Empirical Critical Loads
Simkin et al., 2016

DESCRIPTION OF HERBACEOUS BIODIVERISTY

Metadata for supporting GIS files (large files):

NCLD_EMP_pts_Simkin_v31.gdb

NCLD_EMP_ER_Poly_Simkin_v31.gdb (Large file size - 704 MB zipped)
NCLD_EMP_ER3_Open_Simkin_v31*
NCLD_EMP_ER3_Closed_Simkin_v31*
NCLD_EMP_ER4_Open_Simkin_v31*
NCLD_EMP_ER4_Closed_Simkin_v31*

*Also stored in individual geodatabases (size range from 120 to 247 MB zipped)

NCLD_EMP_ER_Rasters_Simkin_v31.gdb (grid) (Large file size - 1.13 GB zipped)
NCLD_ER3_Closed
NCLD_ER3_Open
NCLD_ER4_Closed
NCLD_ER4_Open

Content

These geographic information system (gis) files contain only critical loads from Simkin et al. 2016 that are part of the National Critical Load Database v3.1 (NCLD) for Empirical of Herbaceous Biodiversity.

Data and Project Citation

Simkin, S. M., E. B. Allen, W. D. Bowman, C. M. Clark, J. Belnap, M. L. Brooks, B. S. Cade, S. L. Collins, L. H. Geiser, F. S. Gilliam, S. E. Jovan, L. H. Pardo, B. K. Schulz, C. J. Stevens, K. N. Suding, H. L. Throop, and D. M. Waller. 2016. Conditional vulnerability of plant diversity to atmospheric nitrogen deposition across the United States. Proceedings of the National Academy of Sciences 113:4086-4091

NCLD Database Citation

Lynch, J.A., Phelan, J., Pardo, L.H., McDonnell, T.C., Clark, C.M., and Bell, M.D. 2020. Detailed Documentation of the National Critical Load Database (NCLD) for U.S. Critical Loads of Sulfur and Nitrogen, version 3.1, National Atmospheric Deposition Program, Wisconsin State Laboratory of Hygiene, Madison, WI.

Critical Load Introduction and Background

This section describes the background and procedures for determining the herbaceous biodiversity CLs from Simkin et al., (2016). These CLs are for N deposition, and describe the level of N deposition above which decreases in herbaceous plant species biodiversity are observed. They were derived from Simkin et al., (2016) which included a nationwide statistical analysis of 15,136 plots (**Figure 3A-1**) assembled from 12 distinct datasets, and represent empirical CLs of N.

The CLs 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 DR, 2014). The CLs were derived statistically, using multiple regression models relating the species richness of a plot to up to eight factors: N deposition (Ndep), temperature (T), precipitation (P), soil pH (pH), Ndep*T, Ndep*P, Ndep*pH, and $Ndep^2$.

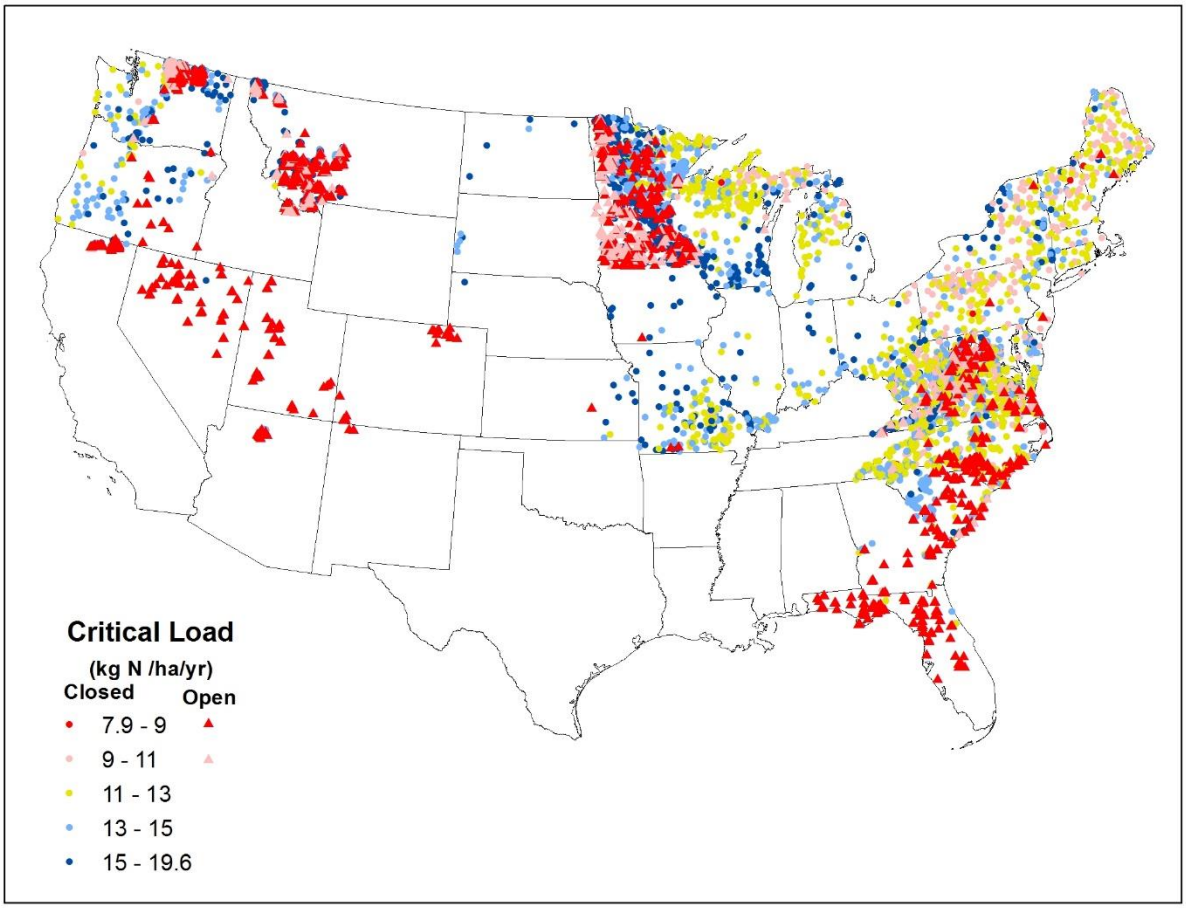

Figure 3A-1: Critical loads for nitrogen deposition based on total graminoid plus forb species richness (colored symbols) from Simkin et al., (2016). The 3,317 open canopy sites (combined grassland, shrub land, and woodland vegetation types) are portrayed with triangles, and the 11,819

closed canopy sites (deciduous, evergreen, and mixed forests) are portrayed with circles. Modified from Simkin et al., (2016).

The CLs were calculated using the partial derivative with respect to N (∂/∂N, equations **3A-2** to **3A-5**) of the best statistical model for species richness and solving for N deposition. This expression (**Eq. 3A-5**) represents the rate of N deposition (kg/ha-yr) above which reductions in herbaceous biodiversity begins to occur, using local values for soil pH, temperature, and precipitation.

The full statistical model with all possible terms is (some may drop out if they are not significant):

$$SR = \beta_0 + \beta_1(Ndep) + \beta_2(P) + \beta_3(T) + \beta_4(pH) + \beta_5(Ndep)(pH) + \beta_6(Ndep)(T) + \beta_7(Ndep)(P) + \beta_8(Ndep^2) \quad \text{(Eq. 3A-2)}$$

which after one takes the partial derivative with respect to N becomes,

$$\frac{\partial}{\partial N}(SR) = \beta_1 + \beta_5(pH) + \beta_6(T) + \beta_7(P) + 2\beta_8(Ndep) \quad \text{(Eq. 3A-3)}$$

To obtain the CL, we set Eqn. 2 to less than zero (i.e. species loss with N deposition) and solve for Ndep,

$$\frac{\partial}{\partial N}(SR) = 0, \quad \text{(Eq. 3A-4)}$$

which becomes in terms of Ndep,

$$CL(Ndep) = \frac{\beta_1+\beta_5(pH)+\beta_6(T)+\beta_7(P)}{-2\beta_8} \quad \text{(Eq. 3A-5)}$$

Using the statistical results from Simkin et al. (2016), these equations for open (**Eq. 3A-6**) and closed (**Eq. 3A-7**) canopy systems are:

$$CL(Ndep) = 4.75 + 0.481 * pH + 0.00182 * precip - 0.0739 * temp \quad \text{(Eq. 3A-6)}$$

$$CL(Ndep) = 1.80 + 2.17 * pH \quad \text{(Eq. 3A-7)}$$

Further details on the original CLs are available in Simkin et al. (2016). We converted these point estimates of CLs into two different versions for the NCLD that are described below: (1) point based CLs, and (2) Ecoregion (Level I-IV) area based area CLs. There is a third version under development that will be gridded values of the herbaceous biodiversity CL based on Eq. 4 that were not available at the time of this update to the NCLD v3.0.

Location Based Critical loads

Location (point) based CLs are directly from the "Data Dryad" public database from Simkin et al., (2016) (e.g. Simkin_et_al_2016_data_from_PNAS_Div_and_N_dep.csv). No modifications were made to the CLs, although additional information was added to the NCLD database. Please note that both LatDD and LongDD have been "fuzzed" (accuracy reduced from 8 to 4 digits), as required by the data owner(s). For this reason, some plot locations will fall outside of their correct Ecoregion. Use caution when comparing the plot locations in this dataset with other GIS spatial data. Coordinates values may be obtained by contacting Chris Clark, USEPA (Clark.Christopher@epa.gov). This fuzzing is only true for the point-

based version of the database, true locations were used prior to averaging at larger Ecoregions levels for the area-based versions (below).

Attribute Descriptions for Location Based Critical loads

NCLD_EMP_pts_Simkin_v3

Variable	Explanation	Format
CLID	Unique(!) identifier across all three CL grouping: Forest Ecosystem, Surface Waters, and Empirical Nitrogen.	Text
PRID	Unique(!) identifier of the CL project.	Integer
LOCID	Unique(!) identifier of a particular location (e.g. lake, stream reach, or sample plot), gridded area, or Ecoregion I-IV. Lakes and stream reaches are classified by NHDPlusV2. In many cases, a single lake/stream reach or ecoregion may have more than one CL value. The LOCID can be used to aggregate CLs for a particular location.	Text
CL_Class	Critical load type across all tables: Empirical Terrestrial Nitrogen	Text
SiteID	Project specific identifier of the site.	Text
LatDD	Latitude (decimal degrees). These values are "fuzzed" in order to protect the specific location of the plots as required by the data owner.	Double
LongDD	Longitude (decimal degrees). These values are "fuzzed" in order to protect the specific location of the plots as required by the data owner.	Double
CL_Type	Critical load type: Empirical.	Text
CLN	Empirical CL of N reported (kg/ha-yr).	Double
CLN_e2_5	Critical load error as a quintile of 2.5% CL of N (kg/ha-yr).	Double
CLN_e97_5	Critical load error as a quintile of 97.5% CL of N (kg/ha-yr).).	Double
Canopy	Closed canopy or Open canopy. Based on the National Vegetation Classification System where woodlands, grasslands, and shrublands were "open" and forests were "closed."	Text
RecepI	Biological and physical entity being affected: Herbaceous plant community.	Text
Response	The negative response of that biological or physical entity that is to be avoided: Reduction in community composition	Text
Threshold	The threshold of related to the receptor and its response: No biodiversity loss	Text
PrimRef	Publication citation for primary study for the CL. For some CLs, there is more than one publication.	Text

	For CLs with more than one publication, use Tables 5 and 6 to determine the additional references.	
DepoUnitsStudy	Deposition unit for study kg/ha-yr.	Text

Projections

USA_Contiguous_Albers_Equal_Area_Conic_USGS_version	
Projection: Albers	Geographic Coordinate System: GCS_North_American_1983
False_Easting: 0.00000000	Datum: D_North_American_1983
False_Northing: 0.00000000	Prime Meridian: Greenwich
Central_Meridian: -96.00000000	Angular Unit: Degree
Standard_Parallel_1: 29.5.00000000	
Standard_Parallel_2: 45.00000000	
Latitude_of_Origin: 23.00000000	
Linear_Unit: Meter	

No Data Values

Missing numeric values are noted as -9999, -9999.99, -9999.999, which indicate both situations where information is not determined or does not apply. Missing text values where information is not determined are noted as "(no data)" while "(n/a)" indicates missing information that does not apply.

Linking/Joining to Database Tables

NCLD tables (1C, 2C, and 3C) can be joined to this feature dataset by the CLID.

Ecoregion (Area) based Critical loads

The Ecoregion area-based CLs used the unfuzzed point/plot estimates from Simkin et al. (2016) to extrapolate plot-based CLs to similar ecosystem types. This extrapolation was limited to Ecoregion levels III and IV to maintain confidence in the extrapolation. A statistical check was performed to determine if the sample sizes within each Ecoregion (III and IV) were adequate to calculate statistical summary CL values (e.g. the mean, 10^{th} percentile, etc.), given a predefined error rate and confidence described below. If the statistical checks were met within Ecoregion IV, then the sample size was considered adequate for the given CL statistic, and thus the value derived from the sample Ecoregion IV was used. If the criteria did not meet the confidence level, then the statistic CL derived for Ecoregion III (i.e., coarser scale) was determined for the Ecoregion. If the criteria were not met for either Ecoregion III or IV, no CL was extrapolated for the Ecoregion. This method was used to calculate CLs for the: (1) average, (2) minimum, (3) 1^{st} quantile (Q1), (4) 5^{th} quantile (Q5), (5) 10^{th} quantile (Q10), (6) 50^{th} quantile (Q50), and (7) the maximum. The details of the calculations are provided below.

The standard statistical equation for a recommended sample size is given by:

$$n = \left(\frac{t_{\propto/2} * \sigma}{E}\right)^2, \qquad \text{(Eq. 3A-8)}$$

where *n* is the recommended minimum sample size, given the desired error rate *E*, standard deviation from the sample σ, and desired confidence as specified by the two-tailed t-statistic $t_{\alpha/2}$. In the NCLD v3.0, we assume an error rate of 0.5 kg N/ha-yr (i.e. +/- 0.5 kg N/ha-yr, within 1 kg N/ha-yr of the true CL), and a 95% confidence for *t* based on the number of plots in the sample. Given that the true deposition is not known to this degree of accuracy in many areas, constraining the CL to an accuracy higher than +/- 0.5 kg or 95% was not considered necessary. However, individual users can input different values of *E* or *t* if they desire using standard statistical tables for t. Thus, Ecoregions that were more variable would have a higher σ, and therefore require a larger sample size for a given error rate and confidence. Also, Ecoregions that had fewer samples, would have a larger *t*, and also require a larger sample size for the given error rate and standard deviation.

Equation 3A-8 is valid whether one is estimating the sample size for the mean, or any quantile - what changes is the value of σ. For estimating the sample size required for the mean, σ is the standard deviation of the mean, that is readily calculated with any statistical package. For estimating the sample size required for a specific quantile, σ is the standard deviation around that quantile. This estimate is not commonly available, but is readily estimated using a delta method argument and the "density" function in R[1]. This function uses a standard procedure (fast Fourier Transform) to estimate the density of points around any quantile specified by the user. That density is then used to estimate the standard deviation of the sample around that quantile. The script is below:

```
# x is your data
# q is your desired quantile level, i.e. 0.01 or 0.05

quant = function(input) {quantile(input, prob = q, type = 1, names = FALSE)}

xi.hat = quant(x)
f.hat.temp = density(x, from = xi.hat, to = xi.hat, n = 1)
f.hat = f.hat.temp$y
se = sqrt(q*(1-q)/n)/f.hat
sd = sqrt(q*(1-q))/f.hat
```

These estimates are only available from the NCLD v3.1 for the specified statistics above, but interested users are welcome to use the R code above to estimate σ for any quantile between Q1 and Q99. More extreme quantiles require additional assumptions and procedures that are not readily available.

A few caveats and additional comments are warranted. First, the expectation that more data is required the further on the tail (e.g. Q10 versus Q50) depends heavily on the distribution of the data. An earlier draft of this database used a simpler approach for estimating the sample size needed for quantiles – it assumed that the sample size for any quantile needed to be triple that of the mean. This approach was usually conservative (i.e. was a larger sample than from using the density estimator function above), but is not statistically robust. That assumption, that more data is needed further on the tail, depends on the

[1] https://www.rdocumentation.org/packages/stats/versions/3.4.1/topics/density

assumption of normality. Although logical, closer inspection of the critical loads identified many Ecoregions where the data is not normal, either strongly skewed left, right, or even bimodal (i.e. included sensitive and non-sensitive areas). In these cases, the assumption that more data is needed for the tails is not necessarily valid. For example, in a skewed-right distribution (i.e. a long right tail, **Figure 3A-2**), there is more data on the low end than the average, and thus fewer sample may be needed for the Q10 than the average. In an extreme case, for a bimodal distribution (**Figure 3A-2**) there are few samples near the mean, thus there is a larger sample size required to estimate the average with the same error rate and confidence than either of the modes. If users want to calculate the sample size requirements for quantiles not offered here, we recommend using the R script above. Users may use the "triple the requirement for the average" rule, as it is often more conservative, but in non-normal cases which are common at smaller scales it is not advised.

Second, we required there to be a minimum sample of 10 to perform these checks for any statistic (mean, Q1, etc.). A robust estimate of σ, whether for the average or any quantile, requires a reasonable number of points to sample the underlying (unknown) population. Commonly, for normally distributed data, the recommended minimum sample size is 30. Also common is a recommendation based on which quantile you're trying to estimate, where you want 3-5 samples on either side of a given quantile. Using a central value of 4, that translates to a recommendation of 8 for the median, and 40 for the Q10. Generalizing, the recommended sample size for any quantile (irrespective of the data) is 4/min(q, 1-q) (where q is the quantile being estimated, so for Q50, that is 4/0.5 = 8 samples; for Q1 or Q99, that is 4/0.01 = 400 samples. This assumption, however, ignores how variable your samples actually are, and the acceptable error rate and confidence. Since our acceptable error rate is high relative to the variation in most Ecoregions, and we were interested in providing estimates for as many Ecoregions as is defensible, we consulted with statisticians on relaxing these guidelines and determined that a minimum of 10 would be acceptable. Users are not encouraged to consider any estimate, especially the tails, as reliable if N<10 since much of these data are non-normal, especially at smaller Ecoregions. For example, with an N=5 and left skewed data, the average of your sample is probably closer to Q80 than the mean, and the minimum of your sample may be closer to the average of the true population.

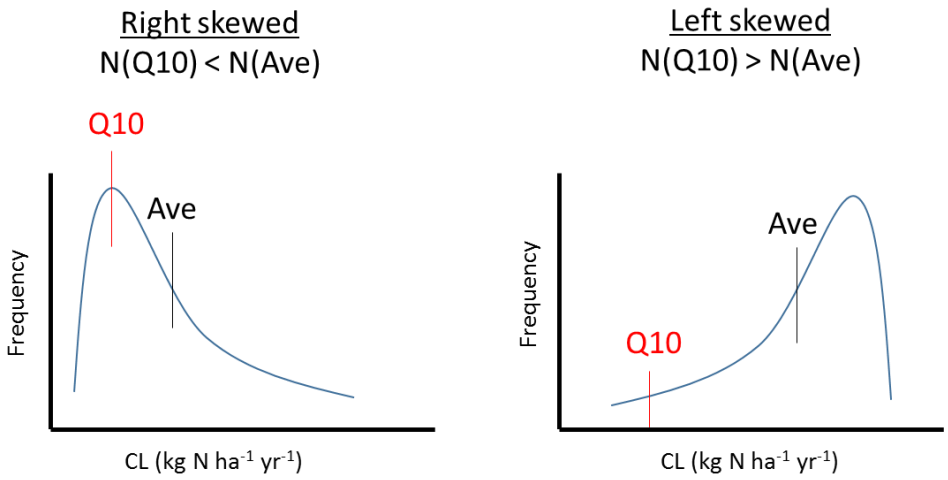

Figure 3A-2. Examples of non-normal distributions affecting sample size requirements. In right skewed distribution (and bimodal), fewer samples may be required for lower quantiles than for the average. The opposite is predicted for left skewed (and normal) distributions.

Third, there are some instances where the recommended sample size is very low (e.g. 1-2 is not uncommon). This is not unexpected because in many cases the standard deviation among samples (esp. for Open canopy systems) is very low relative to the acceptable error rate. Thus, only a few points are needed to estimate the statistics within the relatively large acceptable error rate. This does not mean that one should use an estimate of the Q10 based on a sample of one, which is why the minimum sample size to perform these checks at all is 10. Rather, it means that the sample of 1 is all you actually needed to be within the specified quantile given the acceptable error rate. One would not have known that without the original sample of 10.

Fourth, there is no way to estimate the sample size for the minimum or the maximum. These are at the extremes of the data and thus theoretically require sampling the entire population (n= ∞). Thus, as an approximation, we assumed that if the Q1 criteria was met, then we could estimate the minimum and maximum CL with some confidence.

Fifth, there were cases where n could not be calculated with **Eq. 3A-8** because there was zero variability in the sample (σ=0; N=11 and 108 individual Ecoregions at Level III, and IV, respectively). This could occur two ways: if there was a sample size of one, or if there was no variation among individual samples. If the sample size was one, the sample size under the threshold of 10 and the next highest level is recommended for the CL statistics. If the sample had no variation but 10 or more points, the CL was estimated to not vary and the required sample size is predicted to be 1. This occurred solely because for Closed Canopy systems in the Temperate Sierras Level I Ecoregion (N=42) and all nested sub Ecoregions, all CL values were the same. Here, soil pH had the same value in all sites and was the only modifying factor in the equation for the CL. In these cases, only a mean value is presented since it is not appropriate to infer a quantile when all values are identical. Furthermore, soil pH likely varies across sites in this Ecoregion, and updated soil pH values will be used once they become available.

This approach is valid for setting minimum sample sizes for other critical loads as well (e.g. for sulfur, aquatic acidification) with appropriate modifications, and will be explored in future versions of the NCLD. Below are the results for all Ecoregion levels (**Table 3A-3**).

Table 3A-3. Sample Size Results for All Ecoregions

				Mean		Q50		Q10		Q5		Q1	
Canopy Type	**Ecoregion Level**	**# Ecoregions in US**	**# Ecoregions with Plots**	**# Yes**	**%**	**# Yes**	**%**	**# Yes**	**%**	**# Yes**	**%**	**# Yes**	**%**
Closed	III	84	52	29	56%	25	48%	23	44%	23	44%	30	58%
	IV	967	340	93	27%	77	23%	76	22%	77	23%	96	28%
Open	III	84	39	27	69%	26	67%	26	67%	27	69%	27	69%
	IV	967	162	78	48%	76	47%	75	46%	74	46%	78	48%

GIS Filename, Formats, Attribute Descriptions for Area based Critical Loads

Features:

NCLD_EMP_ER4_Closed_Simkin_v31
NCLD_EMP_ER4_Open_Simkin_v31
NCLD_EMP_ER3_Closed_Simkin_v31
NCLD_EMP_ER3_Open_Simkin_v31

Rasters (no attribute data available for the rasters):

NCLD_ER3_Closed
NCLD_ER3_Open
NCLD_ER4_Closed
NCLD_ER4_Open

Variable	Explanation	Format
CLID	Unique(!) identifier across all three CL grouping: Forest Ecosystem, Surface Waters, and Empirical Nitrogen.	Text
PRID	Unique(!) identifier of the CL project.	Integer
LOCID	Unique(!) identifier of a particular location (e.g. lake, stream reach, or sample plot), gridded area, or Ecoregion I-IV. Lakes and stream reaches are classified by NHDPlusV2. In many cases, a single lake/stream reach or ecoregion may have more than one CL value. The LOCID can be used to aggregate CLs for a particular location.	Text
CL_Class	Critical load type across all tables: Empirical Terrestrial Nitrogen	Text
CL_Type	Critical load type across all tables: Empirical Terrestrial Nitrogen	Text
StudyScale	Ecoregion scale at which Simkin CLs were summarized	Text
EcoRegionIII /EcoRegionIV	Ecoregion number classification	Text
CLN_q5	5th quantile of the distribution of Empirical CL of N plots within polygon when sample size requirement is met (kg/ha-yr).	Integer
No_plots	Number of plots present within the Ecoregion	Integer
No_5	The sample size require to calculate a statistically relevant 5th quantile	Integer
Canopy	Closed canopy or Open canopy. Based on the National Vegetation Classification System where woodlands, grasslands, and shrublands were “open” and forests were “closed.”	Text
RecepI	Biological and physical entity being affected: Herbaceous plant community.	Text
Response	The negative response of that biological or physical entity that is to be avoided: Reduction in community composition	Text
Threshold	The threshold of related to the receptor and its response: No biodiversity loss	Text
PrimRef	Publication citation for primary study for the CL. For some CLs, there is more than one publication. For CLs with more than one publication, use Tables 5 and 6 to determine the additional references.	Text

DepoUnitsStudy	Deposition unit for study: kg/ha-yr.	Text

Projections

USA_Contiguous_Albers_Equal_Area_Conic_USGS_version	
Projection: Albers	Geographic Coordinate System: GCS_North_American_1983
False_Easting: 0.00000000	Datum: D_North_American_1983
False_Northing: 0.00000000	Prime Meridian: Greenwich
Central_Meridian: -96.00000000	Angular Unit: Degree
Standard_Parallel_1: 29.5.00000000	
Standard_Parallel_2: 45.00000000	
Latitude_of_Origin: 23.00000000	
Linear_Unit: Meter	

Development of Area Based Herb Richness CL rasters

The Ecoregion III and IV CLs were made into a Raster GIS format based on Q5 statistic. Polygons for Ecoregion IV were used in both sets of analyses as they provide a more refined coastline. Plots were grouped into open and closed datasets and analyzed separately. For each Ecoregion polygon where the sample size criteria were met, the Q5 CL value was assigned to those polygons. The Ecoregion IV boundaries are subsets of Ecoregion III boundaries. Thus, the Ecoregion IV polygons with CLs were subsituted for the Ecoregion III areas.

The National Land Cover Dataset (NLCD) from 2011 was used to define the spatial extent of "open "or "closed" canopies ecosystems across the conterminous US (Homer et al. 2011). The Open Canopy Layer are defined by the land cover classes of Shrub/Scrub (52) and Grassland/Herbaceous (71). The Closed Canopy Layer are defined as Deciduous Forest (41), Evergreen Forest (42), and Mixed Forest (43) classes. All other land cover classes were excluded from the layer. The combined polygon Ecoregion CL layer was converted to a 30m raster to be aligned with the National NLCD raster. The Ecoregion raster was then merged separately with the Open Canopy Layer and the Closed Canopy Layer, creating two distinct rasters that define herb richness for appropriate open and closed canopy ecosystems.

National Critical Load Database (NCLD) Information Use Conditions

Disclaimer

The National Atmospheric Deposition Program (NAPD) Critical Loads of Atmospheric Deposition (CLAD) Science Committee National Critical Loads Database (NCLD) for Nitrogen (N) and Sulfur (S) was developed cooperatively with individuals or groups sharing critical load (CL) data and is NOT intended to be comprehensive of all known CLs for the U.S. While substantial efforts are made to ensure the accuracy of data and documentation contained in the NCLD, complete accuracy of the information cannot be guaranteed. The qualities and accuracy of the CLs are best described in the associated research publication(s). It is important to review material and information in the cited papers prior to using the CL data within the NCLD. In addition, any opinions, findings, conclusions, or recommendations as part of these datasets do not necessarily reflect the views of CLAD, NADP, and/or respective members' affiliations.

Use Condition and Citation

The intended use of the NCLD is for scientific, policy-related, and/or educational purposes. Any published use of the database information must acknowledge the original source(s) of the data. Each CL value is linked to its origin source(s) through the RefID field. The proper citations for each RefID can be found in Table 6 of the database. In addition, whenever the Data User presents and/or publishes research based on CLs in the database, NADP and CLAD must be acknowledged. A suggested Acknowledgement is:

"We acknowledge the Critical Loads of Atmospheric Deposition (CLAD) Science Committee of the National Atmospheric Deposition Program (NADP) for their role in making available NCLD_v3.0 datasets"

and please cite:

Lynch, J.A., Phelan, J., Pardo, L.H., McDonnell, T.C., Clark, C.M., and Bell, M.D. 2020. Detailed Documentation of the National Critical Load Database (NCLD) for U.S. Critical Loads of Sulfur and Nitrogen, version 3.1, National Atmospheric Deposition Program, Wisconsin State Laboratory of Hygiene, Madison, WI.

We request one copy of any printed publications using data from the NCLD to be sent to the NADP Program Office at the address below. Citations or electronic copies are acceptable. For online uses, we request that the author notify the Program Office of the URL address of the online publications or website that includes NCLD data. We encourage teachers and professors to send the program office a brief description of how they have used the NCLD in their curriculum. Students who use the NCLD to complete academic assignments are not required to seek permission from the Program Office, but must acknowledge NADP and CLAD in any publications (e.g., a thesis).

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Questions, Errors and Corrections

Please contact NCLD manager, Jason Lynch (US EPA) with any questions about the NCLD or to report errors or corrections at lynch.jason@epa.gov or 202-343-9257.

References:

Neufeld, H., and Young. DR. 2014. Ecophysiology of the herbaceous layer in temperate deciduous forests. Pages pp 34–95 *in* F. Gilliam, editor. The Herbaceous Layer in Forests of Eastern North America. Oxford University Press, New York.

Simkin, S. M., E. B. Allen, W. D. Bowman, C. M. Clark, J. Belnap, M. L. Brooks, B. S. Cade, S. L. Collins, L. H. Geiser, F. S. Gilliam, S. E. Jovan, L. H. Pardo, B. K. Schulz, C. J. Stevens, K. N. Suding, H. L. Throop, and D. M. Waller. 2016. Conditional vulnerability of plant diversity to atmospheric nitrogen deposition across the United States. Proceedings of the National Academy of Sciences **113**:4086-4091.

USNVC. 2016. United States National Vegetation Classification Database, V2.0. Federal Geographic Data Committee, Vegetation Subcommittee, Washington DC. [usnvc.org].

Document Information

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