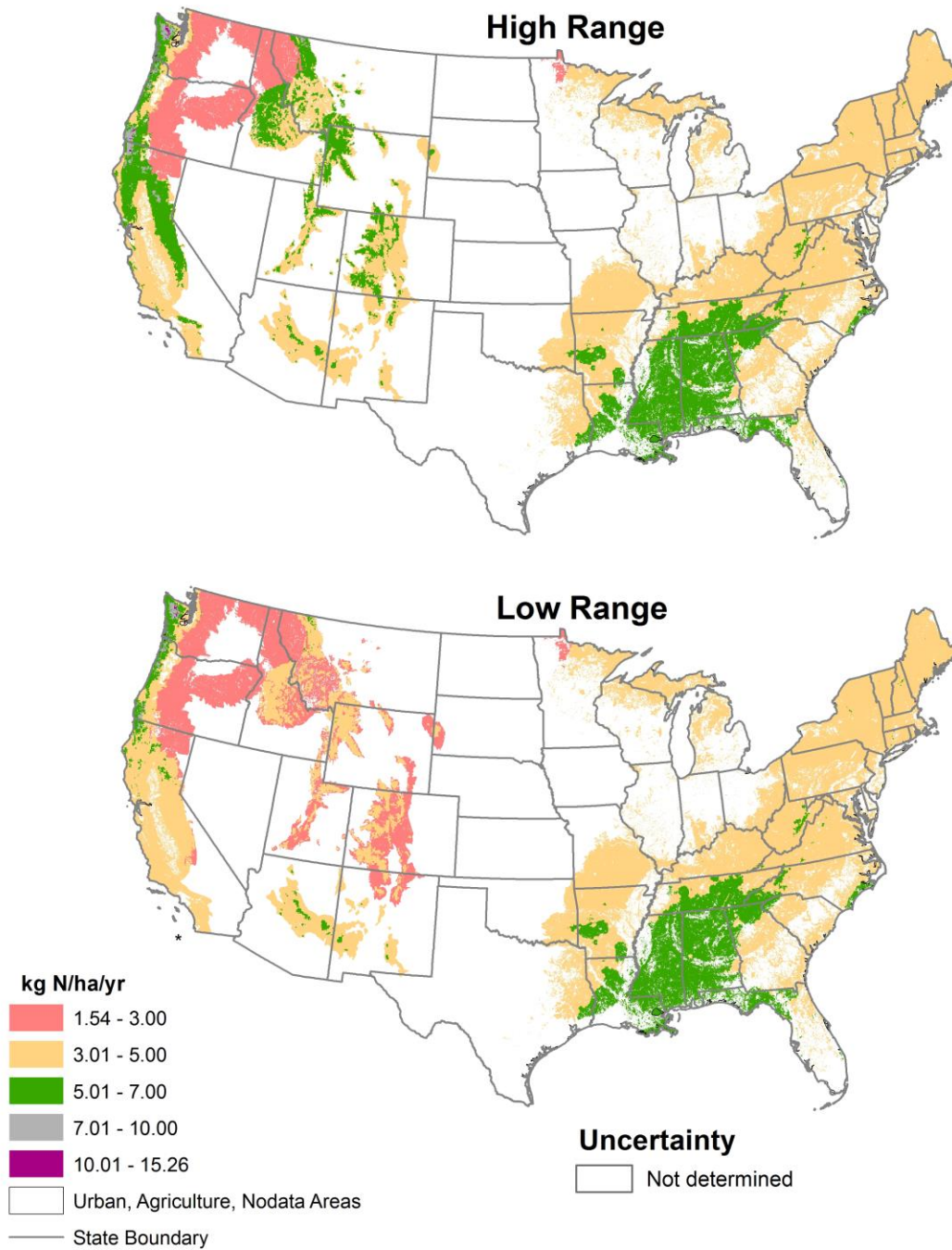
### Empirical Critical Loads for Nitrogen - Mycorrhizal Fungi



Empirical Critical Loads for Nitrogen for Lichens (top) and Mycorrhizal Fungi (bottom) (Reference: Pardo et al. 2011a, 2011b). The color schemes presented here are different from the original (Pardo et al. 2011a, 2011b) publication.



## Empirical Critical Load for Nitrogen - Lichens

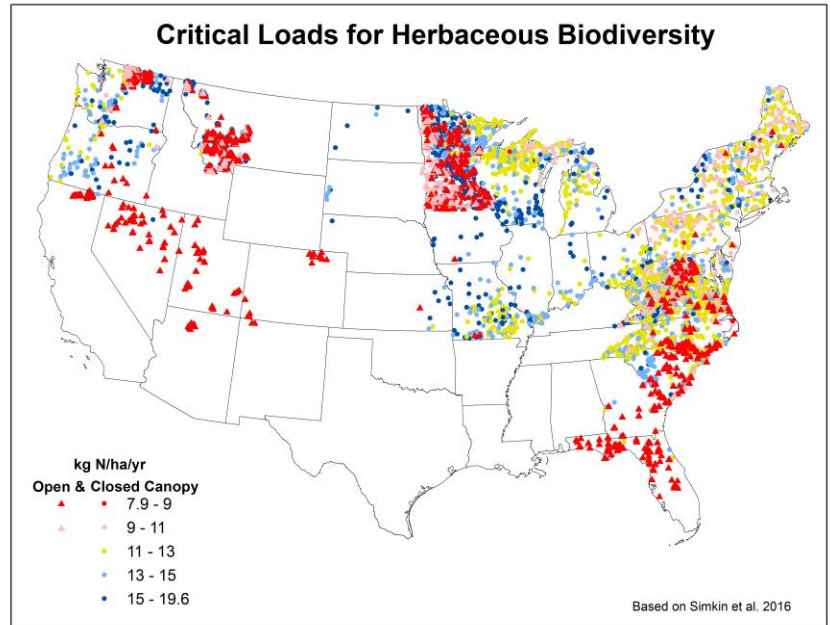


Empirical Critical Loads for Nitrogen for Lichens high range (top) and low range (bottom) (Geiser et al. 2010; Root et al. 2015).

# Critical Loads for Herbaceous Biodiversity and Exceedances

## Critical Load

The critical loads for herbaceous biodiversity are from Simkin et al. (2016). These critical loads are for total N deposition (wet and dry), and describe the level of N deposition above which decreases in herbaceous plant species richness (i.e. total species at a site) are observed. They are expressed in terms of kilograms of nitrogen deposition per hectare per year (kg N/ha/yr). They were derived from Simkin et al. (2016) which included a nationwide statistical analysis of 15,136 plots assembled from 12 distinct datasets (see adjacent map).



The critical loads from Simkin et al. (2016) are calculated separately for “Open Canopy” and “Closed Canopy” systems based on Level 1 of the National Vegetation Classification (USNVC 2016), where the former includes grasslands, shrub lands, and woodlands, and the latter includes forested understories. This was done because light-limited herbaceous systems (closed canopy) function differently from systems where light is not limiting (open canopy) (Neufeld and Young 2014). A total of 11,819 plots were located in closed canopy while 3,317 were in open canopy systems. The critical loads were derived statistically, using multiple regression models relating the species richness of a plot to up to eight environmental factors that included: N deposition, temperature, precipitation, soil pH, and others. The critical load was then estimated using a two-step process where the partial derivative of the best statistical model was selected, which yielded an equation for the critical load based only on temperature, precipitation, and soil pH. Using that expression, the critical load for

nitrogen was calculated at a given plot using local environmental data.

In addition, to the plot level critical loads (above), Ecoregion area-based values are presented on pages 29 to 30. These ecoregions area-based critical loads are based on the plot values from Simkin et al. (2016), which were aggregated at the Ecoregion I to IV levels. Critical loads were determined for each Ecoregion for seven different statistics: (1) average, (2) minimum, (3) 1<sup>st</sup> quantile (Q1), (4) 5<sup>th</sup> quantile (Q5), (5) 10<sup>th</sup> quantile (Q10), (6) 50<sup>th</sup> quantile (Q50), and (7) the maximum. Maps on pages 27 to 30 show the 5<sup>th</sup> quantile for both closed and open canopies for the four Ecoregions.

A statistical check was performed to determine if the sample sizes within each Ecoregion (separately for Levels I-IV) were adequate to calculate statistical summary values (e.g., the mean, 10<sup>th</sup> quantile, etc.) given a predefined error rate and confidence described below. If

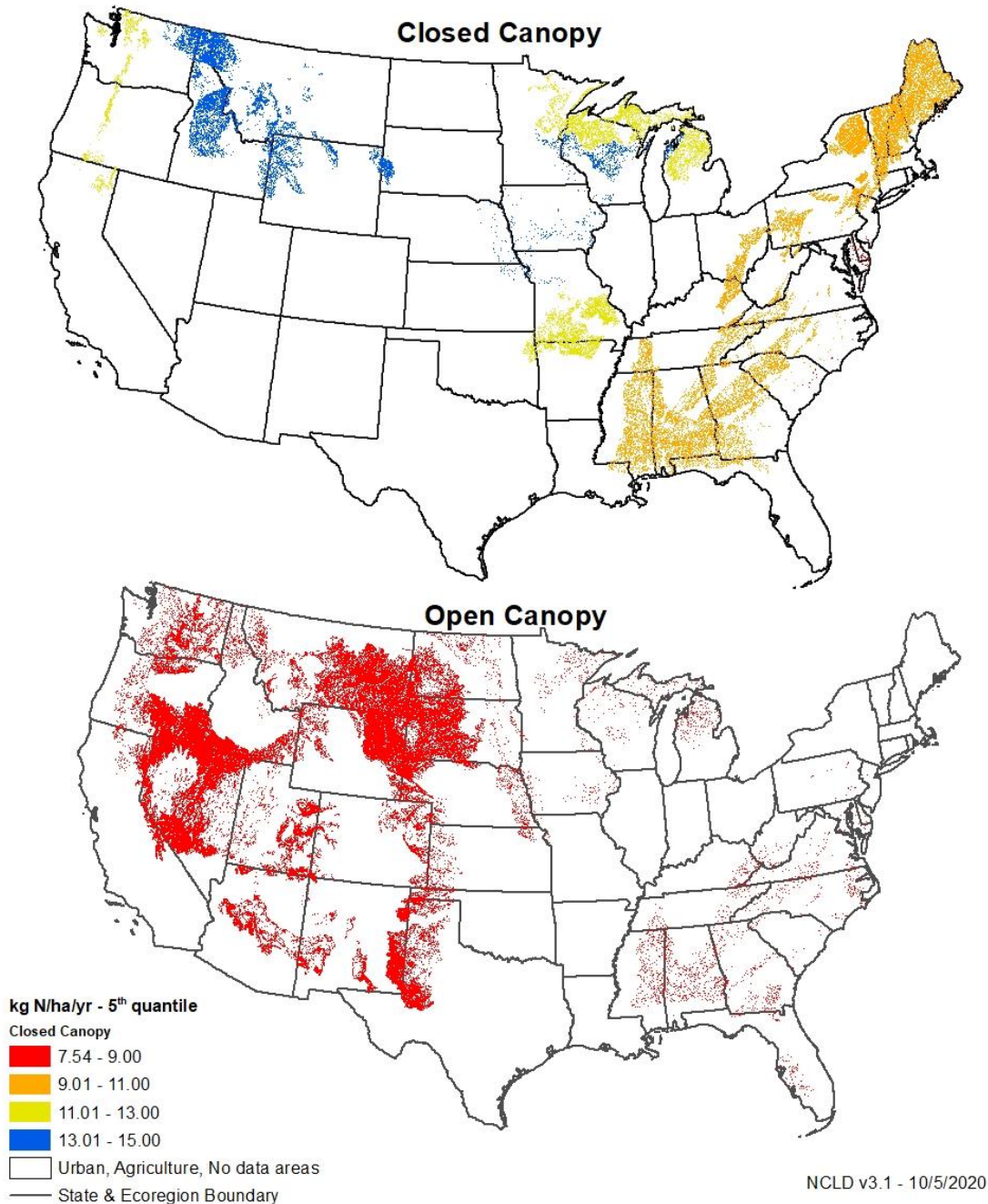
the statistical checks were met, then the sample size was considered adequate for the given statistic, and thus the value derived from the sample Ecoregion was used. Not surprisingly, for larger Ecoregions the sample size checks were satisfied more frequently. Grey areas within the maps indicate situations where sample size was insufficient to calculate the specified statistic.

### **Critical Load Exceedances**

The maps on page 31 show Critical load exceedances for herbaceous biodiversity for plot level for closed and open canopy. Critical load exceedances are for N only based on average TDep deposition for the years 2015-2018. The uncertainty of the herbaceous critical load is determined by the 2.5 and 97.5 percentile of the critical load estimate. Plots likely to exceed are where N deposition is above the 97.5 percentile critical load, while those likely not to exceed were below 2.5 percentile critical load. Plots where deposition is between 2.5 and 97.5 percentiles are within the critical load margin of error and may or may not exceed with confidence.

# Critical Load for Herbaceous Biodiversity

## Ecoregion III - 5<sup>th</sup> quantile

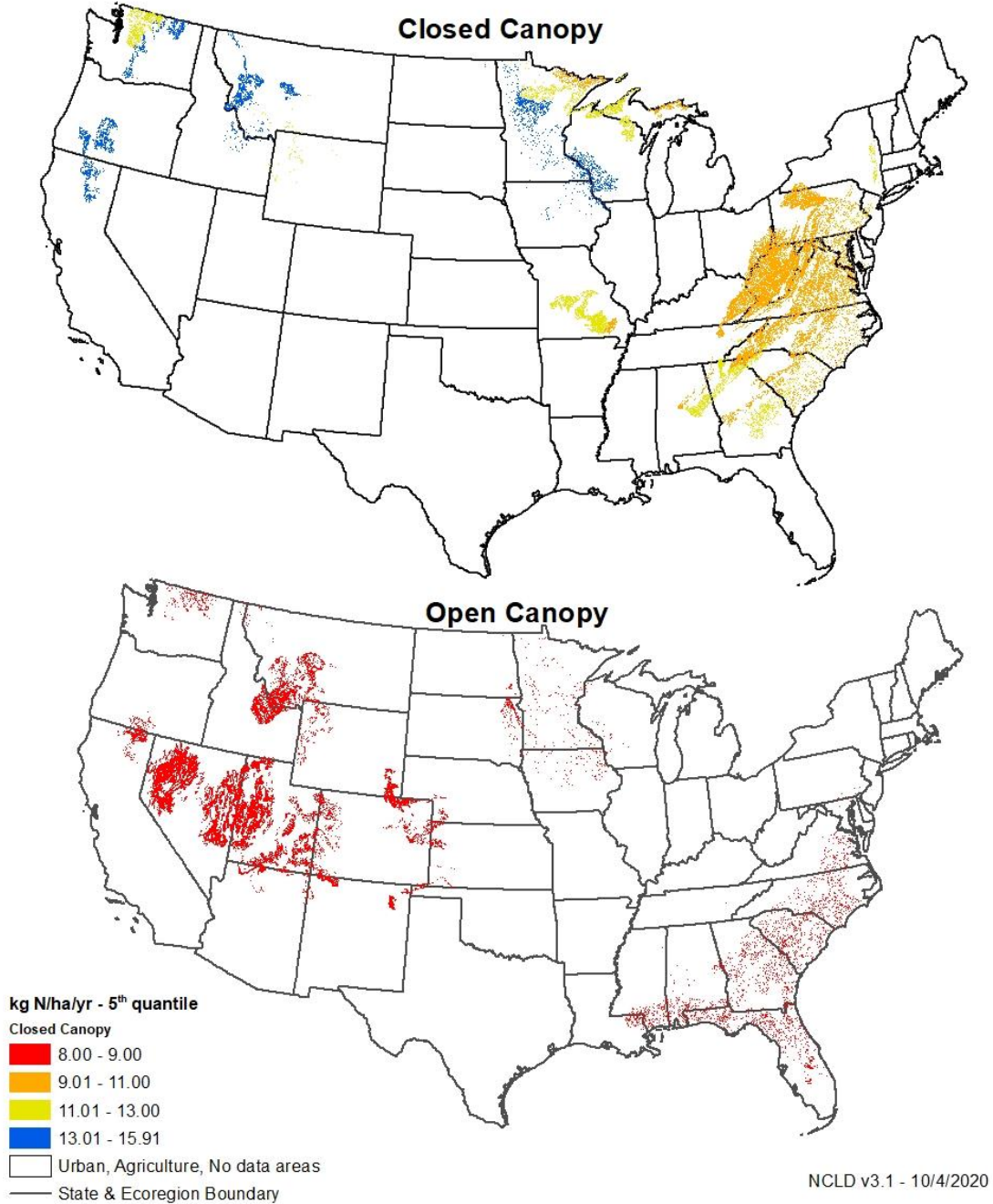


Critical loads for herbaceous biodiversity for Ecoregion level II for Closed Canopy (top) and open Canopy (bottom) for the 5<sup>th</sup> quantile based on Simkin et al. (2016). Urban and agriculture areas removed from the map using National Land Cover Data (NLCD).



# Critical Load for Herbaceous Biodiversity

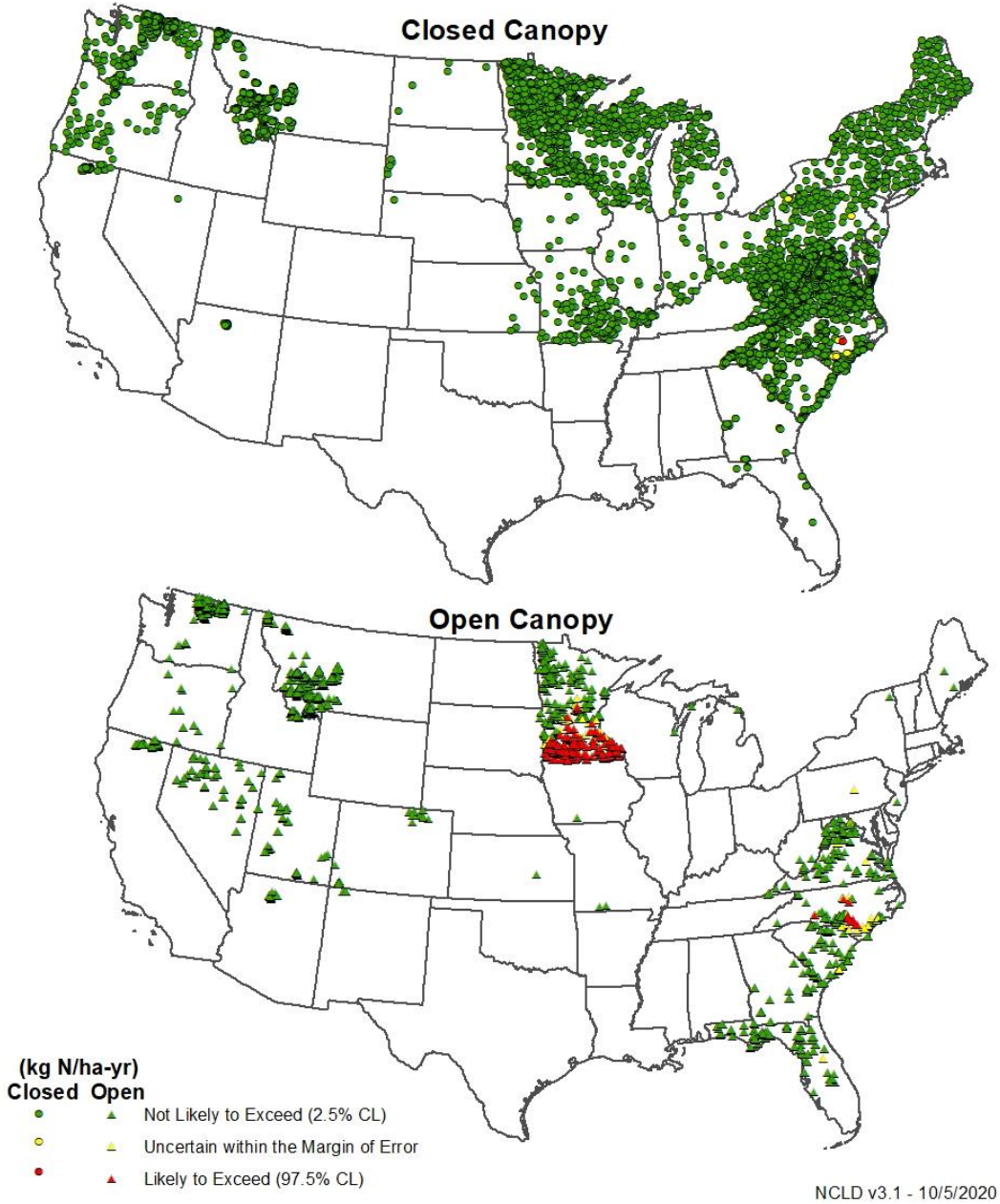
## Ecoregion IV - 5<sup>th</sup> quantile



Critical loads for herbaceous biodiversity for Ecoregion level IV for Closed Canopy (top) and Open Canopy (bottom) for the 5<sup>th</sup> quantile based on Simkin et al. (2016). Urban and agriculture areas removed from the map using National Land Cover Data (NLCD).

# Critical Load for Herbaceous Biodiversity

## Exceedances



Critical load exceedances for herbaceous biodiversity for plot level for closed canopy (top) and open canopy (bottom) based on Simkin et al. (2016). Critical load exceedances are for N only based on average Tdep deposition for the years 2015-2018. Plots that exceeds (red) the critical load are where total N deposition is above the 97.5 percentile critical load, while those likely not to exceed (green) were below 2.5 percentile critical load. Plots (yellow) where deposition is between 2.5 to 97.5 percentile of the critical load are within the margin of may or may not exceed.

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