Nitrogen Critical Loads by Site Methods

25 February 2018

Nitrogen Critical Loads by Site (N-CLAS) is a GIS-based tool designed for resource managers and policy makers to assess the effects of nitrogen deposition and climate change on forest ecosystems in the Northeastern United States. N-CLAS can be used to determine critical loads and exceedance for individual tree species or all tree species present for user selected areas (Table 1), including national forests and parks, wilderness areas, and ecoregions (areas with similar ecosystem structure and function; as defined by the Commission for Environmental Cooperation (CEC; http://www3.cec.org/islandora/en/item/1701-ecological-regions-north-america-toward-common-perspective; https://www.epa.gov/eco-research/ecoregions). N-CLAS uses geospatial data for abiotic modifying factors (topographic, climatic, and soil parameters) to predict whether growth in each 30m x 30 m pixel is likely to be optimal or suboptimal for each species (Figure 1).

The combined effect of all the abiotic modifying factors on growth determines whether the critical load for a species will be in the bottom half or upper half of the species' critical load range (Figures 2 and 3). In N-CLAS, suboptimal growth conditions are expected to increase sensitivity to N deposition and thus shift the critical load to the bottom half of the species' critical loads range. Optimal growth conditions are expected to result in increased N demand and thus shift the critical load to the upper half of the critical loads range.

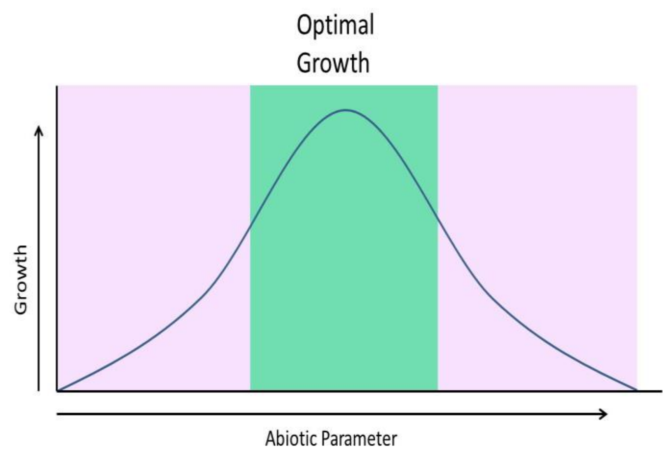

Figure 1—A range of values exists for optimal growth (green region) for each abiotic parameter; above and below that range of values, growth is not optimized.

Table 1

User selected areas
State
Entire study region*
Ecoregions level II
Ecoregions level III
National Park Service units
Forest Service administrative areas
Forest Service wilderness areas
Class I areas (NPS and USFS)
* based on Ecoregion level II boundaries: Atlantic Highlands, Mixed Wood Plains, Mixed Wood Shield

N-CLAS tool function

N-CLAS calculates critical loads for individual species for each 30m x 30 m. The critical loads can then be reported for individual species or aggregated for all the tree species present in a pixel and reported in a combined format. (For example, identifying the lowest critical loads of all the species present in that pixel—which is a way of determining what deposition would protect all the species present). Abiotic modifying factors and spatial data layers used in the N-CLAS GIS tool included in this report are shown in Table 2. Abiotic modifying factors include topographic (elevation, aspect, slope gradient), climatic (measures of annual and seasonal temperate and precipitation), and soil (pH, clay and sand content, permeability, depth to bedrock) parameters. The process by which N-CLAS calculates critical loads for each pixel includes: (1) identifying the species present; (2) evaluating whether the effect of each abiotic modifying factors is more likely to lead to optimal or suboptimal conditions for growth; (3) weighing the strength of evidence for the response of each abiotic factor; (4) incorporating the relative ecological significance of each abiotic factor; and (5) adjusting the critical load value based on the combined effect of all abiotic modifying factors .

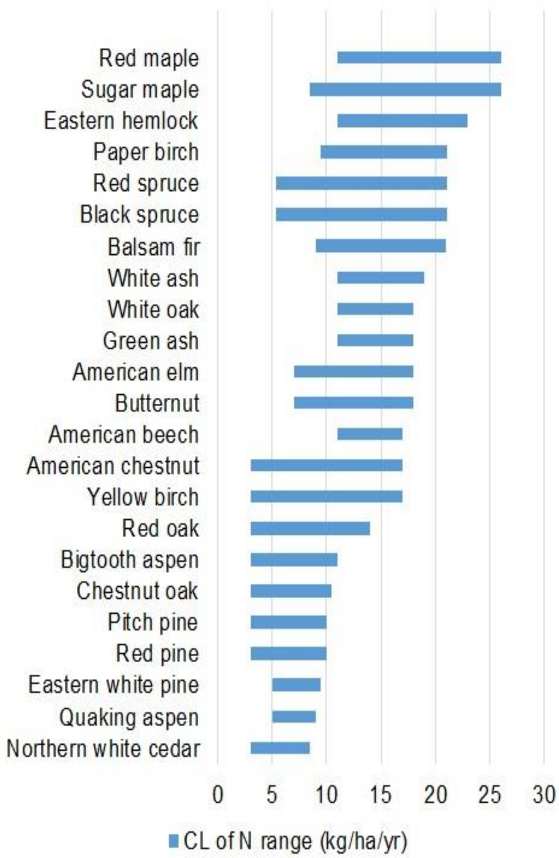

Figure 2 –Adjusted critical load range by species (Robin-Abbott and Pardo 2017);

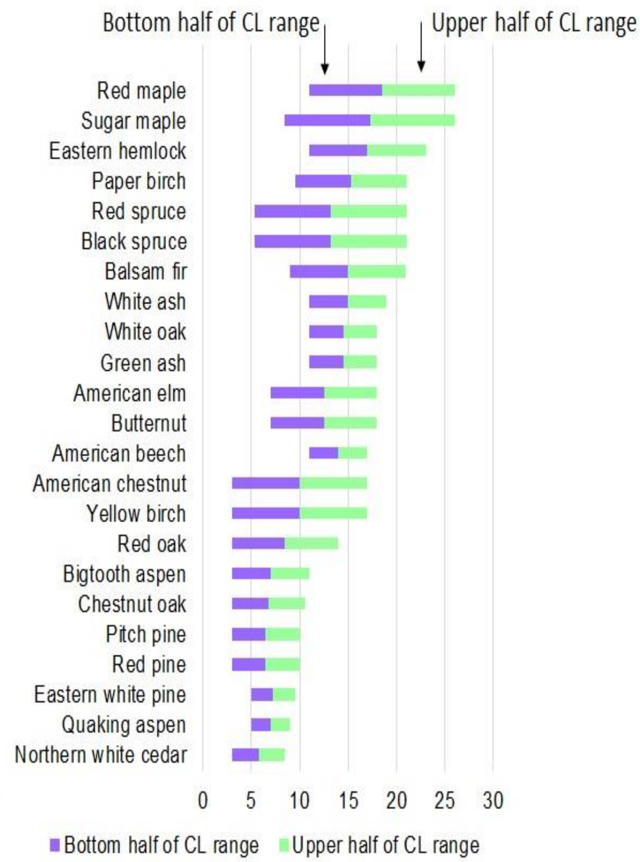

Figure 3 – Bottom and upper half of adjusted critical load range by species

Table 2 – Abiotic modifying factors and data sources

Abiotic modifying factor	Units	Primary Data source
Elevation, northeastern U.S.	m	Beckage et al 2008, Leak and Graber 1974, Burns and Honkala 1990
Aspect		NRCS 2014
Slope Gradient	%	Soil Conservation Service 1991[a]
January temperature average	°C	Hayhoe et al. 2007 [a]
July temperature average	°C	Hayhoe et al. 2007 [a]
May to September temperature average	°C	Hayhoe et al. 2007 [a]
Precipitation, annual	mm	Hayhoe et al. 2007 [a]
Precipitation, May to September	mm	Hayhoe et al. 2007 [a]
Soil pH		Soil Conservation Service 1991 [a]
Soil clay	%	Soil Conservation Service 1991 [a]
Soil coarse sand	%	Soil Conservation Service 1991 [a]
Soil permeability	cm hr^{-1}	Soil Conservation Service 1991 [a]
Soil depth to bedrock (minimum rooting depth)	m	NRCS 2014

[A] As cited in the Climate Change Atlas (U.S. Forest Service n.d.)

The ***first step*** is to determine the species present in each pixel using LANDFIRE geospatial data (www.landfire.gov), which provides SAF (Society of American Foresters) forest cover type for existing vegetation. We created a list of species included in each SAF forest cover type (Supplemental Table S1) from information in Eyre (1980) and the USDA fire effects information system (https://www.feis-crs.org/feis/)and used a data layer that delineates the range for each species (Little's range; https://esp.cr.usgs.gov/data/little/) to determine which species from the SAF forest cover type are expected to be present in each pixel. N-CLAS includes 23 species of management concern, of commercial interest and dominant species in the northern forest (Table 3).

The ***second step*** is to evaluate whether the abiotic conditions in the pixel are optimal for growth. For each tree species in this study, Robin-Abbott and Pardo (2017) identified the optimal range for growth for specified topographic, climatic, and soil abiotic modifying factors (Appendix 2; https://www.fs.fed.us/nrs/pubs/download/gtr_nrs172_appendix2.pdf) based on importance values and distribution data (Appendix 1: https://www.fs.fed.us/nrs/pubs/download/gtr_nrs172_appendix1.pdf) from the Climate Change Atlas (U.S. Forest Service, n.d.) and information from other sources, including the Forest Service silvics handbook, "Silvics of North America" (Burns and Honkala 1990); the PLANTS database (NRCS 2014); and additional literature sources. For each species in each pixel, N-CLAS compares the actual data value for each of 13 topographic, climate, and soil abiotic modifying factors with the optimal range for that species (Robin-Abbott and Pardo 2017). Each abiotic modifying factor is then assigned to either the optimal or suboptimal category (Figure 4).

Table 3 – Species of management interest, commercial concern, or dominant species.

Scientific name	Common name	Reason for concern
Abies balsamea	Balsam fir	Wildlife habitat; commercial
Acer rubrum	Red maple	Wildlife, commercial
Acer saccharum	Sugar maple	Commercial–sap, lumber
Betula alleghaniensis	Yellow birch	Wildlife; commercial–lumber
Betula papyrifera	Paper birch	Wildlife; commercial–lumber
Castanea dentata	American chestnut	Rare species
Fagus grandifolia	American beech	Wildlife habitat
Fraxinus americana	White ash	Wildlife; commercial–lumber
Fraxinus pennsylvanica	Green ash	Wildlife; commercial–lumber
Juglans cinerea	Butternut	Rare species in the northeast
Picea mariana	Black spruce	Wildlife habitat
Picea rubens	Red spruce	Commercial–lumber
Pinus resinosa	Red pine	Commercial–lumber
Pinus rigida	Pitch pine	Rare species in the northeast
Pinus strobus	Eastern white pine	Commercial–lumber
Populus grandidentata	Bigtooth aspen	Wildlife habitat; commercial–pulp
Populus tremuloides	Quaking aspen	Wildlife habitat; commercial–pulp
Quercus alba	White oak	Wildlife; commercial–lumber
Quercus prinus	Chestnut oak	Rare species in the northeast
Quercus rubra	Northern red oak	Wildlife; commercial–lumber
Thuja occidentalis	Northern white-cedar	Wildlife; commercial–lumber
Tsuga canadensis	Eastern hemlock	Commercial; wildlife habitat
Ulmus americana	American elm	Wildlife habitat; commercial

In the ***third step***, the weight of evidence is used to determine the impact of each abiotic modifying factor in N-CLAS calculations based on the strength of evidence currently available for that species' response to each abiotic factor. A factor with more certainty will have a high weight of evidence, and will thus have more impact on the calculations that determine whether a site is more likely to be optimal or suboptimal for a species. The scale for the weight of evidence is ranges from 1 (weak) to 5 (strong), in keeping with the 5-point scale for rating uncertainty in CL calculations in the US National Framework (Clark and Pardo, *in prep.*). The weight of evidence varies by factor and by species and is reported in Robin-Abbott and Pardo (2017; Supplemental Tables S2 and S3). This weighting system is based on the endorsement theory, which is described in detail in Hall and Wadsworth (2010). In N-CLAS calculations, in each pixel, for each factor in the optimal range, the values for the weight of evidence are summed and then compared to the sum of the weights of evidence for modifying factors in the suboptimal range. If the sum of the weight of evidence of suboptimal factors is higher, growth is likely to be suboptimal. If the sum of the weight of evidence of optimal factors is higher, growth is likely to be optimal.

Step A: Determine whether abiotic conditions are optimal or sub-optimal for growth

		Growth conditions		
Abiotic modifying factor	**Example Plot data**	**Sub-Optimal**	**Optimal**	**Weight of evidence**
Elevation (m)	**1043**	<610; >1200	**610-1200**	2
Aspect	**62**	south; west	**north; east**	2
January temperature average (°C)	**-10.3**	**<(-10), >-7**	-10 to -7	4
July temperature average (°C)	**17**	**<18; >19**	18 to 19	4
precipitation (mm)	**1624**	**<1012; >1320**	1012-1320	3
Permeability (cm/hr)	**7.2**	<1.5, >12.7	**1.5-12.7**	3

Step B: Determine the impact of each abiotic modifying factor in N-CLAS calculations

	Weight of evidence impact	
Abiotic modifying factor	**Sub-Optimal growth conditions**	**Optimal growth conditions**
Elevation (m)		**2**
Aspect		**2**
January temperature average (°C)	**4**	
July temperature average (°C)	**4**	
precipitation (mm)	**3**	
Permeability (cm/hr)		**3**

Step C: Determine if the sum of sub-optimal growth conditions or the sum of optimal growth conditions is greater

	Sub-Optimal growth conditions	**Optimal growth conditions**
Sum	**11**	7

In this example, the sum of sub-optimal growth conditions is greater than the sum of optimal growth conditions. Critical loads will be in the bottom half of the critical loads range.

Figure 4 – Effect of abiotic modifying factors

In the ***fourth step***, N-CLAS assesses the weight of influence. Not all factors are equally important in determining the ultimate growth response of a given tree species and its susceptibility to N deposition. Note that the weight of influence reflects the ecological significance of the factor which is different than the weight of evidence—which address the strength of the relationship shown by the data. In the current version of N-CLAS, climate factors are given the highest weight of influence. If any climate factor for a species in a pixel is suboptimal, growth is assumed to be suboptimal. If all climate factors are optimal, N-CLAS assigns growth categories based on the weight of evidence calculation. In the future, if further information becomes available, the weight of influence could be adjusted.

In the ***fifth step***, for each species in the pixel, N-CLAS assigns critical load. The critical load will either be the bottom half of the critical loads range—if the net effect of the abiotic factors is sub-optimal--or the upper half of the critical loads range--if the net effect of the abiotic factors is optimal (Figure 3; Robin-Abbott and Pardo 2017).

Finally, the critical load is aggregated across the whole area being assessed for each individual species and for all species combined. Because critical loads values are provided as a range, for each species in each pixel there will be a minimum and maximum critical load value (Figure 5).

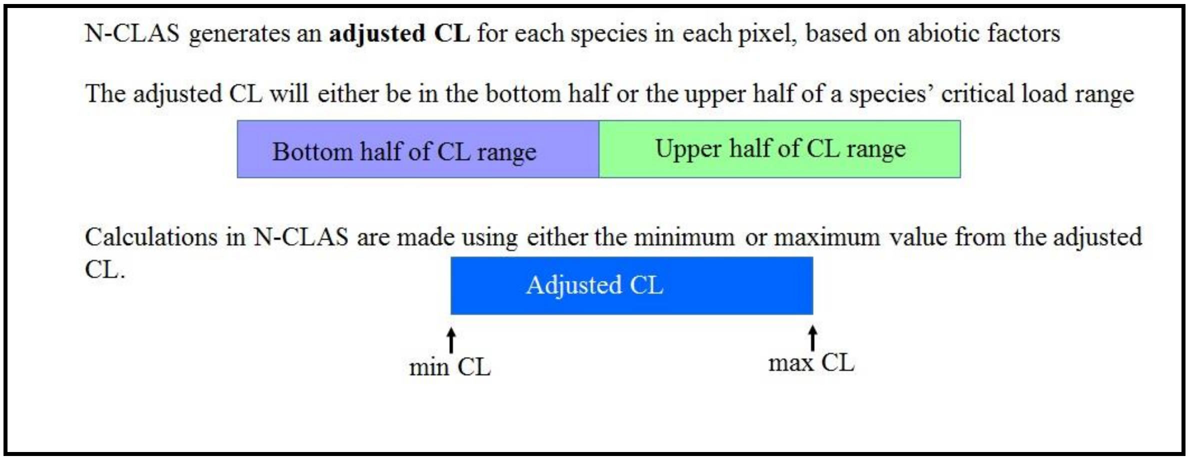

Figure 5 – The adjusted critical load with minimum and maximum values

Exceedance of the critical load is a metric useful in communicating the extent of risk to ecosystems under current and future deposition scenarios. Exceedance = Total N deposition – Critical load of N. N-CLAS calculates exceedance of the minimum and maximum critical loads (Figure 6).

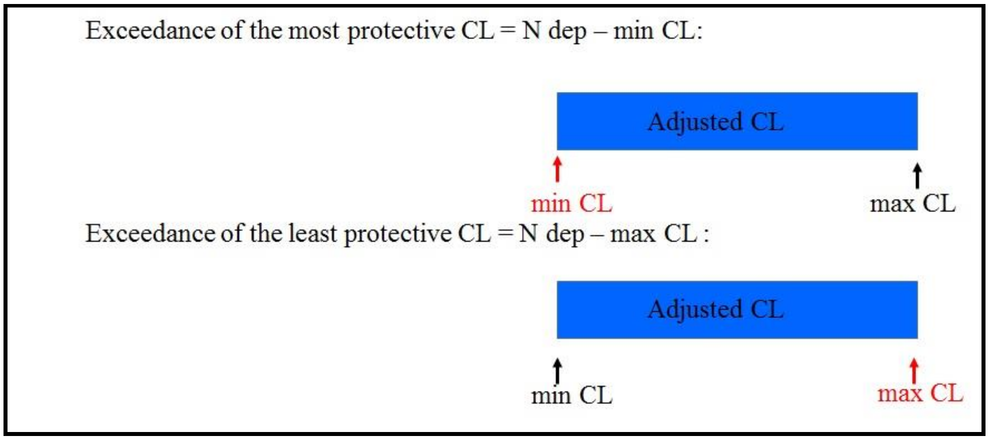

Figure 6 – Exceedance of minimum and maximum critical loads.

Total N deposition comes from TDEP 2013-2015 average N deposition (CASTNET; https://www.epa.gov/castnet). Exceedance of the minimum critical load indicates that negative impacts from N deposition are possible; exceedance of the maximum critical load indicates the negative impacts from N deposition are likely (Figures7 a and b).

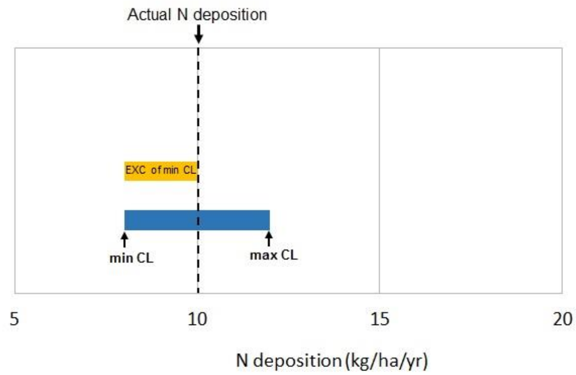

Figure 7 a – Example of exceedance of minimum critical load of N

- If the actual deposition is 10 kg/ha/yr: EXC of the min CL is 2 kg/ha/yr; there is no EXC of the max CL

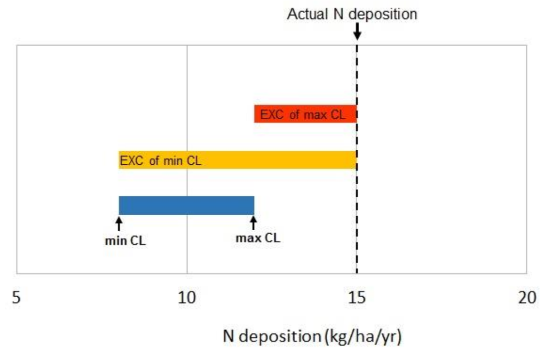

Figure 7 b – Example of exceedance of minimum and maximum critical loads of N

- If the actual deposition is 15 kg/ha/yr: EXC of the min CL is 7 kg/ha/yr; EXC of the max CL is 3 kg/ha/yr

Critical loads and exceedance aggregated across all species

N-CLAS also aggregates the critical loads for all species present across the area being assessed. Each pixel in N-CLAS contains data for multiple species, each with a minimum and maximum critical load. The critical loads and exceedance function for all species combined in N-CLAS allows tool users to select different levels of protection for the forest.

Four different critical load scenarios for all species combined are calculated for each pixel (Figure 8):

CL A = most protective CL for most sensitive species
CL B = most protective CL for least sensitive species
CL C = CL at which all species are severely at risk
CL D = CL at which at least one species is severely at risk

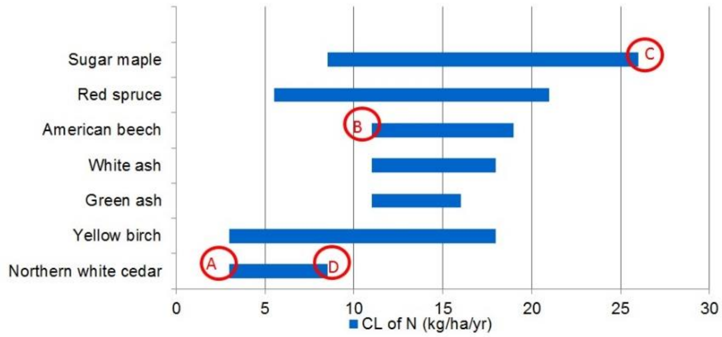

Figure 8 – Critical load scenarios for all species combined

Exceedance for all species combined (Total N deposition – critical load of N) is calculated for each pixel in N-CLAS. There are four different exceedance scenarios for all species combined (Figure 9 a, b, and c):

EX A = exceedance of most protective CL for most sensitive species
EX B = exceedance of most protective CL for least sensitive species
EX C = exceedance of CL at which all species are severely at risk
EX D = exceedance of CL at which at least one species is severely at risk

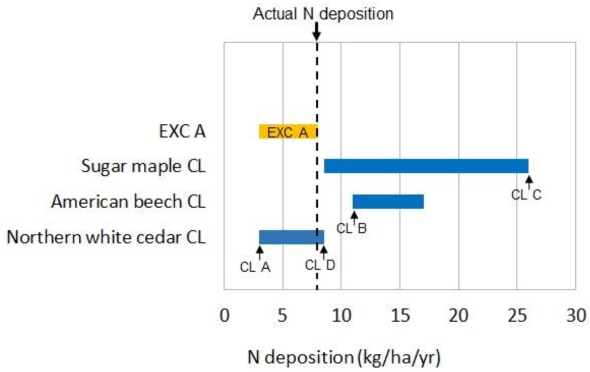

Figure 9 a– Exceedance of critical loads for all species combined.

- If deposition is 7 kg/ha/yr: EXC A is 4; there is no EXC for CL B, C, or D

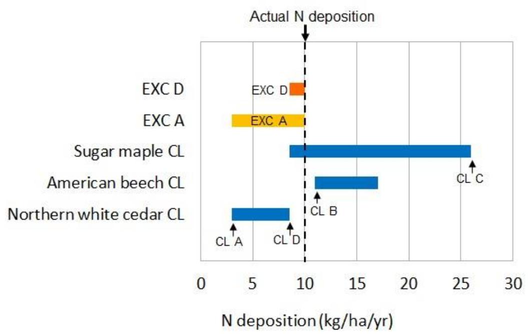

Figure 9 b – Exceedance of critical loads for all species combined.

- If deposition is 10 kg/ha/yr: EXC A is 7; EXC D is 1.5; there is no EXC for CL B, or C

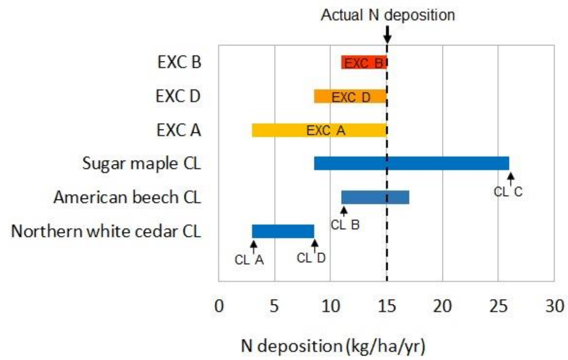

Figure 9 c – Exceedance of critical loads for all species combined.

- If deposition is 15 kg/ha/yr: EXC A is 12; EXC D is 6.5; EXC B is 4; there is no EXC for CL C
- There will only be EXC of CL when deposition is >26

Supplemental Material

Supplemental Table 1 is a separate file and explains how the species in each SAF forest type were determined.

The weight of evidence for abiotic modifying factor thresholds is set using either FIA-based importance value data from the Climate Change Atlas (Table S2) or literature-based data (Table S3).

The overall uncertainty rating for FIA based data (Table S2) was determined through the arithmetic mean of three weighting criteria:

- number of samples included in the FIA assessment,
- shape of the importance value response curve over the range of each factor, and
- accuracy of factor values

Table S2 – Weight of evidence assessment for FIA based thresholds

Weight of evidence assessment for abiotic modifying factor thresholds based on FIA importance values (IV)					
			Weight of Evidence		
Weighting Criteria	**Weak – 1**	**Moderately weak - 2**	**Moderate – 3**	**Moderately strong – 4**	**Strong - 5**
Number of samples	<50	50-149	150-299	300-449	>450
Shape of response curve	Weak response, no obvious peak, points dispersed over a wide range	Some clustering of points; points dispersed over wide range	Definite peak but numerous points outside of the main peak; thresholds unclear	Definite peak, several points outside of the main peak make determining precise thresholds difficult	Clear peak, clear thresholds, no or single outliers
Accuracy of parameter measurements	Inaccurate measurement techniques; geospatial values represent highly generalized data	Inaccurate measurement techniques; geospatial values represent primarily modeled data	Accurate measurement techniques; geospatial values represent primarily modeled data	Accurate measurement techniques; geospatial values represent mix of real data and modeled data	Accurate measurement techniques; geospatial values represent real data or very accurate models

Another matrix (Table S3) was used to assign the weight of evidence for abiotic modifying thresholds set using data from the Forest Service silvics handbook, “Silvics of North America” (Burns and Honkala 1990), PLANTS database (NRCS 2014), or other literature sources.
The matrices used to assign the weight of evidence for abiotic factors is described in Robin-Abbott and Pardo (2017).

Table S3 – Weight of evidence for literature based thresholds

Weight of evidence assessment for literature-based abiotic modifying factor thresholds				
		Weighting Criteria		
Weak – 1	**Moderately weak - 2**	**Moderate – 3**	**Moderately strong – 4**	**Strong - 5**
General value, unreliable source	General value, reliable source	Species value, reliable source	Species value, multiple studies, reliable source	Species value, thresholds well established