



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



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ON THE COVER

Hallett Peak, Rocky Mountain National Park

Photo by Ben Hoppe

Extrapolating Critical Loads of Nitrogen for Alpine Vegetation and Assessing Exceedance in National Parks Based on TDep Total N from 2002–2016

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Executive Summary

Excessive deposition of atmospheric nitrogen can have harmful impacts to vegetation and wildlife, especially within alpine ecosystems. Alpine environments receive high levels of reactive nitrogen deposition from upslope winds, but shallow soils and sparse vegetation make these ecosystems particularly susceptible to the negative impacts of nitrogen deposition. Bowman et al. (2012) established critical load thresholds, deposition levels below which harmful ecosystem effects do not occur, for preventing alpine vegetation community changes ($3.0 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) and soil nitrate leaching ($10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$). Critical loads give land managers and policy makers the ability to assess the amount of risk imposed by different levels of deposition and develop responsive management plans. This report compares these critical loads with the estimated total nitrogen deposited in the alpine area of national parks from 2002 and 2016 to identify national parks at risk of soil nitrate leaching or changes to their alpine vegetation. 14 National Parks contain alpine ecosystems, defined here as having any area above tree-line. 10 of the 14 parks are currently at risk to changes in their alpine vegetation communities and exceeded the alpine vegetation critical load in at least 80% of their alpine area in 2016. Eight of these parks either increased in exceedance area or remained at 100% exceedance from 2002–2016. The critical load of N for soil nitrate leaching was exceeded in two parks, Sequoia and Kings Canyon National Parks, in 2002 and by 2016, deposition levels in all alpine areas fell below the $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ critical load. Our results are likely most relevant in the four national parks (Glacier, Grand Teton, Rocky Mountain and Yellowstone National Parks) containing the indicator species, *Carex rupestris*, used to establish the alpine vegetation critical load. While the lack of the target species within the herbaceous community critical load indicates research is needed on additional alpine herbaceous communities, the consistency of herbaceous responses in low nutrient environments suggests that there are likely to be shifts in alpine community structure across all NPS units. Additionally, preliminary research in the Pacific Northwest has shown indications of soil N leaching at levels as low as $3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ which enhances the value of this analysis to prioritize areas for follow-up research. High use or disturbed alpine areas are most likely to be impacted by community shifts, but all alpine areas above the critical load should be monitored to prevent the cascading impacts to wildlife and park visitor experience.

Introduction

National Parks protect ecosystems across the United States from the lowest elevations at Badwater basin in Death Valley National Park to the highest mountain peaks at Denali National Park. Below some of these mountain peaks are alpine meadows that contain a diverse array of wildflowers and grasses that attract marmots, mountain goats, big horn sheep, and millions of park visitors a year. Alpine meadow environments are particularly susceptible to changing environmental stressors because of the sparse cover of vegetation, short growing seasons, large areas of exposed bedrock and talus, and snowmelt nutrient releases (Williams et al., 1996; Nanus et al., 2012). One of the main stressors threatening alpine ecosystems is deposition of atmospheric nitrogen (N) and sulfur (S) pollutants. Here we evaluate the terrestrial effects of N deposition to the sensitive alpine meadows across the National Park Service, that not only provide habitat for a variety of animals, but also feed into the sensitive alpine lakes.

The shallow soils, short growing seasons, and sparse vegetation create a N limited ecosystem that makes alpine environments sensitive to increased levels of N inputs through precipitation, snowmelt, and upslope winds, while preventing efficient uptake of these nutrients. Alpine ecosystems are historically either N limited or co-limited by N and phosphorus (Bowman et al., 2006; Williams et al., 2016). As a result, these environments are susceptible to N saturation and have low acid-neutralizing capacities (ability to absorb or utilize acidic compounds), so even small inputs of N can cause acidification (Williams et al., 1996; Baron et al., 2011). The high altitude of alpine environments allows for steady wind currents and abundant precipitation that can carry high levels of reactive N deposition (Williams and Tonneson, 2000). Air masses traveling from sources at lower elevation can carry pollutants from the surrounding agricultural and industrial sectors and deposit large amounts of N to these remote ecosystems (Benedict et al., 2013; Kühnel et al., 2011; Omernik and Griffith, 1986). At appropriate levels of input, N stimulates plant growth but at high concentrations, it can have harmful effects on sensitive species and alter biotic communities (Bowman et al., 1995; Fenn et al., 2003b; Neff et al., 2002; Seastedt and Vaccaro, 2001).

The response of alpine vegetation to increased inputs of N is often species specific (Bowman et al., 1993). Usually, the strongest response to N deposition is seen in the subdominant species which increase in abundance, while the dominant taxa remain relatively unchanged (Fenn et al., 2003a). This shift in abundance leads to changes in the overall vegetation community composition. Additionally, N deposition can negatively affect the growth patterns of plants. Many studies have found that excessive N deposition increases the ratio of aboveground growth to belowground growth in alpine vegetation (Bassin et al., 2013; Gill, 2014; Meyer-Grünefeldt et al., 2016; Volk et al., 2014). The shift towards aboveground growth leads to loss of structural support and susceptibility to both drought and strong winds, which can occur frequently in alpine environments (Meyer-Grünefeldt et al., 2016).

Outside of species-specific responses, alpine ecosystems are also vulnerable to acidification of soils either through direct acidic deposition or from nutrient N enrichment (Baron et al., 2011). Once N saturation occurs, nutrient base cations begin to leach and soluble aluminum increases, which

collectively causes soil acidification and loss of diversity (Bowman et al., 2012). Base cations (Ca, Mg, Na, K) usually buffer soil from the acidifying effects of N deposition but are flushed from the soil during high N enrichment (Helliwell et al., 2008). Most alpine catchments are susceptible to acidification because they are underlain by bedrock with relatively low concentrations of base cations (Omernik and Griffith, 1986).

In order to help communicate the impacts of deposition to sensitive ecosystems, researchers have developed the concept of the critical load, which establishes a threshold level of exposure to environmental pollutants below which no negative ecological effects occur (Burns et al., 2008; Nilsson and Grennfelt, 1988; Porter et al., 2005). Critical loads give land managers and policy makers the ability to assess the amount of risk imposed using current models of deposition and develop responsive management plans. Critical loads for N deposition have been established for preventing negative effects to trees, herbaceous species, lichen, alpine lakes, and many other receptors (Baron et al., 2011; Clark et al., 2019; Geiser et al. 2019; Simkin et al., 2016). This study applies critical loads for protecting alpine ecosystems from soil nitrate leaching and vegetation community changes to alpine areas within National Park Service boundaries. Critical loads for alpine ecosystems have been established through a N-fertilization study in the southern Rocky Mountains, Colorado, U.S.A. (Bowman et al., 2012). They found that the percent cover of the indicator species, *Carex rupestris*, increased with N deposition over $3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$. Especially in nutrient limited areas, an increase in cover of an individual species risks reducing floral diversity. Within the same sites, inorganic N concentrations in the soil rose above background levels with N deposition over $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$. Therefore, Bowman et al. (2012) established critical loads of $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ for alpine soil nitrate leaching and $3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ for an increase in *C. rupestris* cover.

Many of the national parks in the western United States contain alpine ecosystems. Protecting these areas from the negative effects of N deposition is important for the surrounding ecosystems and also for the visitor experience. The goal of this study is to assess the risk to alpine vegetation from nitrogen deposition. To do so, we extrapolate the threshold for a change in *C. rupestris* to the likely response of alpine vegetation community in all areas above tree line. We use geospatial analysis to compare the alpine critical loads to total N deposition estimates from 2000-2002 and 2014-2016 (NADP 2018) in order to identify alpine areas in national parks at risk of vegetation changes and soil leaching.

Methods

Alpine Critical Loads

Two critical loads for alpine meadows were defined by Bowman et al. (2012): a critical load of nitrogen (N) for an increase in *Carex rupestris* cover ($3.0 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$; Figure 1) and the critical load of N for increased nitrate leaching from alpine meadows ($10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$). We expand this analysis outside of the initial study site, and outside the range of *C. rupestris*, so here we label the vegetation response as the critical load of N for a shift in the alpine vegetation community (hereafter vegetation CL). The nitrate leaching response is expanded outside of the alpine meadows from the initial study so is labeled here as the critical load of N for increased nitrate leaching from alpine soils (hereafter soil chemistry CL).



Figure 1. *Carex rupestris* ©Mike Oldham

National Alpine Landcover

We used the 30-meter grid 2011 Gap Analysis Project Landfire National Terrestrial Ecosystems imagery (GAP; USGS, 2016) to develop alpine raster layers in ArcMap 10.6.1. Using the attribute table for the Landfire imagery, pixel index values were selected that correlated with alpine ecosystems. Ecosystem types were classified as either vegetated or non-vegetated to assess those areas more likely to respond to nitrogen deposition. The index values and correlating ecosystem types (ECOLSYS_LU) are shown in Table 1. We extracted these ecosystem types to create three rasters: vegetated landcover, non-vegetated landcover, and total alpine landcover.

Table 1. List of index values used to develop the all alpine raster from the 2011 GAP Landfire National Terrestrial Ecosystems imagery from the USGS.

Index Value	Ecosystem
308	North Pacific Alpine and Subalpine Dry Grassland
438	Rocky Mountain Alpine-Montane Wet Meadow
500	Acadian-Appalachian Alpine Tundra
501	Rocky Mountain Alpine Dwarf-Shrubland
502	Rocky Mountain Alpine Fell-Field
503	Rocky Mountain Alpine Turf
504	Mediterranean California Alpine Dry Tundra
505	Mediterranean California Alpine Fell-Field
506	North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow
507	Rocky Mountain Alpine Tundra/Fell-field/Dwarf-shrub Map Unit
549	Rocky Mountain Alpine Bedrock and Scree
550	Mediterranean California Alpine Bedrock and Scree
551	North Pacific Alpine and Subalpine Bedrock and Scree
554	North American Alpine Ice Field

To assess the accuracy of the vegetated and non-vegetated rasters, the areas were compared with the Vegetation Mapping Inventory (VMI) for Rocky Mountain National Park (Salas et al., 2005). This park was chosen due to the proximity to the location of where the Bowman et al. (2012) critical loads were developed. Similar to the GAP dataset, alpine map classes from the VMI were identified as vegetated and non-vegetated. The map classes selected from the VMI are shown in Appendix B. Vegetated, non-vegetated, and total alpine area from GAP and VMI were compared to each other. The vegetation raster of each type did not have enough overlap (43%) to justify using the GAP vegetated alpine dataset at a national scale, but the GAP total alpine contained 97% of the VMI total alpine area (Figure 2 and Appendix B). Therefore, the decision was made to use the GAP total alpine raster as a conservative estimate of where alpine vegetation could grow and rely on local knowledge to determine the highest risk areas when applying the critical load.

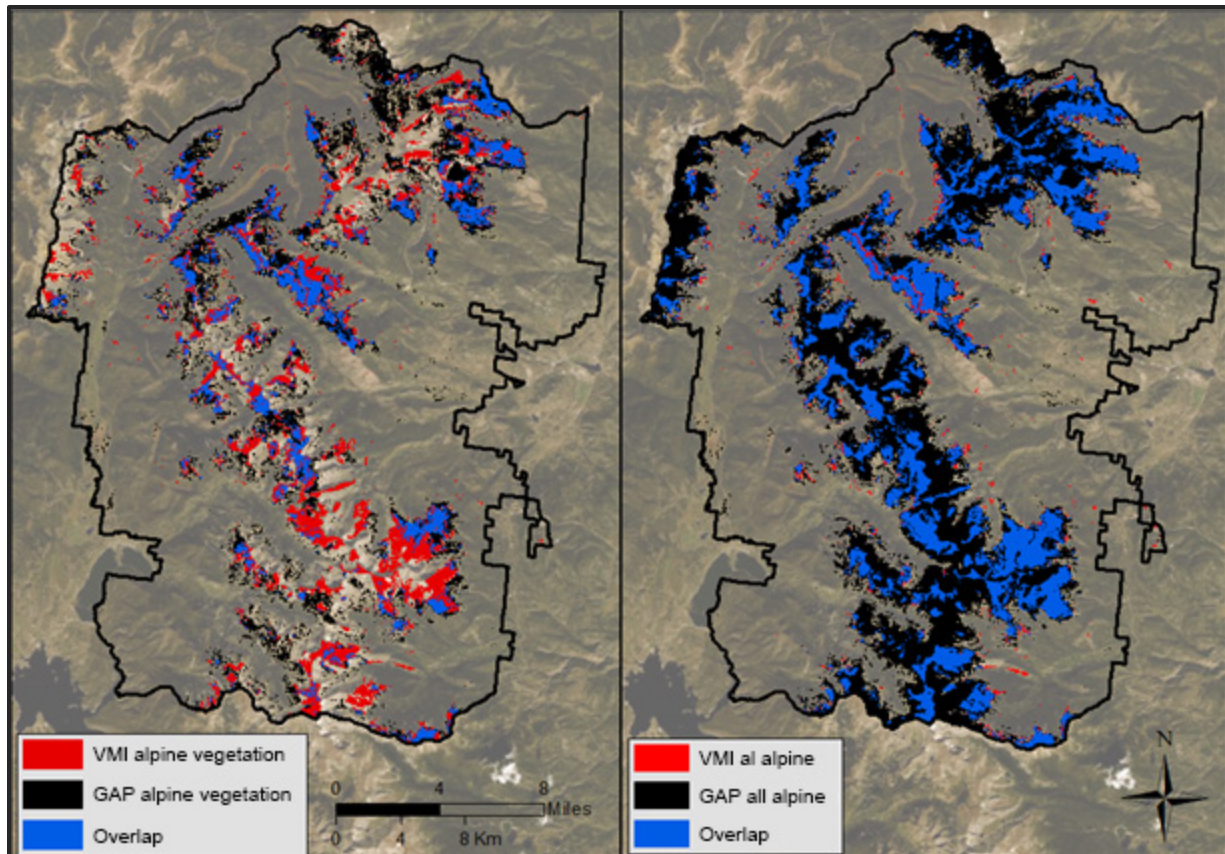


Figure 2. Comparison between the National Park Service alpine coverage (red) with the GAP alpine coverage (black) at Rocky Mountain National Park. The alpine vegetation coverages are shown on the left and the all alpine coverages are shown on the right.

An initial examination of aerial maps and the Landsat alpine rasters suggested that the all-alpine raster included some subalpine ecosystems, including artifacts of the GAP analysis that showed alpine areas in desert environments. Since the elevation at which alpine ecosystems begin varies with latitude and mountain range, we used the U.S. EPA Ecoregion Level III boundaries to regionalize alpine systems and identify a representative tree line for each (Omernik and Griffith, 2014). Ecoregion III subsets were evaluated against aerial photography to identify the elevation of the subalpine-alpine boundary (Appendix A). The subalpine-alpine boundary was identified and then clipped to only include area above the tree line for each ecoregion using a 1-meter grid USGS digital elevation model (USGS, 2017). Trimming the data by elevation removed $\sim 2500 \text{ km}^2$ (8% of the total area) of the original alpine raster area. The final all-alpine raster is shown in Figure 3. For more details on the ecoregions and elevations used, see Appendix A.

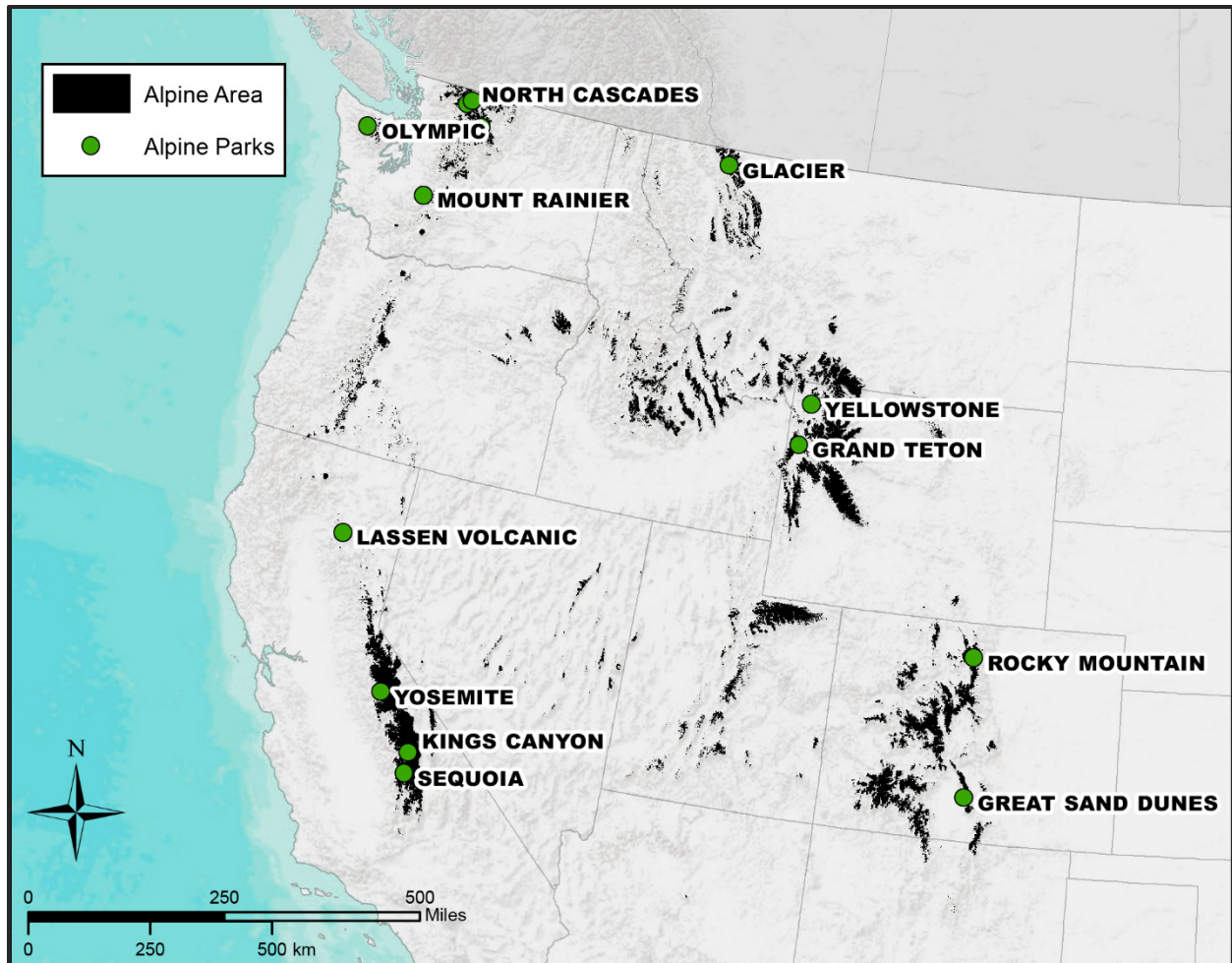


Figure 3. Map of the alpine raster created from the GAP Landfire National Terrestrial Ecosystems imagery (black shaded regions) and the national park units that contained alpine area (green circles).

Identifying national parks with alpine ecosystems

National Park Service unit boundaries were overlaid onto the modified alpine rasters to identify which units include alpine ecosystems. Fourteen park units were identified within 5 NPS Inventory and Monitoring Networks (Table 2).

Calculating exceedances of critical loads

Exceedances of the critical load of N for a shift in alpine vegetation community (vegetation CL; $3.0 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) and the critical load for nitrate leaching from alpine soil (soil chemistry CL; $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) were evaluated against modeled deposition of Total N using the National Atmospheric Deposition Program Total Deposition (TDep; v. 2018.02) model (4.0 km-grid; Schwede and Lear 2014). The TDep model (v.2018.02) uses concentration measurements of HNO_3 and NO_3 and wet deposition measurements of NO_3 and NH_4 to modify the CMAQ model (v.5.0.2), and then incorporates modeled dry deposition of gaseous NH_3 , PAN, N_2O_5 , NO, NO_2 , HONO, and organic nitrates (Schwede and Lear, 2014).

Table 2. Overview of park units containing alpine ecosystems. Included is the Inventory and Monitoring Network name, the lowest elevation at which alpine ecosystems exist in each park, the percentage of each park area that contains alpine, the area of the alpine portion, and the range of total N deposition in the alpine area for 2002 and 2016 (TDep).

Park Name	I & M Network	Elevation of alpine (m)	Area of alpine (km ²)	% of Park in Alpine Ecosystem	Annual alpine N deposition, minimum-maximum 2002 (kg-N ha ⁻¹ yr ⁻¹)	Annual alpine N deposition, minimum-maximum 2016 (kg-N ha ⁻¹ yr ⁻¹)
Glacier National Park	Rocky Mountain	2000	603	14.8	1.8 – 7.1	2.2 – 7.4
Grand Teton National Park	Greater Yellowstone	2700	212	16.9	2.8 – 8.5	2.9 – 7.6
Great Sand Dunes National Park and Preserve	Rocky Mountain	3100	33	5.4	2.1 – 6.2	2.0 – 5.9
Kings Canyon National Park	Sierra Nevada	3000	1052	56.6	5.4 – 10.7	5.0 – 9.4
Lake Chelan National Recreation Area	North Coast and Cascades	1600	13	5.2	1.8 – 2.8	1.9 – 2.8
Lassen Volcanic National Park	Klamath	2300	32	7.3	3.2 – 5.9	2.5 – 3.9
Mount Rainier National Park	North Coast and Cascades	1450	144	15.1	2.9 – 4.9	2.4 – 4.6
North Cascades National Park	North Coast and Cascades	1550	328	16.2	2.1 – 4.2	2.2 – 4.6
Olympic National Park	North Coast and Cascades	1400	68	1.8	1.8 – 4.9	1.5 – 3.9
Rocky Mountain National Park	Rocky Mountain	2900	354	32.8	4.4 – 9.5	3.1 – 7.0
Ross Lake National Recreation Area	North Coast and Cascades	1650	4	0.8	2.0 – 3.7	2.2 – 3.8
Sequoia National Park	Sierra Nevada	2900	611	37.1	6.4 – 11.2	5.2 – 9.5
Yellowstone National Park	Greater Yellowstone	2600	329	3.7	1.9 – 5.9	2.2 – 5.8
Yosemite National Park	Sierra Nevada	2800	903	29.9	4.6 – 6.7	3.8 – 6.1

To determine how risk to alpine ecosystems within national parks has changed over time, the earliest available TDep raster (three year average annual deposition 2000–2002; 2002) was compared to the most recent TDep raster available at the time of our analysis (average deposition 2014–2016; 2016). TDep values were compared to the two CLs to assess the exceedances for 2002 and 2016. An exceedance is calculated by subtracting the critical load from deposition. When deposition exceeds the critical load, the ecosystem is at risk of change. The NPSpecies database was queried for *Carex rupestris* to identify which parks contained the alpine species shown to respond to increased deposition (NPSpecies 2020; see Results section).

Critical load exceedance was evaluated by spatially attributing the CL values to the GAP total alpine raster and subtracting TDep Total N. Each national park unit containing alpine area was analyzed to determine the percent of its alpine area Below CL ($>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ below the CL), At CL ($\pm 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ of the CL), and Above CL ($>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ above the CL).

Results

According to the GAP total alpine dataset, 14 out of the 357 national park units analyzed within the continental United States contained alpine area (Figure 3). All of the parks were in the western United States, located across the Rocky Mountain, Sierra Nevada, and Cascade ranges. Sequoia and Kings Canyon National Parks had the highest percentage of land area covered by alpine ecosystems (57% and 37%, respectively). Next were Rocky Mountain National Park and Yosemite National Park with 33% and 30% alpine, respectively. Most of the parks contained under 20% alpine area. The elevation at which alpine ecosystems begin varies with park latitude. In general, the further north the park is located, the lower the starting elevation of the alpine ecosystem within the park. Starting alpine elevations ranged from 1400 m (Olympic National Park) to 3100 m (Great Sand Dunes National Park and Preserve; Table 2).

The NPSpecies database showed that 4 of the 14 parks contained *Carex rupestris* (Table 3). All parks with *C. rupestris* are along the Rocky Mountains and are within the Rocky Mountain and Greater Yellowstone networks. Additional National Park Service units within Alaska also contain *C. rupestris*, but since the TDep model does not have results for the area, those parks were not included in this analysis.

Trends in total nitrogen (TN) from the NADP TDep model showed modest declines in the Western U.S. for maximum deposition from 2000-2002 (2002) to 2014-2016 (2016) (Figure 4). The maximum nitrogen deposition in alpine areas per park ranged from ~ 3 to ~ 11 kg-N ha⁻¹ yr⁻¹ in 2002, while the maximum deposition in 2016 ranged from ~ 3 to ~ 9 kg-N ha⁻¹ yr⁻¹. The average change in maximum TN per park between the two time periods was -0.70 kg-N ha⁻¹ yr⁻¹. The most noticeable change in TN deposition occurred at Rocky Mountain National Park, which experienced a decline in maximum deposition from 9.5 to 7.0 kg-N ha⁻¹ yr⁻¹. Lassen Volcanic National Park also showed a large decrease in maximum TN deposition (-2.0 kg-N ha⁻¹ yr⁻¹). Evaluating change by NPS Inventory and Monitoring (I&M) networks showed a decline in deposition to alpine areas across all networks with the most prominent change occurring in the Sierra Nevada Network; experiencing an average decline in maximum TN deposition in its alpine ecosystems of -1.2 kg-N ha⁻¹ yr⁻¹ from 2002 to 2016. The North Coast and Cascades Network displayed the smallest decline of around -0.15 kg-N ha⁻¹ yr⁻¹ in its alpine ecosystems. In the North Coast and Cascades Network, both North Cascades National Park and Ross Lake National Recreation Area experienced increases in maximum annual deposition (0.41 and 0.11 kg-N ha⁻¹ yr⁻¹, respectively).

Table 3. Area in exceedance of the critical load of N for a shift in the alpine vegetation community using TDep N deposition 3-year averages. Presence/absence data for *Carex rupestris* comes from NPSpecies (2020). Columns for 'Below CL', 'At CL,' or 'Above CL' show the percentage of park alpine area that is below, at (+/- 0.5 kg-N ha⁻¹ yr⁻¹ of the CL), or above the alpine vegetation critical load (3.0 kg-N ha⁻¹ yr⁻¹).

Park Name	<i>Carex rupestris</i> Presence	Below CL in 2002 (%)	At CL in 2002 (%)	Above CL in 2002 (%)	Below CL in 2016 (%)	At CL in 2016 (%)	Above CL in 2016 (%)	Change in Above CL from 2002 to 2016 (%)
Glacier National Park	Present	0.0	0.8	99.2	0.0	0.0	100.0	0.8
Great Sand Dunes National Park and Preserve	Absent	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Grand Teton National Park	Present	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Kings Canyon National Park	Absent	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Lake Chelan National Recreation Area	Absent	41.7	58.3	0.0	44.2	55.8	0.0	0.0
Lassen Volcanic National Park	Absent	0.0	0.0	100.0	0.0	12.2	87.8	-12.2
Mount Rainier National Park	Absent	0.0	7.1	92.9	0.0	18.9	81.1	-11.8
North Cascades National Park	Absent	5.5	40.6	54.0	3.7	36.4	59.9	6.0
Olympic National Park	Absent	0.0	33.6	66.4	37.1	45.3	17.7	-48.8
Ross Lake National Recreation Area	Absent	0.0	100.0	0.0	0.0	100.0	0.0	0.0
Rocky Mountain National Park	Present	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Sequoia National Park	Absent	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Yellowstone National Park	Present	0.1	16.7	83.2	0.0	11.0	89.0	5.9
Yosemite National Park	Absent	0.0	0.0	100.0	0.0	0.0	100.0	0.0

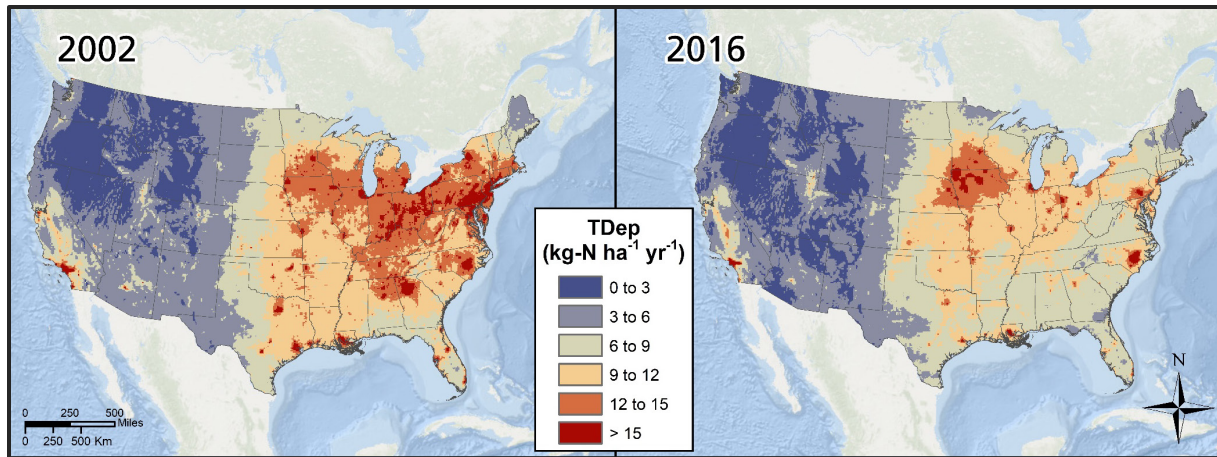


Figure 4. Total nitrogen deposition in the continental United States in 2000-2002 and 2014-2016. Deposition values taken from the National Atmospheric Deposition Program's TDep modeling results (in $\text{kg-N ha}^{-1}\text{yr}^{-1}$).

In 2002, 11 of the 14 National Park Service units had no alpine area below the critical load of N for a shift in the alpine vegetation community (vegetation CL, Table 3, Appendix D). Only two parks, Lake Chelan and Ross Lake National Recreation Areas, didn't have any alpine area in exceedance in 2002. Nine of the fourteen parks exceeded the vegetation CL in at least 90% of their alpine area in 2002. Seven of these parks experienced little to no change in exceedance by 2016. However, Lassen Volcanic and Mount Rainier National Parks, with 100% of area exceeding the CL in 2002, saw declining deposition to result in about 12% of alpine area below the CL in 2016. The largest decline in CL exceedance area occurred at Olympic National Park (-49%), with 37% of the area below the CL in 2016. Yellowstone and North Cascades National Parks were the only parks to experience a noticeable increase (5.9 and 6.0%, respectively) in exceedance area from 2002 to 2016. The other 12 parks experienced less than 1% increases between 2002 and 2016. When the parks with alpine area were grouped by network, the most concerning results were in the Sierra Nevada and Rocky Mountain networks. The Sierra region experienced exceedance of the alpine vegetation CL in 100% of their alpine area throughout the entire time period while the Rocky Mountain region showed an increase in exceedance area from 99% to 100% from 2002 to 2016. The Greater Yellowstone Network increased from 92% to 95% exceedance area from 2002 to 2016. The Klamath and North Coast and Cascades networks both experienced moderate declines in average exceedance area (-12% and -11%, respectively).

Only 2 park units had an exceedance of the critical load of N for increased nitrate leaching of alpine soils ($10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) in 2002 (Table 4). These two units, Sequoia and Kings Canyon National Parks, are adjacent to one another and exceeded the soil chemistry CL in 2.3% and 1.5% of their total alpine area, respectively. By 2016, deposition levels in both of these units (and all others) were below the CL for increased nitrate leaching (Table 4).

Table 4. Area in exceedance of the critical load of N for increased nitrate leaching of alpine soils using TDep N deposition 3-year averages. Presence/absence data for *Carex rupestris* comes from NPSpecies (2020). Columns for 'Below CL', 'At CL,' or 'Above CL' show the percentage of park alpine area that is below, at (+/- 0.5 kg-N ha⁻¹ yr⁻¹ of the CL), or above the critical load for soil N leaching (10 kg-N ha⁻¹ yr⁻¹).

Park Name	<i>Carex rupestris</i>	Below CL in 2002 (%)	At CL in 2002 (%)	Above CL in 2002 (%)	Below CL in 2016 (%)	At CL in 2016 (%)	Above CL in 2016 (%)	Change in Above CL from 2002 to 2016 (%)
Glacier National Park	Present	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Great Sand Dunes National Park and Preserve	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Grand Teton National Park	Present	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Kings Canyon National Park	Absent	94.1	4.4	1.5	100.0	0.0	0.0	-1.5
Lake Chelan National Recreation Area	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Lassen Volcanic National Park	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Mount Rainier National Park	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
North Cascades National Park	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Olympic National Park	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Ross Lake National Recreation Area	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Rocky Mountain National Park	Present	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Sequoia National Park	Absent	85.9	11.8	2.3	100.0	0.0	0.0	-2.3
Yellowstone National Park	Present	100.0	0.0	0.0	100.0	0.0	0.0	0.0
Yosemite National Park	Absent	100.0	0.0	0.0	100.0	0.0	0.0	0.0

Discussion

Exceedance of critical load of N for an increase in *Carex rupestris*

This study compared total N deposition from NADP's TDep coverage maps (3-year averages, 2000-2002 and 2014-2016) with the critical load of N for an increase in *Carex rupestris* and critical load of N for increased nitrate leaching of alpine meadows from Bowman et al. (2012) to assess which national parks are at risk for negative impacts to their alpine ecosystems. Here we extrapolate the threshold for a change in *C. rupestris* to the likely response of alpine vegetation community in all areas above tree line. The majority of parks analyzed in this study (10 out of 14) are at risk of changes to their alpine vegetation community, due to park nitrogen deposition levels exceeding the CL ($3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) derived from Bowman et al. (2012; Figure 4). These 10 parks exceeded the alpine vegetation CL in at least 80% of their alpine area in 2016 (Table 3). The area in exceedance at Glacier (+0.8%), North Cascades (+6.0%) and Yellowstone (+5.9%) National Parks has increased since 2002 (Figure 5). The alpine area in exceedance at Lassen Volcanic and Mount Rainier National Parks has declined since 2002 (-12.2 and -11.8%, respectively; Figure 5), but both parks still have areas at risk for alpine vegetation change, with over 80% of their alpine areas in exceedance of the CL (Table 3). Parks with alpine areas within the Greater Yellowstone, Rocky Mountain, and Sierra Nevada networks have the most area at risk of changes to their alpine vegetation, with average exceedances of 95%, 100% and 100% of their alpine area in 2016, respectively (Appendix C).

The park exceedance values were calculated with CLs adopted from the Bowman et al. 2012 study in Rocky Mountain National Park. The alpine vegetation CL ($3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) was based on the change in abundance of a nitrophilic indicator species, *C. rupestris*. The study used the difference in the rate of change in cover of *C. rupestris* between the ambient and the treatment plots to establish the N deposition threshold for the ecosystem. They found elevated N deposition above $3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ in the alpine ecosystem can lead to changes in the percent cover of this sedge species from 2–7% per year. This means that if the alpine area received high N deposition for 10 years, the percent coverage of *C. rupestris* would increase by over 60% and by 2050, over 320% (using a 5 %/year model).

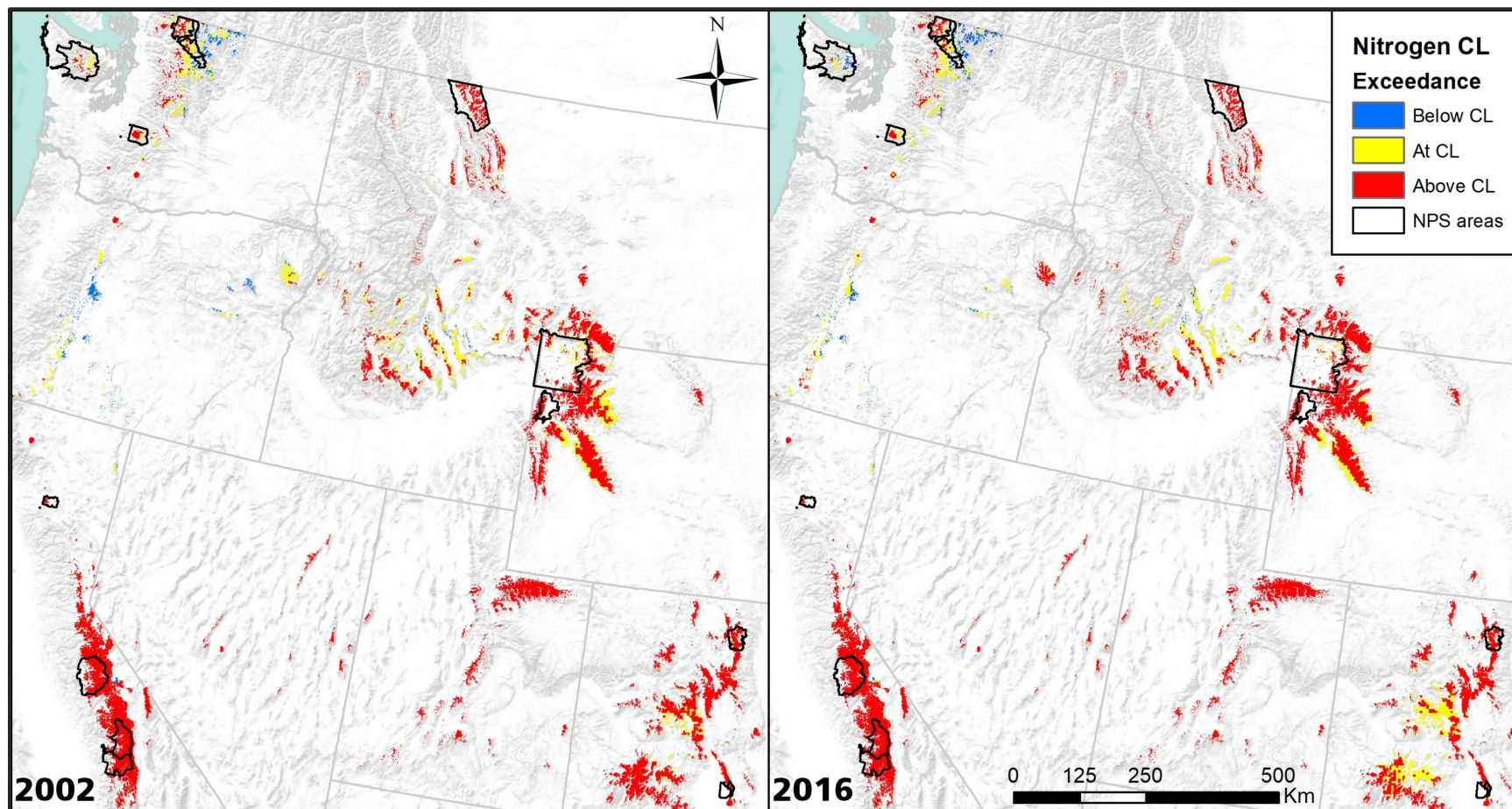


Figure 5. National exceedance map for the critical load of N for alpine vegetation ($3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$). National park units are represented by the black outlines and exceedance is denoted by the colored coverage in $\text{kg-N ha}^{-1} \text{ yr}^{-1}$.

One issue with using the *C. rupestris* critical load for all alpine area is that this particular sedge species is only present in four of the parks in the study (Glacier, Grand Teton, Rocky Mountain and Yellowstone NP's). These park units are all in the Rocky Mountain and Greater Yellowstone networks and represent only a portion of the ecosystem types in the alpine classification. For example, parks in the Sierra Nevada Network generally contain fewer alpine meadows, so the critical load of N for changes in alpine sedges may be less relevant in the alpine areas of those parks. National park units in Alaska were not considered in this study because the TDep model does not extend to this region. However, almost every park unit in Alaska contains *C. rupestris*. This critical load might be most relevant to the parks in Alaska and the Rocky Mountain range that contain *C. rupestris*, but a review of nitrogen enrichment studies has shown that closely related plant species respond similarly to N addition (Wooliver et al. 2016). The 14 alpine parks included in this study contained at least 50 species from the *Carex* genus, according to NPSpecies, and around 10 *Carex* species at each park are frequently found in alpine areas (Hurd et al. 1998; NPSpecies, 2020). This suggests that national park units with alpine areas that do not contain *C. rupestris* could be experiencing similar plant responses to N deposition.

The justification of using a single species response across all alpine areas is that other studies in low-nutrient, high stress environments have shown responses at similar levels of deposition. The critical load for this analysis ($3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) was based on changes to the cover of a single sedge species of the N-limited alpine environment of the Rocky Mountains. Another study in Rocky Mountain National Park estimated a similar but more sensitive critical load of N for protecting subalpine vegetation from changes to biodiversity, between $1.9\text{--}3.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ (McDonnell et al. 2014). This study suggested that subalpine vegetation in Rocky Mountain National Park has already changed by more than 10% due to N deposition over the past century and future climate change is expected to increase these changes. Other N-limited environments have been found to have similar critical loads for changes to their vegetation community (Townsend et al., 1996). Rao et al. (2010) found a CL of $3.2\text{--}3.9 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ for increased fire risk due to N deposition-influenced vegetation changes in the desert ecosystem of Joshua Tree National Park. Another study in northern Alberta, Canada, studied the effects of N deposition in a N-limited boreal bog and found a CL of $3 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ for negative impacts to the geochemical cycling in this ecosystem (Wieder et al. 2019).

One possible source of uncertainty in our critical load exceedance estimates is our choice of vegetation classes to include in the alpine vegetation raster. When the GAP dataset was compared to the Rocky Mountain National Park Vegetation Mapping Inventory (VMI), the overlap between the two alpine vegetation coverage maps (43%) was not enough to justify using the GAP alpine vegetation raster at a national scale. Therefore, we used the GAP all-alpine raster (97% overlap with the VMI) for our national assessment of alpine vegetation critical load exceedance. Much of this area is exposed rock and talus, from which it is expected that deposited N will dissolve and flow directly into surface water. These soil types are not likely to have much vegetation, which may result in an overestimation of the alpine vegetation area in exceedance. Alternatively, using the alpine vegetation GAP raster left a high chance of excluding vegetated area from our analysis and underestimating the risk to alpine vegetation. While our analysis was conservative in this aspect, future research would benefit from alpine vegetation rasters that used vegetation maps specific to each park, like the VMI.

Exceedance of critical load of N for soil nitrate leaching

Based on our analysis, there are no national parks with alpine area in exceedance of the critical load of N for soil nitrate leaching from alpine meadows ($10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$; Bowman et al. 2012). In 2002, Sequoia and Kings Canyon National Parks experienced N deposition at or above the critical load in 14% and 5.9% of their alpine area, respectively. However, by 2016, N deposition fell below the $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ CL in 100% of the alpine area in both parks.

Although none of the parks had alpine area in exceedance of this critical load, alpine ecosystems may still be at risk from current levels of N deposition. Areas of exposed rock and non-vegetated soil, which are often present in alpine areas, have a much lower ability to retain N than vegetated soils, leading to higher rates of N leaching (Williams et al., 1996). This leachate has the potential to travel downstream to alpine aquatic systems at lower elevation. Alpine lakes in the U.S. are historically N limited and are sensitive to excess N deposition. Additionally, a study by Poinsatte et al. (2017) found a critical load for N leaching at $3\text{--}6 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ in Mount Rainier compared to the N leaching critical load from Rocky Mountain evaluated here (Bowman et al., 2012). As this study has yet to be peer-reviewed and published, it is provided here as preliminary data that should be further assessed. Based on 2016 deposition, there are no exceedances within Mount Rainier, North Cascades, or Olympic National Parks at the high end of this range, while the low end is comparable to exceedances of the critical load for a shift in the alpine vegetation community (Figure 3).

Critical loads for nutrient enrichment and aquatic phytoplankton species composition changes range from $1.0\text{--}3.0 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$, which is well below the N deposition levels that most of the alpine areas in the parks are receiving (Baron, 2006; Baron et al., 2011; Nanus et al., 2012; Nanus et al., 2017; Saros et al., 2011; Sheibley et al., 2014; Williams et al., 2017b). Therefore, additional analyses should be taken into consideration when evaluating total risk to alpine environments.

Generalizing alpine responses

Alpine ecosystems in different parks may vary in their sensitivity to N deposition due to differences in physical environmental factors. One of these factors is that the elevation at which alpine areas start decrease with increasing latitude and are lower along the Pacific Coast mountain ranges than in interior mountain ranges. The soil type and the resulting retention of N deposition can vary along elevation gradients. Garten (2004) found that higher elevation sites tend to have less soil organic matter decomposition due to low C:N ratio in the soil, leading to more N release. Therefore, the highest elevations above tree line might have a lower ability to retain excess N deposition and have higher soil N leaching.

Another physical factor that could affect the ecosystem response to N deposition is the timing of snowmelt and the duration of the growing season. For example, the initial snowmelt at Mount Rainier National Park occurs around 17 days after the snowmelt at Rocky Mountain National Park, resulting in a shorter growing season for Mount Rainier (O'Leary III et al., 2019). The shorter growing season at Mount Rainier likely allows for less microbial uptake of N deposition, resulting in N leaching at even lower N deposition levels than at Rocky Mountain (Morse et al., 2015). However, the insulating effect of snowpack has also been shown to protect fine roots and microorganisms from freezing events, leading to less soil N loss (Filippa et al., 2009; Groffman et al., 2001).

Evaluating current deposition rates and exceedances in alpine ecosystems is complicated by uncertainties in total deposition rates due to the overestimation of snowpack contributions and model uncertainties at high elevation (Clow et al. 2015). The deposition model that we used for our analyses, TDep, has been documented to overestimate inorganic wet deposition, especially at high elevation sites (Williams et al., 2017a). In Rocky Mountain National Park, where the Bowman et al. (2012) study took place, the TDep model did slightly overestimate wet N deposition for the time periods of interest when compared to wet deposition directly measured by the National Trends Network (NTN; NADP, 2018). The measured total wet N deposition for the 2000–2002 and 2014–2016 averaging periods (3.09 and 3.07 kg-N ha⁻¹ yr⁻¹, respectively) were slightly lower than the estimated wet deposition values from TDep three-year averages (3.64 and 3.96 kg-N ha⁻¹ yr⁻¹, respectively) for the same time periods, in part due to ROMO having collectors in and near alpine areas. Another contribution to critical load exceedance uncertainty is the high proportion of deposition to alpine areas that falls as snowpack. A large proportion of snowmelt exits the alpine system as surface runoff without being absorbed into the soil, leading to an overestimation of the critical load exceedances in alpine areas (Farnes, 1971).

Management implications

Ten of the parks in this study are currently at risk of changes to their alpine vegetation community (Figure 3). We have the highest confidence of this risk in the four parks that contain the indicator species, *C. rupestris* used to establish the alpine vegetation CL (Glacier, Grand Teton, Rocky Mountain, and Yellowstone National Parks). Glacier and Yellowstone National Parks increased in mean total N deposition and area in exceedance from 2002–2016. Our confidence is high that other parks experiencing enhanced N deposition also are at risk of vegetation changes due to the similarities in response in other low nutrient systems. In addition to the total alpine area in exceedance for each park, the intensity of the exceedances could also be used by managers to identify the at-risk areas within the parks (Appendix D and E).

There are no parks from this study currently at risk of exceedance of the CL for alpine soil nitrate leaching within the Rocky Mountains (10 kg-N ha⁻¹ yr⁻¹; Bowman et al., 2012). When evaluating the CL developed by Poinsatte et al. (2017) within the Pacific Northwest (3 to 6 kg-N ha⁻¹ yr⁻¹), Glacier, Grand Teton, Kings Canyon, Rocky Mountain, and Sequoia National Parks exceed the critical load at the lower end of the range indicating the need for additional research on soil responses to deposition. In both cases, the CLs were based on N deposition to vegetated soils. The large areas of talus and exposed bedrock within the alpine areas of the parks are likely to have lower thresholds for retaining excess N. As N leaches to the downstream aquatic ecosystems, these systems become at risk of exceeding critical loads for nutrient enrichment, potentially leading to algal blooms and shifts in diatom communities (1–3 kg-N ha⁻¹ yr⁻¹; Saros 2005, Baron 2006, Nanus et al. 2017, Williams et al. 2017b). The combination of N and S deposition can lead to acidifying effects on lakes and streams making waters unhealthy for fish and insects (Baron et al. 2011). Therefore, the ten parks that are at risk for alpine vegetation changes could also be at risk of nitrate leaching to their alpine aquatic ecosystems.

Continuous N deposition to at-risk national parks may negatively affect the ecosystem services of the alpine ecosystems in the parks. As nitrophilic species like *C. rupestris* increase, more rare species decline as a result of higher competition, leading to an overall loss of biodiversity (Bowman et al., 2012; Suding et al., 2005). Above tree line, this could mean less variety of flowering alpine plants, a park resource enjoyed by countless visitors and photographers. Additionally, the cascading effects of these changes to the vegetation community could impact pollinators, birds, and other wildlife in the alpine ecosystem.

Further study of multiple stressors on the alpine-subalpine ecosystem, including visitor use impacts, will help determine where changes are most likely. Disturbance from foot traffic could accentuate the impacts of N deposition in the alpine areas with exceedances of the alpine vegetation CL, so trails through the alpine are likely to be more at risk (Monz, 2002). Additionally, off-trail use is likely to remove vegetation and thus root systems that take up deposited N, and thus lead to an increase in N leaching. Portions of the trail systems that intersect with the exceedance areas could be important places to focus monitoring and active management.

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Appendix A: Ecoregion III used to clip alpine raster

Table A1. List of Ecoregions (level III) used to create the alpine coverage map. Included is the lowest elevation at which alpine area exists within the ecoregion, the final area of alpine after the coverage map was clipped to these elevations, and the area and percent of area lost after the clipping.

Ecoregion III Name	Elevation of alpine (m)	Final Alpine Area (km ²)	Area Lost (km ²)	% of Alpine Area Lost
Arizona/New Mexico Mountains	3300	4	5	54
Blue Mountains	2100	180	193	52
Canadian Rockies	1900	1064	23	2
Cascades	1500	629	21	3
Central Basin and Range	2300	488	13	3
Coast Range	1400	0	1	76
Colorado Plateaus	2800	1	59	99
Eastern Cascades Slopes and Foothills	1600	26	8	23
Idaho Batholith	2300	473	127	21
Klamath Mountains/California High North Coast Range	2000	9	6	38
Middle Rockies	2500	9563	587	6
North Cascades	1400	1357	26	2
Northeastern Highlands	1350	1	5	81
Northern Rockies	1700	5	174	97
Sierra Nevada	2300	5861	302	5
Southern Rockies	3100	8100	566	7
Wasatch and Uinta Mountains	2700	1656	94	5
Total	–	29418	2500	8

Appendix B: Comparison of the alpine rasters within Rocky Mountain National Park

This is a comparison of the NPS vegetation class polygons with the USGS GAP rasters for identifying alpine area in Rocky Mountain National Park (ROMO; Table B1). The ‘NPS Only’ and ‘USGS Only’ columns show the percentage of the park’s geography classified as an alpine ecosystem by only one of these datasets. This analysis groups the NPS vegetation class polygons into 133.9 km² for All Alpine (vegetated and non-vegetated alpine area) and 121.8 km² for Alpine Vegetation (vegetated alpine area only) classes, and groups the USGS GAP rasters into 148.6 km² for Alpine Vegetation and 355.9 km² for All Alpine (Table B2). The Overlap column shows the percentage of the park’s geography classified as alpine by both datasets. When including both the non-overlapping and overlapping alpine areas classified by both datasets, ROMO contains 366.9 km² of All Alpine ecosystems and 218.7 km² of Alpine Vegetation. A map of the comparison is shown in Figure B1.

Table B1. Vegetation classes used by Rocky Mountain National Park (ROMO) to describe ecosystems classified in this analysis as alpine ecosystems. The column ‘Class description’ identifies the different vegetation communities or geologic features used for creating the herbaceous polygon layers for ROMO. The column ‘Type’ indicates whether the class contains vegetated area or non-vegetated rocky areas. Data from Salas et al. (2005).

Vegetation Class #	Class Description	Type
1	Herbaceous Upland Alpine > 9600 ft	Vegetated
2	Herbaceous Upland Alpine Fellfield	Vegetated
10	Rock (Alpine-Upper Subalpine)	Non-vegetated
49	Cliff Face - Bare Soil / Rock	Non-vegetated
9	Glacier	Non-vegetated
7	Herbaceous Wetland Subalpine / Alpine - Alpine Meadow	Vegetated
13	Shrub Upland Alpine	Vegetated
46	Talus	Non-vegetated
120	Shrub Riparian Cross Zone > 9600 ft	Vegetated

Table B2. Comparison of the NPS vegetation class polygons with the USGS GAP rasters for identifying alpine area in Rocky Mountain National Park (ROMO).

Vegetation Type	NPS Only	USGS Only	Overlap	NPS Area Captured by USGS
Alpine Vegetation	32.1%	44.3%	23.6%	42.5%
All Alpine	3.0%	63.5%	33.5%	91.8%

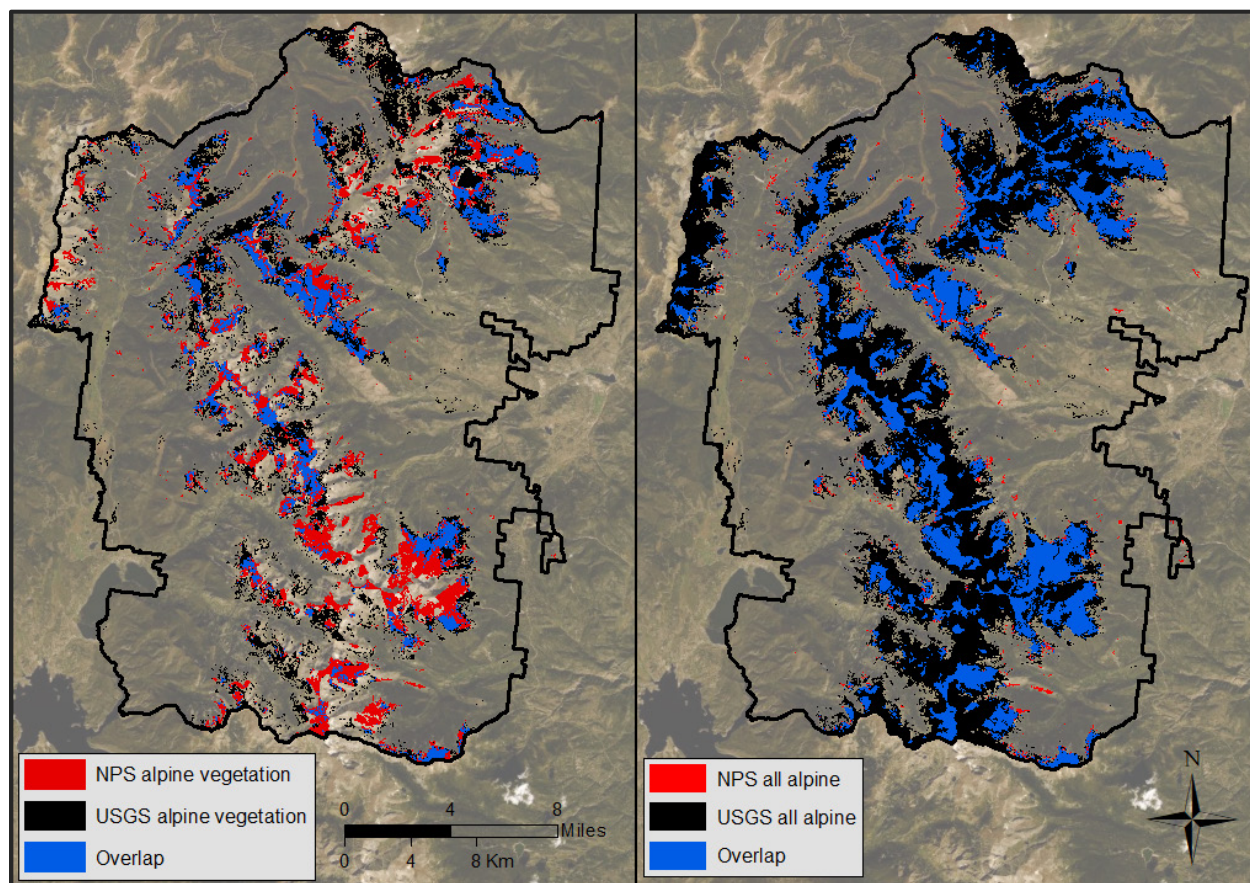


Figure B1. Comparison between the National Park Service alpine coverage (red) with the GAP alpine coverage (black) at Rocky Mountain National Park. The alpine vegetation coverages are shown on the left and the all alpine coverages are shown on the right.

Appendix C: Alpine critical load exceedances summarized by Inventory & Monitoring Network

Table C1. Percent of alpine area in exceedance of the alpine vegetation CL, summarized by Inventory & Monitoring (I&M) Network.

I & M Network	Below CL in 2002 (%)	At CL in 2002 (%)	Above CL in 2002 (%)	Below CL in 2016 (%)	At CL in 2016 (%)	Above CL in 2016 (%)	Change in Above CL from 2002 to 2016 (%)
Greater Yellowstone	0.1	8.3	91.6	0.0	5.5	94.5	2.9
Klamath	0.0	0.0	100.0	0.0	12.2	87.8	-12.2
North Coast and Cascades	9.4	47.9	42.7	17.0	51.3	31.7	-10.9
Rocky Mountain	0.0	0.3	99.7	0.0	0.0	100.0	0.3
Sierra Nevada	0.0	0.0	100.0	0.0	0.0	100.0	0.0

Appendix D: Park-specific alpine vegetation critical load exceedance maps

Maps of alpine vegetation critical load exceedance are shown in Figures D1–D6.

Rocky Mountain National Park

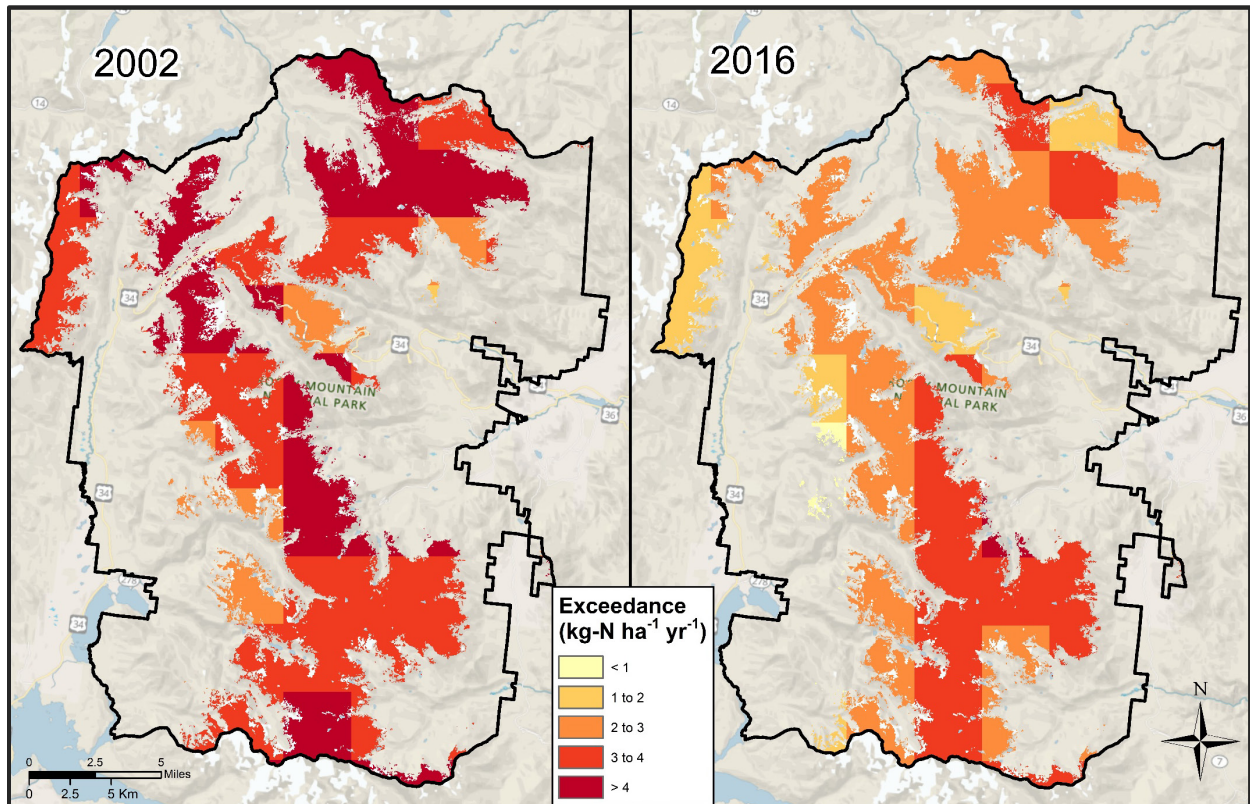


Figure D1. Maps of the intensity of the exceedance of the critical load of N for a shift in the alpine vegetation community at Rocky Mountain National Park in 2002 and 2016 (TDep total N).

Olympic National Park

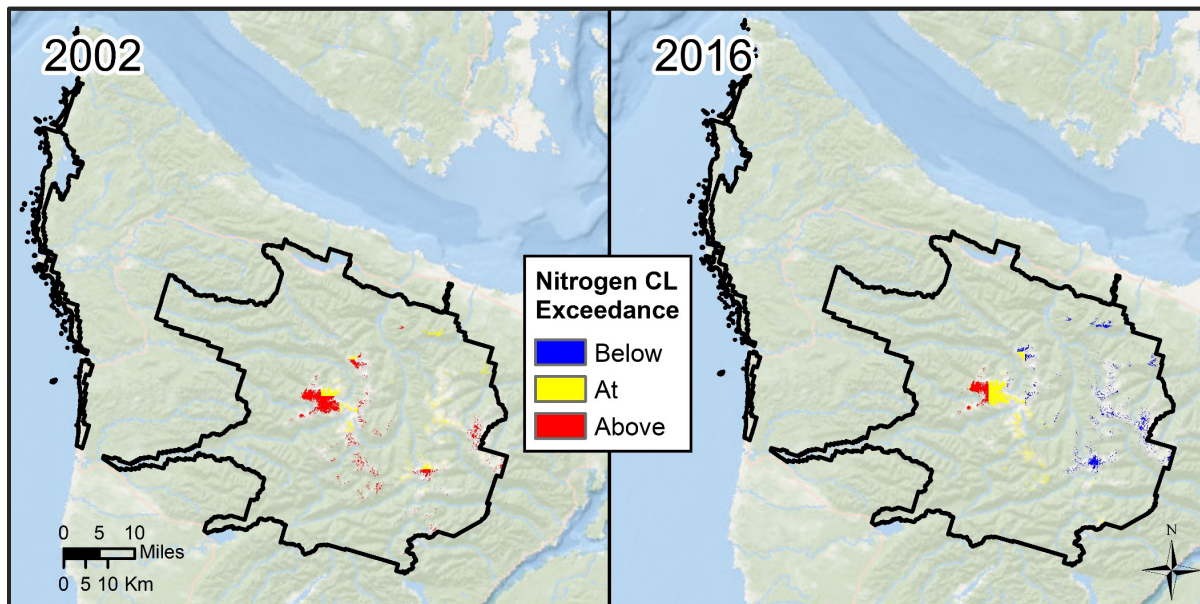


Figure D2. Maps of the exceedance of the critical load of N for a shift in the alpine vegetation community at Olympic National Park in 2002 and 2016. Alpine area labeled as below (blue; $<-0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), at (yellow; $-0.5 \text{ to } 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), or above (red; $>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) the vegetation CL (TDep total N).

Mount Rainier National Park

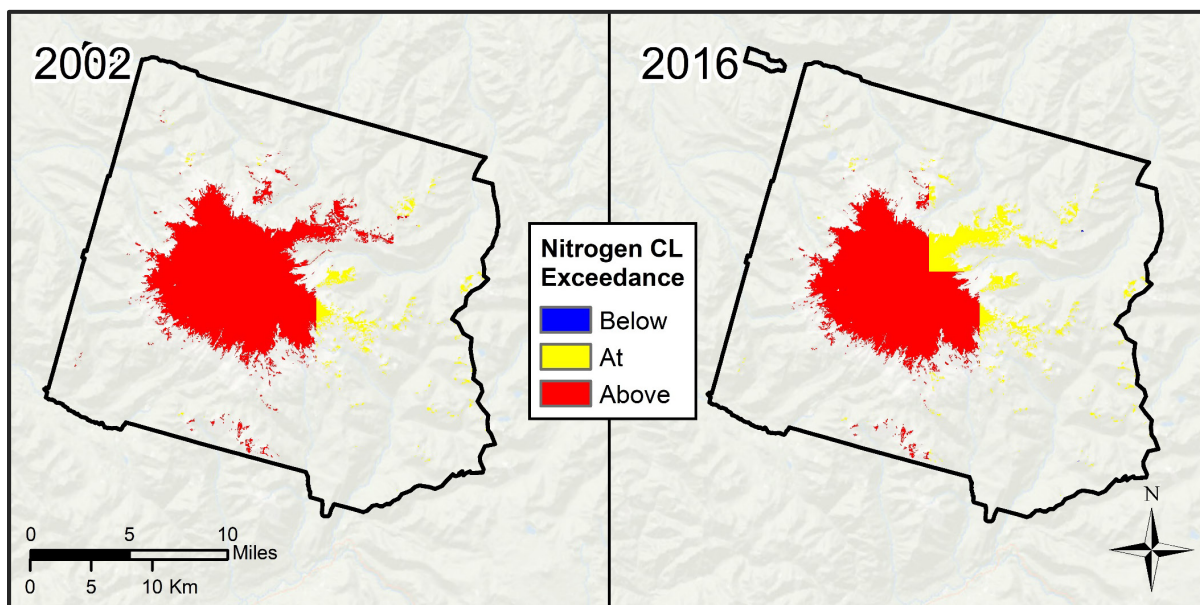


Figure D3. Maps of the exceedance of the critical load of N for a shift in the alpine vegetation community at Mount Rainier National Park in 2002 and 2016. Alpine area labeled as below (blue; $<-0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), at (yellow; $-0.5 \text{ to } 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), or above (red; $>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) the vegetation CL (TDep total N).

North Cascades National Park, Lake Chelan and Ross Lake NRAs

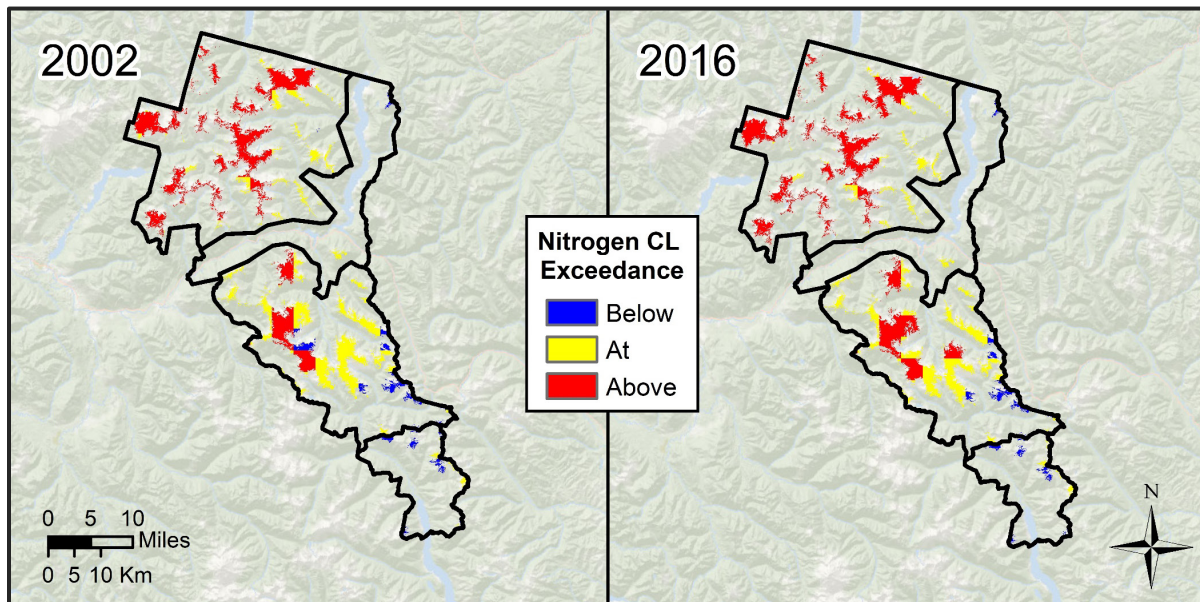


Figure D4. Maps of the exceedance of the critical load of N for a shift in the alpine vegetation community at North Cascades National Park (with Lake Chelan and Ross Lake National Recreation Areas) in 2002 and 2016. Alpine area labeled as below (blue; $<0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), at (yellow; $-0.5 \text{ to } 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), or above (red; $>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) the vegetation CL (TDep total N).

Yellowstone National Park

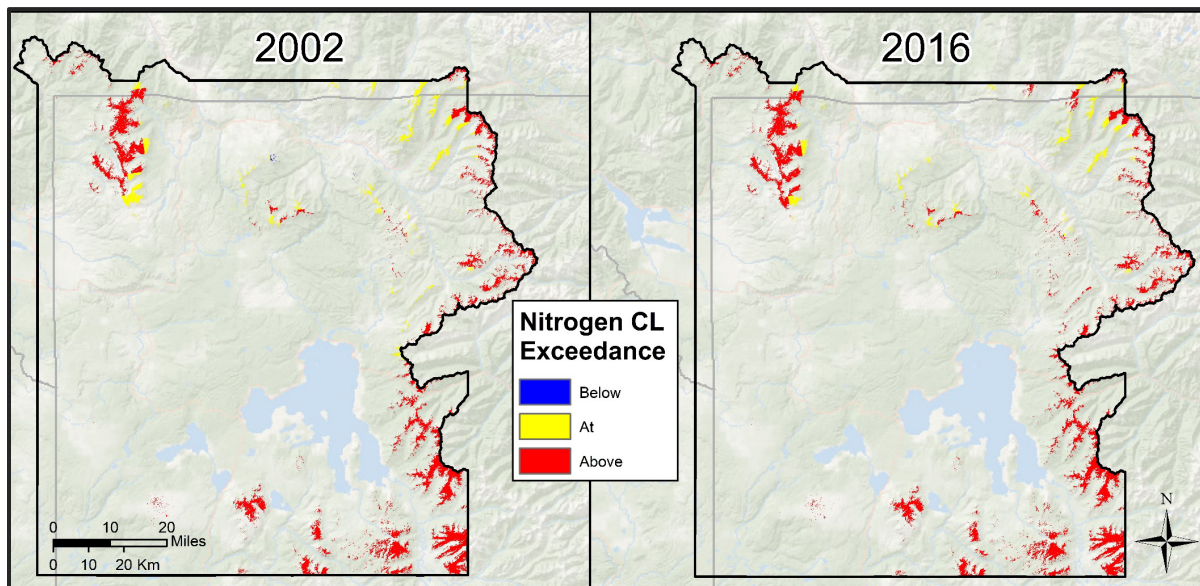


Figure D5. Maps of the exceedance of the critical load of N for a shift in the alpine vegetation community at Yellowstone National Park in 2002 and 2016. Alpine area labeled as below (blue; $<0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), at (yellow; $-0.5 \text{ to } 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), or above (red; $>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) the vegetation CL (TDep total N).

Lassen Volcanic National Park

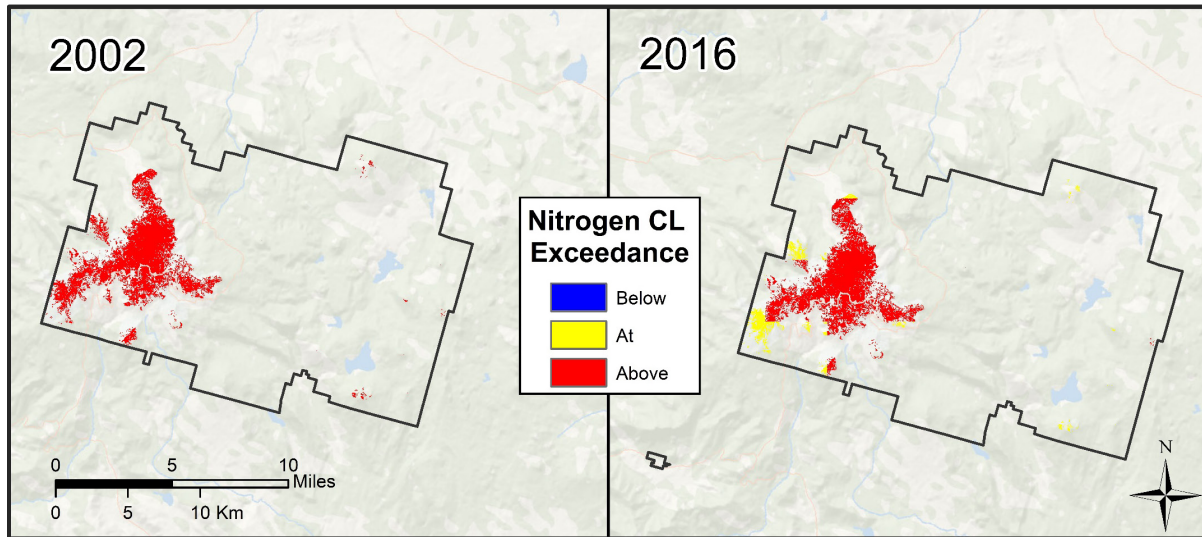


Figure D6. Maps of the exceedance of the critical load of N for a shift in the alpine vegetation community at Lassen Volcanic National Park in 2002 and 2016. Alpine area labeled as below (blue; $<-0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), at (yellow; $-0.5 \text{ to } 0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$), or above (red; $>0.5 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) the vegetation CL (TDep total N).

Appendix E: Exceedance intensity by park

Table E1. Range of exceedances of the alpine vegetation critical load within the alpine area of national parks for 2002 and 2016.

Park Name	Alpine area (km ²)	Min – Max Exceedance in 2002 (kg ha ⁻¹ yr ⁻¹)	Min – Max Exceedance in 2016 (kg ha ⁻¹ yr ⁻¹)	Change in Max Exceedance (kg ha ⁻¹ yr ⁻¹)
Glacier National Park	597	-0.5 – 4.1	0.1 – 4.4	0.2
Grand Teton National Park	212	1.1 – 5.5	0.4 – 4.6	-0.9
Great Sand Dunes National Park and Preserve	33	0.7 – 3.2	0.7 – 2.9	-0.3
Kings Canyon National Park	1052	2.4 – 7.7	2.0 – 6.4	-1.3
Lake Chelan National Recreation Area	13	-1.0 – -0.2	-0.9 – -0.2	0.0
Lassen Volcanic National Park	32	0.7 – 2.9	0.1 – 0.9	-2.0
Mount Rainier National Park	144	0.0 – 1.9	-0.5 – 1.6	-0.3
North Cascades National Park	319	-0.9 – 1.2	-0.8 – 1.6	0.4
Olympic National Park	68	-0.4 – 1.6	-1.3 – 0.9	-0.7
Rocky Mountain National Park	354	1.6 – 6.5	0.3 – 4.0	-2.4
Ross Lake National Recreation Area	4	-0.8 – 0.7	-0.7 – 0.8	0.1
Sequoia National Park	611	3.4 – 8.2	2.2 – 6.3	-1.9
Yellowstone National Park	329	-0.7 – 2.9	-0.5 – 2.8	0.0
Yosemite National Park	903	1.6 – 3.7	0.8 – 3.1	-0.6

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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