Critical Loads of Atmospheric Nitrogen and Sulfur Deposition for Protection of Sensitive Aquatic and Terrestrial Resources in the Intermountain Region of the USDA Forest Service

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EXECUTIVE SUMMARY

Human-caused nitrogen (N) and sulfur (S) deposition have widespread and important acidifying and fertilizing effects on natural ecosystems in the United States (Vitousek et al. 1997). Acids in N and S deposition flush soil nutrients, including calcium and magnesium, out of soils and increase the acidity of soil and drainage water. The structure of the biological community can also change in response to fertilization effects from N deposition, including effects on tree growth and lifespan, lichen populations, fish and other aquatic species.

The critical load (CL) specifies the levels of pollutant deposition below which significant ecological harm to a specific ecosystem is not expected (Nilsson and Grennfelt 1988). The CL concept has been applied to protect sensitive resources including some lakes, streams, lichens, plants, and forest soils from N and S air pollutants. For many years, critical loads have been used in Europe to inform land management and policy decisions. North American land managers and policy makers are following this lead, using critical loads to inform key decisions. This report summarizes CLs and areas where they are exceeded by current deposition to lands managed by the U.S. Forest Service (USFS) in the Intermountain Region.

This report is specifically developed to provide information to the process of making revisions to forest management plans. It may also be useful in evaluating projects and informing the public of the status of the land under USFS management. Under the National Forest Management Act, the USFS is required "to provide for the sustainability of ecosystems and resources while meeting the need for forest restoration and conservation, watershed protection, and species diversity and conservation" (CFR Title 36: §219.1b).

Critical Loads are reported here for both terrestrial and aquatic environments, which are broadly connected even though they are calculated differently. Critical loads related to four types of chemical and biological impacts were evaluated:

1. Surface water acidification
2. Surface water eutrophication
3. Lichen species richness and forage lichen abundance
4. Tree growth and survival

This report maps the available CLs of N deposition, along with associated exceedances of these CLs, providing the baseline CLs analysis required under the 2012 Planning Rule for forest plan assessments. This report and associated geospatial analyses may be used by forests to inform land management decisions where the effects of atmospheric N and S deposition may be relevant. Deposition of S was incorporated into the CLs for surface water acidification and tree growth and survival, but was not considered for the other two types of CLs listed above.

Substantial portions of the Intermountain Region are exposed to levels of N deposition that exceed CLs, which may have caused adverse impacts. Critical loads protective of surface water acidification were in exceedance at some locations on three-quarters (n = 9) of the national forests (NFs) of the Intermountain Region. These locations of exceedance are expected to be at increased risk for reductions in abundance and diversity of aquatic species caused by atmospheric N and S deposition. Streams and lakes within portions of all NFs (n = 12) in the Intermountain Region are likely experiencing the onset of eutrophication impacts, which can alter competitive interactions among primary producers and have cascading effects at higher levels of the food web. Effects on lichen species richness and forage lichen abundance are expected within large portions of all (n = 12) NFs of the region. Reduced diversity and occurrence of lichen species, particularly forage lichens, can lead to detrimental impacts on lifeforms such as large mammals, birds, rodents, lagomorphs, and invertebrates (Geiser et al. In preparation). Additionally, changes in growth and probability of survival of several tree species commonly found within the Intermountain Region have been associated with N deposition at reported levels within some portions of all (n = 12) NFs of the region. Higher N deposition is expected to increase growth for several tree species. This would likely cause a change in the character of forest communities, including those found in wilderness areas. Growth and probability of survival of other species are expected to decrease with increasing N deposition, potentially contributing to a change in forest composition among other ecological effects. Working with regulators to reduce emissions and deposition of N and S will likely improve the health of both aquatic and terrestrial ecosystems in the region.

1 BACKGROUND

1.1 Pollutants of Concern

Human-caused air pollution causes elevated atmospheric sulfur (S) and nitrogen (N) deposition which can have widespread and important acidifying and fertilizing effects on natural ecosystems in the United States (U.S. EPA 2008). Anthropogenic air pollution largely originates from coal-fired electrical power generation, other industrial air pollution sources, motor vehicles, and agriculture. The gases and particles found in emissions from these sources can travel several hundred miles before they wash out in the rain or snow or attach to a surface such as a tree leaf or lake. Because of this long-distance transport, even relatively remote areas of the U.S. can be exposed to air pollution, and portions of nearly all National Forests and Grasslands administered by the USFS are among these areas (McDonnell and Sullivan 2014).

Since the 1970 Clean Air Act, emissions from stationary sources of S and N oxides have decreased across much of the United States (U.S. EPA 2016). This has resulted in corresponding declines in the deposition of S and total inorganic N in precipitation (Lehmann and Gay 2011, Du et al. 2014). However, compared to natural background levels, S and N deposition remain elevated throughout most of the eastern United States and in localized parts of the west (Pardo et al. 2011). Emissions and deposition of N may be increasing in some western localities with intensification of agriculture, increased size and frequency of wildland fires, energy development, increased wind-driven dust due to warmer and drier conditions, and international long range pollutant transport, especially from Canada, Mexico and Asia (Neff et al. 2008, Zhang et al. 2008, Weinhold 2012, Ellis et al. 2015, Li et al. 2016, Lu et al. 2016).

1.2 Ecosystem Effects of Air Pollution

Acidic atmospheric deposition contains a mixture of N and S compounds. Effects can be both acidifying and fertilizing (Sullivan and Jenkins 2014). The acids acidify groundwater and flush nutrients, including calcium and magnesium out of soils into drainage water. Increased acidity of soil and surface water can harm plant roots, fish, and other organisms (U.S. EPA 2008). The various N compounds in acidic deposition can also serve as nutrients, which are taken up by plant roots, stored in biomass, released by decay, and cycled into new growth. When N is in short supply, it is generally stored within the ecosystem in soil, vegetation, and microbial biomass. However, if N becomes more available, excess N leaches into groundwater and moves to streams and lakes where it acts as a fertilizer, increasing the growth of algae (Baron 2006, Greaver et al. 2012). Efficient N uptake by plants becomes less important under high N supply, and this can cause a decrease in fine root biomass, resulting in increased sensitivity to drought and decreased diversity of mycorrhizal fungi (Greaver et al. 2012). In response to N accumulation in the ecosystem, the structure of the biological community can change. Species that use N to stimulate growth may out-compete species that thrive in a low-N environment (Bobbink et al. 2010). Rare species and species adapted to low N availability may decrease in abundance or be lost from the ecosystem (Allen and Geiser 2011, Bowman et al. 2011, Clark et al. 2013, Sullivan and Jenkins 2014, Geiser et al. 2019).

High elevation areas, which often include protected wilderness areas, can be particularly sensitive to acidification and nutrient enrichment effects caused by atmospheric S and N deposition in part because soils in these areas are either very thin or non-existent. Furthermore, many lichen species occur above the soil on tree stems and within the canopy. Because of direct exposure to N and S deposition, lichens are among the most sensitive terrestrial species to adverse impacts from air pollution. Soil organic matter and base cation nutrients, such as calcium and magnesium, can protect plants and aquatic biota from some of the effects of atmospheric N and S deposition.

1.3 Critical Loads and Forest Planning

The critical load (CL) specifies the levels of pollutant deposition below which significant ecological harm to a specific ecosystem is not expected (Nilsson and Grennfelt 1988). Critical loads are used to simplify complex scientific information and effectively communicate ecosystem air pollution thresholds to federal land managers, policy makers, and the public (Burns et al. 2008, Burns et al. 2011, Blett et al. 2014). The CL concept has been applied to S and N air pollutants for the protection of sensitive resources, including lakes, streams, lichens, plants, and forest soils (Sullivan 2017). Critical loads have been used in Europe over many years and are increasingly incorporated in North America to assess ecosystem or resource risk from air pollutants for land management, policy, and decision making.

Land managers in the U.S. Forest Service (USFS) are confronted with questions regarding how to manage or remediate natural resources impacted by acid and nutrient deposition. To inform resource managers regarding possible air pollutant impacts, it is important to 1) identify what are the thresholds of concern where impacts to natural resources may be unacceptable, 2) describe the linkages between deposition and biological impacts, 3) locate areas of concern for possible impacts to natural resources, and 4) develop remediation and protection strategies.

As part of the assessment required for land management plans and revisions and sometimes as part of permitting or NEPA analyses, air specialists compare deposition to CLs to determine where CL exceedance may occur. Areas where deposition is greater than the CL are considered to be in exceedance. This analysis, coupled with trends in emissions or projected increased emissions from large projects, can help Forest Service managers to develop land management plans and understand where resources are vulnerable to possible impacts from new emissions sources. Quantifying the ecological harm that can be caused by different levels of S and N deposition can help land managers anticipate ecological effects due to new pollution sources, plan mitigation strategies, and determine if air quality is sufficient to protect ecosystem integrity and air-pollution-sensitive natural resources (Geiser et al. In review).

Since permitting of major air pollution sources falls under regulatory agency control, Forest Service managers in the region have little direct influence over atmospheric deposition beyond projects carried out or permitted by the Forest Service. However, there may be options to alter nutrient supply, protect or improve soil buffering capacity, or otherwise improve the health of aquatic and terrestrial species. Organisms vary greatly in their sensitivity to N and S deposition and some CLs vary by species within a forest. As part of CL assessments, land managers consider which CLs are best suited to guide protection of resources under their management.

2 OBJECTIVES

This report offers considerations for federal land managers regarding the use of scientific data developed through CL investigations. These considerations are illustrated through the example of recently completed reports, journal articles, and databases that have calculated CLs of atmospheric S and/or N in the Intermountain Region of the USFS. This report maps these CLs, and associated exceedances, and discusses aspects of these investigations with an aim of informing Forest plan assessments and FS staff who make forest management decisions related to ecosystem elements that are expected to be affected by N and S deposition.

This report primarily focuses on CLs of N deposition, and exceedances thereof, to protect against acidification and nutrient enrichment effects on specified biological resources of the National Forests and wilderness areas of the Intermountain Region. The effect of ambient S deposition, which has acidifying effects and relatively high deposition rates in portions of the Intermountain Region, is incorporated into the CLs of N to protect against surface water acidification and tree growth/survival.

To assess overall ecosystem effects and risk, CLs are reported for both terrestrial and aquatic environments, which are broadly connected even though they are calculated differently. Critical loads related to four types of biological impacts were evaluated:

1. Surface water acidification
2. Surface water eutrophication
3. Lichen species richness and forage lichen abundance
4. Tree growth and survival

The most current state of science was used to estimate and map these CLs and CL exceedances, which represent the risk and extent of effects, respectively. A qualitative assessment of the uncertainty of these CLs is also provided along with an indication of which CLs are most useful to consider with respect to management on each forest.

3 CRITICAL LOAD DATABASES

This section includes background information regarding the four types of biological impacts that were evaluated in this study. Descriptions of the primary data sources used to map the CLs included in this report are also included here.

3.1 Surface Water Acidification

Surface water acid neutralizing capacity (ANC) reflects the ability of a watershed to neutralize acidic inputs. As the rate of acidic deposition increases, ANC often decreases, particularly in watersheds with shallow or sparse soils which offer little buffering capacity. Various ANC thresholds are associated with different biological effects on different aquatic species (U.S. EPA 2009). There is concern for lakes and streams with ANC below 50 μeq L^{-1}. This is because that level is recognized as providing general ecosystem protection and because these surface waters are often susceptible to lowering ANC below zero during rainfall or snowmelt events (Baldigo et al. 2007, Robison et al. 2013), which can result in increased acidity and mobilization from soil to drainage water of inorganic and potentially toxic aluminum (Al_i). At ANC concentrations less than about 20 μeq L^{-1}, water acidity and/or Al_i concentration can be lethal to many aquatic species (U.S. EPA 2009).

Water quality data throughout the U.S. have been compiled for the purposes of calculating CLs for surface water acidification by Lynch et al. (2019). This database uses the Steady State Water Chemistry model (Henriksen and Posch 2001) to determine the maximum amount of acidic deposition that will allow for surface water ANC to remain above a preselected threshold value as long as the environmental conditions specified in the model remain constant over time.

Surface water acidification CLs generated using steady-state mass balance models are uncertain. They are based on the assumption that the ecosystem has reached a balance point (or equilibrium). This condition may not be reached within a management time frame. It may take decades to centuries before the water chemistry comes into equilibrium with the deposition load. Uncertainty also exists for each of the terms of the Steady-State Water Chemistry model. Uncertainties are primarily related to the estimation of base cation (e.g., calcium and magnesium) weathering and the degree to which the available water quality data match the long-term condition that one seeks to protect.

3.2 Surface Water Eutrophication

High rates of N deposition have been shown to affect the nutrient status and function of high-elevation aquatic ecosystems in the western United States (Baron 2006). Aquatic ecosystems in mountain regions can be especially sensitive to nutrient enrichment effects due to steep topography, shallow rocky soils, sparse vegetation growth, short growing season, and rapid release of pollutants in snowmelt runoff during the spring season (Nanus et al. 2012, Sullivan 2017). Such effects have included elevated surface water NO_3^- concentration and associated increases in algal abundance (Nanus et al. 2012).

Algae can respond rapidly to favorable environmental changes because of their diversity and short generation times. Algae-based CLs for aquatic eutrophication are used as early warning indicators of ecosystem change by resource managers, largely because algal species are some of the first organisms to respond. Using the most sensitive known group of organisms, such as algae, provides broad protection across both terrestrial and aquatic ecosystems (U.S. EPA 2009).

Estimates of CLs of wet N deposition to protect against nutrient enrichment in aquatic ecosystems were developed by Nanus et al. (2012) for a portion of the Intermountain Region using statistical relationships between surface water nitrate measurements and watershed characteristics, including the annual rate of wet N deposition received by the watershed. Several studies have indicated that the algal species *Asterionella formosa* can be used as a sensitive indicator of N enrichment to surface waters (Saros et al. 2005, Saros et al. 2011, Slemmons et al. 2015). The Nanus et al. (2012) study defined a surface water nitrate threshold by quantifying the growth rate of *A. formosa* to experimental N addition. The maximum growth rate for *A. formosa* occurred at a nitrate concentration of 0.5 μeq L^{-1}. Nanus et al. (2012) concluded that 0.5 μeq L^{-1} could be considered the surface water nitrate concentration that caused a substantial change in this highly sensitive species. Therefore, 0.5 μeq L^{-1} was judged to be the nitrate threshold indicative of the onset of surface water eutrophication.

A later study by Nanus et al. (2017) followed a similar approach as the 2012 study, but the 2017 study developed CLs of total (wet + dry) N deposition rather than only wet N deposition and focused on the Greater Yellowstone Ecosystem. Because of the relatively narrow scope of this specialized study, these data were only available for the Bridger-Teton NF. Calculations by Nanus et al. (2017) suggested that lakes begin showing an increase in nitrate concentration in response to wet + dry N deposition at a deposition loading of about 3.0 kg N ha^{-1} yr^{-1}. The CL estimates generated by Nanus et al. (2017) were sensitive to differences in watershed characteristics, modeled deposition estimates, and changes in the selected nitrate threshold value at which ecological effects are thought to occur.

Generation of CL and exceedance estimates for protecting against water eutrophication, such as those provided by Nanus et al. (2012), were found to be sensitive to the subjective selection of a NO_3^- concentration threshold. Uncertainty in the NO_3^- threshold value extends or propagates directly to estimates of CLs; uncertainty in the N deposition value affects both the estimated CLs and the exceedances. Uncertainty in estimating total N deposition is especially important in complex terrain where land cover and deposition change dramatically over short distances (McDonnell et al. 2010). This analysis by Nanus et al. (2017) only included lake nitrate concentrations that were measured during the late-growing season; additional data would be needed to capture effects of seasonality.

Estimation of low CL suggests an increased likelihood of resource sensitivity to adverse ecological impact, rather than exact levels of sensitivity. Exceedance suggests an increased likelihood of adverse ecological impact at the estimated levels of atmospheric deposition that occur, or could occur, in the future. The results summarized here should not be taken to represent precise risk.

3.3 Lichen Species Richness and Abundance

Lichens consist of one or more fungi (mycobiont) in symbiosis with algal and/or cyanobacterial photobiont(s). Epiphytic macrolichens (non-crustose lichens growing on trees and shrubs) are sensitive to acidic and fertilizing air pollutants containing N and S. This sensitivity is mostly due to the exposed location of lichens in the canopy, dependence on aerial sources of nutrition, nutritional balance among symbionts, and aspects of their unique physiology and morphology (Geiser et al. In review). The lack of structural barriers in lichens, such as guard cells, root stele, or epidermal wax, that are found in many vascular plants reduce lichen control of contaminant entry (Nash 2008).

Some lichens that grow in forest ecosystems are highly sensitive to air-pollution. Thus, CLs to protect lichens can broadly protect other forest resources as well. The USFS Forest Inventory and Analysis and Air Resource Management programs have used nationally standardized survey protocols to monitor the presence and abundance of lichens across U.S. forests for more than two decades (USFS 2011). Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services. These include provision of important food and habitat resources for many wildlife species (Geiser et al. In review). Protecting good air quality and continued improvements in air quality will contribute to future climate resilience of lichens and the surrounding biota.

Geiser et al. (2019) used statistical methods to develop relationships between N and S deposition and epiphytic macrolichen response metrics including species richness and abundance of various functional groups. National-scale lichen survey data available through the USFS Forest Inventory and Analysis program were used to define the level of deposition associated with 20, 50, and 80% declines in lichen species richness (number of species present) and abundance. These thresholds were considered to represent low, moderate, and high ecological risk from N and S deposition. Critical loads were defined at the low risk cut-off of 20% reduction in total species richness, sensitive species richness, forage lichen abundance, and cyanolichen abundance (**Table** 3.1).

Table 3.1. Critical loads for various lichen response metrics as determined by Geiser et al. (2019).

Lichen Response Metric	Critical Load of N Deposition (kg N ha^{-1} yr^{-1})	Critical Load of S Deposition (kg S ha^{-1} yr^{-1})
Total species richness	3.5	6.0
Sensitive species richness	3.1	2.5
Forage lichen abundance	2.0	2.6
Cyanolichen abundance	1.3	2.3

Geiser et al. (2019) addressed the issue of uncertainty in their estimation of CLs and exceedances for lichens across the United States. As they pointed out, broad regional empirical studies do not necessarily reflect cause and effect. Interactions between and among pollutants, the lack of high S deposition sites in the West, and uncertainties in deposition estimates, species recovery rates, and species capture are main sources of uncertainty in lichen CL and risk analyses. Nevertheless, the analyses reported by Geiser et al. (2019) were based on a very large data set (n=8855 plots), representing 362 lichen species, and provide strong starting points for understanding ecological risk.

The lichen CLs developed by Geiser et al. (2019) were based on deposition data from the Community Multi-scale Air Quality Model (CMAQ), which is believed to underestimate wet deposition (Zhang et al. 2018) leading to lower CLs and therefore higher levels of exceedance. To be consistent among all the CL types included in this report, exceedance of the lichen CLs, along with the others, were calculated using deposition estimates from the Total Deposition (TDep) assessment of Schwede and Lear (2014). Given this, the magnitude and extent of lichen CL exceedance shown in this report may be conservative (estimating higher exceedances), nonetheless, this analysis provides a good estimate of relative risk to lichen.

3.4 Tree Growth and Survival

Nitrogen inputs can have a fertilizing effect on trees. This could be perceived as beneficial for some species. However, elevated N inputs can also lead to detrimental effects on some species (Nihlgård 1985). These can be associated with soil acidification, development of plant nutrient imbalances, declines in plant health, changes in species composition, increases in invasive species, and/or increased susceptibility to secondary stresses such as freezing, drought, and insect outbreaks (Galloway et al. 2003, U.S. EPA 2009, McNulty and Boggs 2010, Pardo et al. 2011).

This analysis reports the variability of tree growth and survival for 71 species as functions of N and S deposition, among other variables, across the conterminous United States described by Horn et al. (2018). They analyzed nearly 1.5 million trees from forest plots inventoried by the Forest Inventory and Analysis program between 2000 and 2016. Results suggested that the growth and/or survival of the vast majority of tree species in the analysis were significantly affected by atmospheric N or S deposition, either positively or negatively, or some more complex reflection of both. Relationships between tree response (growth or survival) and deposition were described as increasing, decreasing, threshold, or flat (**Figure** 3-1).

While tree species responses to N deposition varied, the growth and/or probability of survival of some species declined at even very low levels of N input. Other species did not exhibit a threshold at which negative effects occurred, or were unaffected by increased availability of this frequently limiting nutrient.

Although air temperature, precipitation, tree size, and competition were included as potential predictor variables (in addition to N and S deposition), the authors of the Horn et al.

(2018) study noted that uncertainty existed due to other factors that influence growth and/or survival that were not considered in the analysis. Such confounding factors might include ozone exposure, seasonal drought, insect infestation, disease, or other environmental or climatological factor(s).

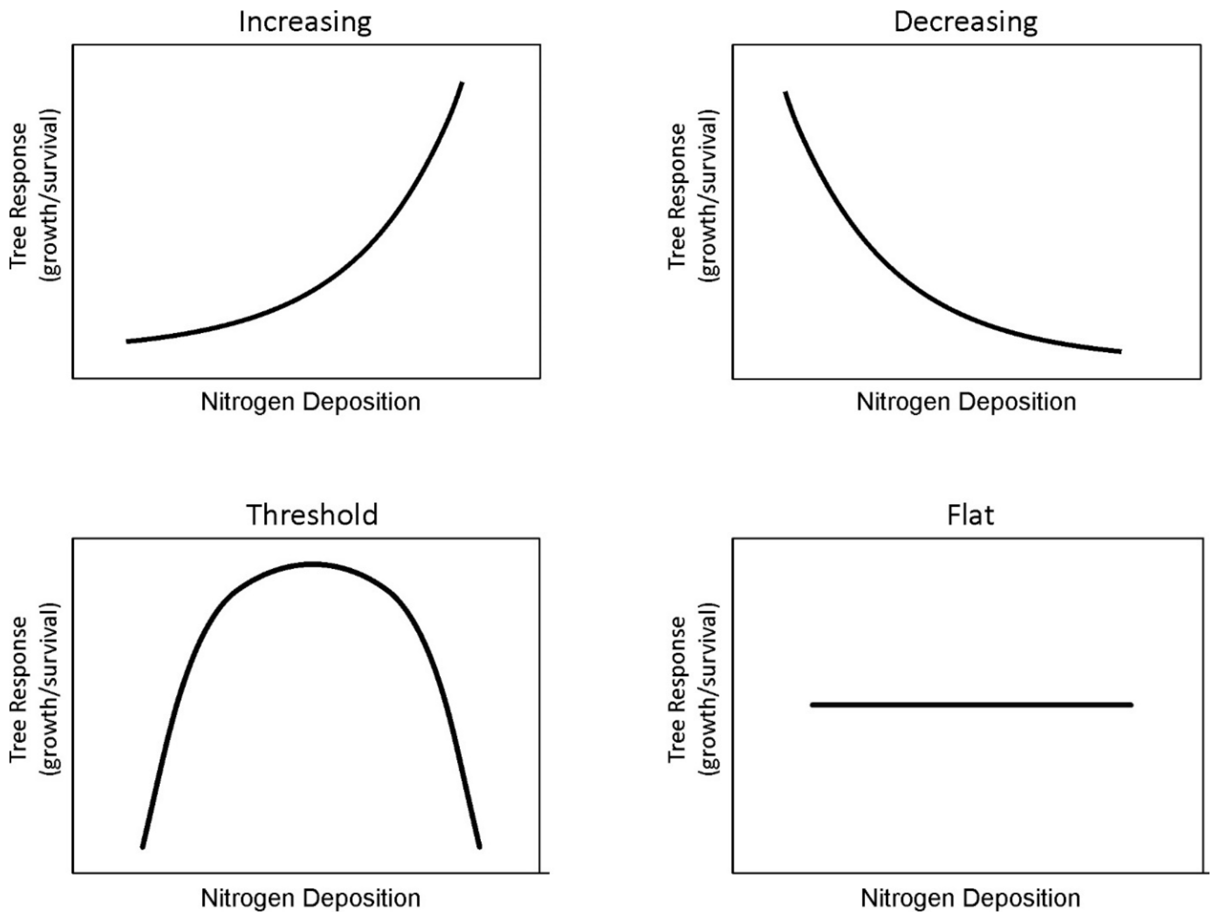

Figure 3-1. Conceptual diagrams showing the four main response types for tree growth and survival reported by Horn et al. (2018).

3.5 Herbaceous Plants and Mycorrhizae

Pardo et al. (2011) published CLs for N deposition effects on herbaceous plants and mycorrhizae. These CLs were assigned to large geographic scales (i.e., “ecoregions”) and vary widely. Since the Intermountain Region consists of diverse landforms, bedrock geology, ecological communities, deposition, climate and other factors, these broad-scale CLs, that were largely developed form data collected outside the Intermountain Region, were determined to be of limited use at this time for USFS land management planning.

4 APPROACH

All 12 National Forests and Grasslands, and their wilderness areas within the Intermountain Region were included in this CL assessment (**Figure** 4-1). The primary CL datasets used for this assessment are listed in **Table** 4-1. **Figures** 4-2 through 4-5 show our estimates of ambient N and S deposition throughout the region and were used in calculating CL exceedances.

Table 4.1. Primary critical load datasets used in this analysis.

Focus	Citation(s)
Surface water acidification	Scheffe et al. (2014), Lynch et al. (2019)
Surface water eutrophication	Nanus et al. (2012), Nanus et al. (2017)
Lichen richness and abundance	Geiser et al. (2019)
Tree growth and survival	Horn et al. (2018)

4.1 Surface Water Acidification

Critical loads of N deposition which protect against biological impacts from surface water acidification were determined at specific locations on lakes or streams, as determined from water quality data reported in Lynch et al. (2019). These CLs of N are expected to prevent ANC from decreasing below 50 $\mu eq\ L^{-1}$ and 20 $\mu eq\ L^{-1}$. The ANC values of some surface waters in the region are expected to have been less than 50 $\mu eq\ L^{-1}$ prior to the onset of elevated N and S deposition. As such, it might be considered inappropriate to develop a CL to result in ANC = 50 $\mu eq\ L^{-1}$ for these waters. However, given that most (92%) of the available water quality sample results for surface waters of the Intermountain Region indicate that current ANC is greater than 50 $\mu eq\ L^{-1}$, CLs to result in ANC = 50 $\mu eq\ L^{-1}$ were considered most appropriate and were used for map display. It is important to note that for a given stream or lake that currently exhibits an ANC = 75 $\mu eq\ L^{-1}$, for example, sustained deposition at the CL to result in ANC = 50 $\mu eq\ L^{-1}$ would ultimately cause ANC to decline by 25 $\mu eq\ L^{-1}$, a loss of one-third of the acid neutralizing capacity. As such, the CLs for these types of systems represent the maximum deposition that the system can tolerate without dropping below 50 $\mu eq\ L^{-1}$, but they would not be fully protective of current water quality conditions (i.e., ANC = 75 $\mu eq\ L^{-1}$ in this example). Exceedance of these CLs was determined based on total (wet + dry) N deposition (2015 – 2017, average TDep v2018.02). Exceedance was calculated as total N deposition minus

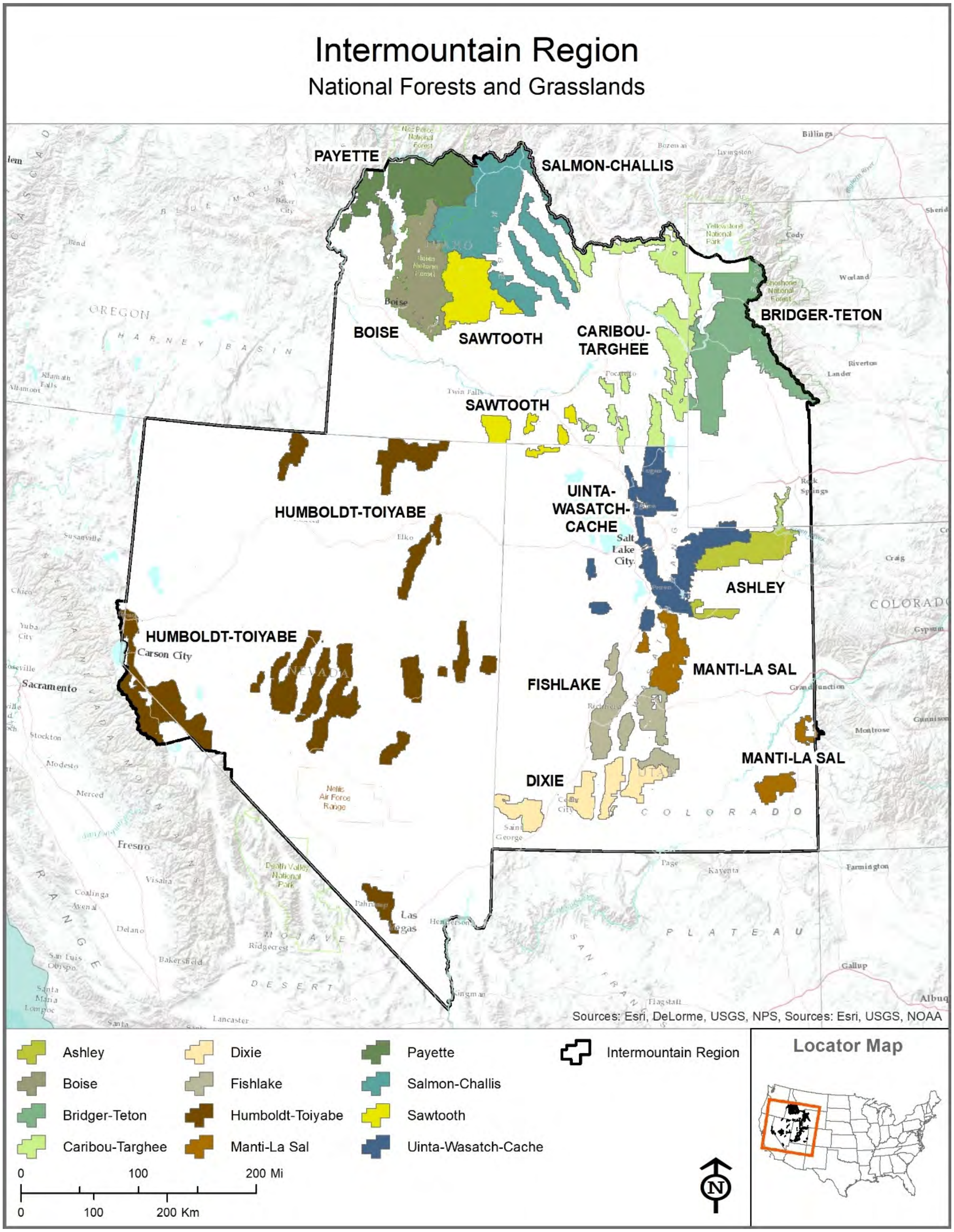

Figure 4-1. Forests and Grasslands within the U.S. Forest Service Intermountain Region.

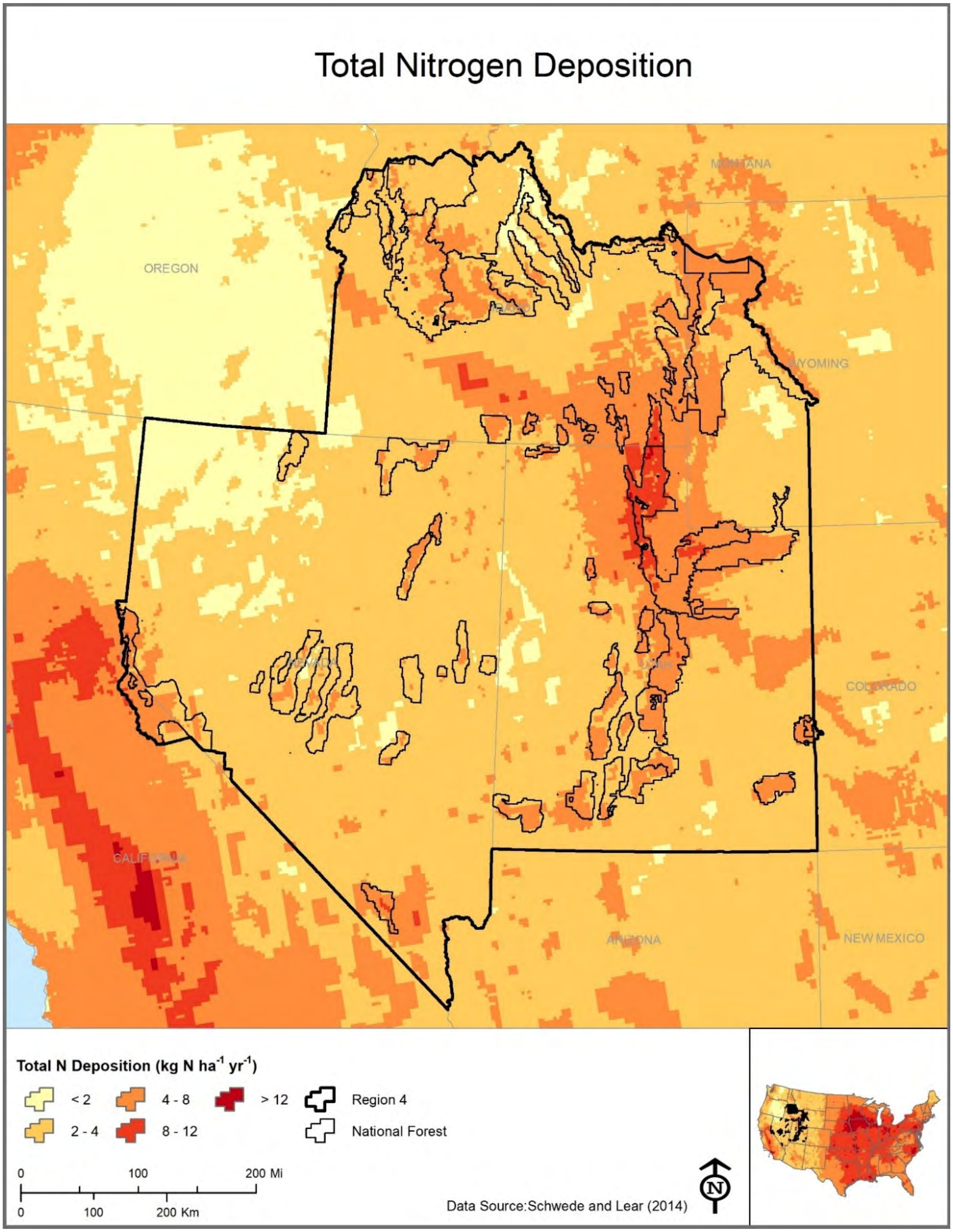

Figure 4-2. Total (wet + dry) nitrogen (N) deposition in the vicinity of the Intermountain Region.

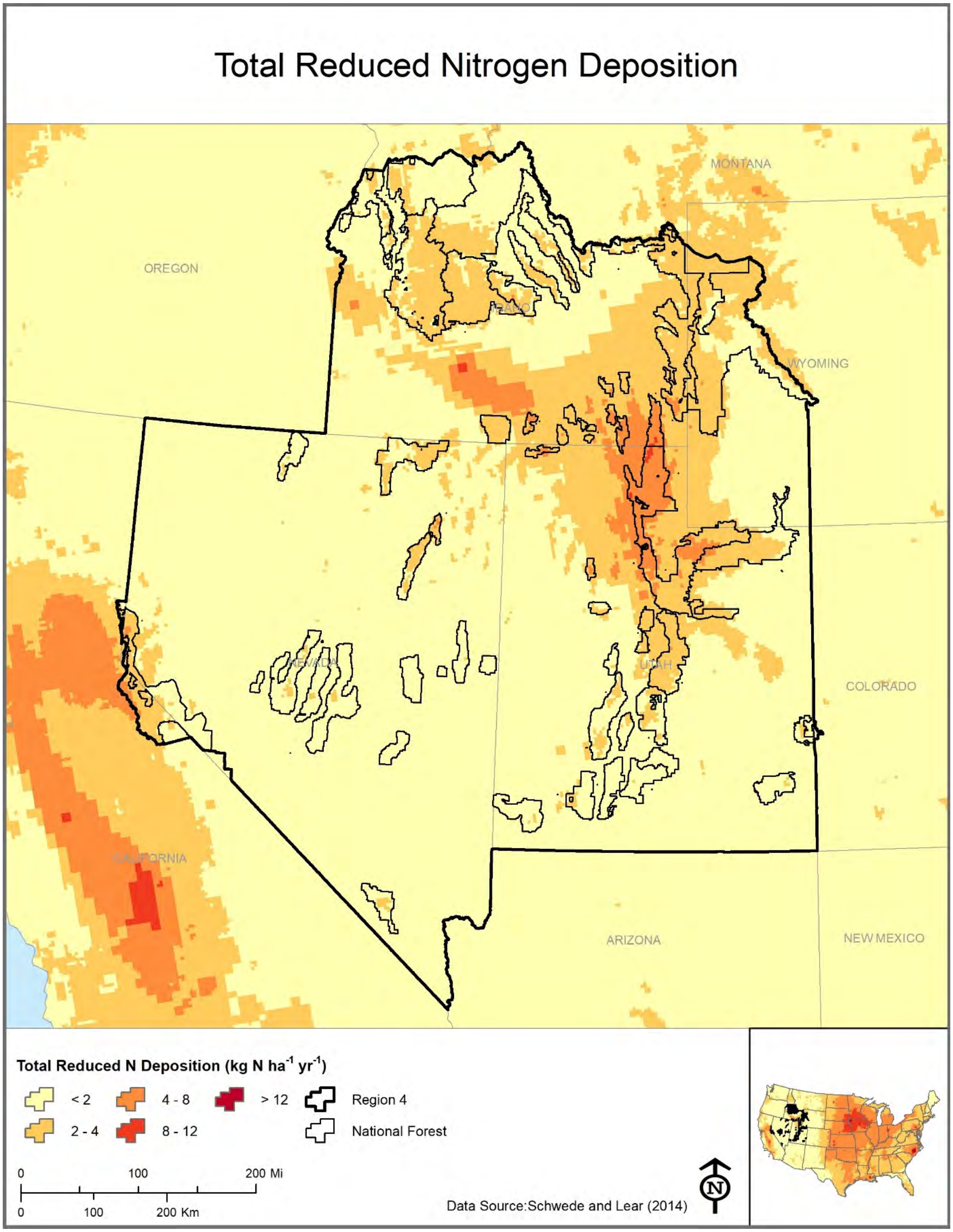

Figure 4-3. Total (wet + dry) reduced nitrogen (N) deposition in the vicinity of the Intermountain Region.

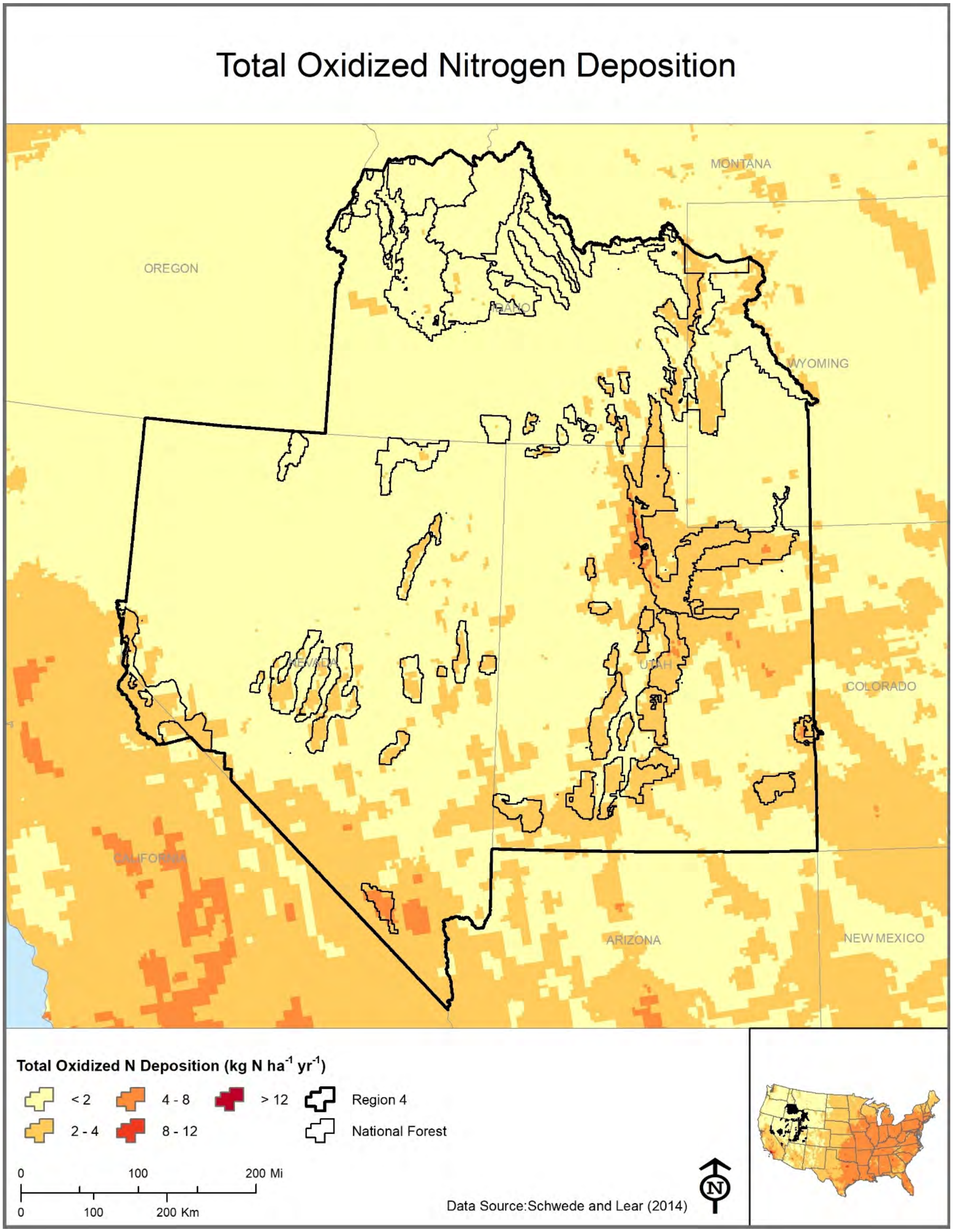

Figure 4-4. Total (wet + dry) oxidized nitrogen (N) deposition in the vicinity of the Intermountain Region.

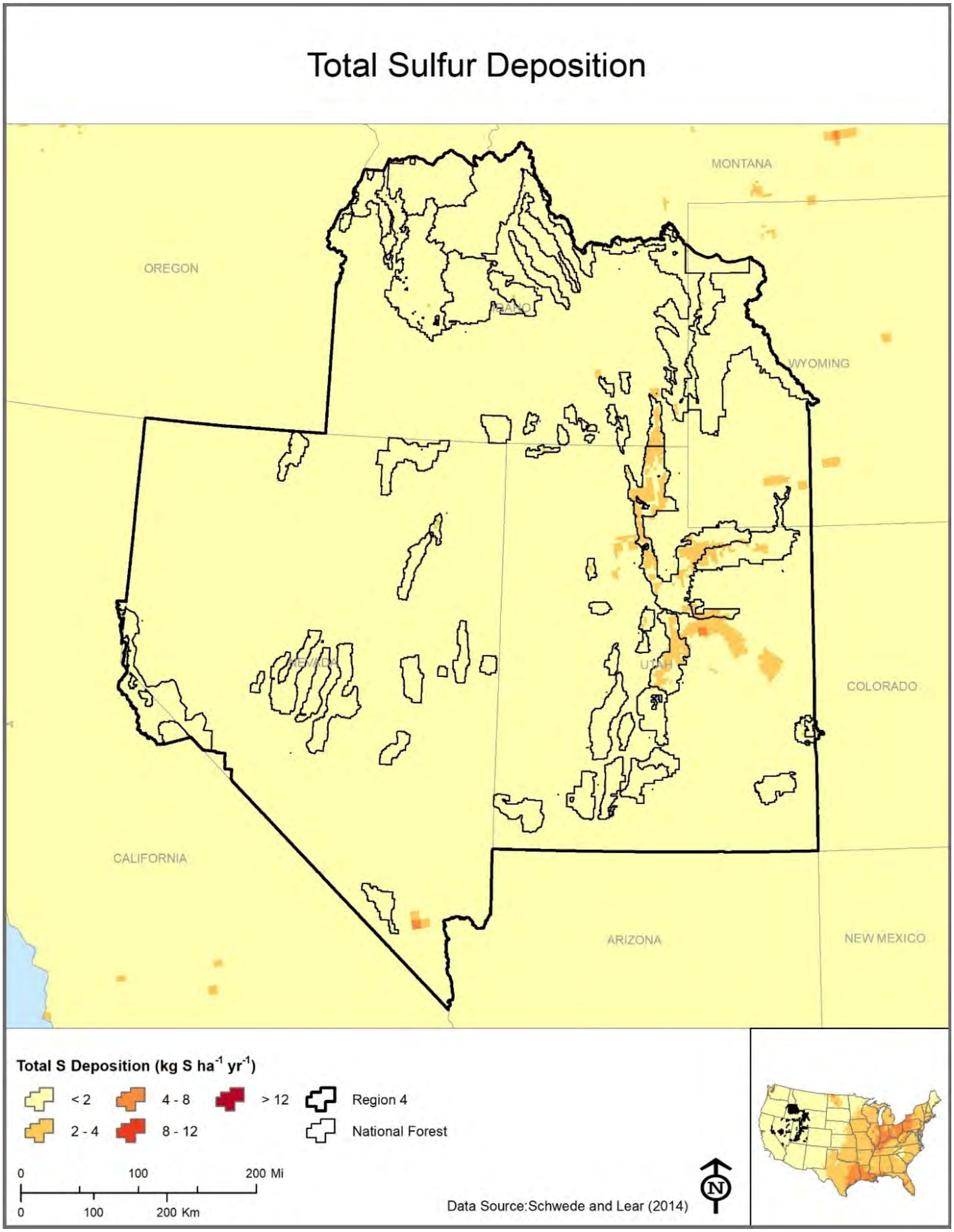

Figure 4-5. Total (wet + dry) sulfur (S) deposition in the vicinity of the Intermountain Region.

the CL, with positive values resulting in exceedance of the CL. The surface water acidification CLs in this report were determined for N deposition under current levels of S deposition. Increases in S deposition would decrease the CLs of N reported and would increase any levels of exceedance.

4.2 Surface Water Eutrophication

Critical loads of N deposition to protect against biological impacts from surface water eutrophication were mapped based on results from Nanus et al. (2017) for the Bridger-Teton NF and Nanus et al. (2012) for the remainder of the region. Critical loads based on a nitrate threshold ($NO_{3(threshold)}$) = 0.5 μeq L^{-1} were used for mapping and were expressed according to the watershed boundaries generated by Nanus et al. (2012, 2017). The $NO_{3(threshold)}$ of 0.5 μeq L^{-1} was associated with the observed maximum growth rate of the N-sensitive algal species *A. formosa* (Nanus et al. 2012), thus representing an early onset of biological impacts to surface waters. Changes in the abundance of primary producers such as *A. formosa* can have cascading effects on higher trophic levels. The CLs from Nanus et al. (2017) were developed from total N deposition, whereas those from Nanus et al. (2012) were based on wet N deposition. Critical load exceedance was determined based on wet N deposition and total N deposition (2015 – 2017, average TDep v2018.02) for the Nanus et al. (2012) and Nanus et al. (2017) CLs, respectively.

4.3 Lichen Species Richness and Abundance

Critical loads of N deposition to protect against decreases in lichen species richness and forage lichen abundance used as the basis for this assessment are 2.0 and 3.5 kg N ha^{-1} yr^{-1}, respectively (Geiser et al. 2019). Critical load exceedances were mapped based on results from Geiser et al. (2019), which showed that decreases in lichen species richness and forage lichen abundance were directly related to N deposition. The N deposition associated with specified levels of impact on lichen species richness and forage lichen abundance (**Table** 4-2) were used as the category breaks for mapping total N deposition (2015 – 2017, average TDep v2018.02). As such, the maps illustrate the areas of a given forest in exceedance of these various effects thresholds that exist beyond the CL of N considered to be protective of lichen species richness and forage lichen abundance. The ranges of N deposition shown in the map legends are associated with specified levels of lichen impact (Geiser et al. 2019) and thus the highest N

Table 4-2. Level of N deposition (kg N ha^{-1} yr^{-1}) associated with various magnitudes of impact on lichen species richness and forage lichen abundance.

Response	Magnitude of Impact (decrease from maximum count or abundance)	N Deposition (kg N ha^{-1} yr^{-1})
Lichen Species Richness	20%	3.5
	30%	5.65
	40%	8.55
Forage Lichen Abundance	20%	2.00
	30%	2.93
	40%	4.03
	50%	6.63
	80%	8.27

legend categories are used to illustrate which portions of a forest have N deposition anywhere within the range of specified. Although Geiser et al. (2019) also generated CLs for S deposition, these CLs were not included in this Intermountain Region assessment due to uncertainty introduced by the narrow gradient in S deposition in the western U.S. Furthermore, suitable habitat for epiphytic lichens is not found throughout all of the Intermountain Region, particularly within high alpine zones and grasslands.

4.4 Tree Growth and Survival

Critical loads for tree growth and probability of survival (over 10 years) were evaluated for five tree species. These species were evaluated because of 1) their ecological and commercial significance to the region and 2) CLs from Horn et al. (2018) were available. The scientific name was used to refer to these species throughout the report; however, common names can be found in **Table** 4-3. Critical loads of N deposition to protect against decreases in tree growth and

Table 4-3. List of tree species and associated common names included in the assessment of critical loads for tree growth and survival.

Species	Common Name
Juniperus osteosperma	Utah juniper
Pinus monophylla	singleleaf pinyon
Populus balsamifera	balsam poplar
Populus tremuloides	quaking aspen
Pseudotsuga menziesii	Douglas fir

survival vary among the species considered and the specified level of response (Horn et al. 2018; **Table** 4-4). Data available through the region's Vegetation Classification, Mapping, and Quantitative Inventory Program (VCMQ) were used for mapping the locations of species with either decreasing or threshold responses to N deposition. The VCMQ data provide modeled spatial datasets of existing vegetation at the mid-level (generally 1:100,000 scale), which is defined as:

> "Mid-level products are intended to support forest and multi-forest information needs including forest planning, forest/region resource assessment and monitoring, and fire/fuels modeling. Products at this level provide a synoptic and consistent view of existing vegetation across all ownerships within the map extent. They typically are developed programmatically from remotely sensed data and field data. Standard base-level maps, where they exist, should be considered for integration into mid-level map products." (Brohman and Bryant 2005)

The mid-level existing vegetation map units were delineated based on modeling the canopy of the dominant/co-dominant vegetation. Both overrepresentation and underrepresentation of species extent and distribution can occur. There may be some areas that are not fully comprised of the specified dominant/co-dominant vegetation and other areas that may contain a species of interest that is not dominant/co-dominant in that area. Map units for each Forest that were used for mapping a given species with dominant/co-dominant canopy are included in **Appendix** A. More information regarding VCMQ methods and products is available at: http://www.fs.usda.gov/goto/landmanagement/projects/VCMQ.

The extent of CL exceedance was mapped for each species that occurred on a forest by using the CL values (grey highlights in **Table** 4-4) as category breaks for mapping total N deposition (2015 – 2017, average TDep v2018.02). As such, the maps illustrate the areas of a given forest in exceedance of the CLs based on specified levels of impact to tree growth and survival, which included 1%, 5%, and 10% reductions in growth and probability of survival over a 10-year period. Although Horn et al. (2019) also generated CLs for S deposition, these CLs were not included in this Intermountain Region assessment due to the narrow gradient of S deposition available to develop the response models for species that are predominantly distributed within the western U.S.

Table 4-4. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the region. Grey highlights indicate species responses with critical loads.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth		
				1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies grandis	grand fir	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Abies lasiocarpa	subalpine fir	Growth	Increasing	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus monosperma	oneseed juniper	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Juniperus occidentalis	western juniper	Growth	Threshold[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Juniperus osteosperma	Utah juniper	Growth	Increasing	N/A	N/A	N/A
		Survival	Threshold	3.9	10.7	23.6
Larix occidentalis	western larch	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Picea glauca	white spruce	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	singleleaf pinyon	Growth	Increasing	N/A	N/A	N/A
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	Douglas fir	Growth	Increasing	N/A	N/A	N/A
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effect

Critical loads were mapped using the best model for species with a decreasing or threshold response to N. One exception was the survival model used for *Populus balsamifera* (balsam poplar). Response of *P. balsamifera* was based on the second best model because it included N deposition as a driver of effects and was considered to be generally statistically equivalent to the best model, which did not include N deposition as a driver. All species models considered here included at least 2,000 trees for model development. Although growth response models for *Juniperus occidentalis* (western juniper) and *Picea engelmannii* (Engelmann spruce) and survival models for *Abies grandis* (grand fir) and *Picea engelmannii* showed decreasing/threshold responses to N deposition, the CLs of N for these models were considered too uncertain for mapping because N deposition showed high correlations with other variables included in the model. The high correlation makes it impossible to separate changes in growth or survival related to N deposition from other factors in the model such as aspects of climate.

5 RESULTS AND DISCUSSION

Total annual N deposition (average 2015 – 2017) in some portions of the Intermountain Region were of similar magnitude (8 – 12 kg N ha^{-1} yr^{-1}) to many areas within central and southern California (**Figure** 4-2). Areas of the region that were furthest from urban development and agriculture tended to receive lower levels of total N deposition (2 – 4 kg N ha^{-1} yr^{-1}). The dominant component of total N deposition in more impacted areas was reduced N, such as that from ammonia emissions, with many locations receiving up to 4 – 8 kg N ha^{-1} yr^{-1} of reduced N (**Figure** 4-3). Total oxidized N deposition, typically a product of fossil fuel combustion, was generally less than 2 kg N ha^{-1} yr^{-1} within the region (**Figure** 4-4). Isolated locations of the Intermountain Region, mostly in northern and central Utah, received total S deposition greater than 2 kg S ha^{-1} yr^{-1}, which is relatively high for the region (**Figure** 4-5).

5.1 Summary Data Tables

5.1.1 Surface Water Acidification

The CLs that result in surface water ANC = 50 μeq L^{-1} were lower and were more often exceeded relative to CLs to result in ANC = 20 μeq L^{-1} (**Tables** 5-1 and 5-2). Low CLs (< 4 kg N ha^{-1} yr^{-1}) to result in ANC = 50 μeq L^{-1} were most commonly found on the Ashley NF, Bridger-Teton NF and Sawtooth NF; therefore, these forests also showed the largest extent of surface water CL exceedance. Using the less conservative CL associated with ANC = 20 μeq L^{-1}, the majority of sampled waterbodies in all forests showed CLs greater than 8 kg N ha^{-1} yr^{-1} and were not in exceedance of this less protective CL.

Much of the surface water monitoring for acidification effects was specifically designed to focus on waterbodies that were expected to be sensitive to air pollution (e.g., high elevation lakes). Therefore, these data points cannot be considered representative of the entire population of waterbodies on the forests.

5.1.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) to protect against effects from surface water eutrophication, based on a threshold NO_3^- concentration of 0.5 μeq L^{-1}, were common throughout the Intermountain Region (**Table** 5-3). Other than the Bridger-Teton NF, where CLs were based on total rather than only wet deposition, all forests had at least 25% of their area with CLs < 2 kg

Table 5-1. Critical load classes for the number and percent of waterbodies on each Forest which would result in surface water ANC = 50 µeq L^{-1} and 20 µeq L^{-1}.

Critical ANC Threshold (µeq L^{-1})	Forest Name	Total	Critical Load Class (kg N ha^{-1} yr^{-1}) < 2		2-4		4-6		6-8		> 8	
			#	%	#	%	#	%	#	%	#	%
ANC=50	Ashley NF	40			10	25.0	9	22.5	7	17.5	14	35.0
	Boise NF	8									8	100.0
	Bridger-Teton NF	203	20	9.9	36	17.7	32	15.8	25	12.3	90	44.3
	Caribou-Targhee NF	17					2	11.8	1	5.9	14	82.4
	Dixie NF	3									3	100.0
	Fishlake NF	8	1	12.5	1	12.5	1	12.5			5	62.5
	Humboldt-Toiyabe NF	34			3	8.8	1	2.9	3	8.8	27	79.4
	Manti-La Sal NF	3									3	100.0
	Payette NF	51	1	2.0	7	13.7	4	7.8	5	9.8	34	66.7
	Salmon-Challis NF	18	2	11.1			3	16.7	1	5.6	12	66.7
	Sawtooth NF	56	13	23.2	7	12.5	7	12.5	4	7.1	25	44.6
	Uinta-Wasatch-Cache NF	33			2	6.1	3	9.1	9	27.3	19	57.6
ANC=20	Ashley NF	40					5	12.5	13	32.5	22	55.0
	Boise NF	8									8	100.0
	Bridger-Teton NF	203	3	1.5	12	5.9	28	13.8	37	18.2	123	60.6
	Caribou-Targhee NF	17									17	100.0
	Dixie NF	3									3	100.0
	Fishlake NF	8			1	12.5	2	25.0			5	62.5
	Humboldt-Toiyabe NF	34					1	2.9	4	11.8	29	85.3
	Manti-La Sal NF	3									3	100.0
	Payette NF	51					1	2.0	7	13.7	43	84.3
	Salmon-Challis NF	18	1	5.6	1	5.6			3	16.7	13	72.2
	Sawtooth NF	56			2	3.6	16	28.6	5	8.9	33	58.9
	Uinta-Wasatch-Cache NF	33					1	3.0	2	6.1	30	90.9

Table 5-2. The magnitude of surface water CL exceedance (kg N ha^{-1} yr^{-1}) by Forest for the number and percent of waterbodies.

Critical ANC Threshold (μeq L^{-1})	Forest Name	Total	Exceedance (kg N ha^{-1} yr^{-1})											
			No Exceedance		< 1		1-2		2-5		> 5		Total Number and Percent in Exceedance	
			#	%	#	%	#	%	#	%	#	%	#	%
ANC=50	Ashley NF	40	16	40.0	2	5.0	7	17.5	14	35.0	1	2.5	24	60.0
	Boise NF	8	8	100.0									0	0.0
	Bridger-Teton NF	203	142	70.0	22	10.8	16	7.9	23	11.3			61	30.0
	Caribou-Targhee NF	17	15	88.2	1	5.9	1	5.9					2	11.8
	Dixie NF	3	3	100.0									0	0.0
	Fishlake NF	8	5	62.5	1	12.5			2	25.0			3	37.5
	Humboldt-Toiyabe NF	34	31	91.2			2	5.9	1	2.9			3	8.8
	Manti-La Sal NF	3	3	100.0									0	0.0
	Payette NF	51	45	88.2	2	3.9	3	5.9	1	2.0			6	11.8
	Salmon-Challis NF	18	16	88.9			2	11.1					2	11.1
	Sawtooth NF	56	29	51.8	7	12.5	1	1.8	19	33.9			27	48.2
	Uinta-Wasatch-Cache NF	33	24	72.7	3	9.1	2	6.1	2	6.1	2	6.1	9	27.3
ANC=20	Ashley NF	40	27	67.5	6	15.0	5	12.5	2	5.0			13	32.5
	Boise NF	8	8	100.0									0	0.0
	Bridger-Teton NF	203	185	91.1	8	3.9	6	3.0	4	2.0			18	8.9
	Caribou-Targhee NF	17	17	100.0									0	0.0
	Dixie NF	3	3	100.0									0	0.0
	Fishlake NF	8	6	75.0	1	12.5			1	12.5			2	25.0
	Humboldt-Toiyabe NF	34	33	97.1	1	2.9							1	2.9
	Manti-La Sal NF	3	3	100.0									0	0.0
	Payette NF	51	51	100.0									0	0.0
	Salmon-Challis NF	18	17	94.4			1	5.6					1	5.6
	Sawtooth NF	56	43	76.8	9	16.1	4	7.1					13	23.2
	Uinta-Wasatch-Cache NF	33	30	90.9	1	3.0			1	3.0	1	3.0	3	9.1

Table 5-3. National forest area[1] and percent of area in surface water eutrophication critical load classes using a water nitrate concentration of 0.5 μmol/L.

Forest Name	Critical Load Class (kg N ha^{-1} yr^{-1})										
	Forest Area	<1		1-2		2-3		3-5		5-8	
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	5670.7	2008.3	35.4	589.0	10.4	670.1	11.8	1385.1	24.4	1018.2	18.0
Boise NF	9767.7	4101.5	42.0	2067.2	21.2	1708.8	17.5	1667.3	17.1	222.9	2.3
Bridger-Teton NF	14029.6	363.5	2.6	1040.6	7.4	7201.6	51.3	5356.3	38.2		0.0
Caribou-Targhee NF	9286.4	2419.2	26.1	1144.4	12.3	1770.9	19.1	2612.7	28.1	1339.1	14.4
Dixie NF	4978.8	703.3	14.1	590.3	11.9	784.1	15.7	2081.9	41.8	819.1	16.5
Fishlake NF	6271.9	1320.3	21.1	676.8	10.8	964.2	15.4	2589.4	41.3	721.3	11.5
Humboldt-Toiyabe NF	NA										
Manti-La Sal NF	5620.1	1560.9	27.8	833.4	14.8	1272.4	22.6	1628.3	29.0	325.3	5.8
Payette NF	8533.9	3793.7	44.5	1265.3	14.8	1547.0	18.1	1847.6	21.6	80.3	0.9
Salmon-Challis NF	17790.7	11405.6	64.1	3069.7	17.3	1821.7	10.2	1398.9	7.9	94.9	0.5
Sawtooth NF	6303.0	4505.6	71.5	886.3	14.1	486.8	7.7	366.7	5.8	57.6	0.9
Uinta-Wasatch-Cache NF	9673.9	2587.1	26.7	1295.1	13.4	1884.4	19.5	2916.7	30.2	990.6	10.2

[1] determined by administrative boundary

N ha^{-1} yr^{-1}. The highest CL, which is representative of the least sensitive waterbody, among all NF areas was 7.9 kg N ha^{-1} yr^{-1}. Nine NFs exceeded the surface water eutrophication CL for more than one-half of the forest area (**Table** 5-4). The extent of exceedance was particularly high (72 – 90%) within the Bridger-Teton NF, Salmon-Challis, Sawtooth NF, and Uinta-Wasatch-Cache NF.

Table 5-4. National forest area[1] and percent of area in each surface water eutrophication exceedance class.

		Exceedance Class										Total Area and Percent in Exceedance	
	Forest Area	No Exceedance		< 1		1-2		2-5		>5			
Forest Name	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	5670.7	2280.4	40.2	631.7	11.1	808.9	14.3	1877.3	33.1	72.4	1.3	3390.3	59.8
Boise NF	9767.7	3121.7	32.0	1943.8	19.9	2285.7	23.4	2416.5	24.7		0.0	6646.1	68.0
Bridger-Teton NF	14029.6	1347.9	9.6	3164.0	22.6	4498.3	32.1	4932.6	35.2	86.8	0.6	12681.7	90.4
Caribou-Targhee NF	9286.4	3967.6	42.7	1346.1	14.5	1563.5	16.8	2100.2	22.6	309.0	3.3	5318.8	57.3
Dixie NF	4978.8	4009.0	80.5	386.2	7.8	538.0	10.8	45.6	0.9	0.0	0.0	969.8	19.5
Fishlake NF	6271.9	4367.2	69.6	528.7	8.4	808.1	12.9	567.9	9.1	0.0	0.0	1904.7	30.4
Humboldt-Toiyabe NF	NA												
Manti-La Sal NF	5620.1	2182.7	38.8	1077.5	19.2	1291.5	23.0	1042.7	18.6	25.7	0.5	3437.4	61.2
Payette NF	8533.9	3867.6	45.3	1594.3	18.7	2529.4	29.6	542.6	6.4	0.0	0.0	4666.3	54.7
Salmon-Challis NF	17790.7	4861.3	27.3	5277.9	29.7	5115.7	28.8	2535.8	14.3	0.0	0.0	12929.4	72.7
Sawtooth NF	6303.0	663.7	10.5	691.3	11.0	1098.6	17.4	3849.3	61.1	0.0	0.0	5639.2	89.5
Uinta-Wasatch-Cache NF	9673.9	1599.7	16.5	979.4	10.1	1252.0	12.9	4283.8	44.3	1559.0	16.1	8074.2	83.5

[1] determined by administrative boundary

5.1.3 Lichen Species Richness and Abundance

All NFs showed at least 25% of the area in exceedance of the CL protective of lichen species richness (**Table** 5-5). Most NFs (n = 9) had over 70% of the area in exceedance. Nearly all of the Manti-La Sal and Uinta-Wasatch-Cache exceeded the CL and these two forests, along with the Ashley, also represented the greatest proportional extents above the N deposition threshold associated with relatively high magnitudes (30 – 40% reductions) of effects on lichen species richness.

Table 5-5. Area[1] and percent of forest within various categories of exceedance of the critical load for lichen species richness (3.5 kg N ha^{-1} yr^{-1}).

Forest Name	Forest Area	Exceedance Class (reduction in species richness)								Total Area and percent in Exceedance	
		No Exceedance		20-30%		30-40%		40-50%			
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	5670.3	738.2	13.0	1929.0	34.0	2991.0	52.7	12.1	0.2	4932.1	87.0
Boise NF	10225.6	3060.0	29.9	7095.8	69.4	69.7	0.7	0.0	0.0	7165.6	70.1
Bridger-Teton NF	14029.0	2832.8	20.2	10387.4	74.0	808.8	5.8	0.0	0.0	11196.2	79.8
Caribou-Targhee NF	12454.5	1278.4	10.3	8303.7	66.7	2328.9	18.7	543.4	4.4	11176.1	89.7
Dixie NF	6925.1	1648.5	23.8	5128.8	74.1	147.8	2.1	0.0	0.0	5276.6	76.2
Fishlake NF	7236.4	1318.9	18.2	5420.0	74.9	497.5	6.9	0.0	0.0	5917.5	81.8
Humboldt-Toiyabe NF	27137.0	11566.9	42.6	12571.2	46.3	2981.7	11.0	17.2	0.1	15570.1	57.4
Manti-La Sal NF	5722.8	93.0	1.6	3404.3	59.5	2207.9	38.6	17.6	0.3	5629.8	98.4
Payette NF	9748.1	7362.7	75.5	2385.4	24.5	0.0	0.0	0.0	0.0	2385.4	24.5
Salmon-Challis NF	17789.8	12050.6	67.7	5708.4	32.1	30.9	0.2	0.0	0.0	5739.3	32.3
Sawtooth NF	8863.7	1188.9	13.4	7302.8	82.4	364.2	4.1	7.8	0.1	7674.8	86.6
Uinta-Wasatch-Cache NF	11789.2	80.6	0.7	1622.5	13.8	6662.3	56.5	3423.8	29.0	11708.6	99.3

[1] determined by administrative boundary

The lower CL to protect against effects on forage lichen abundance was exceeded throughout nearly all NFs and the majority of the area in exceedance experienced N deposition associated with between 30% and 50% reductions in forage lichen abundance (**Table** 5-6). The Uinta-Wasatch-Cache NF contained the highest level of exceedance, with 65% of the forest area above the N deposition threshold expected to decrease forage lichen abundance by 50% or more.

5.1.4 Tree Growth and Survival

Tree growth and survival CLs were relatively high for *P. tremuloides* (quaking aspen). All NF areas in which *P. tremuloides* is expected to occur were not in exceedance of CLs associated with growth reductions above 1%, with the exception of a small (3.9 km^2) portion of the Uinta-Wasatch-Cache NF (**Table** 5-7). Critical loads to protect against reductions in probability of 10-year survival for *P. tremuloides* (**Table** 5-8) were lower than for reductions in growth. This resulted in more than 5% of the area in exceedance within four forests. The highest portions of area in exceedance for *P. tremuloides* probability of survival were found in the Manti-La Sal NF and Uinta-Wasatch-Cache NF, each with nearly one-third to two-thirds of their area found to be in exceedance.

Table 5-6. Area[1] and percent of forest within various categories of exceedance of the critical load for forage lichen abundance (2.0 kg N ha^{-1} yr^{-1}).

	Forest Area	Exceedance Class (reduction in species richness)												Total Area and Percent in Exceedance	
		No Exceedance		20-30%		30-40%		40-50%		50-80%		>80%			
Forest Name	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	5670.3	0.0	0.0	600.8	10.6	349.4	6.2	3711.9	65.5	987.0	17.4	21.2	0.4	5670.3	100.0
Boise NF	10225.6	0.0	0.0	112.8	1.1	6797.7	66.5	3315.1	32.4	0.0	0.0	0.0	0.0	10225.6	100.0
Bridger-Teton NF	14029.0	0.0	0.0	457.6	3.3	5154.1	36.7	8400.5	59.9	16.8	0.1	0.0	0.0	14029.0	100.0
Caribou-Targhee NF	12454.5	0.0	0.0	398.3	3.2	3397.4	27.3	7013.4	56.3	1033.7	8.3	611.8	4.9	12454.5	100.0
Dixie NF	6925.1	0.0	0.0	241.8	3.5	3174.6	45.8	3508.8	50.7	0.0	0.0	0.0	0.0	6925.1	100.0
Fishlake NF	7236.4	0.0	0.0	228.7	3.2	2642.8	36.5	4363.6	60.3	1.4	0.0	0.0	0.0	7236.4	100.0
Humboldt-Toiyabe NF	27137.0	43.9	0.2	4256.0	15.7	13121.9	48.4	8230.4	30.3	1374.8	5.1	110.0	0.4	27093.1	99.8
Manti-La Sal NF	5722.8	0.0	0.0	3.1	0.1	537.9	9.4	4307.8	75.3	856.4	15.0	17.6	0.3	5722.8	100.0
Payette NF	9748.1	45.4	0.5	4300.6	44.1	4813.0	49.4	589.2	6.0	0.0	0.0	0.0	0.0	9702.7	99.5
Salmon-Challis NF	17789.8	574.4	3.2	7548.0	42.4	6848.4	38.5	2819.0	15.8	0.0	0.0	0.0	0.0	17215.4	96.8
Sawtooth NF	8863.7	0.0	0.0	126.9	1.4	3224.4	36.4	5424.3	61.2	73.9	0.8	14.3	0.2	8863.7	100.0
Uinta-Wasatch-Cache NF	11789.2	0.0	0.0	0.0	0.0	196.6	1.7	3998.2	33.9	3354.2	28.5	4240.2	36.0	11789.2	100.0

[1] determined by administrative boundary

Table 5-7. Area[1] and percent of forest within various classes of reductions in growth of *Populus tremuloides*. Areas with growth reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against growth reductions beyond 1%, 5%, and 10% (13.6, 17.5, and 21.3, kg N ha^{-1}yr^{-1} respectively). The total area of each forest represents the area in which *Populus tremuloides* is expected to occur.

		Growth Reduction Category ("Exceedance")								Total Area and Percent in Exceedance	
	Species Area	No Exceedance (< 1%)		1-5%		5-10%		> 10%			
Forest Name	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	754.5	754.5	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Boise NF	120.4	120.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Bridger-Teton NF	698.4	698.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Caribou-Targhee NF	1740.2	1740.2	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Dixie NF	698.5	698.5	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Fishlake NF	915.1	915.1	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Humboldt-Toiyabe NF	860.4	860.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Manti-La Sal NF	976.3	976.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Payette NF	33.3	33.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Salmon-Challis NF	102.4	102.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Sawtooth NF	445.2	445.2	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Uinta-Wasatch-Cache NF	1879.7	1875.8	99.8	3.9	0.2	0	0.0	0	0.0	3.9	0.2

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

Table 5-8. Area[1] and percent of forest within various classes of reductions in probability of survival of *Populus tremuloides* over a 10-year period. Areas with reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against reductions in probability of survival beyond 1%, 5%, and 10% (6.6, 11.8, and 18.4 kg N ha^{-1}yr^{-1}, respectively). The total area of each forest represents the area in which *Populus tremuloides* is expected to occur.

		Reduction in Probability of Survival Category ("Exceedance")								Total Area and Percent in Exceedance	
	Species Area	No Exceedance (< 1%)		1-5%		5-10%		> 10%			
Forest Name	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	754.5	712.9	94.5	41.6	5.5	0.0	0.0	0.0	0.0	41.6	5.5
Boise NF	120.4	120.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bridger-Teton NF	698.4	698.3	100.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Caribou-Targhee NF	1740.2	1411.2	81.1	324.6	18.7	4.4	0.3	0.0	0.0	329.1	18.9
Dixie NF	698.5	698.5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fishlake NF	915.1	914.9	100.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Humboldt-Toiyabe NF	860.4	827.0	96.1	33.5	3.9	0.0	0.0	0.0	0.0	33.5	3.9
Manti-La Sal NF	976.3	677.1	69.4	299.2	30.6	0.0	0.0	0.0	0.0	299.2	30.6
Payette NF	33.3	33.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmon-Challis NF	102.4	102.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sawtooth NF	445.2	439.1	98.6	6.1	1.4	0.0	0.0	0.0	0.0	6.1	1.4
Uinta-Wasatch-Cache NF	1879.7	694.5	36.9	1166.8	62.1	18.4	1.0	0.0	0.0	1185.2	63.1

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

Although *P. balsamifera* is generally not widespread within the Intermountain Region, CLs to protect against at least a 1% reduction in growth of *P. balsamifera* were exceeded within at least 14% of the area on all NFs in which the species is expected to occur (n = 10; **Table** 5-9). Of these 10 forests, eight showed at least 50% of the expected area of occurrence to be in exceedance of growth CLs. Critical loads for reductions in probability of 10-year survival were higher, which resulted in less area in exceedance (**Table** 5-10). However, the Manti-La Sal NF and Uinta-Wasatch-Cache NF had 67% and 95%, respectively, of the area in exceedance, and these two forests also had the highest occurrence (or coverage) of *P. balsamifera*.

Critical loads associated with reductions in probability of survival over 10 years for *Pseudotsuga menziesii* (Douglas fir) were exceeded within at least some portion of all NFs (**Table** 5-11). More than 80% of the area expected to contain *P. menziesii* was in exceedance within three-quarters (n = 9) of the NFs. Critical loads associated with reductions in *P. menziesii* growth were not evaluated because this species showed an increasing relation between growth and N deposition.

Table 5-9. Area[1] and percent of forest within various classes of reductions in growth of *Populus balsamifera*. Areas with growth reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against growth reductions beyond 1%, 5%, and 10% (3.4, 4.2, and 5.4 kg N $ha^{-1}yr^{-1}$, respectively). The total area of each forest represents the area in which *Populus balsamifera* is expected to occur.

		Growth Reduction Category ("Exceedance")								Total Area and Percent in Exceedance	
	Species Area	No Exceedance (< 1%)		1-5%		5-10%		> 10%			
Forest Name	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley NF	NA										
Boise NF	148.9	31.8	21.4	72.9	48.9	42.7	28.7	1.5	1.0	117.1	78.6
Bridger-Teton NF	1.5	0.8	50.0	0.6	36.8	0.2	13.2	0.0	0.0	0.8	50.0
Caribou-Targhee NF	NA										
Dixie NF	34.1	5.0	14.8	11.9	34.9	15.6	45.7	1.6	4.7	29.0	85.2
Fishlake NF	45.6	8.2	18.0	16.6	36.5	17.3	37.9	3.5	7.6	37.4	82.0
Humboldt-Toiyabe NF	14.9	7.0	46.6	4.5	30.0	3.1	20.9	0.4	2.4	8.0	53.4
Manti-La Sal NF	28.4	0.1	0.4	2.4	8.5	9.3	32.7	16.6	58.5	28.3	99.6
Payette NF	48.2	41.1	85.2	7.0	14.5	0.2	0.3	0.0	0.0	7.2	14.8
Salmon-Challis NF	131.8	77.4	58.8	29.1	22.1	24.8	18.8	0.4	0.3	54.3	41.2
Sawtooth NF	81.3	20.5	25.2	42.4	52.2	17.0	20.9	1.4	1.7	60.8	74.8
Uinta-Wasatch-Cache NF	118.0	0.1	0.1	0.2	0.1	15.0	12.7	102.8	87.1	118.0	99.9

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

Table 5-10. Area[1] and percent of forest within various classes of reductions in probability of survival of *Populus balsamifera* over a 10-year period. Areas with reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against reductions in probability of survival beyond 1%, 5%, and 10% (5.0, 7.5 and 10.2 kg N $ha^{-1}yr^{-1}$, respectively). The total area of each forest represents the area in which *Populus balsamifera* is expected to occur.

Forest Name	Species Area	Reduction in Probability of Survival Category ("Exceedance")								Total Area and Percent in Exceedance	
		No Exceedance (< 1%)		1-5%		5-10%		> 10%			
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	NA										
Boise NF	148.9	145.4	97.6	3.6	2.4	0.0	0.0	0.0	0.0	3.6	2.4
Bridger-Teton NF	1.5	1.5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caribou-Targhee NF	NA										
Dixie NF	34.1	30.4	89.1	3.7	10.9	0.0	0.0	0.0	0.0	3.7	10.9
Fishlake NF	45.6	36.8	80.8	8.8	19.2	0.0	0.0	0.0	0.0	8.8	19.2
Humboldt-Toiyabe NF	14.9	13.6	91.4	1.2	8.3	.04	0.3	0.0	0.0	1.3	8.6
Manti-La Sal NF	28.4	9.3	32.7	18.6	65.5	0.5	1.8	0.0	0.0	19.1	67.3
Payette NF	48.2	48.2	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmon-Challis NF	131.8	129.8	98.5	2.0	1.5	0.0	0.0	0.0	0.0	2.0	1.5
Sawtooth NF	81.3	77.0	94.7	4.0	5.0	0.2	0.3	0.0	0.0	4.3	5.3
Uinta-Wasatch-Cache NF	118.0	6.0	5.1	80.3	68.0	29.6	25.0	2.2	1.8	112.0	94.9

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

Table 5-11. Area[1] and percent of forest within various classes of reductions in probability of survival of *Pseudotsuga menziesii* over a 10-year period. Areas with reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against reductions in probability of survival beyond 1%, 5%, and 10% (3.5, 7.4, and 13.2 kg N $ha^{-1}yr^{-1}$, respectively). The total area of each forest represents the area in which *Pseudotsuga menziesii* is expected to occur.

Forest Name	Species Area	Reduction in Probability of Survival Category ("Exceedance")								Total Area and Percent in Exceedance	
		No Exceedance (< 1%)		1-5%		5-10%		> 10%			
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	197.9	13.6	6.9	184.4	93.1	0.0	0.0	0.0	0.0	184.4	93.1
Boise NF	2087.2	331.0	15.9	1756.2	84.1	0.0	0.0	0.0	0.0	1756.2	84.1
Bridger-Teton NF	1010.8	184.0	18.2	826.8	81.8	0.0	0.0	0.0	0.0	826.8	81.8
Caribou-Targhee NF	2805.0	439.0	15.7	2242.8	80.0	123.2	4.4	0.0	0.0	2365.9	84.3
Dixie NF	273.4	26.8	9.8	246.6	90.2	0.0	0.0	0.0	0.0	246.6	90.2
Fishlake NF	111.7	9.5	8.5	102.2	91.5	0.0	0.0	0.0	0.0	102.2	91.5
Humboldt-Toiyabe NF	0.04	0.0	0.0	.04	100.0	0.0	0.0	0.0	0.0	0.04	100.0
Manti-La Sal NF	314.9	2.1	0.7	311.1	98.8	1.7	0.5	0.0	0.0	312.8	99.3
Payette NF	2431.2	2084.0	85.7	347.2	14.3	0.0	0.0	0.0	0.0	347.2	14.3
Salmon-Challis NF	5711.2	4251.4	74.4	1459.8	25.6	0.0	0.0	0.0	0.0	1459.8	25.6
Sawtooth NF	1791.5	210.9	11.8	1573.3	87.8	7.3	0.4	0.0	0.0	1580.6	88.2
Uinta-Wasatch-Cache NF	862.3	251.5	29.2	607.2	70.4	3.6	0.4	0.0	0.0	610.8	70.8

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

All eight NFs on which *Juniperus osteosperma* (Utah juniper) occurs included areas in exceedance of the CL to protect against more than a 1% reduction in probability of survival over 10 years (**Table** 5-12). Four of the NFs included more than two-thirds of the area in exceedance. Only the Uinta-Wasatch-Cache NF included areas in exceedance of the CL associated with a 5% reduction in probability of survival. Critical loads associated with reductions in *J. osteosperma* growth were not evaluated because this species showed an increasing relation between growth and N deposition.

Among all tree species evaluated, *Pinus monophylla* (singleleaf pinyon) occurred on the fewest number (n = 7) of NFs, all of which included some portion of the area (8% to 85%) in exceedance of the CL to protect against a 1% decrease in probability of survival (**Table** 5-13). Critical loads associated with reductions in *P. monophylla* growth were not evaluated because this species showed an increasing relation between growth and N deposition.

Table 5-12. Area[1] and percent of forest within various classes of reductions in probability of survival of *Juniperus osteosperma* over a 10-year period. Areas with reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against reductions in probability of survival beyond 1%, 5%, and 10% (3.9, 10.7, and 23.6 kg N $ha^{-1}yr^{-1}$, respectively). The total area of each forest represents the area in which *Juniperus osteosperma* is expected to occur.

Forest Name	Species Area	Reduction in Probability of Survival Category ("Exceedance")								Total Area and Percent in Exceedance	
		No Exceedance (< 1%)		1-5%		5-10%		> 10%			
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	395.8	124.1	31.3	271.7	68.7	0.0	0.0	0.0	0.0	271.7	68.7
Boise NF	NA										
Bridger-Teton NF	NA										
Caribou-Targhee NF	141.2	14.0	9.9	127.2	90.1	0.0	0.0	0.0	0.0	127.2	90.1
Dixie NF	1834.3	1066.2	58.1	768.0	41.9	0.0	0.0	0.0	0.0	768.0	41.9
Fishlake NF	1549.2	991.5	64.0	557.7	36.0	0.0	0.0	0.0	0.0	557.7	36.0
Humboldt-Toiyabe NF	7377.2	6058.9	82.1	1318.2	17.9	0.0	0.0	0.0	0.0	1318.2	17.9
Manti-La Sal NF	1319.0	262.7	19.9	1056.3	80.1	0.0	0.0	0.0	0.0	1056.3	80.1
Payette NF	NA										
Salmon-Challis NF	NA										
Sawtooth NF	252.6	127.5	50.5	125.1	49.5	0.0	0.0	0.0	0.0	125.1	49.5
Uinta-Wasatch-Cache NF	308.9	22.3	7.2	281.9	91.2	4.8	1.5	0.0	0.0	286.6	92.8

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

Table 5-13. Area[1] and percent of forest within various classes of reductions in probability of survival of *Pinus monophylla* over a 10-year period. Areas with reductions of < 1% are not considered to be in exceedance. Areas included in the other three classes represent areas in exceedance of critical loads to protect against reductions in probability of survival beyond 1%, 5%, and 10% (4.5, 7.4 and 10.9 kg N $ha^{-1}yr^{-1}$, respectively). The total area of each forest represents the area in which *Pinus monophylla* is expected to occur.

	Species Area	Reduction in Probability of Survival Category ("Exceedance")								Total Area and percent in Exceedance	
		No Exceedance (< 1%)		1-5%		5-10%		> 10%			
Forest Name	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley NF	395.8	175.0	44.2	220.8	55.8	0.0	0.0	0.0	0.0	220.8	55.8
Boise NF	NA										
Bridger-Teton NF	NA										
Caribou-Targhee NF	NA										
Dixie NF	1834.3	1547.4	84.4	286.9	15.6	0.0	0.0	0.0	0.0	286.9	15.6
Fishlake NF	1549.2	1427.0	92.1	122.2	7.9	0.0	0.0	0.0	0.0	122.2	7.9
Humboldt-Toiyabe NF	8704.0	7558.4	86.8	981.4	11.3	164.2	1.9	0.0	0.0	1145.6	13.2
Manti-La Sal NF	1319.0	825.2	62.6	493.4	37.4	0.4	0.0	0.0	0.0	493.8	37.4
Payette NF	NA										
Salmon-Challis NF	NA										
Sawtooth NF	252.6	209.8	83.0	42.8	17.0	0.0	0.0	0.0	0.0	42.8	17.0
Uinta-Wasatch-Cache NF	308.9	45.5	14.7	172.2	55.8	87.0	28.2	4.2	1.3	263.4	85.3

[1] area of forest expected to contain the species as dominant/co-dominant in the canopy

5.2 Results by National Forest

5.2.1 Ashley NF

5.2.1.1 Surface Water Acidification

Surface waters with relatively high risk of acidification impacts and thus the lowest CLs were located in the High Uintas Wilderness of the Ashley NF (**Figure** 5-1). Less sensitive waterbodies with higher CLs mostly occurred outside of this wilderness area. Nitrogen deposition was high enough to exceed the CL at 60% (n = 24) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if current N and S deposition rates continue. The highest magnitude of exceedance (> 5 kg N ha^{-1} yr^{-1}) generally occurred within the High Uintas Wilderness (**Figure** 5-2). Given the low representation of CLs in some portions of the Ashley NF, acid-sensitive waterbodies may occur elsewhere.

5.2.1.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout the Ashley NF and represented a total of nearly 2,600 km^2 (46%) of the forest (**Table** 5-3; **Figure** 5-3). The portion of the High Uintas Wilderness located within the Ashley NF was mostly comprised of low CLs. Areas of exceedance followed a similar pattern as the CLs and included nearly 3,400 km^2 (60%) of the forest (**Table** 5-4; **Figure** 5-4). Portions of the High Uintas Wilderness were in exceedance by more than 5 kg N ha^{-1} yr^{-1}. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.1.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 87% and 100%, respectively, of the Ashley NF (**Table**s 5-5 and 5-6). The northern portion of the forest was not in exceedance of the CL for lichen species richness and the central western portion of the forest showed the highest magnitudes of exceedance (> 5 kg N ha^{-1} yr^{-1}) for both lichen CLs (**Figures** 5-5 and 5-6). Critical load exceedance associated with 40 – 80% reductions in forage lichen abundance were common throughout the forest, including within the High Uintas Wilderness.

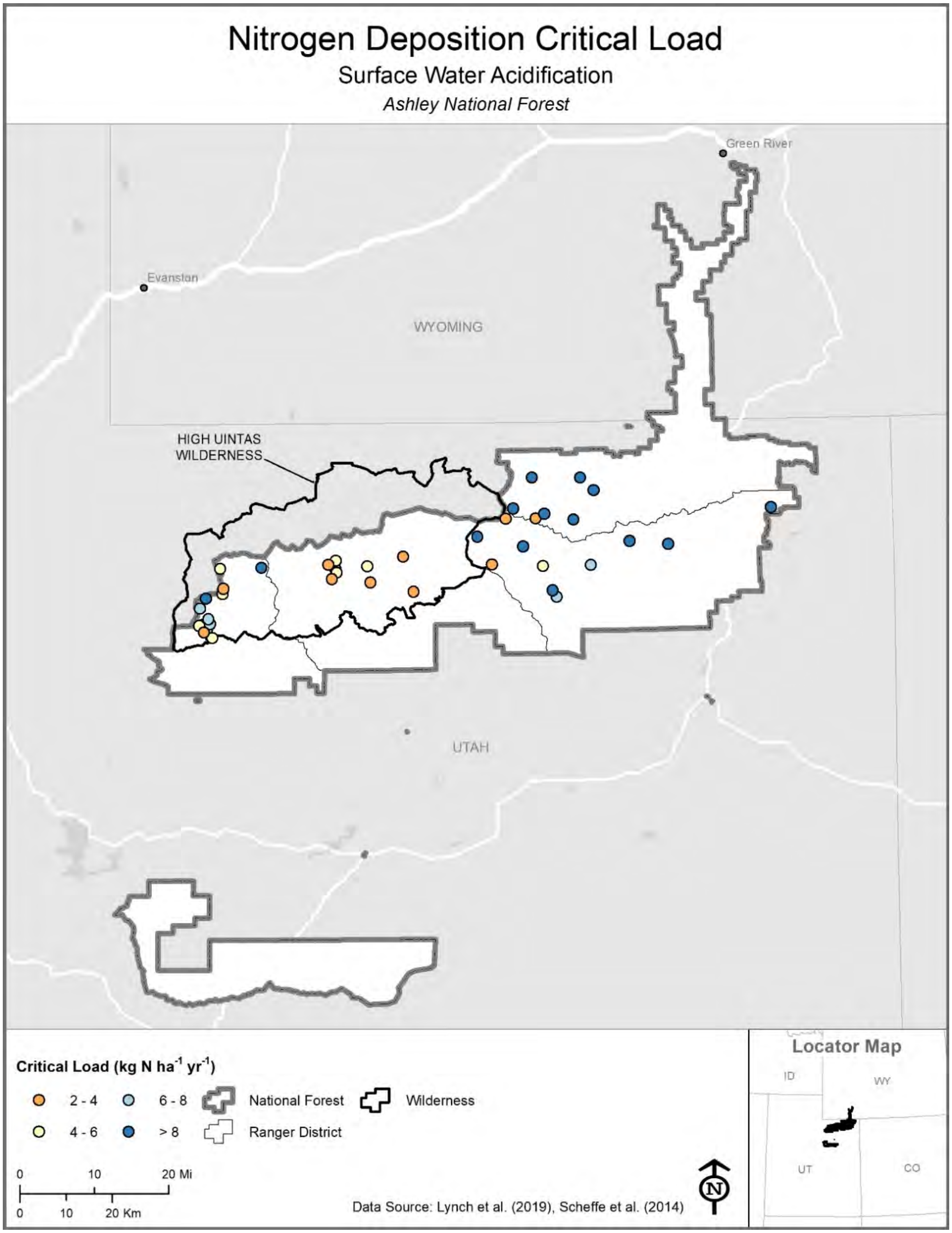

Figure 5-1. **Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Ashley National Forest.**

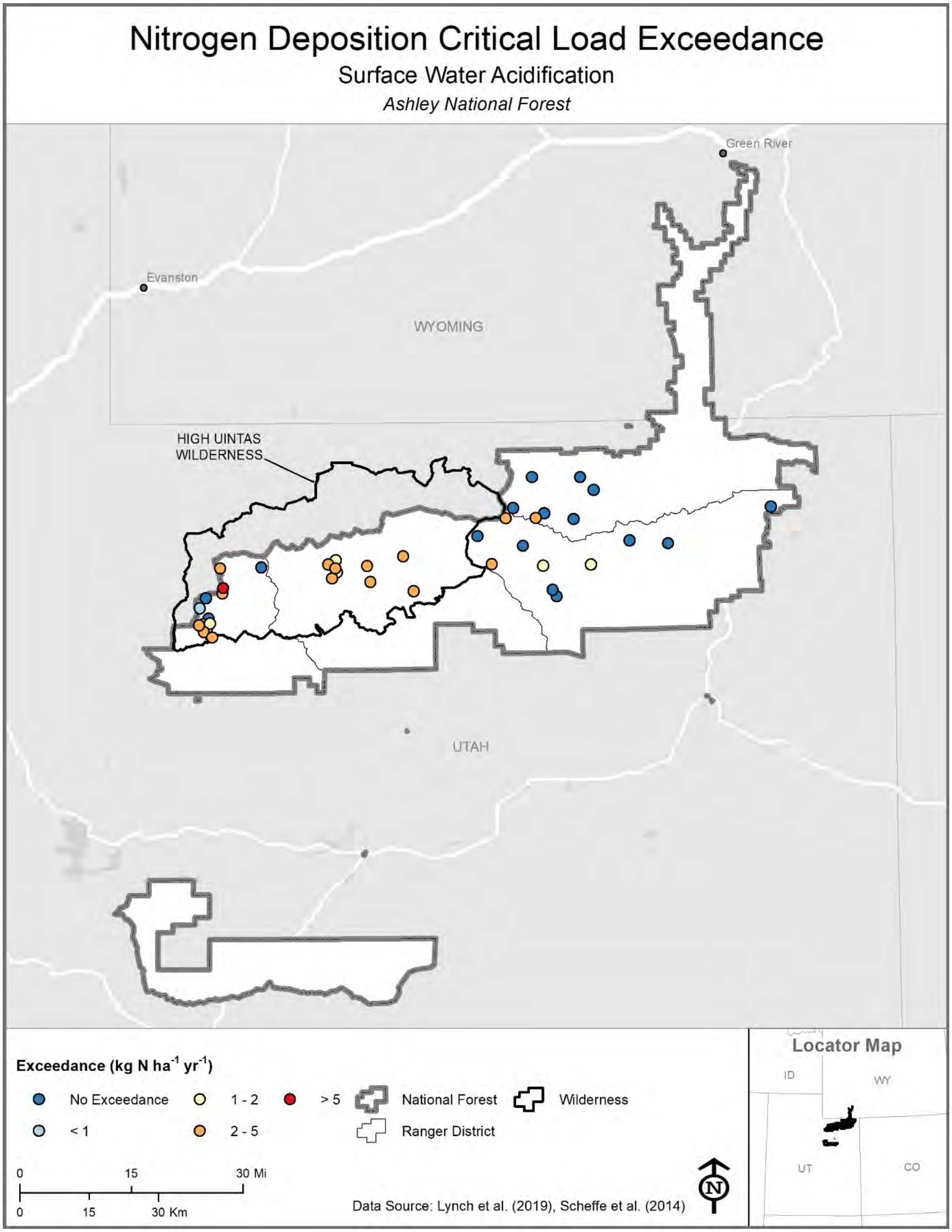

Figure 5-2. Exceedance of the critical load of nitrogen (N) for surface water acidification within the Ashley National Forest.

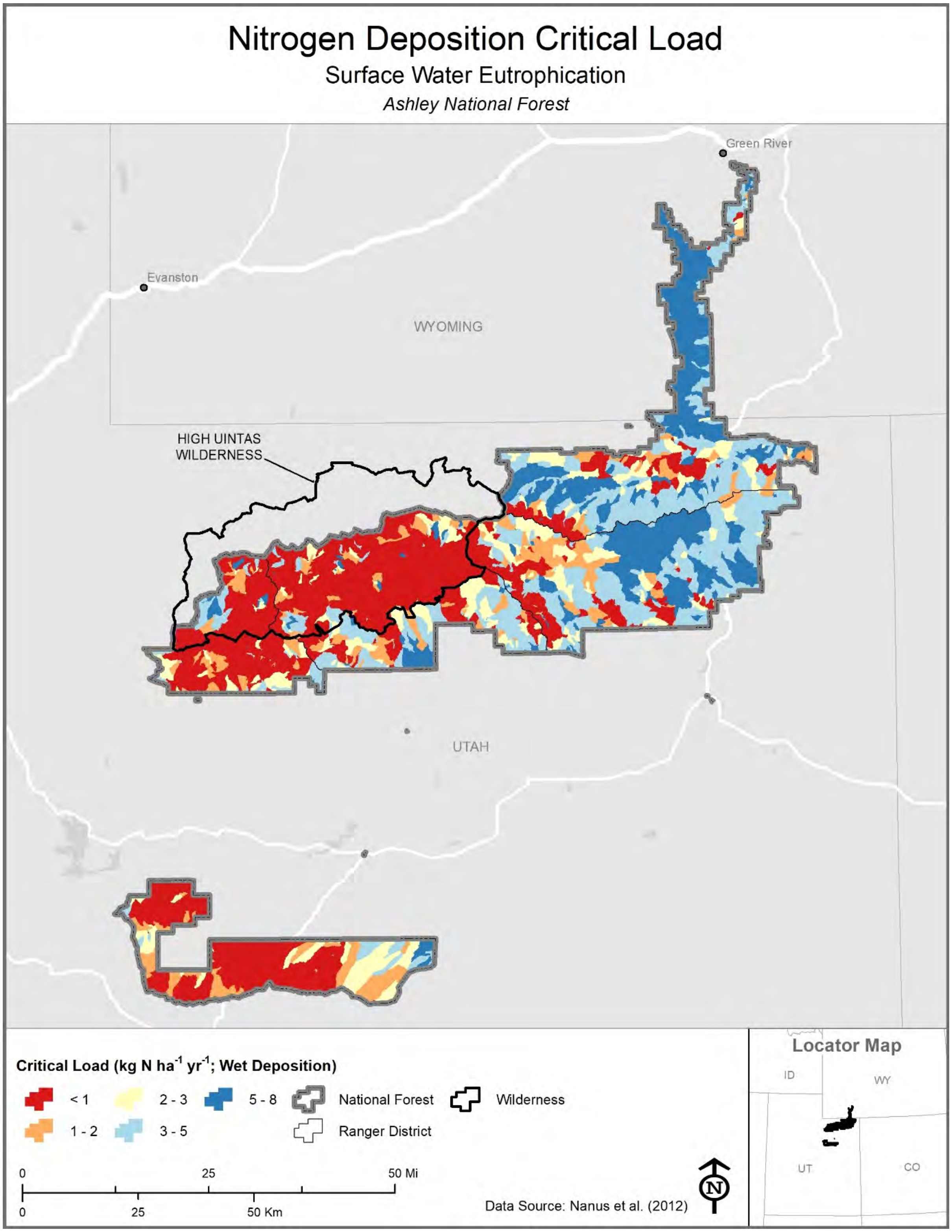

Figure 5-3. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Ashley National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

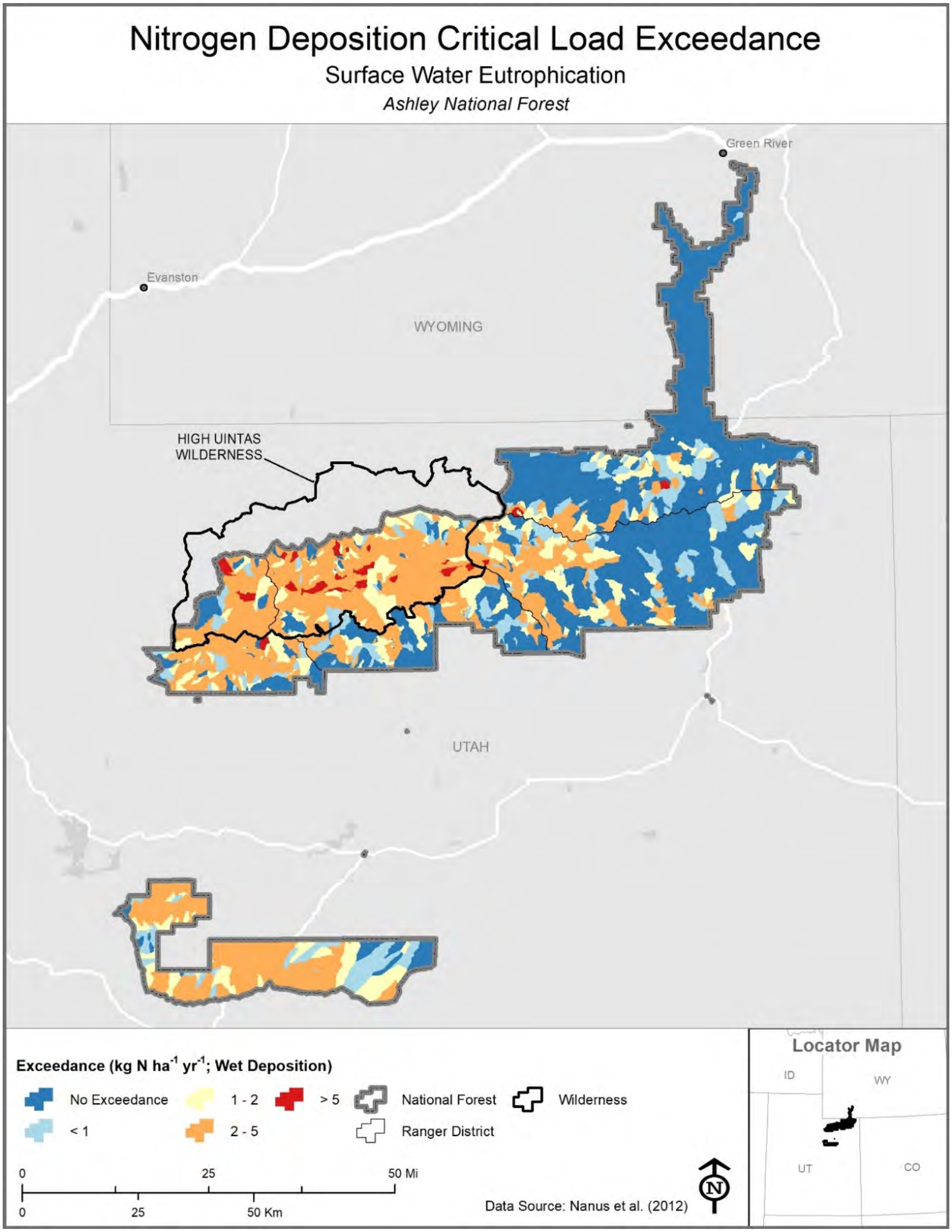

Figure 5-4. Exceedance of the critical load of nitrogen (N) for surface water eutrophication within the Ashley National Forest.

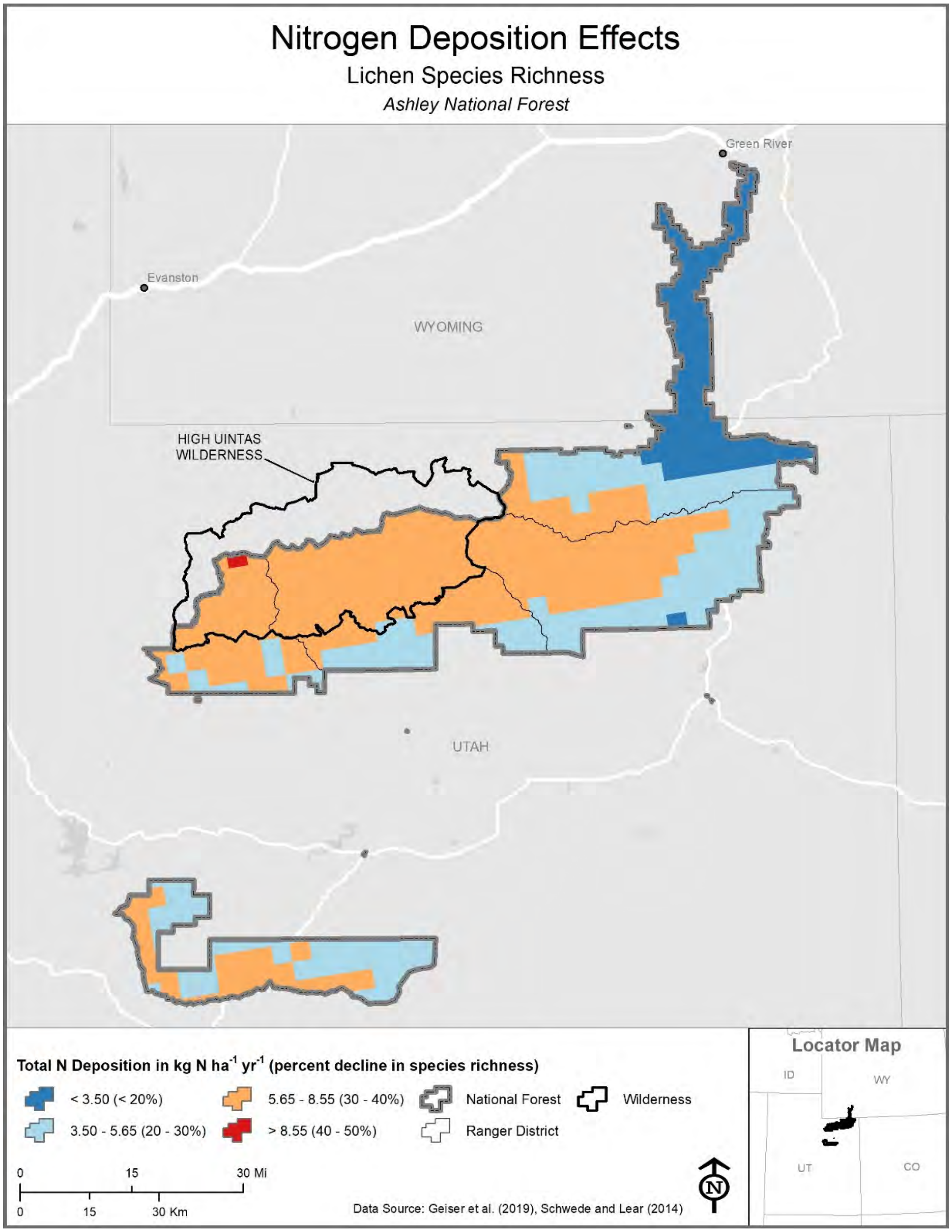

Figure 5-5. **Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Ashley National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.**

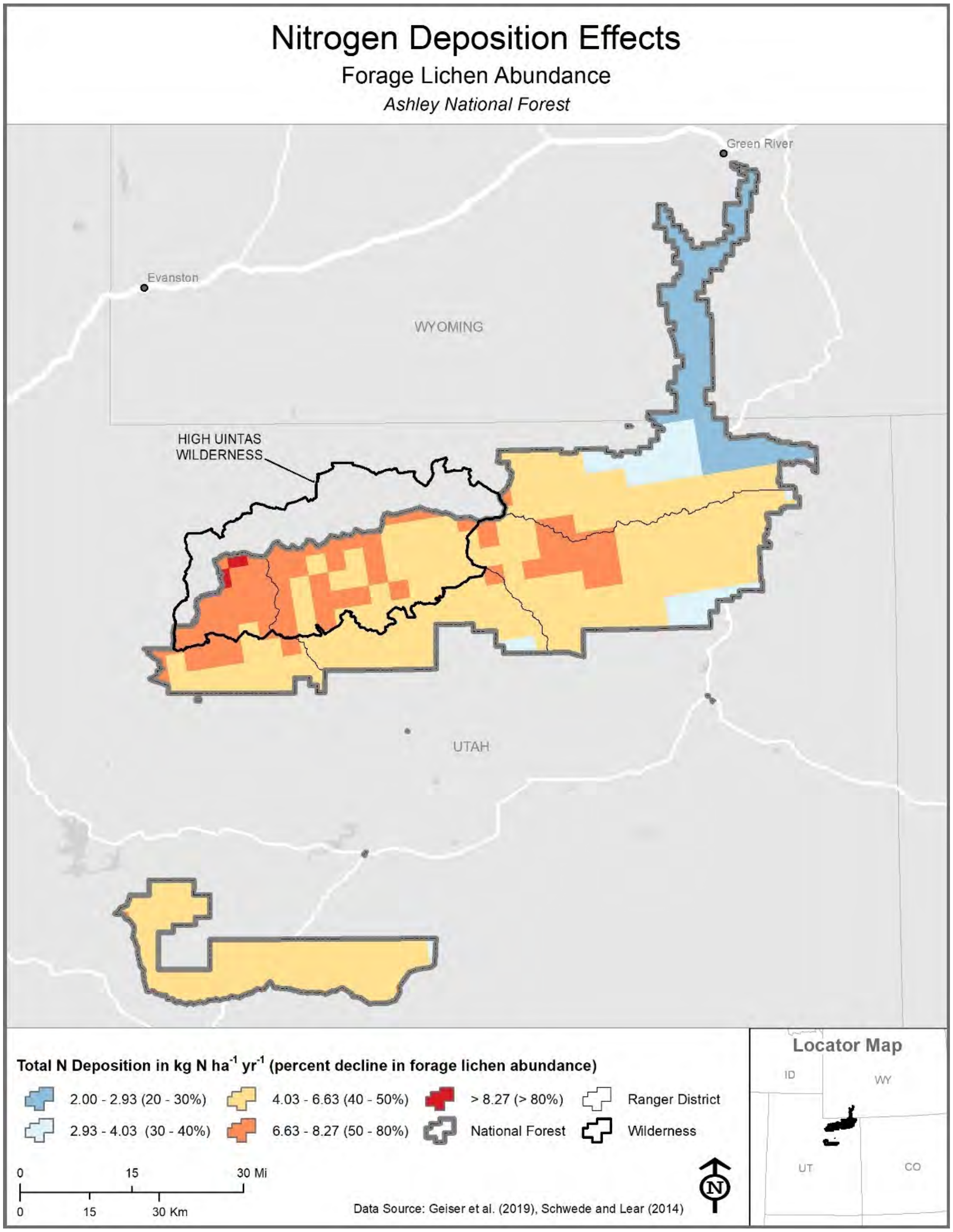

Figure 5-6. **Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Ashley National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.**

5.2.1.4 Tree Growth and Survival

Although there were no exceedances of CLs to protect the growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reduction) within 6% of the area in which this species is expected to occur in the Ashley NF (**Table**s 5-7 and 5-8; **Figure** 5-7). Although exceedance generally occurred within and in the vicinity of the High Uintas Wilderness, the majority of the population of this species occurred outside the wilderness area (**Figure** 5-8).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 93% of the area in which this species is expected to occur (**Table** 5-11). These areas of exceedance mostly occurred in the southern portion of the forest (**Figure** 5-9).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 69% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance mostly occurred in the southern portion of the forest (**Figure** 5-10).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 56% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance mostly occurred in the southern portion of the forest (**Figure** 5-11).

Other species of interest that occurred within the Ashley NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-14). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

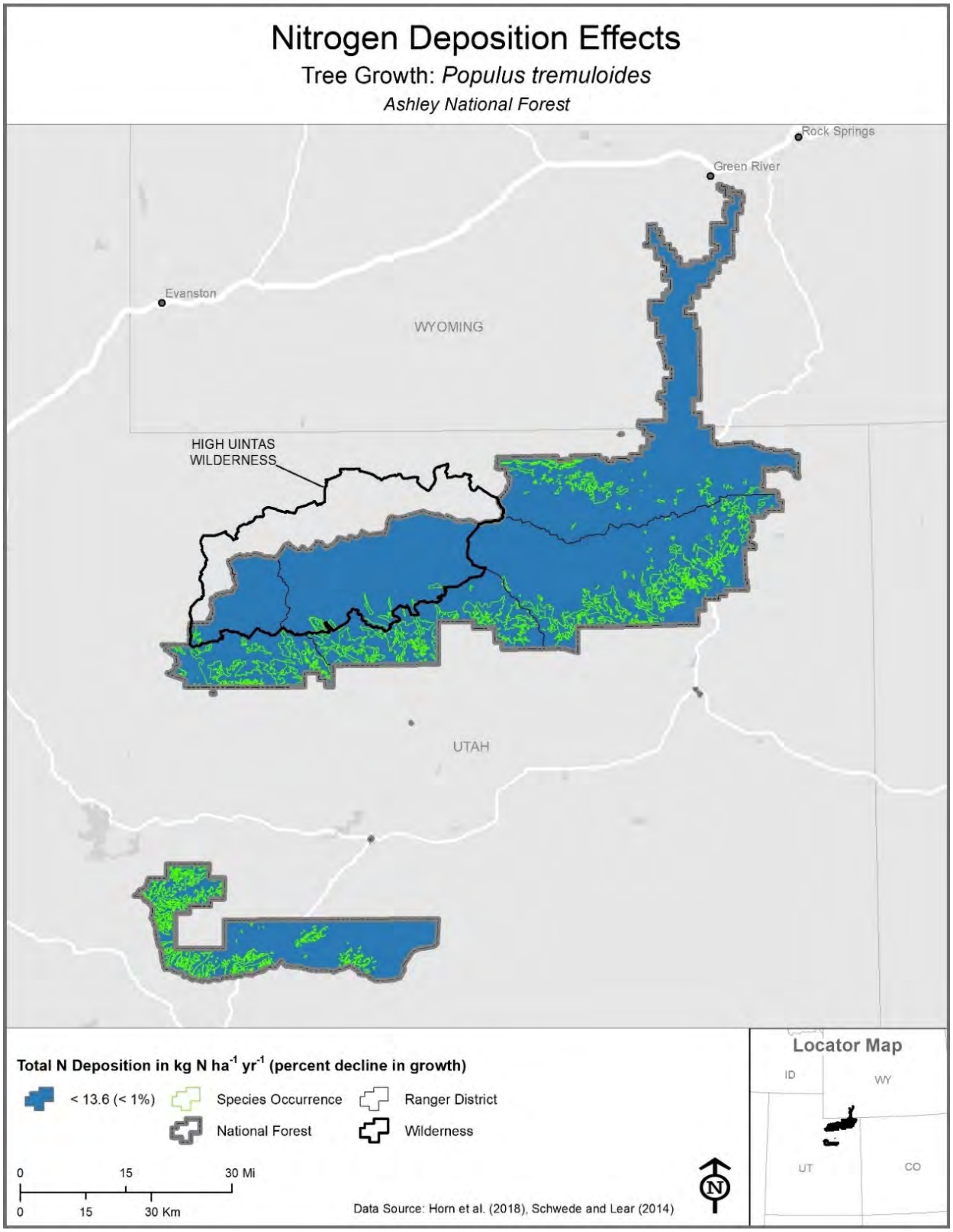

Figure 5-7. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Ashley National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Ashley NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

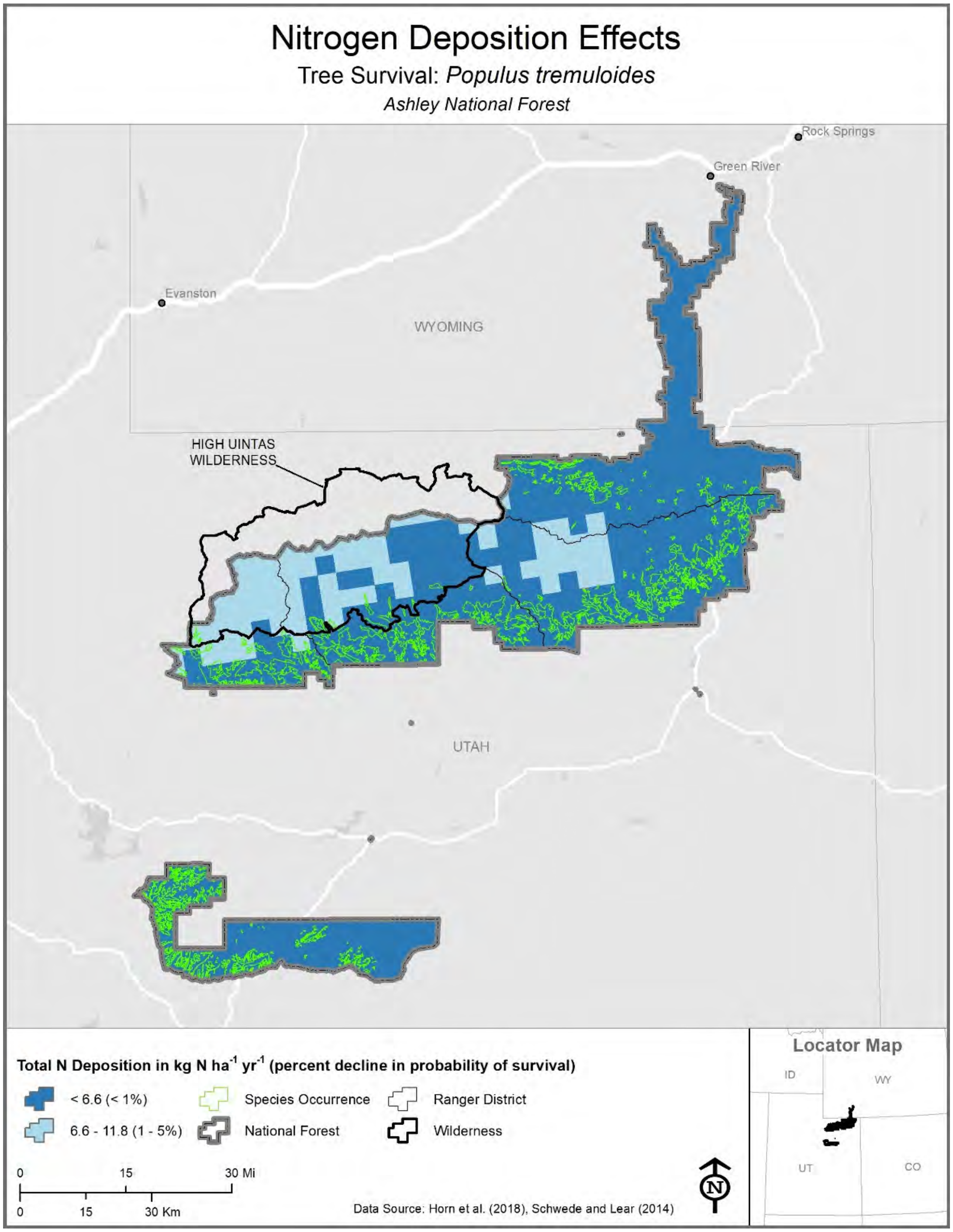

Figure 5-8. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Ashley National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

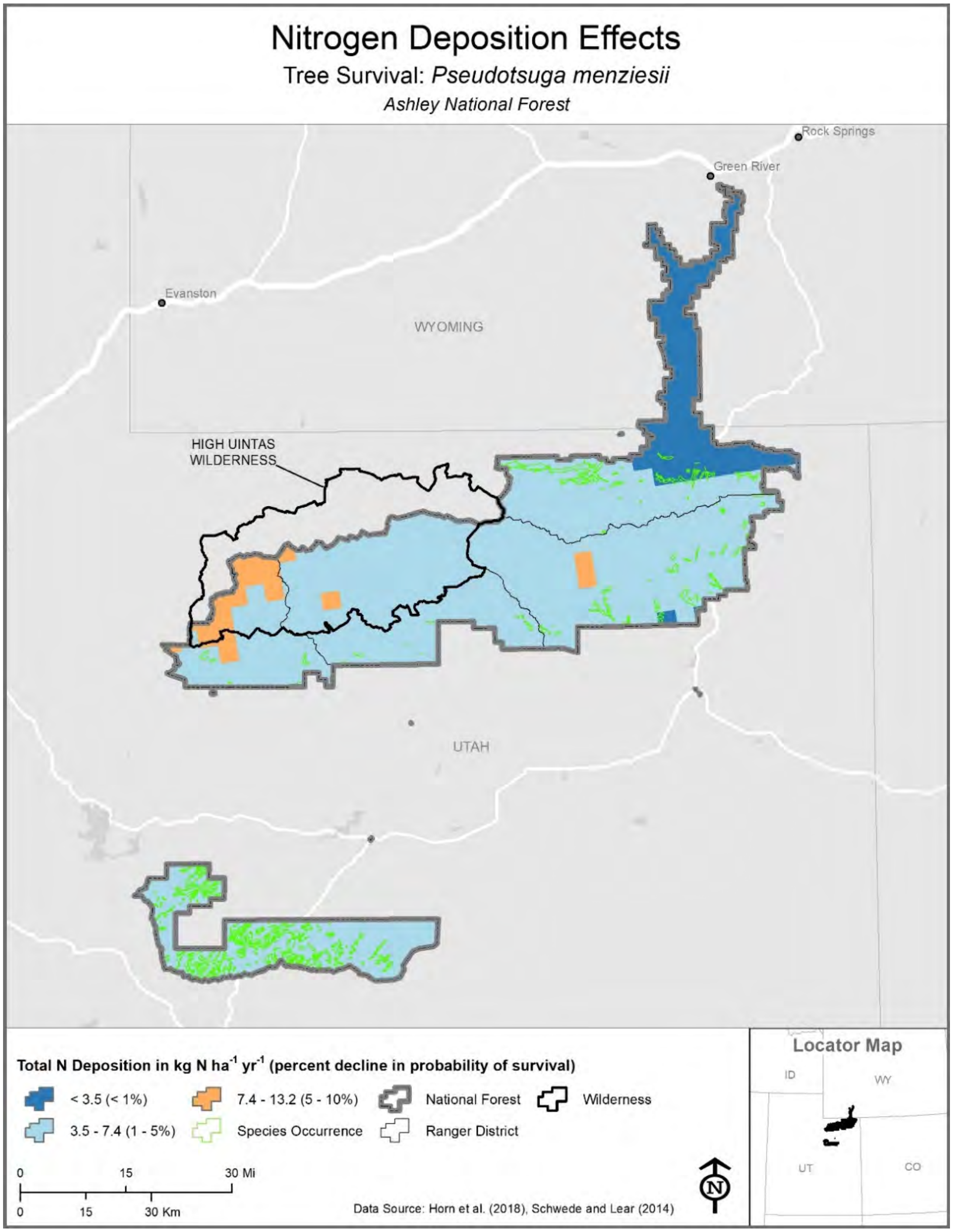

Figure 5-9. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Ashley National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

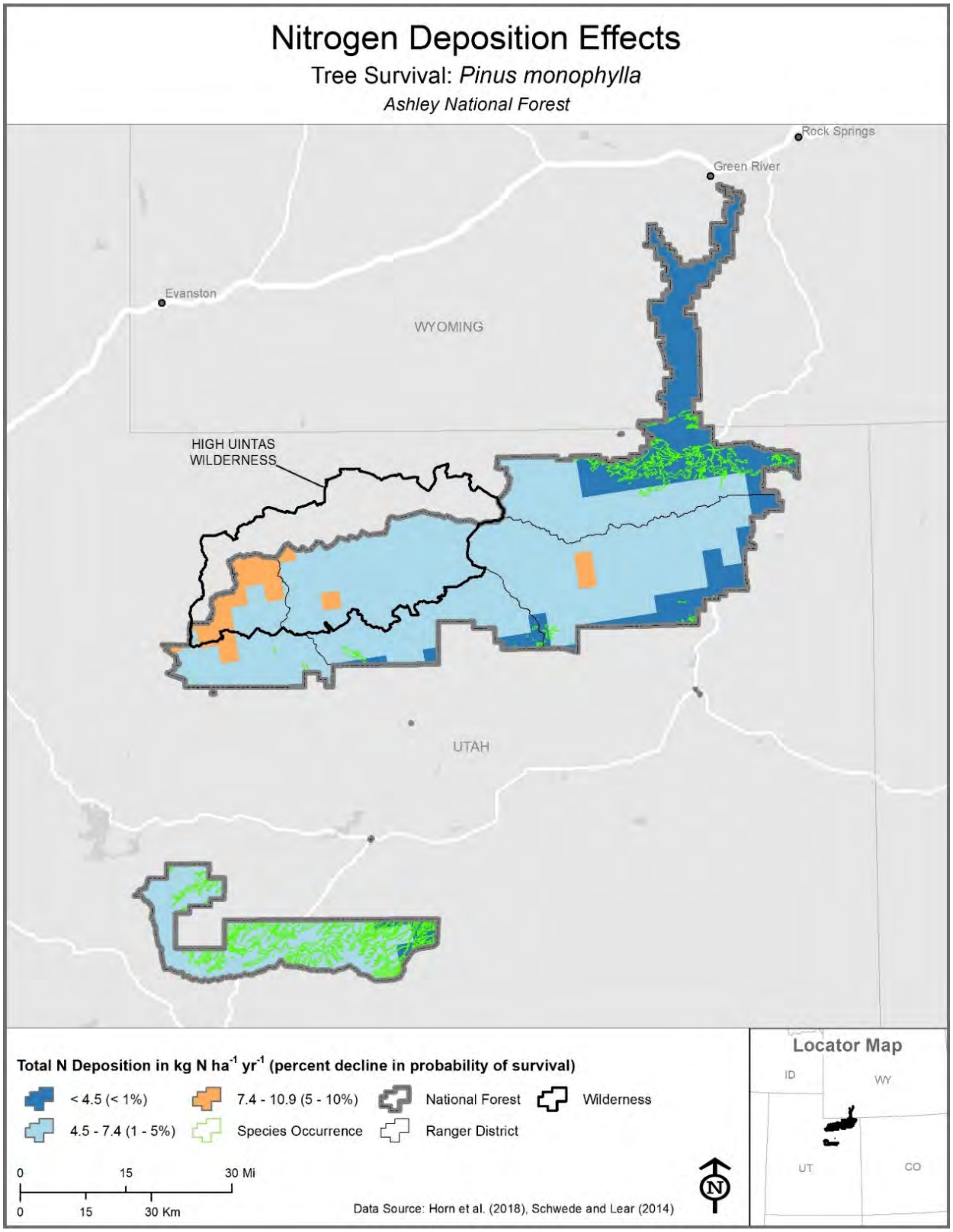

Figure 5-10. **Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Ashley National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.**

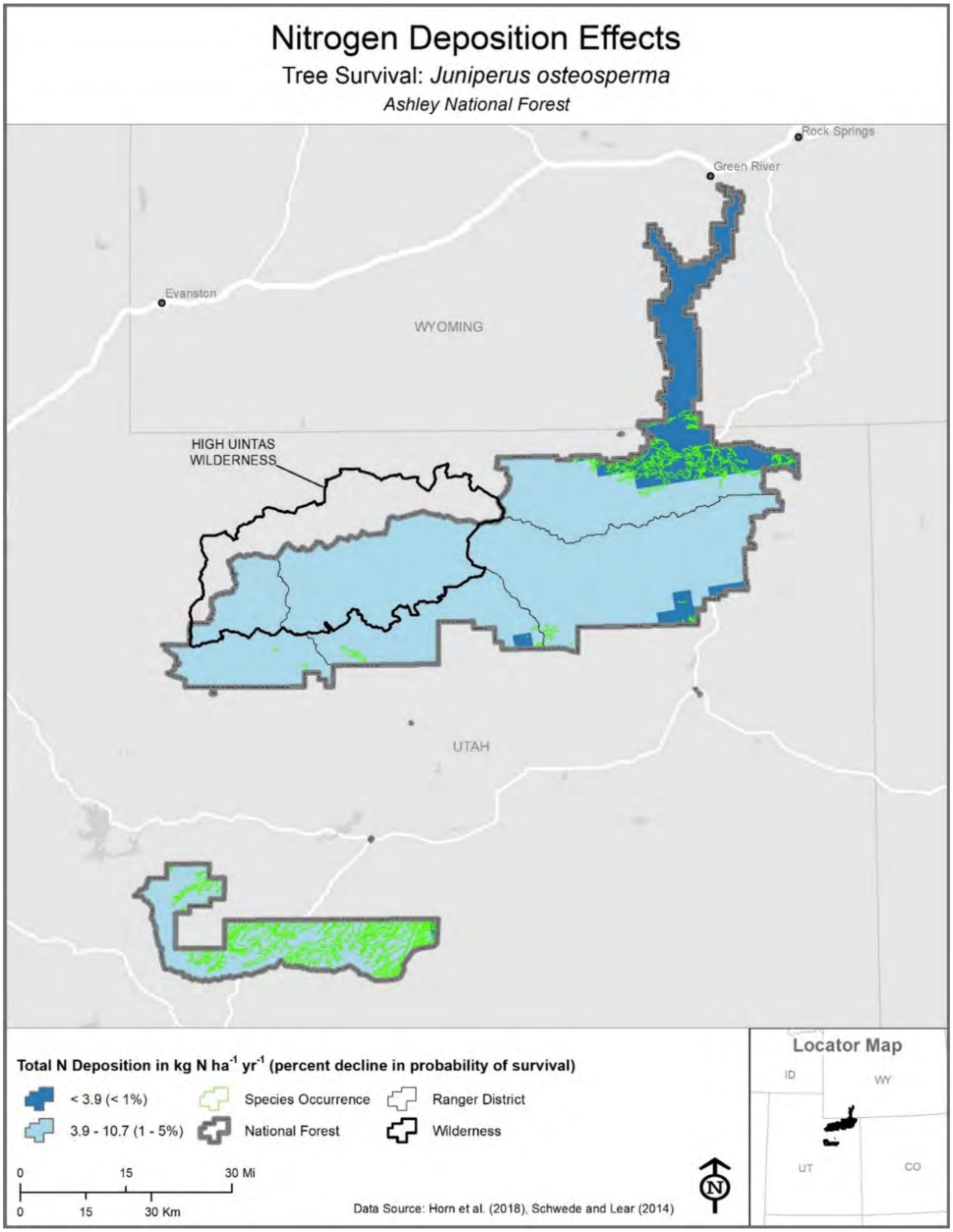

Figure 5-11. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Ashley National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-14. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Ashley National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and survival		
				1%	5%	10%
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.2 Boise NF

5.2.2.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were only available at eight locations throughout the Boise NF (**Figure** 5-12) and the waterbodies at these locations were at relatively low risk (i.e., high CLs) for acidification effects. None of these locations experienced ambient N deposition that was high enough to exceed the CL (**Table** 5-2; **Figure** 5-13). This indicates that these locations are not likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}. However, given the low representation of sites where CLs have been calculated, acid-sensitive waterbodies may occur elsewhere within the Boise NF.

5.2.2.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout most of the Boise NF and represented a total of nearly 6,170 km^2 (63%) of the forest (**Table** 5-3; **Figure** 5-14). Areas of exceedance followed a generally similar pattern as the CLs and included nearly 6,650 km^2 (68%) of the forest (**Table** 5-4; **Figure** 5-15). The highest magnitudes of exceedance (2 – 5 kg N ha^{-1} yr^{-}1) were common throughout the forest. Areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.2.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 70% and 100%, respectively, of the Boise NF (**Table**s 5-5 and 5-6). The western portion of the forest was mostly not in exceedance of the CL for lichen species richness and the eastern portion of the forest showed the highest magnitudes of exceedance (> 2 kg N ha^{-1} yr^{-1}) for both CLs (**Figures** 5-16 and 5-17). Critical load exceedance associated with 30 – 50% reductions in forage lichen abundance were common throughout the forest.

5.2.2.4 Tree Growth and Survival

Total N deposition did not exceed CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within any of the area in which this species is expected to occur within the Boise NF (**Table**s 5-7 and 5-8; **Figures** 5-18 and 5-19).

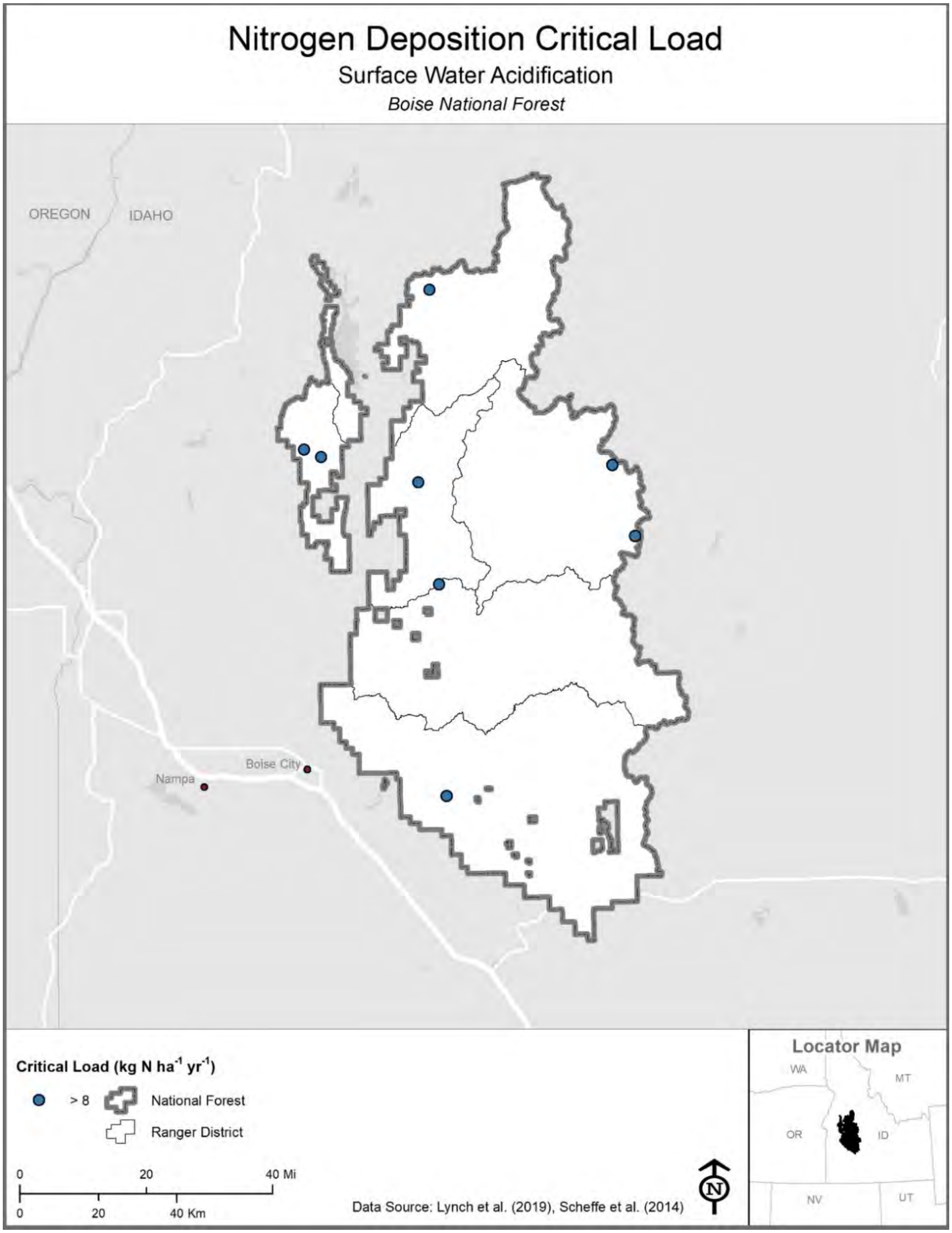

Figure 5-12. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Boise National Forest.

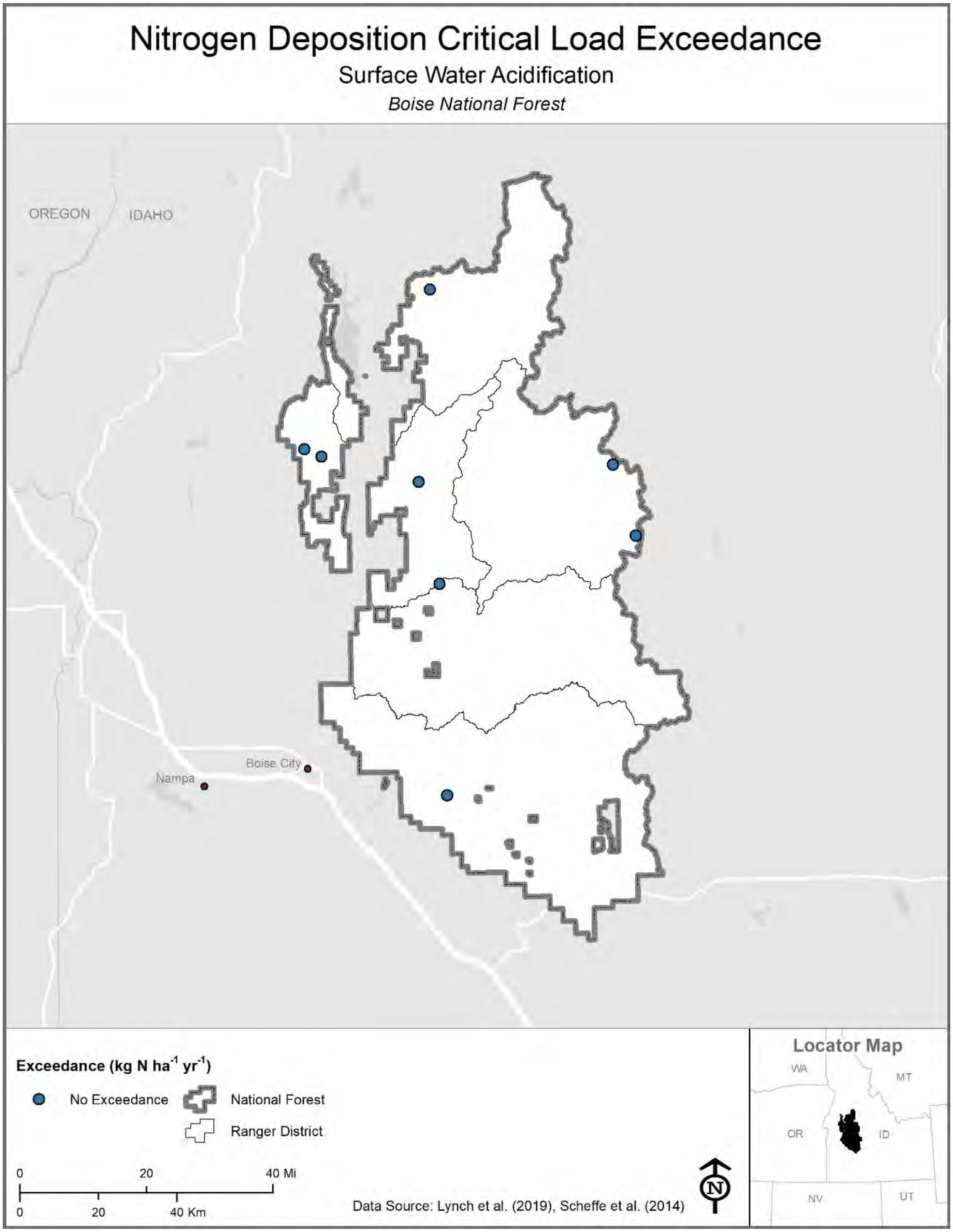

Figure 5-13. Map of the Boise National Forest showing no exceedance of the critical load of nitrogen (N) for surface water acidification.

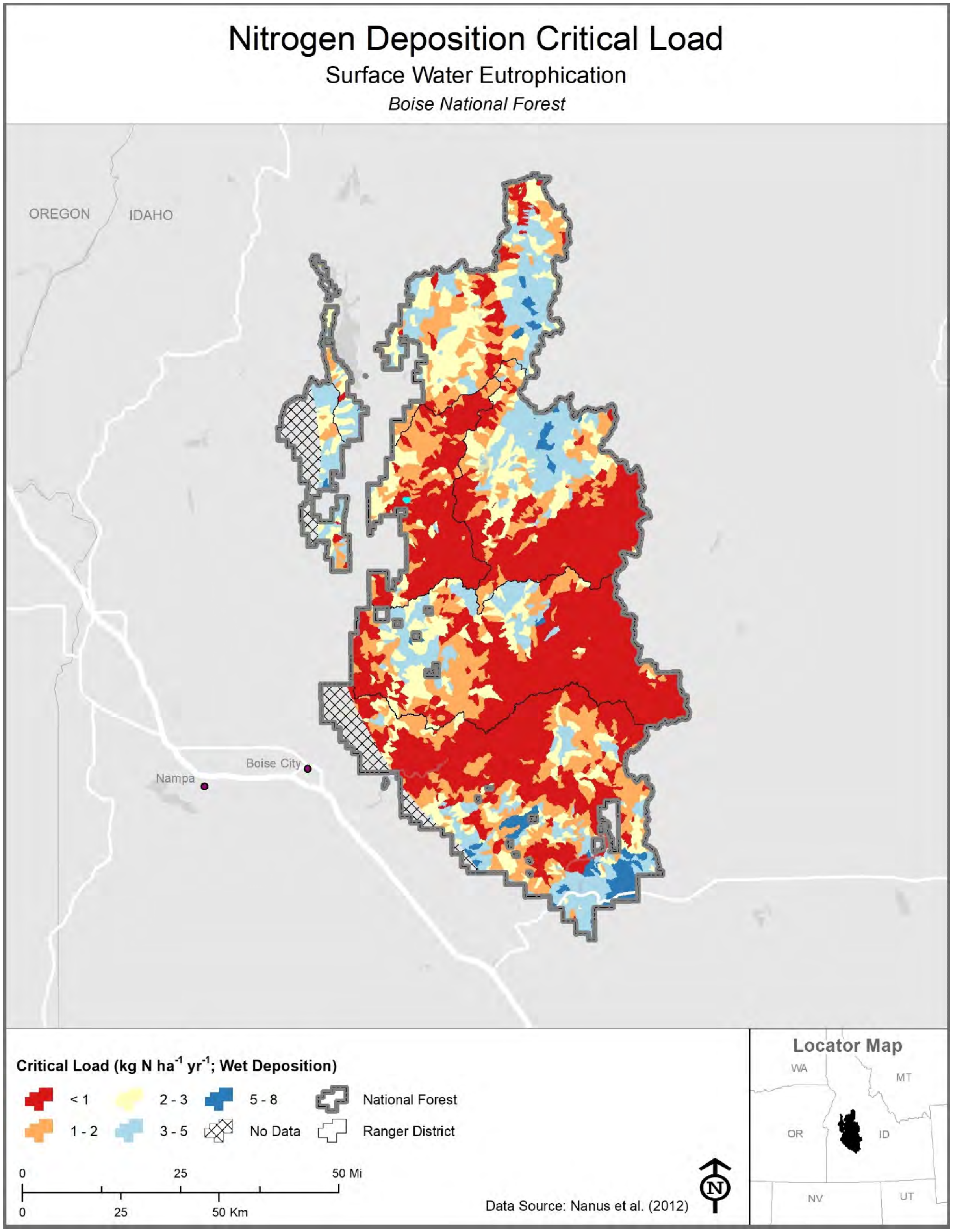

Figure 5-14. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Boise National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

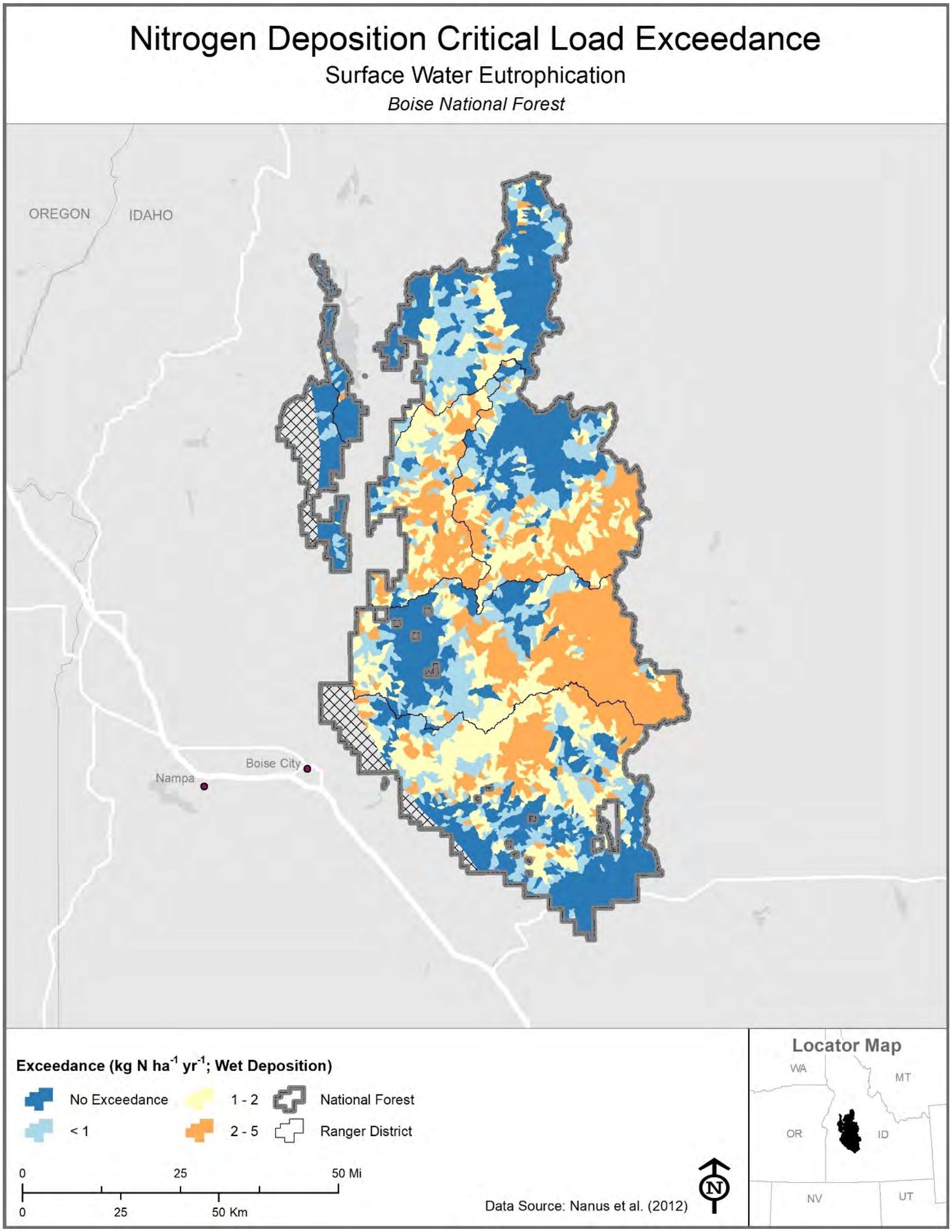

Figure 5-15. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Boise National Forest.

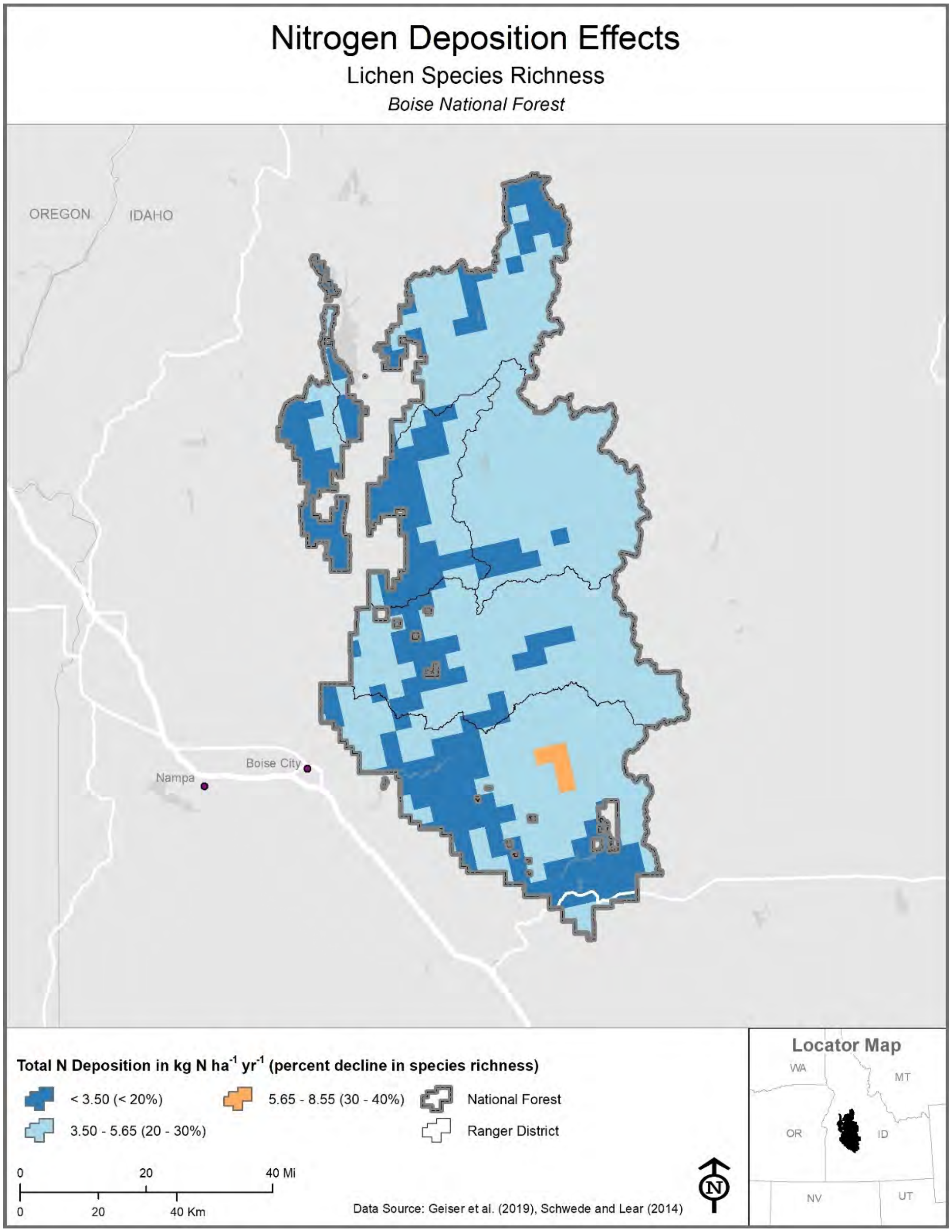

Figure 5-16. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Boise National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

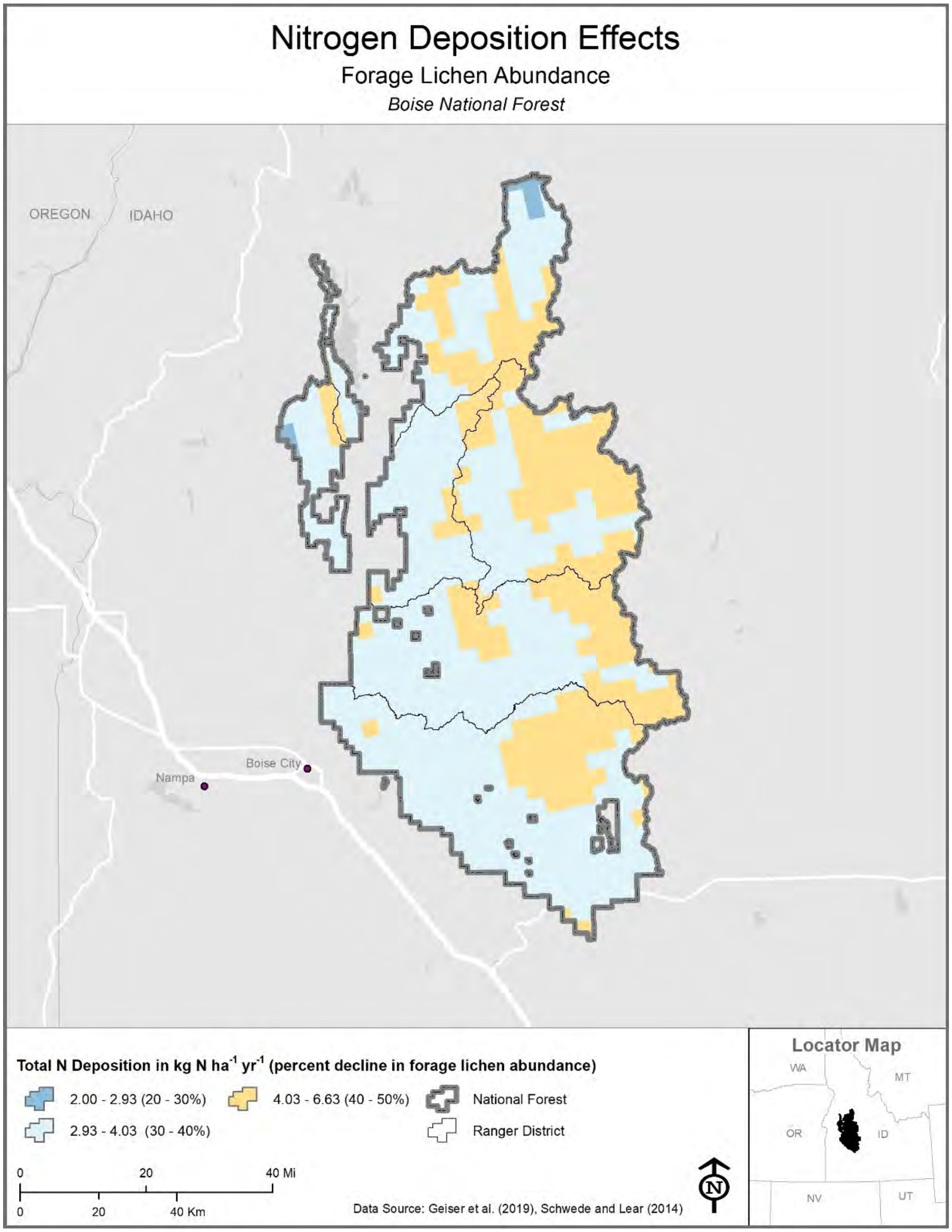

Figure 5-17. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Boise National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in forage lichen abundance.

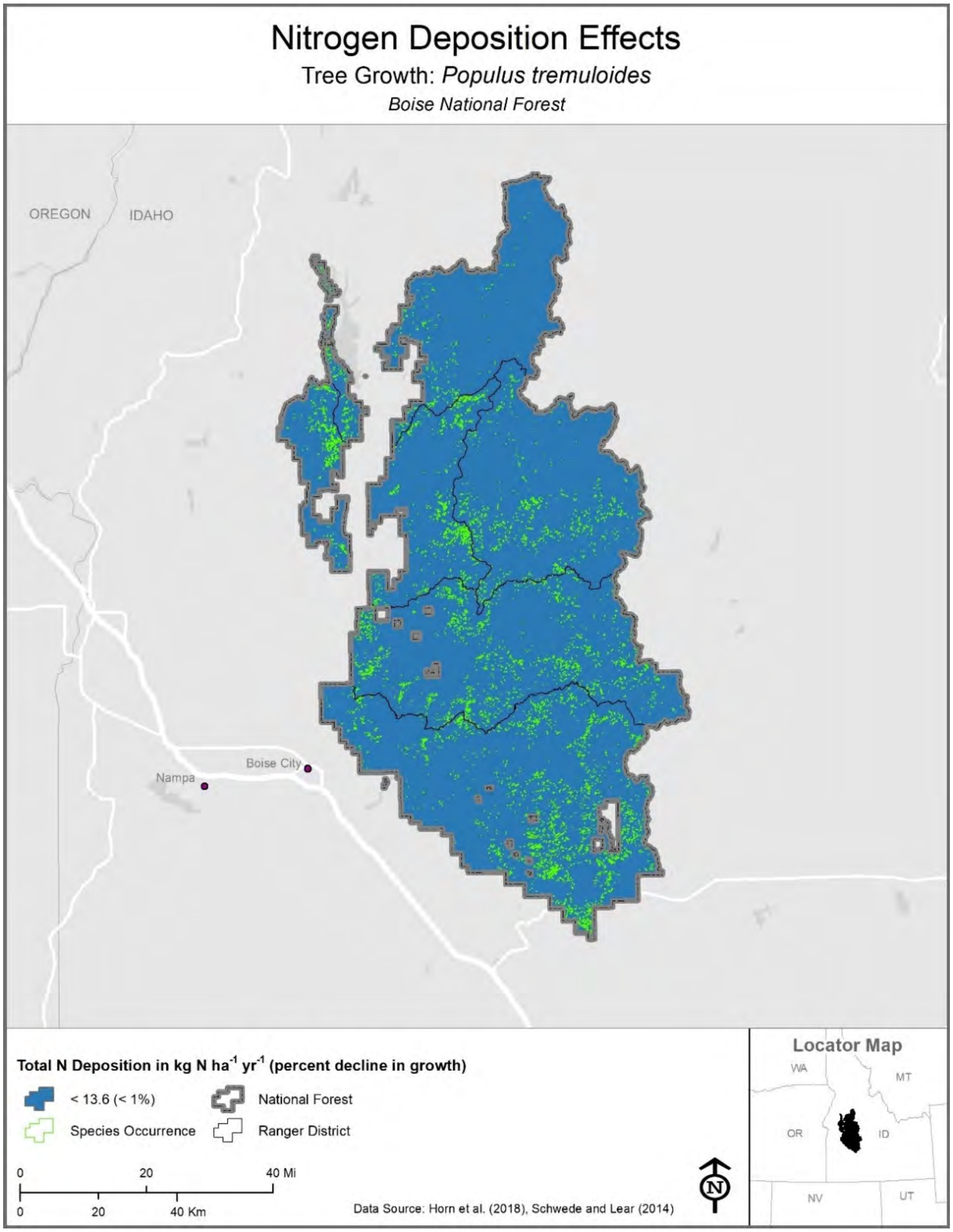

Figure 5-18. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Boise National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Boise NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

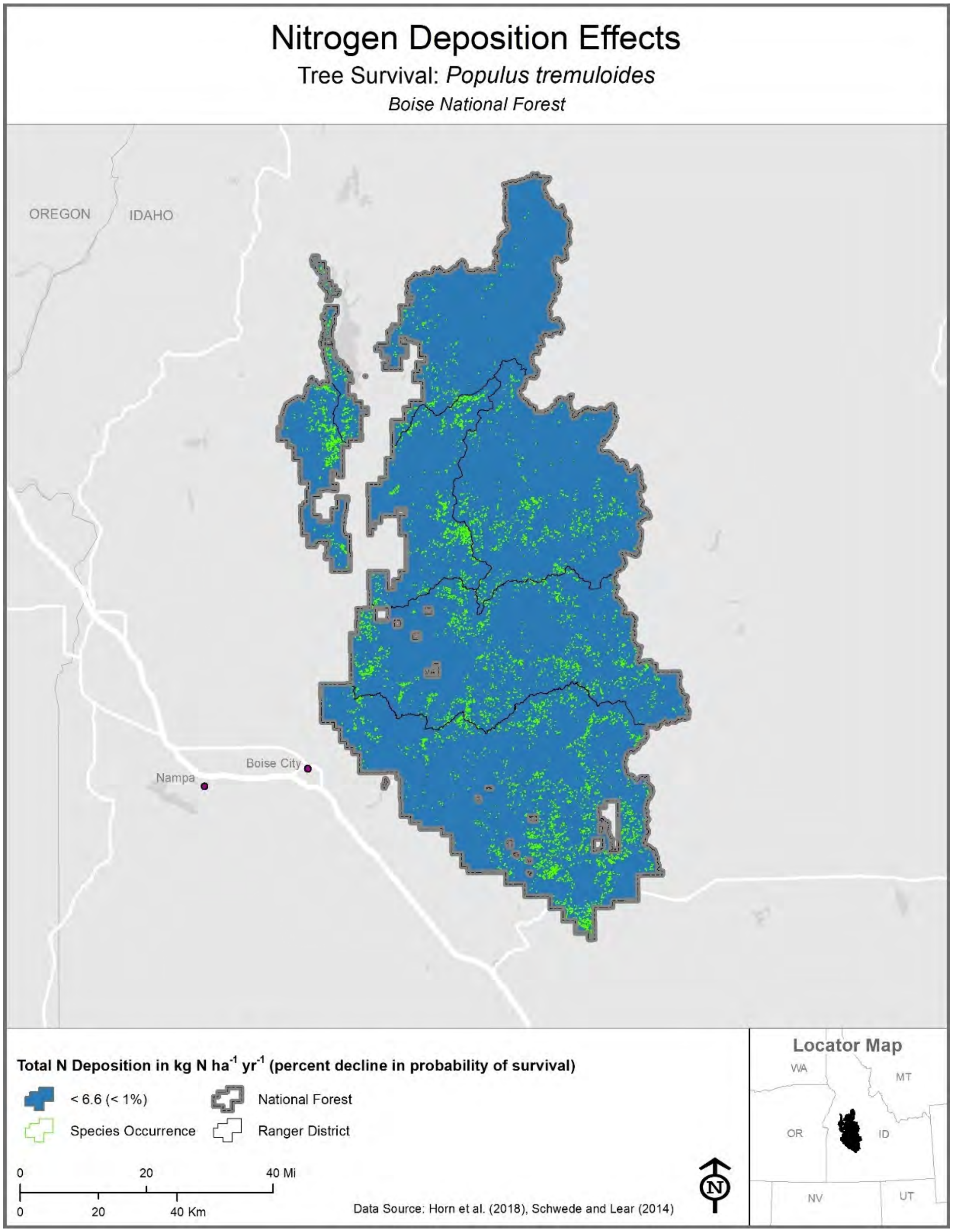

Figure 5-19. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Boise National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Boise NF is below the critical load for 1% reduction in probability of survival of *P. tremuloides.*

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 79% and 2%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Decreases in growth of 5 – 10% were mostly expected to occur in the eastern portion of the forest and the highest growth effects (> 10% reduction) were expected in the southern portion of the forest (**Figure** 5-20). Reductions in probability of survival of 1 – 5% were limited to relatively small areas of the eastern and southern portions of the forest (**Figure** 5-21).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 84% of the area in which this species is expected to occur (**Table** 5-11). These areas of exceedance were common throughout the forest (**Figure** 5-22).

Other species of interest that occurred within the Boise NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-15). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

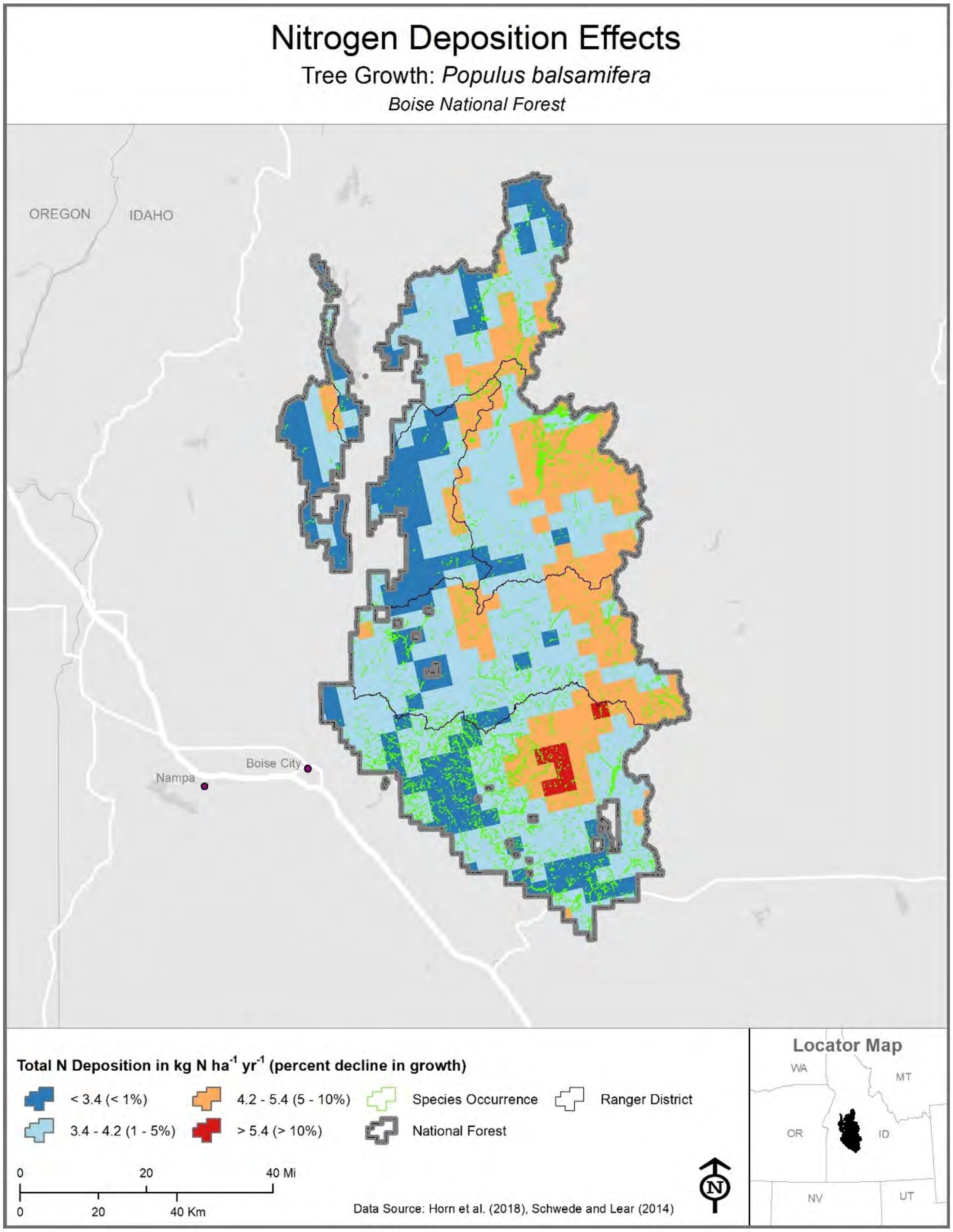

Figure 5-20. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Boise National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

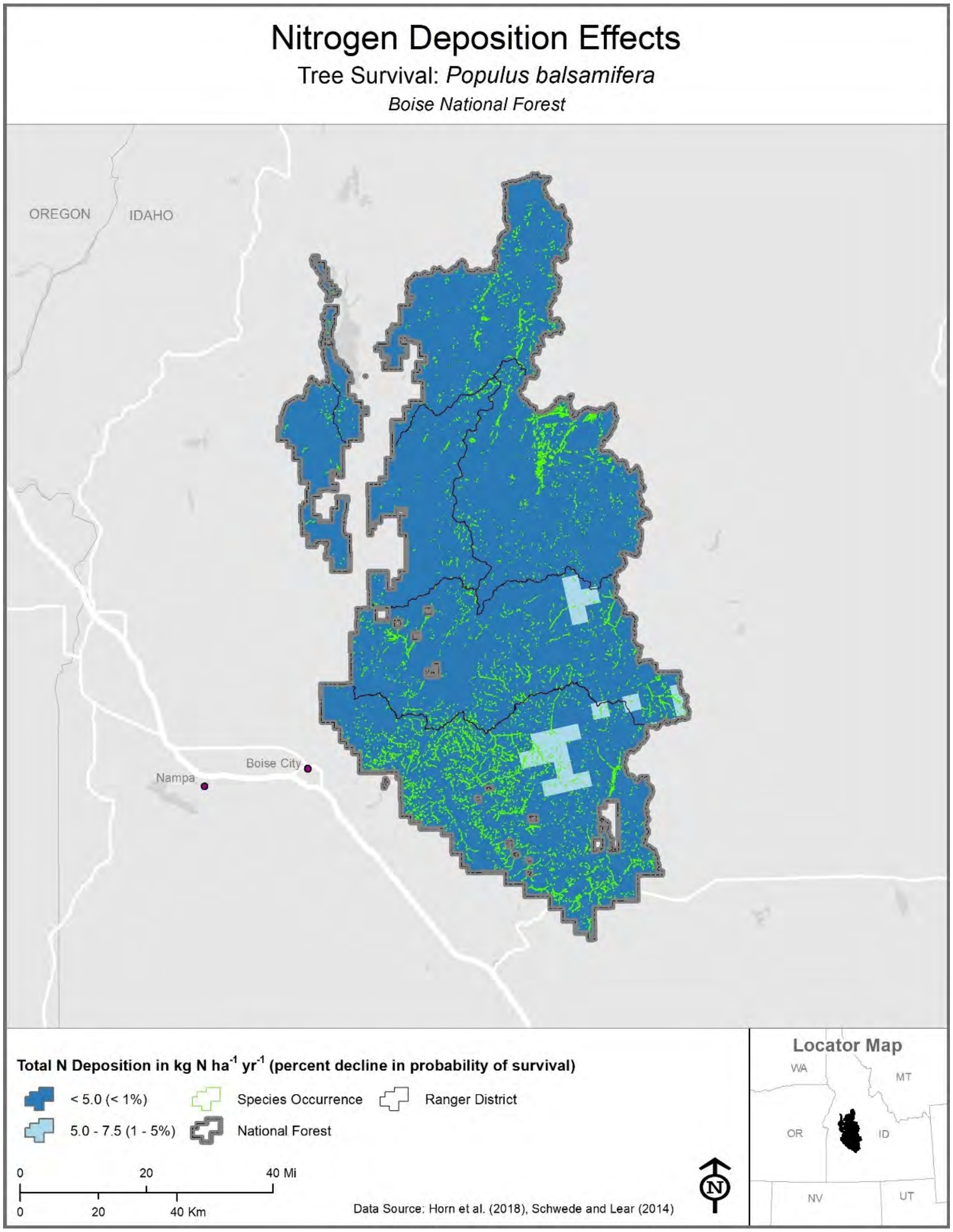

Figure 5-21. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Boise National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

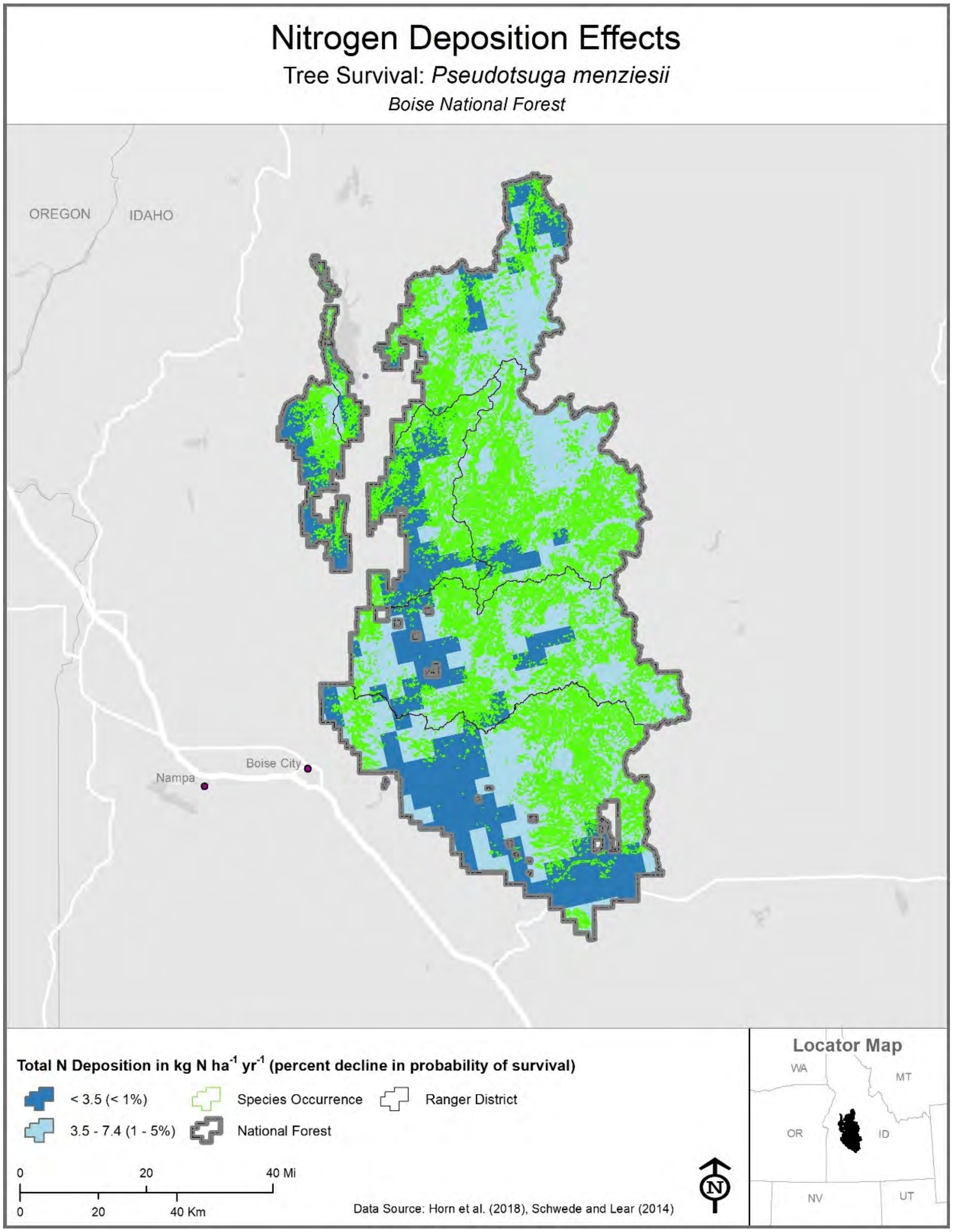

Figure 5-22. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Boise National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-15. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Boise National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies grandis	grand fir	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Larix occidentalis	western larch	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.3 Bridger-Teton NF

5.2.3.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were varied and broadly distributed throughout the Bridger-Teton NF (**Figure** 5-23). Surface waters with relatively high risk of acidification impacts (i.e., low CLs) were mostly located within the Bridger Wilderness and less sensitive (i.e., higher CLs) waterbodies occurred throughout the forest, including within the Bridger Wilderness. Ambient N deposition was high enough to exceed the CL at 30% (n = 61) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 µeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. The highest magnitudes of exceedance (2 – 5 kg N ha^{-1} yr^{-1}) most often occurred within the Bridger Wilderness (**Figure** 5-24). Due to the density of sites in the Bridger Wilderness, expanded views of these CLs and CL exceedances are shown in **Figures** 5-25 and 5-26, respectively. Given the low representation of sites where CLs are calculated in some portions of the Bridger-Teton NF, acid-sensitive waterbodies may occur elsewhere.

5.2.3.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication within the Bridger-Teton NF were mostly concentrated in the Teton Wilderness and Bridger Wilderness and represented a total of more than 1,400 km^2 (10%) of the forest (**Table** 5-3; **Figure** 5-27). However, nearly all the forest (12,682 km^2; 90%; **Table** 5-4) was in exceedance, including most of the Teton Wilderness, Bridger Wilderness, and Gros Ventre Wilderness (**Figure** 5-28). Portions of the Teton Wilderness and Bridger Wilderness were in exceedance by more than 5 kg N ha^{-1} yr^{-1}. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.3.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 80% and 100%, respectively, of the Bridger-Teton NF (**Table**s 5-5 and 5-6). The central eastern portion of the forest was mostly not in exceedance of the CL for lichen species richness and the northern and western portions of the forest generally showed the highest

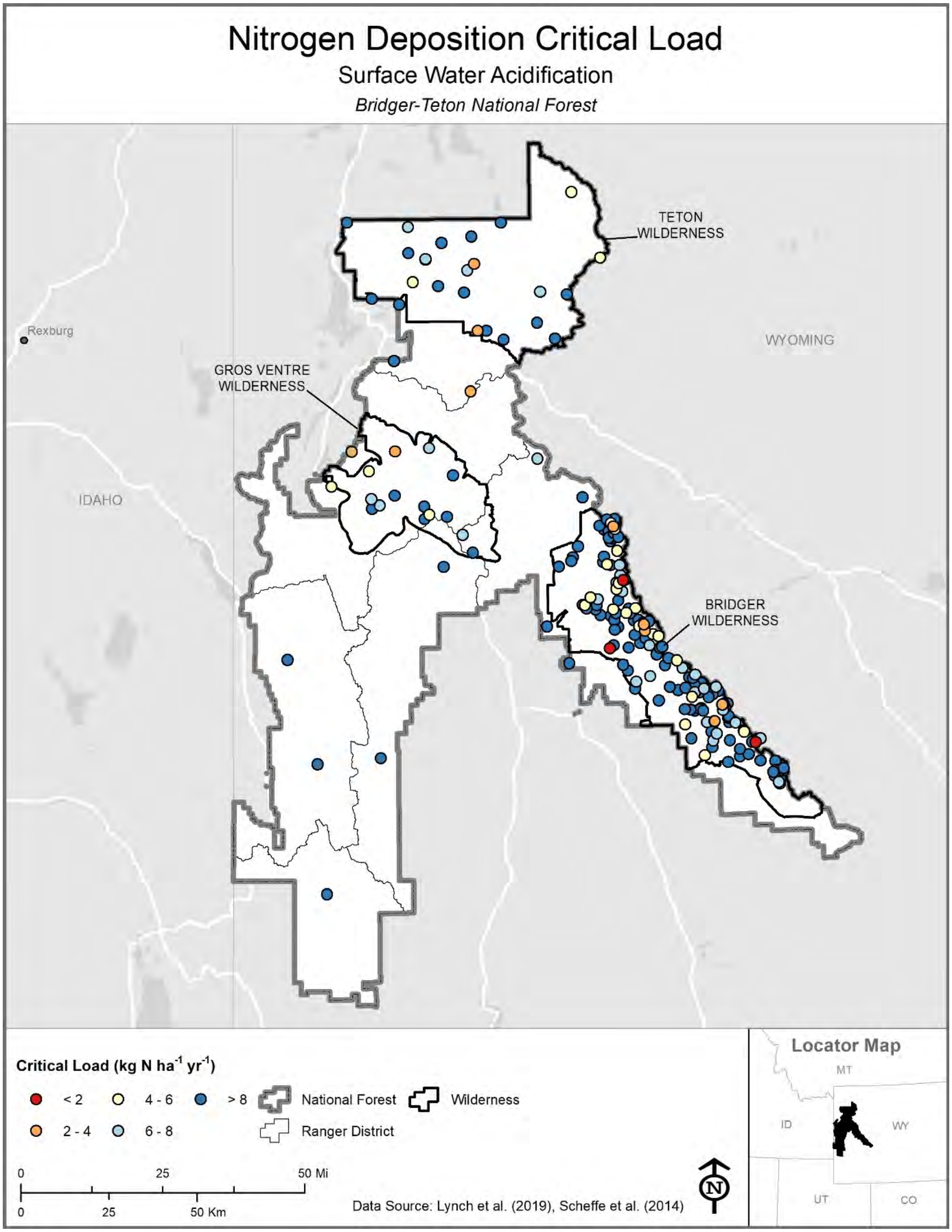

Figure 5-23. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Bridger-Teton National Forest.

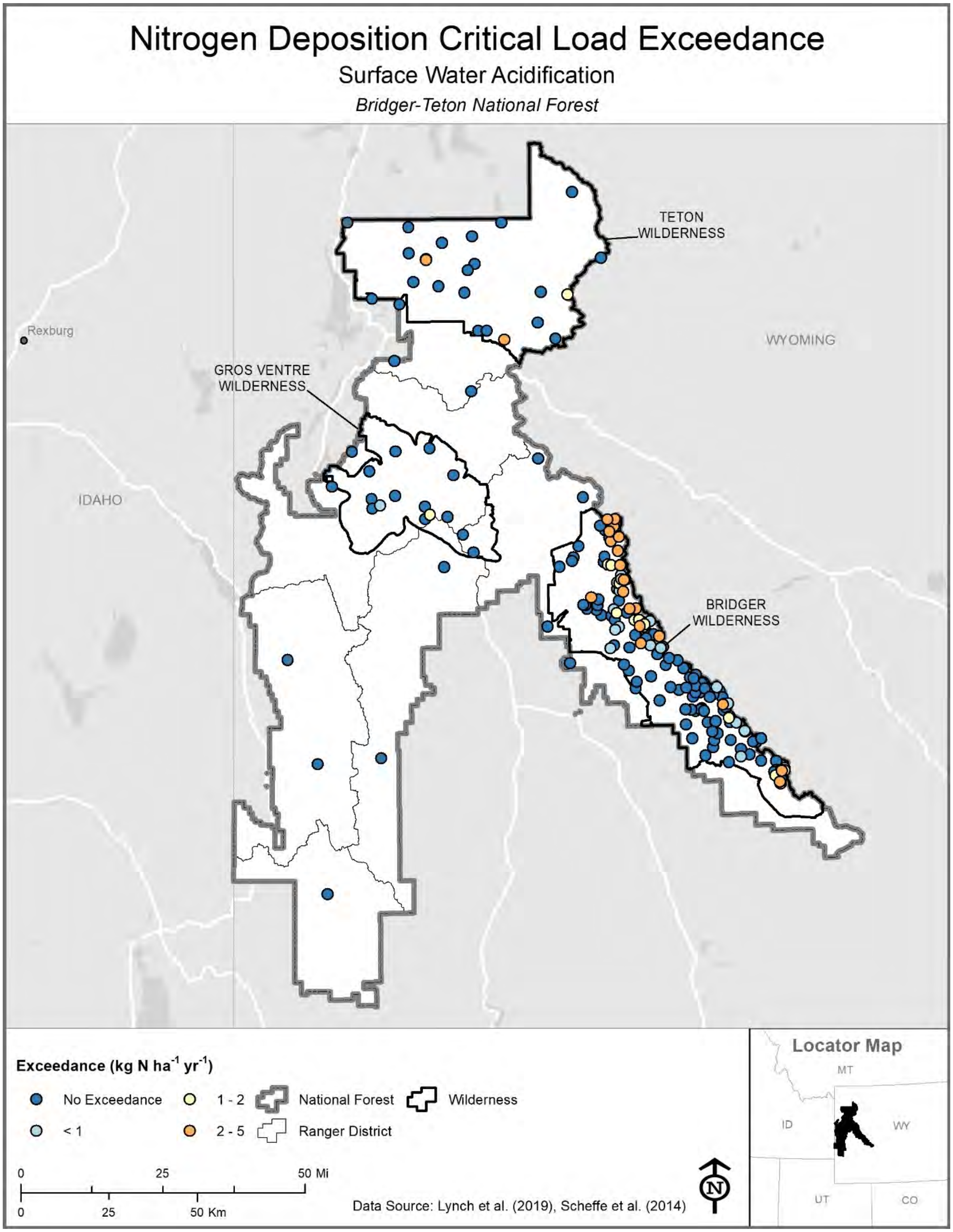

Figure 5-24. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Bridger-Teton National Forest.

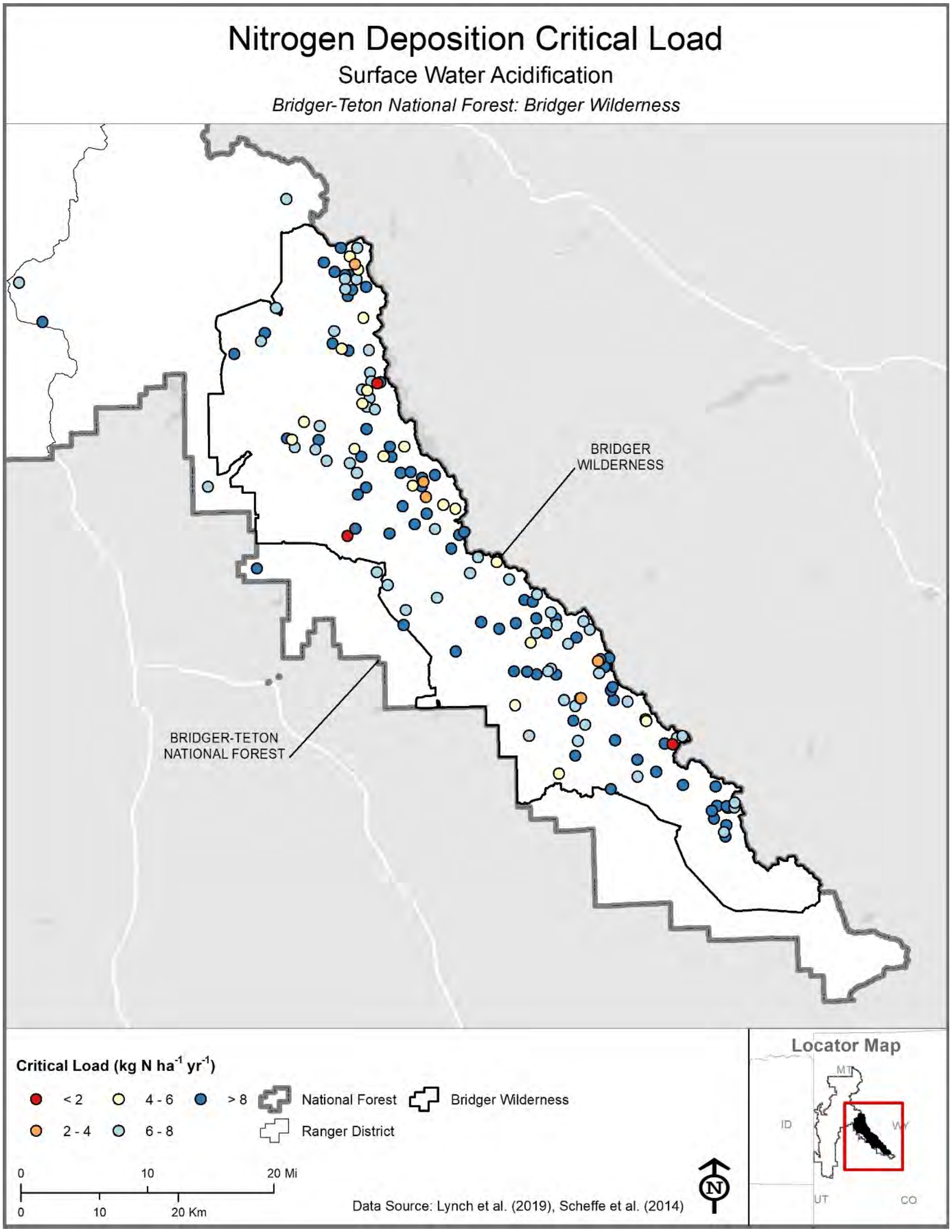

Figure 5-25. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Bridger Wilderness of Bridger-Teton National Forest.

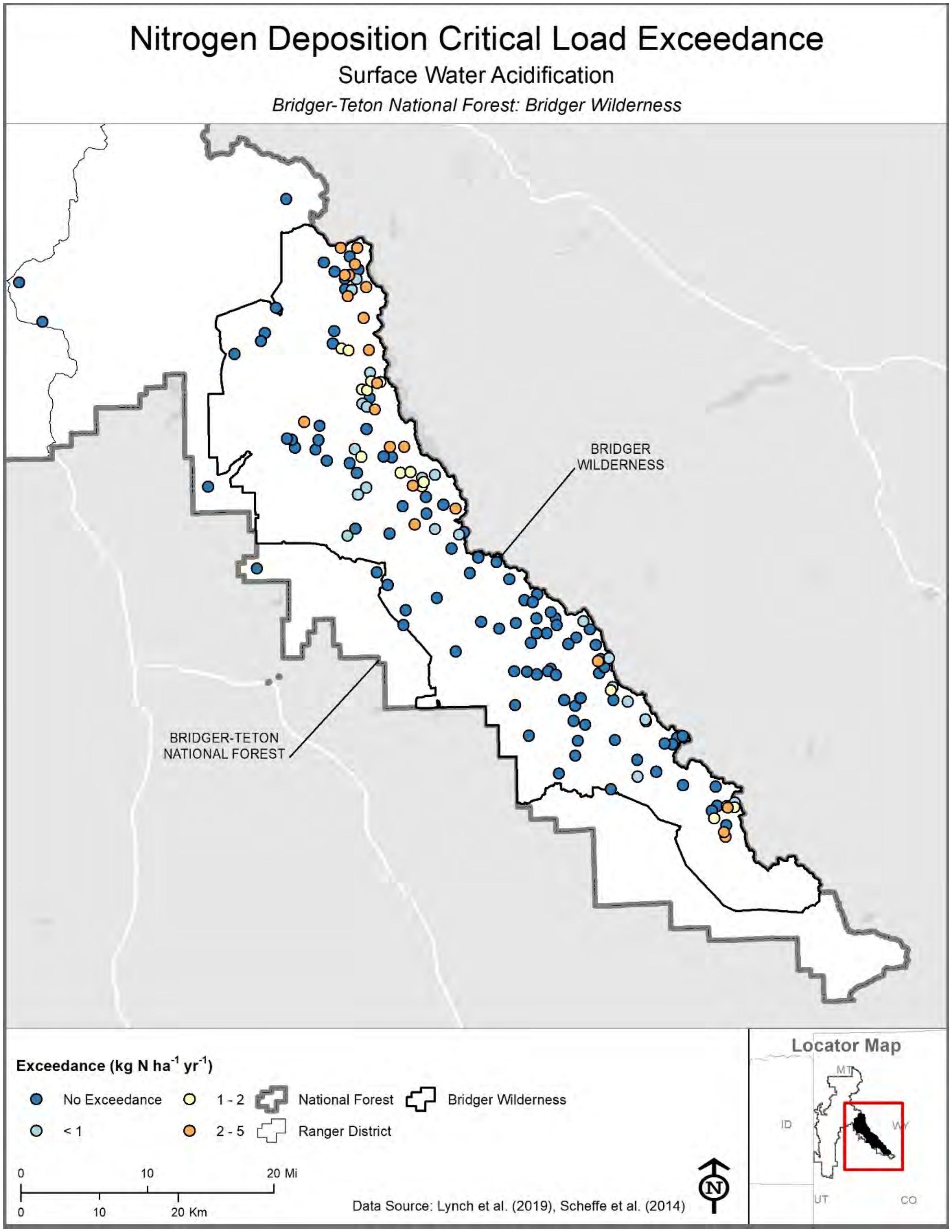

Figure 5-26. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Bridger Wilderness in Bridger-Teton National Forest.

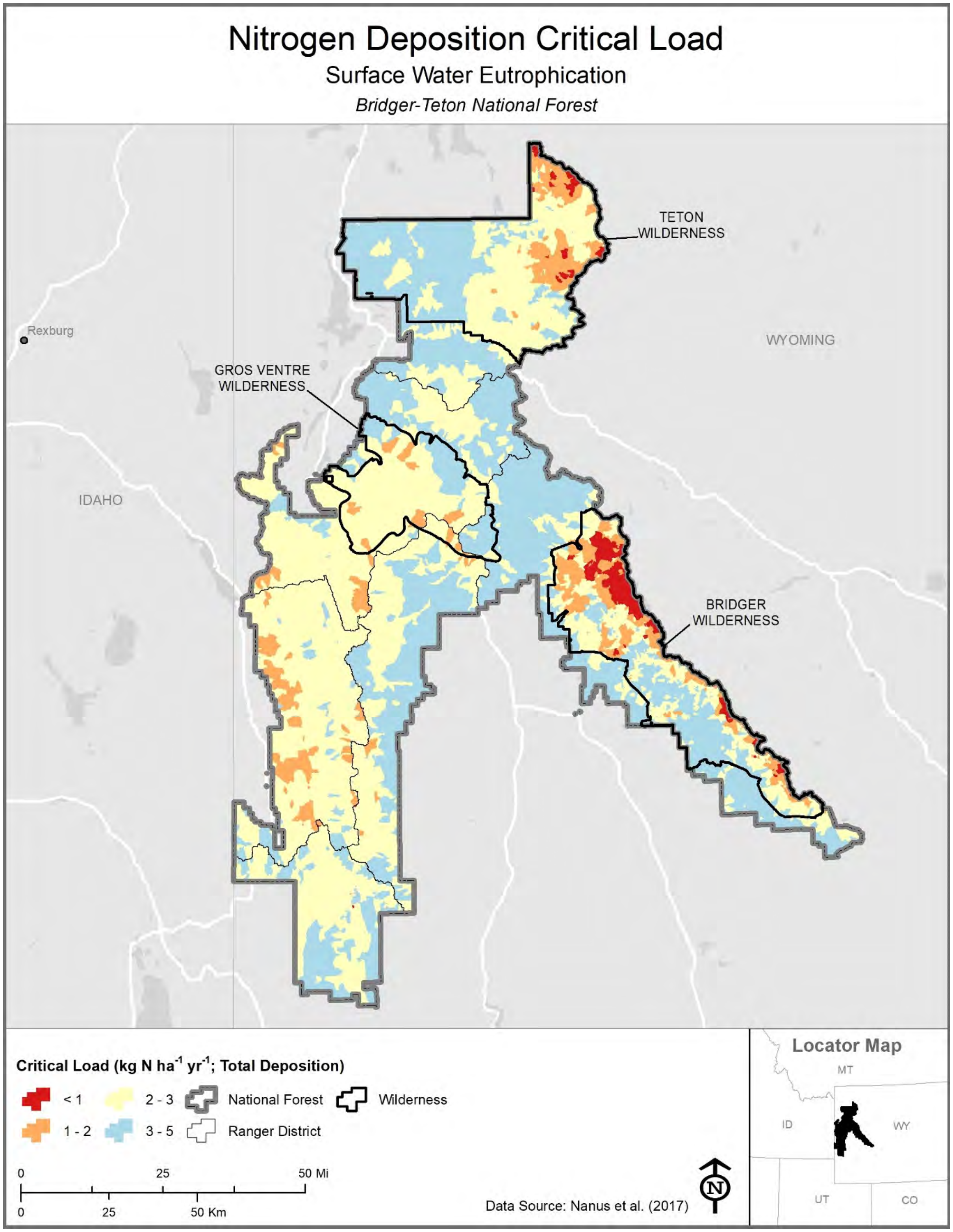

Figure 5-27. Critical loads of total nitrogen (N) deposition to protect against surface water eutrophication within the Bridger-Teton National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

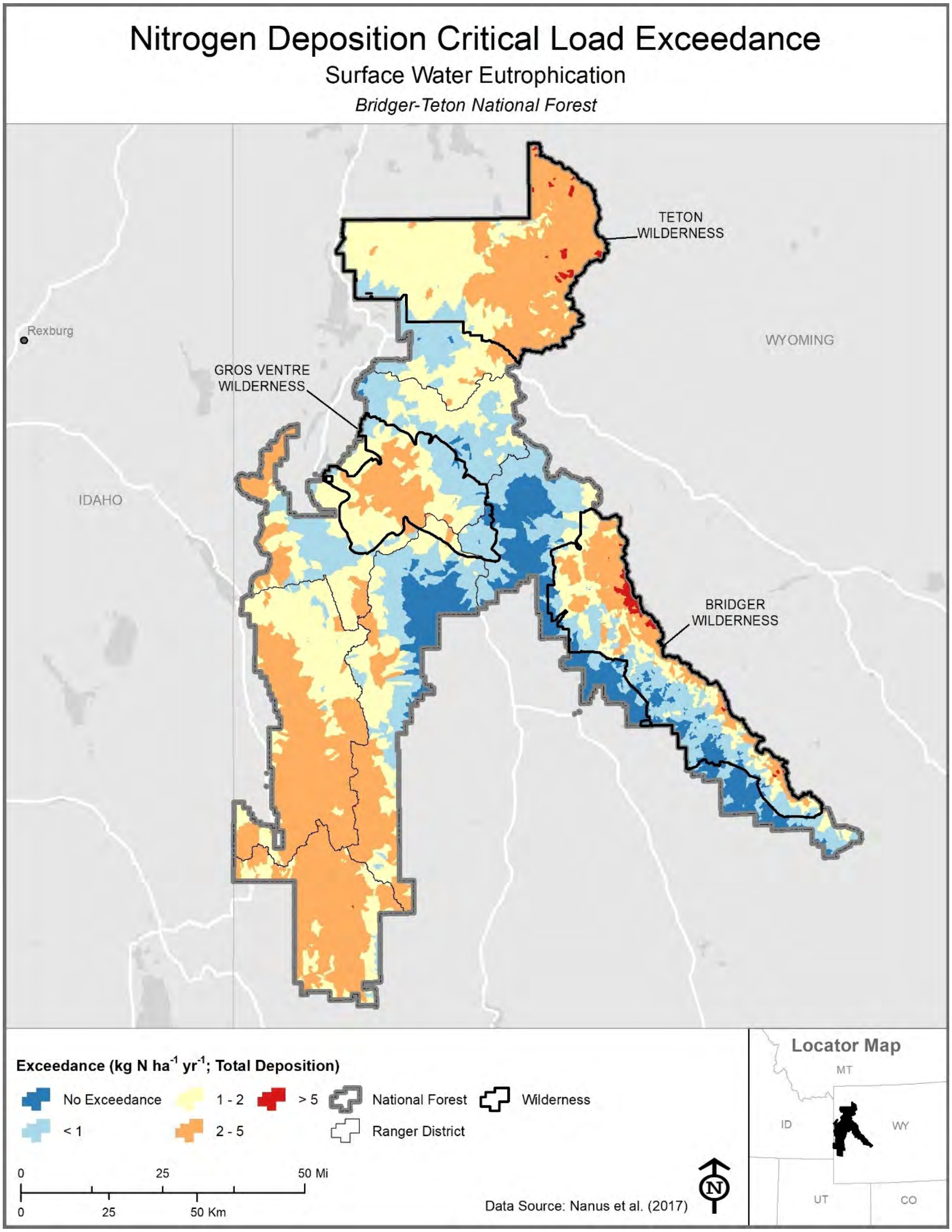

Figure 5-28. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Bridger-Teton National Forest.

magnitudes (> 2 kg N ha^{-1} yr^{-1}) of exceedance for both CLs (**Figures** 5-29 and 5-30). Critical load exceedance associated with 40 – 50% reductions in forage lichen abundance were common throughout the forest, including within all three wilderness areas.

5.2.3.4 Tree Growth and Survival

Total N deposition exceeded CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within 0% and less than 0.1%, respectively, of the area in which this species is expected to occur within the Bridger-Teton NF (**Table**s 5-7 and 5-8; **Figure** 5-31). The very small area (0.1 km^2) of exceedance for 1 – 5% reduction in probability of survival generally occurred in the southwestern portion of the forest (**Figure** 5-32).

Total N deposition exceeded CLs protective of *P. balsamifera* growth (1%, 5%, or 10% reductions) within 50% of the 1.5 km^2 in which this species is expected to occur (**Table** 5-9). The relatively small areas in exceedance of CLs for growth generally occurred in the northern portion of the forest (**Figure** 5-33). There were no areas in which reductions in probability of survival of were expected (**Table** 5-10; **Figure** 5-34).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 82% of the area in which this species is expected to occur (**Table** 5-11). These areas of exceedance were common throughout the forest, including portions of all three wilderness areas (**Figure** 5-35).

Other species of interest that occurred within the Bridger-Teton NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-16). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

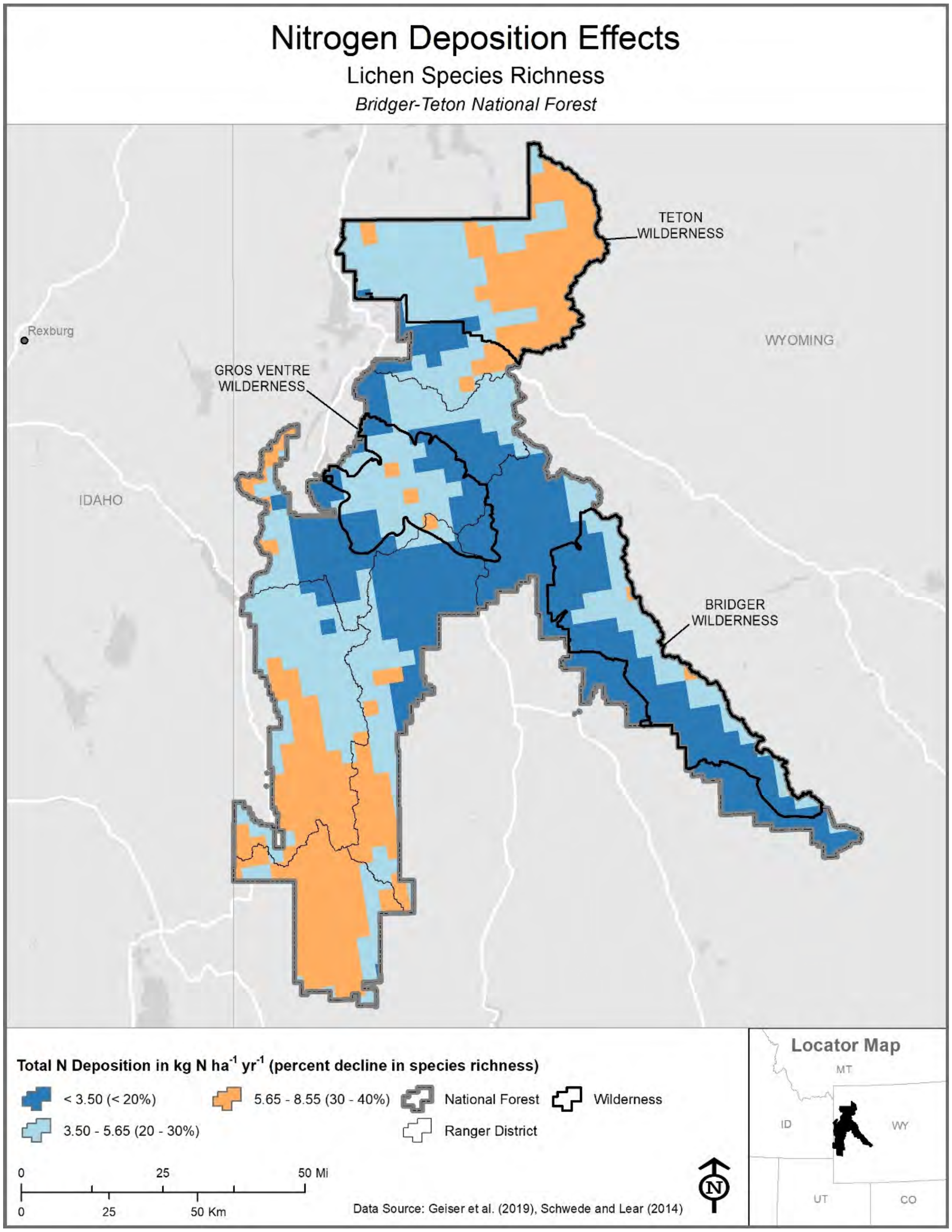

Figure 5-29. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Bridger-Teton National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

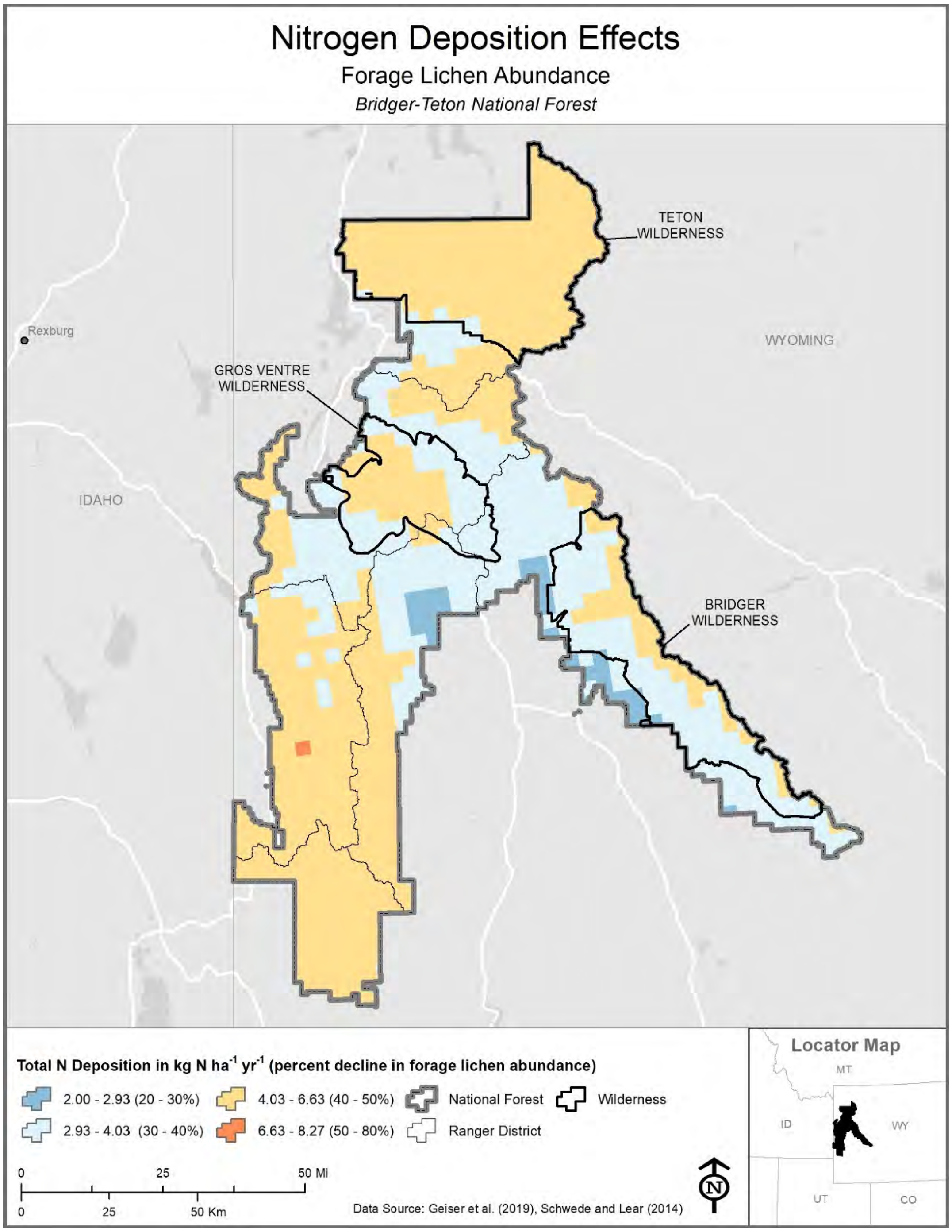

Figure 5-30. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Bridger-Teton National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

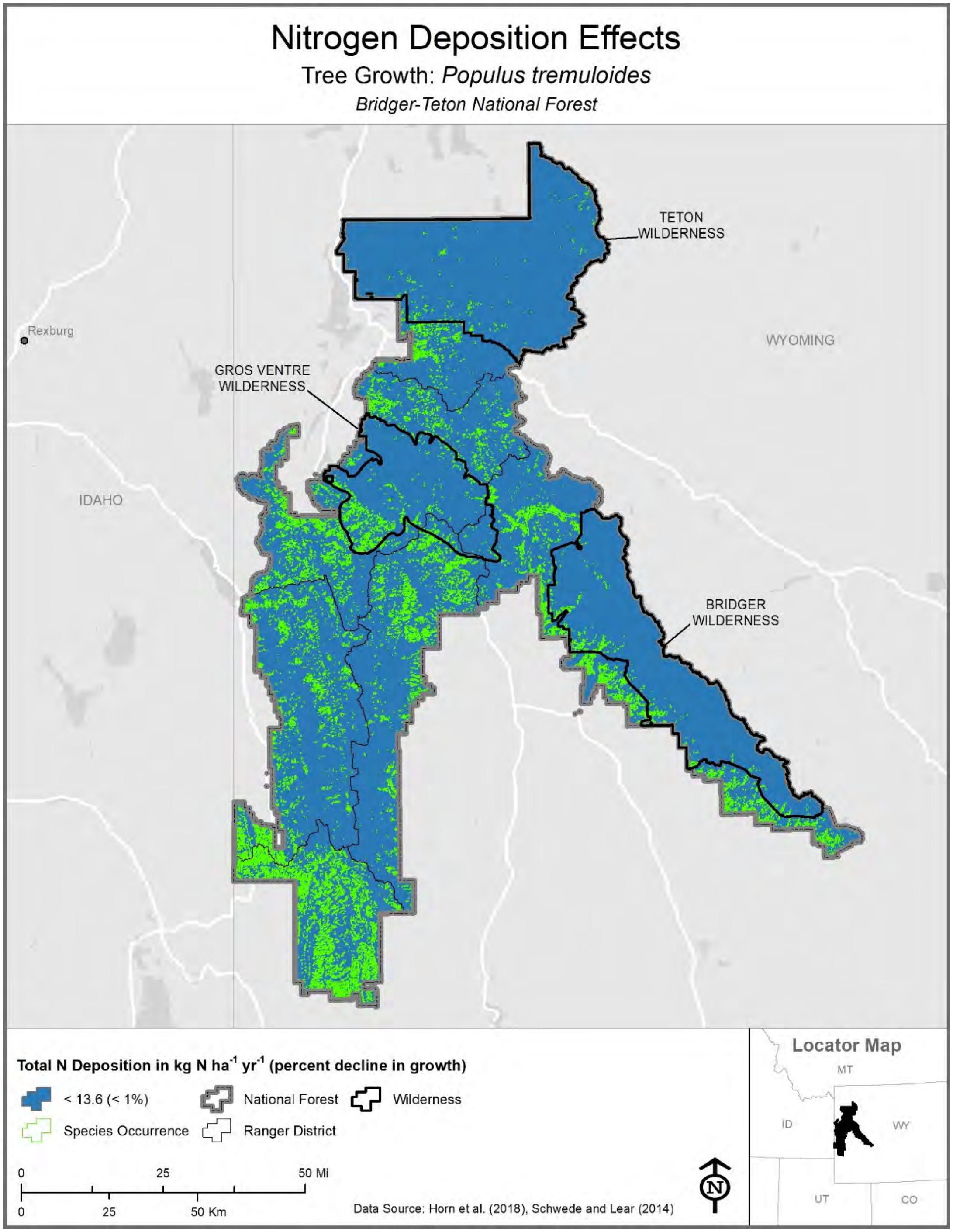

Figure 5-31. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Bridger-Teton National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Bridger-Teton NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

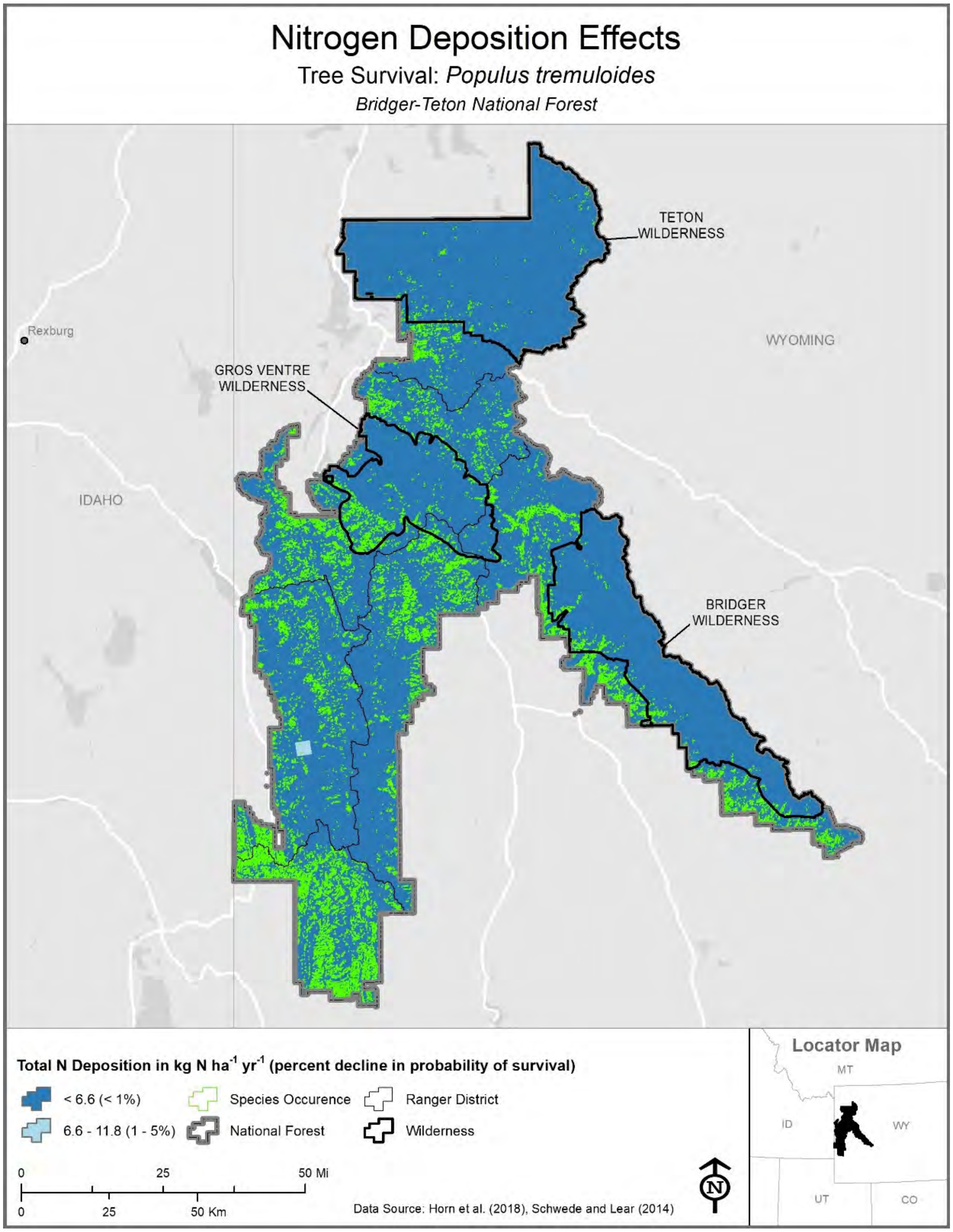

Figure 5-32. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Bridger-Teton National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Bridger-Teton NF is below the critical load for 1% reduction in probability of survival of *Populus tremuloides.*

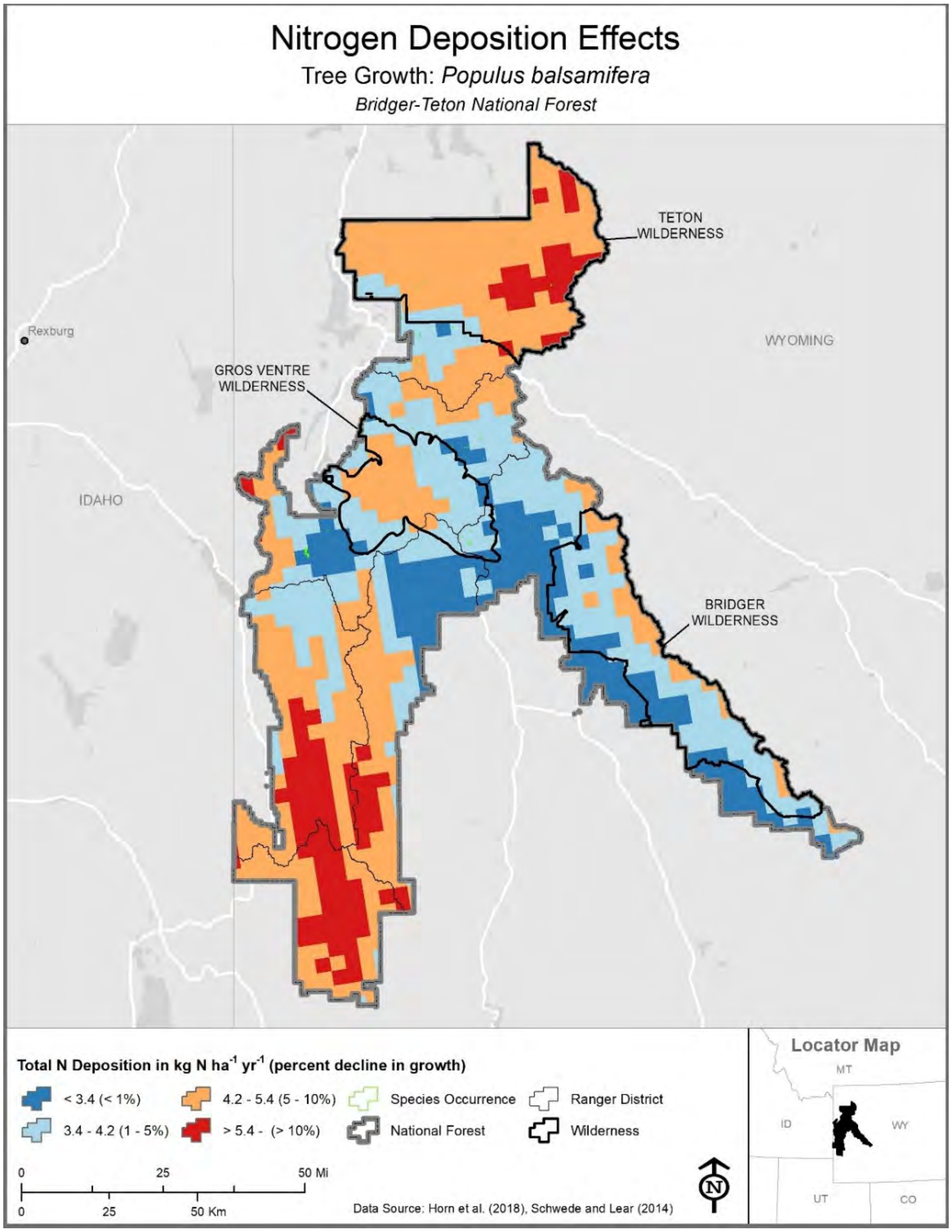

Figure 5-33. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Bridger-Teton National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas of the central and northern portions of the Bridger-Teton NF that are difficult to discern on the map. Table 5-9 indicates the extent to which any of these areas are in exceedance of the specified critical loads.

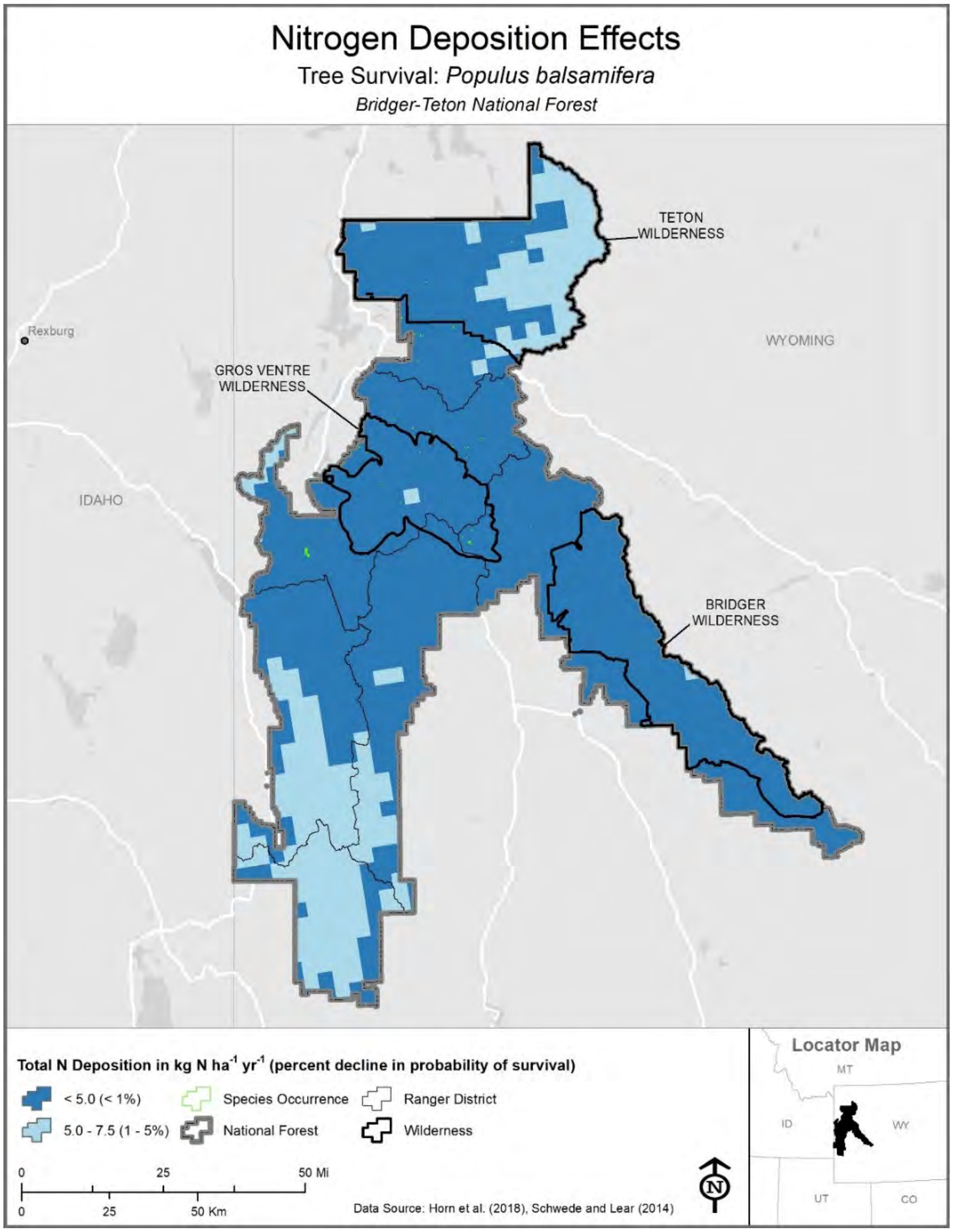

Figure 5-34. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Bridger-Teton National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas of the central and northern portions of the Bridger-Teton NF that are difficult to discern on the map. Table 5-10 indicates the extent to which any of these areas are in exceedance of the specified critical loads.

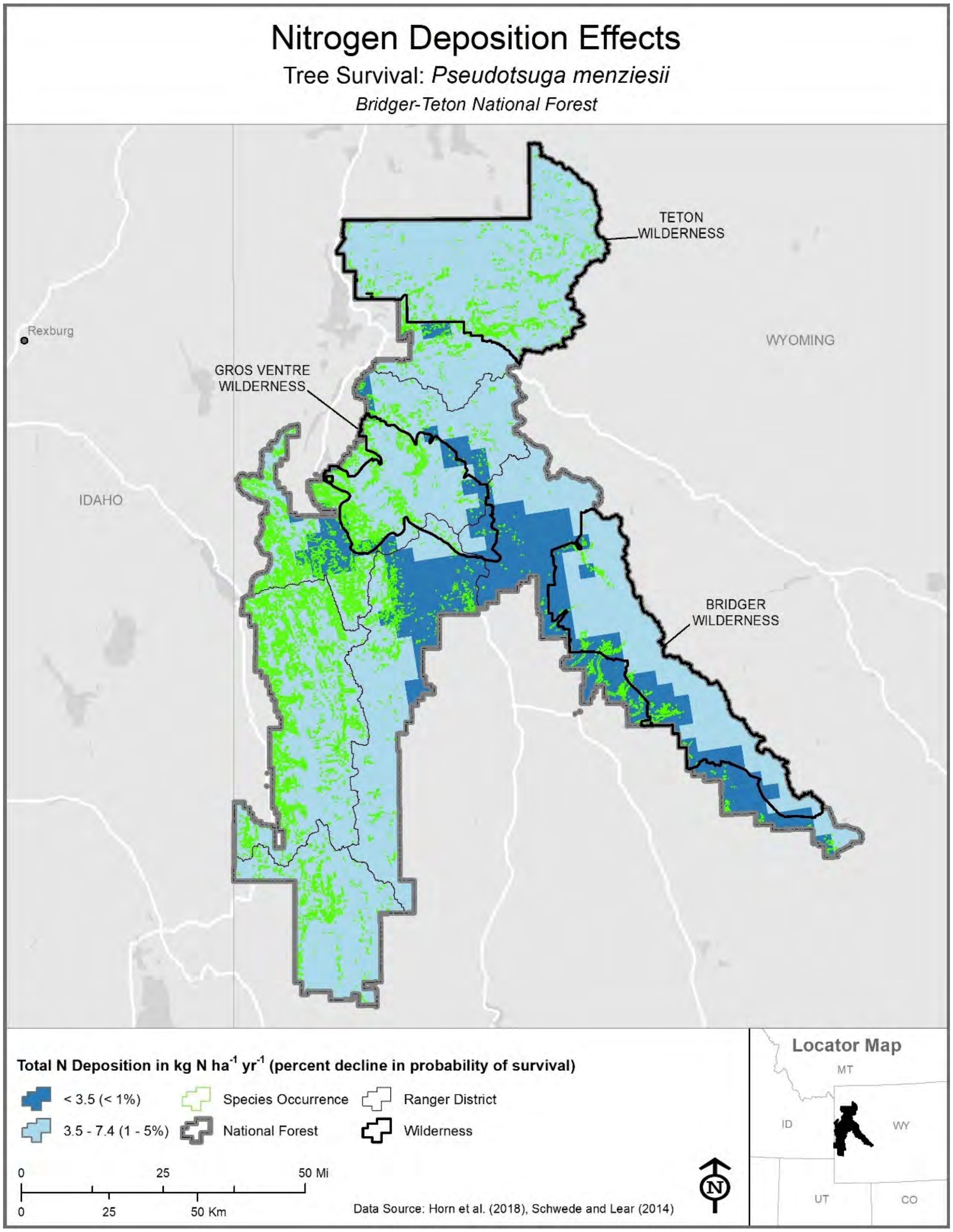

Figure 5-35. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Bridger-Teton National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-16. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Bridger-Teton National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.4 Caribou-Targhee NF

5.2.4.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were mostly located within and in the vicinity of the Winegar Hole Wilderness and the Jedediah Smith Wilderness of the Caribou-Targhee NF (**Figure** 5-36). Although two waterbodies located within the Jedediah Smith Wilderness showed relatively moderate risk for acidification effects and were also in exceedance (**Figure** 5-37), most available CLs indicated relatively low risk (i.e., high CLs) and were not in exceedance, which indicates that these locations are not likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}. However, given the low representation of CLs, acid-sensitive waterbodies may occur elsewhere within the Caribou-Targhee NF. More recently collected data should be evaluated to determine the accuracy of these CLs.

5.2.4.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout most of the Caribou-Targhee NF and represented a total of nearly 3,570 km^2 (38%) of the forest (**Table** 5-3; **Figure** 5-38). The Jedediah Smith Wilderness was mostly comprised of low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included nearly 5,320 km^2 (57%) of the forest (**Table** 5-4; **Figure** 5-39). Portions of the Jedediah Smith Wilderness ranged from 2 to 5 kg N ha^{-1} yr^{-1} in exceedance and some areas in the southern region of the forest were more than 5 kg N ha^{-1} yr^{-1} in exceedance. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.4.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 90% and 100%, respectively, of the Caribou-Targhee NF (**Table**s 5-5 and 5-6). The northwestern portion of the forest showed some areas of non-exceedance of the CL for lichen species richness and the southern portion of the forest showed the highest magnitudes of exceedance (> 5 kg N ha^{-1} yr^{-1}) for both CLs (**Figures** 5-40 and 5-41). The full extents of the Winegar Hole Wilderness and Jedediah Smith Wilderness were in exceedance for both CLs.

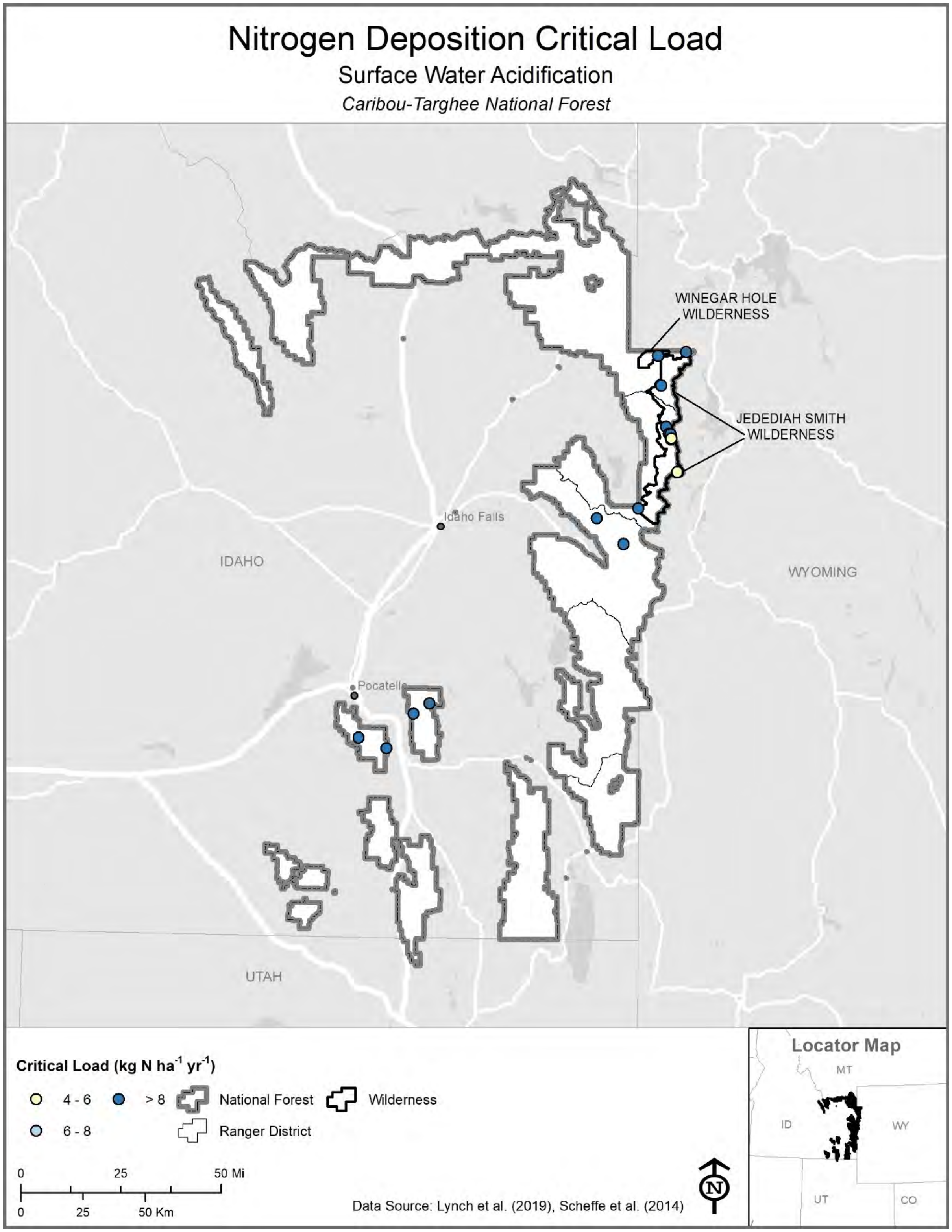

Figure 5-36. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Caribou-Targhee National Forest.

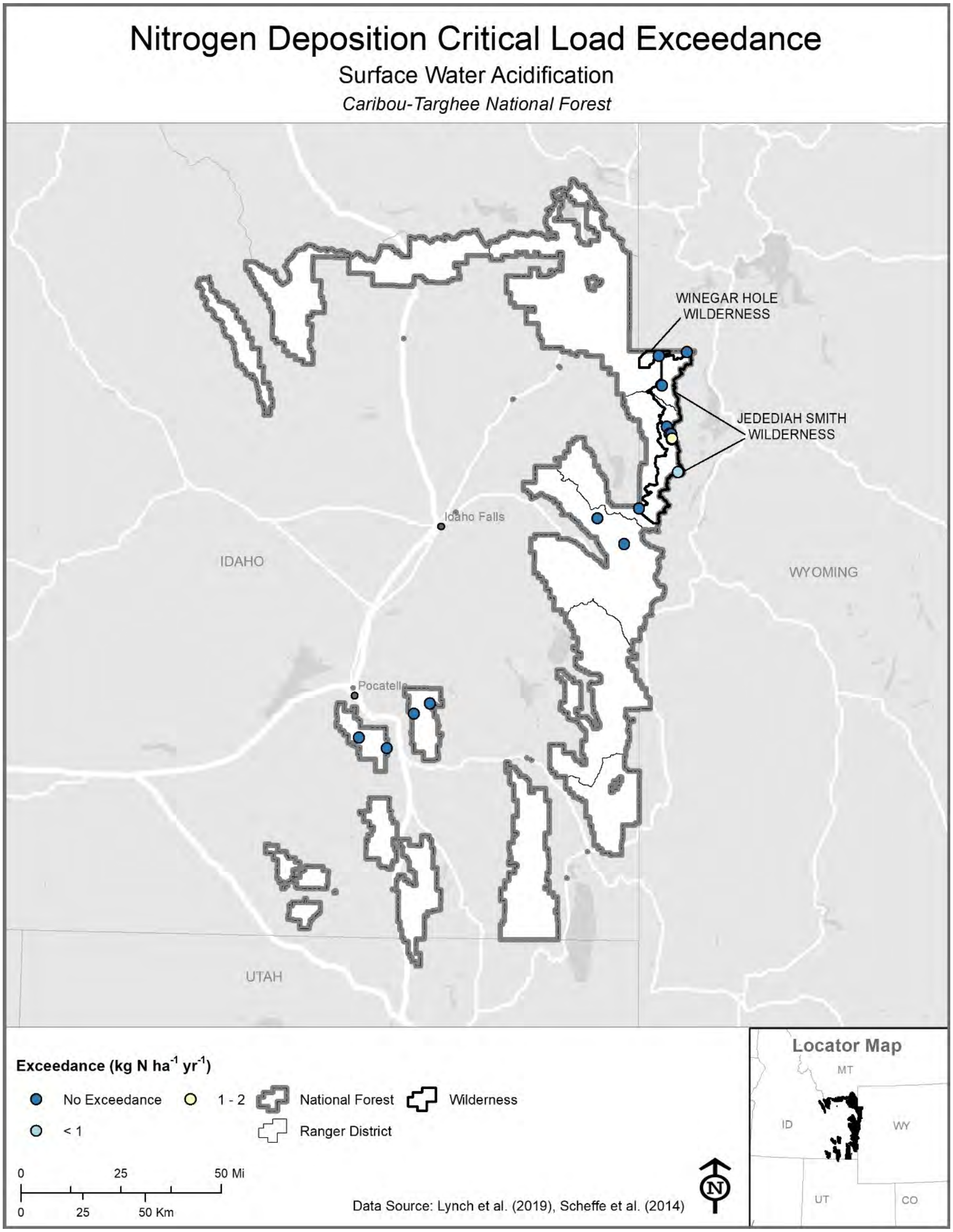

Figure 5-37. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Caribou-Targhee National Forest.

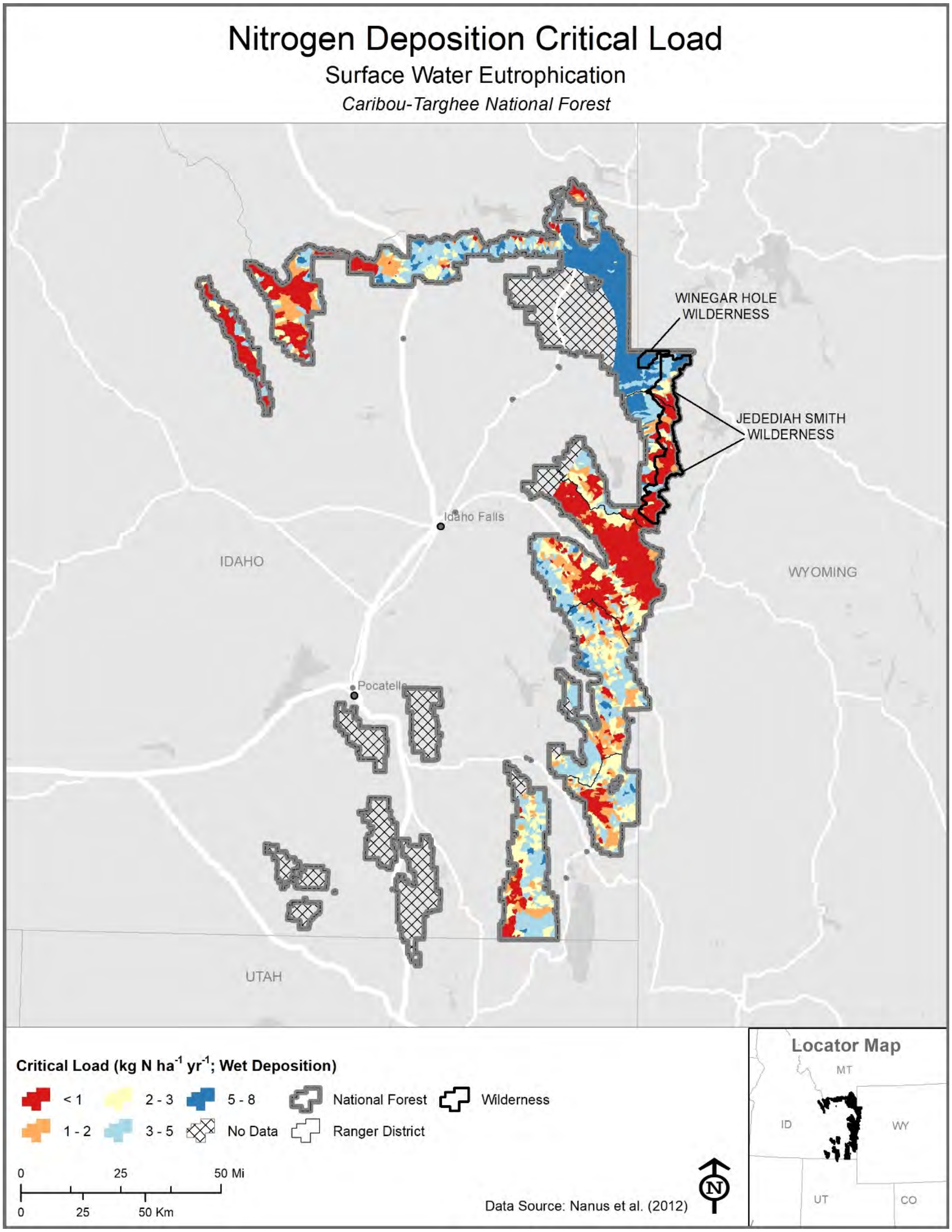

Figure 5-38. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Caribou-Targhee National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

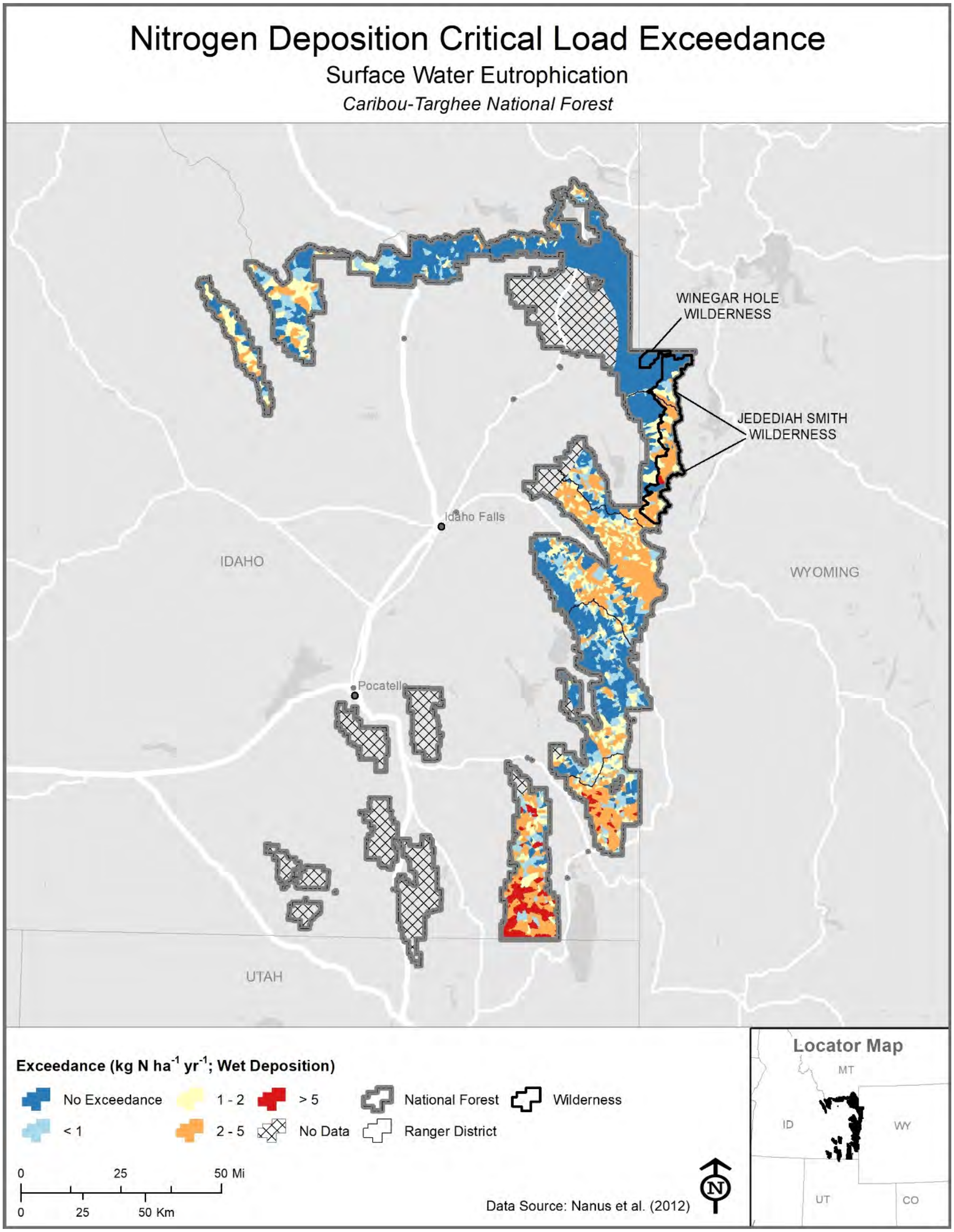

Figure 5-39. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Caribou-Targhee National Forest.

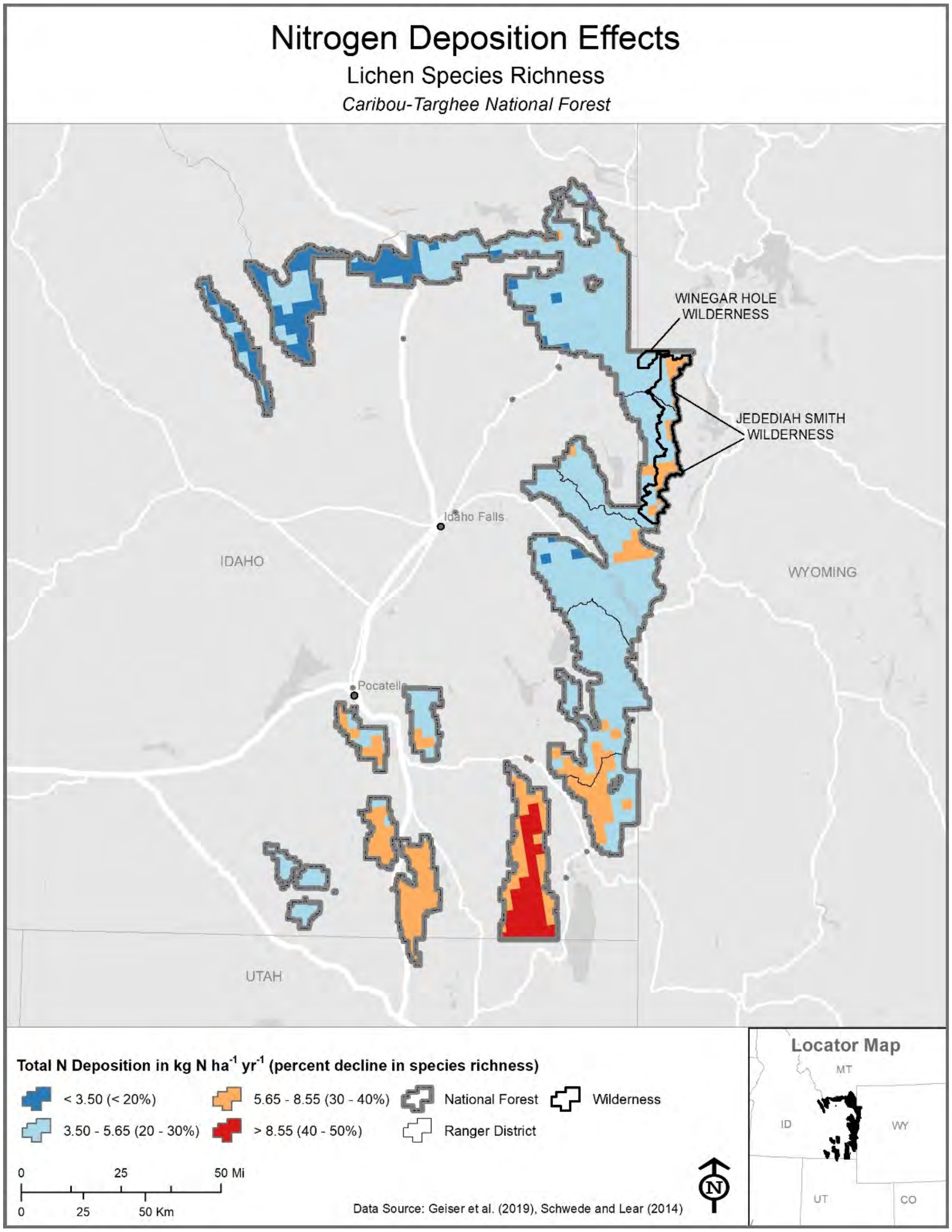

Figure 5-40. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Caribou-Targhee National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.

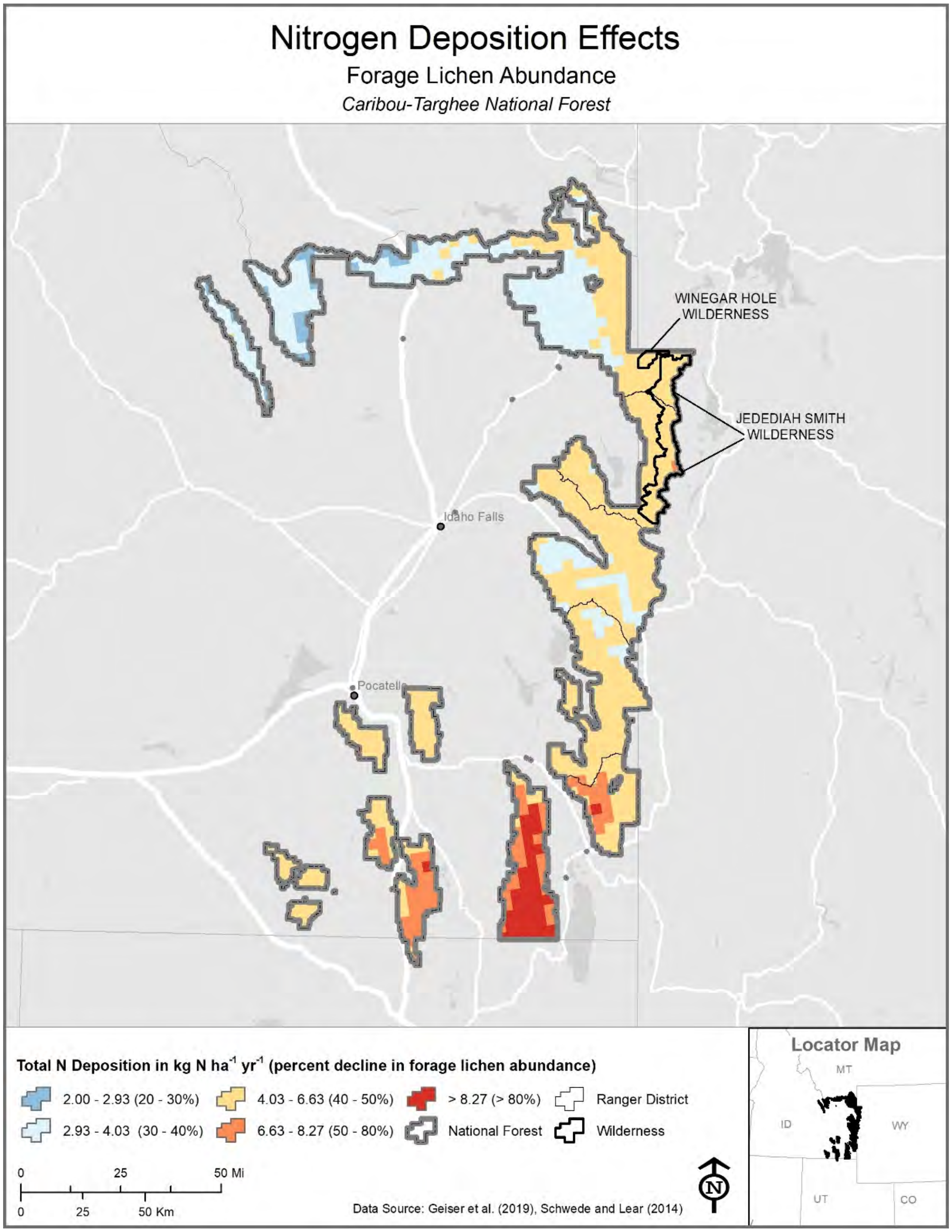

Figure 5-41. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Caribou-Targhee National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

Critical load exceedance associated with at least a 40% reduction in forage lichen abundance were common throughout the forest, including within wilderness areas.

5.2.4.4 Tree Growth and Survival

Although there were no exceedance of CLs to protect growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reductions) within 19% of the area in which this species is expected to occur within the Caribou-Targhee NF (**Table**s 5-7 and 5-8; **Figure** 5-42). Areas in exceedance of CLs for survival generally occurred in the southern portion of the forest (**Figure** 5-43).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 84% of the area in which this species is expected to occur (**Table** 5-11). These areas of exceedance were common throughout the forest, including small portions of the Winegar Hole Wilderness and Jedediah Smith Wilderness (**Figure** 5-44).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 90% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance mostly occurred in the central portion of the forest (**Figure** 5-45).

Other species of interest that occurred within the Caribou-Targhee NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-17). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

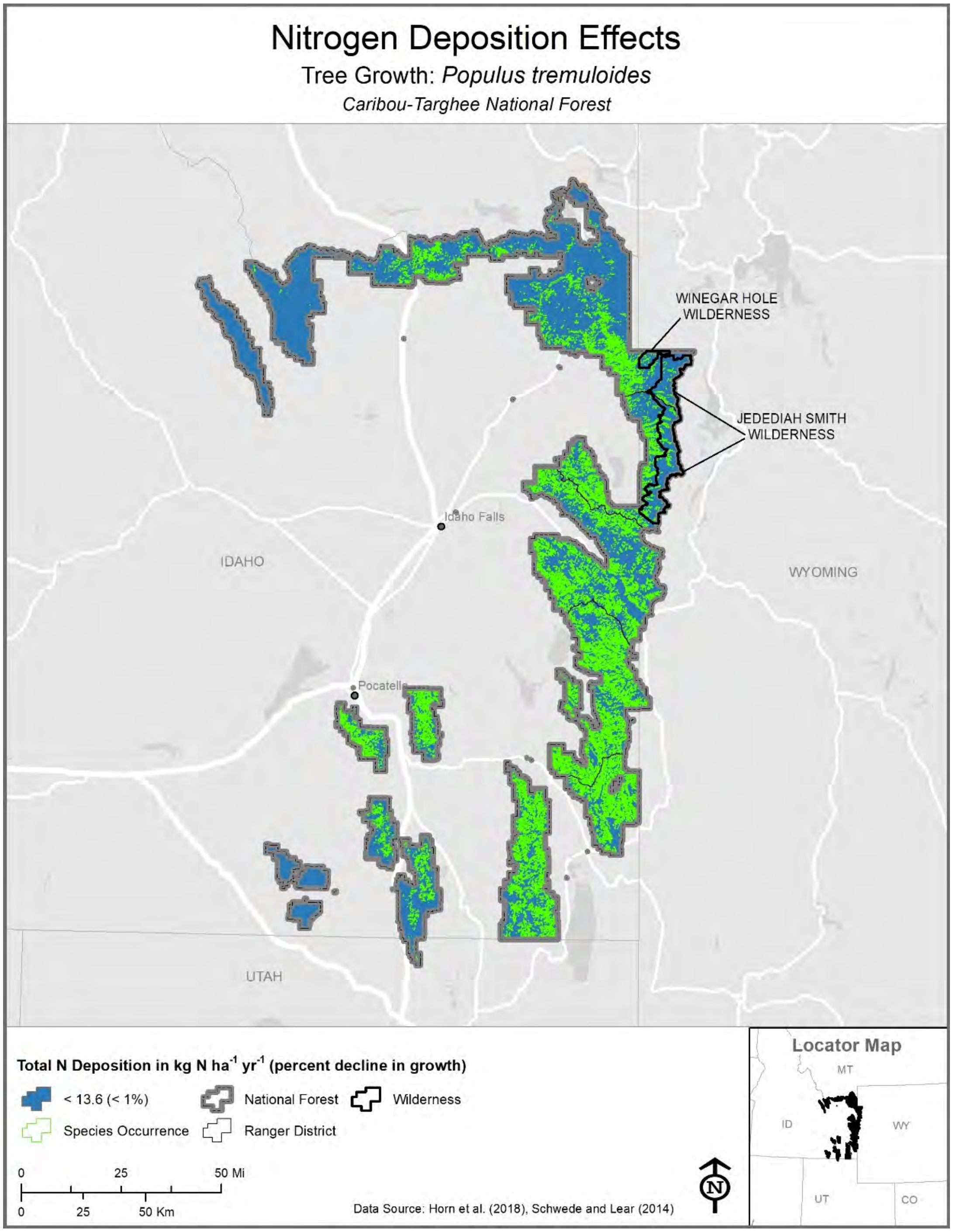

Figure 5-42. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Caribou-Targhee National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Caribou-Targhee NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

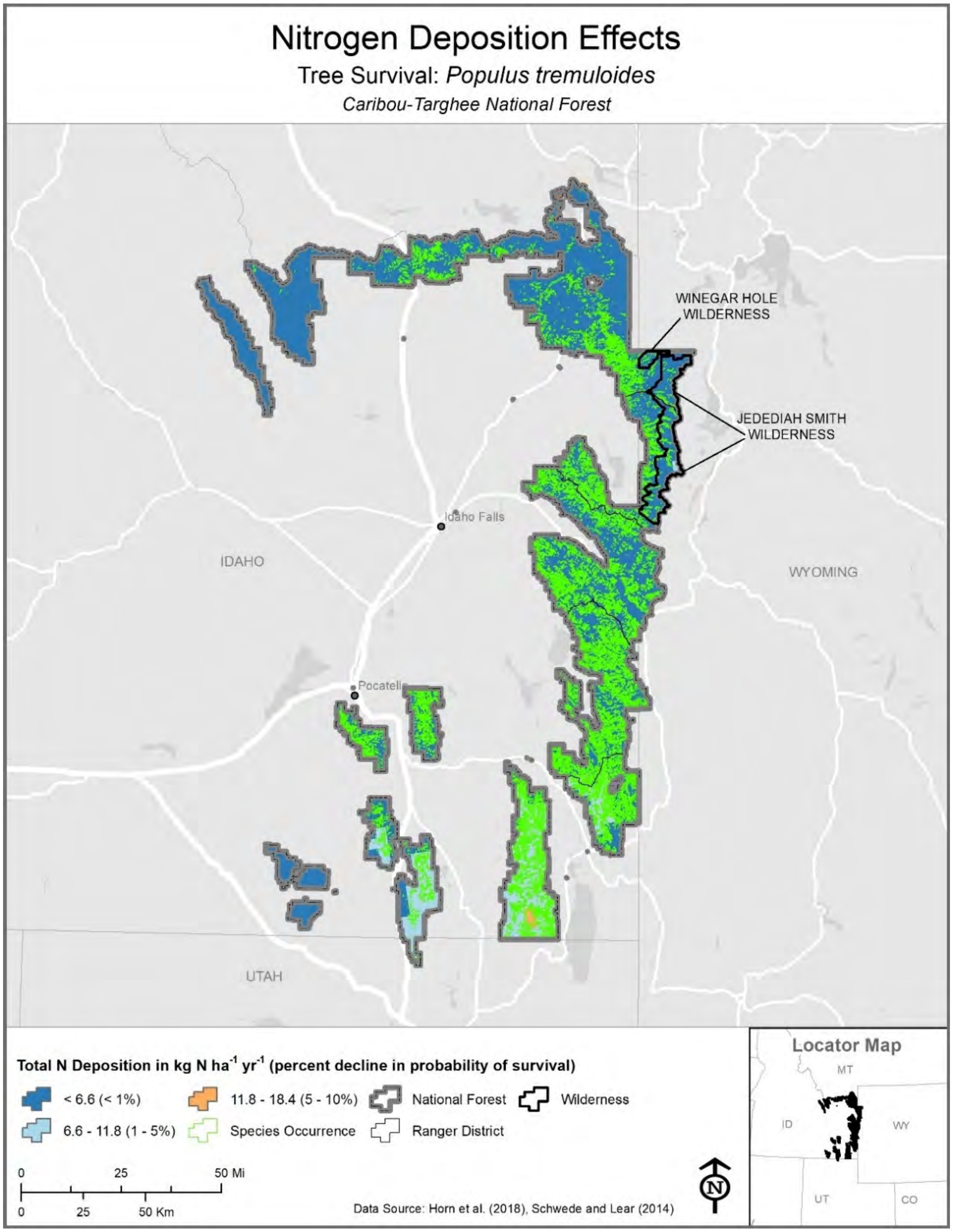

Figure 5-43. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Caribou-Targhee National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

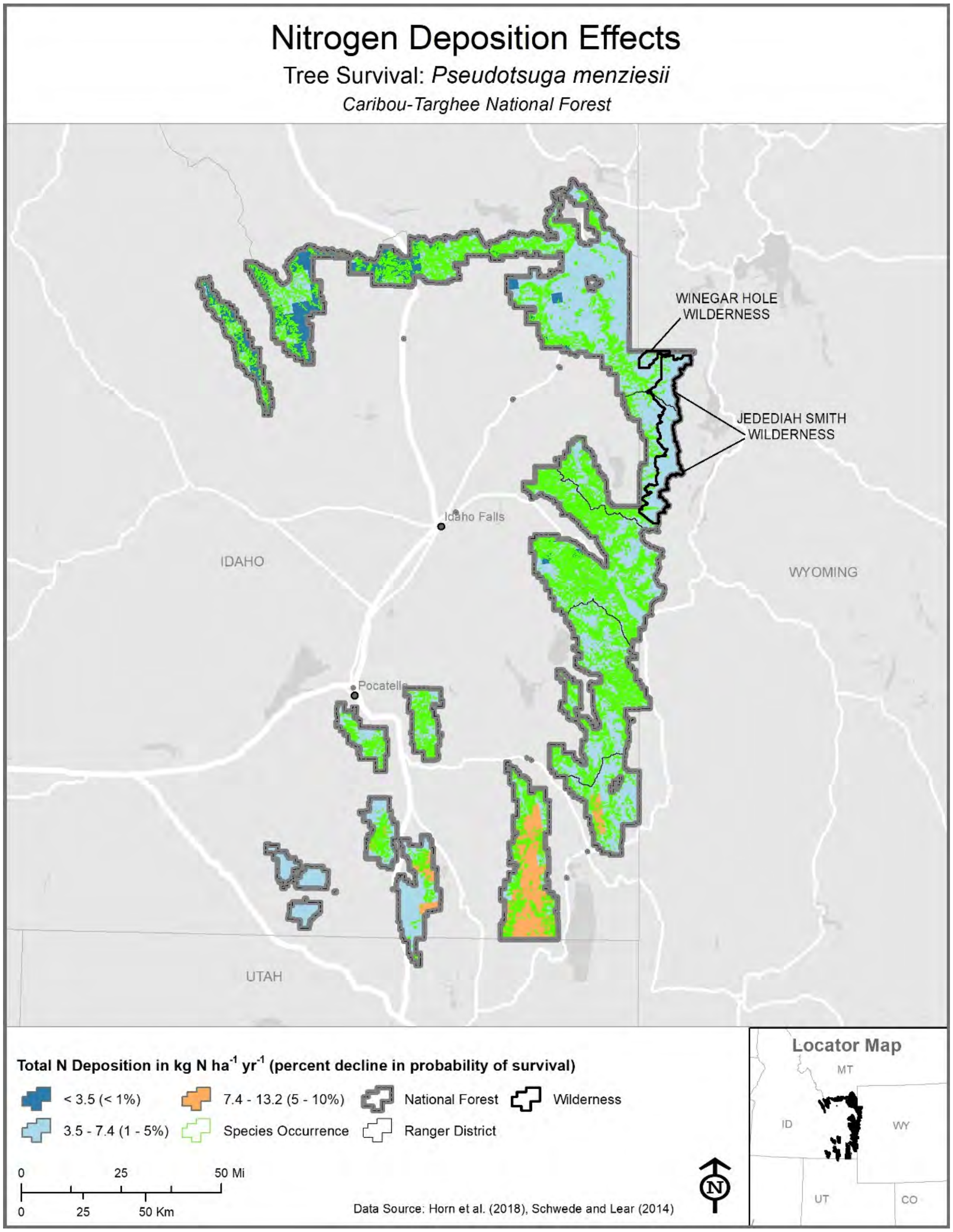

Figure 5-44. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Caribou-Targhee National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

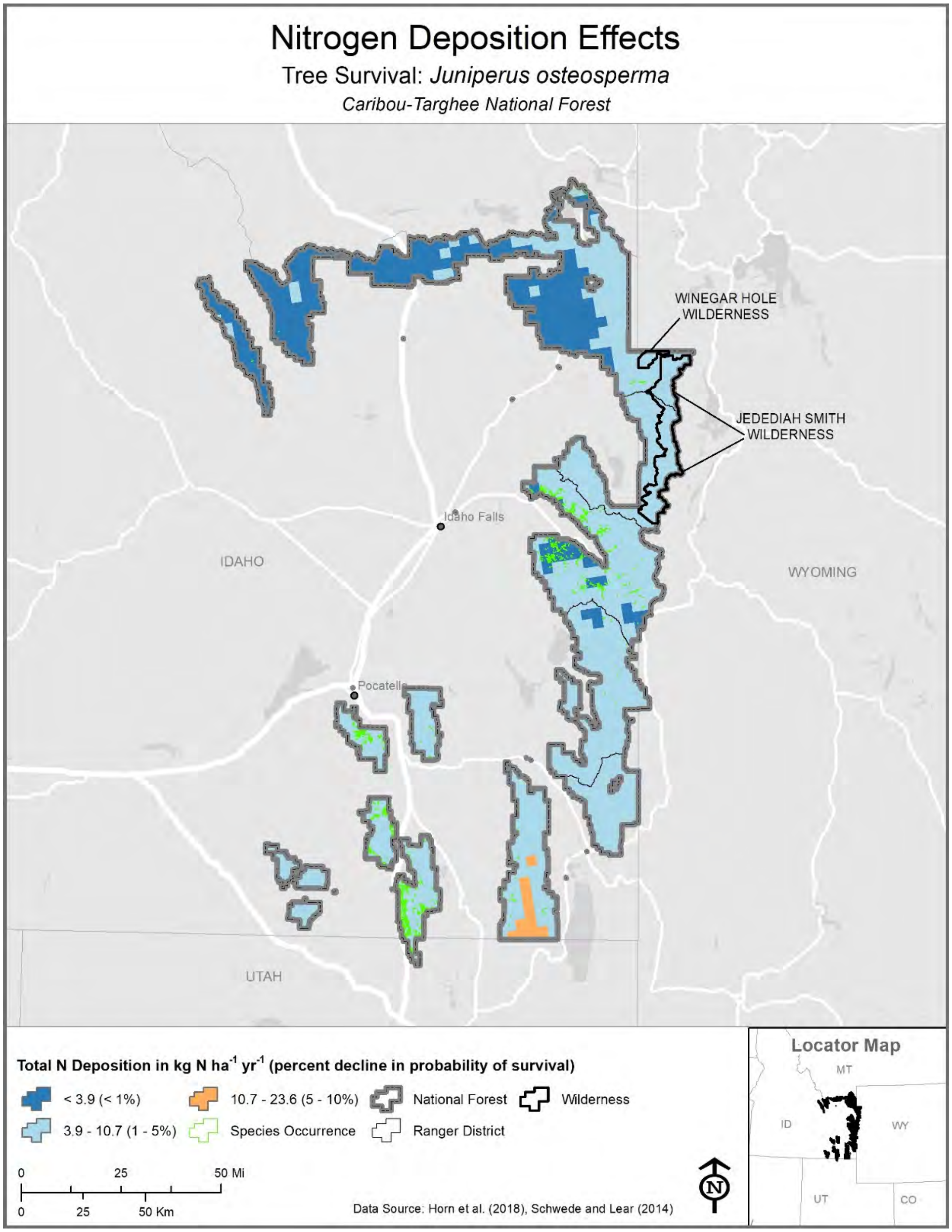

Figure 5-45. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Caribou-Targhee National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-17. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Caribou-Targhee National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.5 Dixie NF

5.2.5.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were only available at three locations throughout the Dixie NF and the waterbodies at these locations were at relatively low risk (i.e., high CLs) for acidification effects (**Figure** 5-46). None of these locations experienced ambient N deposition that was high enough to exceed the CL (**Table** 5-2; **Figure** 5-47). This indicates that these locations are not likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}. However, given the low representation of CLs, acid-sensitive waterbodies may occur elsewhere within the Dixie NF.

5.2.5.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout most of the Dixie NF and represented a total of nearly 1,300 km^2 (26%) of the forest (**Table** 5-3; **Figure** 5-48). The Ashdown Gorge Wilderness and Box-Death Hollow Wilderness were mostly comprised of low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included 970 km^2 (20%) of the forest (**Table** 5-4; **Figure** 5-49). Exceedances occurred within the Ashdown Gorge Wilderness and Box-Death Hollow Wilderness and were generally within the range of 1 – 2 kg N ha^{-1} yr^{-1}. The highest magnitudes of exceedance were between 2 and 5 kg N ha^{-1} yr^{-1}). Areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.5.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 76% and 100%, respectively, of the Dixie NF (**Table**s 5-5 and 5-6). Non-exceedance of the CL for lichen species richness was scattered throughout the forest, with the highest magnitudes (> 2 kg N ha^{-1} yr^{-1}) of exceedance located within and in the vicinity of the Pine Valley Mountain Wilderness and Ashdown Gorge Wilderness (**Figure** 5-50. Critical load exceedance associated with 40 – 50% reductions in forage lichen abundance were common throughout the forest, including within the Pine Valley Mountain Wilderness and Ashdown Gorge Wilderness (**Figure** 5-51).

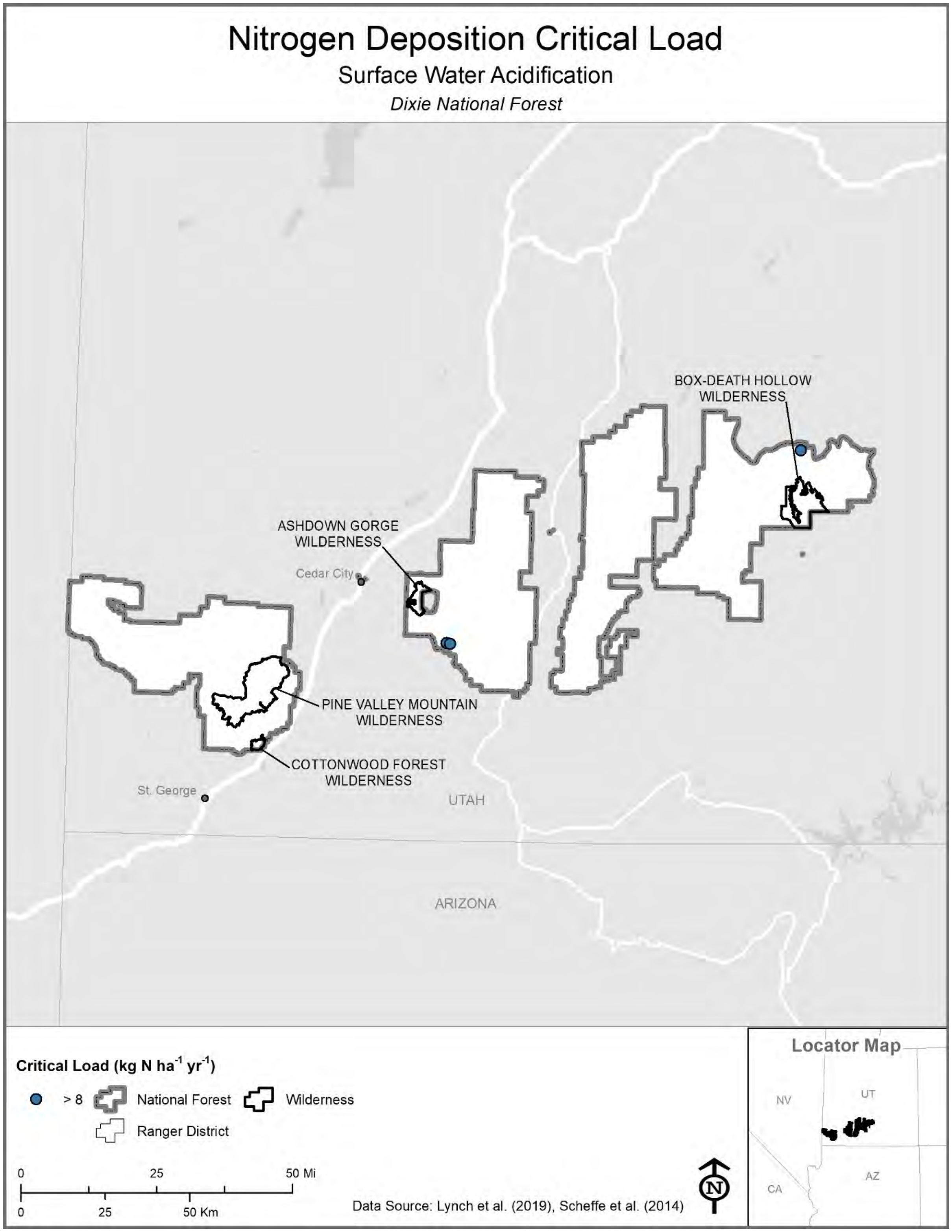

Figure 5-46. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Dixie National Forest.

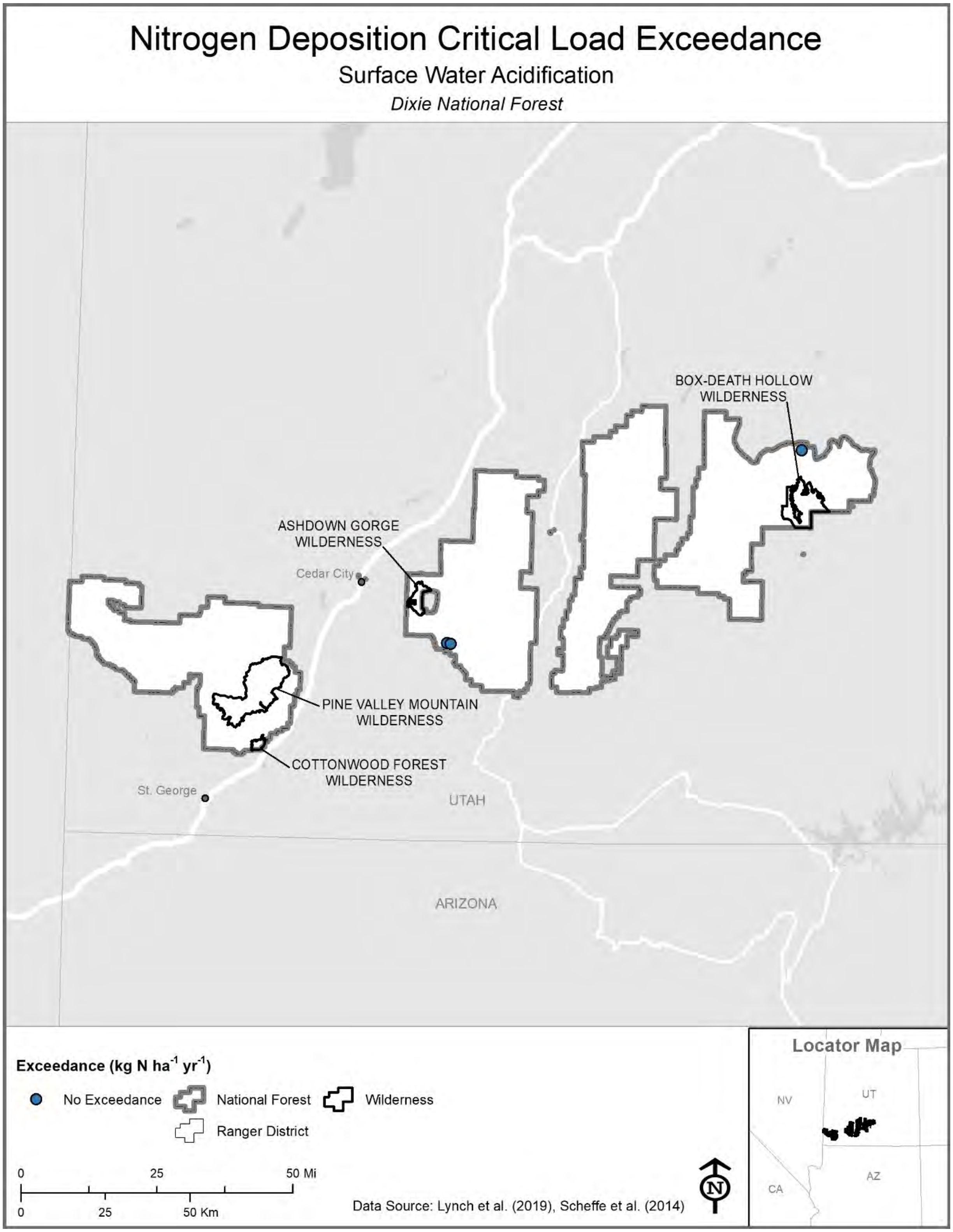

Figure 5-47. Map of the Dixie National Forest showing no exceedance of the critical load of nitrogen (N) for surface water acidification.

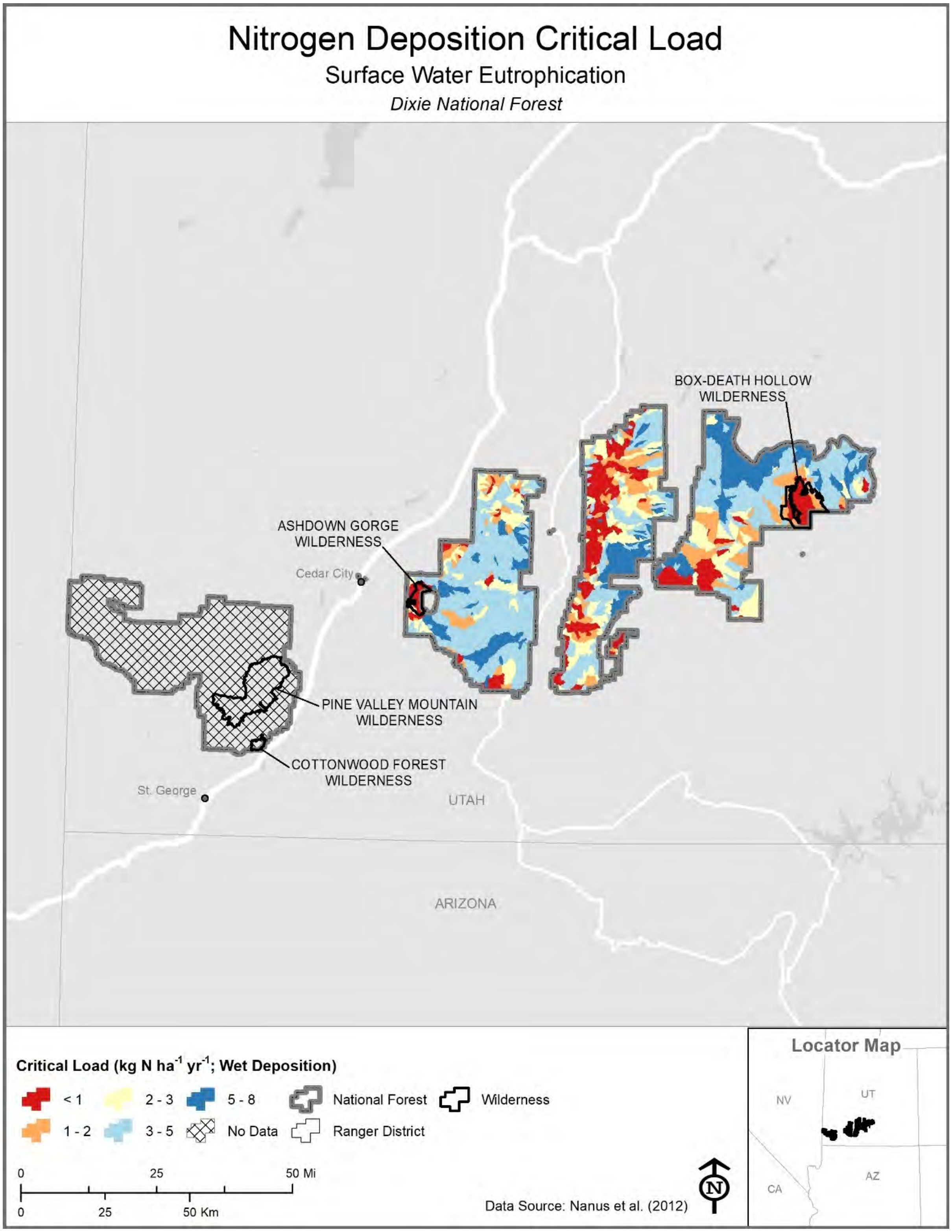

Figure 5-48. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Dixie National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

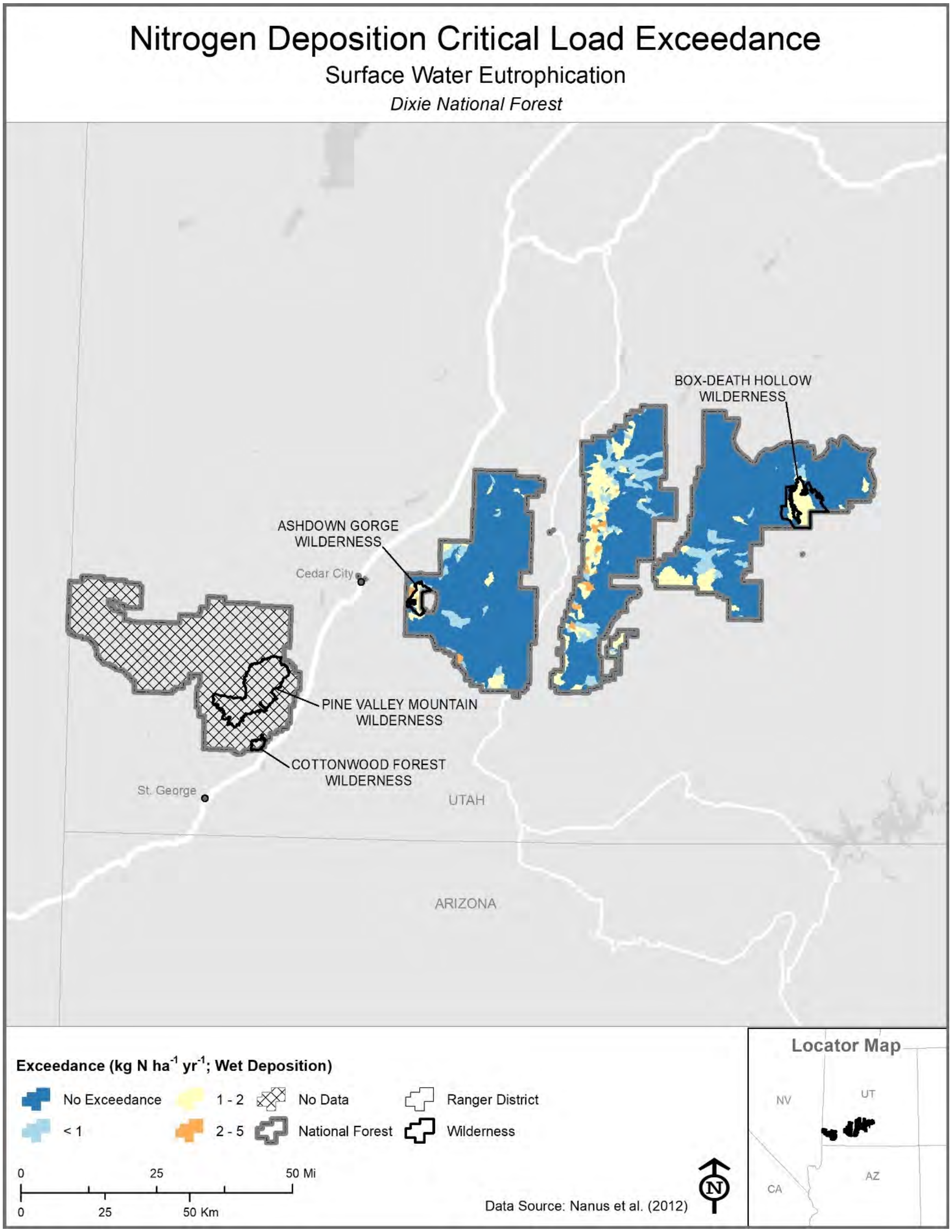

Figure 5-49. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Dixie National Forest.

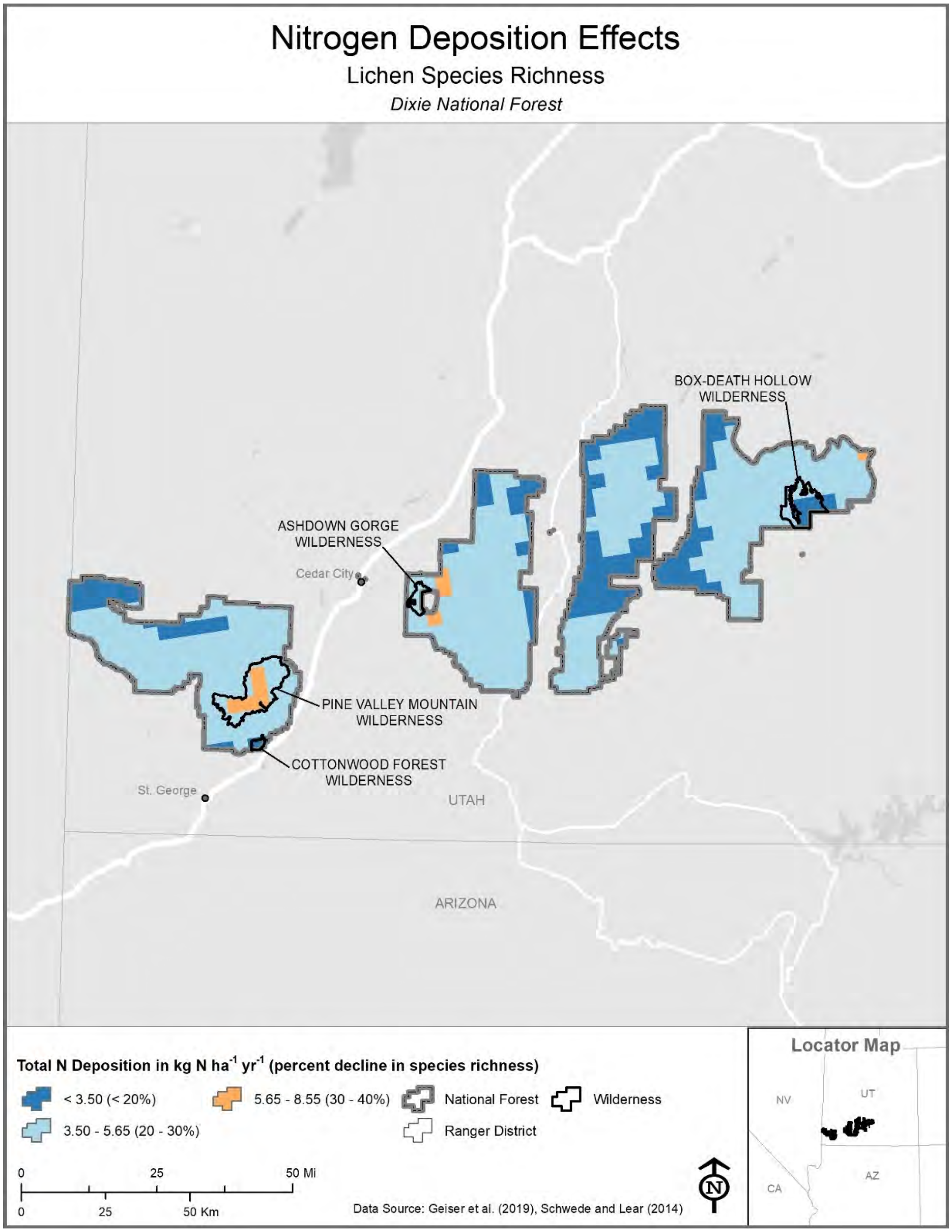

Figure 5-50. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Dixie National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

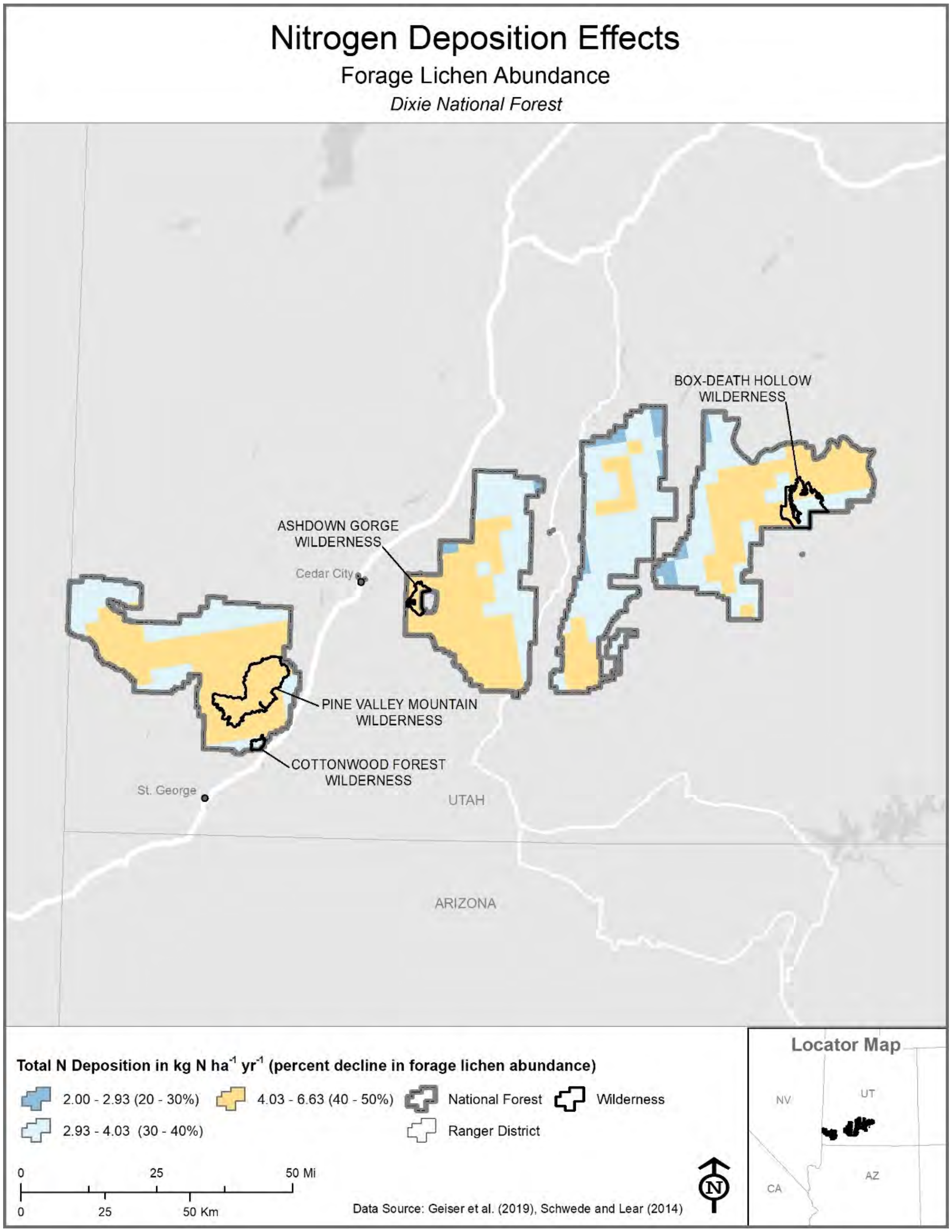

Figure 5-51. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Dixie National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in forage lichen abundance.

5.2.5.4 Tree Growth and Survival

Total N deposition did not exceed CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within any of the area in which this species is expected to occur within the Dixie NF (**Table**s 5-7 and 5-8; **Figures** 5-52 and 5-53).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 85% and 11%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Critical load exceedance for tree growth and survival were most commonly located outside of wilderness areas, which is where this species typically occurred (**Figures** 5-54 and 5-55).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 90% of the area in which this species is expected to occur (**Table** 5-11). Areas of exceedance were common throughout the forest (**Figure** 5-56).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 42% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance mostly occurred in the western and eastern portions of the forest (**Figure** 5-57).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 16% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance mostly occurred in the western portion of the forest (**Figure** 5-58).

Other species of interest that occurred within the Dixie NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (VIF N < 3; bold species shown in **Table** 5-18). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

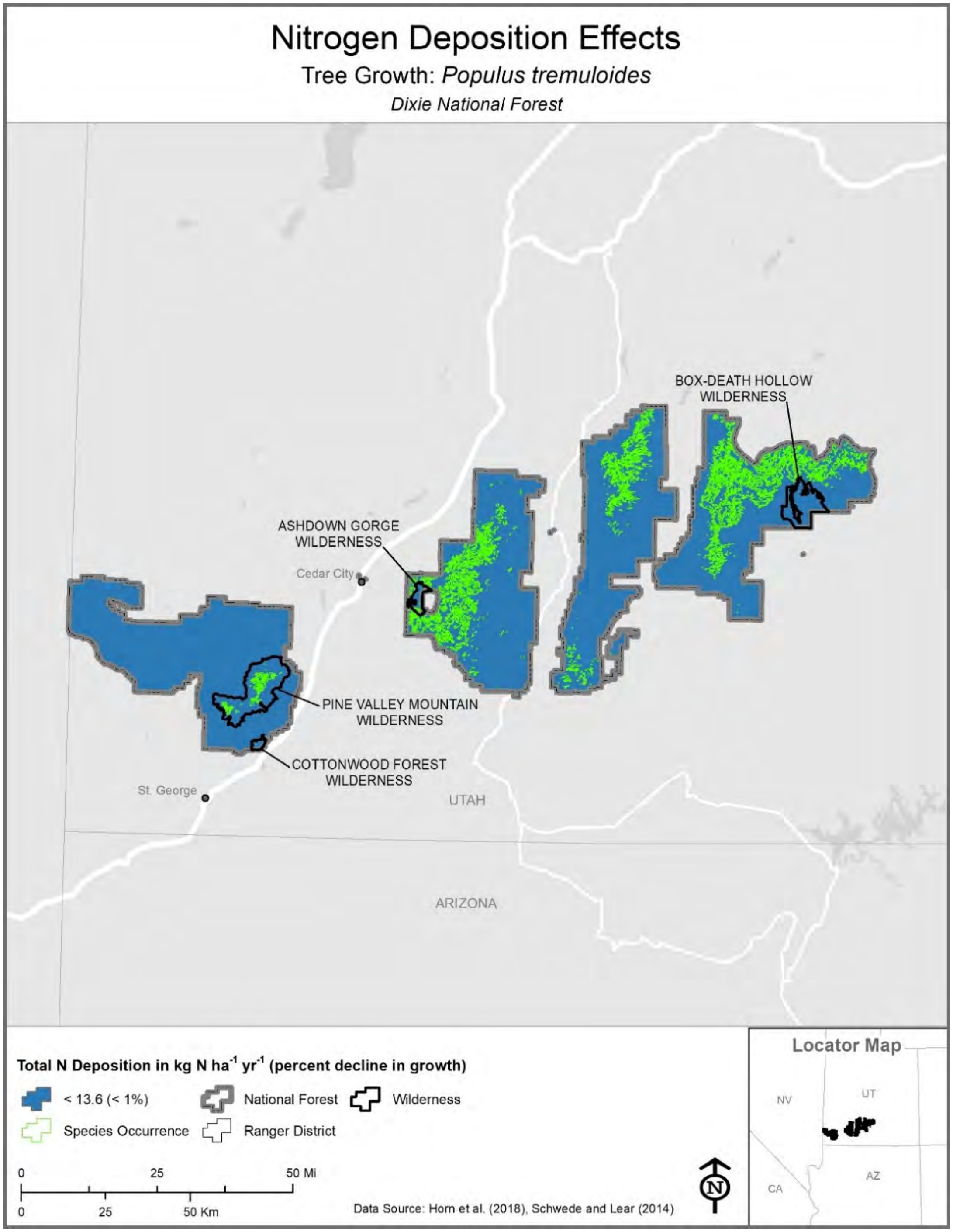

Figure 5-52. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Dixie NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

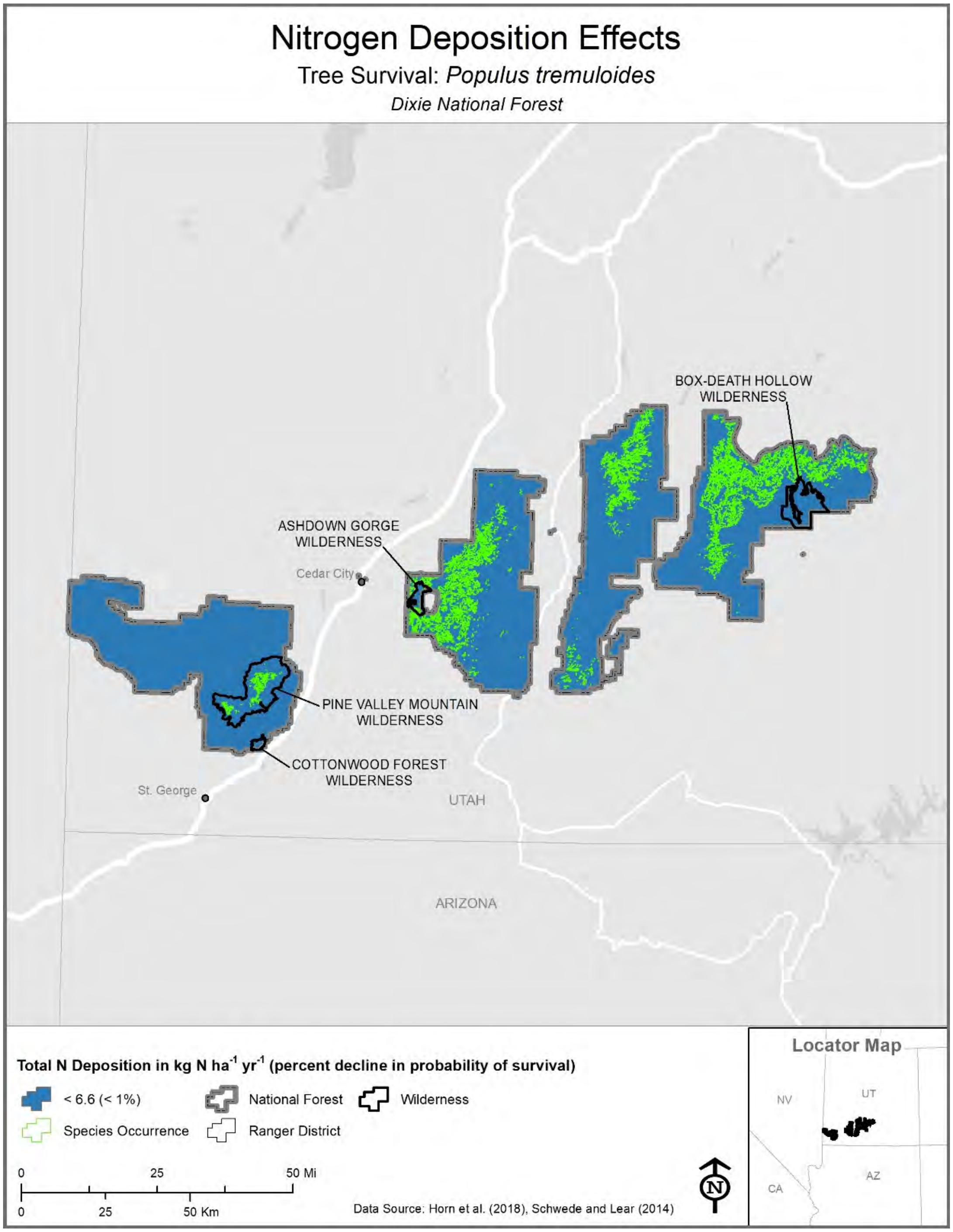

Figure 5-53. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Dixie NF is below the critical load for 1% reduction in probability of survival of *Populus tremuloides.*

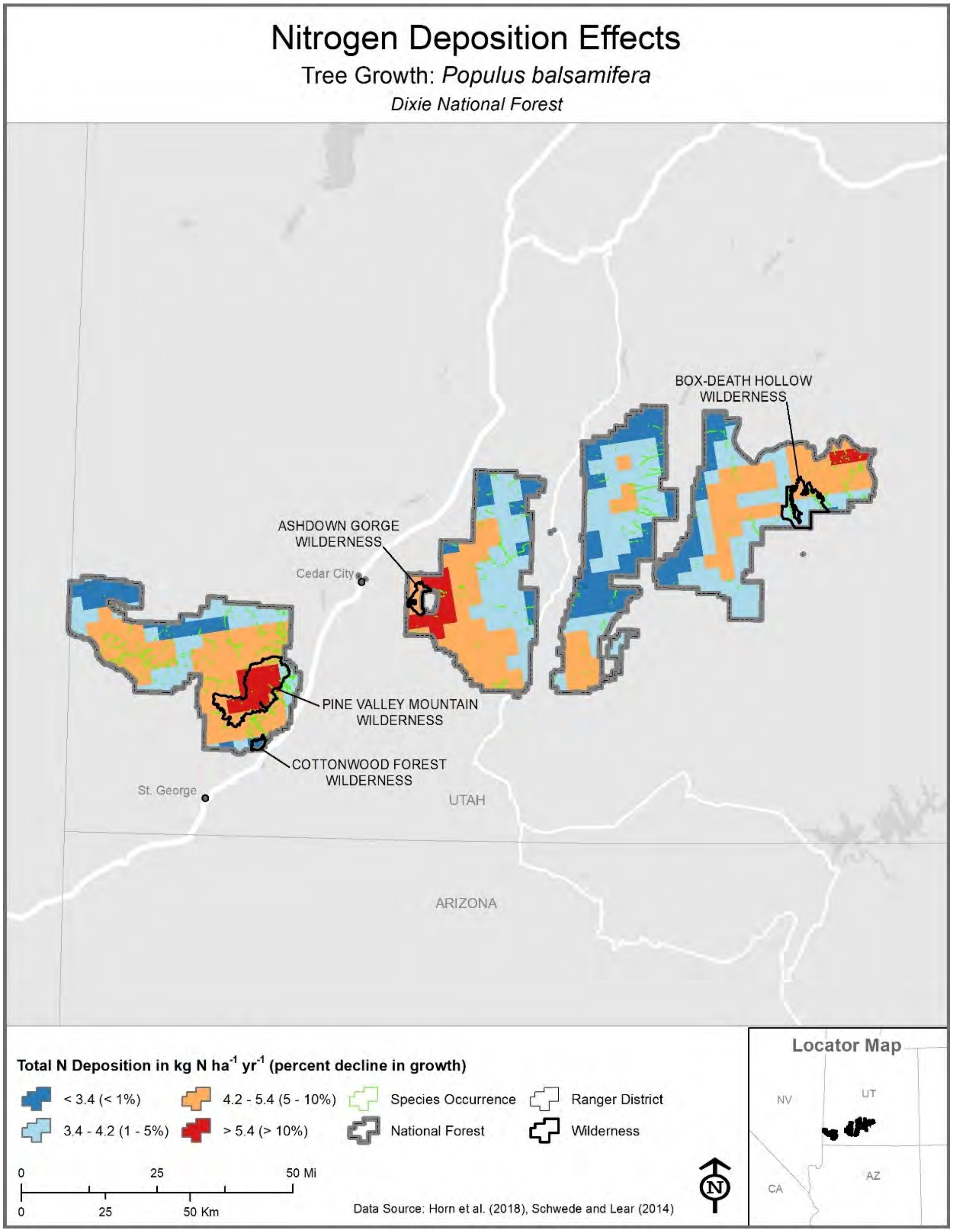

Figure 5-54. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

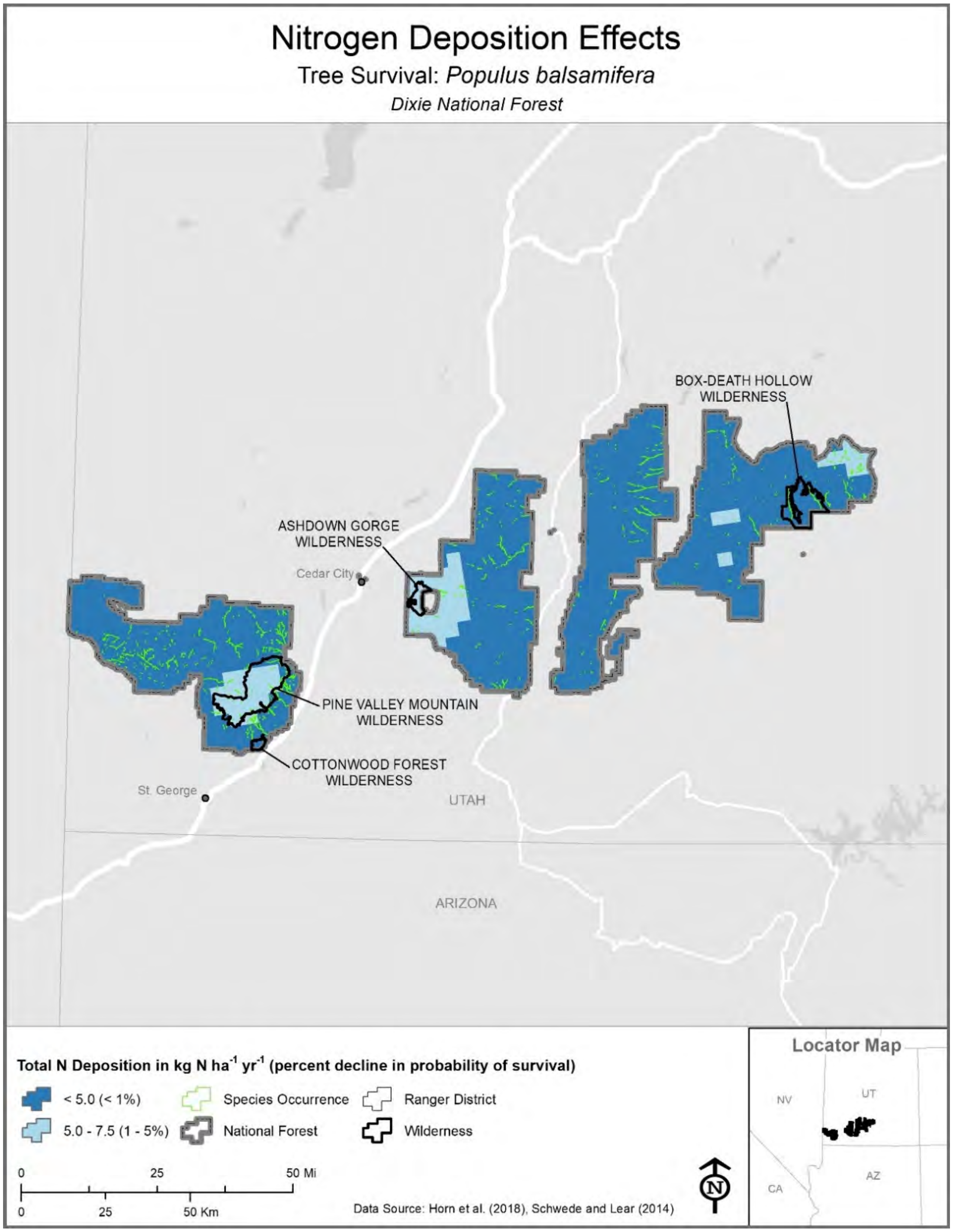

Figure 5-55. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

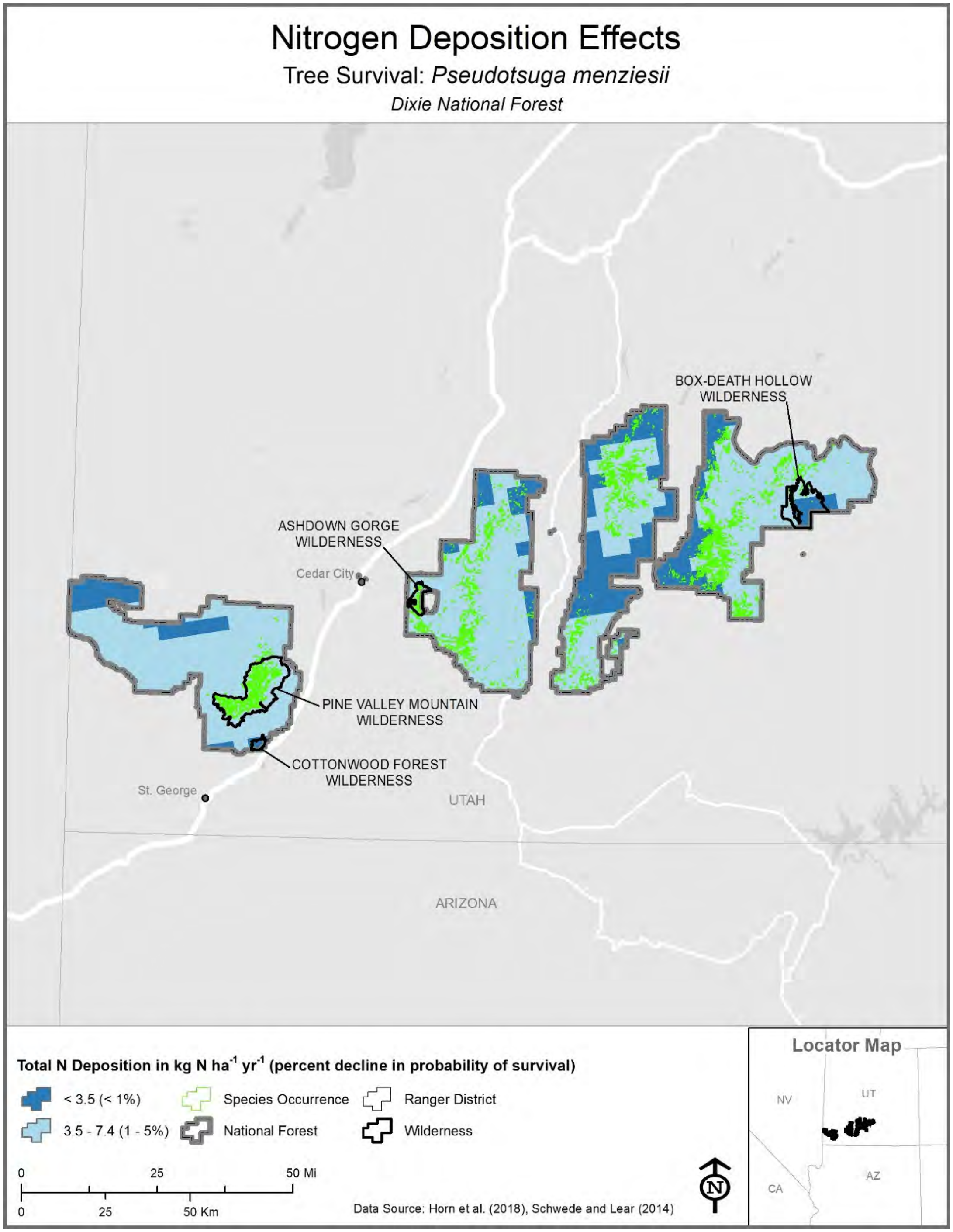

Figure 5-56. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

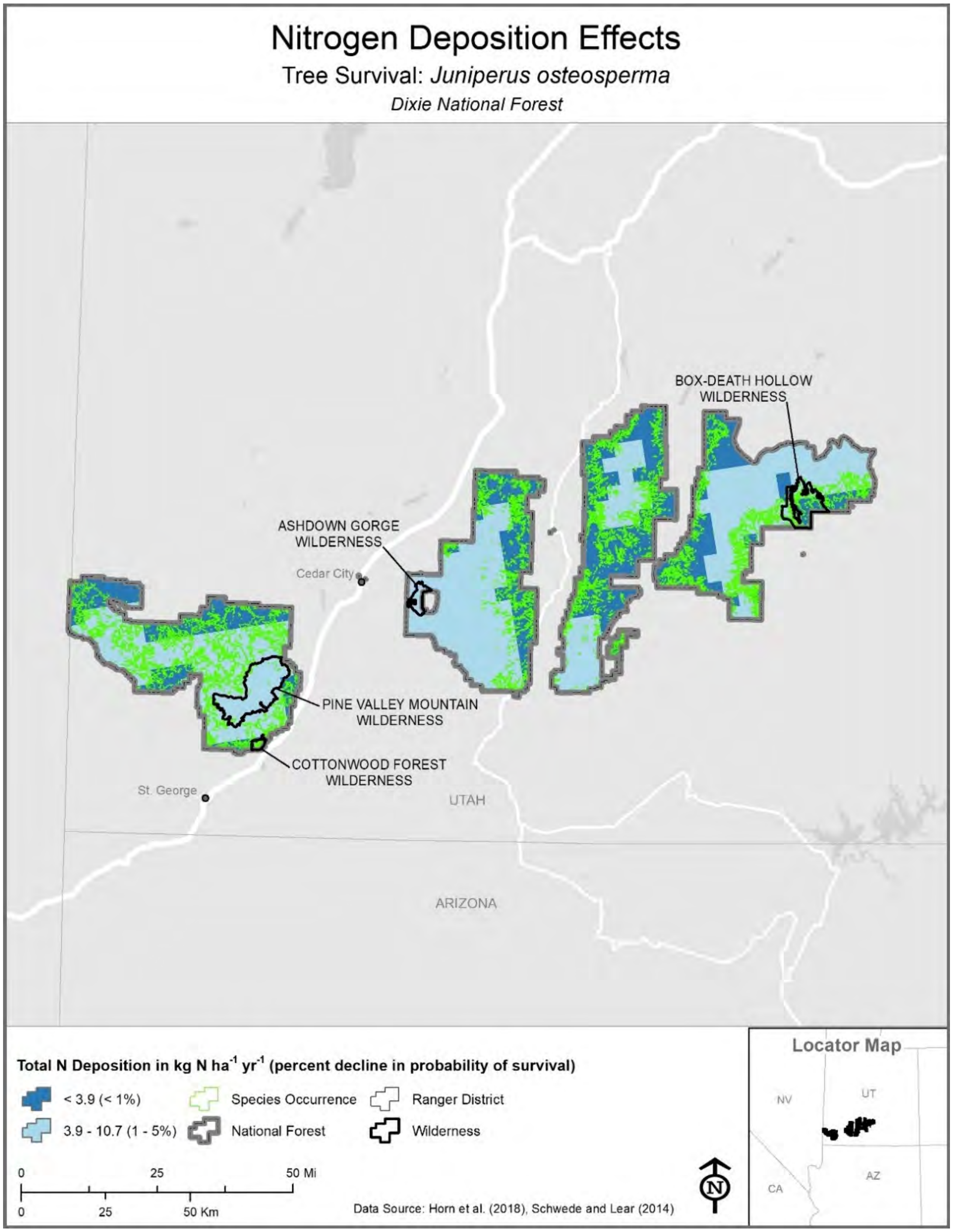

Figure 5-57. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

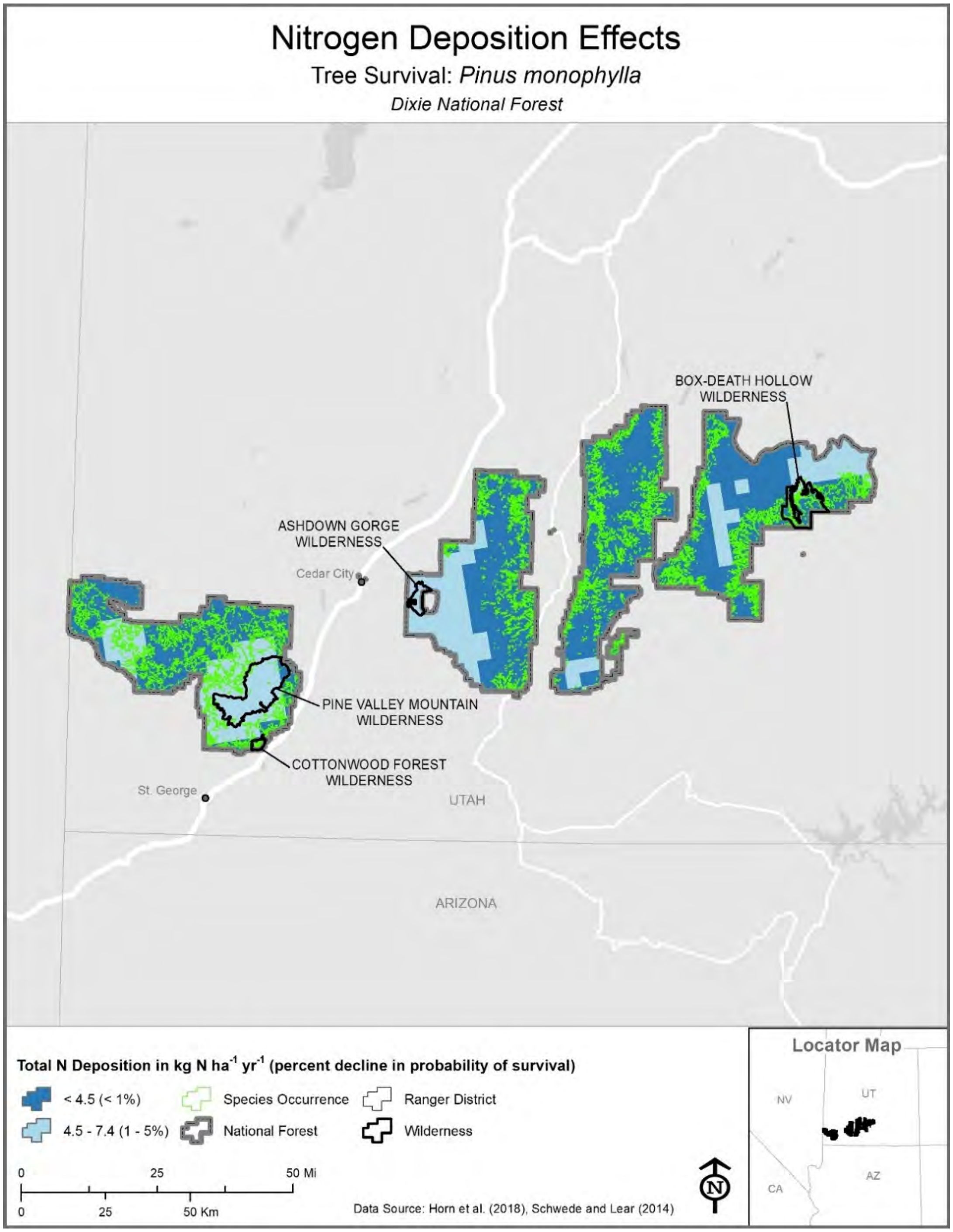

Figure 5-58. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Dixie National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-18. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Dixie National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival 1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies lasiocarpa	subalpine fir	Growth	Increasing	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	Utah juniper	Growth	Increasing	N/A	N/A	N/A
		Survival	**Threshold**	**3.9**	**10.7**	**23.6**
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	singleleaf pinyon	Growth	Increasing	N/A	N/A	N/A
		Survival	**Threshold**	**4.5**	**7.4**	**10.9**
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	**Growth**	**Decreasing**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**5.0**	**7.5**	**10.2**
Populus tremuloides	quaking aspen	**Growth**	**Threshold**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**6.6**	**11.8**	**18.4**
Pseudotsuga menziesii	Douglas fir	Growth	Increasing	N/A	N/A	N/A
		Survival	**Threshold**	**3.5**	**7.4**	**13.2**

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.6 Fishlake NF

5.2.6.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were mostly located within the southeastern portion of the Fishlake NF, where three waterbodies showed relatively low CLs (**Figure** 5-59) and were also in exceedance (**Figure** 5-60). The highest magnitudes of CL exceedance (2 – 5 kg N ha^{-1} yr^{-1}) generally occurred within the southeastern portions of the forest. These three waterbodies are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. Given the low representation of CLs within the Fishlake NF, acid-sensitive waterbodies may occur elsewhere.

5.2.6.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout most of the Fishlake NF and represented a total of nearly 2,000 km^2 (30%) of the forest (**Table** 5-3; **Figure** 5-61). Areas of exceedance followed a generally similar pattern as the CLs and included just over 1,900 km^2 (30%) of the forest (**Table** 5-4; **Figure** 5-62). All areas were less than 5 kg N ha^{-1} yr^{-1} in exceedance. Areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.6.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 82% and 100%, respectively, of the Fishlake NF (**Table**s 5-5 and 5-6). Non-exceedance of the CL for lichen species richness was scattered throughout the forest. The highest magnitudes (> 2 kg N ha^{-1} yr^{-1}) of exceedance were also distributed throughout the forest, with the exception of one small area of forage lichen CL exceedance in greater than 4.5 kg N ha^{-1} yr^{-1} (**Figures** 5-63 and 5-64). Critical load exceedance associated with 40 – 50% reductions in forage lichen abundance were common throughout the forest.

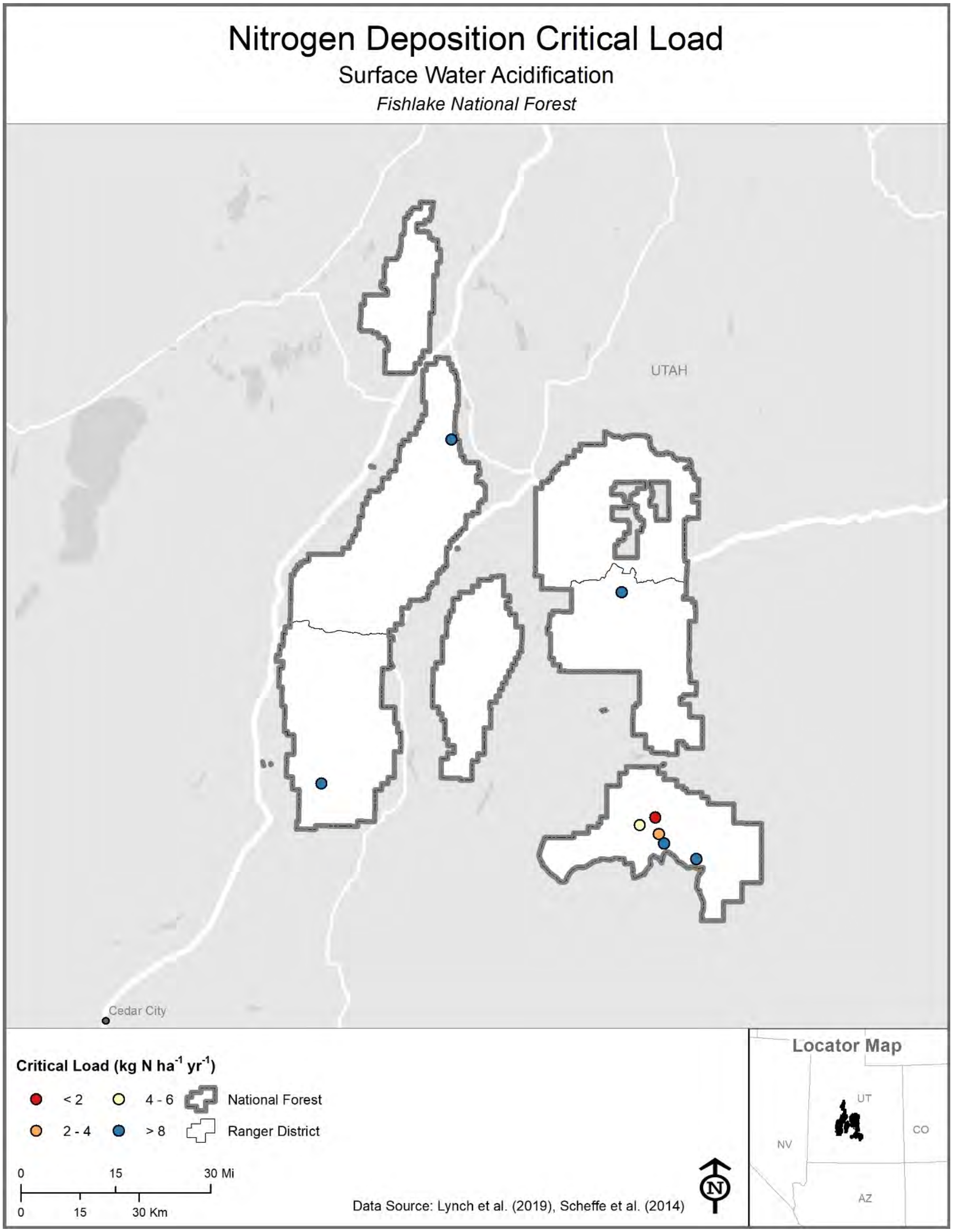

Figure 5-59. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Fishlake National Forest.

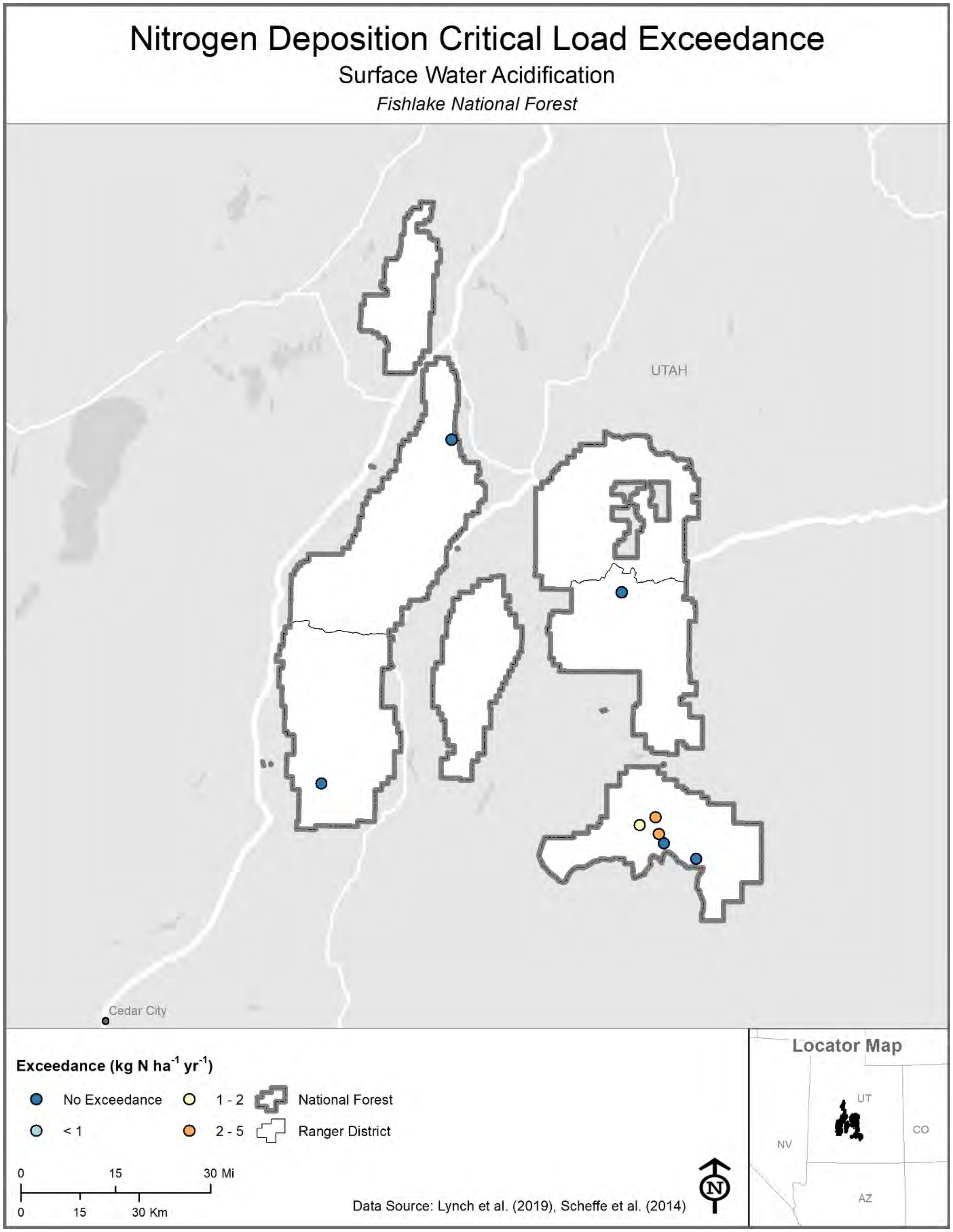

Figure 5-60. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Fishlake National Forest.

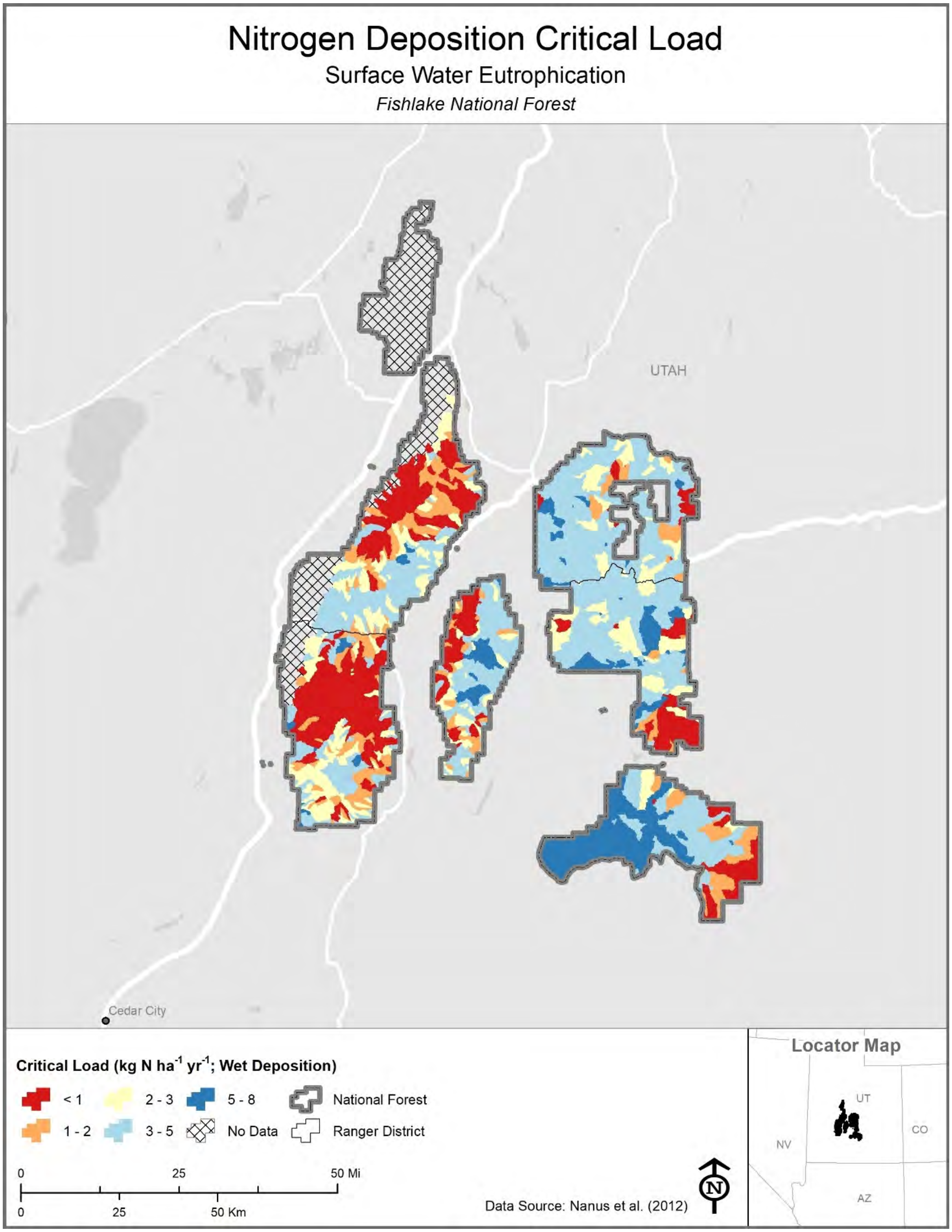

Figure 5-61. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Fishlake National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

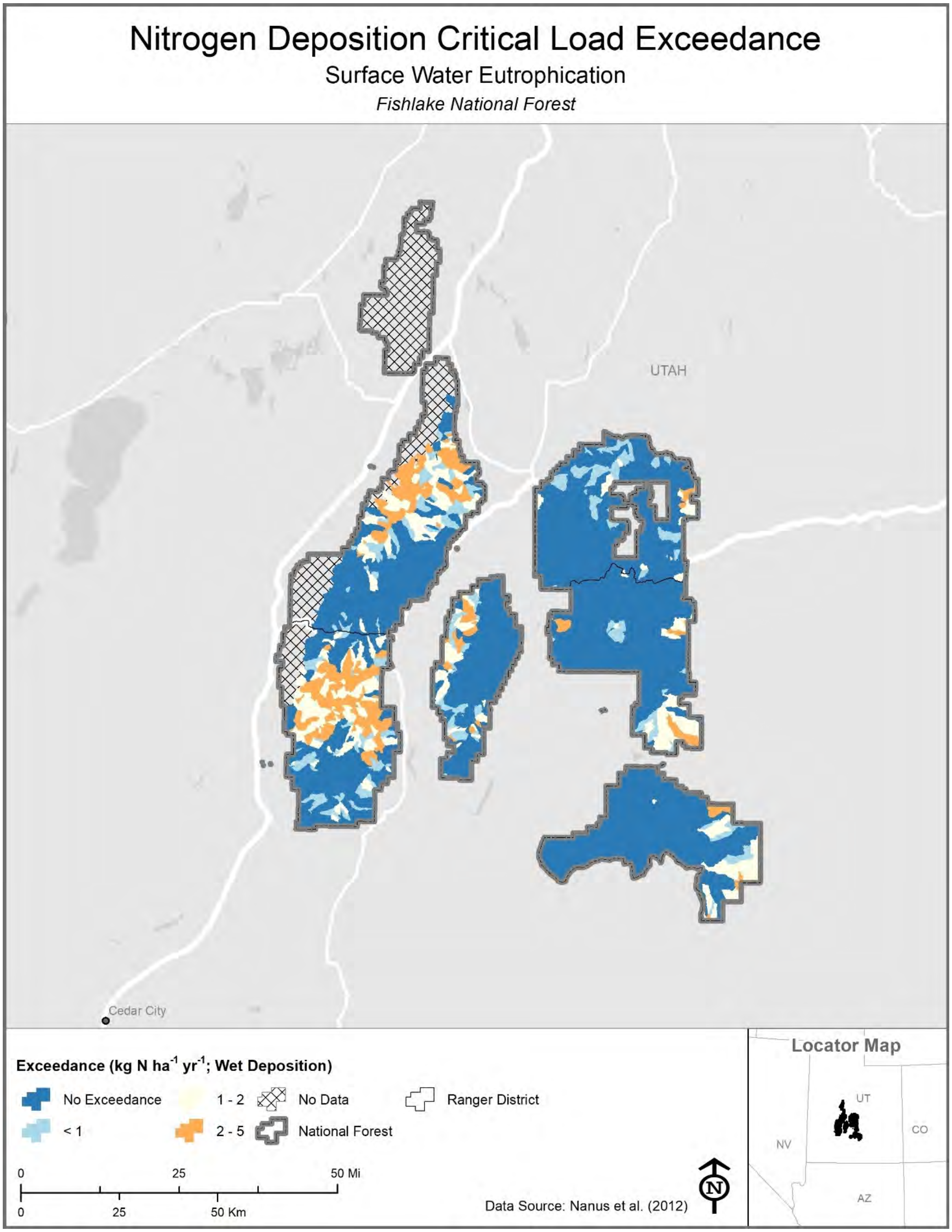

Figure 5-62. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Fishlake National Forest.

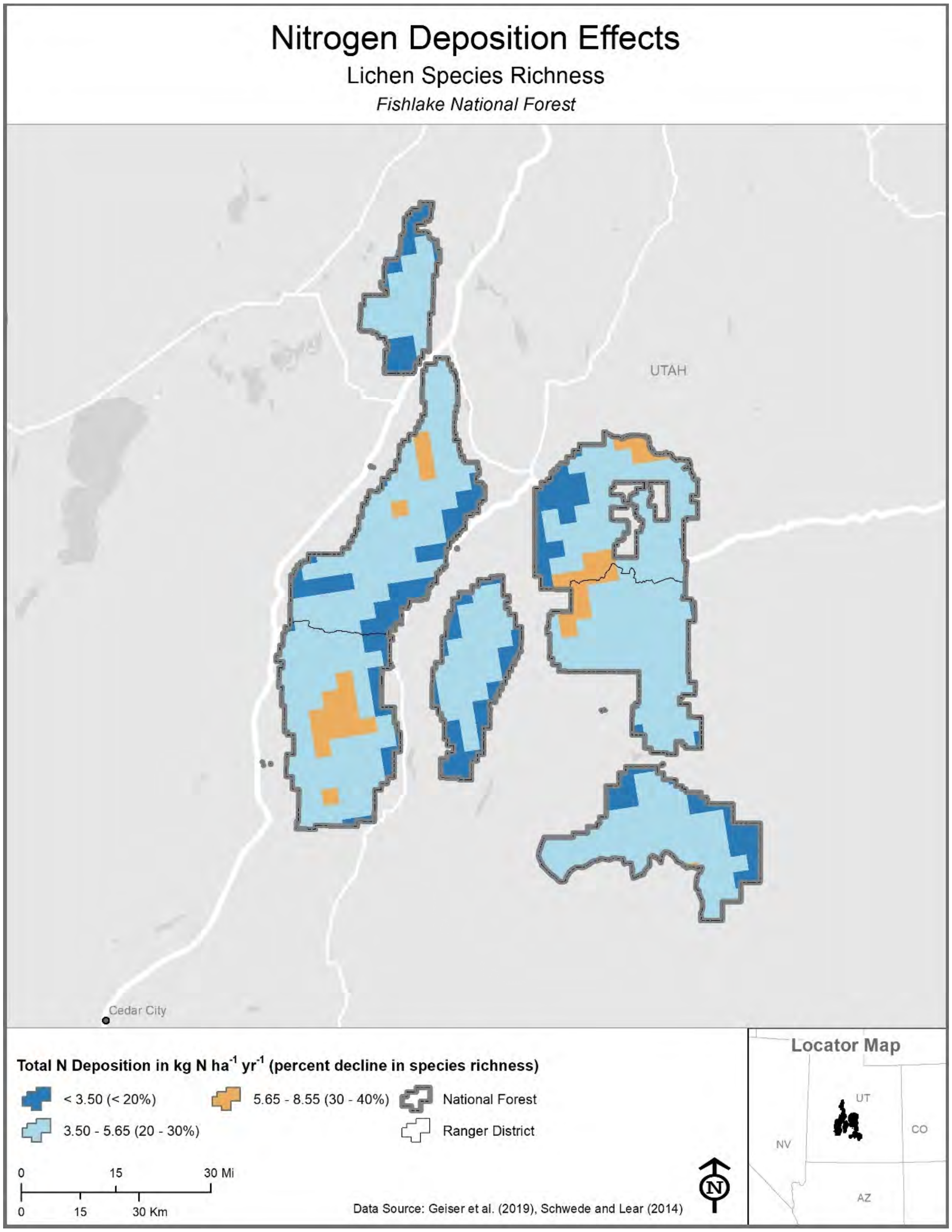

Figure 5-63. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Fishlake National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

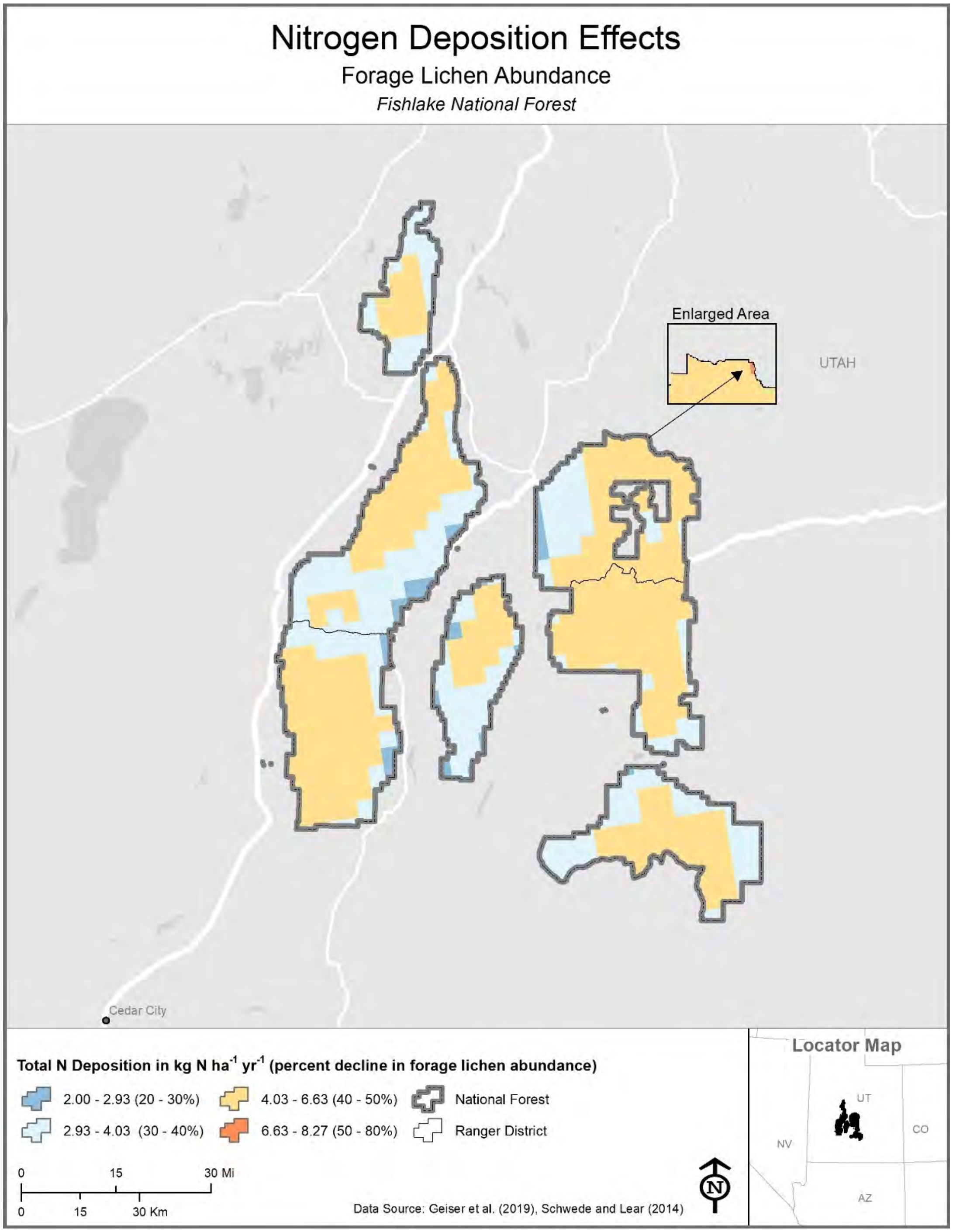

Figure 5-64. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Fishlake National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

5.2.6.4 Tree Growth and Survival

Although there were no exceedances of CLs to protect growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reductions) within less than 0.2% of the area in which this species is expected to occur within the Fishlake NF (**Table**s 5-7 and 5-8; **Figure** 5-65). The very small area (0.2 km^2) of exceedance for probability of survival occurred in the northeastern portion of the forest (**Figure** 5-66; not visible on the map).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 82% and 19%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Decreases in growth of 5 – 10% were expected to occur in various portions of the forest (**Figure** 5-67). Areas of reductions in probability of survival of 1 – 5% were limited to relatively small areas throughout the forest (**Figure** 5-68).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 92% of the area in which this species is expected to occur (**Table** 5-11). Areas of exceedance were common throughout the forest (**Figure** 5-69).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 36% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance mostly occurred in the northern and eastern portions of the forest (**Figure** 5-70).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 8% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance mostly occurred in the northern and eastern portions of the forest (**Figure** 5-71).

Other species of interest that occurred within the Fishlake NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-19). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

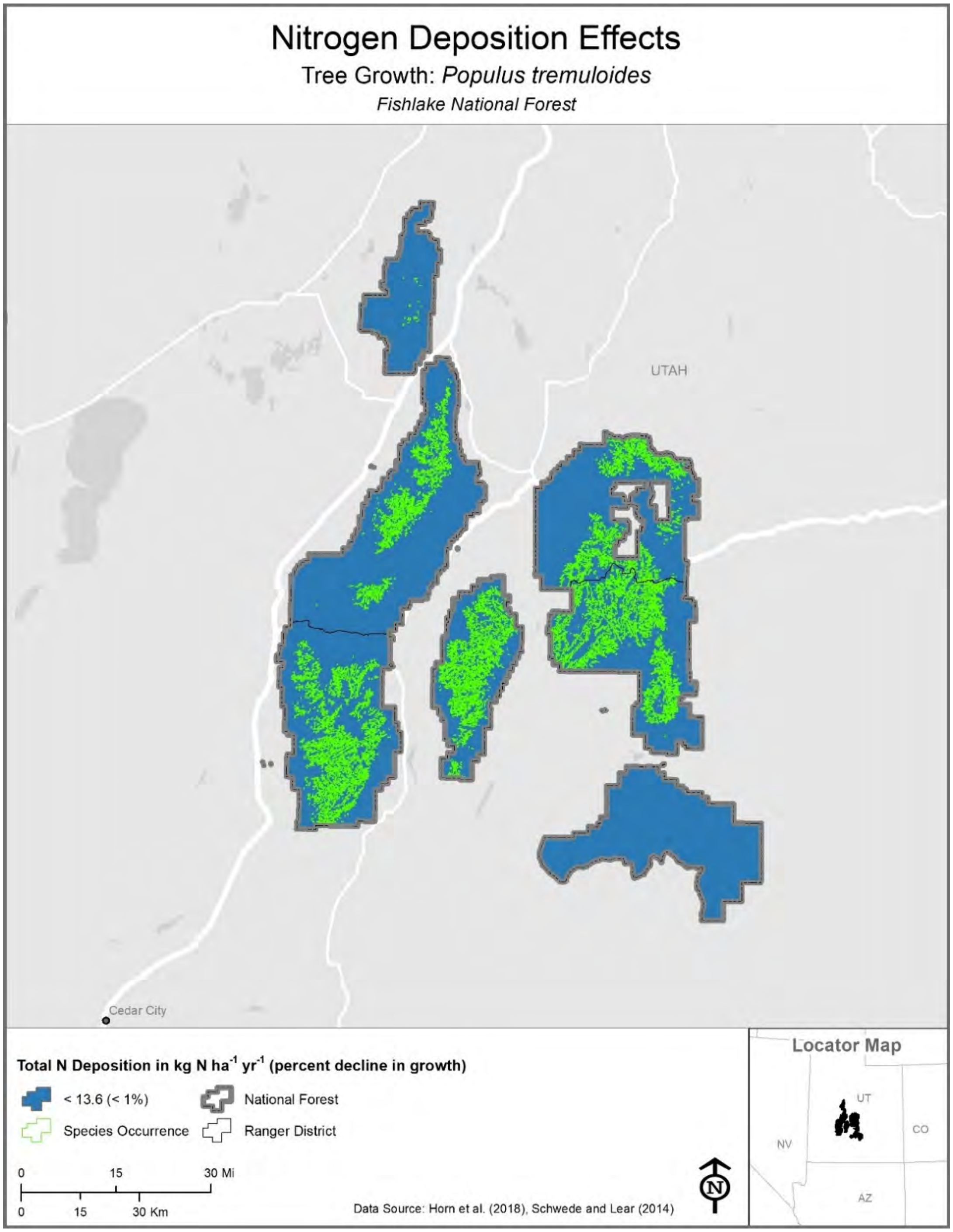

Figure 5-65. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Fishlake NF is below the critical load for 1% growth reduction of *Populus tremuloides.* There are no areas of exceedance for ………..

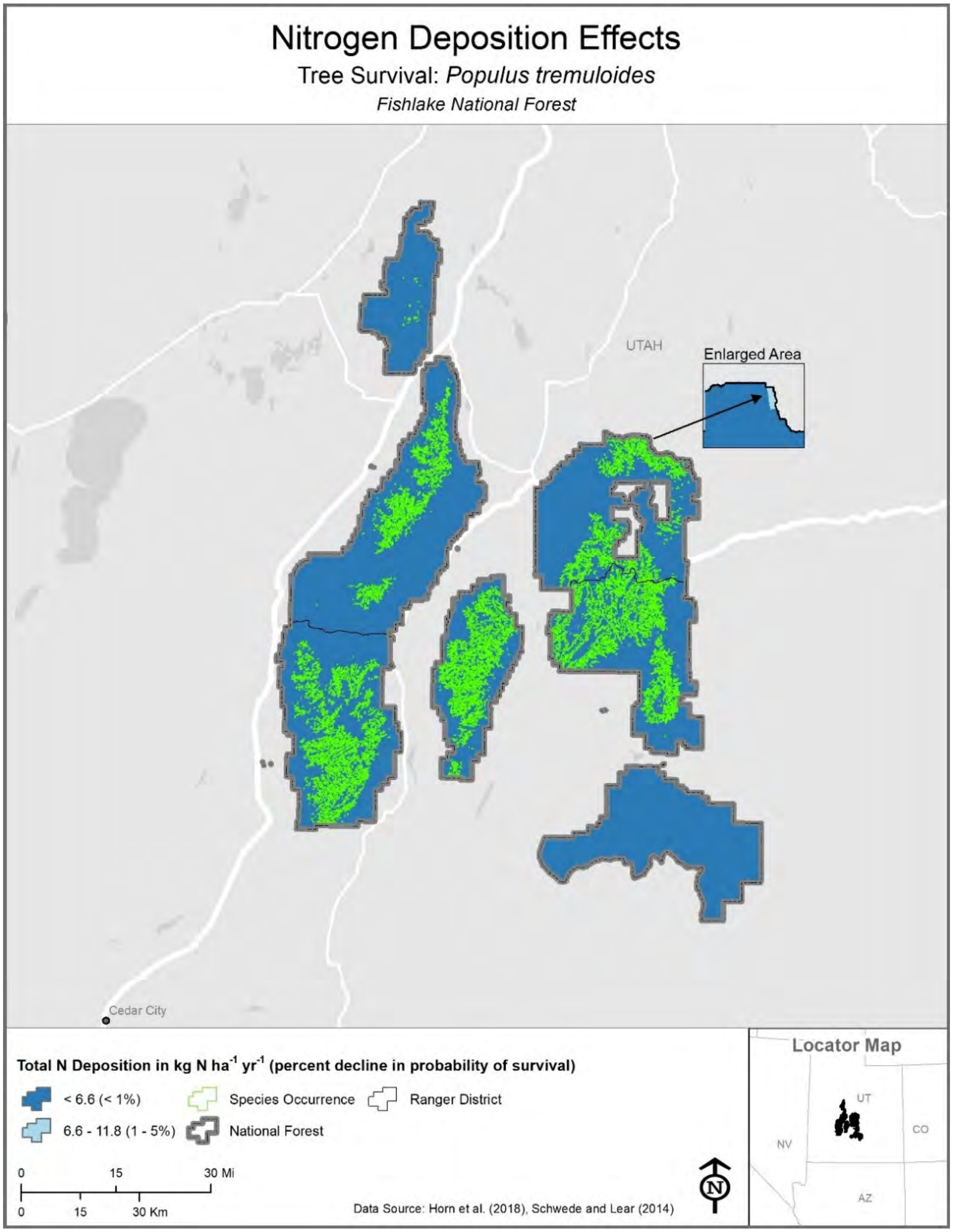

Figure 5-66. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

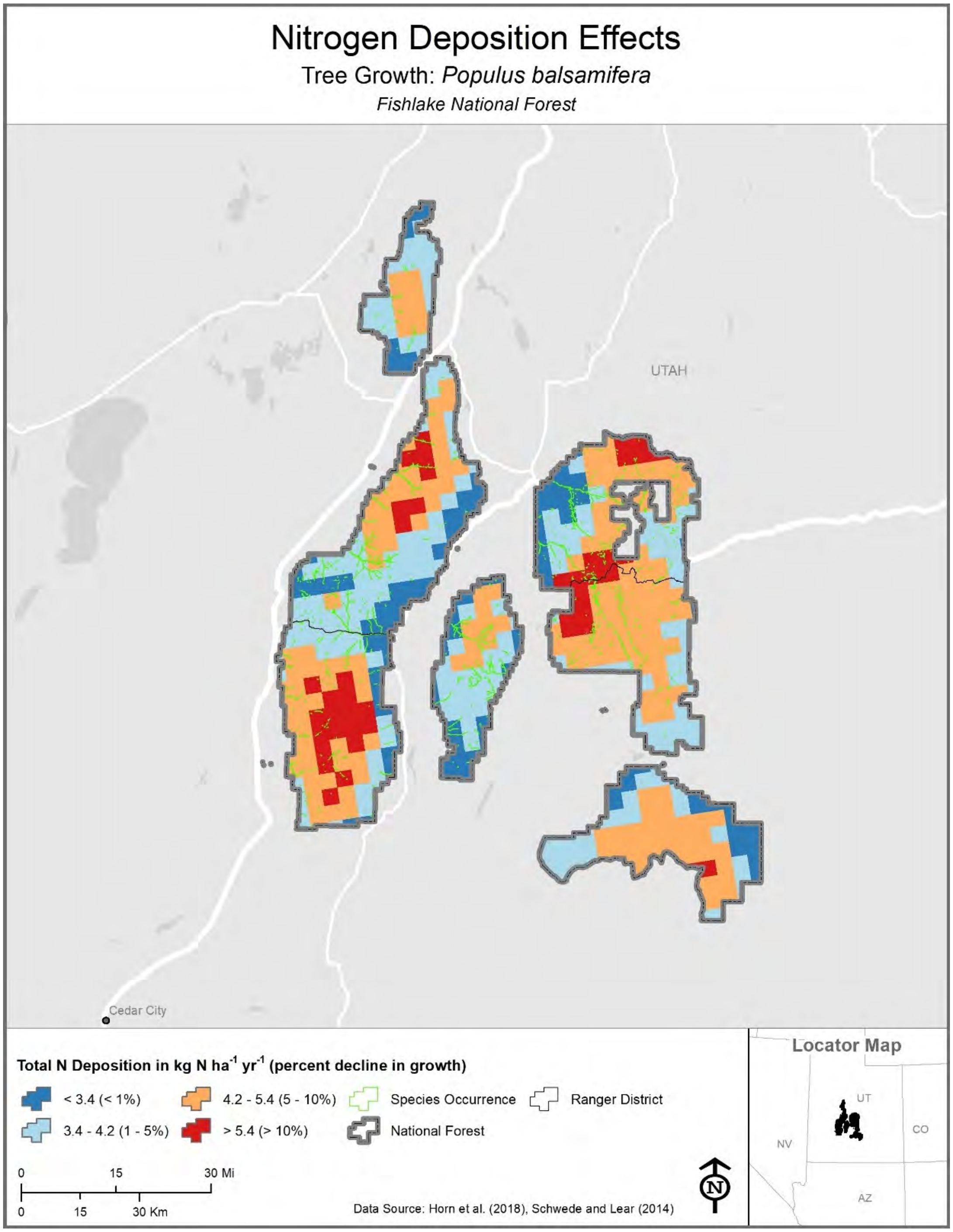

Figure 5-67. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

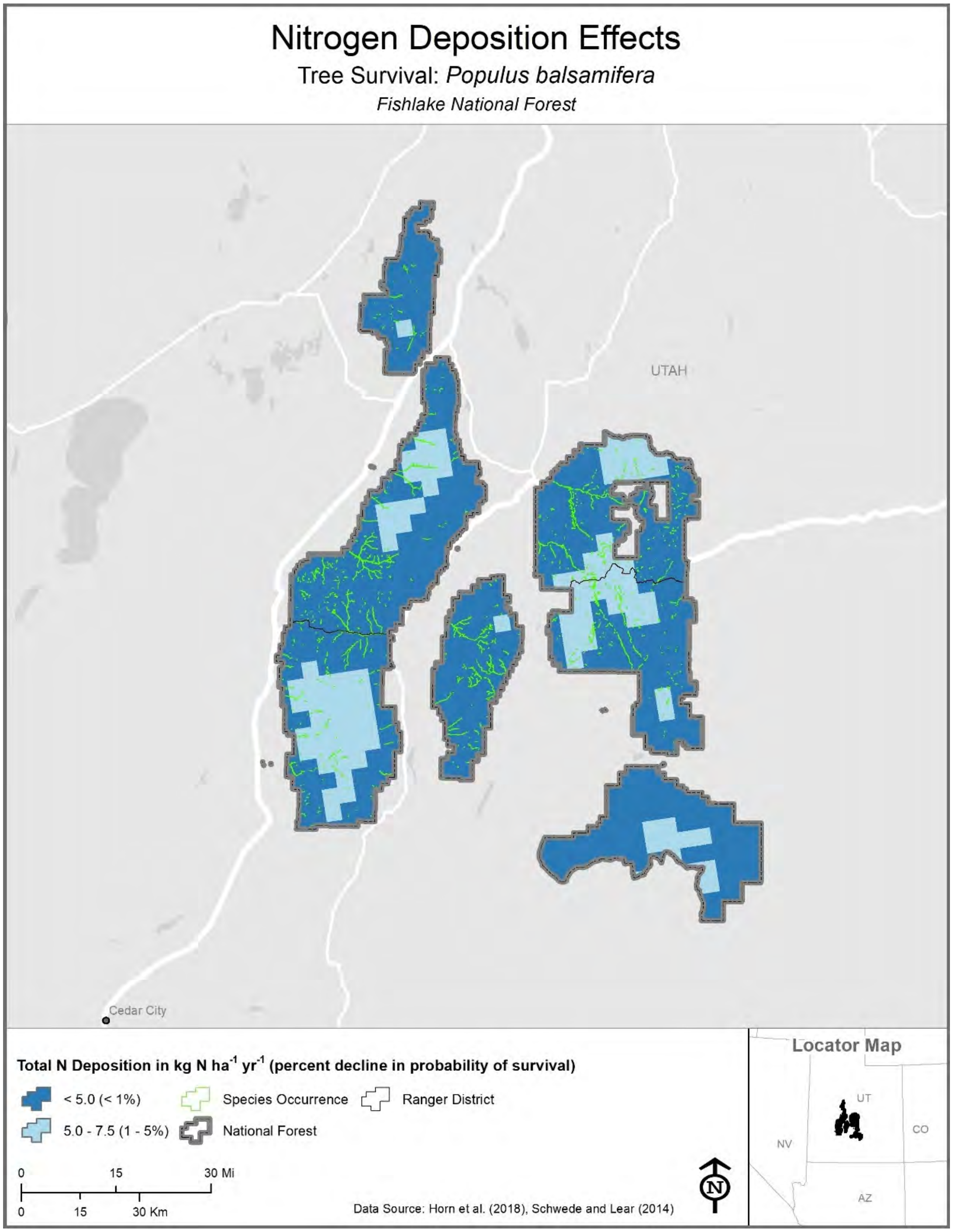

Figure 5-68. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

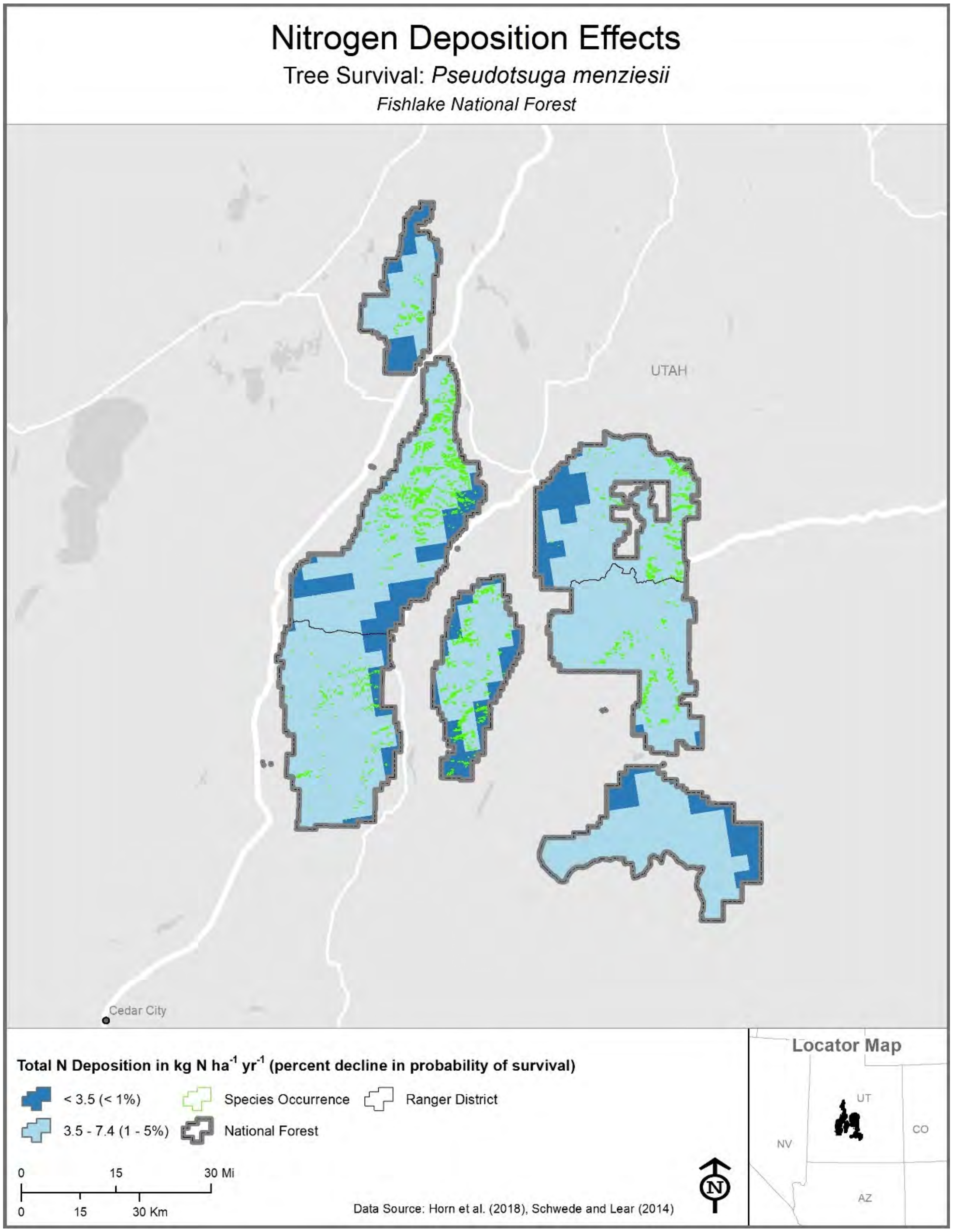

Figure 5-69. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

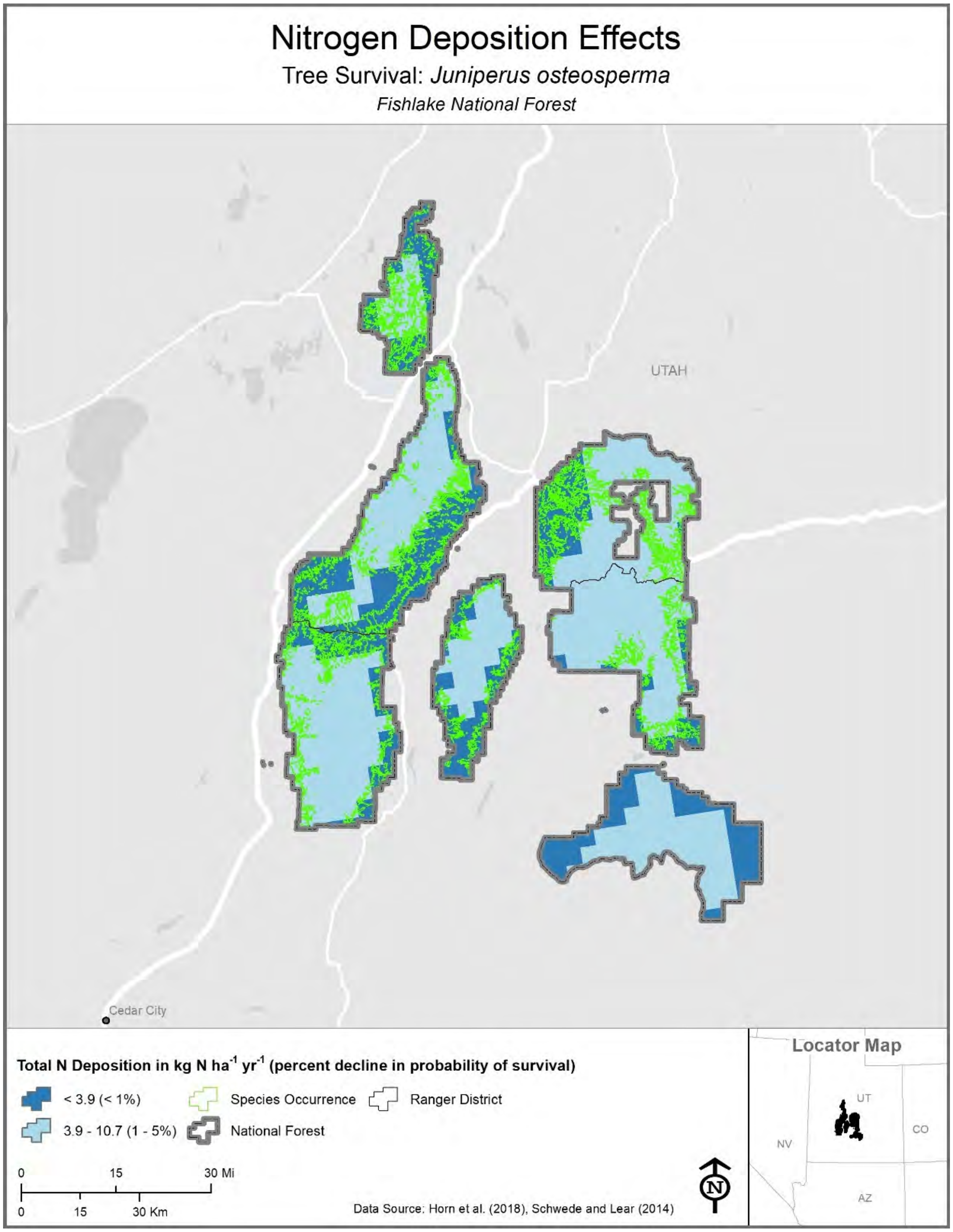

Figure 5-70. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

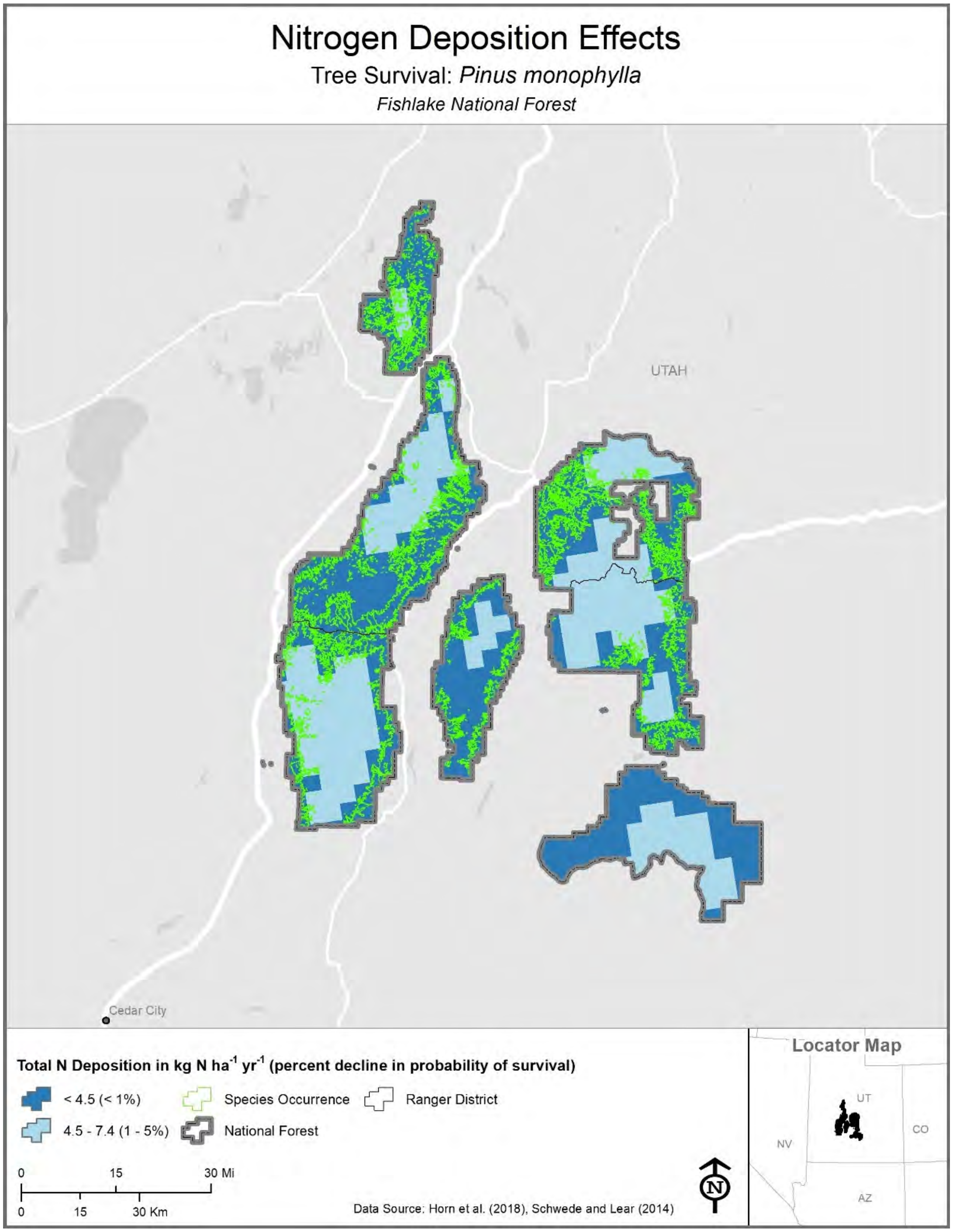

Figure 5-71. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Fishlake National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-19. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Fishlake National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.7 Humboldt-Toiyabe NF

5.2.7.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were typically located within and in the vicinity of wilderness areas of the Humboldt-Toiyabe NF (**Figures** 5-72 through 5-74). Surface waters with relatively high risk of acidification impacts (i.e., low CLs) were mostly located within the Mokelumne Wilderness and Hoover Wilderness and less sensitive (i.e., higher CLs) waterbodies occurred at sites outside the wilderness areas. N deposition was high enough to exceed the CL at 9% (n = 3) of the sites (**Table** 5-2), all of which occurred within wilderness areas (**Figures** 5-75 through 5-77). The highest magnitude of exceedance was between 2 and 5 kg N ha^{-1} yr^{-1}. Exceedance of the CL indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. Surface water CLs were not available for the Ely Ranger District and the Spring Mountains National Recreation Area. Given the low representation of sites where CLs are calculated in some portions of the Humboldt-Toiyabe NF, acid-sensitive waterbodies may occur elsewhere.

5.2.7.2 Surface Water Eutrophication

Spatial data for CLs protective of effects from surface water eutrophication were not available for the Humboldt-Toiyabe NF because these areas were not included in the study reported by Nanus et al. (2017).

5.2.7.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 57% and nearly 100%, respectively, of the Humboldt-Toiyabe NF (**Table**s 5-5 and 5-6). Non-exceedance of CLs for lichen species richness was typically located outside of wilderness areas and all wilderness areas contained at least some portion of their area in exceedance (**Figures** 5-78 through 5-82). The highest magnitudes of exceedance (> 6 kg N ha^{-1} yr^{-1}) occurred within and nearby the Mokelumne Wilderness, Carson Iceberg Wilderness, and Mt. Charleston Wilderness. Although significantly more area was in exceedance of CLs for forage lichen abundance, spatial patterns in the relative magnitude of CL exceedance were

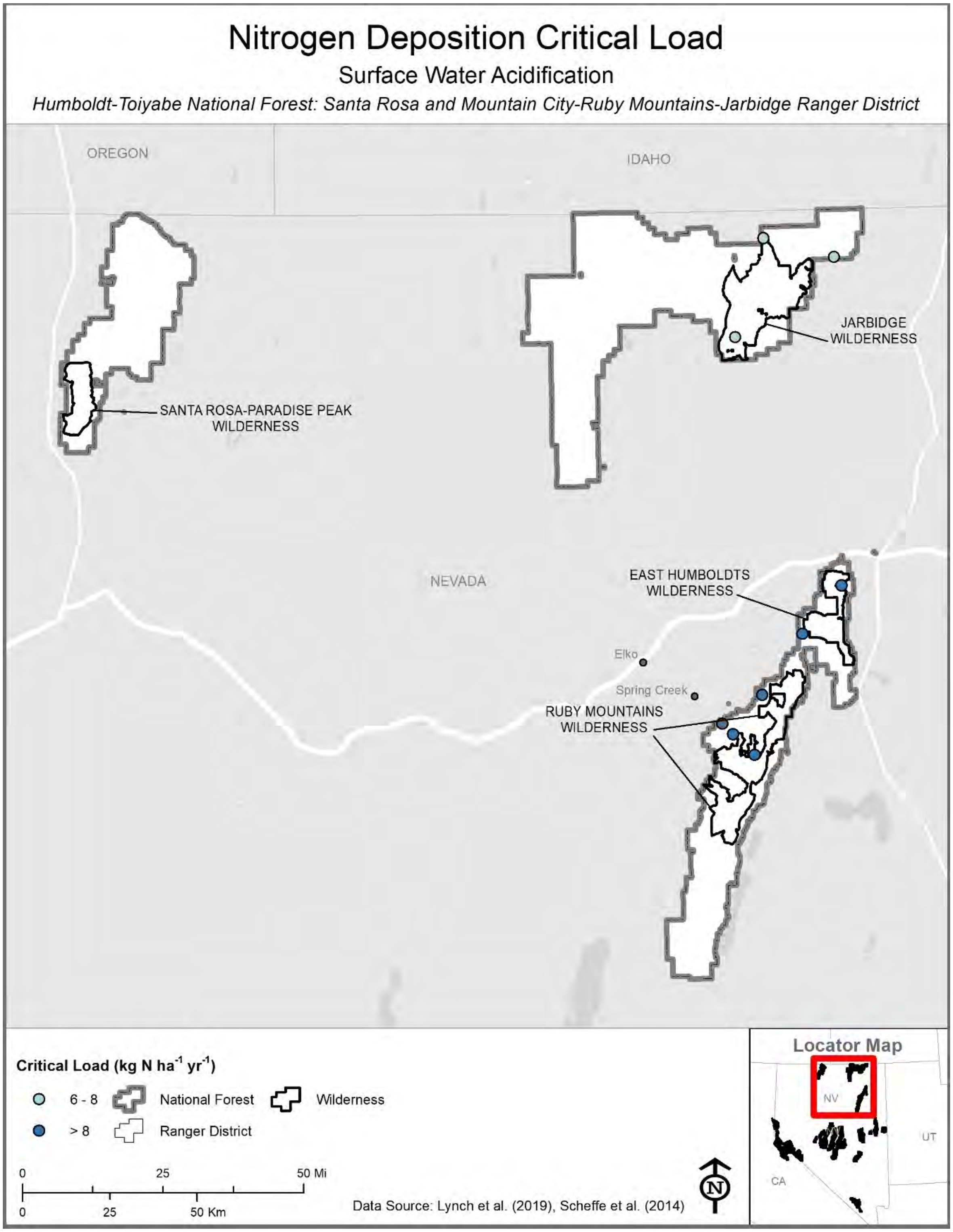

Figure 5-72. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest.

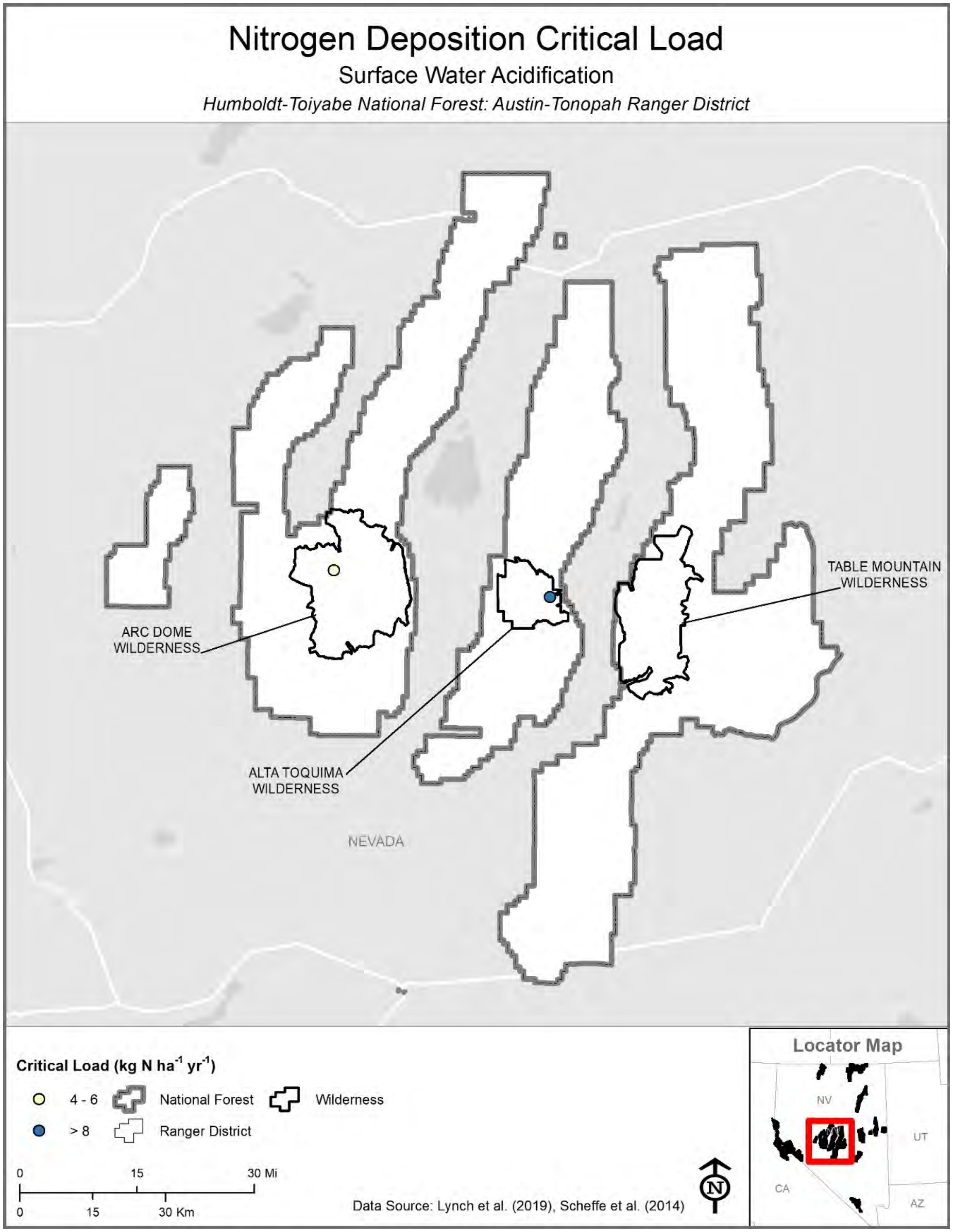

Figure 5-73. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest.

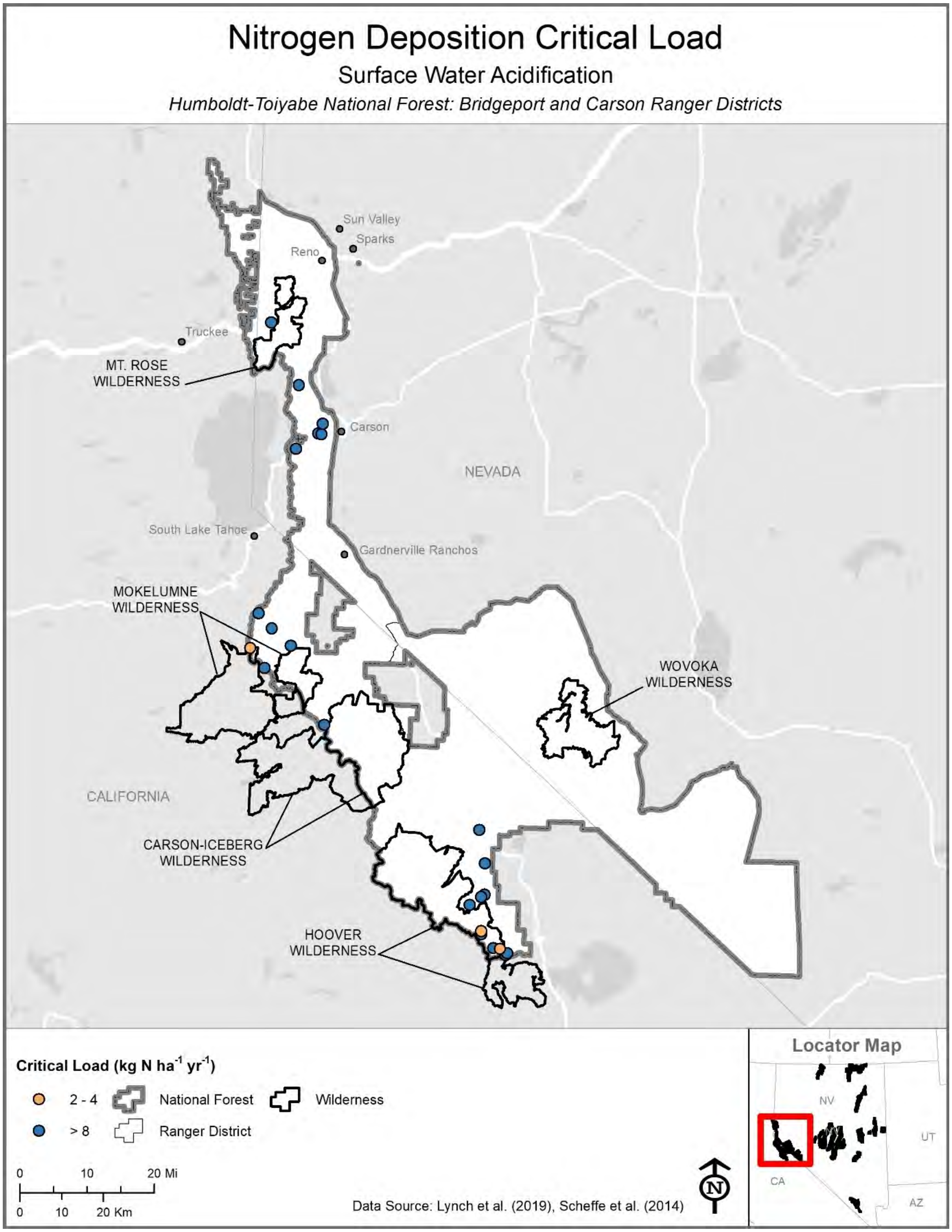

Figure 5-74. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest.

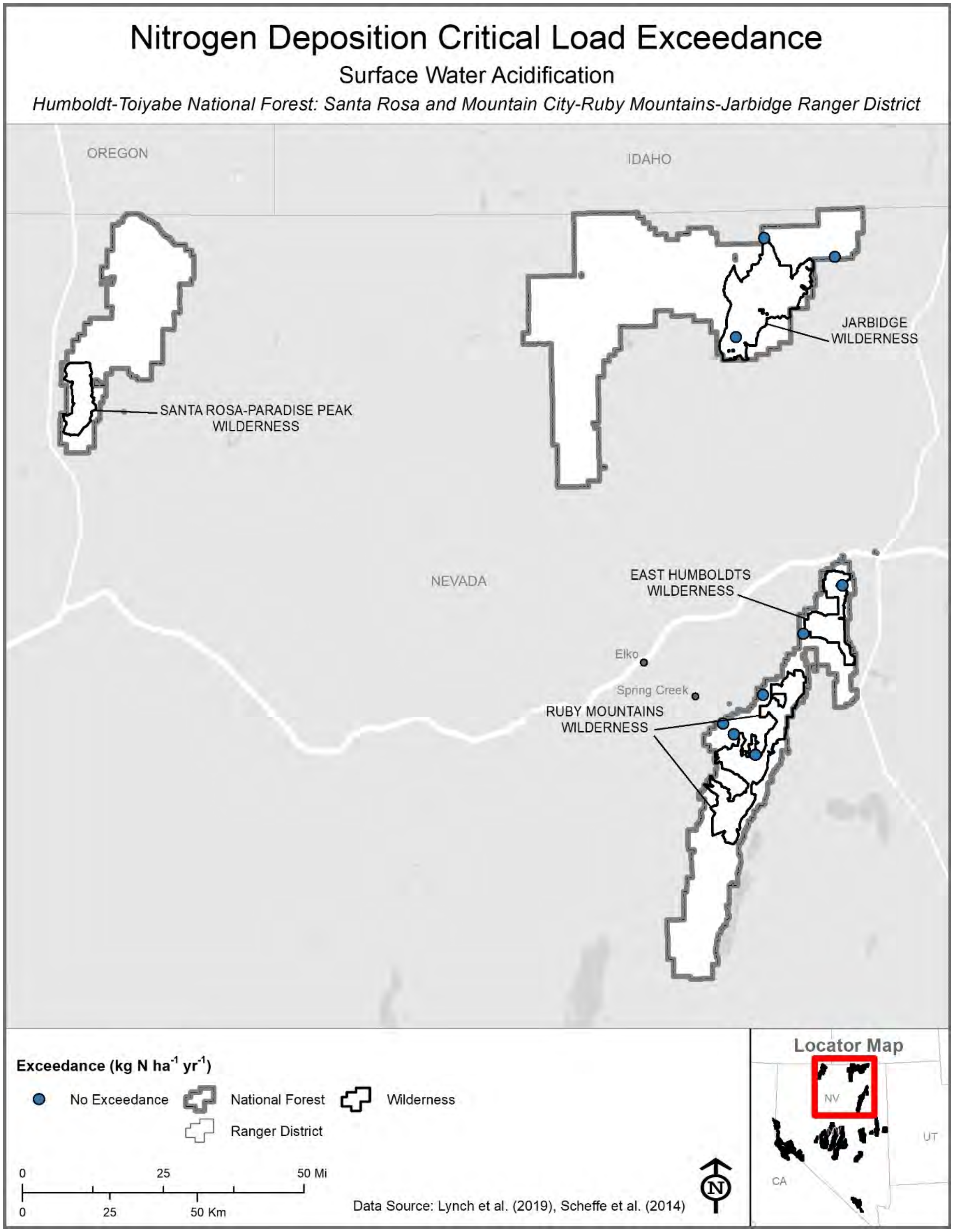

Figure 5-75. Map of the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District of the Humboldt-Toiyabe National Forest showing no exceedance of the critical load of nitrogen (N) for surface water acidification.

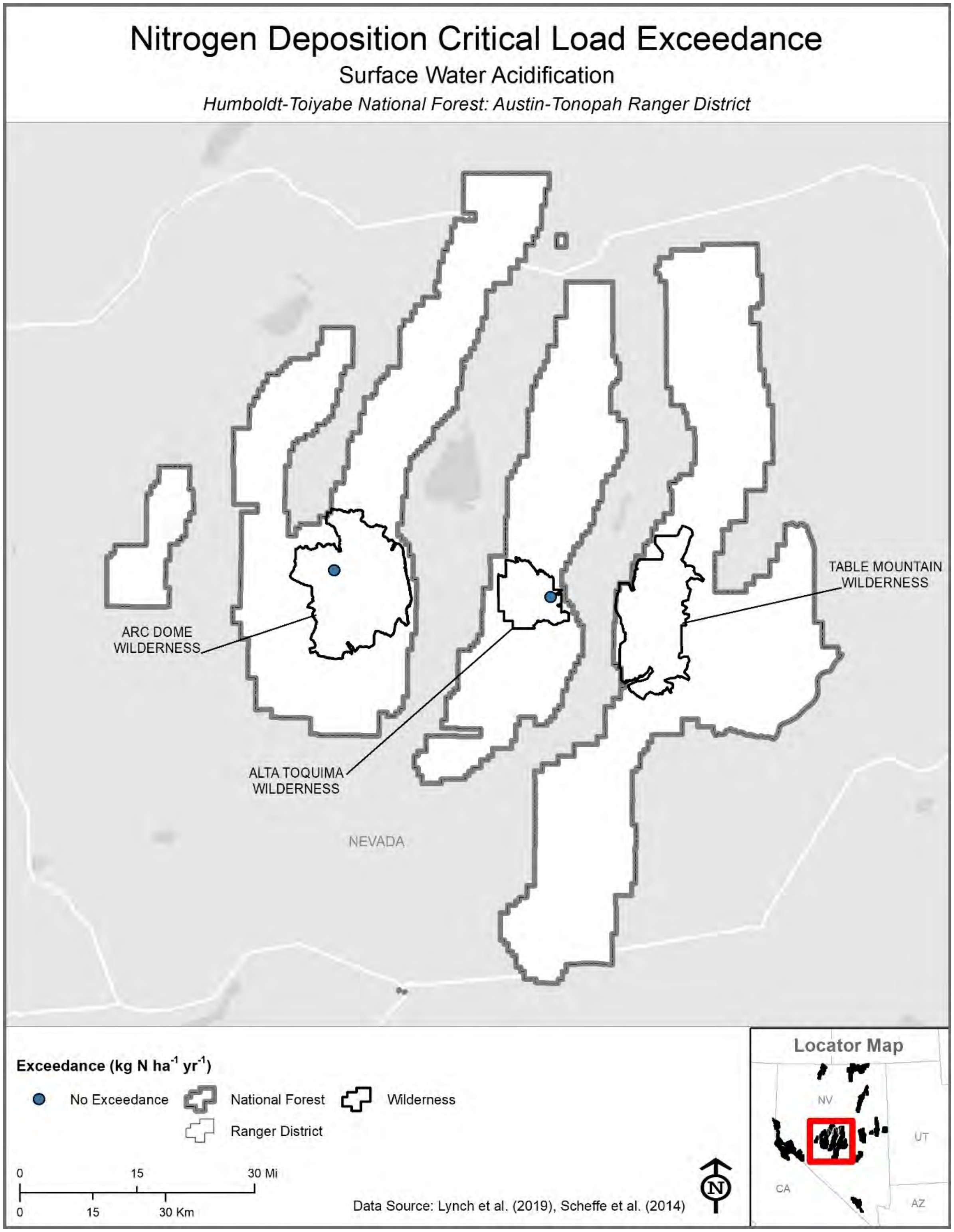

Figure 5-76. Map of the Austin-Tonopah Ranger District of the Humboldt-Toiyabe National Forest showing no exceedance of the critical load of nitrogen (N) for surface water acidification.

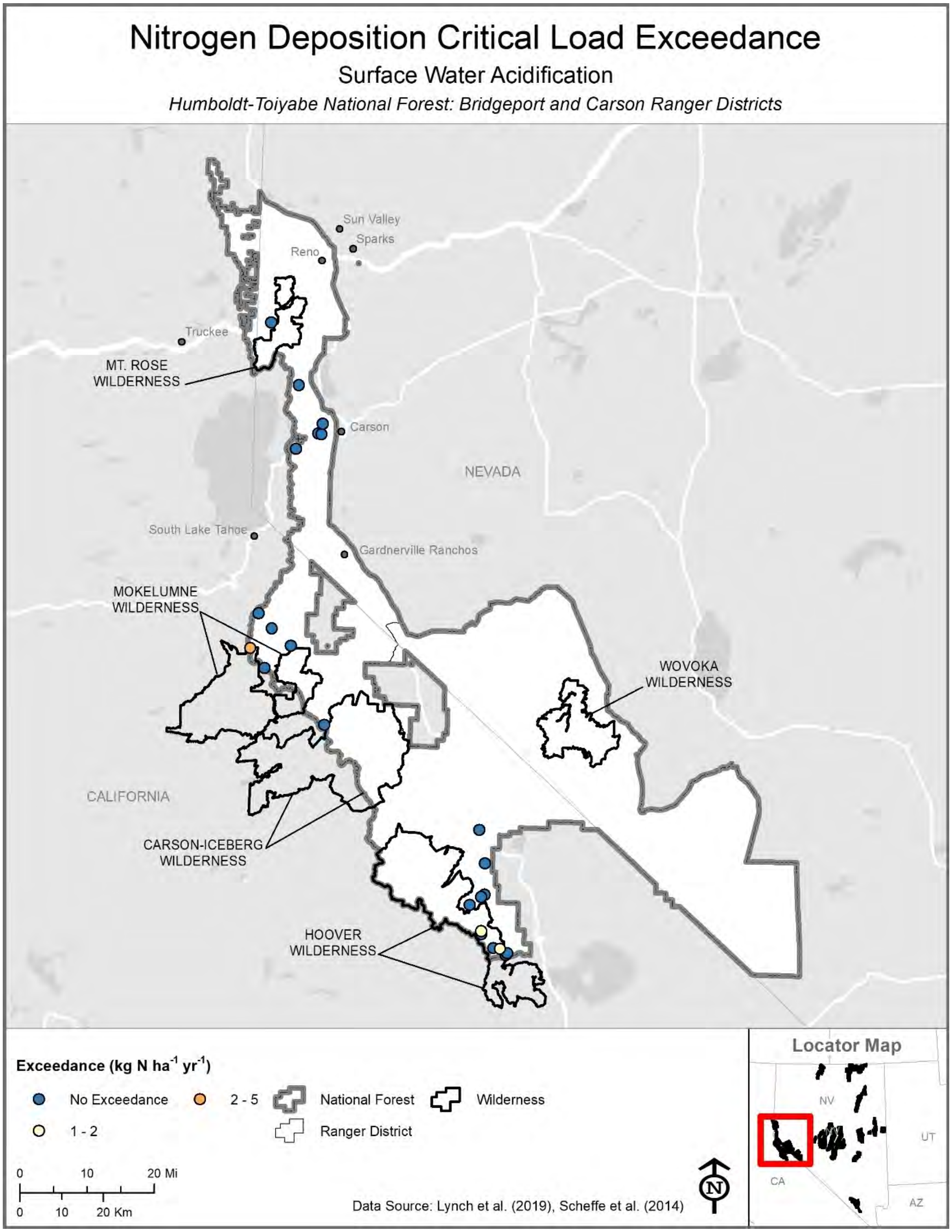

Figure 5-77. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Bridgeport and Carson Ranger District Ranger District in Humboldt-Toiyabe National Forest.

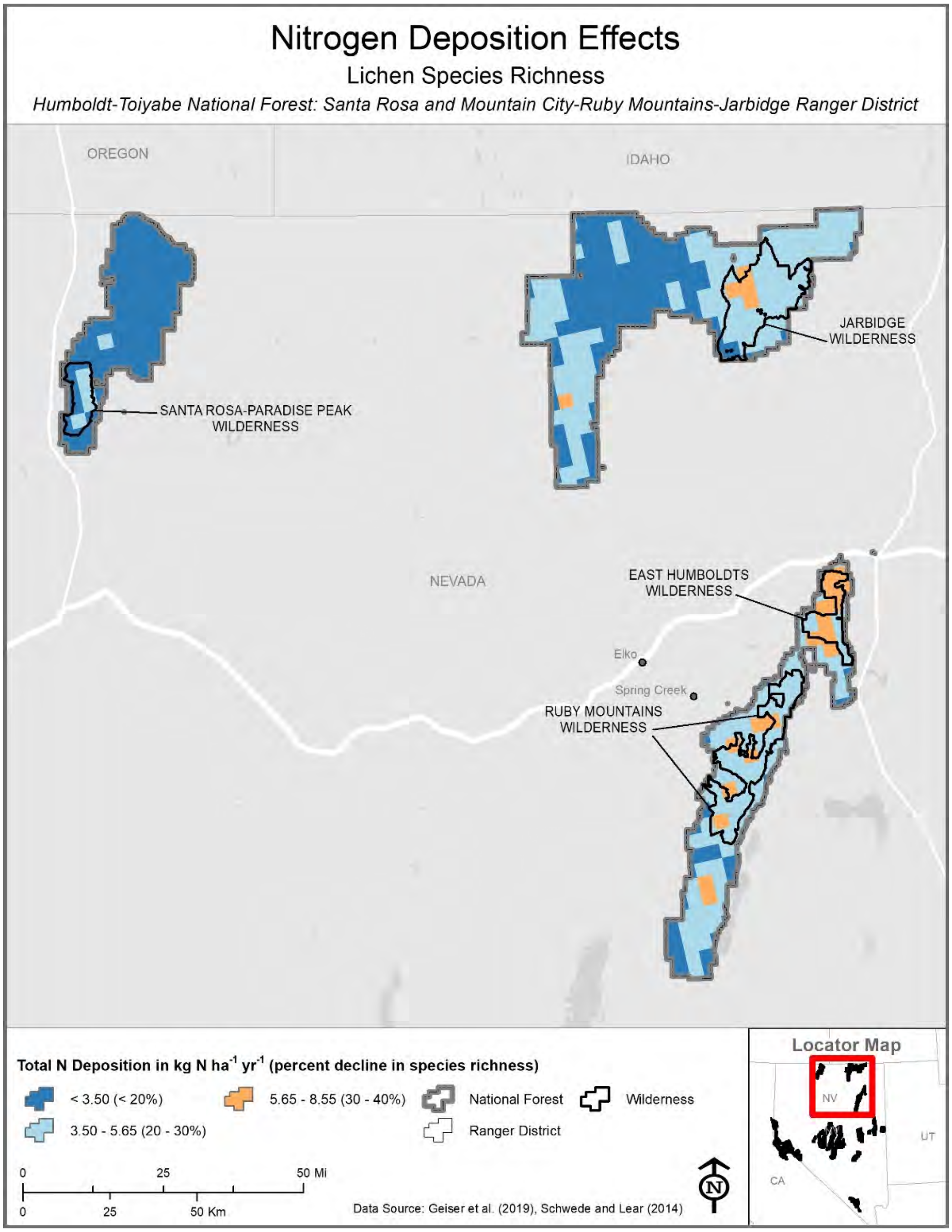

Figure 5-78. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

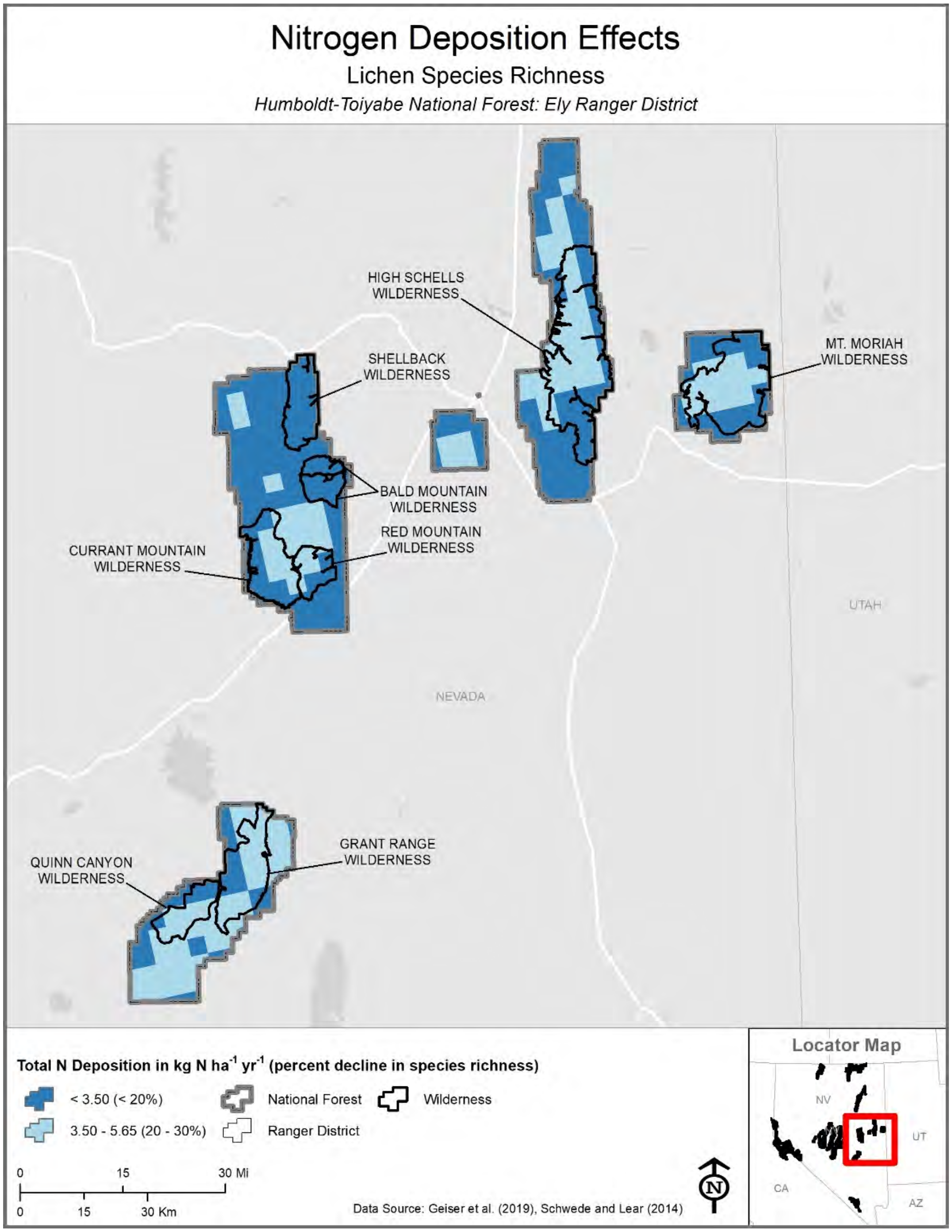

Figure 5-79. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% reductions in lichen species richness.

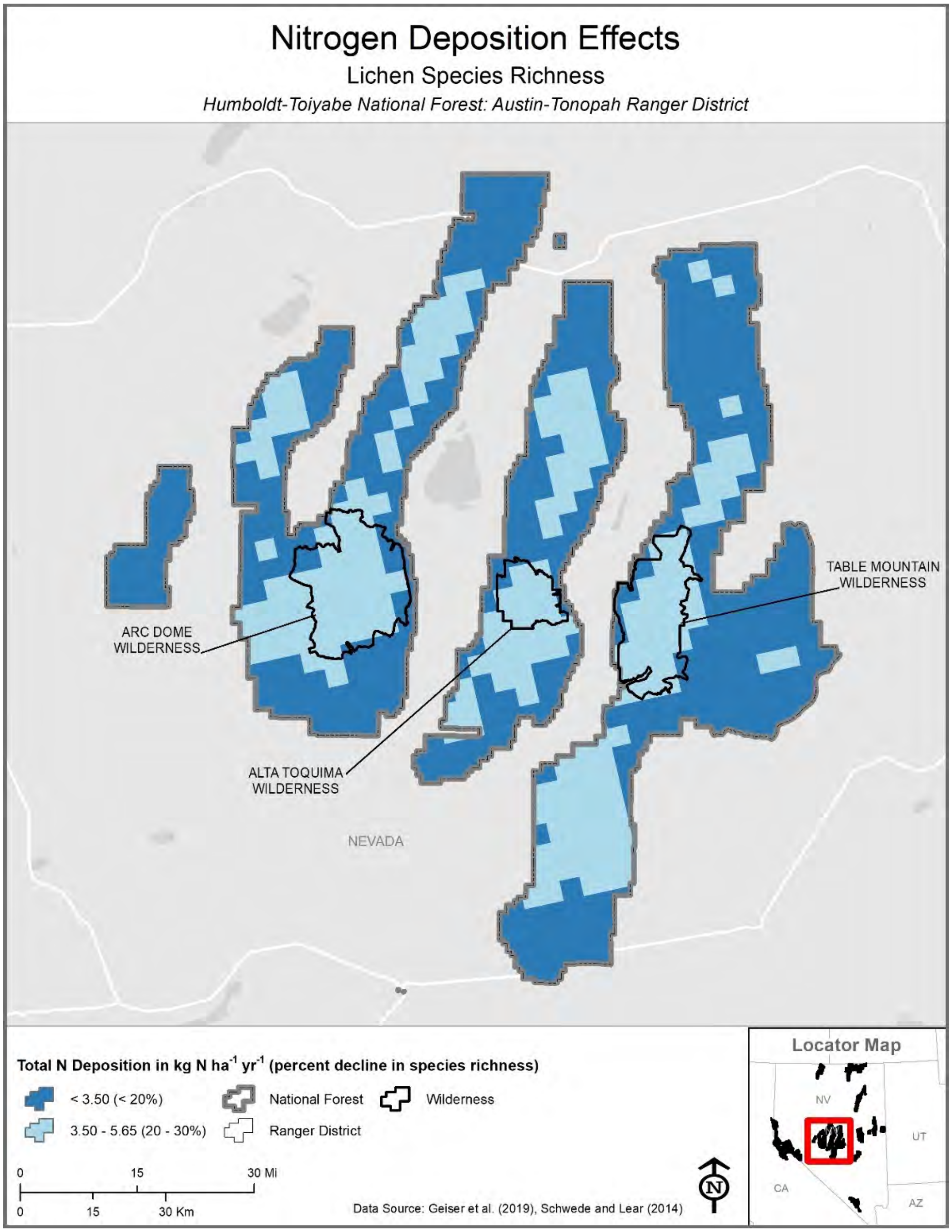

Figure 5-80. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% reductions in lichen species richness.

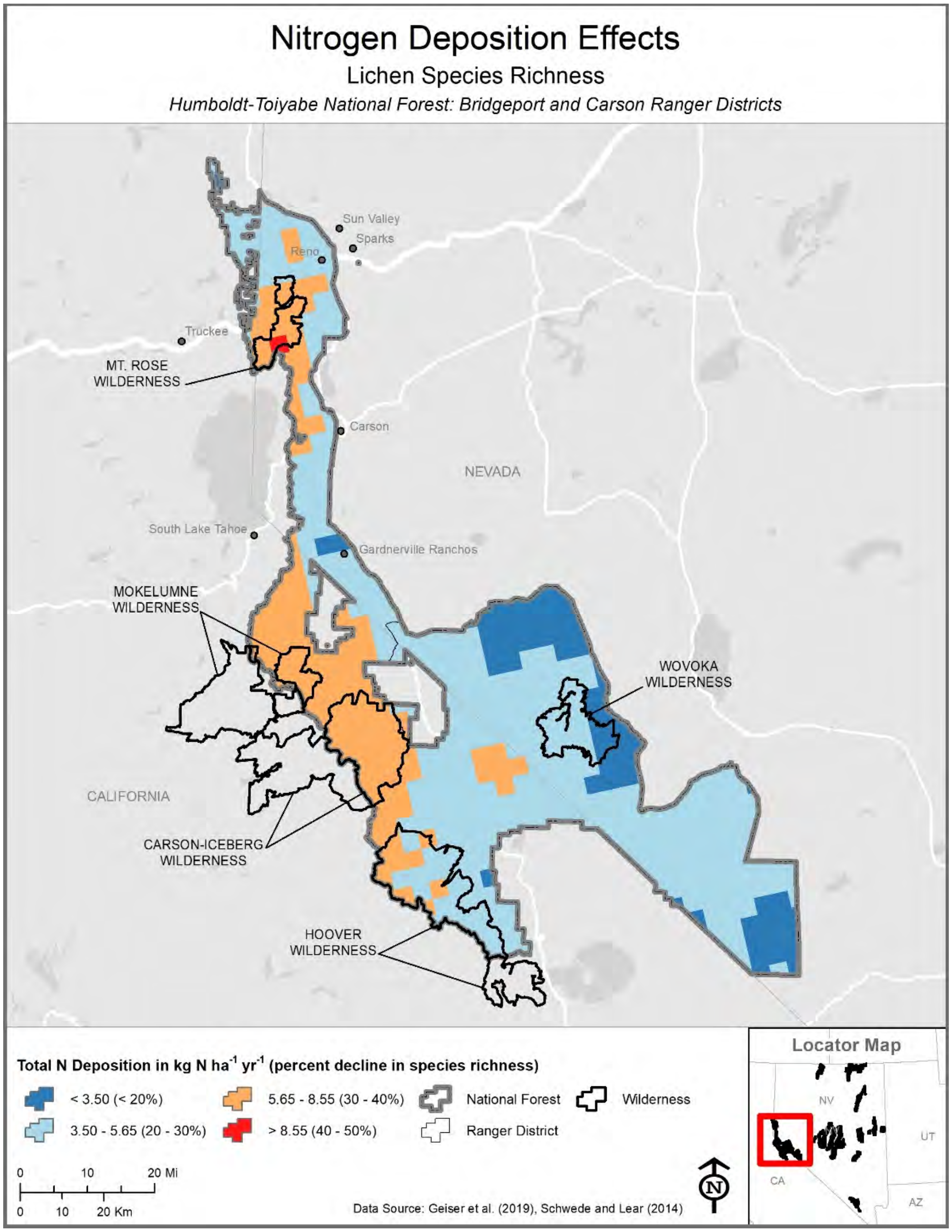

Figure 5-81. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.

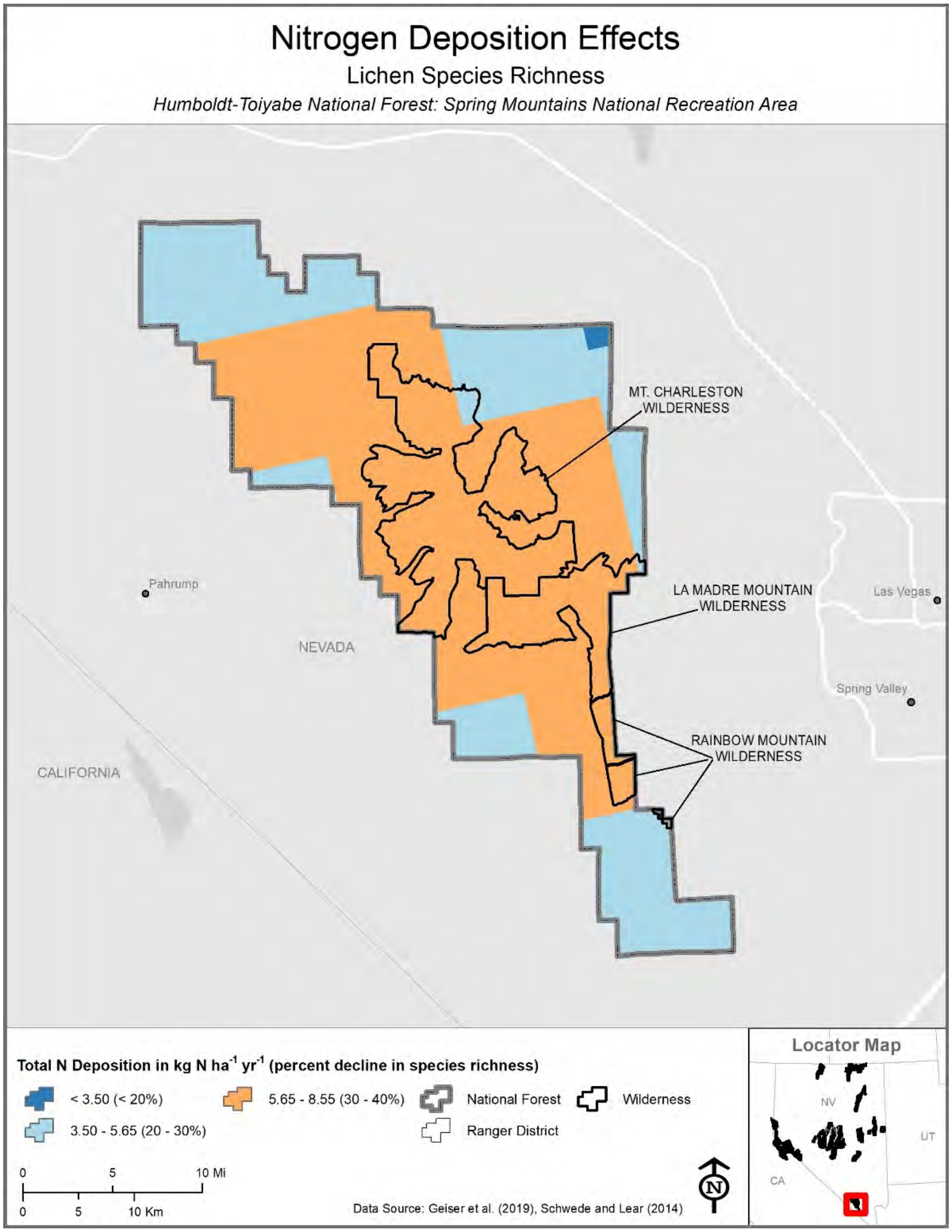

Figure 5-82. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

similar to patterns of exceedance of CLs for species richness (**Figures** 5-83 through 5-87). Critical load exceedance associated with at least a 40% reduction in forage lichen abundance were found within all wilderness areas of the Humboldt-Toiyabe NF, with the exception of the Quinn Canyon Wilderness in which 30 – 40% reductions in forage lichen abundance was expected.

5.2.7.4 Tree Growth and Survival

Although there were no exceedances of CLs to protect growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reductions) within 4% of the area in which this species is expected to occur within the Humboldt-Toiyabe NF (**Table**s 5-7 and 5-8; **Figures** 5-88 through 5-92). The area of exceedance for probability of survival (34 km^2) occurred within and in the vicinity of the East Humboldt Wilderness, Mokelumne Wilderness, Carson-Iceberg Wilderness, and Mt. Charleston Wilderness (**Figures** 5-93 through 5-97).

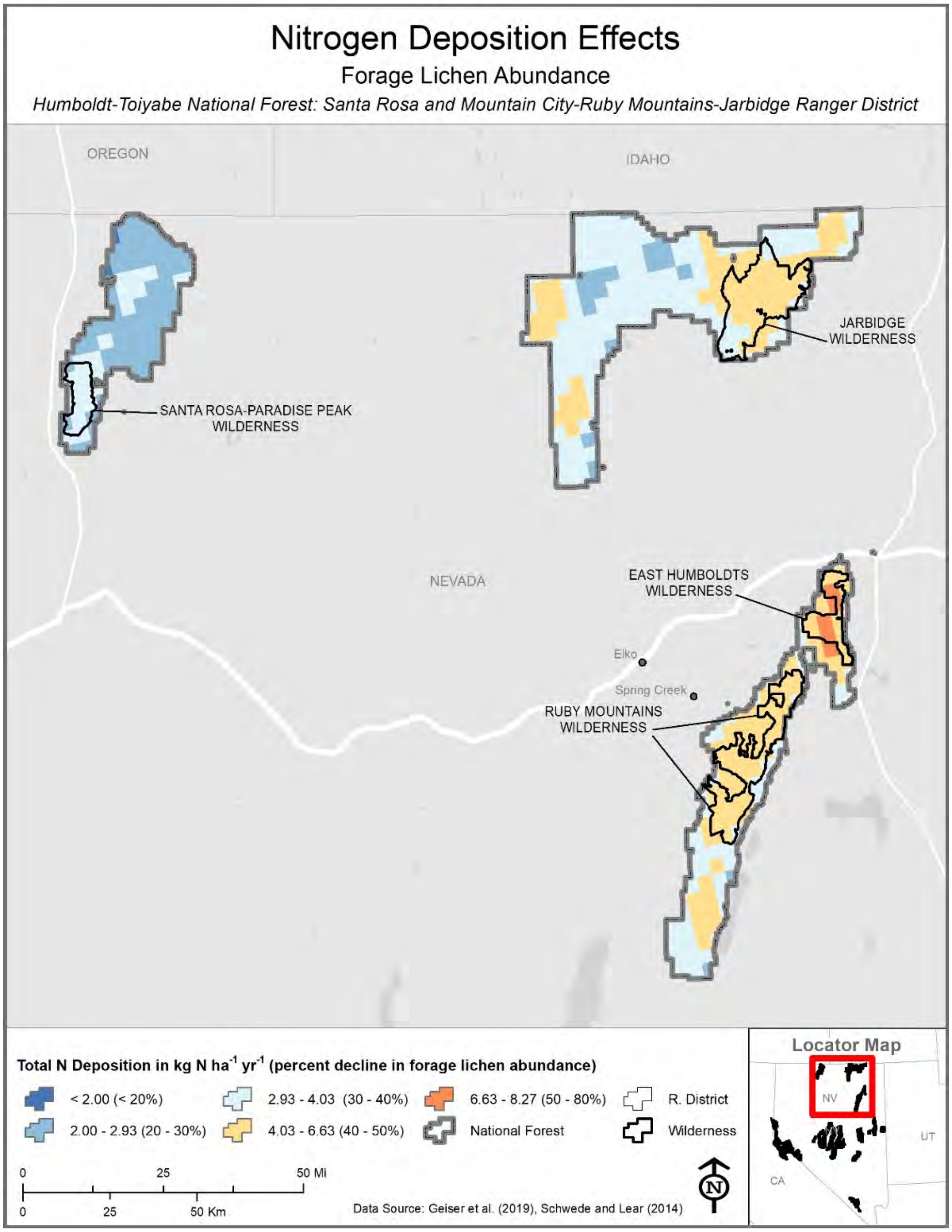

Figure 5-83. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

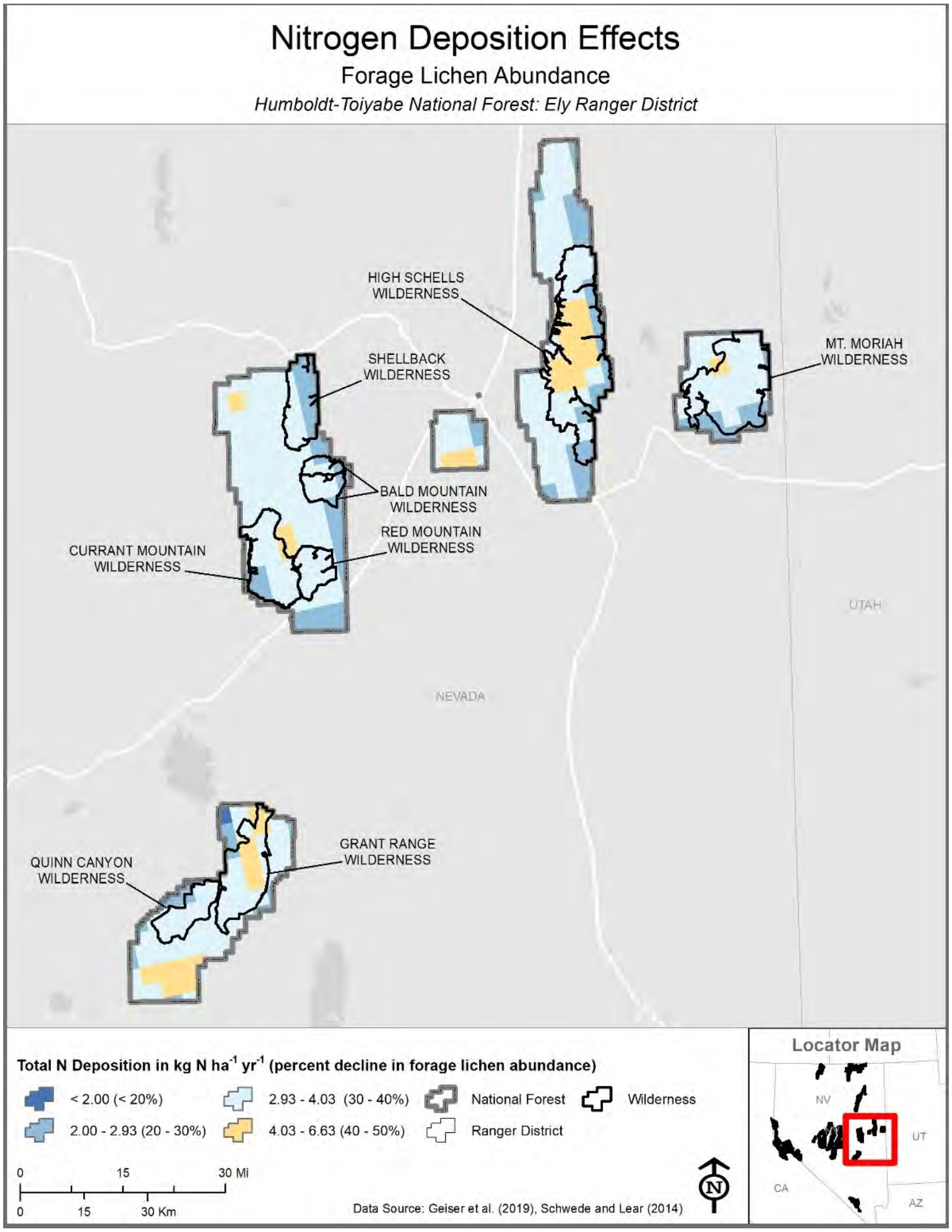

Figure 5-84. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50%, reductions in forage lichen abundance.

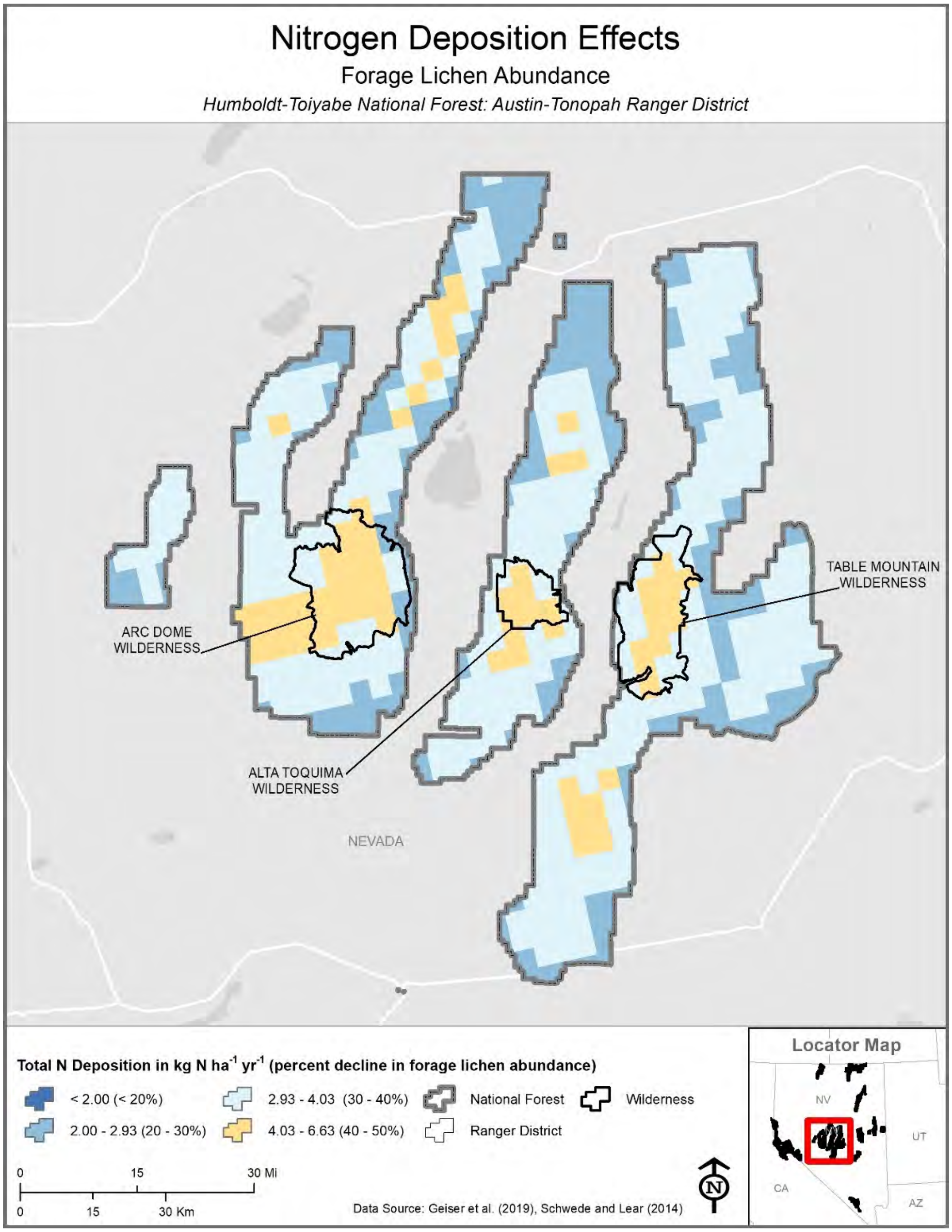

Figure 5-85. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50%, reductions in forage lichen abundance.

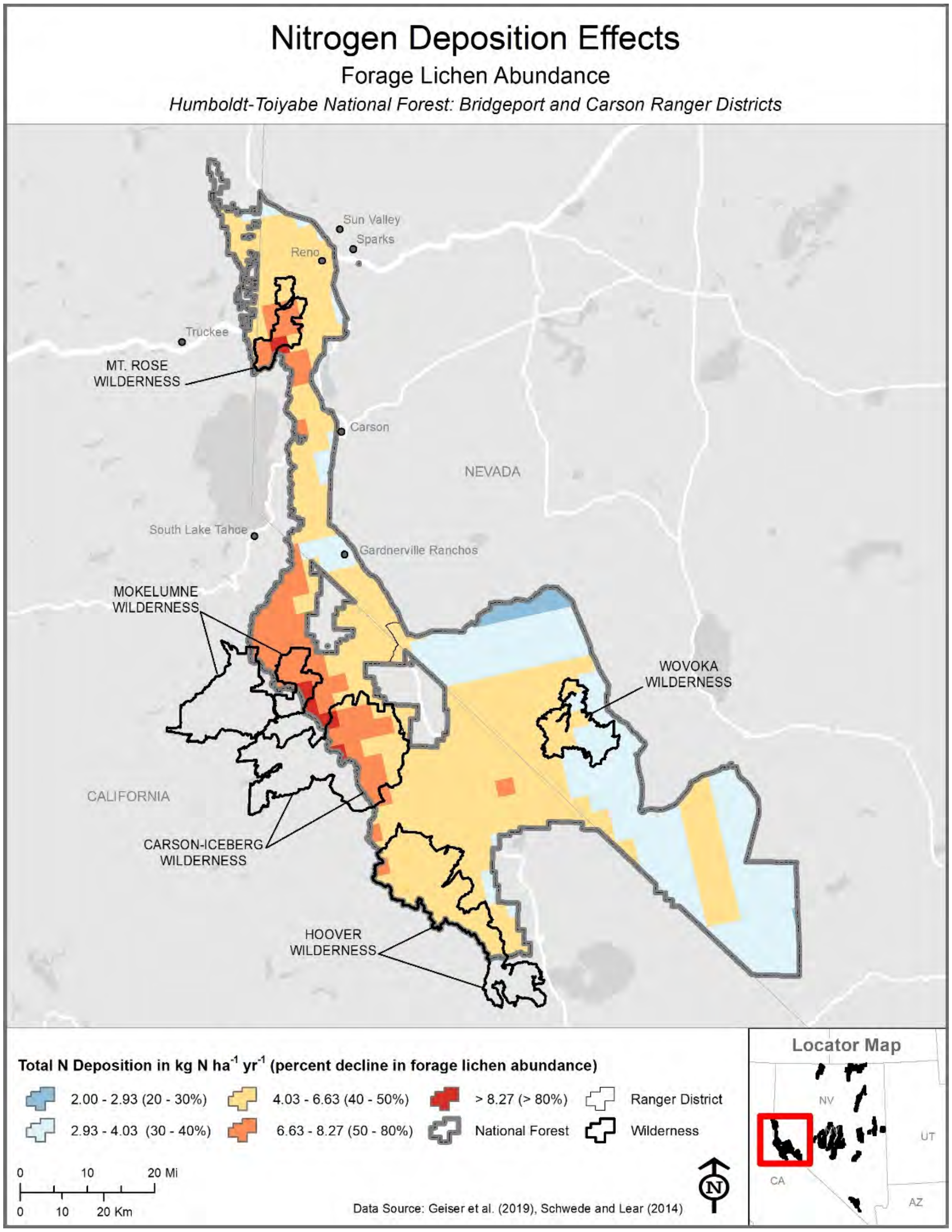

Figure 5-86. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

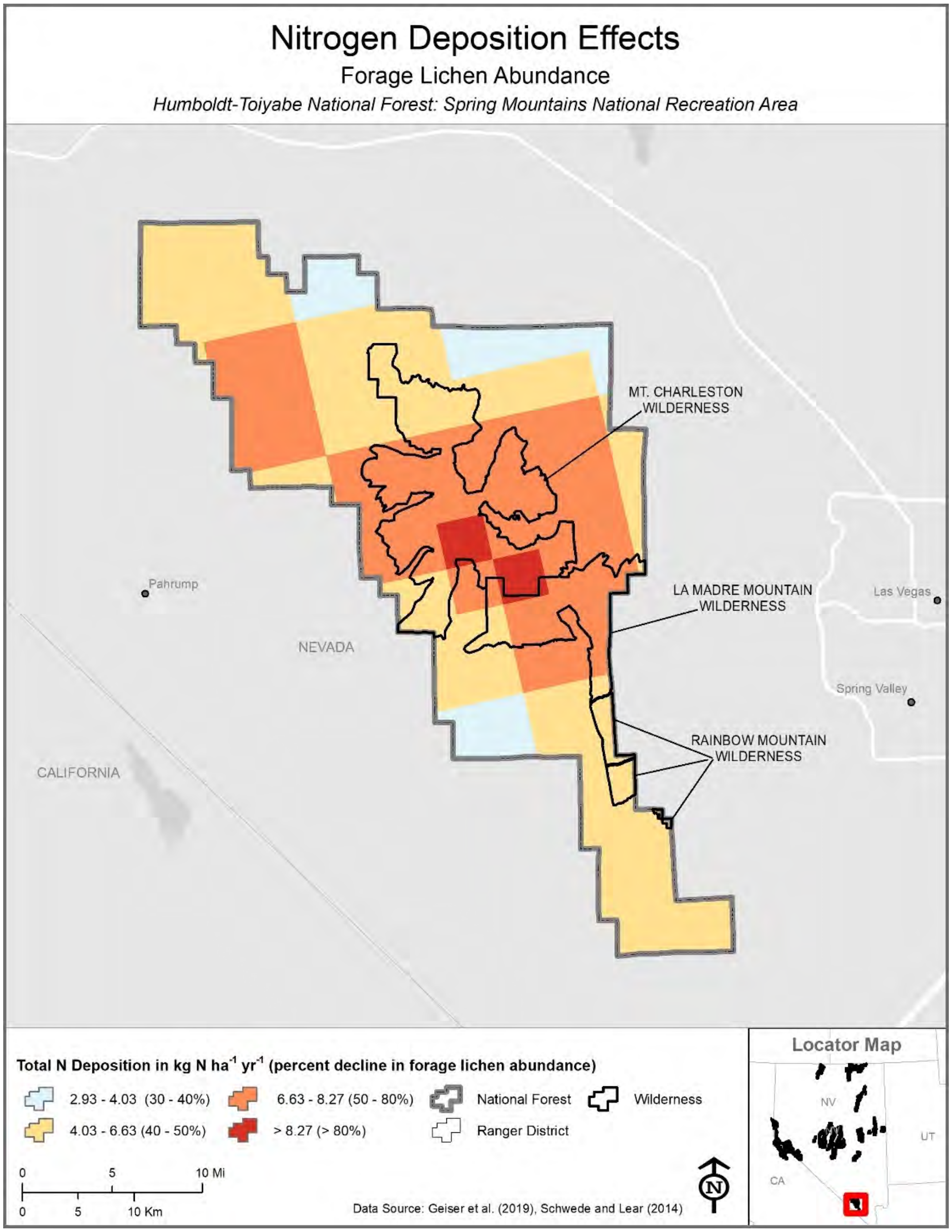

Figure 5-87. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

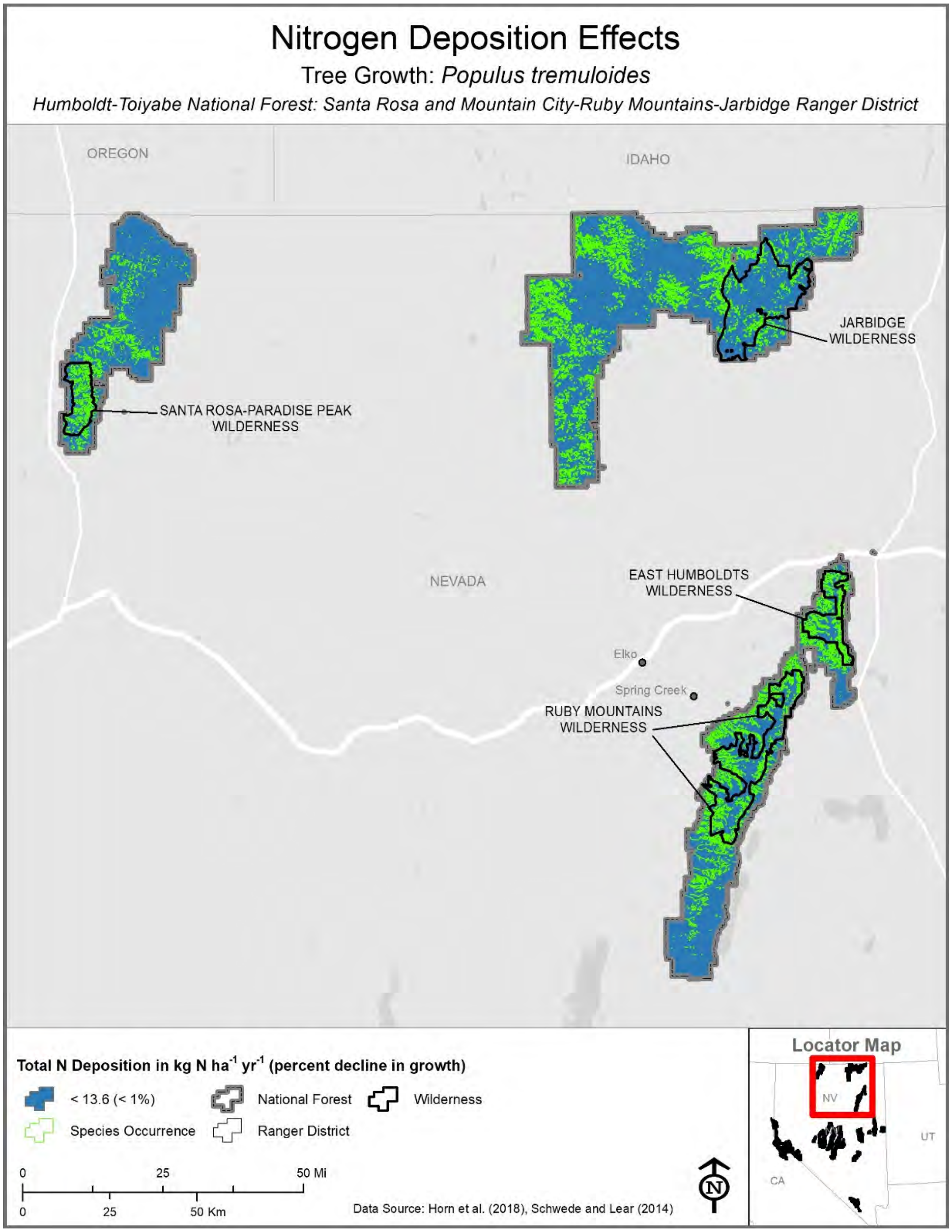

Figure 5-88. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire ranger district is below the critical load for 1% growth reduction of *Populus tremuloides.*

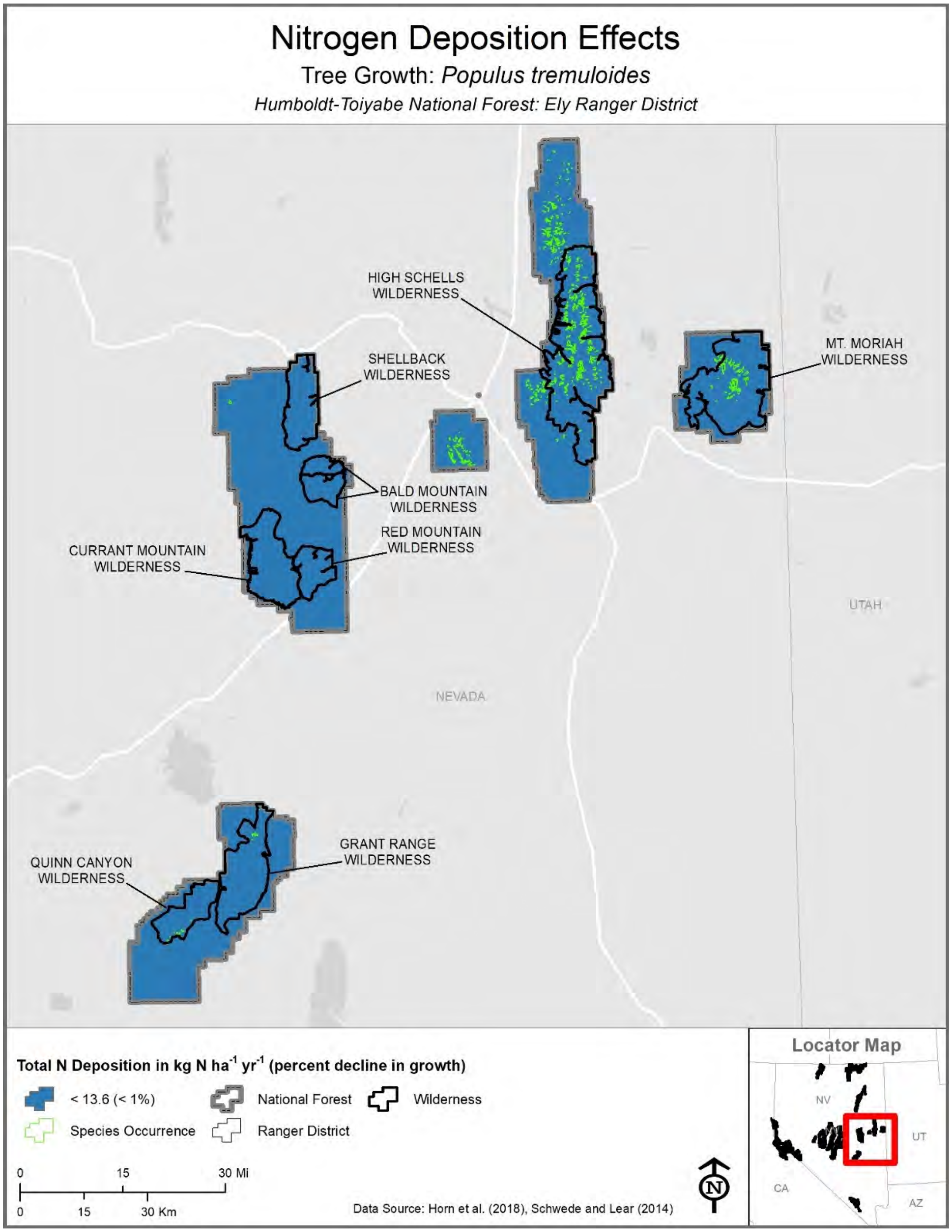

Figure 5-89. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire ranger district is below the critical load for 1% growth reduction of *Populus tremuloides.*

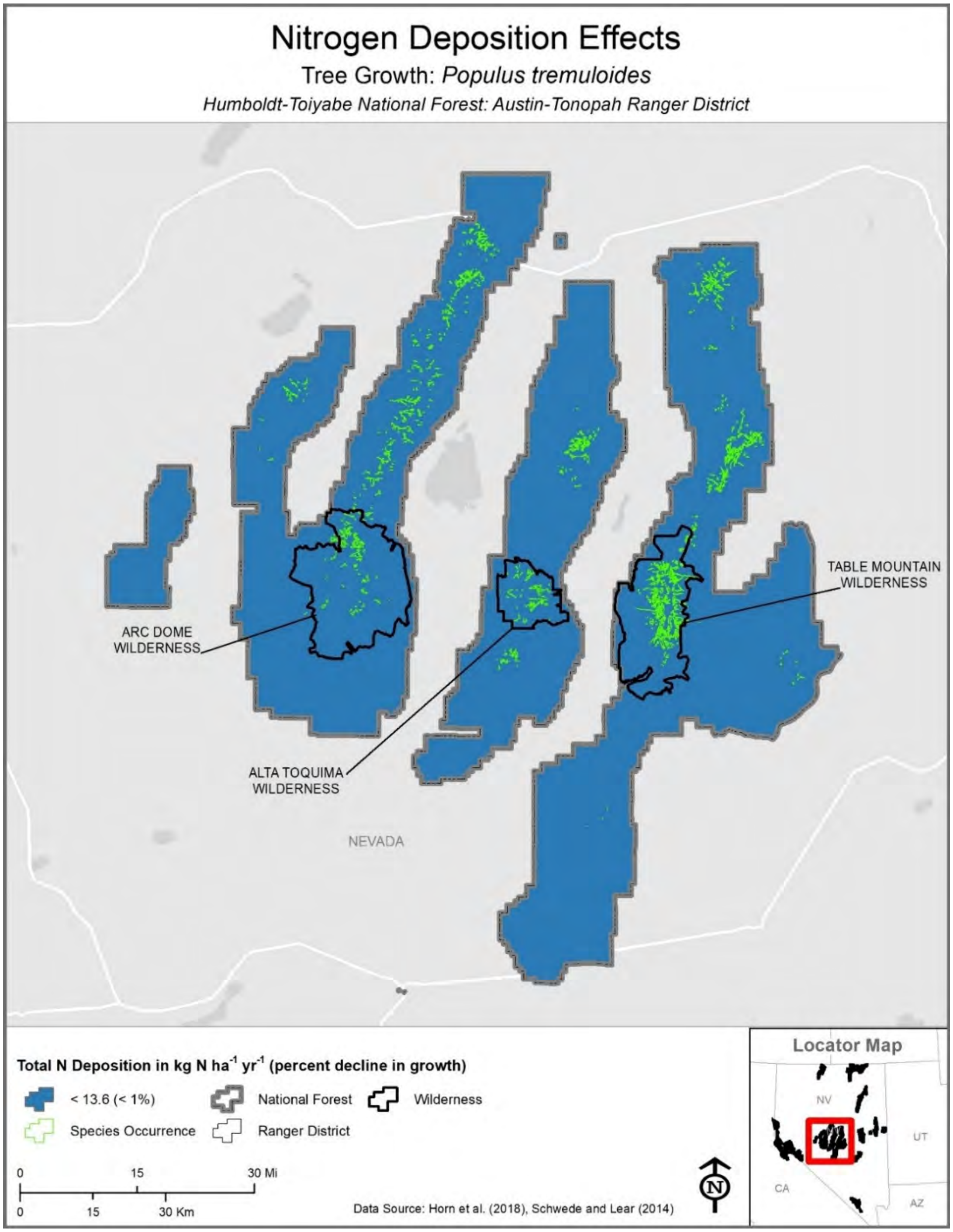

Figure 5-90. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire ranger district is below the critical load for 1% growth reduction of *Populus tremuloides.*

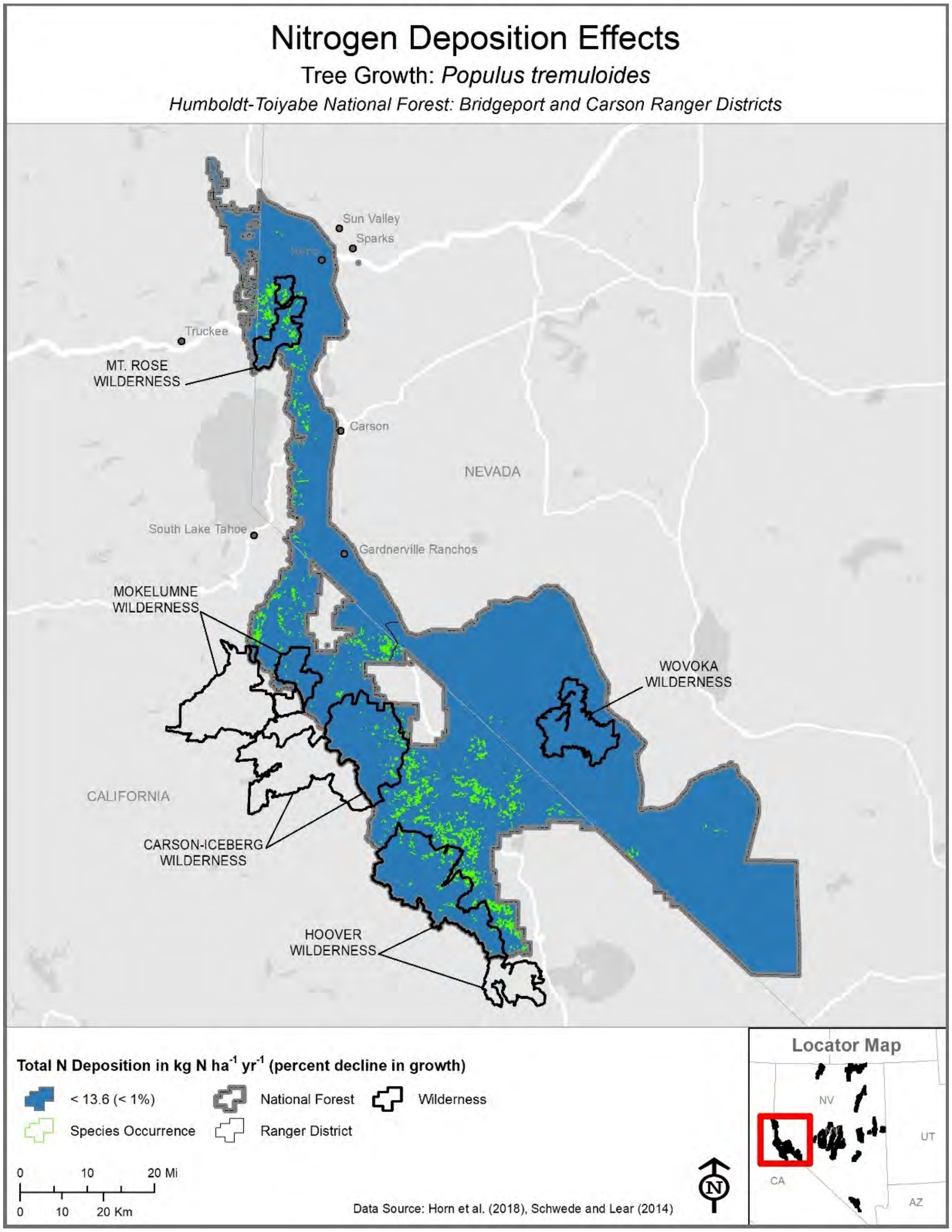

Figure 5-91. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The full extent of both ranger districts is below the critical load for 1% growth reduction of *Populus tremuloides.*

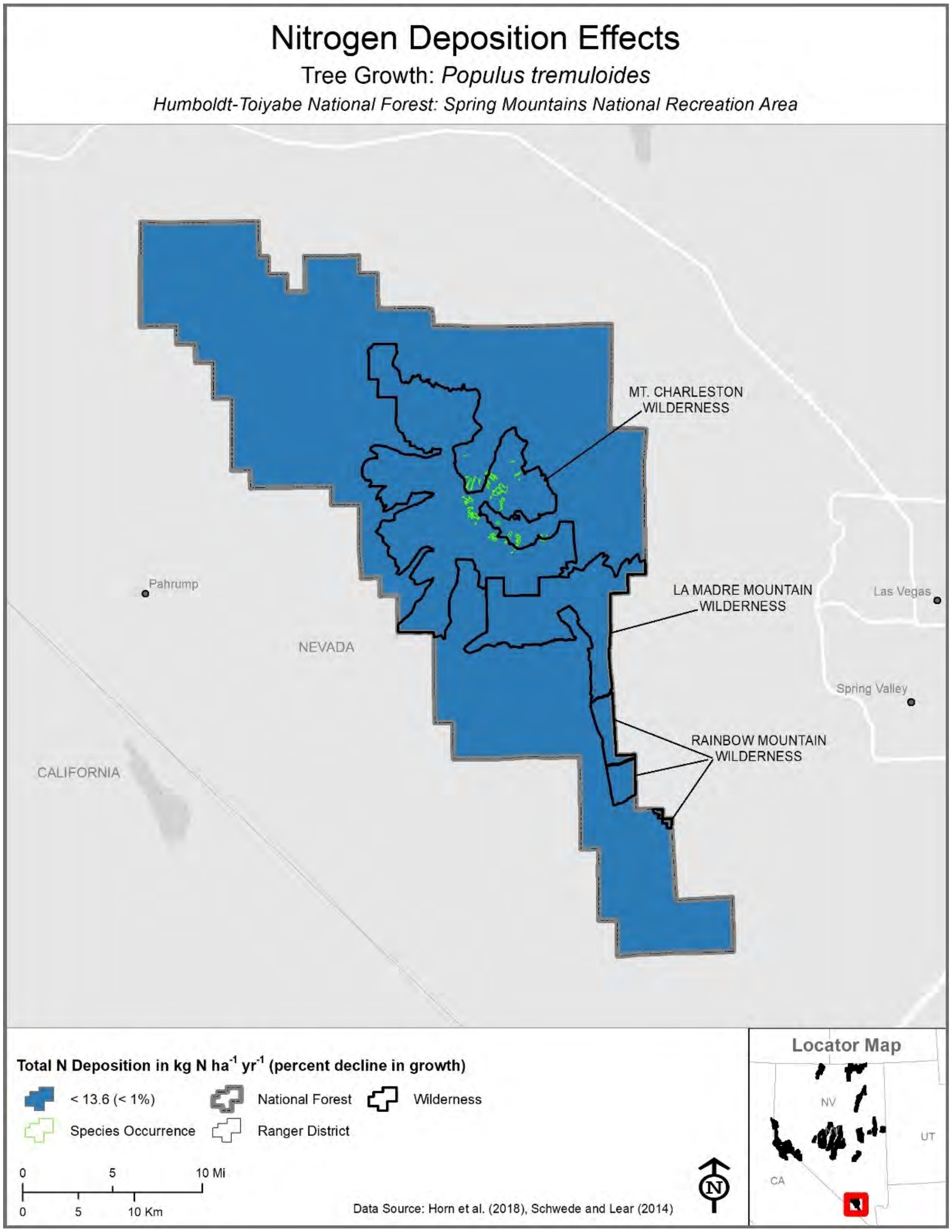

Figure 5-92. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire recreation area is below the critical load for 1% growth reduction of *Populus tremuloides.*

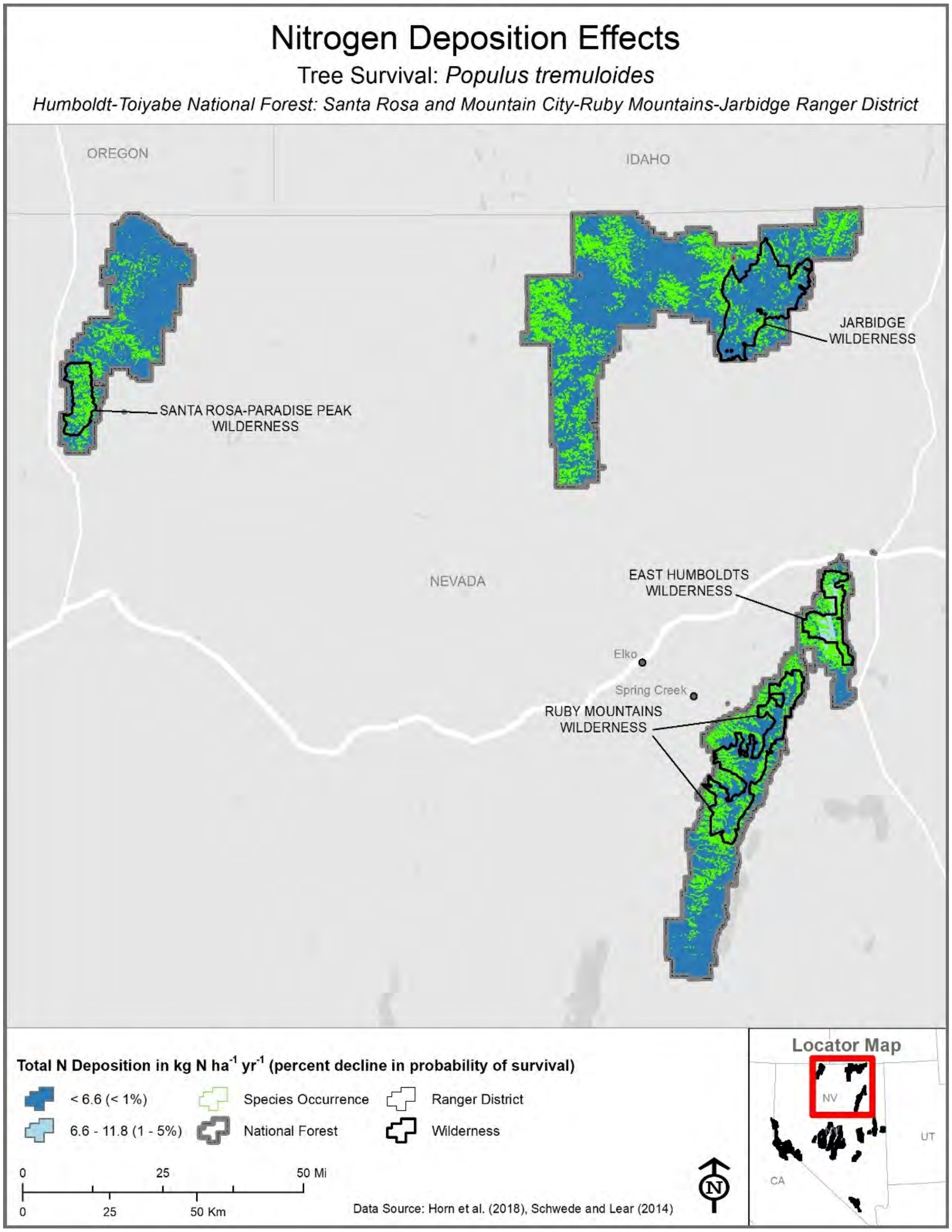

Figure 5-93. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

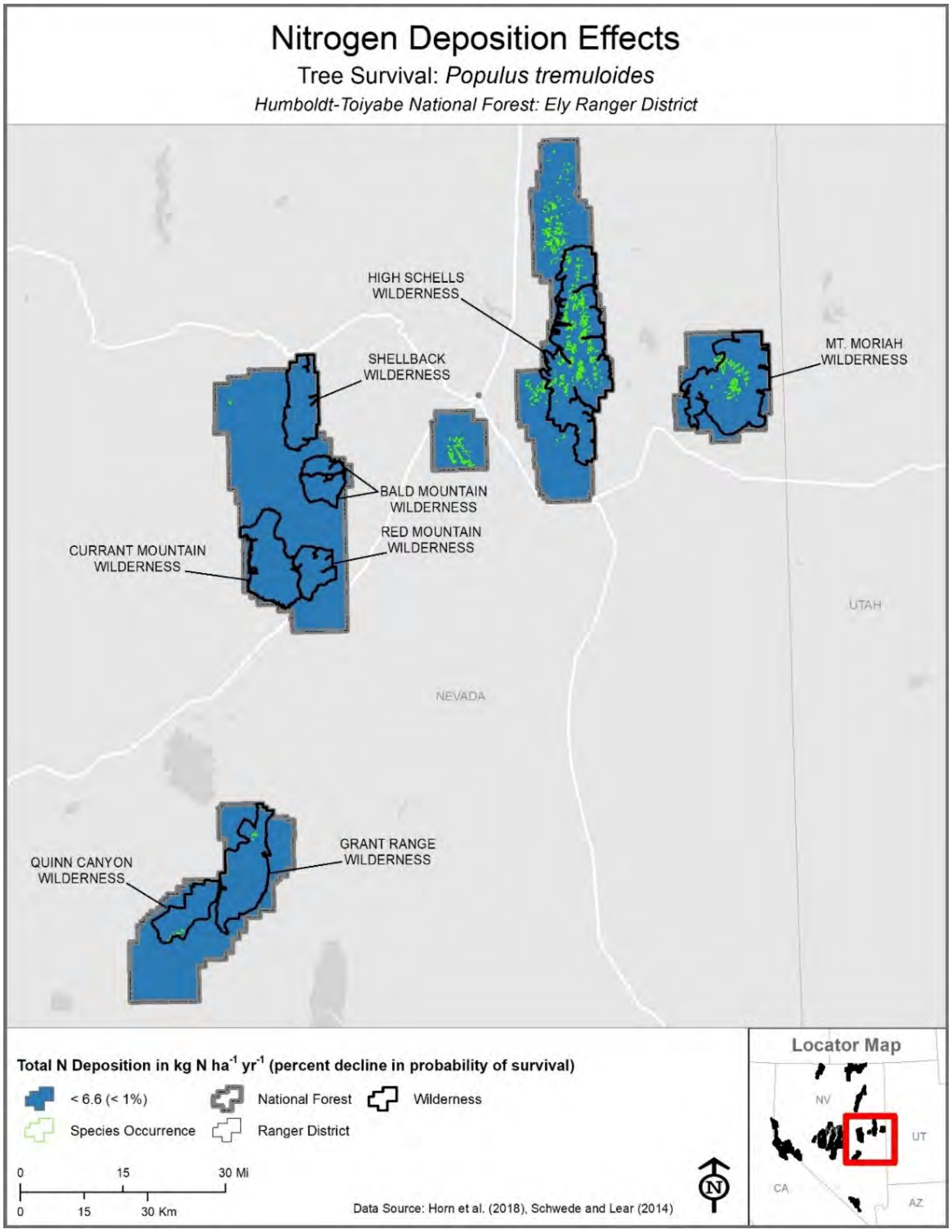

Figure 5-94. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance. The entire ranger district is below the critical load for a 1% reduction in probability of survival of *Populus tremuloides.*

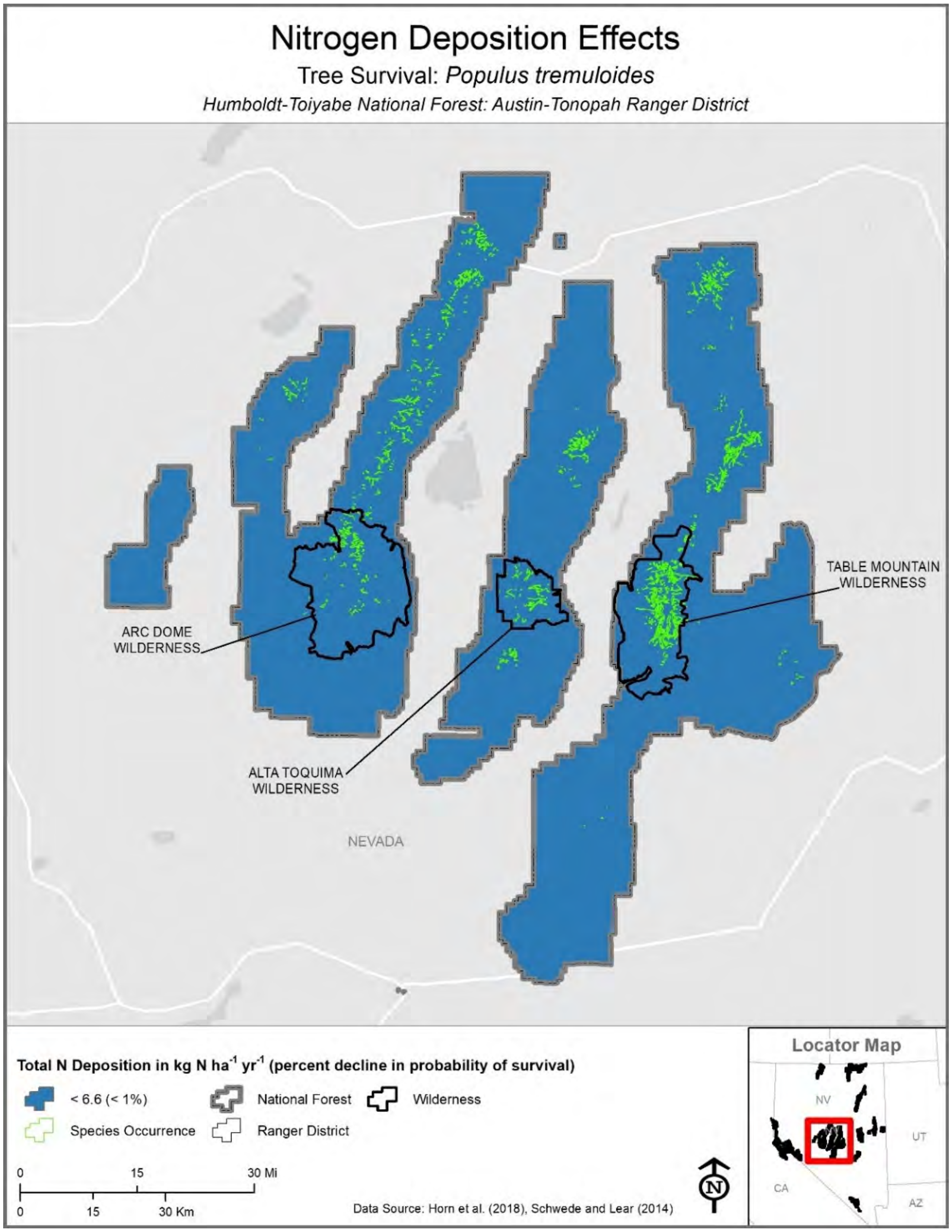

Figure 5-95. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance. The entire ranger district is below the critical load for a 1% reduction in probability of survival of *Populus tremuloides.*

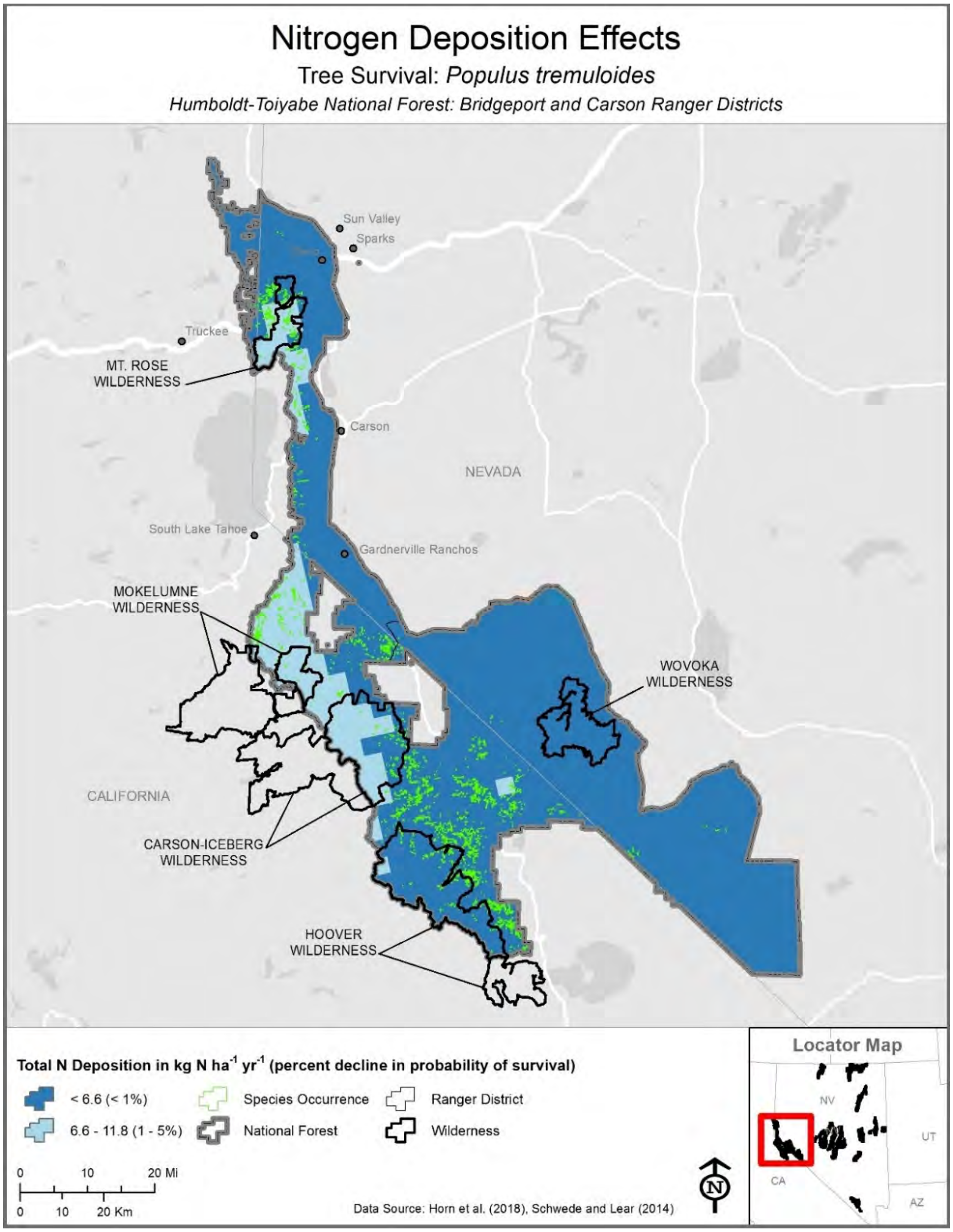

Figure 5-96. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

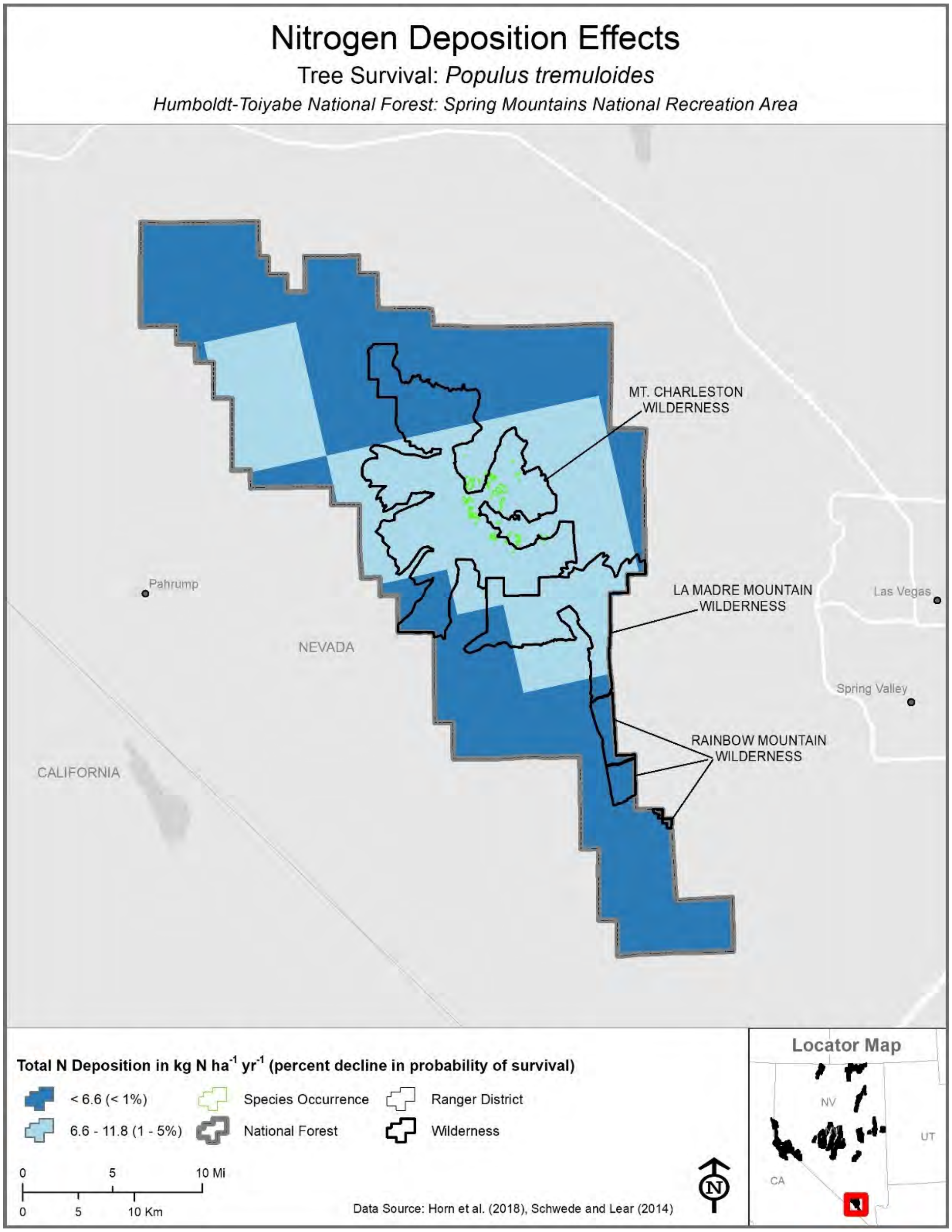

Figure 5-97. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 53% and 9%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Portions of the somewhat small area in exceedance of CLs for growth (8 km^2) occurred in several of the wilderness areas located within the forest (**Figures** 5-98 through 5-101). Reductions in probability of survival of 1 – 5% were limited to relatively small areas throughout the forest (**Figures** 5-102 through 5-105). Maps of *P. balsamifera* exceedance were not included for the Spring Mountains National Recreation Area because this species was not expected to occur in this area.

P. menziesii was only expected to occur in a very small portion (0.04 km^2) of the Bridgeport and Carson Ranger Districts. This area was expected to be in exceedance (**Figure** 5-106).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 18% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance mostly occurred within the Spring Mountains National Recreation Area, including the Mt. Charleston Wilderness and several other wilderness areas (**Figures** 5-107 through 5-111).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 13% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance mostly occurred within the Bridgeport and Carson Ranger Districts and Spring Mountains National Recreation Area, including the Mt. Charleston Wilderness and several other wilderness areas (**Figures** 5-112 through 5-116).

Other species of interest that occurred within the Humboldt-Toiyabe NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-20). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

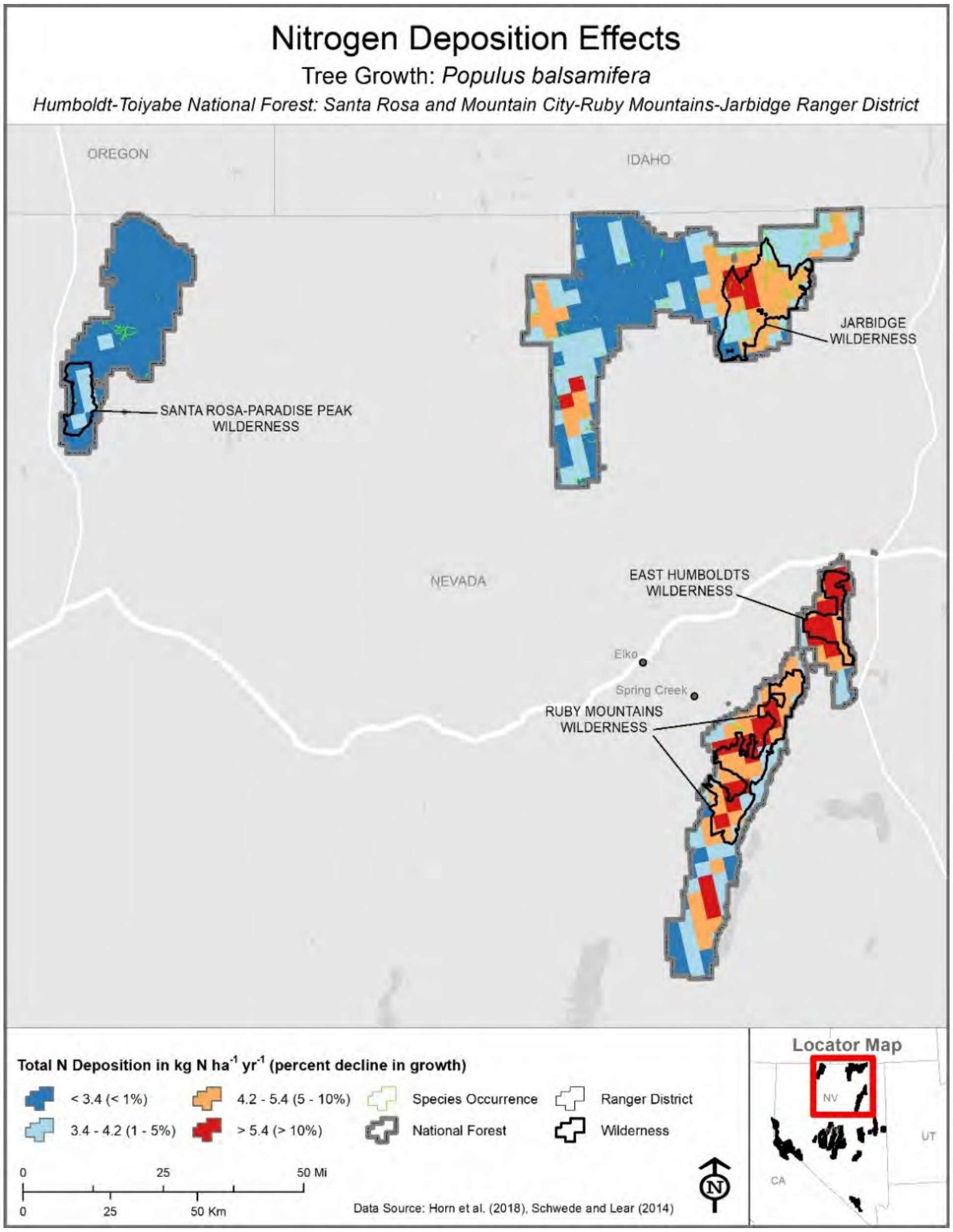

Figure 5-98. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas of the northern portions of this ranger district of the Humboldt-Toiyabe NF that are difficult to discern on the map. Table 5-9 indicates the extent to which any of these areas are in exceedance of the specified critical loads.

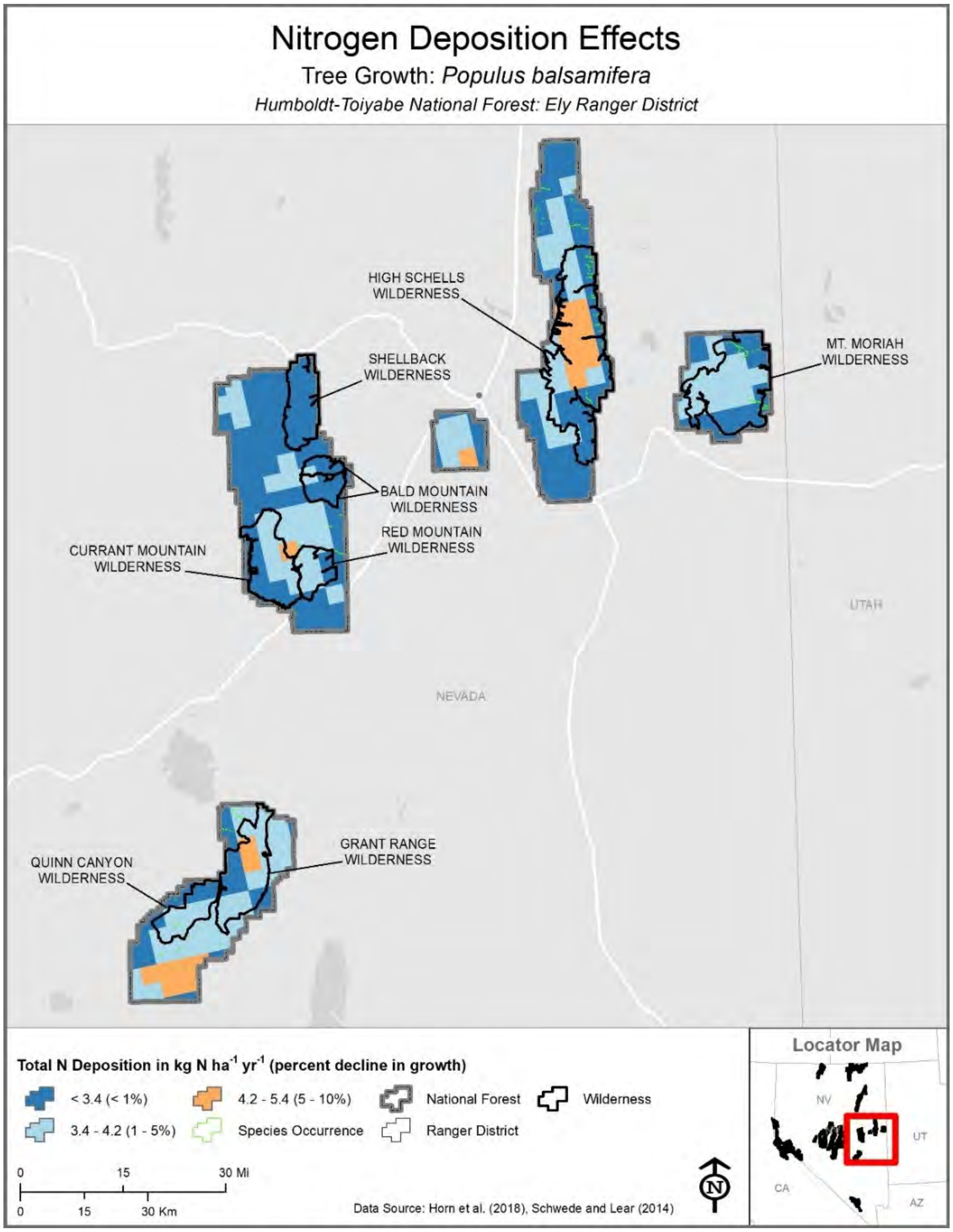

Figure 5-99. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas throughout this ranger district of the Humboldt-Toiyabe NF that are difficult to discern on the map. Table 5-9 indicates the extent to which areas of the Humboldt-Toiyabe NF are in exceedance of the specified critical loads.

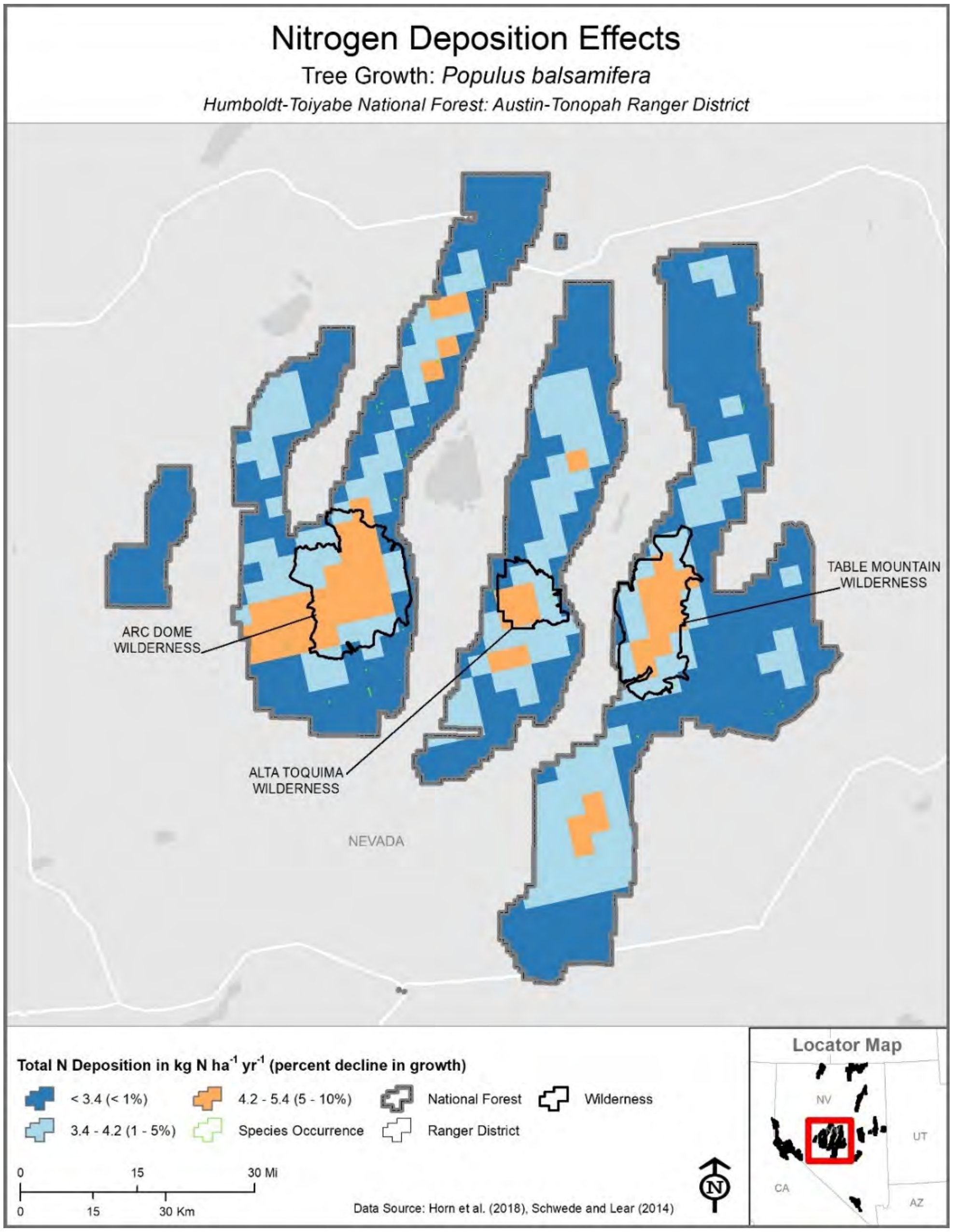

Figure 5-100. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas throughout this ranger district of the Humboldt-Toiyabe NF that are difficult to discern on the map. Table 5-9 indicates the extent to which areas of the Humboldt-Toiyabe NF are in exceedance of the specified critical loads.

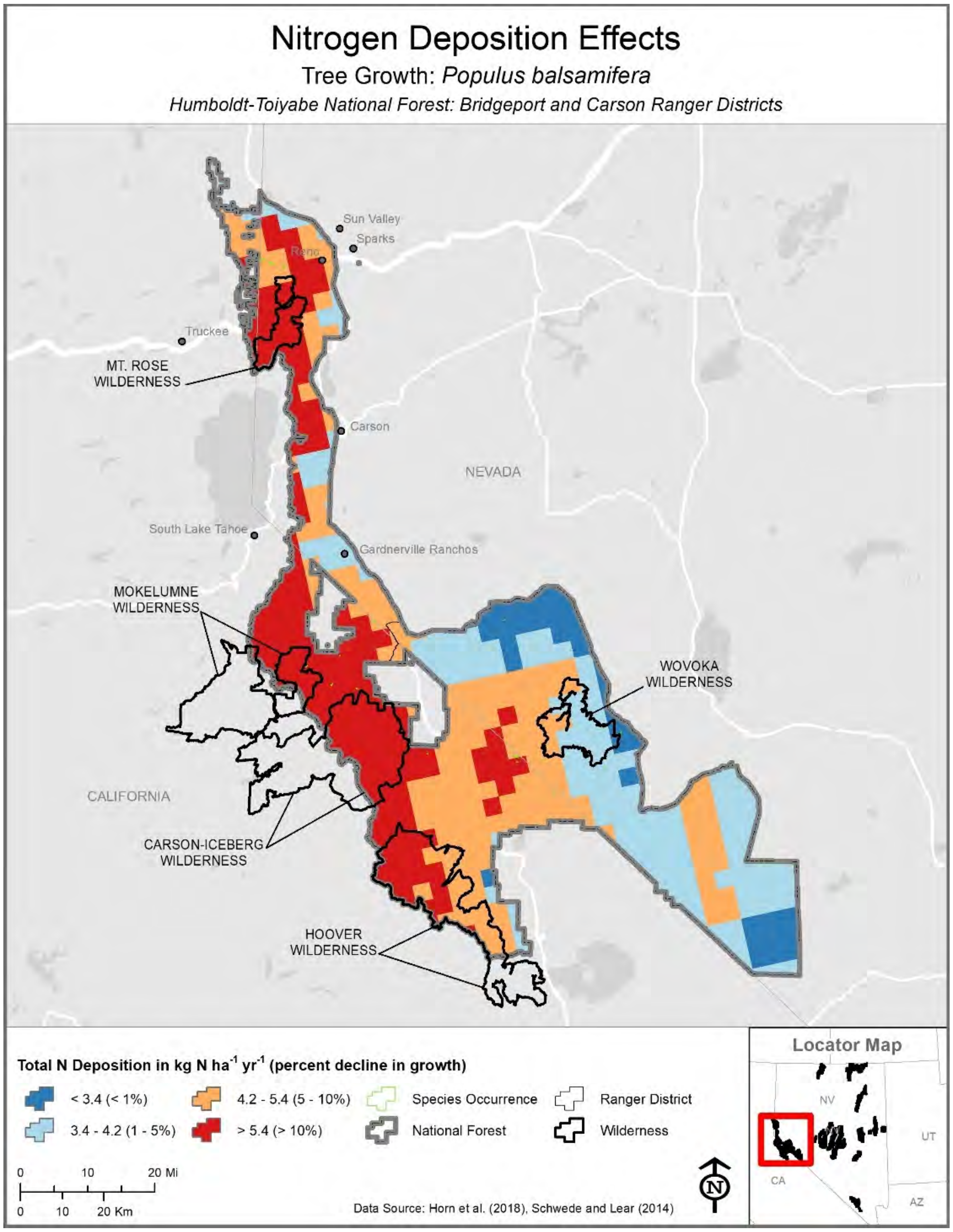

Figure 5-101. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas throughout most of this ranger district of the Humboldt-Toiyabe NF that are difficult to discern on the map. Table 5-9 indicates the extent to which areas of the Humboldt-Toiyabe NF are in exceedance of the specified critical loads.

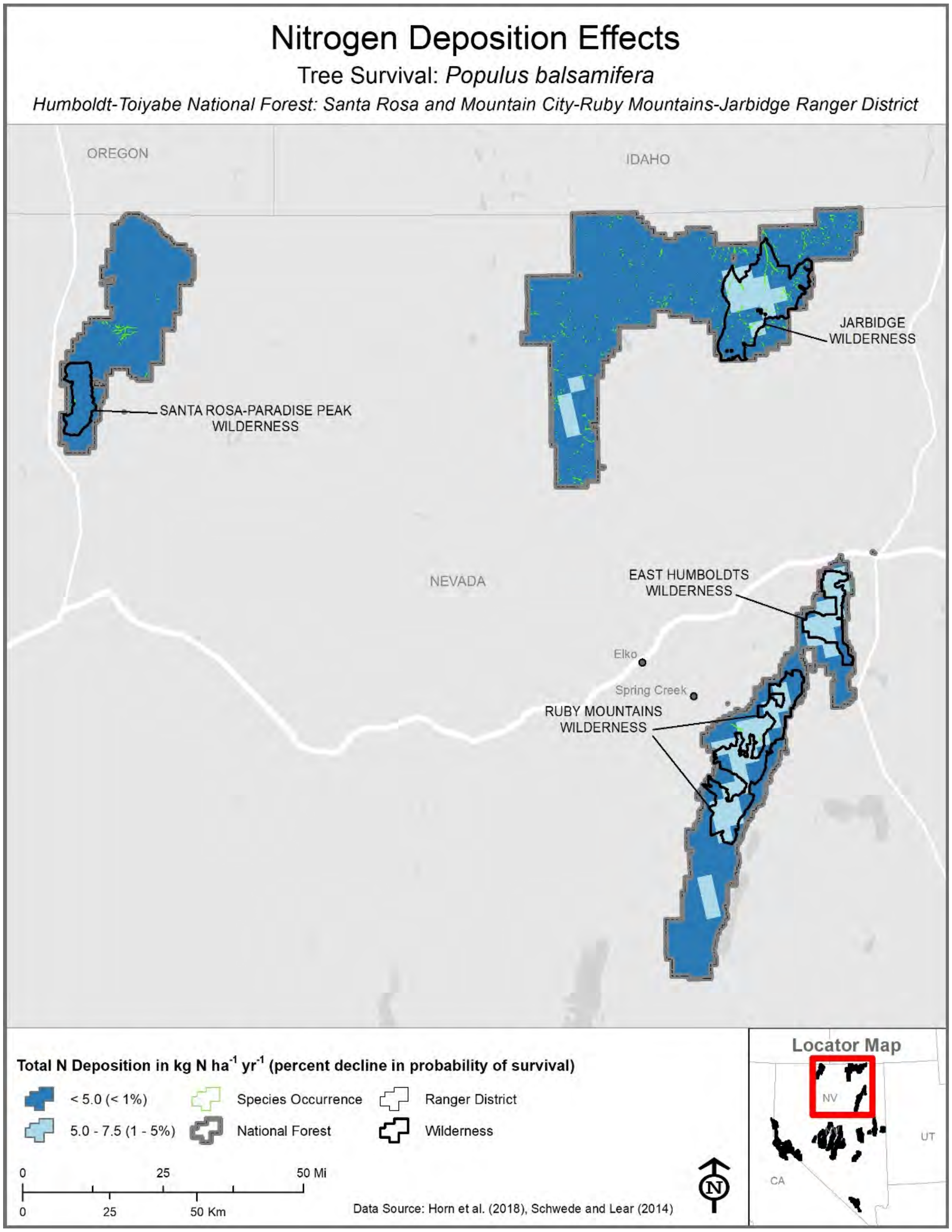

Figure 5-102. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

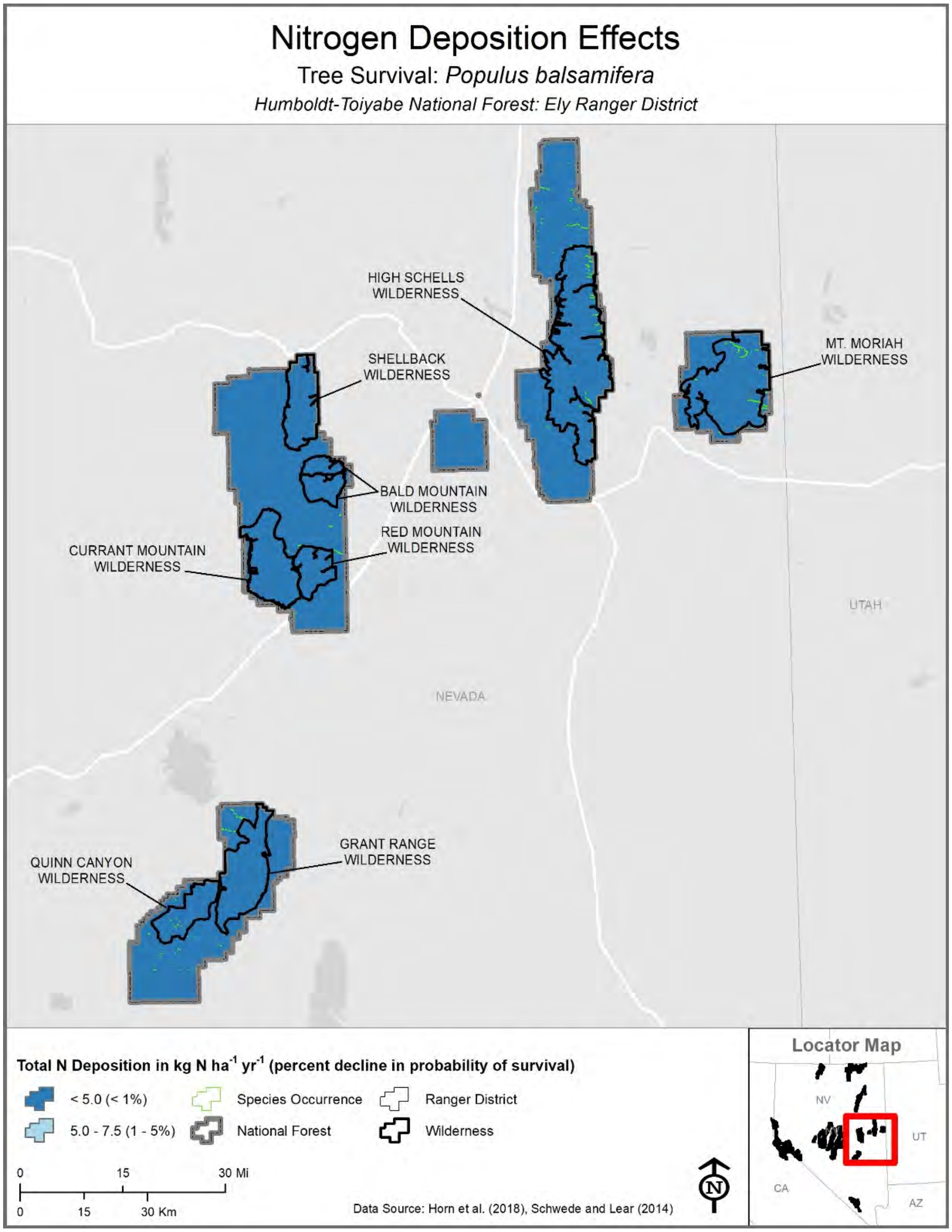

Figure 5-103. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

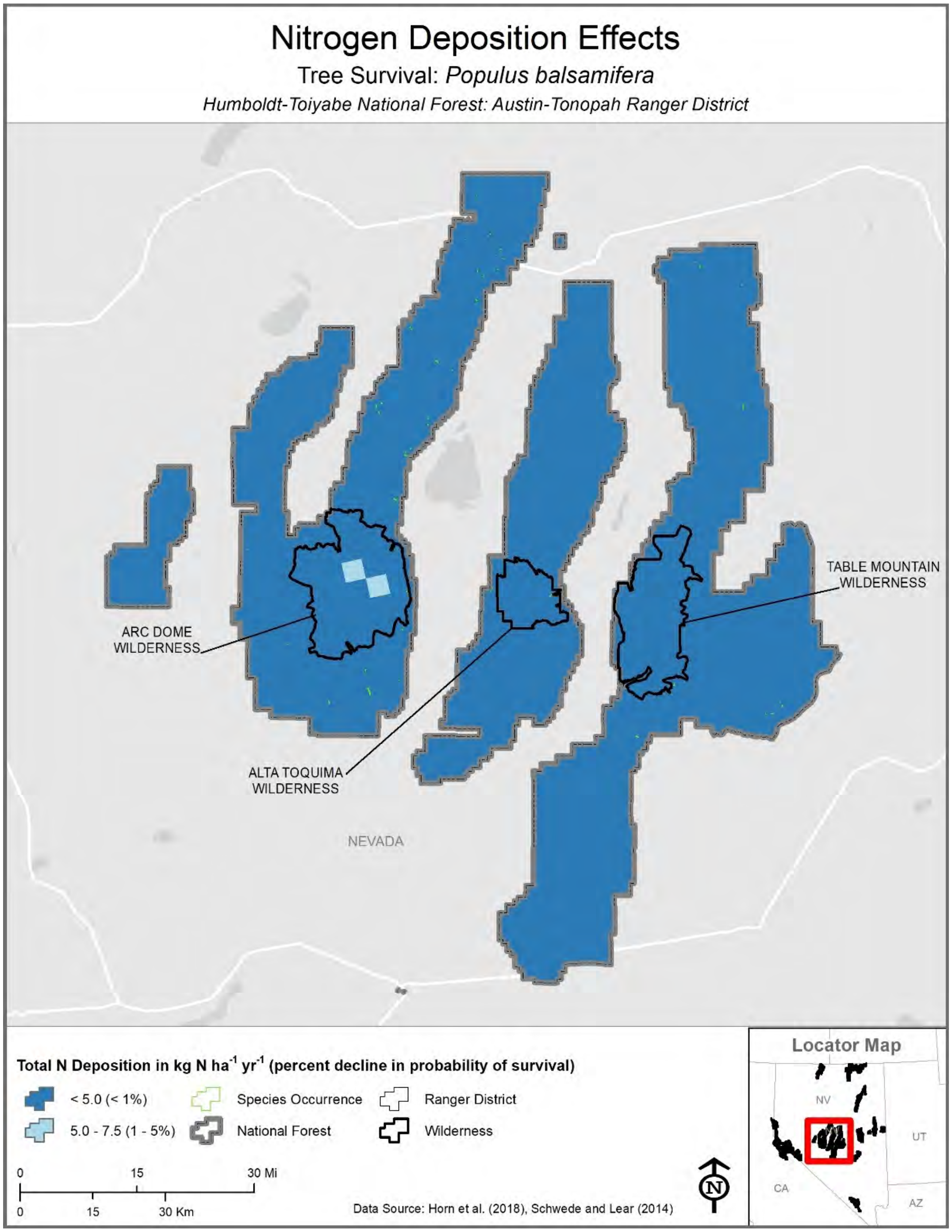

Figure 5-104. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

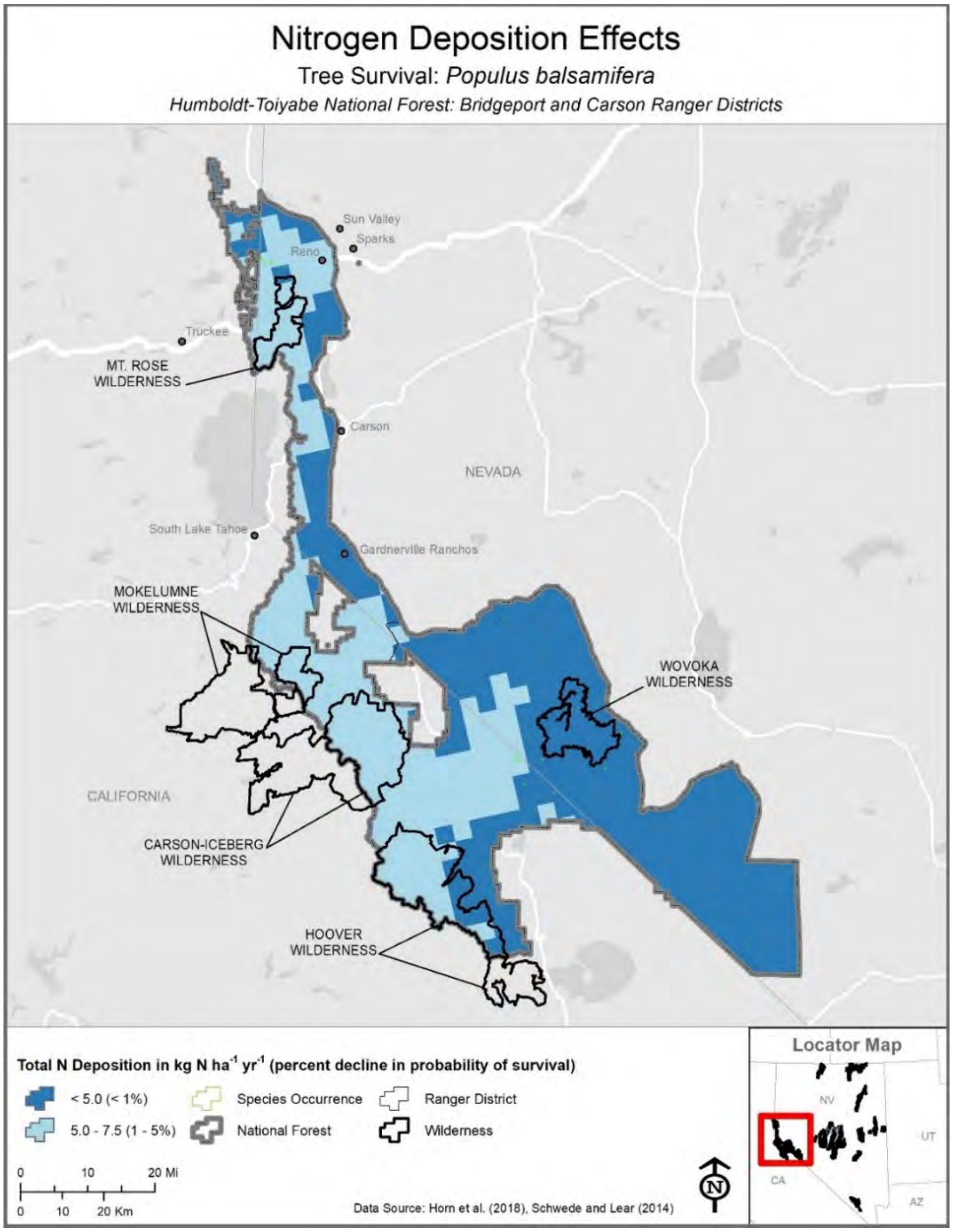

Figure 5-105. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas throughout most of this ranger district of the Humboldt-Toiyabe NF that are difficult to discern on the map. Table 5-10 indicates the extent to which areas of the Humboldt-Toiyabe NF are in exceedance of the specified critical loads.

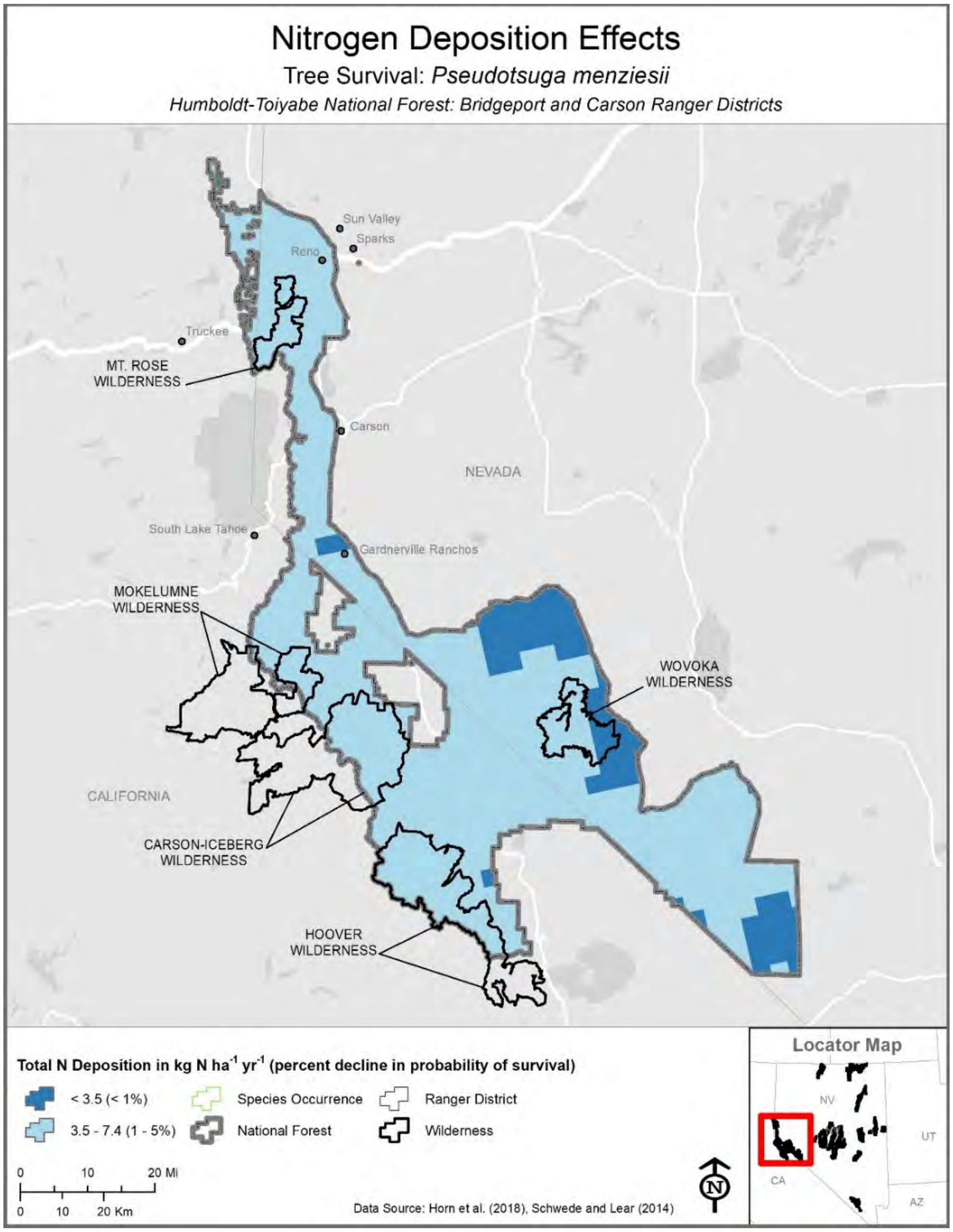

Figure 5-106. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Only one small area of *Pseudotsuga menziesii* occurred just north of the Wovoka Wilderness, all of which is in exceedance of the critical load for a 1% reduction in probability of survival (Table 5-11).

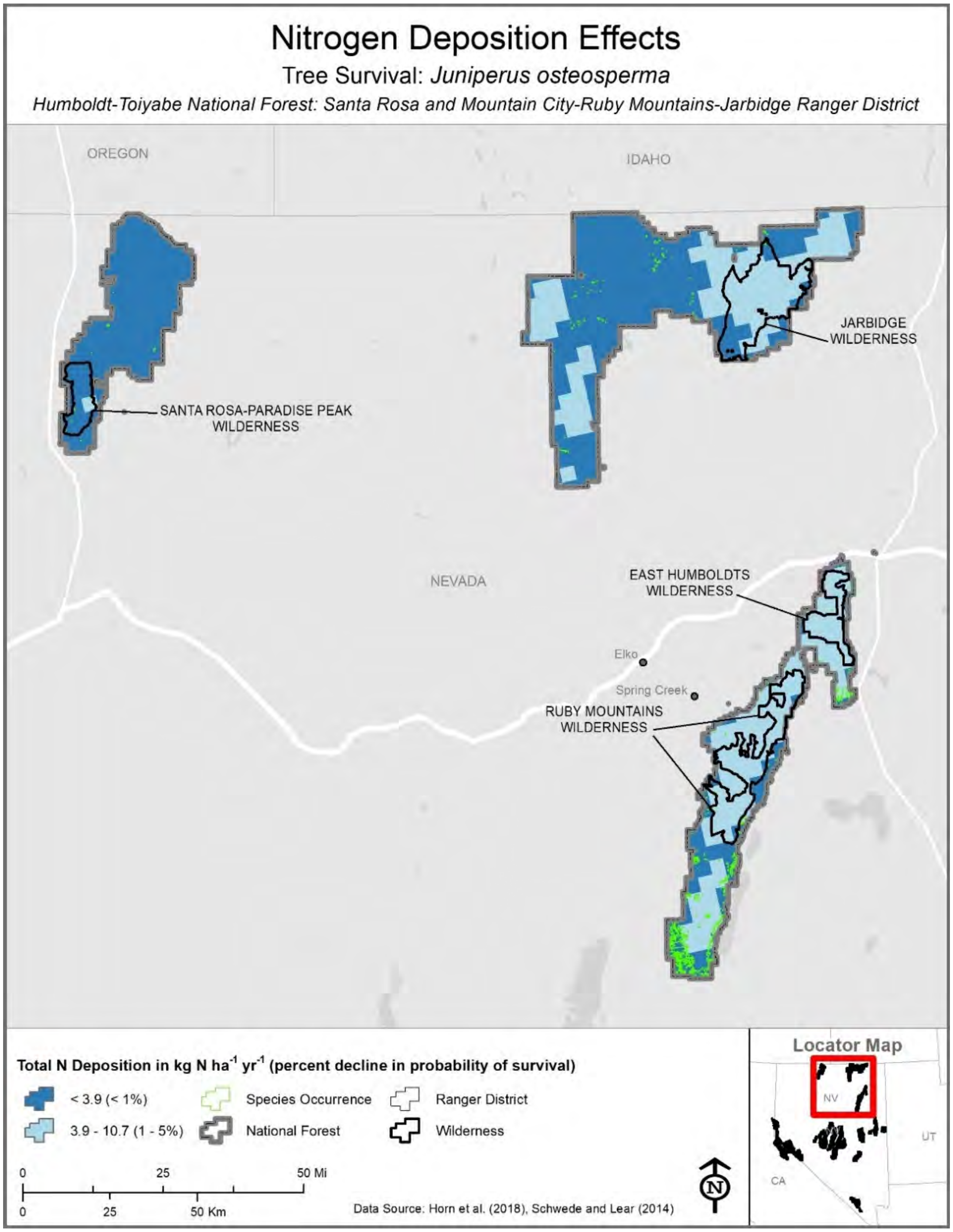

Figure 5-107. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

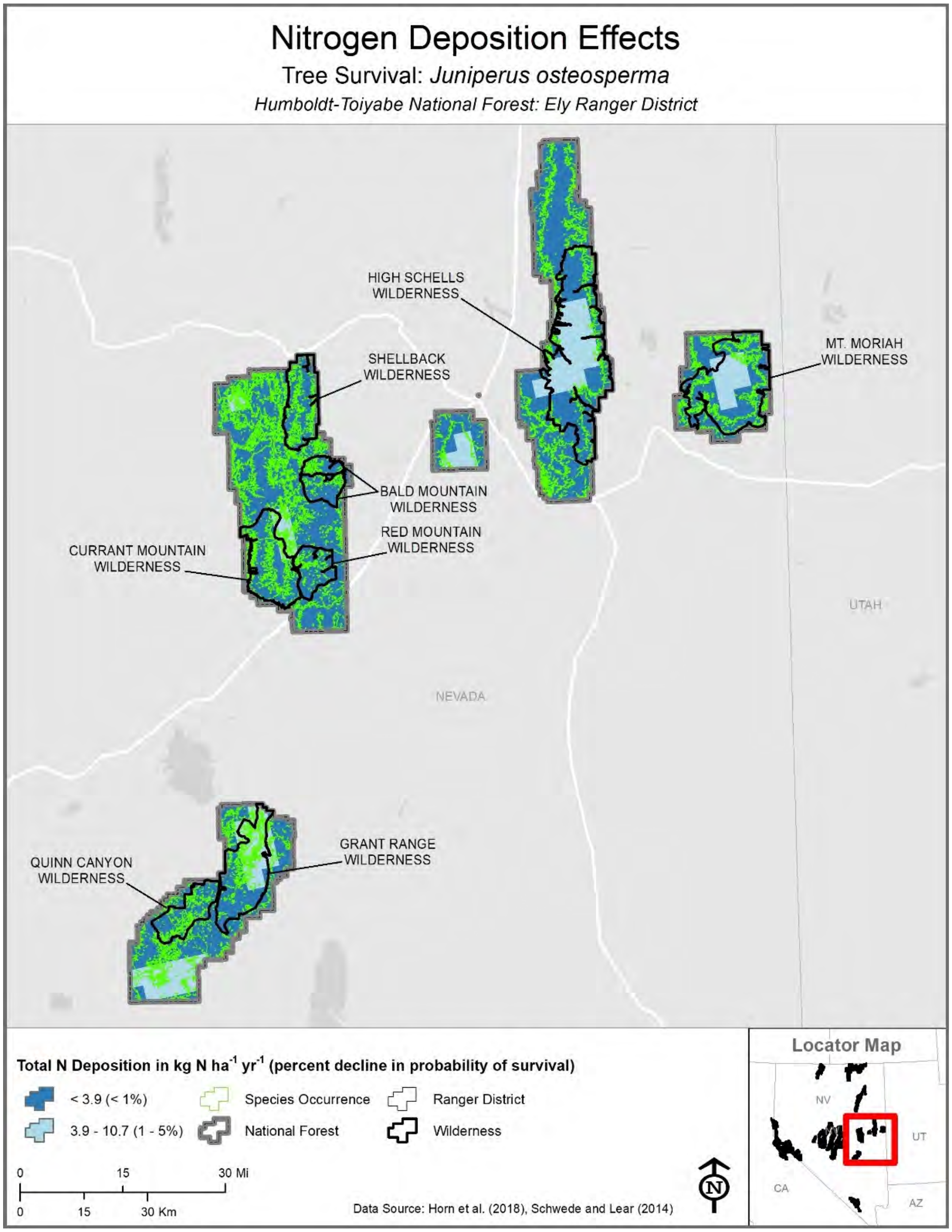

Figure 5-108. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

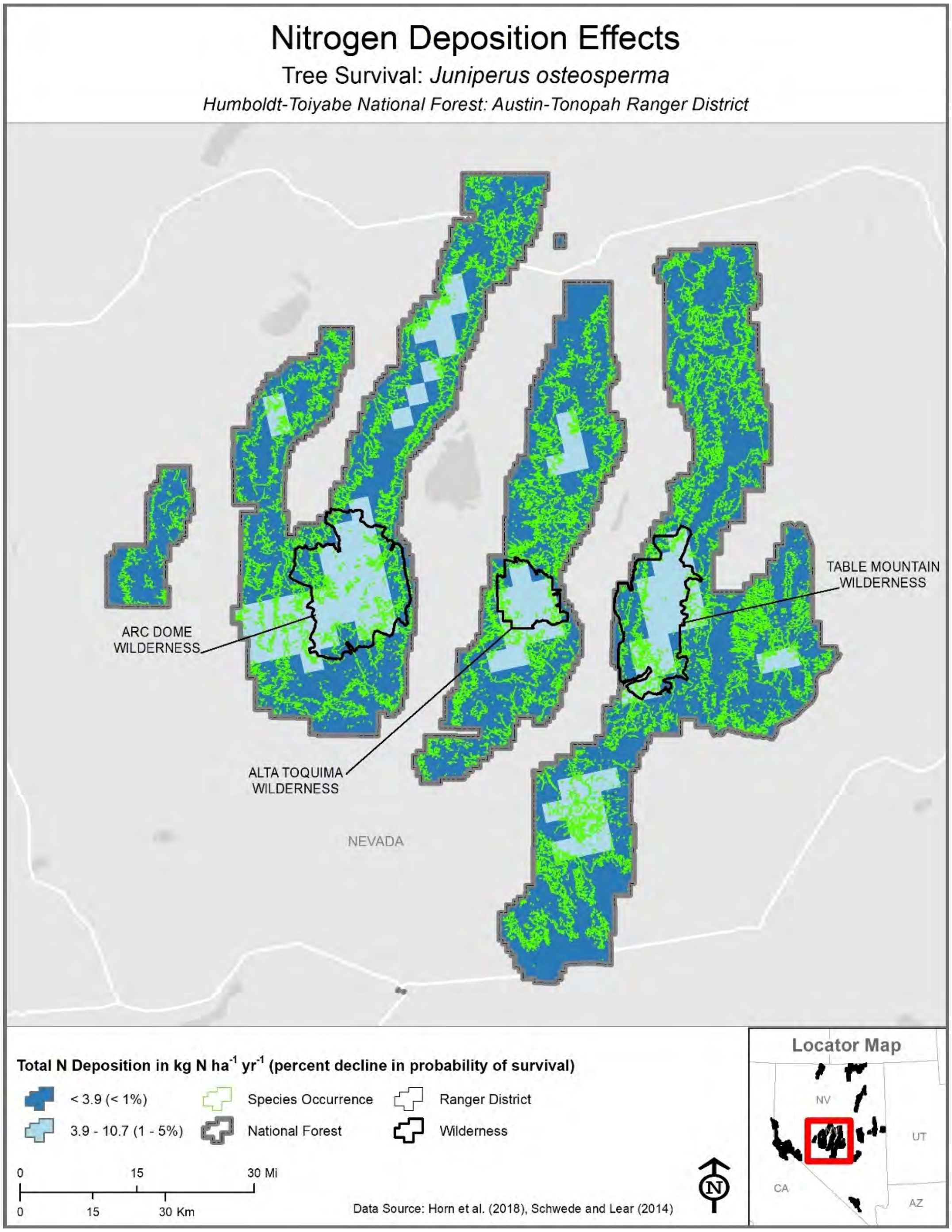

Figure 5-109. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

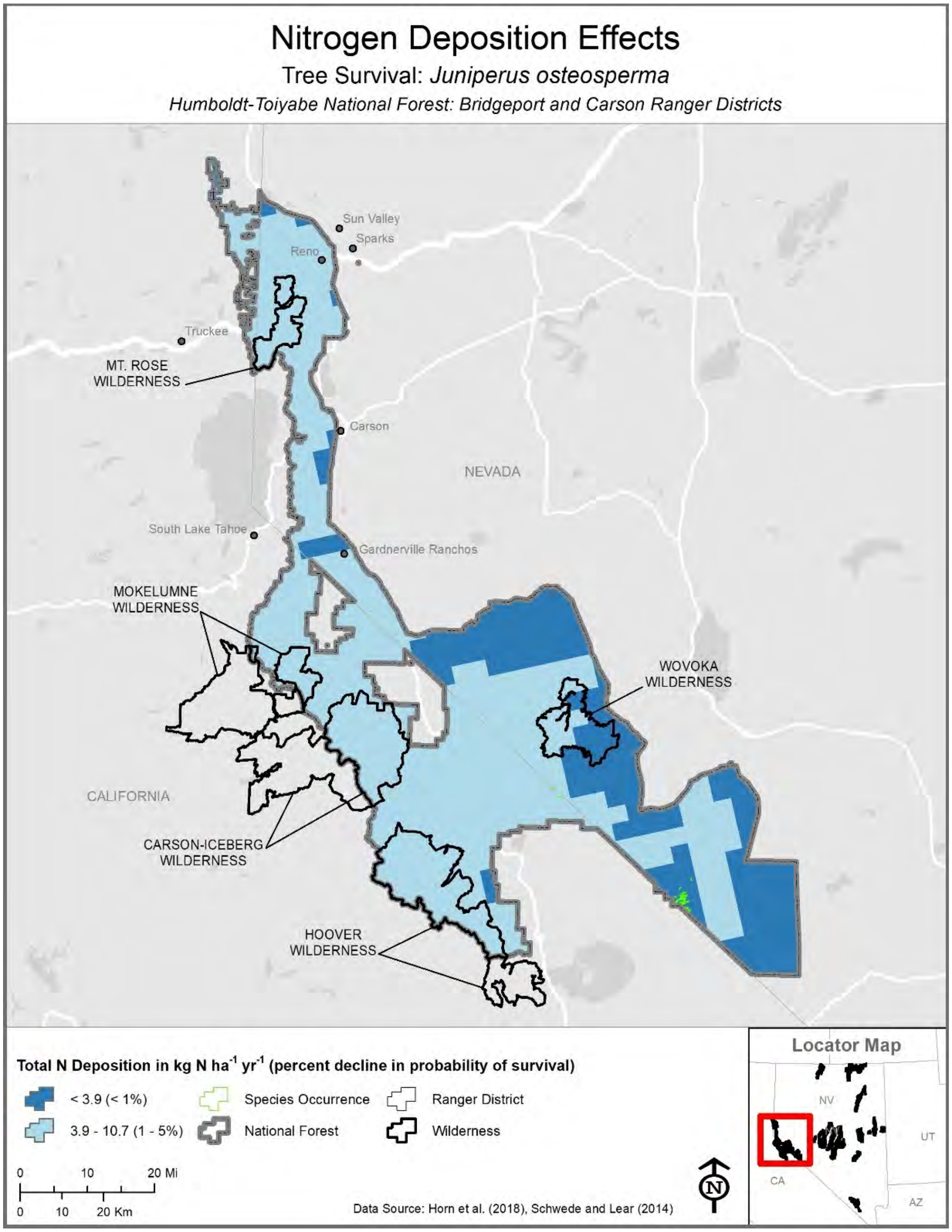

Figure 5-110. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

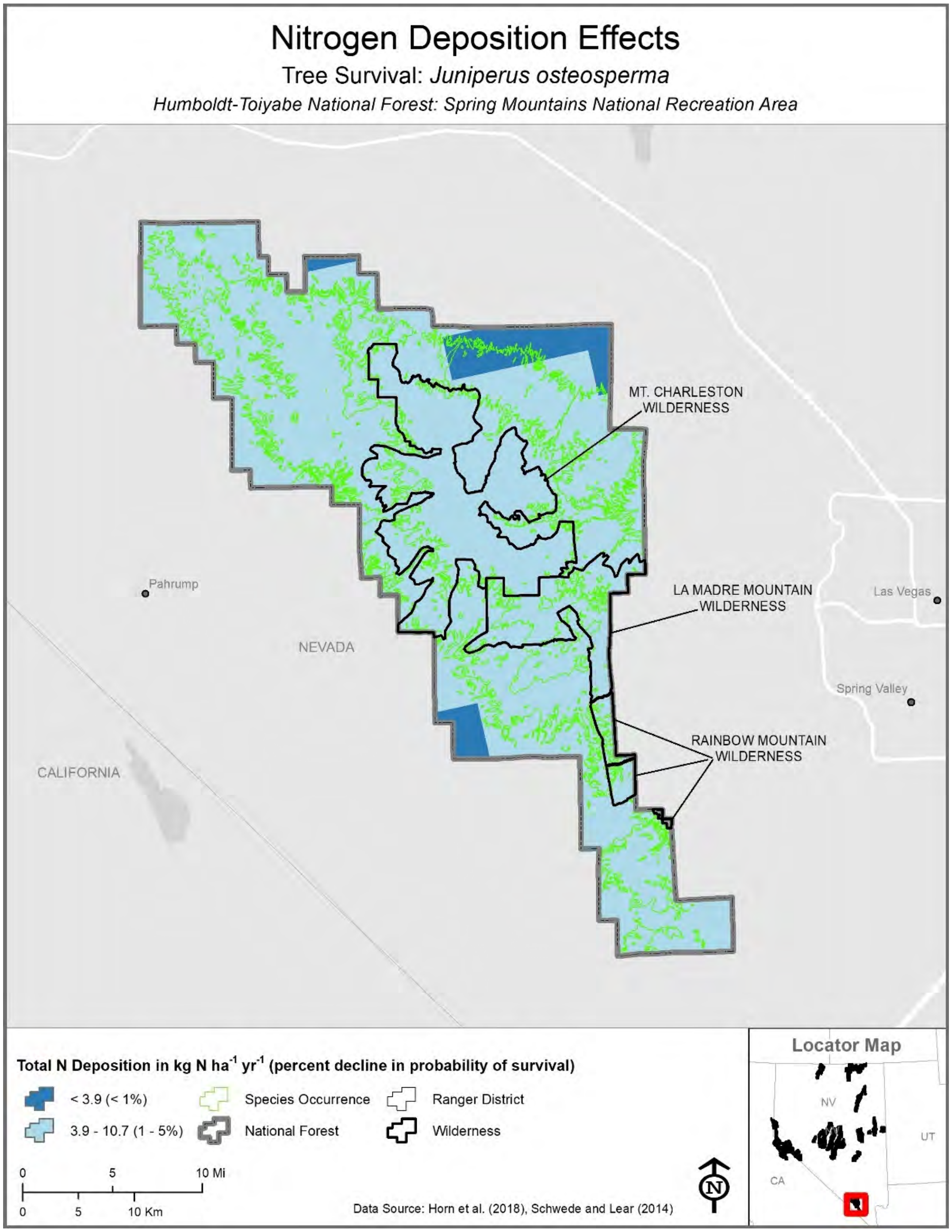

Figure 5-111. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

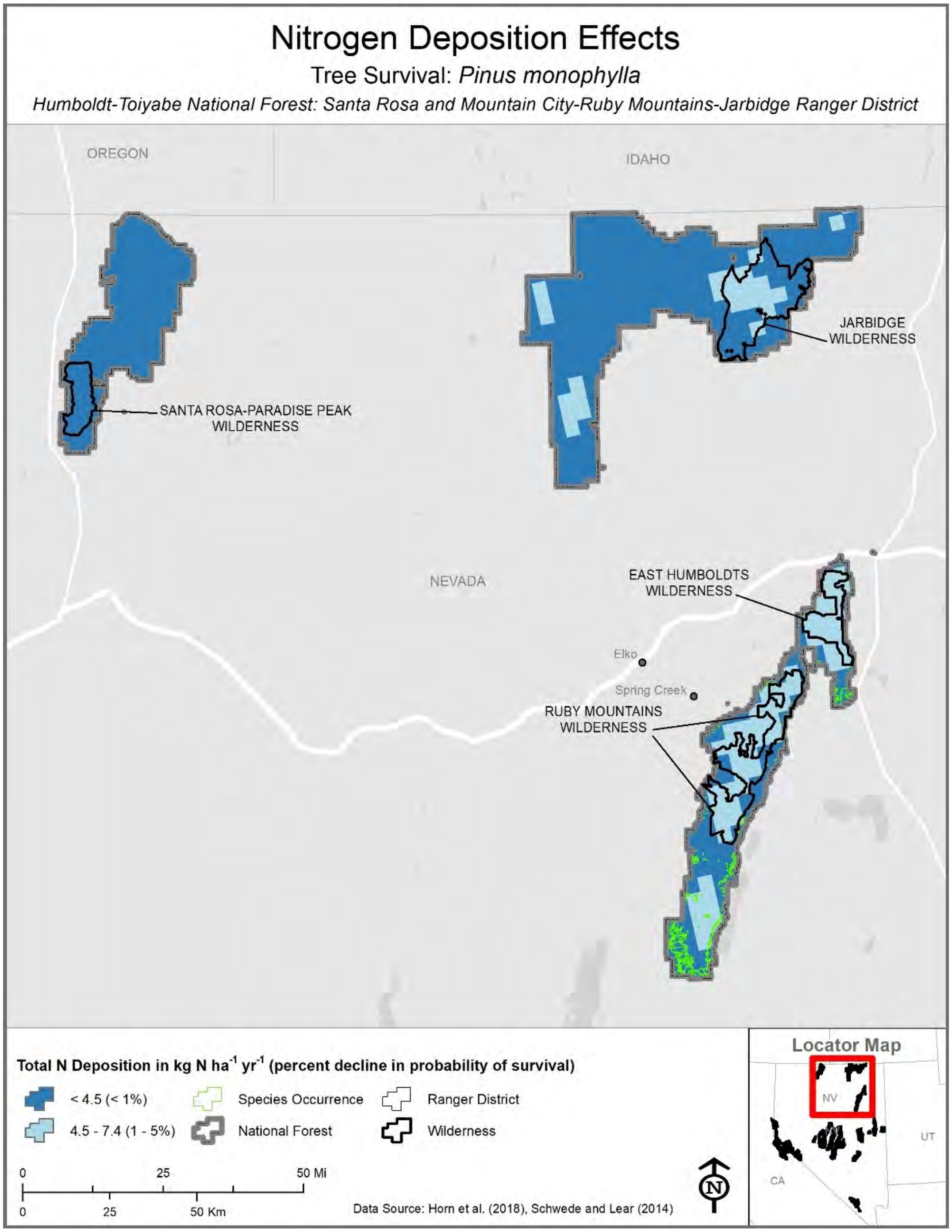

Figure 5-112. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

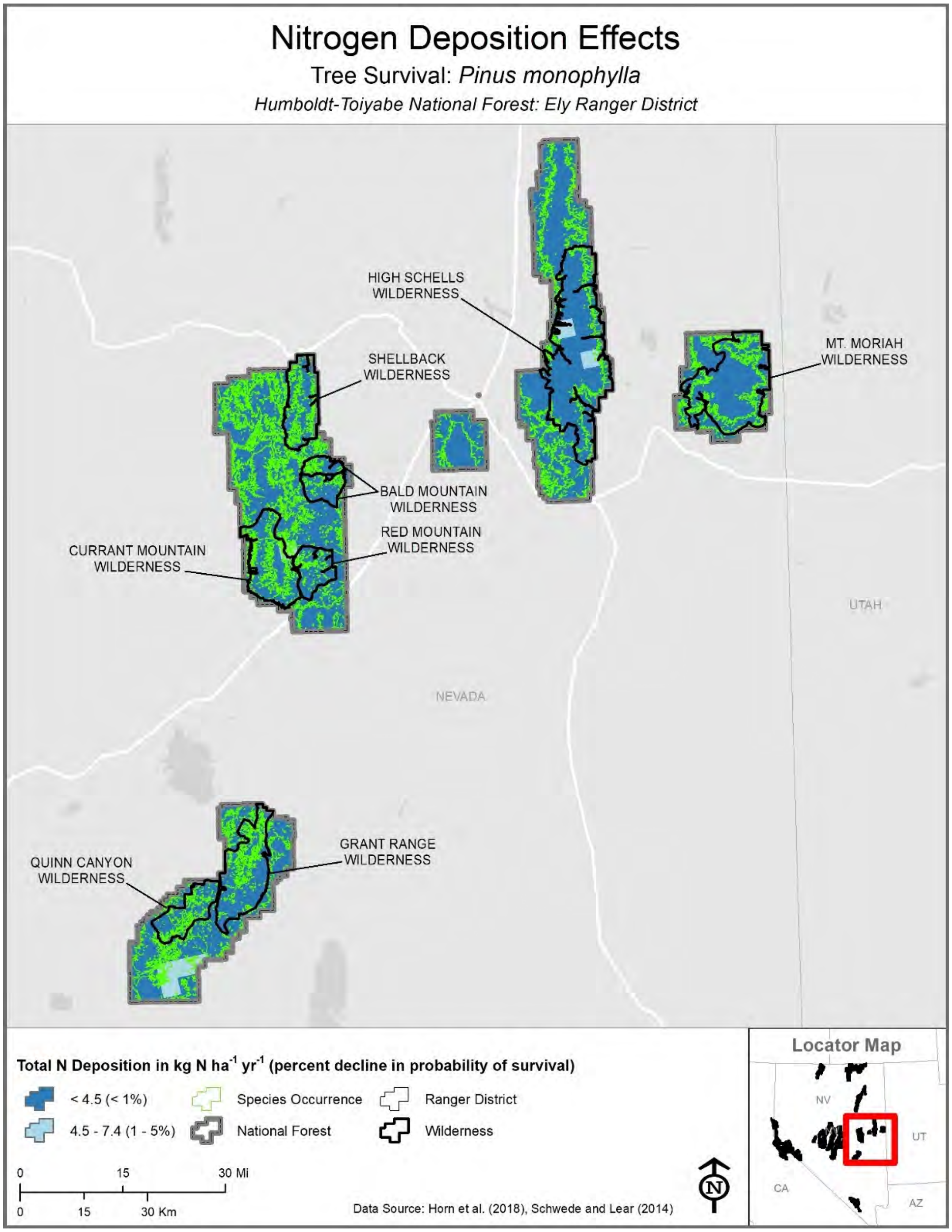

Figure 5-113. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Ely Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

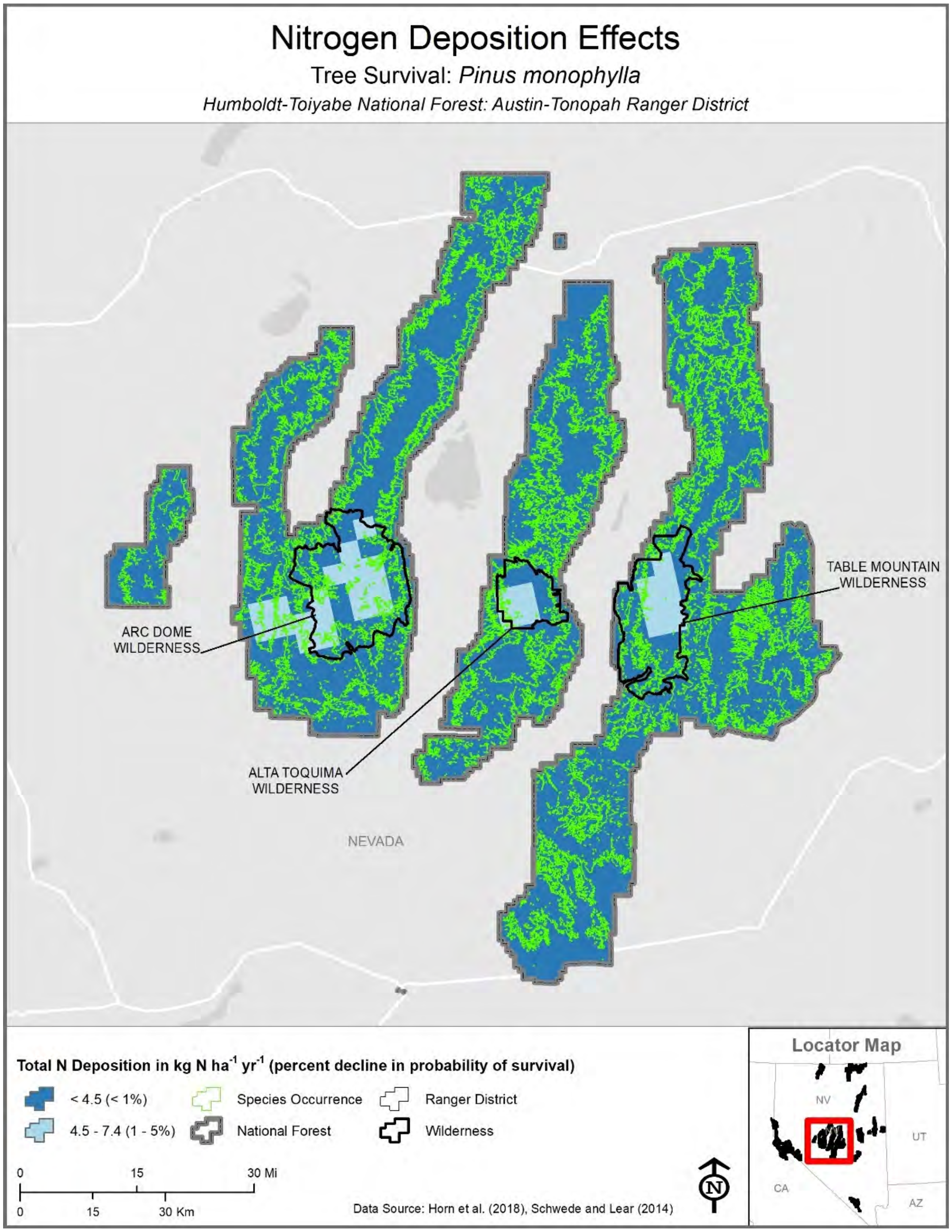

Figure 5-114. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Austin-Tonopah Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

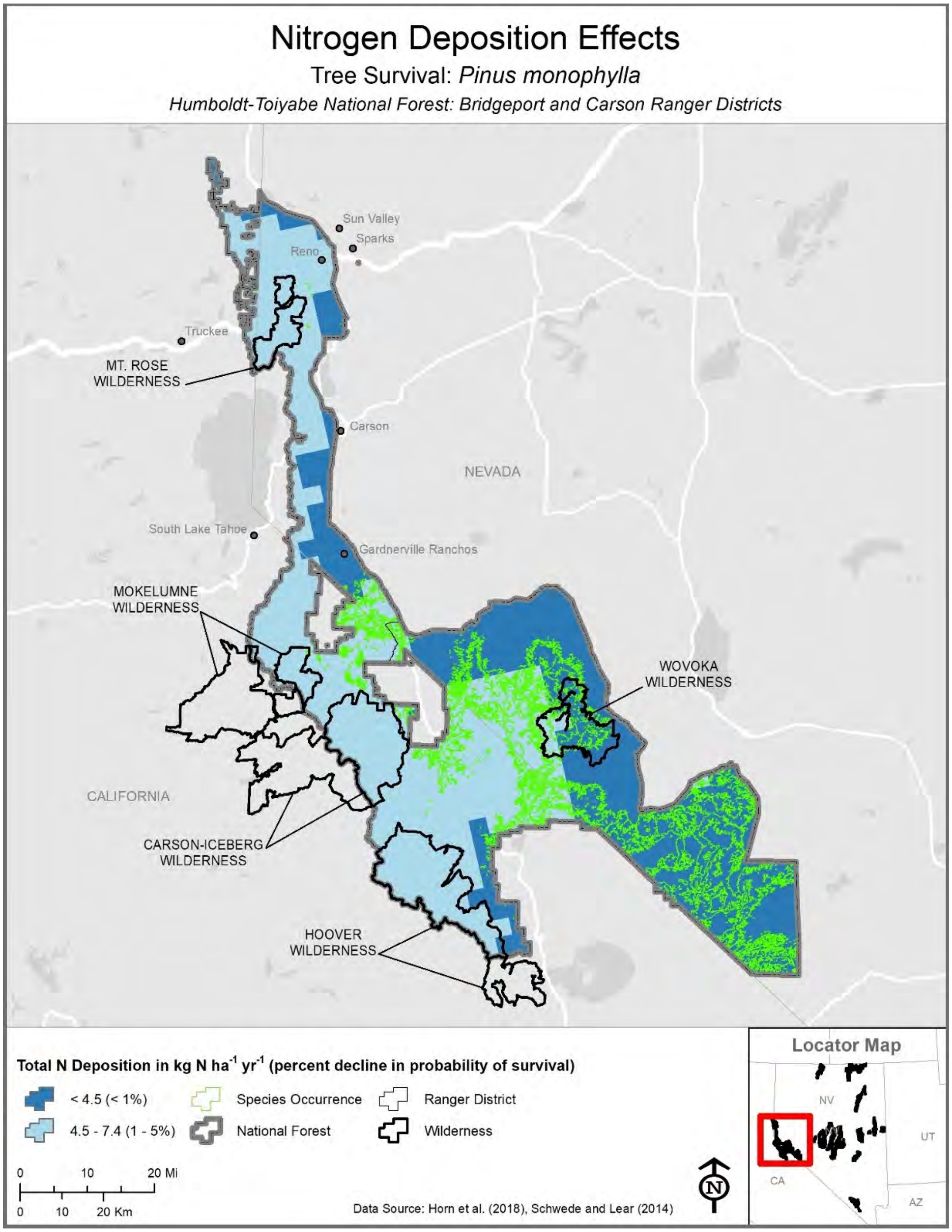

Figure 5-115. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Bridgeport and Carson Ranger District in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

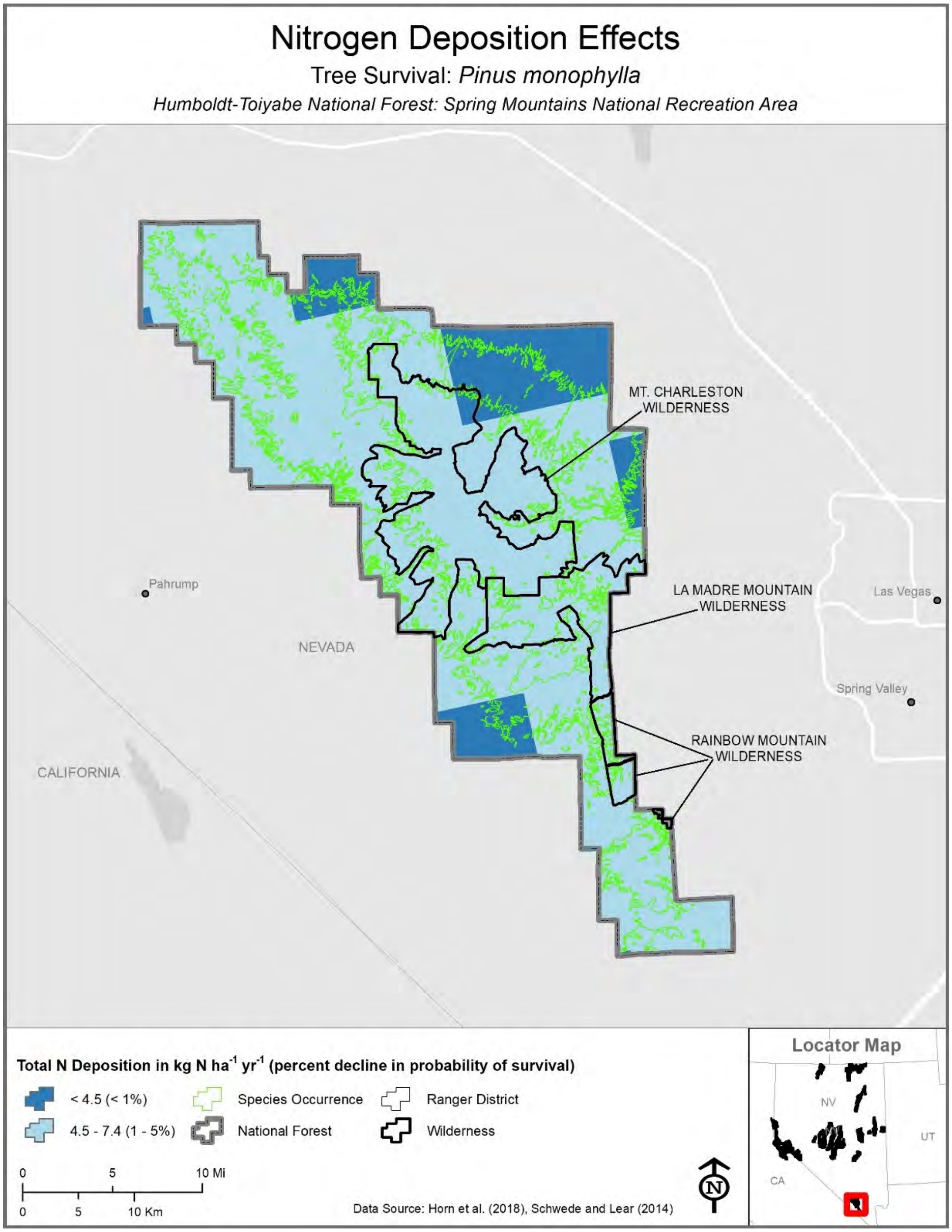

Figure 5-116. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-20. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Humboldt-Toiyabe National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Juniperus occidentalis	western juniper	Growth	Threshold[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.8 Manti-La Sal NF

5.2.8.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification were only available at three locations throughout the Manti-La Sal NF and the waterbodies at these locations were at relatively low risk (i.e., high CLs) for acidification effects (**Figure** 5-117). None of these locations experienced ambient N deposition that was high enough to exceed the CL (**Table** 5-2; **Figure** 5-118). This indicates that these locations are not likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}. However, given the low representation of CLs, acid-sensitive waterbodies may occur elsewhere within the Manti-La Sal NF.

5.2.8.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout most of the Manti-La Sal NF and represented a total of nearly 2,400 km^2 (43%) of the forest (**Table** 5-3; **Figure** 5-119). The Dark Canyon Wilderness was mostly comprised of low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included nearly 3,440 km^2 (61%) of the forest (**Table** 5-4; **Figure** 5-120). Exceedance within the Dark Canyon Wilderness was generally within the range of 1 – 2 kg N ha^{-1} yr^{-1}. The highest magnitudes of exceedance were > 5 kg N ha^{-1} yr^{-1}. Areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.8.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 98% and 100%, respectively, of the Manti-La Sal NF (**Table**s 5-5 and 5-6). The highest magnitudes of exceedance (> 5 kg N ha^{-1} yr^{-1}) for both CLs were mostly located in the northwestern portion of the forest (**Figures** 5-121 and 5-122). The full extent of the Dark Canyon Wilderness was in exceedance of both lichen CLs. Critical load exceedance associated with at least 40 – 50% reductions in forage lichen abundance were common throughout the forest.

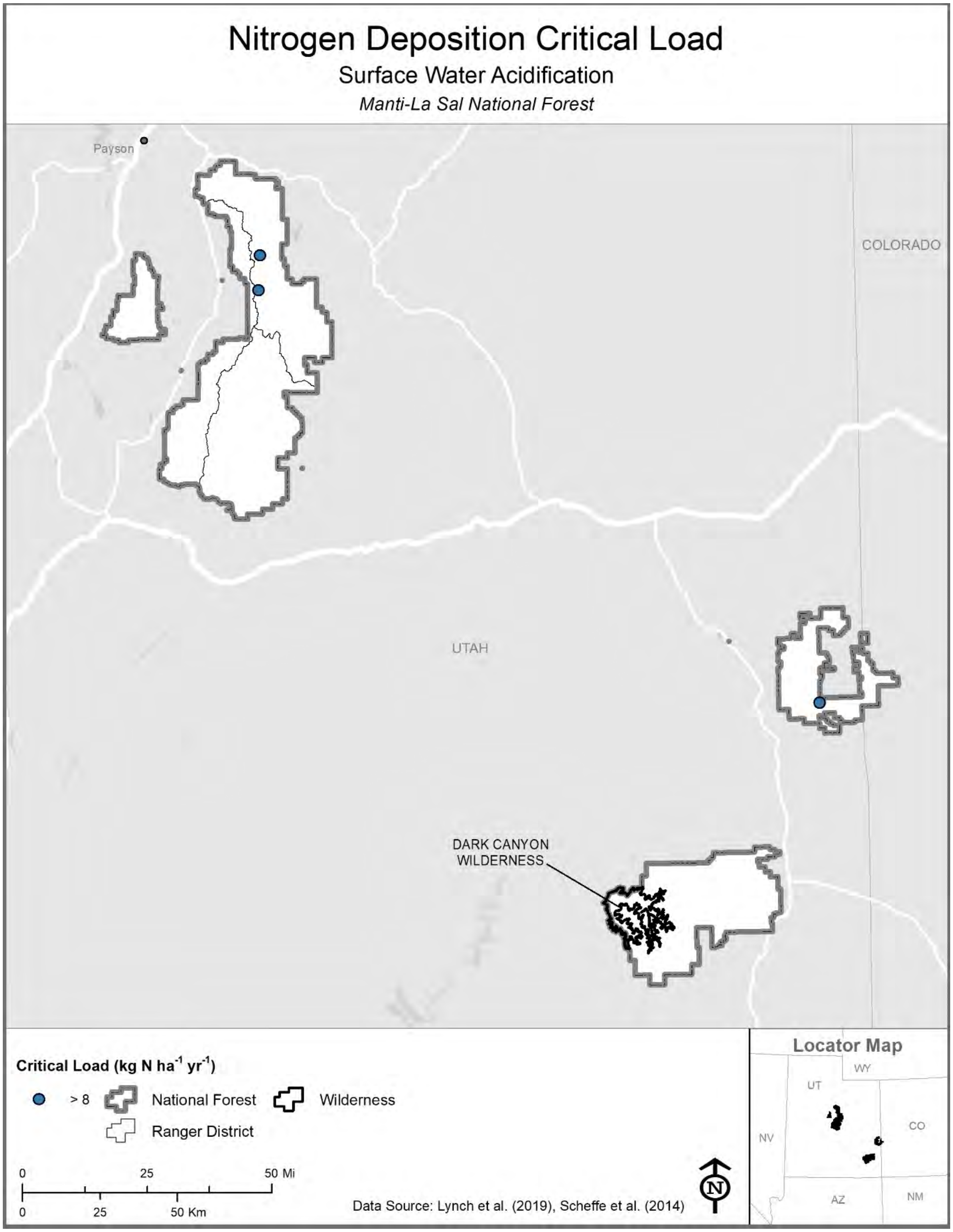

Figure 5-117. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Manti-La Sal National Forest.

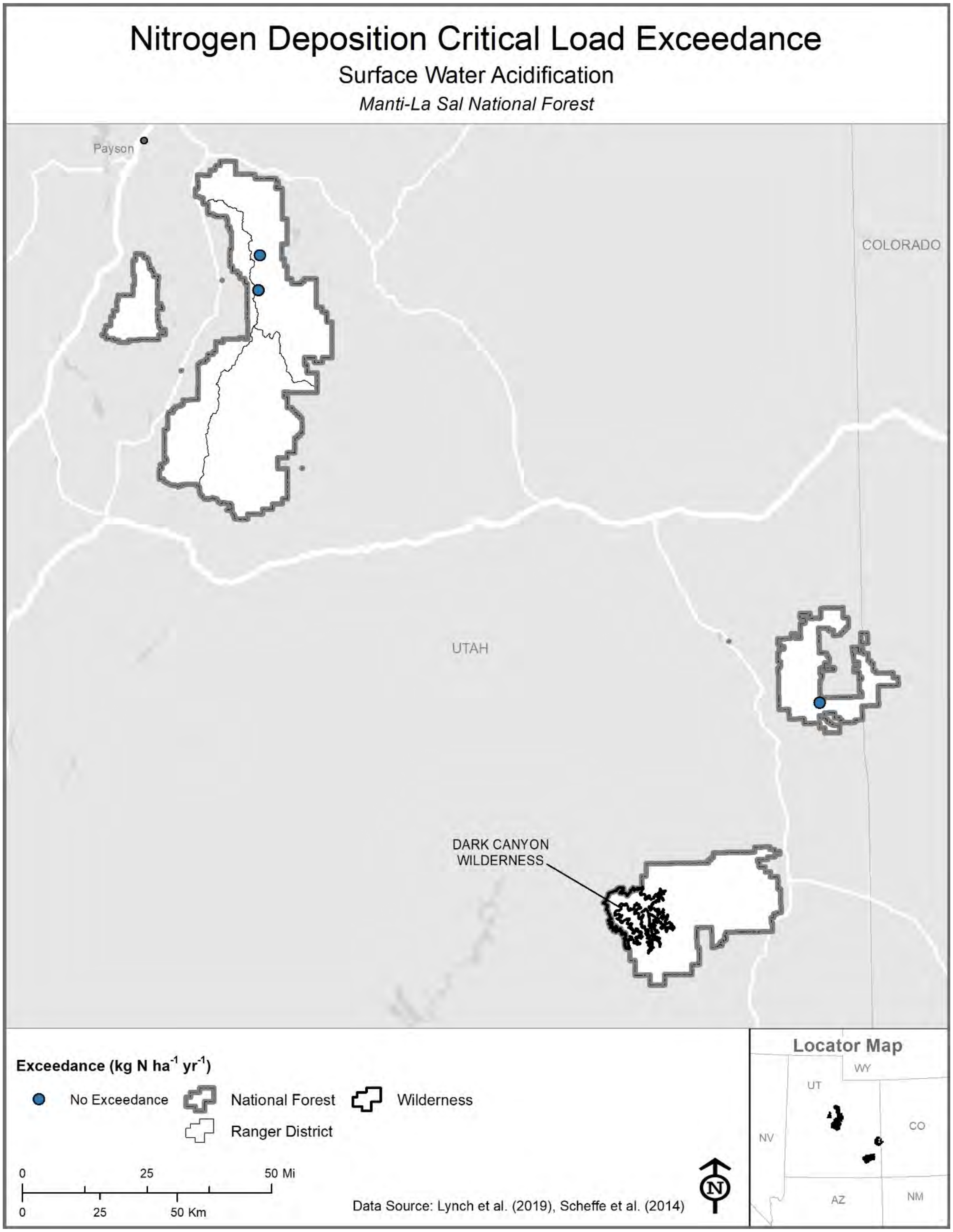

Figure 5-118. Map of the Manti-La Sal National Forest showing no exceedance of the critical load of nitrogen (N) for surface water acidification.

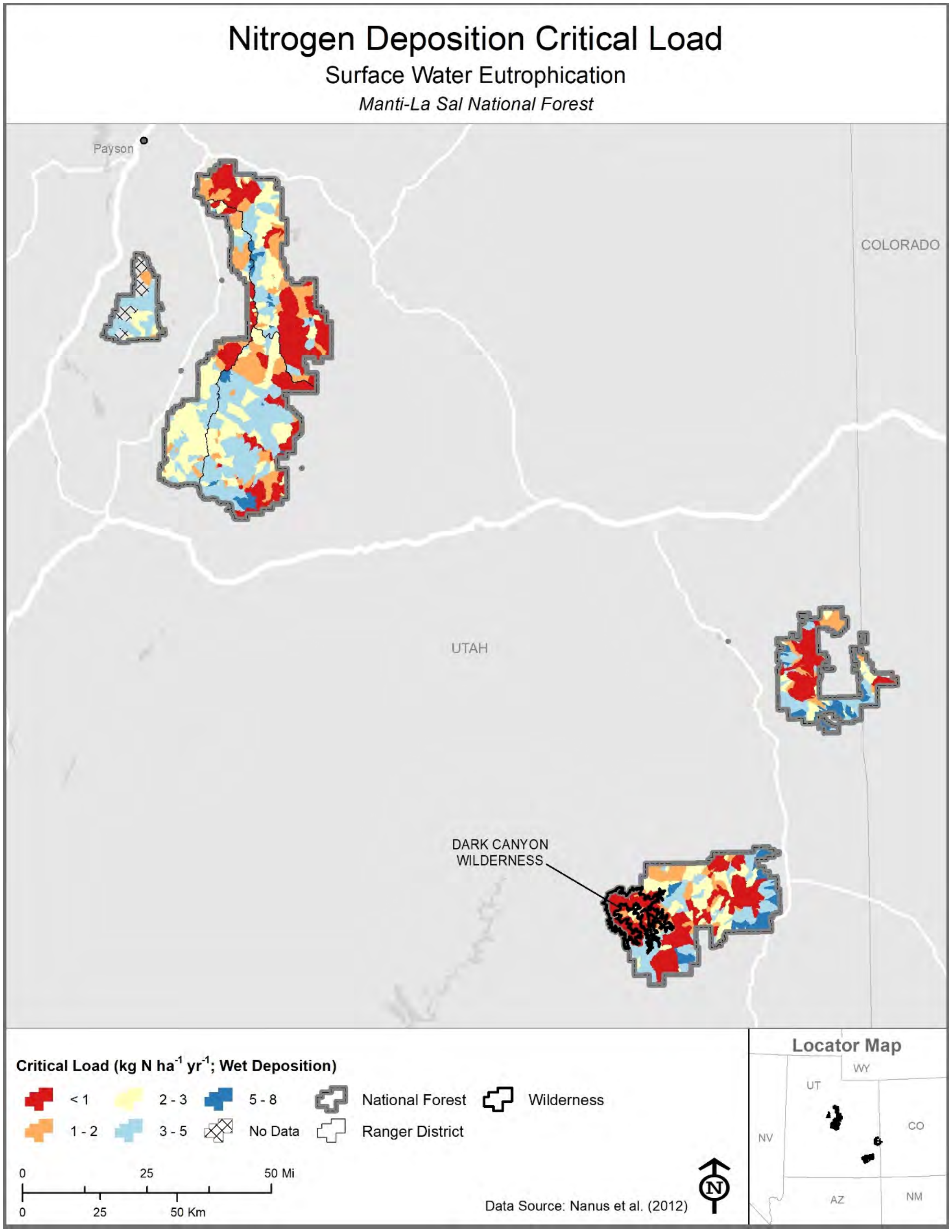

Figure 5-119. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Manti-La Sal National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

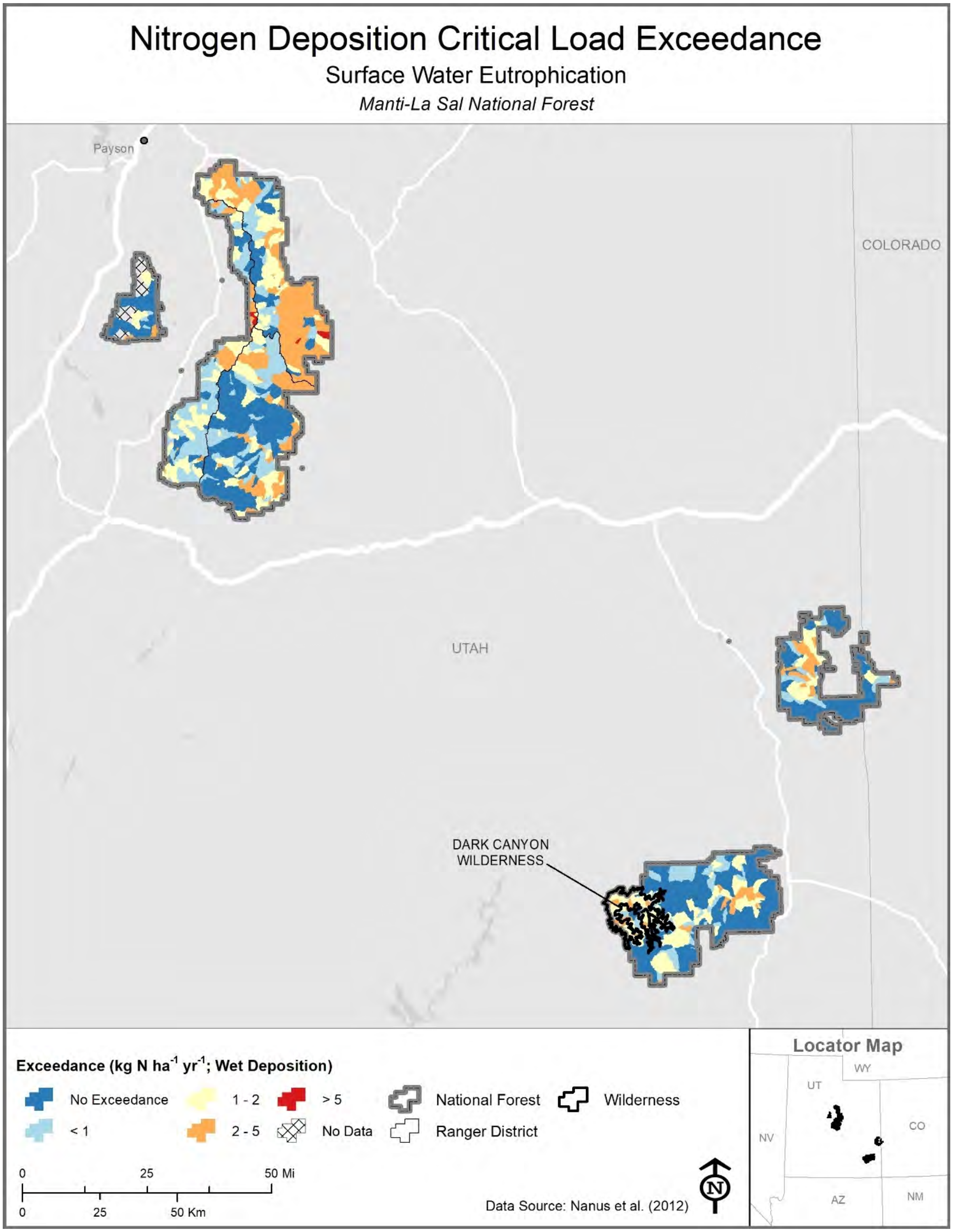

Figure 5-120. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Manti-La Sal National Forest.

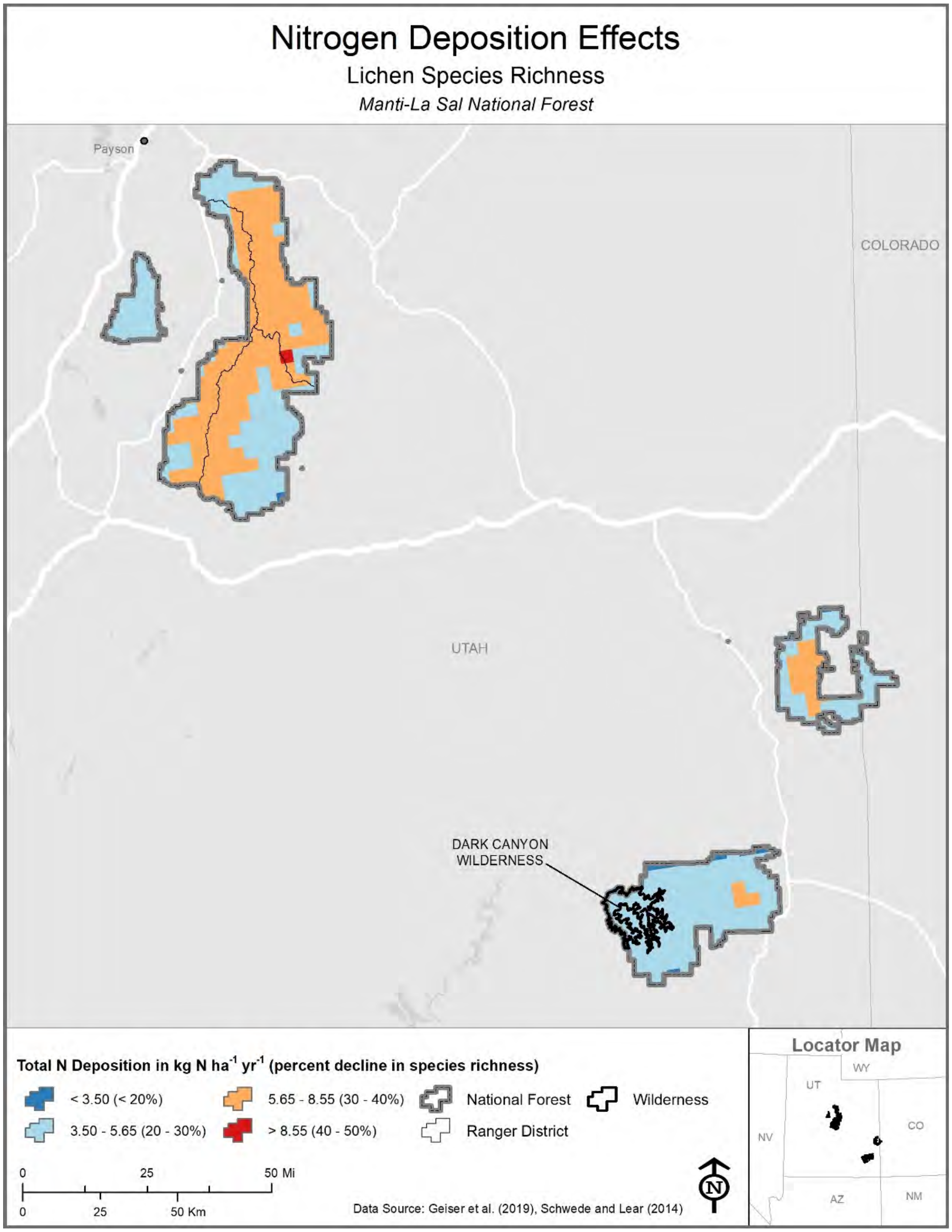

Figure 5-121. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Manti-La Sal National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.

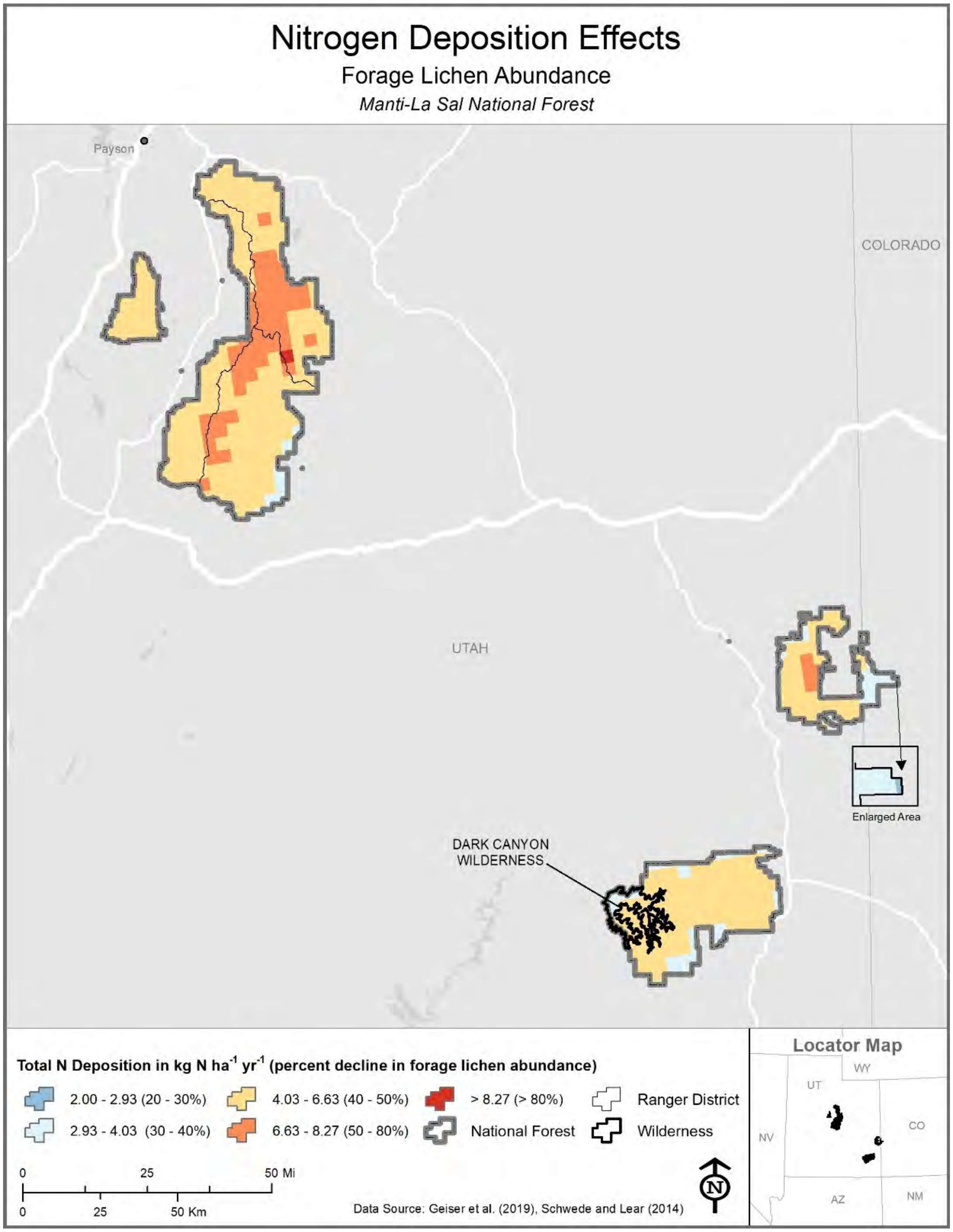

Figure 5-122. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Manti-La Sal National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

5.2.8.4 Tree Growth and Survival

Although there were no exceedances of CLs to protect growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reductions) within 31% of the area in which this species is expected to occur in the Manti-La Sal NF (**Table**s 5-7 and 5-8; **Figure** 5-123). Areas in exceedance for probability of tree survival mostly occurred in the northwestern portion of the forest (**Figure** 5-124).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within nearly 100% and 67%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Decreases in growth of > 10% and probability of survival of 1 – 5% were most common and were expected to occur in the northwestern portion of the forest (**Figures** 5-125 and 5-126). Areas of reductions in probability of survival of 1 – 5% were limited to relatively small areas throughout the forest (**Figure** 5-126).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 99% of the area in which this species is expected to occur (**Table** 5-11). Areas of exceedance were common throughout the forest (**Figure** 5-127).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 80% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance were common throughout the forest, including within the Dark Canyon Wilderness (**Figure** 5-128).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 37% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance were common throughout the forest, including within the Dark Canyon Wilderness (**Figure** 5-129).

Other tree species of interest that occurred within the Manti-La Sal NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (VIF N < 3; bold species shown in **Table** 5-21). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

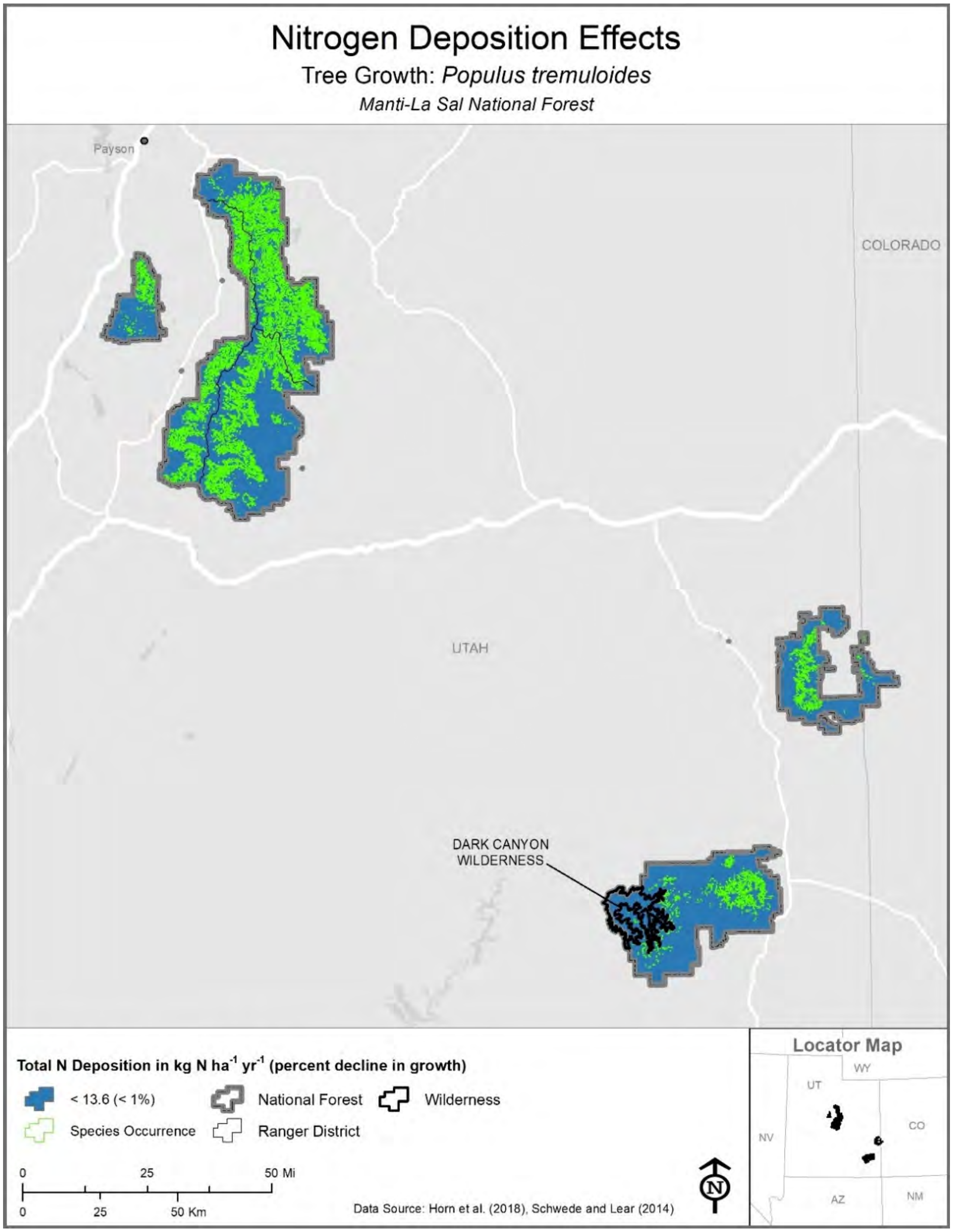

Figure 5-123. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Manti-La Sal NF is below the critical load for 1% growth reduction of *Populus tremuloides*.

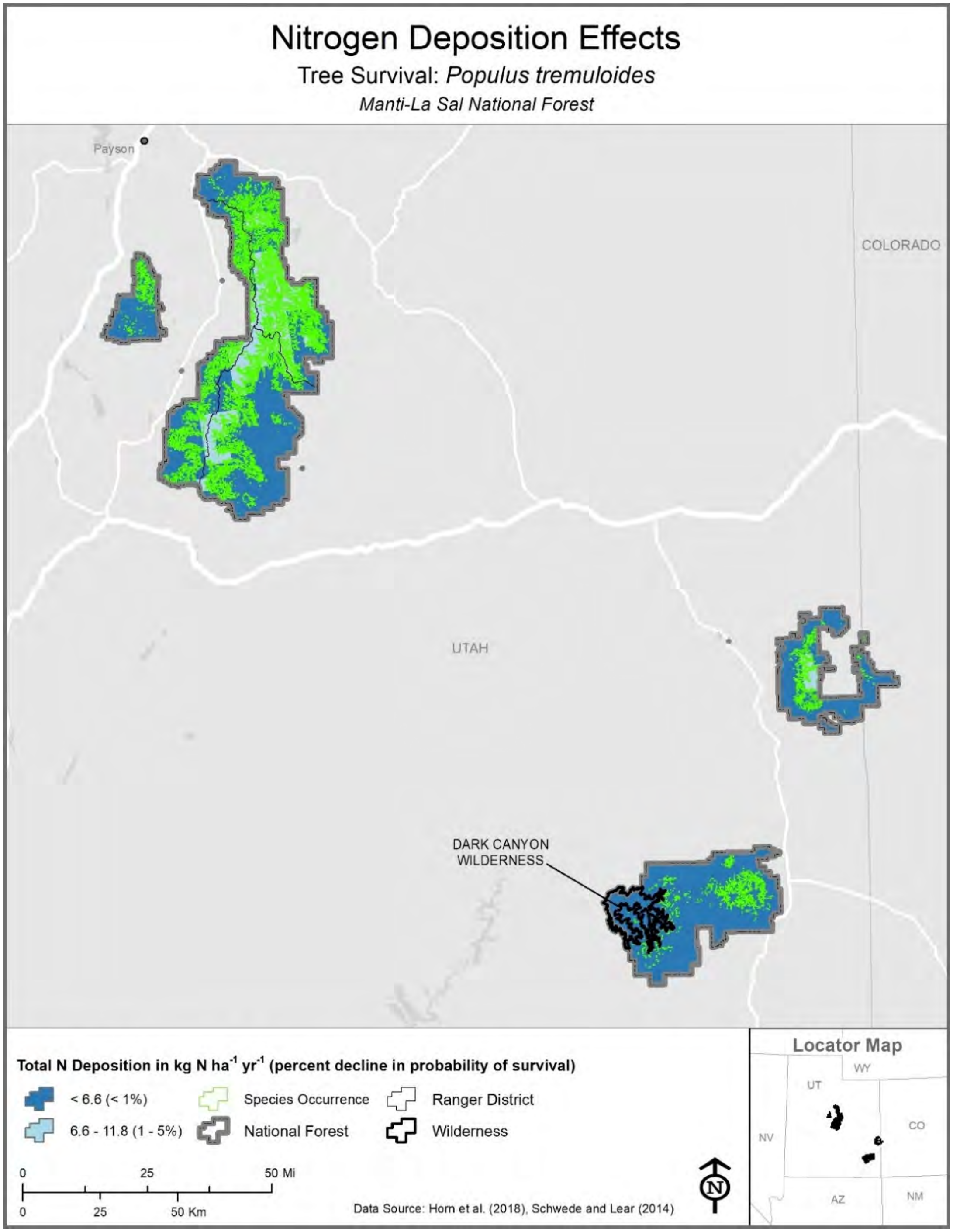

Figure 5-124. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

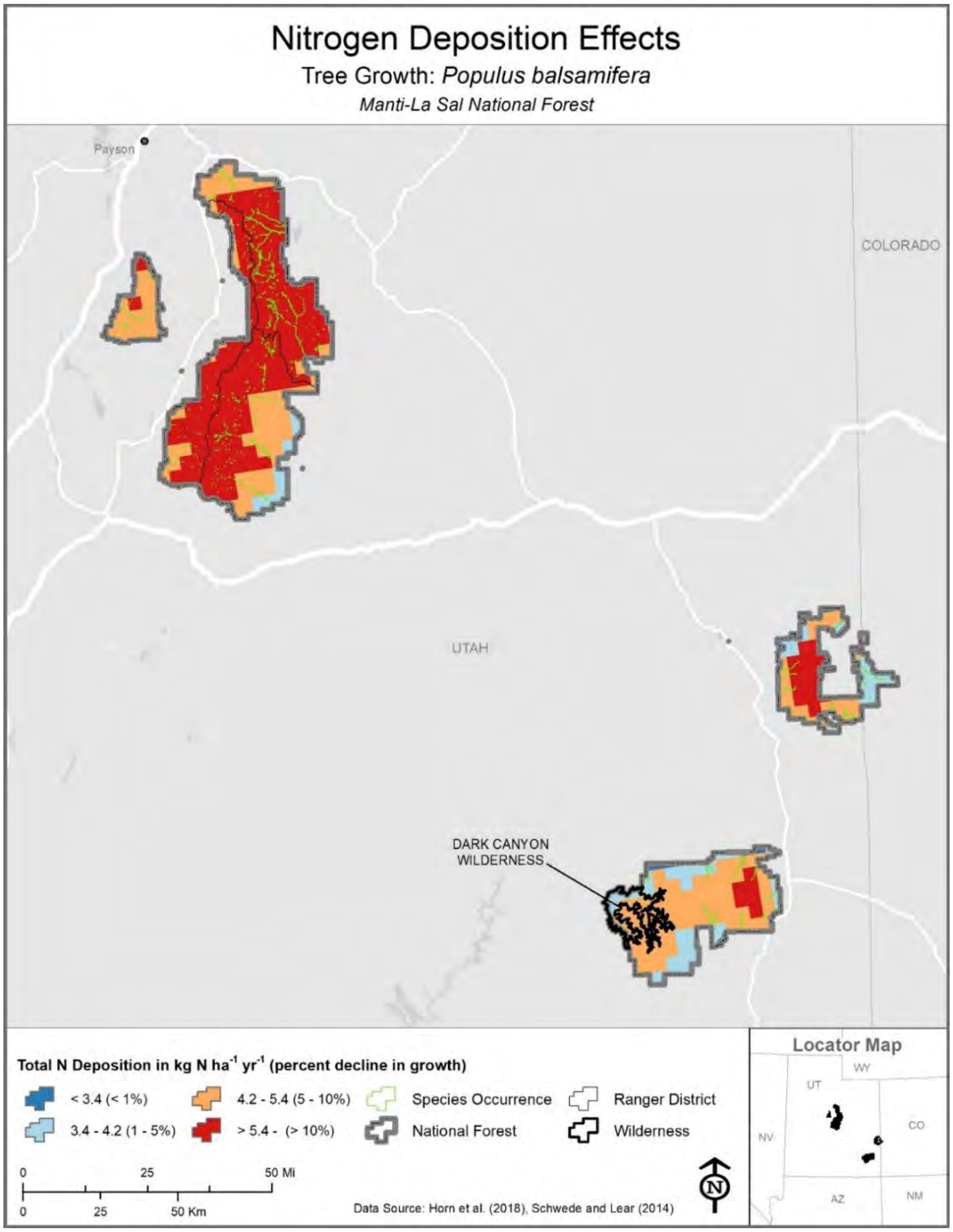

Figure 5-125. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. Occurrence of *Populus balsamifera* is sparse and distributed within isolated areas throughout the Manti-La Sal NF, particularly in the northern portion, that are difficult to discern on the map. Table 5-9 indicates the extent to which any of these areas are in exceedance of the specified critical loads.

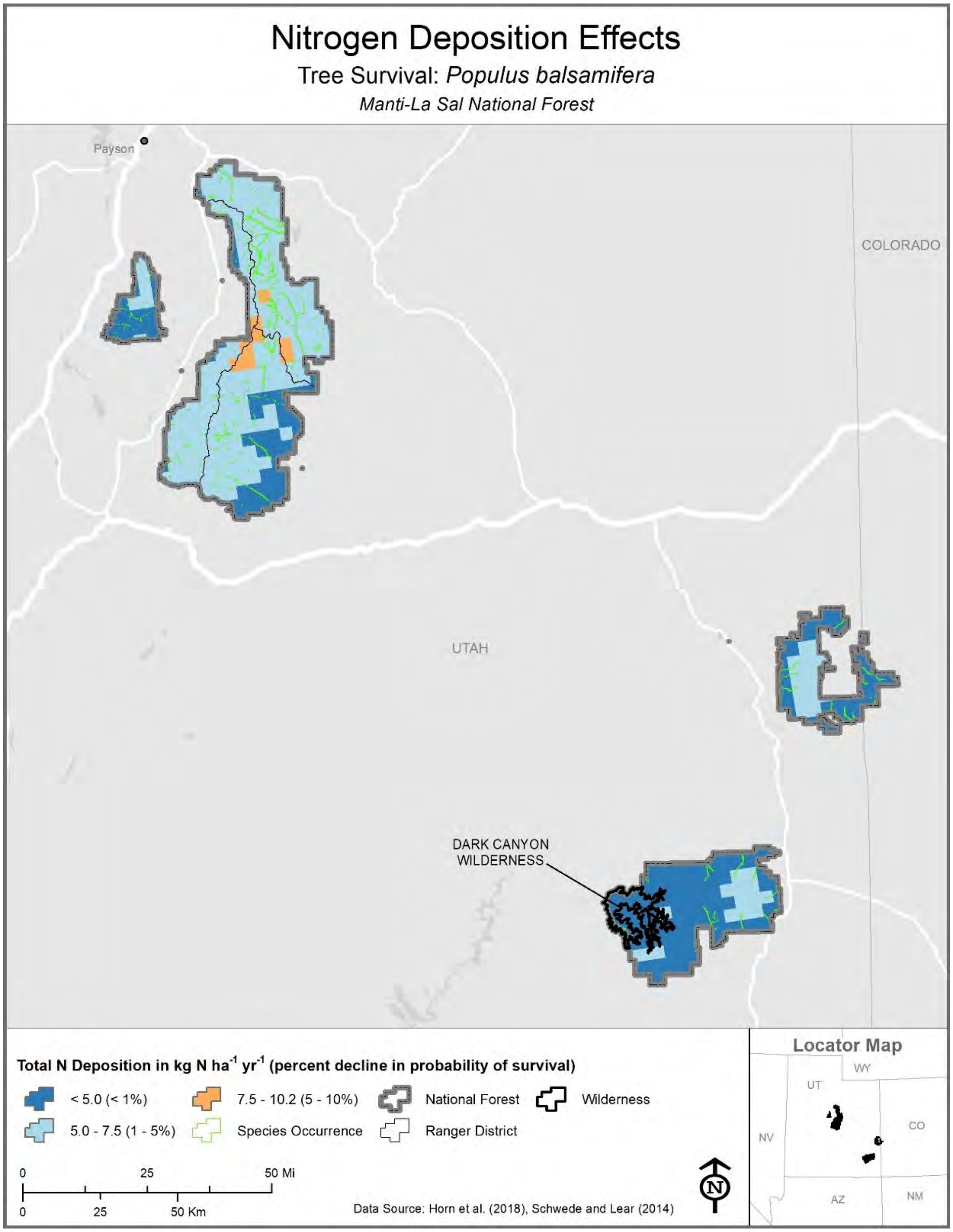

Figure 5-126. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

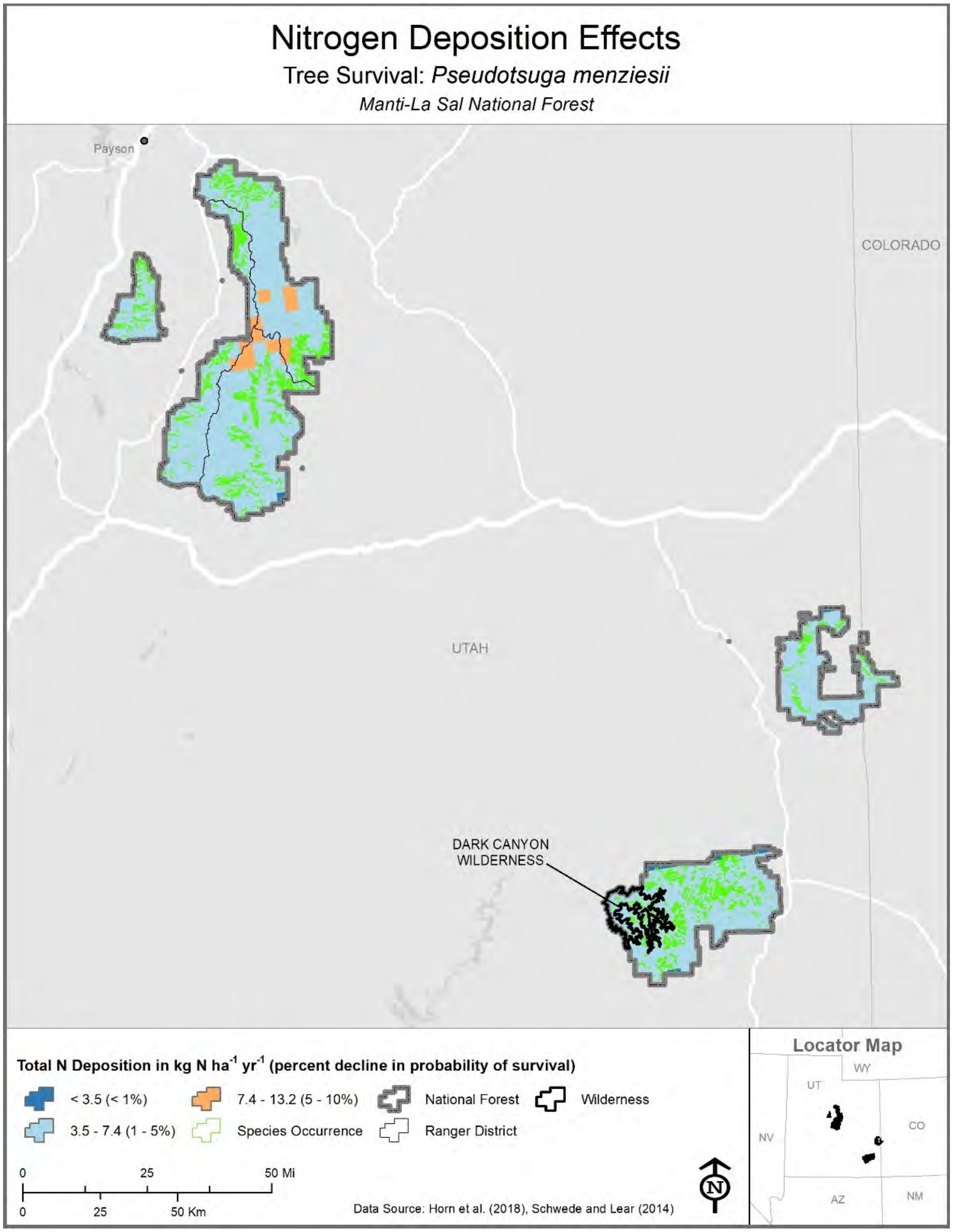

Figure 5-127. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

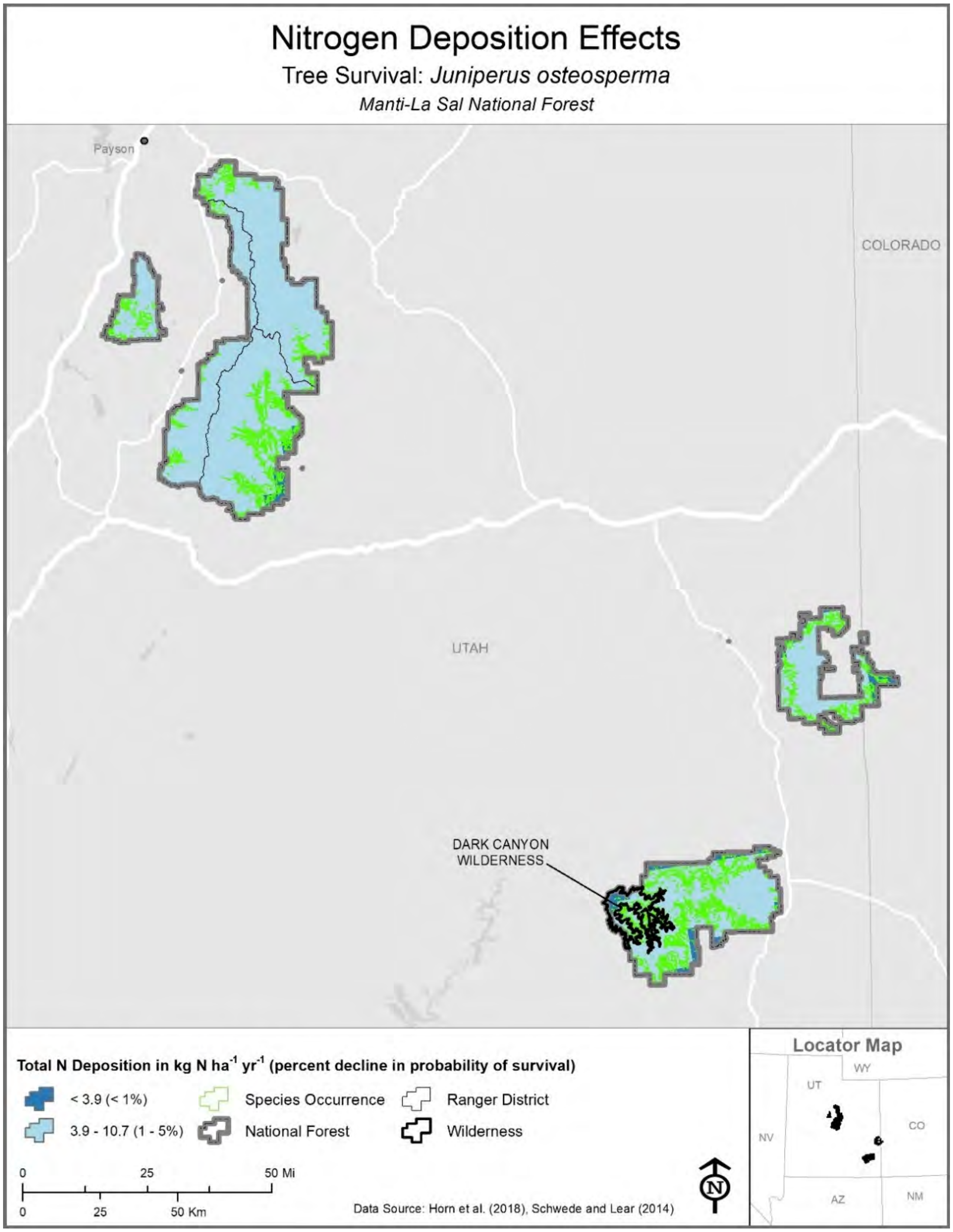

Figure 5-128. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

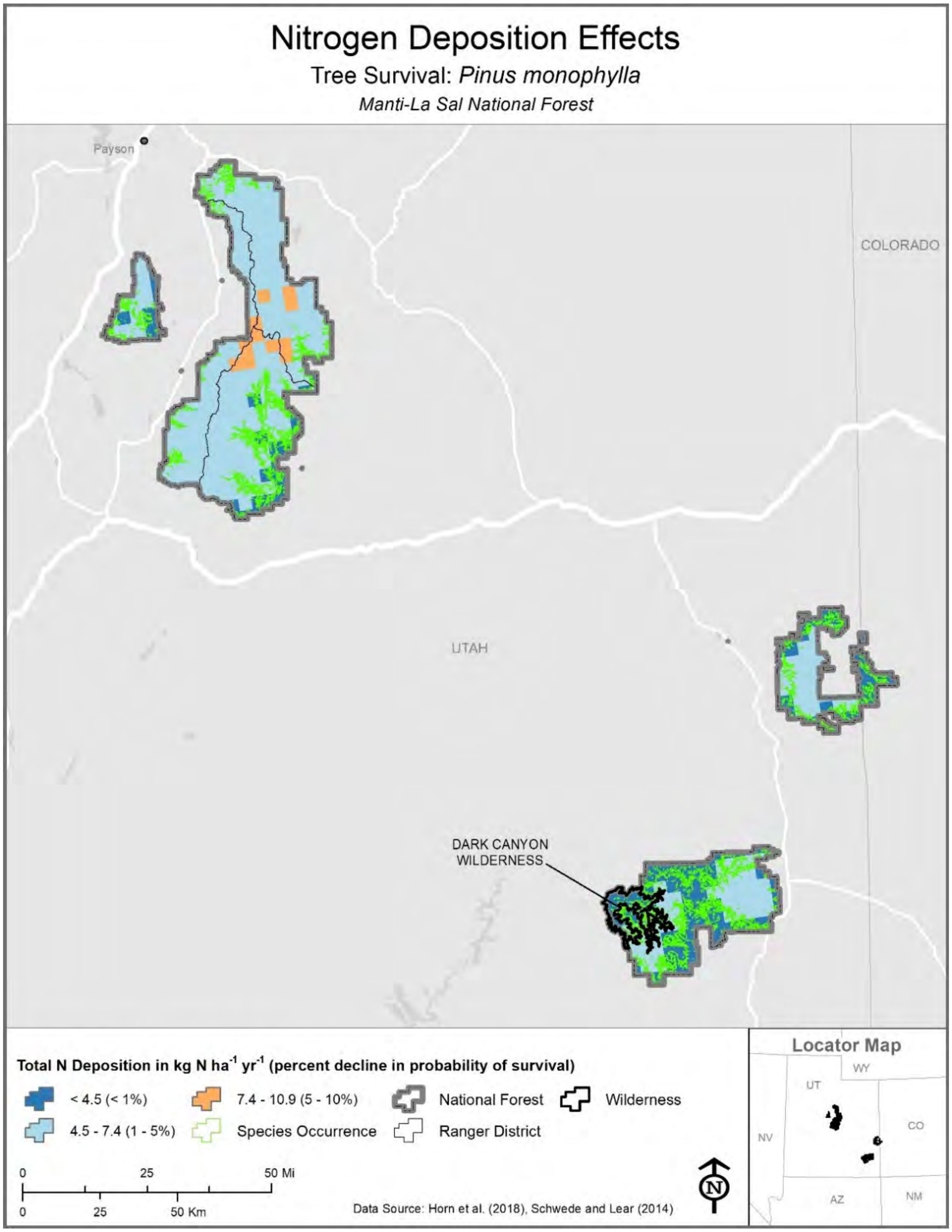

Figure 5-129. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Manti-La Sal National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-21. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Manti-La Sal National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.9 Payette NF

5.2.9.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification within the Payette NF illustrated a range of sensitivity to acidification effects (**Figure** 5-130). Surface waters with relatively high risk of acidification effects (i.e., low CLs) were located within the central portion of the forest and less sensitive (i.e., higher CLs) waterbodies occurred throughout the forest. Ambient N deposition was high enough to exceed the CL at 12% (n = 6) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. The highest magnitude of exceedance was between 2 and 5 kg N ha^{-1} yr^{-1}. None of the waterbodies within the portion of the Frank Church-River of No Return Wilderness administered by the Payette NF were in exceedance (**Figure** 5-131). Given the low representation of sites where CLs are calculated in some portions of the Payette NF, acid-sensitive waterbodies may occur elsewhere.

5.2.9.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout the Payette NF and represented a total of nearly 5,060 km^2 (59%) of the forest (**Table** 5-3; **Figure** 5-132). The portion of the Frank Church-River of No Return Wilderness located within the Payette NF was mostly comprised of low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included nearly 4,670 km^2 (55%) of the forest (**Table** 5-4; **Figure** 5-133). Exceedance within the Frank Church – River of No Return Wilderness was generally within the range of 1 – 2 kg N ha^{-1} yr^{-1}, but some areas were exceeded by as much as 2 – 5 kg N ha^{-1} yr^{-1}. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.9.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 25% and nearly 100%, respectively, of the Payette NF (**Table**s 5-5 and 5-6). The eastern and western portions of the forest, including the portion of the Frank Church-River

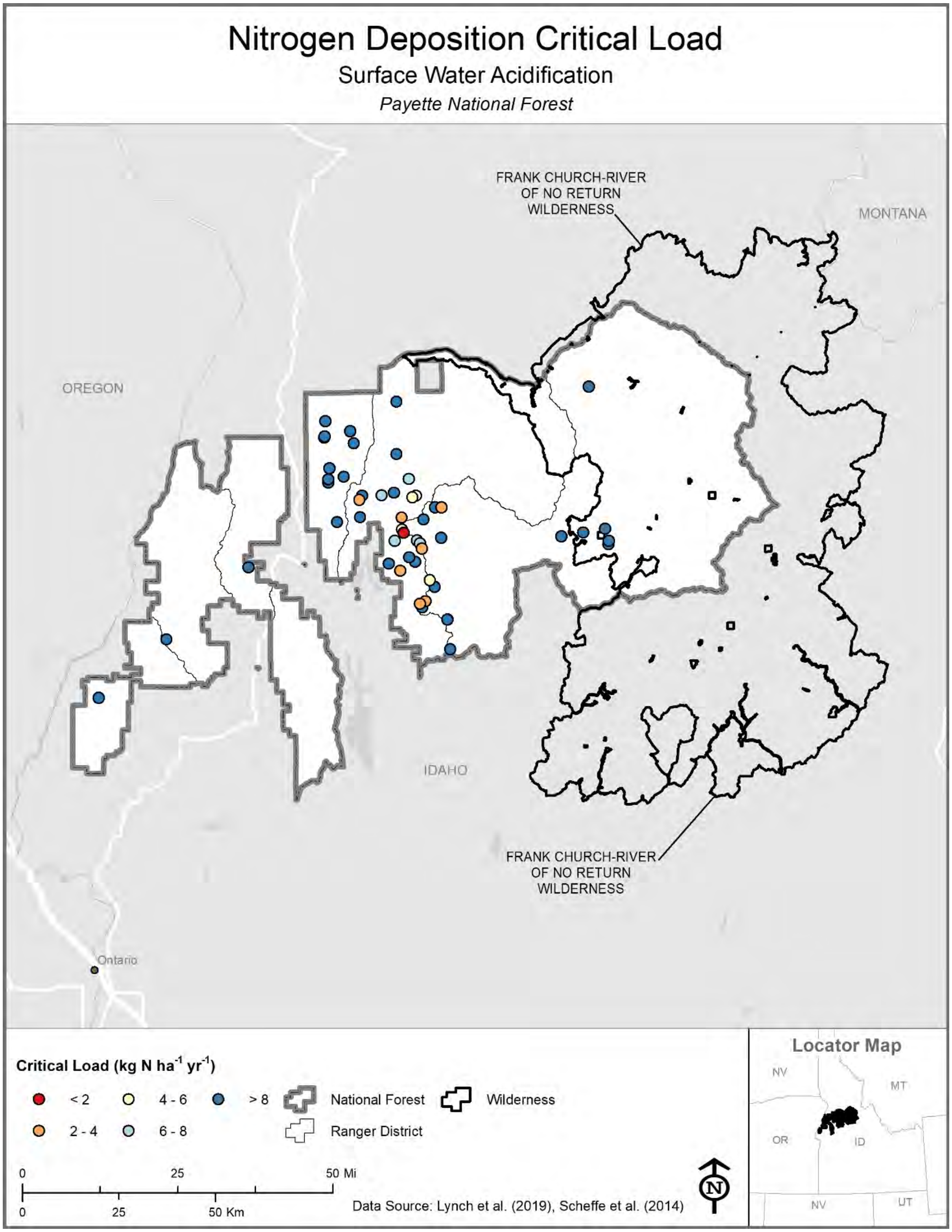

Figure 5-130. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Payette National Forest.

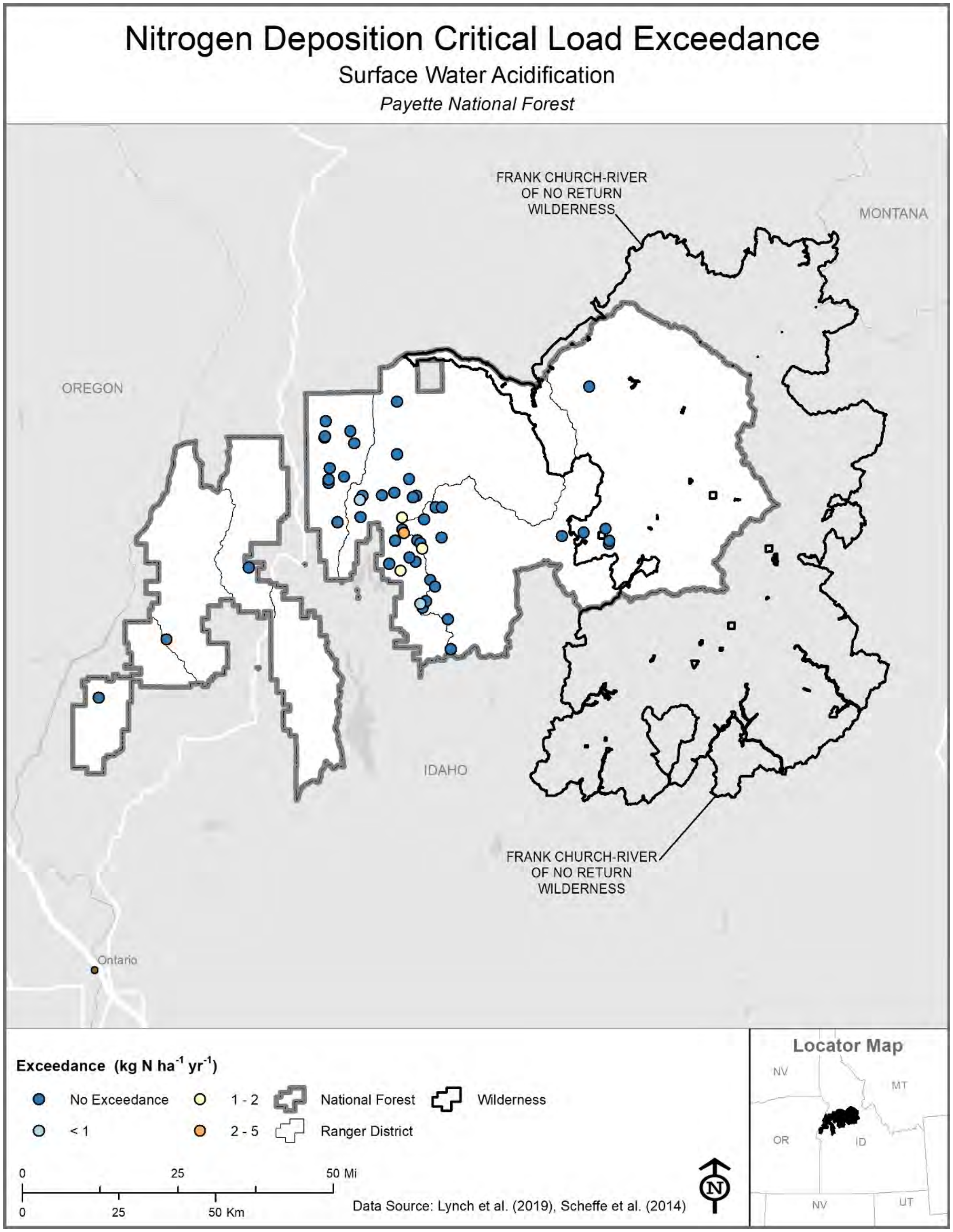

Figure 5-131. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Payette National Forest.

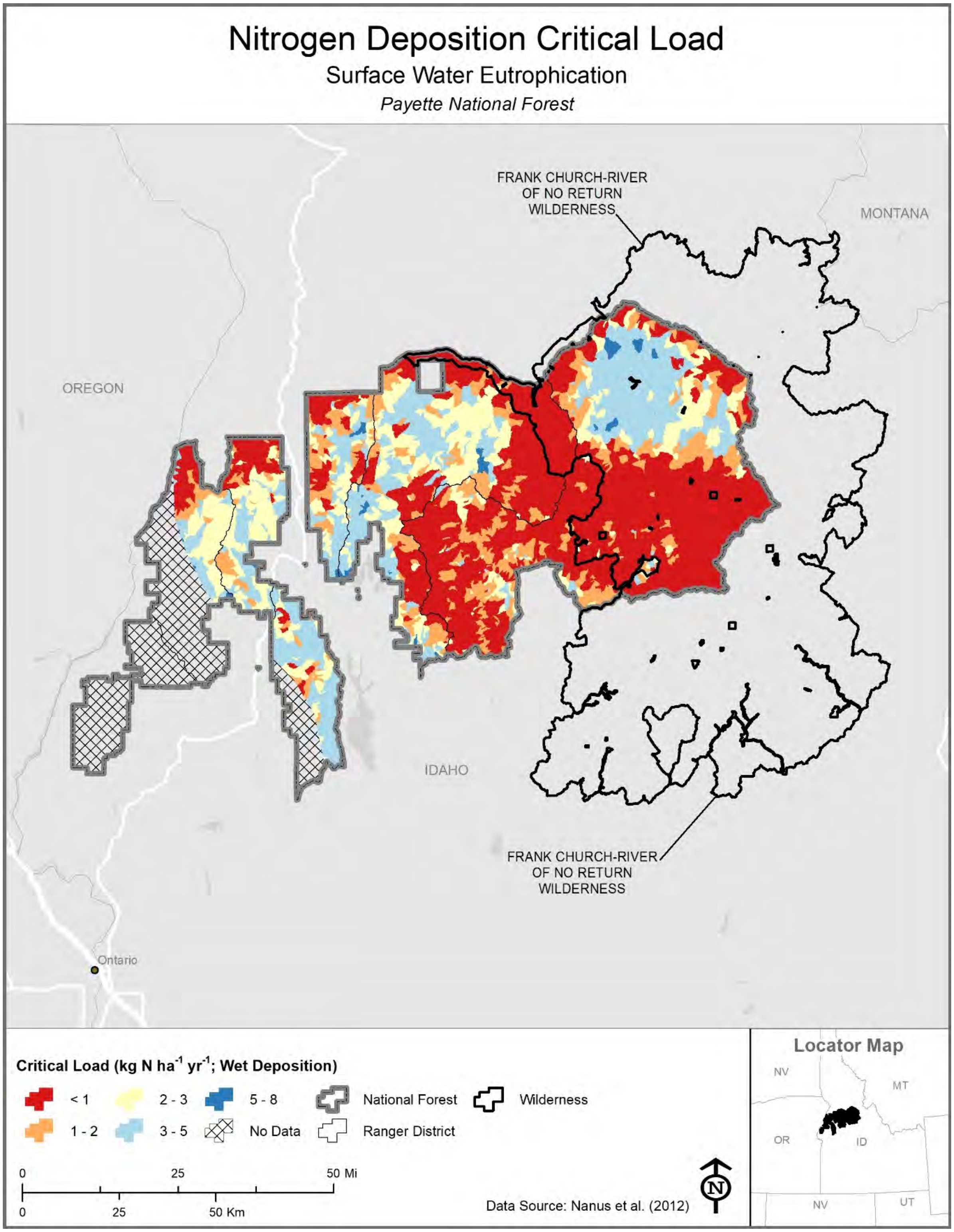

Figure 5-132. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Payette National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

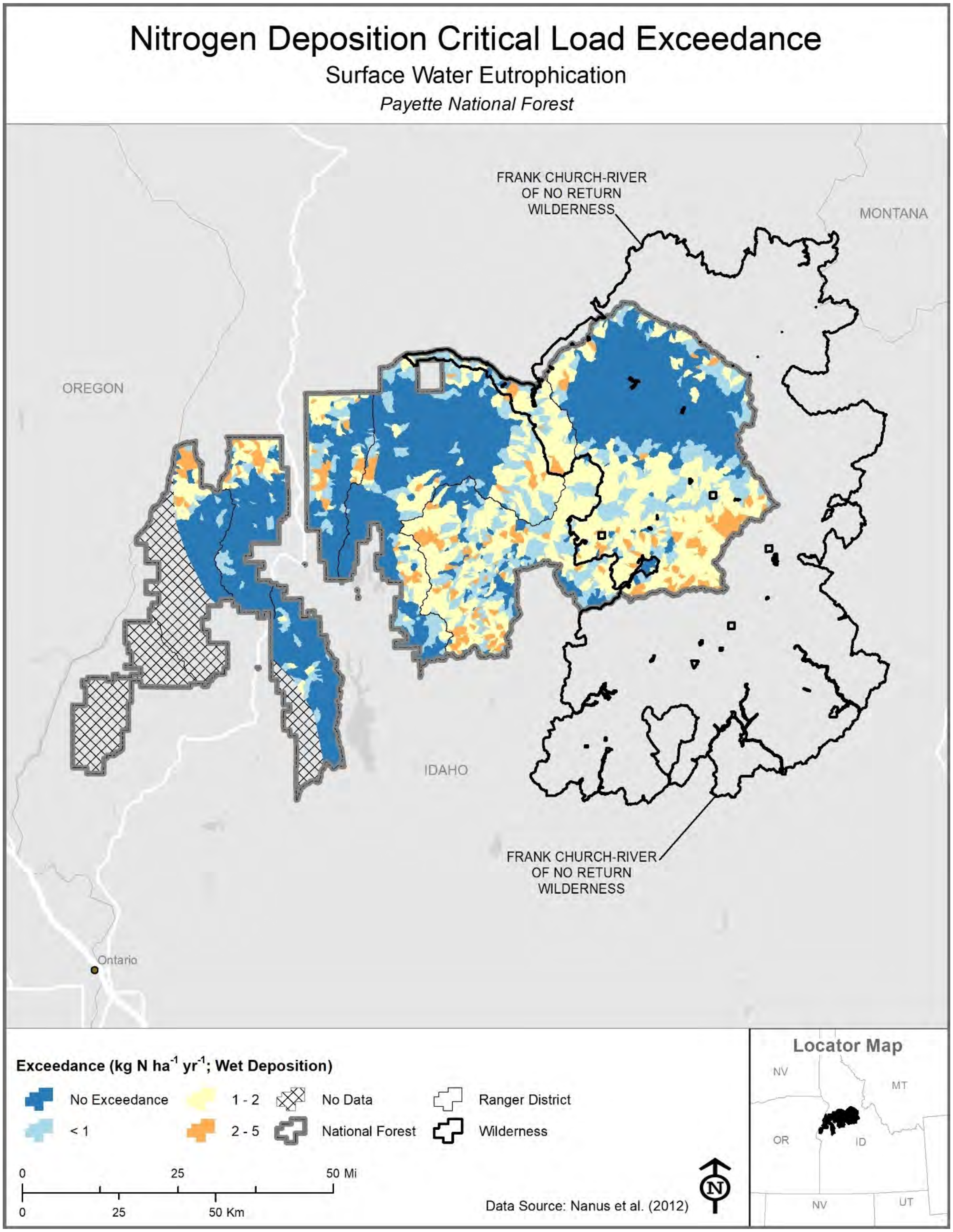

Figure 5-133. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Payette National Forest.

of No Return Wilderness located in the Payette NF, was generally not in exceedance of the CL for lichen species richness (**Figure** 5-134) The highest magnitudes of exceedance (> 2 kg N ha^{-1} yr^{-1}) for both CLs were mostly located in the central portion of the forest (**Figures** 5-134 and 5-135). Critical load exceedance associated with 30 - 40% reductions in forage lichen abundance were common throughout the forest, including within wilderness areas.

5.2.9.4 Tree Growth and Survival

Total N deposition did not exceed CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within any of the areas in which this species is expected to occur within the Payette NF (**Table**s 5-7 and 5-8; **Figures** 5-136 and 5-137).

Total N deposition exceeded CLs protective of *P. balsamifera* growth (1%, 5%, or 10% reductions) within 15% of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Exceedance of CLs for growth mostly occurred in the central and western portions of the forest (**Figure** 5-138). There were no areas in exceedance of CLs for probability of survival (**Figure** 5-139).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 14% of the area in which this species is expected to occur (**Table** 5-11). Exceedance mostly occurred in the central and western portions of the forest (**Figure** 5-140).

Other species of interest that occurred within the Payette NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-22). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

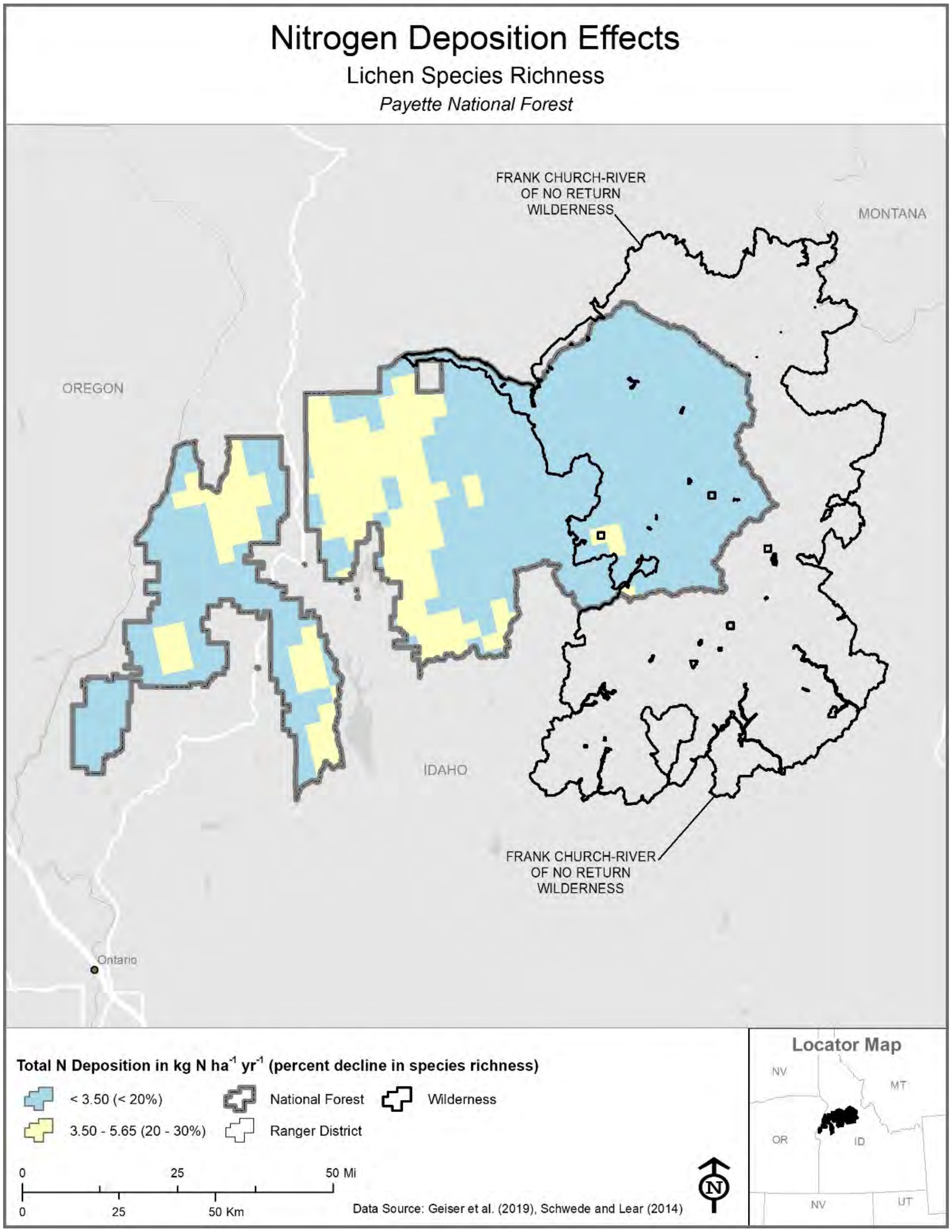

Figure 5-134. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Payette National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% reductions in lichen species richness.

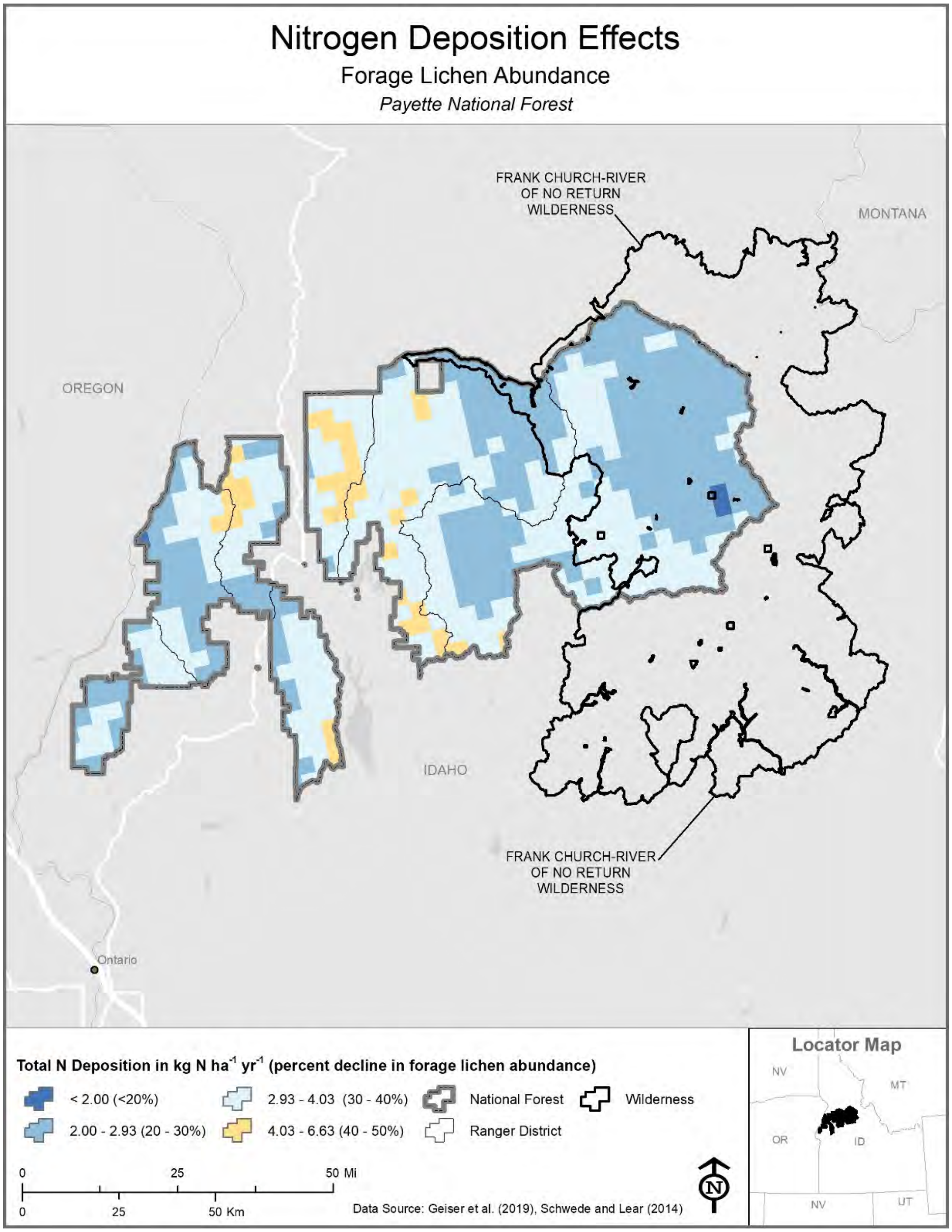

Figure 5-135. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Payette National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance (2.0 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in forage lichen abundance

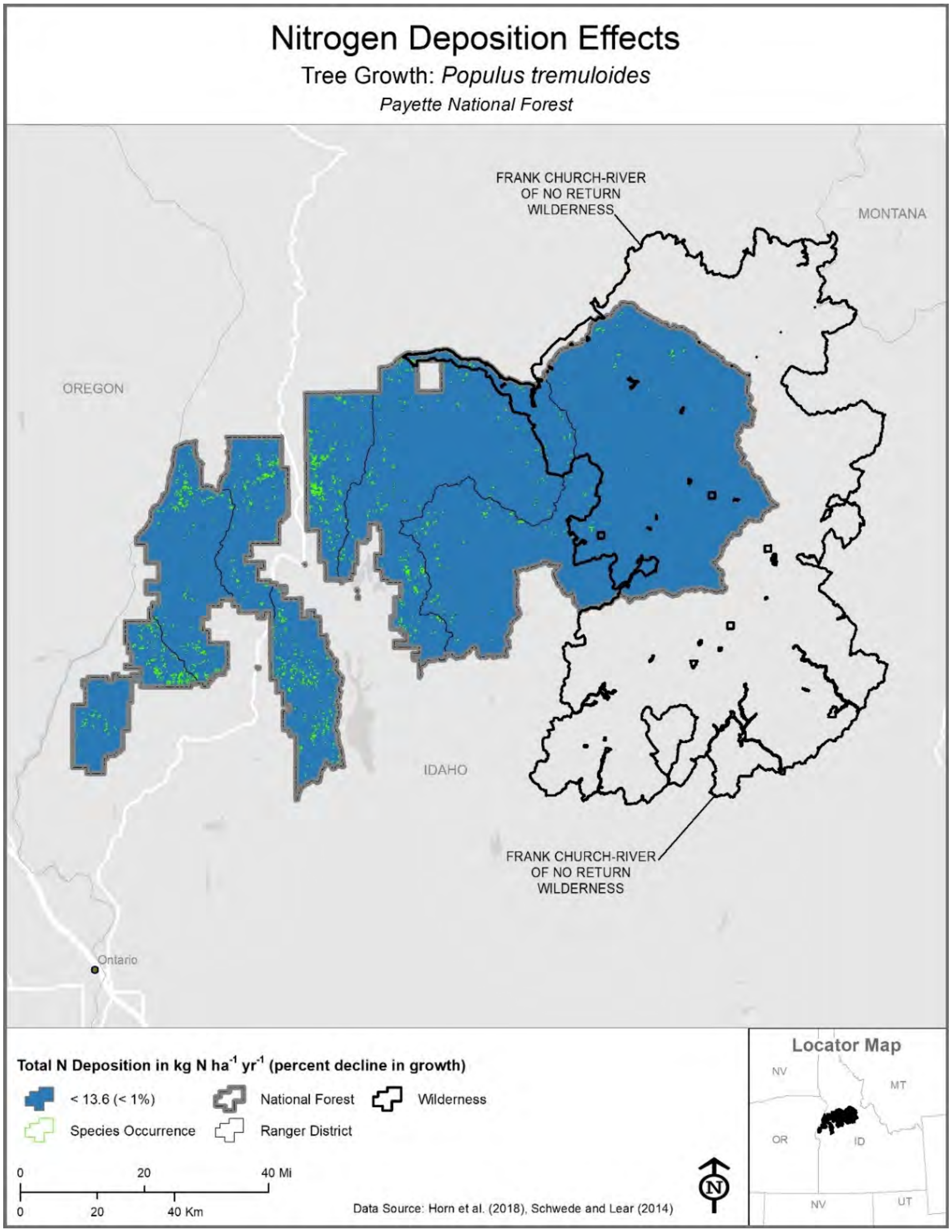

Figure 5-136. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Payette National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance. The entire Payette NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

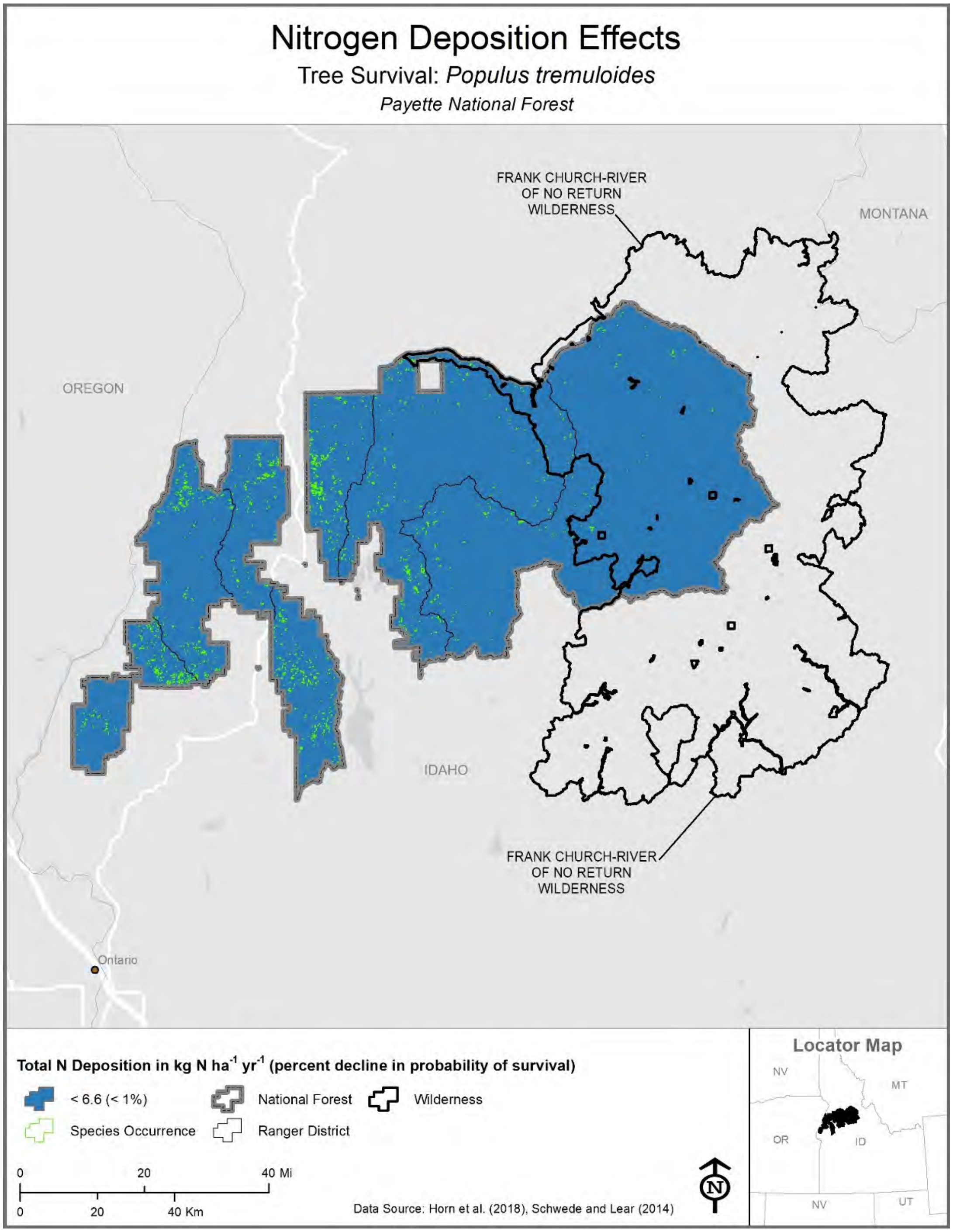

Figure 5-137. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Payette National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Payette NF is below the critical load for a 1% reduction in probability of survival of *Populus tremuloides.*

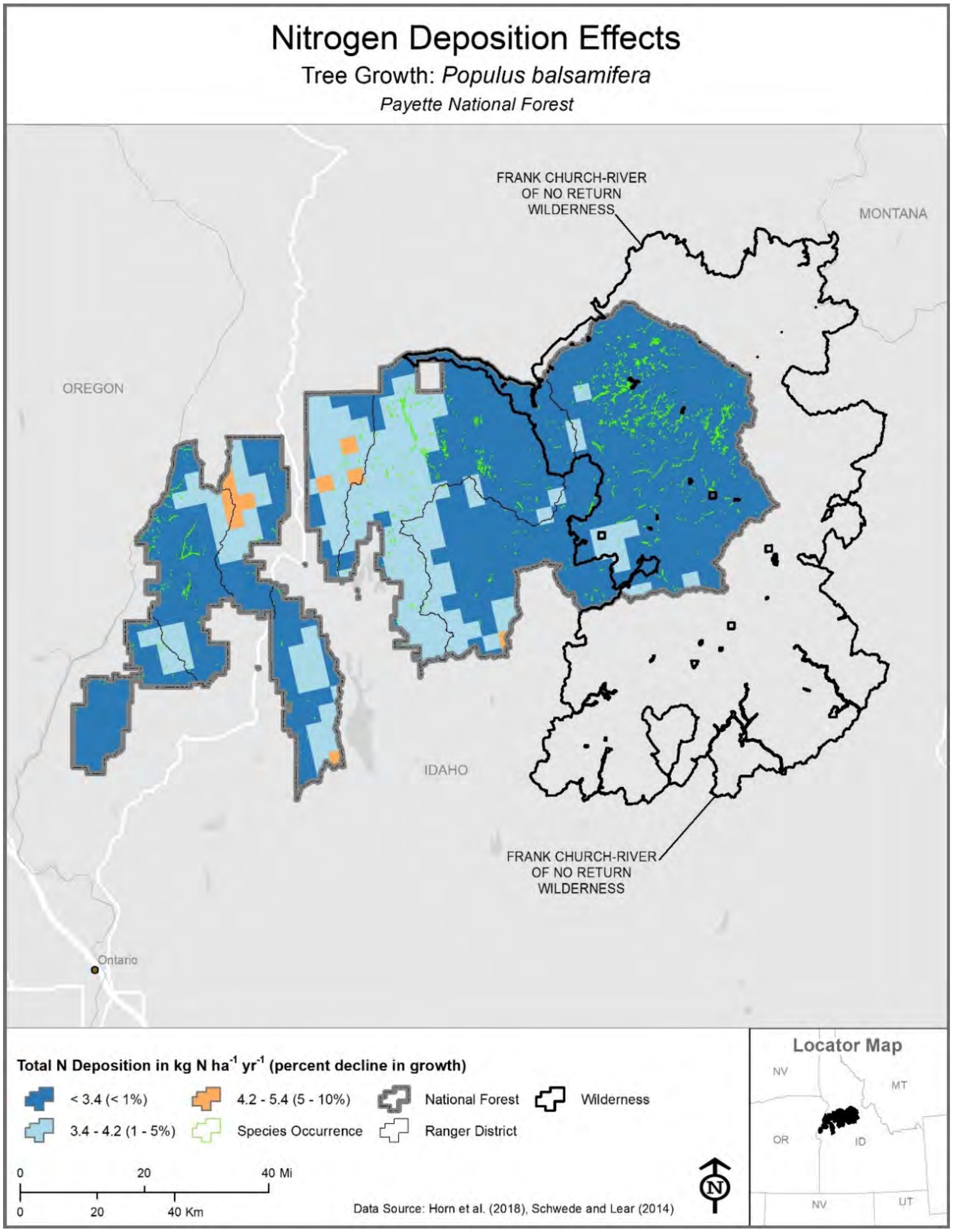

Figure 5-138. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Payette National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

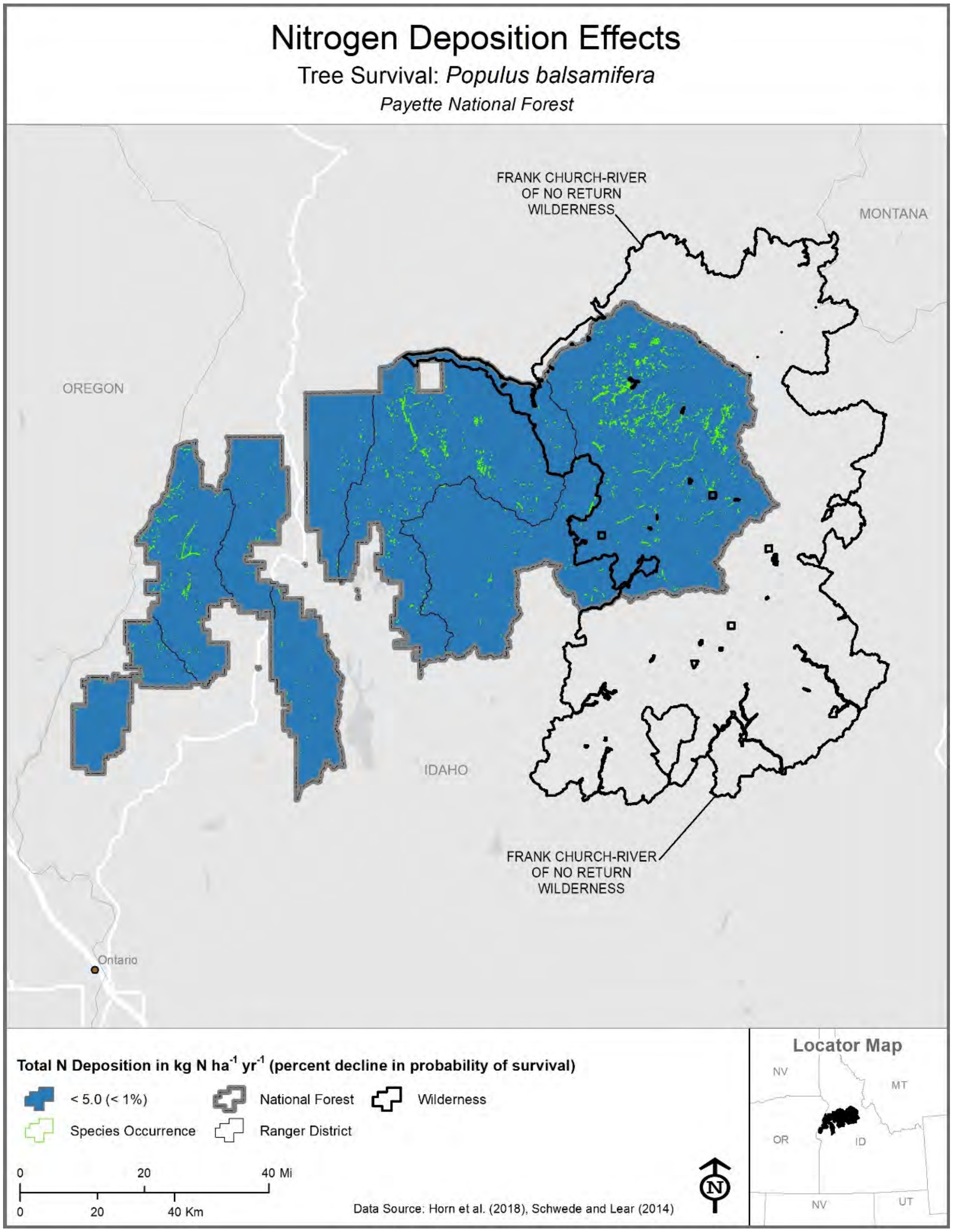

Figure 5-139. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Payette National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Payette NF is below the critical load for a 1% reduction in probability of survival of *Populus balsamifera.*

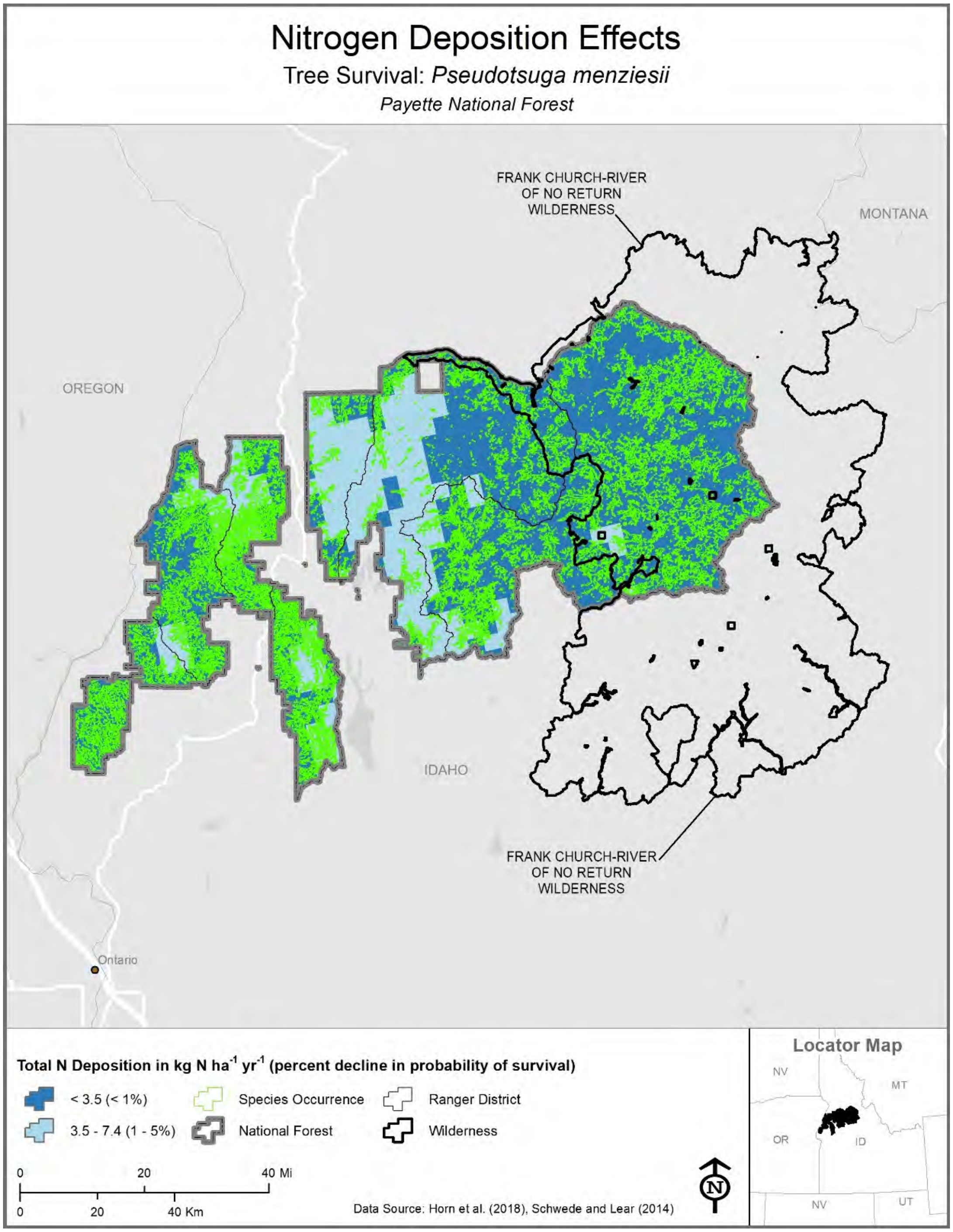

Figure 5-140. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Payette National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-22. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Payette National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival 1%	5%	10%
Abies grandis	grand fir	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Larix occidentalis	western larch	Growth	Increasing[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.10 Salmon-Challis NF

5.2.10.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification within the Salmon-Challis NF illustrated a range of sensitivity to acidification effects (**Figure** 5-141). Surface waters with relatively high risk of acidification effects (i.e., low CLs) were located within the northern and central portions of the forest and less sensitive (i.e., higher CLs) waterbodies occurred throughout the forest. Ambient N deposition was high enough to exceed the CL at 11% (n = 2) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. One of the waterbodies within the portion of the Frank Church-River of No Return Wilderness administered by the Salmon-Challis NF was in exceedance (**Figure** 5-142). The highest magnitudes of exceedance were less than 1 kg N ha^{-1} yr^{-1}. Given the low representation of sites where CLs are calculated in some portions of the Salmon-Challis NF, acid-sensitive waterbodies may occur elsewhere.

5.2.10.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were ubiquitous within the Salmon-Challis NF and represented a total of nearly 14,500 km^2 (81%) of the forest (**Table** 5-3; **Figure** 5-143). The portion of the Frank Church-River of No Return Wilderness located within the Salmon-Challis NF was mostly comprised of low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included nearly 13,000 km^2 (73%) of the forest (**Table** 5-4; **Figure** 5-144). Exceedance within the Frank Church-River of No Return Wilderness was generally by 1 – 2 kg N ha^{-1} yr^{-1}, but some areas were exceeded within the range of 2 – 5 kg N ha^{-1} yr^{-1}. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.10.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 32% and 97%, respectively, of the Salmon-Challis NF (**Table**s 5-5 and 5-6). The northern portion of the forest was generally not in exceedance of the CL for lichen species

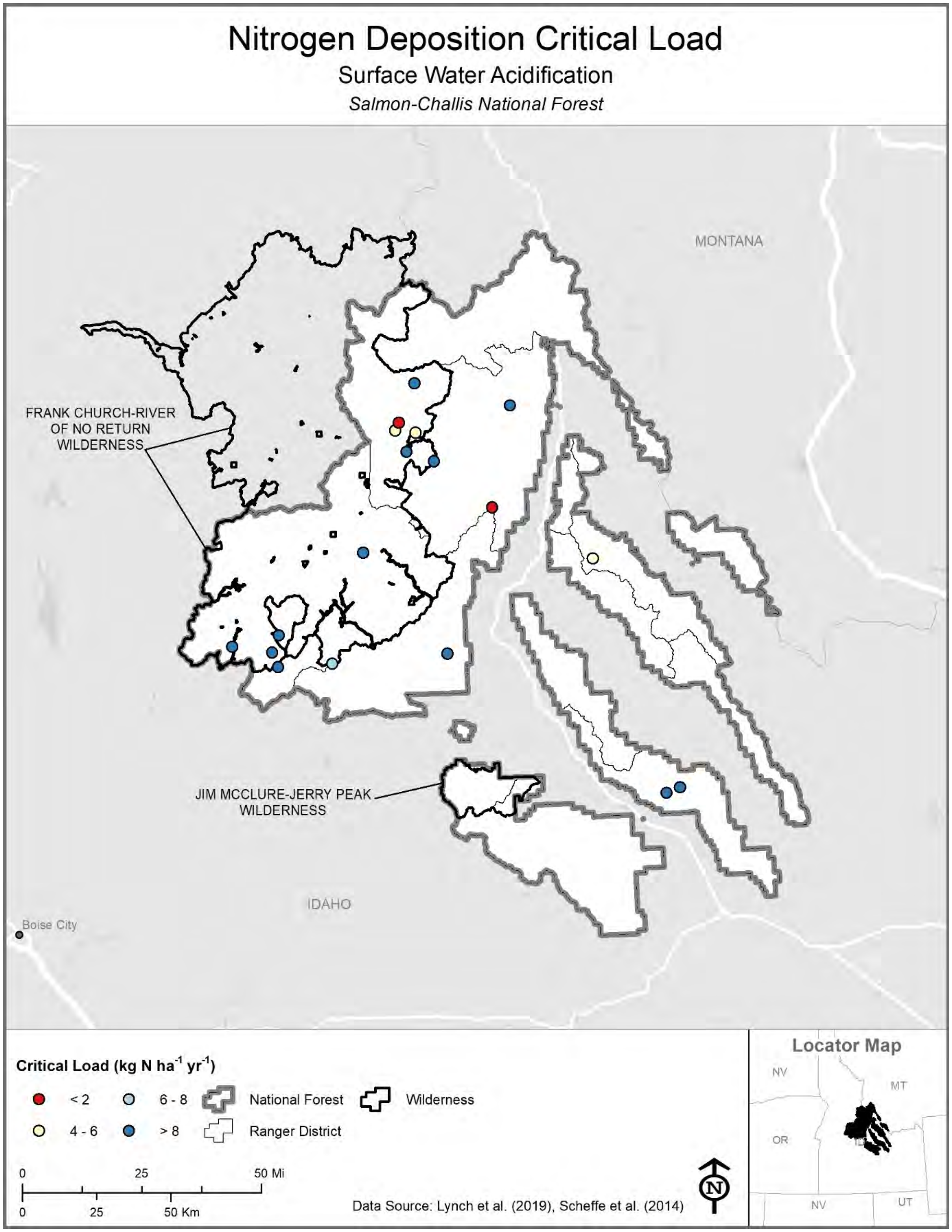

Figure 5-141. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Salmon-Challis National Forest.

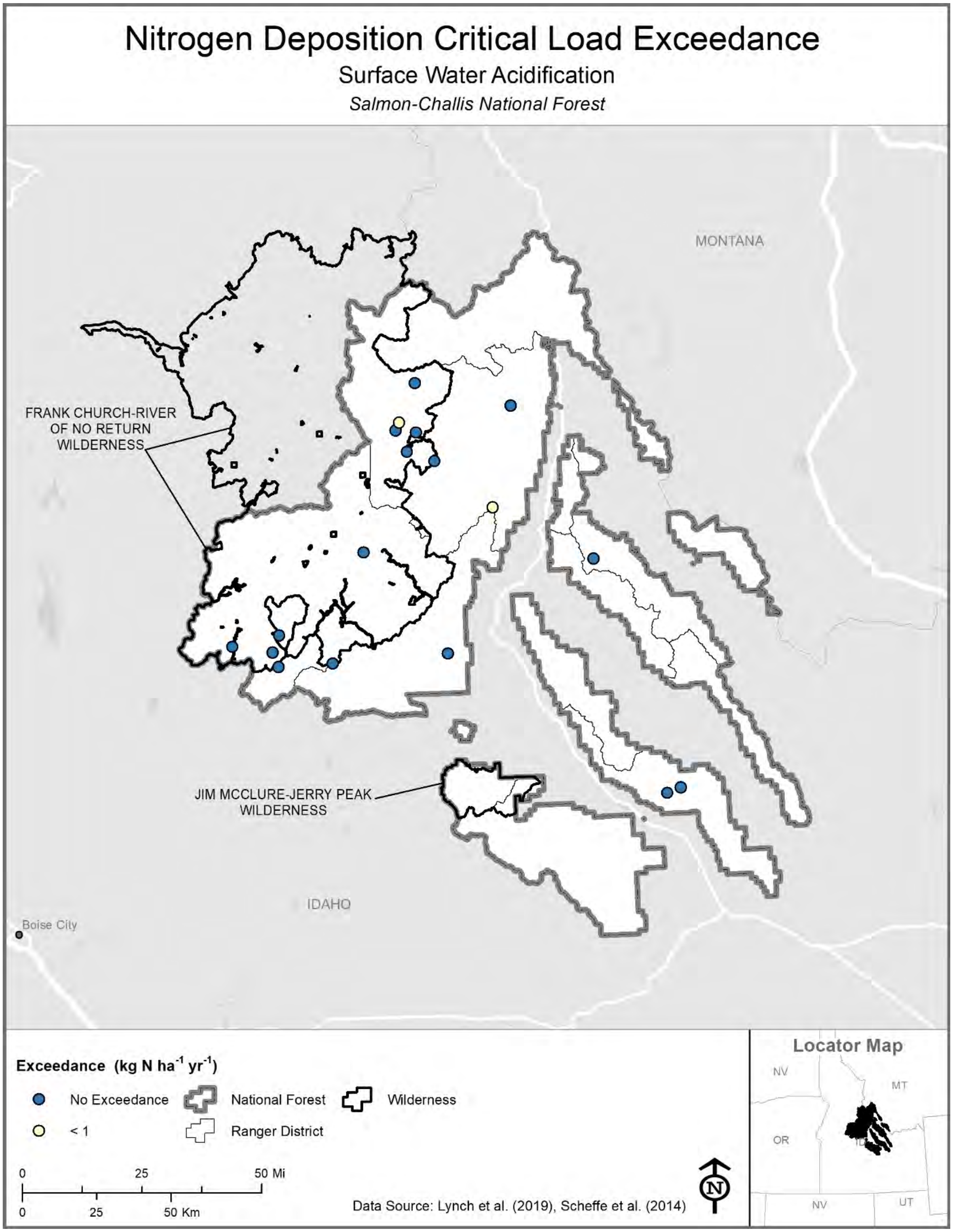

Figure 5-142. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Salmon-Challis National Forest.

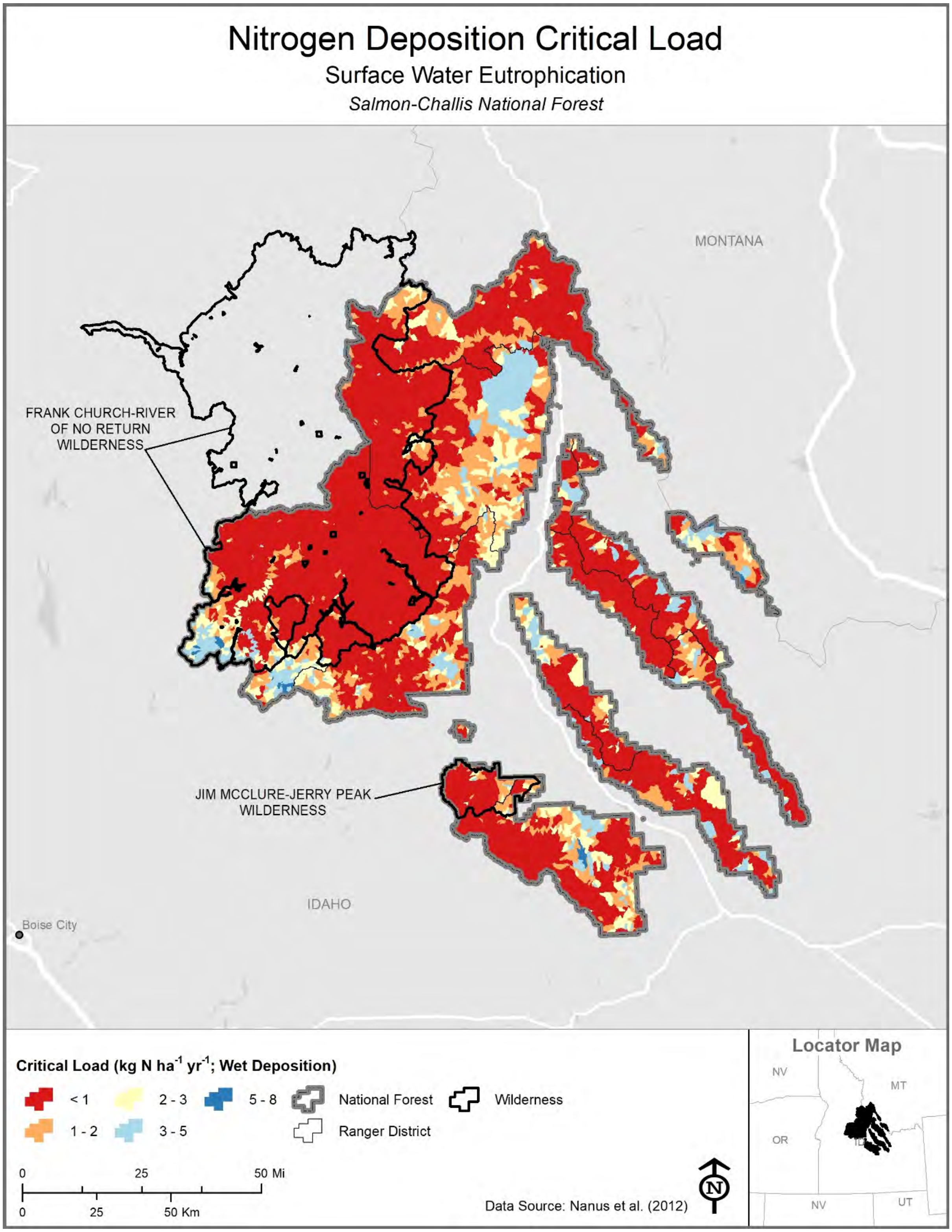

Figure 5-143. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Salmon-Challis National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

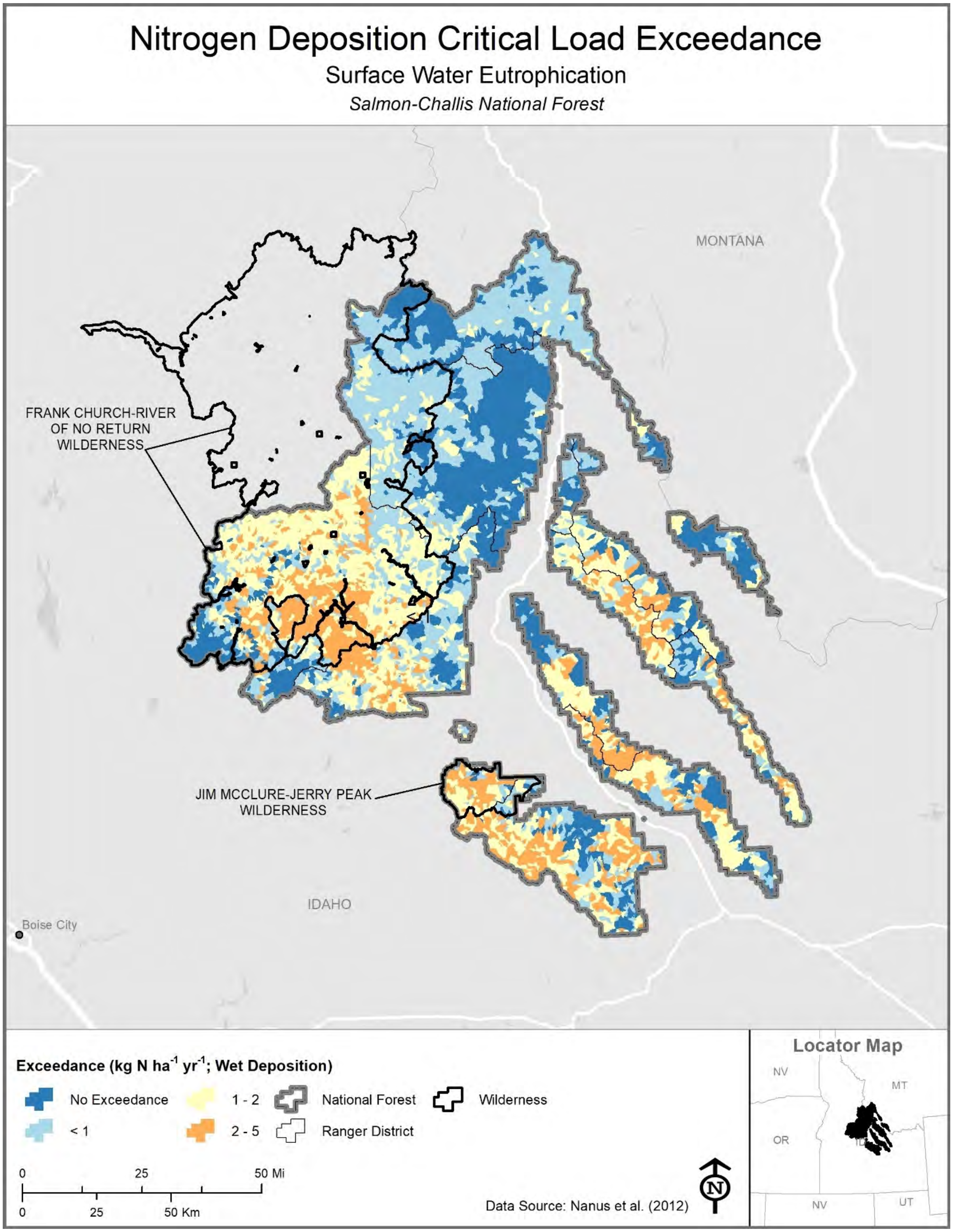

Figure 5-144. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Salmon-Challis National Forest.

richness (**Figure** 5-145). The highest magnitudes (> 2 kg N ha^{-1} yr^{-1}) of exceedance for both lichen CLs were generally located in the southern portion of the forest, including parts of the Frank Church-River of No Return Wilderness and Jim McClure-Jerry Peak Wilderness (**Figures** 5-145 and 5-146). Critical load exceedance associated with at least a 30% reduction in forage lichen abundance were common throughout the forest.

5.2.10.4 Tree Growth and Survival

Total N deposition did not exceed CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within any of the area in which this species is expected to occur within the Salmon-Challis NF (**Table**s 5-7 and 5-8; **Figures** 5-147 and 5-148).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 41% and 1.5%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Exceedance of CLs for growth and probability of survival mostly occurred in the central and southern portions of the forest, including the part of the Frank Church-River of No Return Wilderness that is located in the Salmon-Challis NF (**Figures** 5-149 and 5-150).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 26% of the area in which this species is expected to occur (**Table** 5-11). Exceedance mostly occurred in the central and southern portions of the forest, including the portion of the Frank Church-River of No Return Wilderness located in the Salmon-Challis NF (**Figure** 5-151).

Other species of interest that occurred within the Salmon-Challis NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-23). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

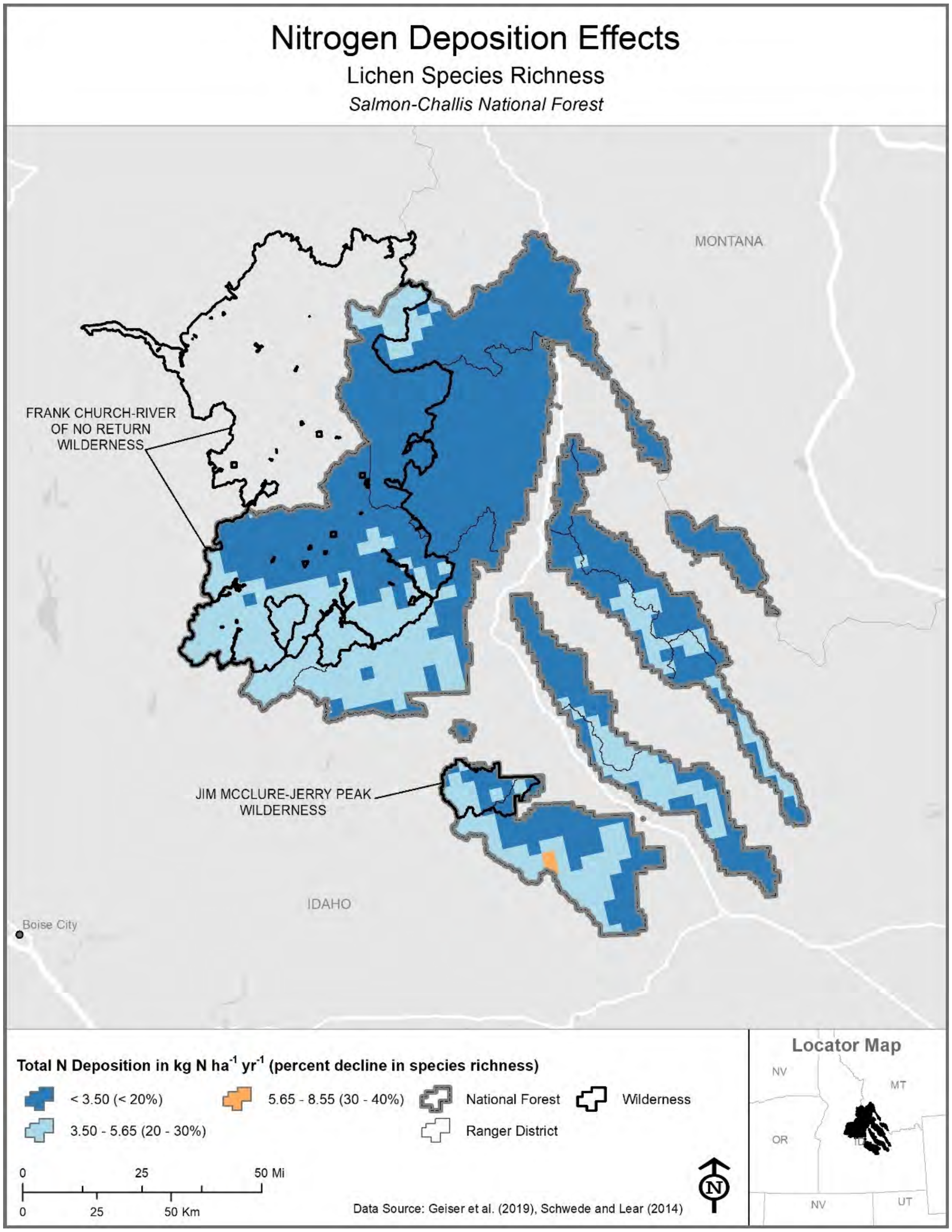

Figure 5-145. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Salmon-Challis National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30% and 40% reductions in lichen species richness.

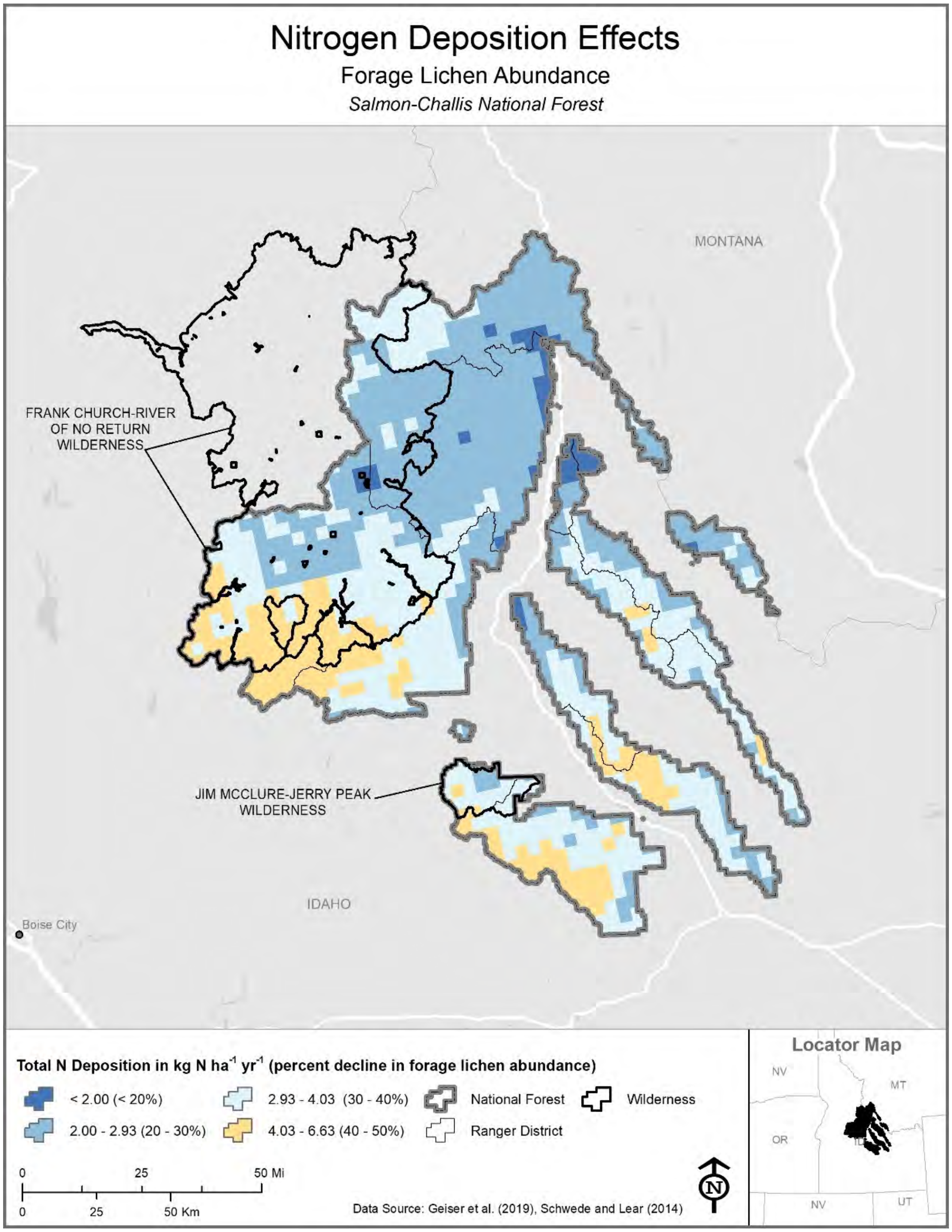

Figure 5-146. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Salmon-Challis National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance (2.0 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in forage lichen abundance.

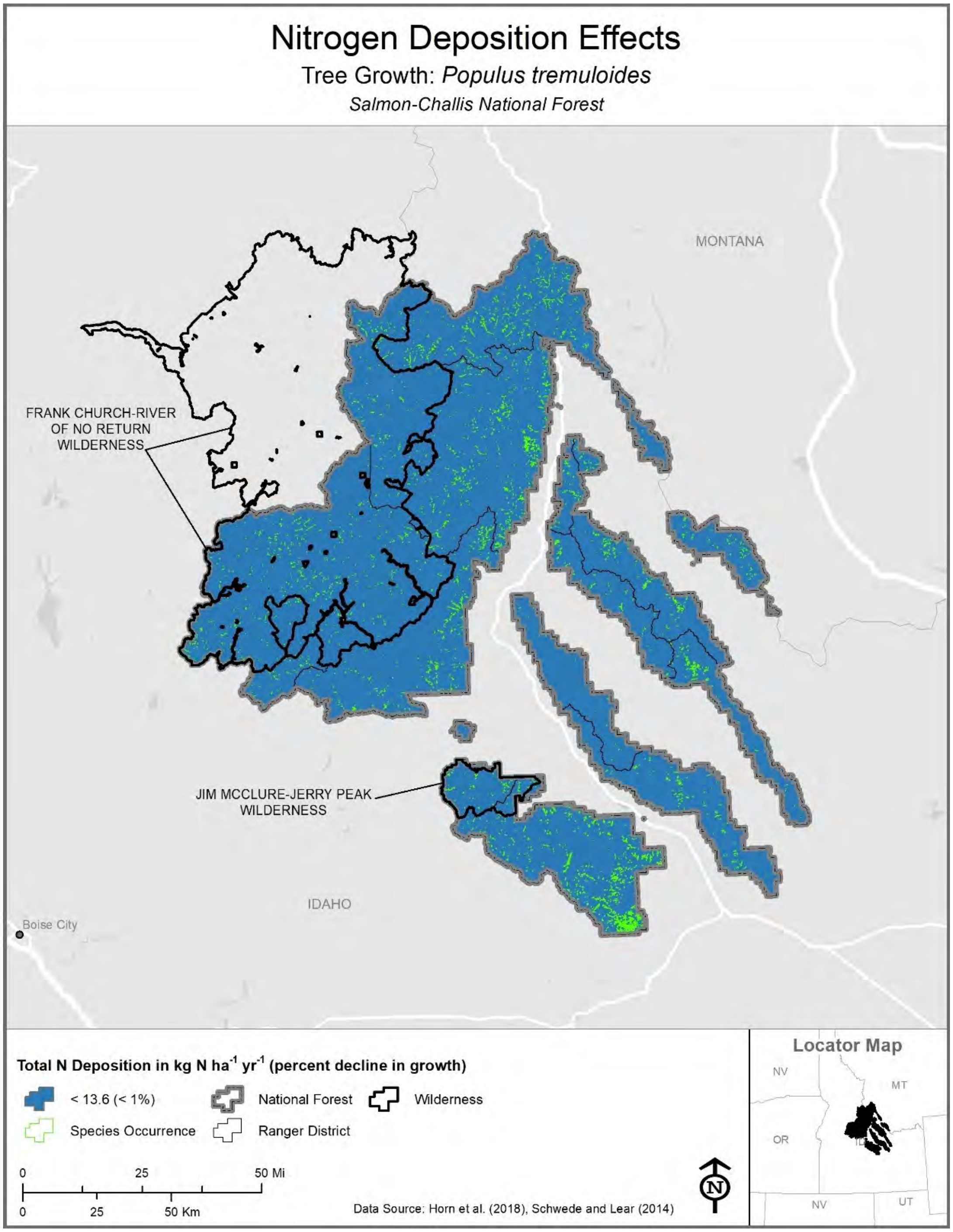

Figure 5-147. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Salmon-Challis National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Salmon-Challis NF is below the critical load for 1% growth reduction of *Populus tremuloides*.

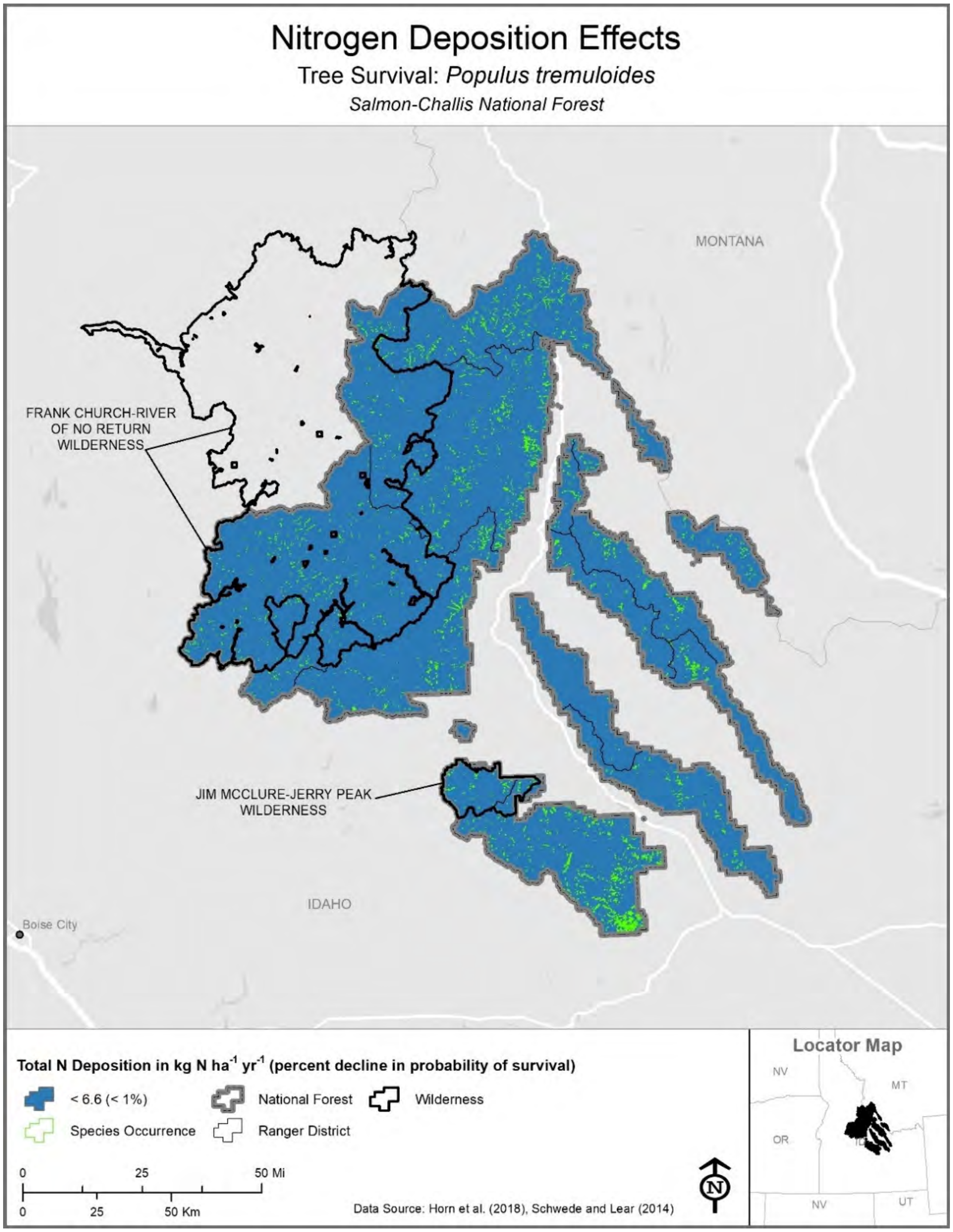

Figure 5-148. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Salmon-Challis National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. The entire Salmon-Challis NF is below the critical load for a 1% reduction in probability of survival of *Populus tremuloides*.

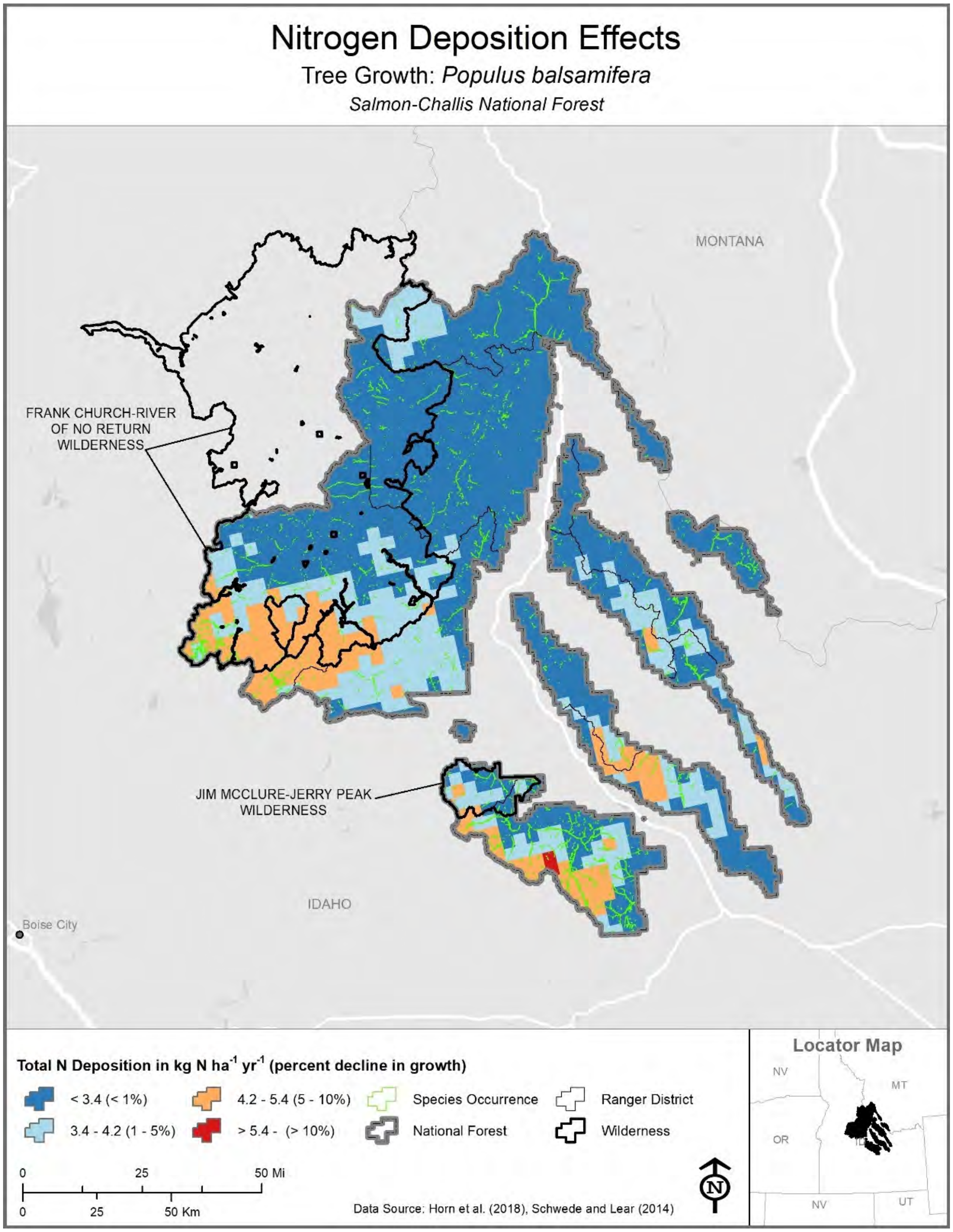

Figure 5-149. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Salmon-Challis National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

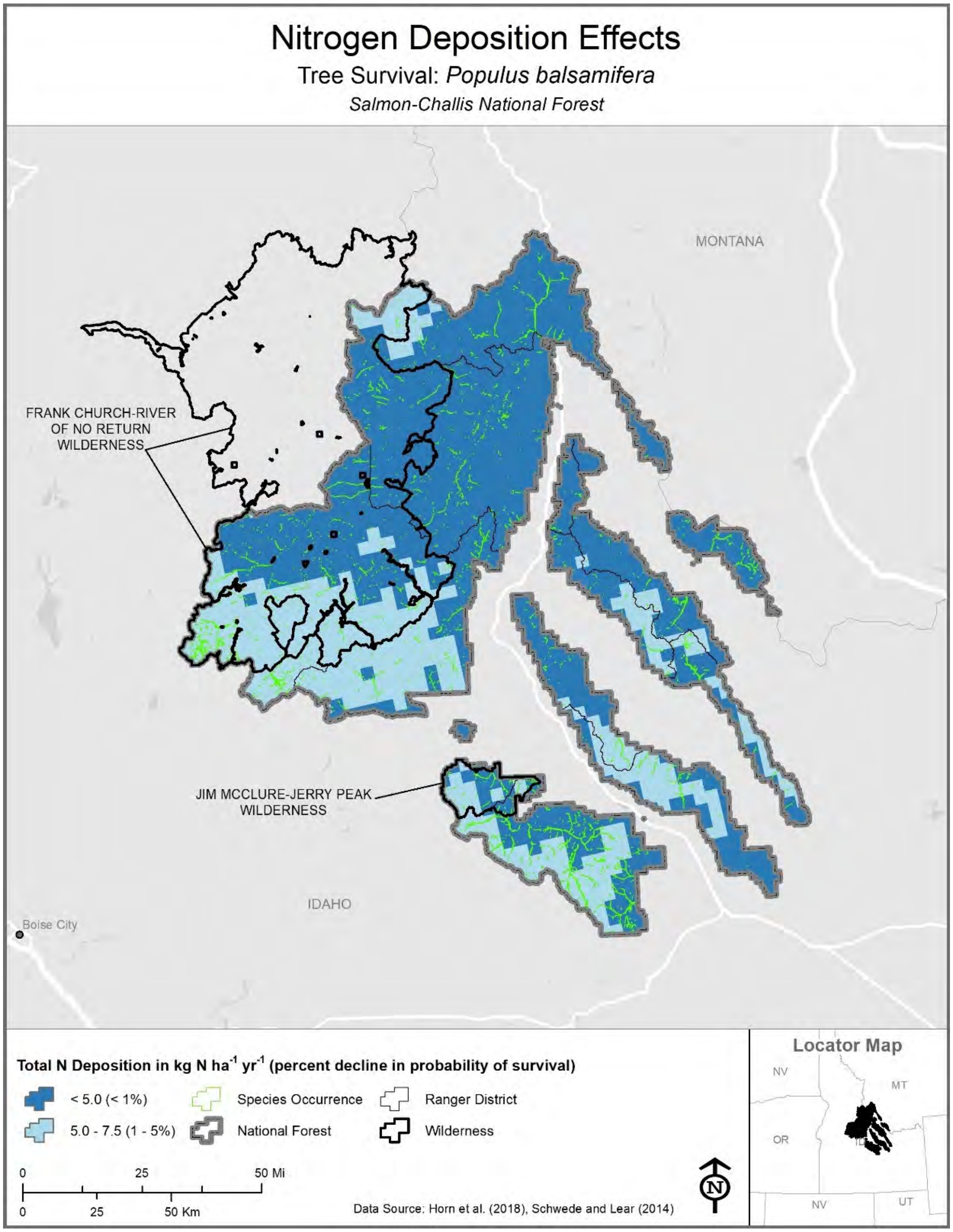

Figure 5-150. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Salmon-Challis National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

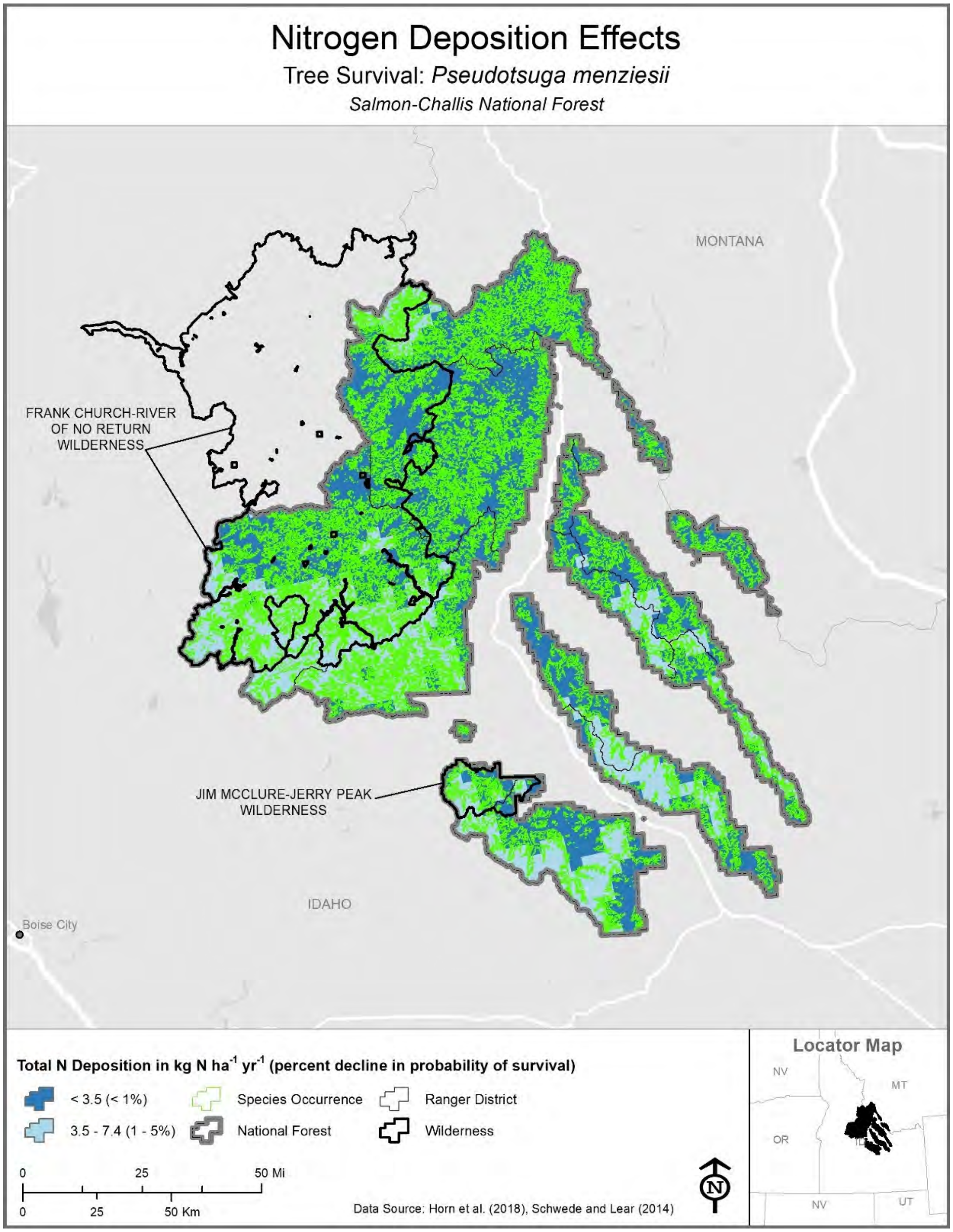

Figure 5-151. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Salmon-Challis National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Table 5-23. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Salmon-Challis National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	Douglas fir	Growth	Increasing	N/A	N/A	N/A
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.11 Sawtooth NF

5.2.11.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification within the Sawtooth NF illustrated a range of sensitivity to acidification effects (**Figure** 5-152). Surface waters with relatively high risk of acidification effects (i.e., low CLs) were located within and in the vicinity of the Sawtooth Wilderness and less sensitive (i.e., higher CLs) waterbodies occurred throughout the forest. Ambient N deposition was high enough to exceed the CL at 48% (n = 27) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. The highest magnitudes of exceedance were between 2 and 5 kg N ha^{-1} yr^{-1}. All of the waterbodies in exceedance were located within the Sawtooth Wilderness (**Figure** 5-153). Due to the density of sites in the Sawtooth Wilderness, an expanded view of these CLs and CL exceedances are shown in **Figures** 5-154 and 5-155, respectively. Given the low representation of sites where CLs are calculated in some portions of the Sawtooth NF, acid-sensitive waterbodies may occur elsewhere.

5.2.11.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were ubiquitous within the Sawtooth NF and represented a total of nearly 5,400 km^2 (86%) of the forest (**Table** 5-3; **Figure** 5-156). The Sawtooth Wilderness, Cecil D. Andrus-White Clouds Wilderness, and the Hemingway-Boulders Wilderness located within the Sawtooth NF were dominated by low CLs. Areas of exceedance followed a generally similar pattern as the CLs and included nearly 5,640 km^2 (90%) of the forest (**Table** 5-4; **Figure** 5-157). The highest magnitudes of exceedance (2 – 5 kg N ha^{-1} yr^{-1}) occurred throughout much of the three wilderness areas. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.11.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 87% and 100%, respectively, of the Sawtooth NF (**Table**s 5-5 and 5-6). Nearly

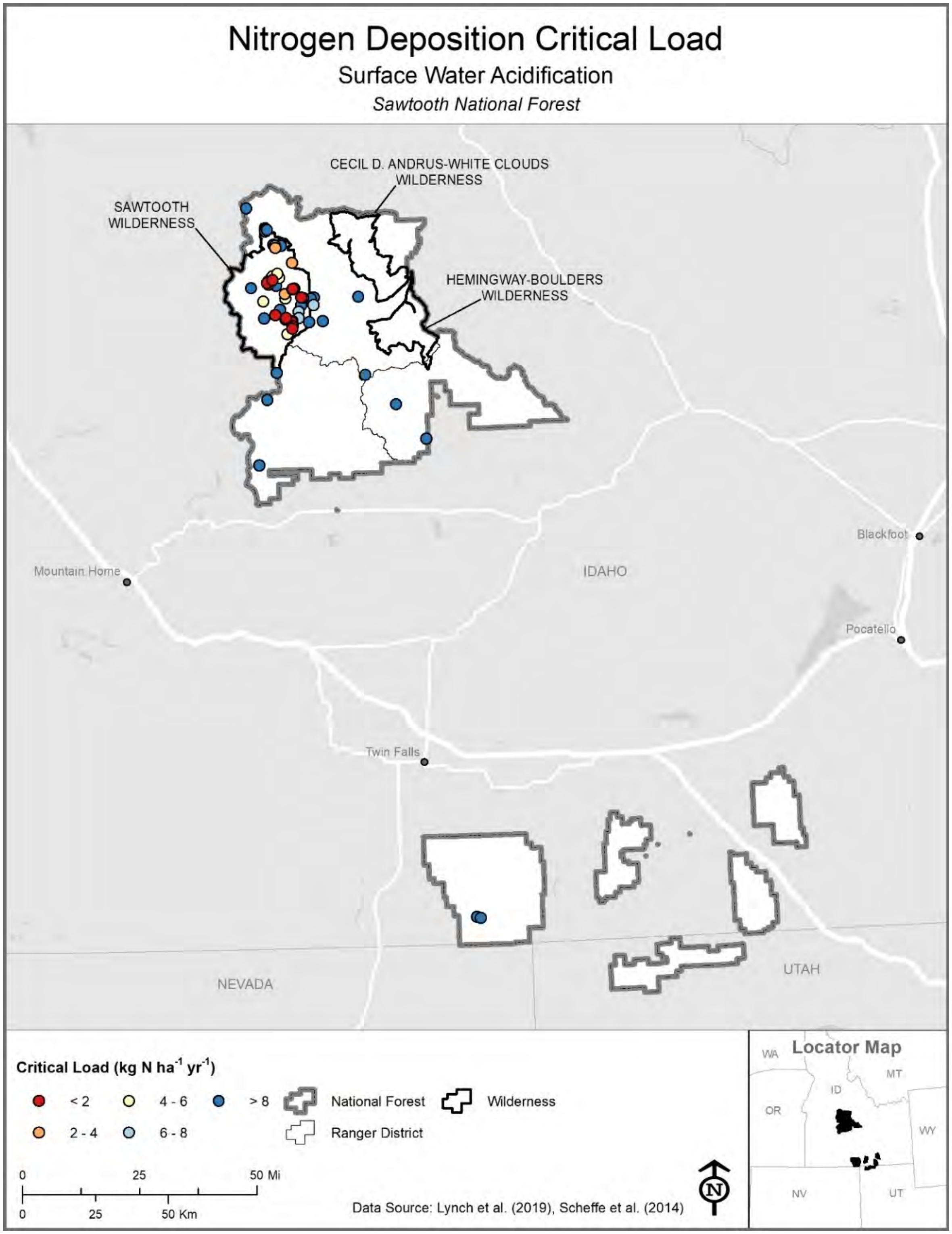

Figure 5-152. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Sawtooth National Forest.

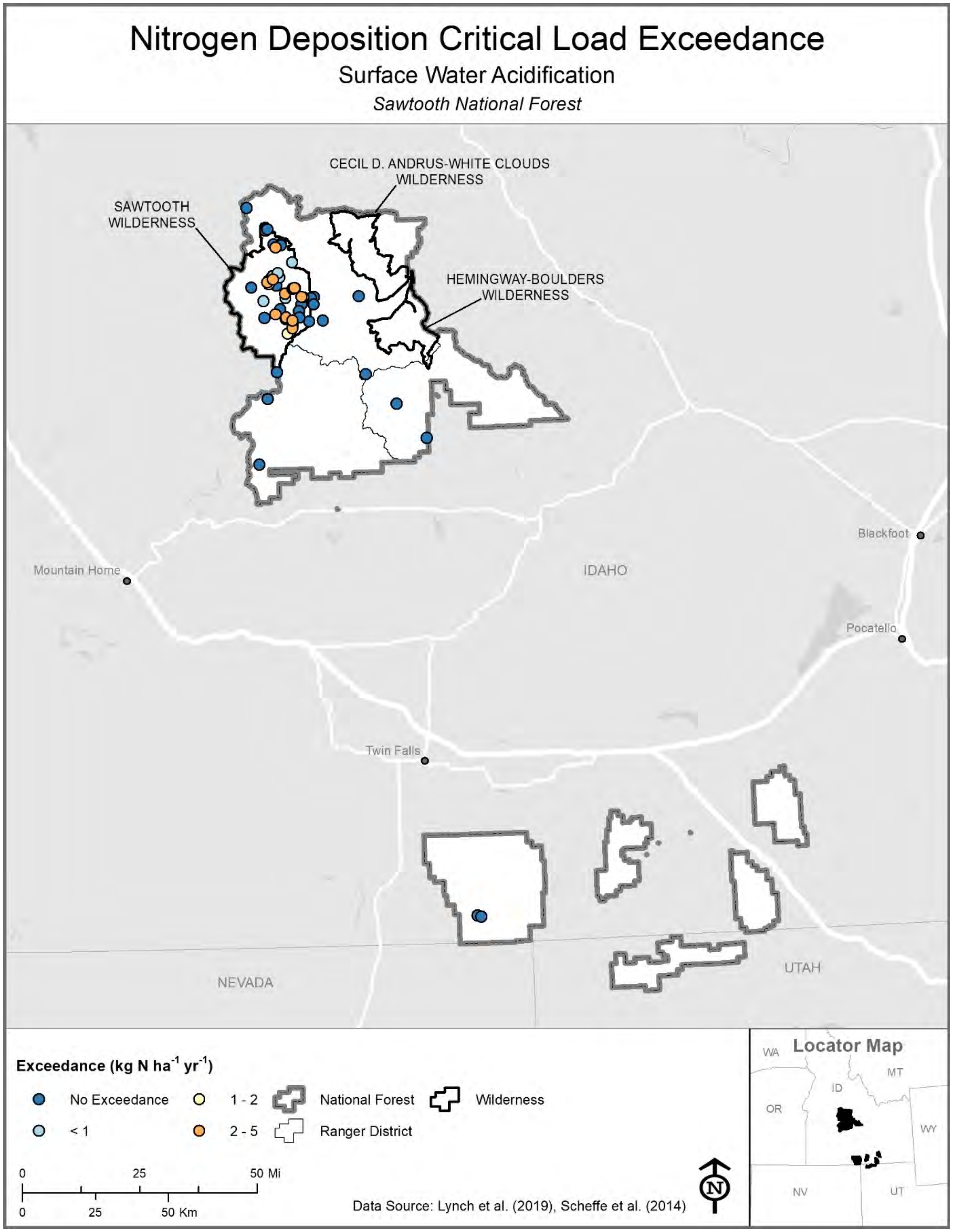

Figure 5-153. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Sawtooth National Forest.

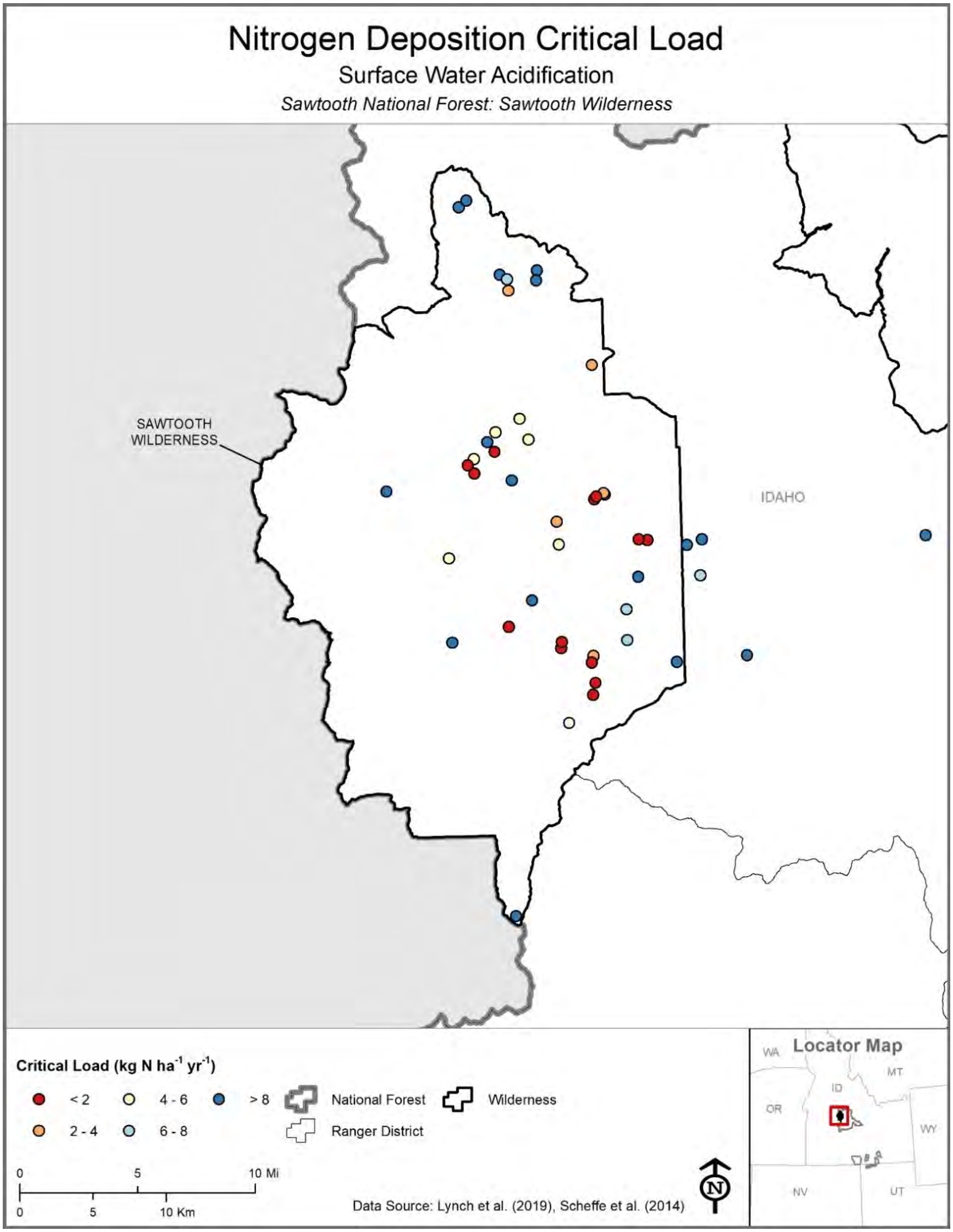

Figure 5-154. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 µeq L^{-1} at lake or stream sample sites located within the Sawtooth Wilderness of the Sawtooth National Forest.

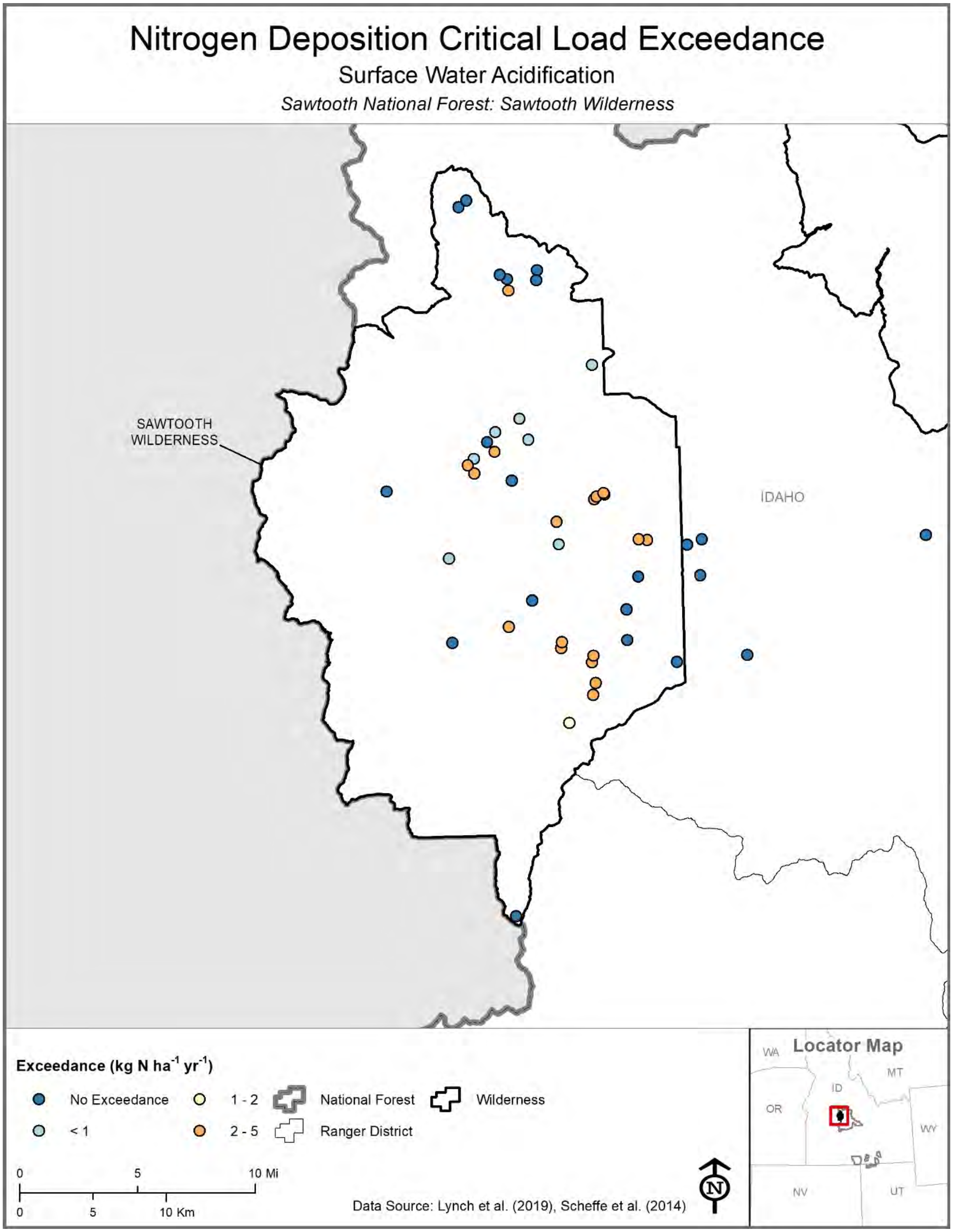

Figure 5-155. Exceedance of critical loads of nitrogen (N) for surface water acidification loads within the Sawtooth Wilderness of the Sawtooth National Forest.

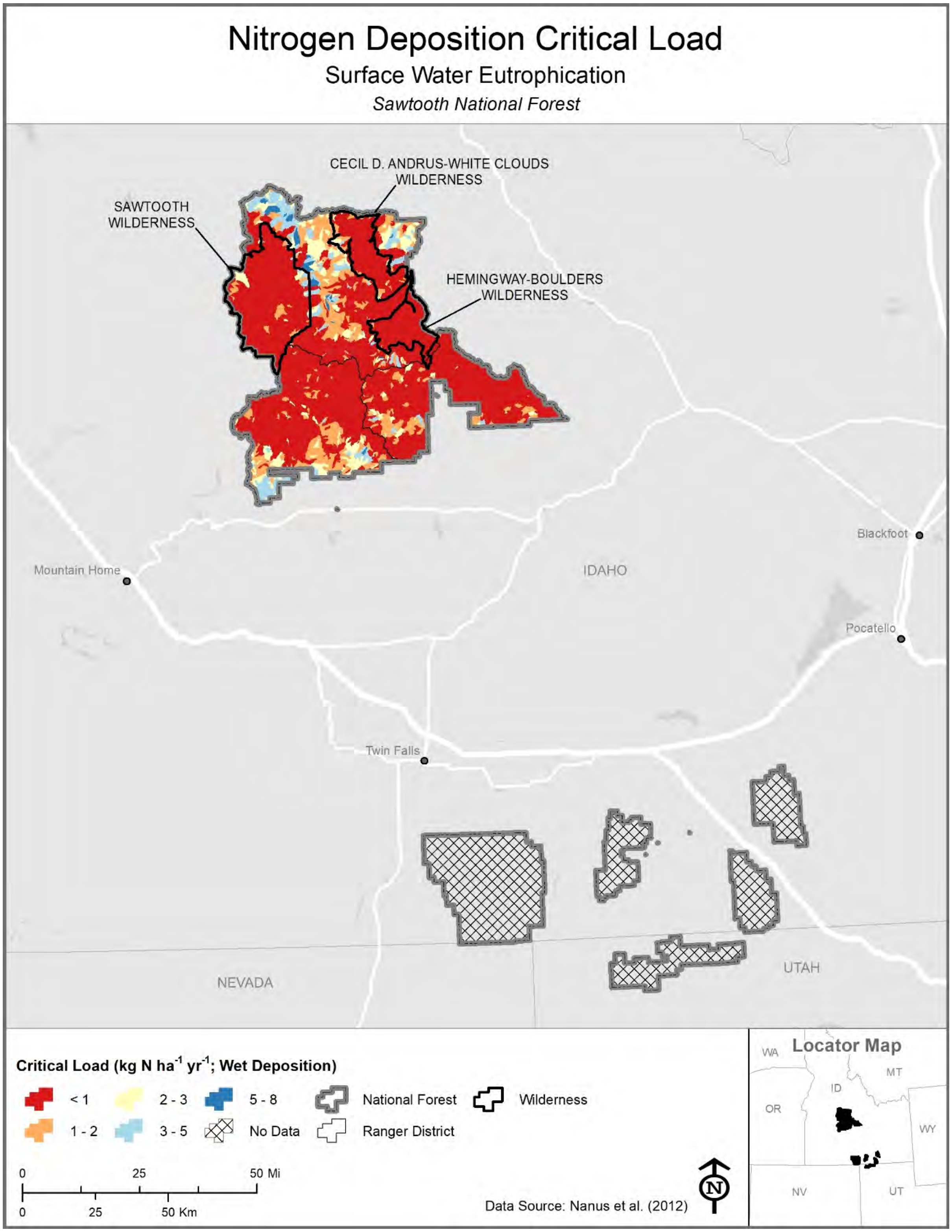

Figure 5-156. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Sawtooth National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

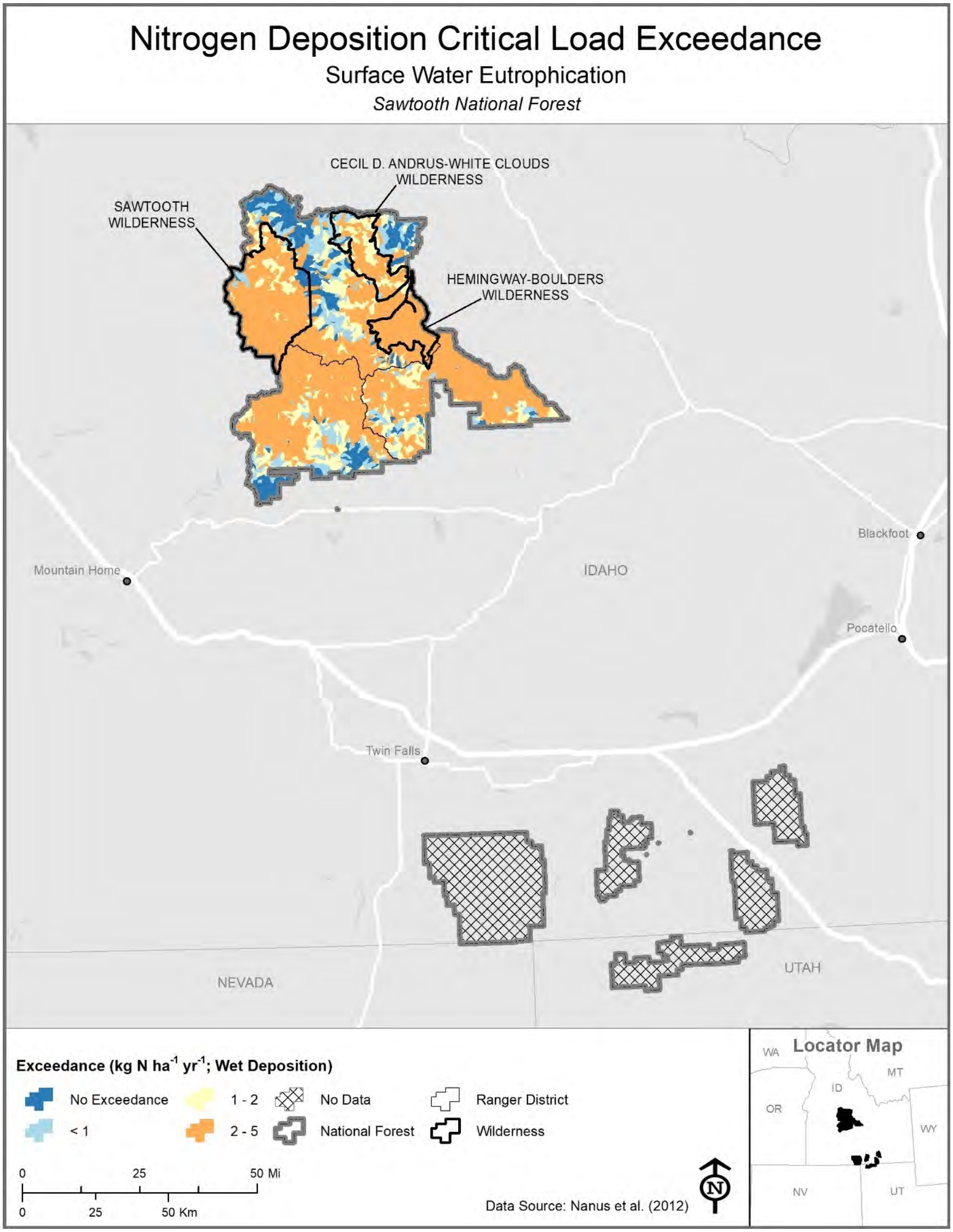

Figure 5-157. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Sawtooth National Forest.

all of the three wilderness areas were in exceedance of both lichen CLs and highest magnitudes (> 5 kg N ha^{-1} yr^{-1}) of exceedance were generally located in the southern portion of the forest (**Figures** 5-158 and 5-159). Critical load exceedance associated with 40 – 50% reductions in forage lichen abundance were common throughout the forest, including within all three wilderness areas.

5.2.11.4 Tree Growth and Survival

Although there was no exceedance of CLs to protect growth of *P. tremuloides,* total N deposition exceeded CLs protective of *P. tremuloides* probability of survival (1%, 5%, or 10% reductions) within 1.4% of the area in which this species is expected to occur within the Sawtooth NF (**Table**s 5-7 and 5-8; **Figure** 5-160). Areas in exceedance for probability of survival occurred in the southern portion of the forest (**Figure** 5-161).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within 75% and 5%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Decreases in growth of >10% were common throughout the forest, including within all three wilderness areas (**Figure** 5-162). Areas of reductions in probability of survival of 1 – 5% were mostly limited to relatively small areas in the southern portion of the forest (**Figure** 5-163).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 88% of the area in which this species is expected to occur (**Table** 5-11). Areas of exceedance were common throughout the forest, including all three wilderness areas (**Figure** 5-164).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 50% of the area in which this species is expected to occur (**Table** 5-12). These areas of exceedance occurred within the southern portion of the forest (**Figure** 5-165).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 17% of the area in which this species is expected to occur (**Table** 5-13). These areas of exceedance occurred within the southern portion of the forest (**Figure** 5-166).

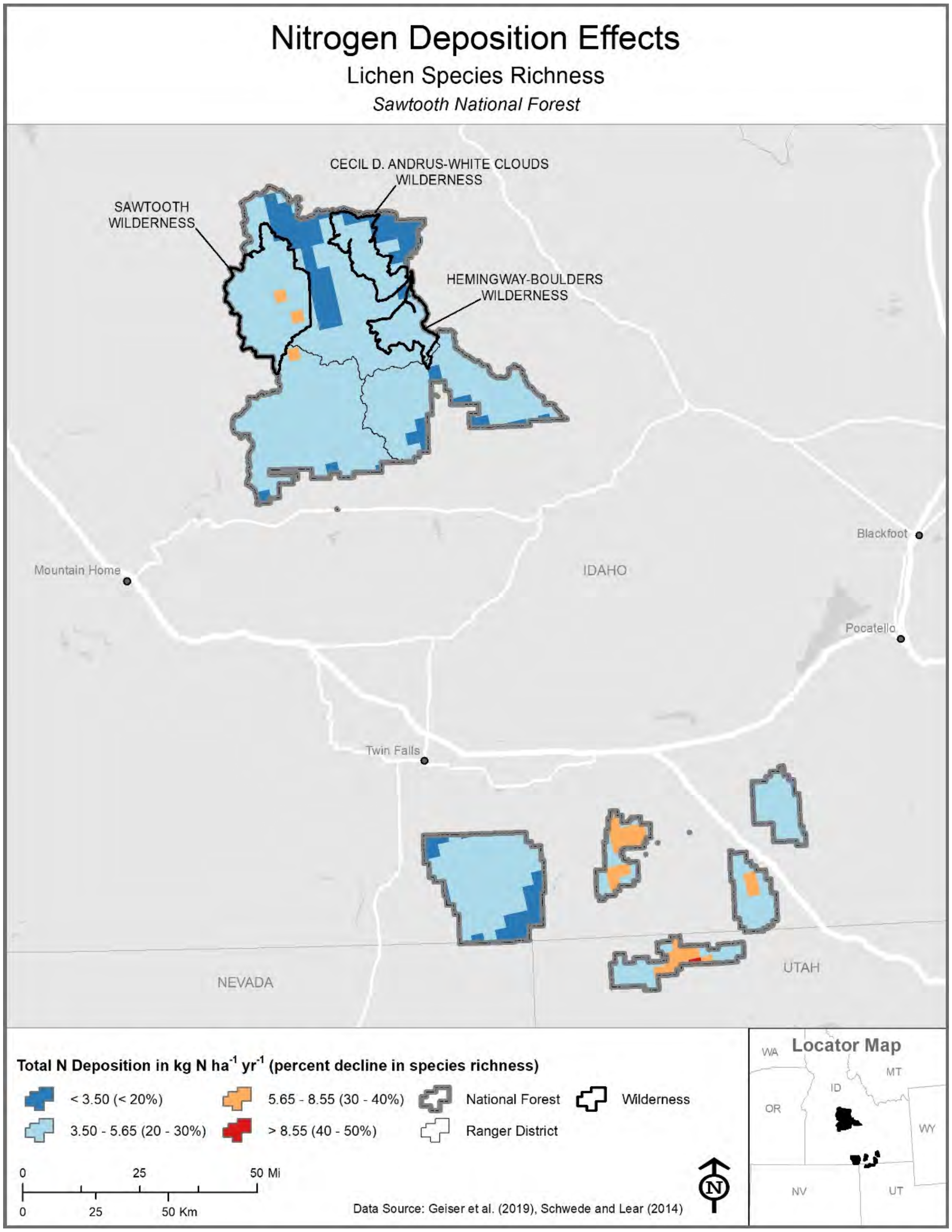

Figure 5-158. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Sawtooth National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.

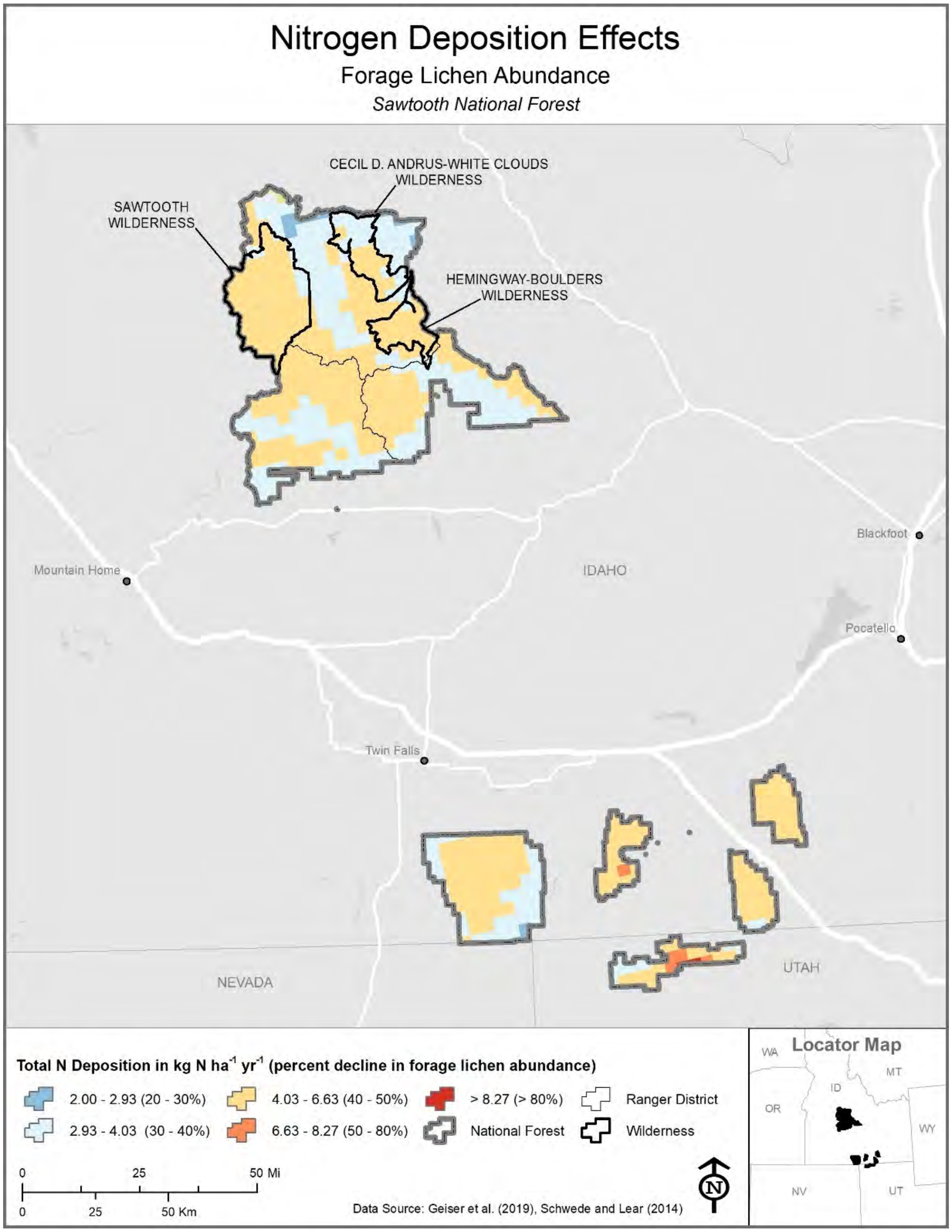

Figure 5-159. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Sawtooth National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

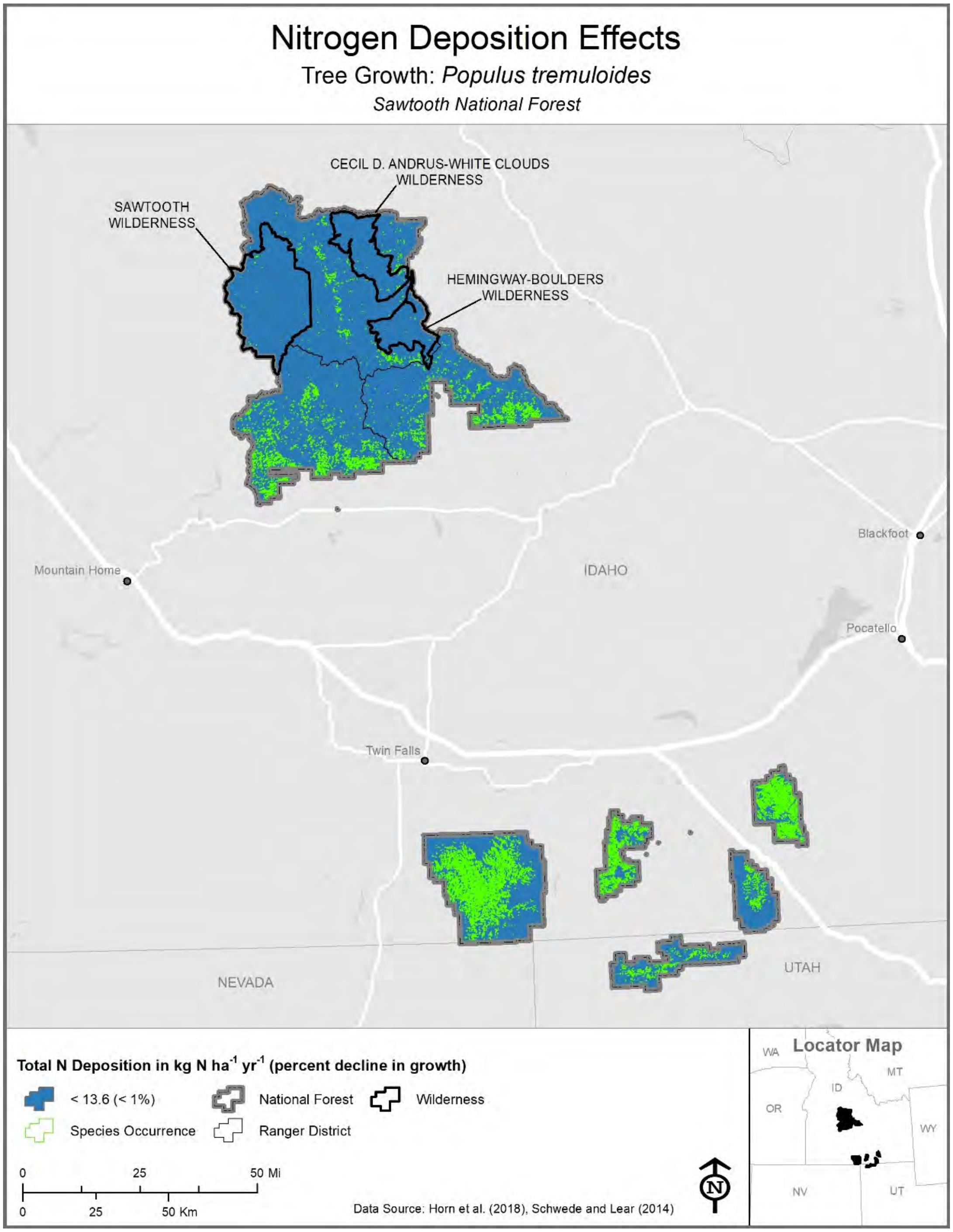

Figure 5-160. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. The entire Sawtooth NF is below the critical load for 1% growth reduction of *Populus tremuloides.*

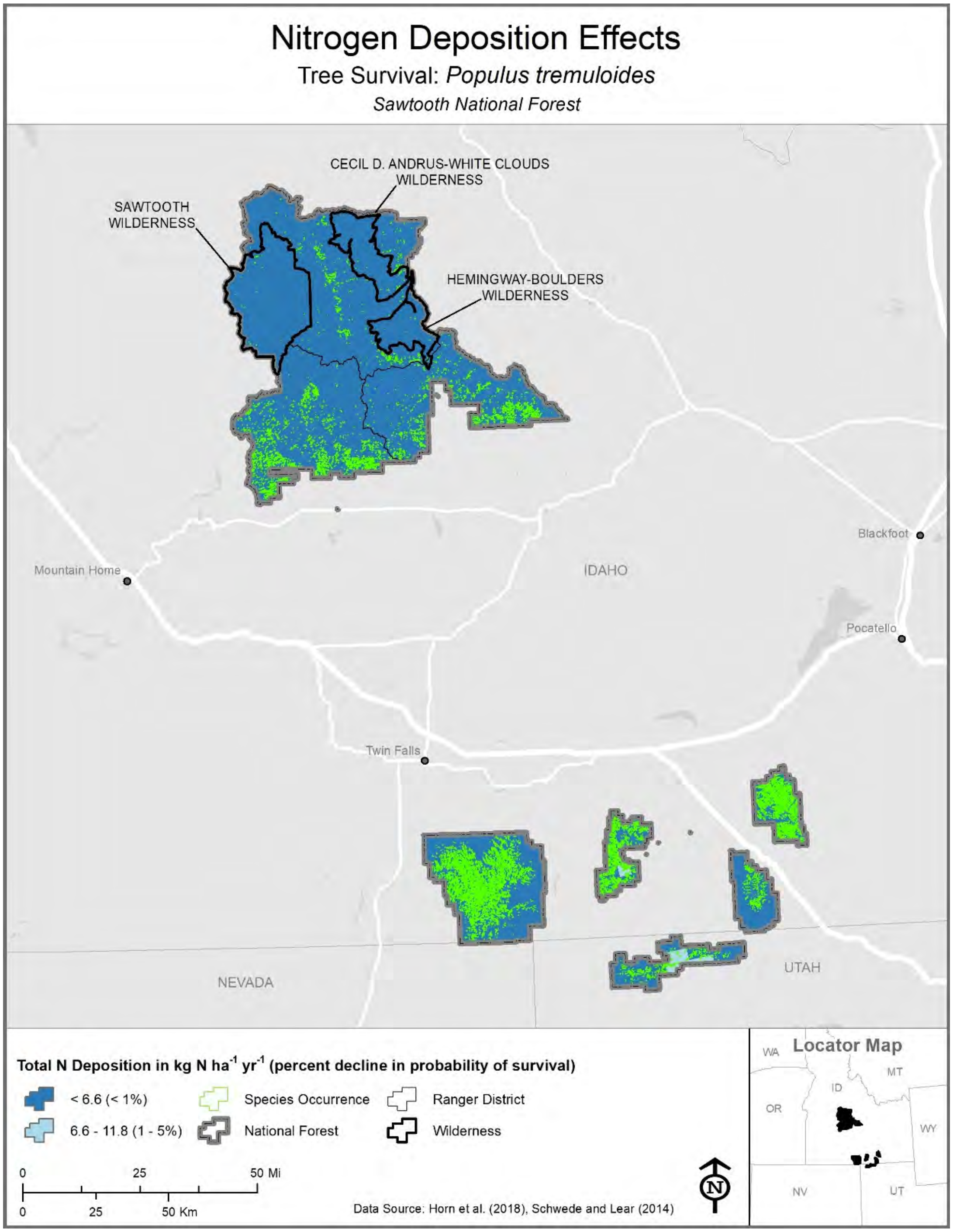

Figure 5-161. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

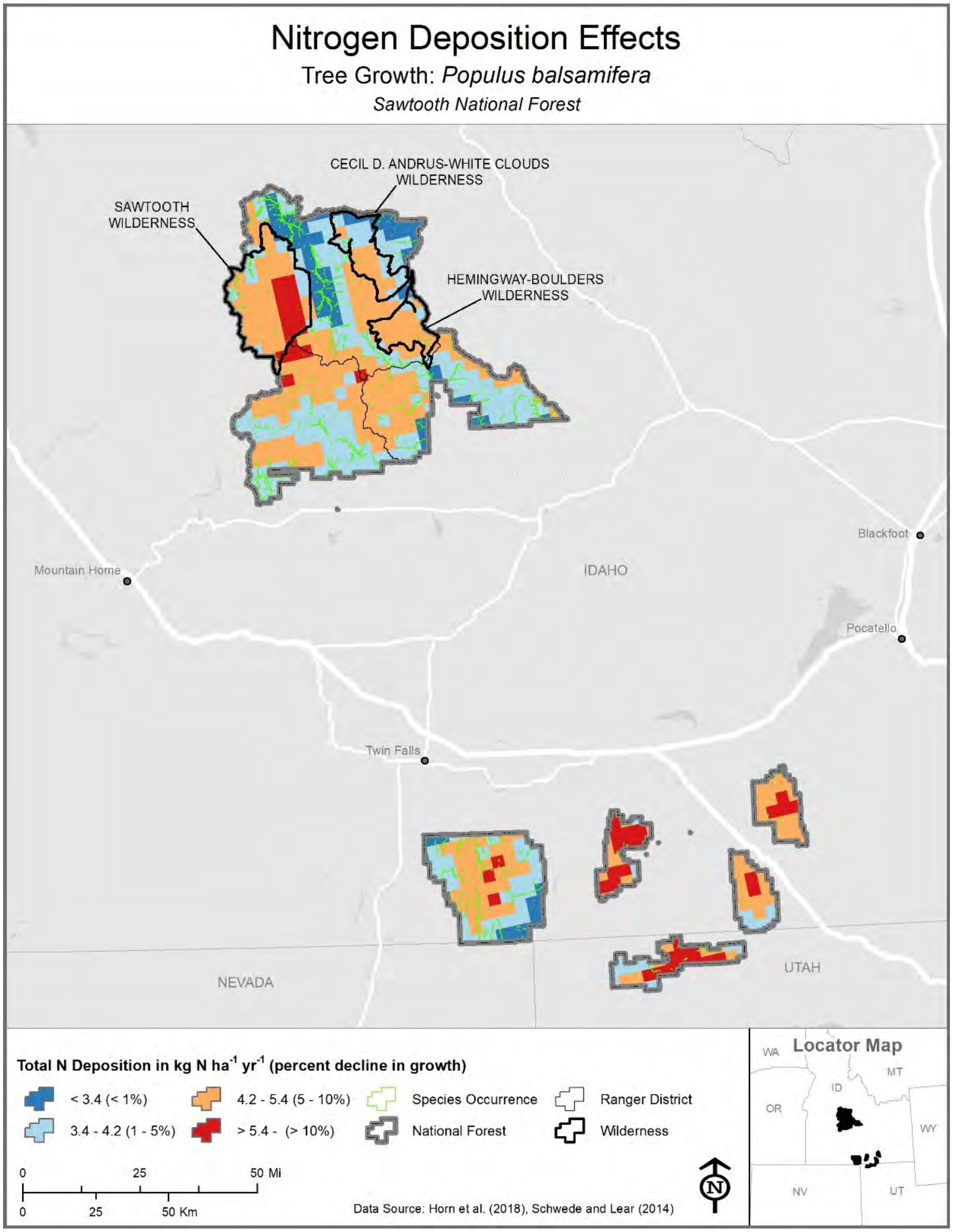

Figure 5-162. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

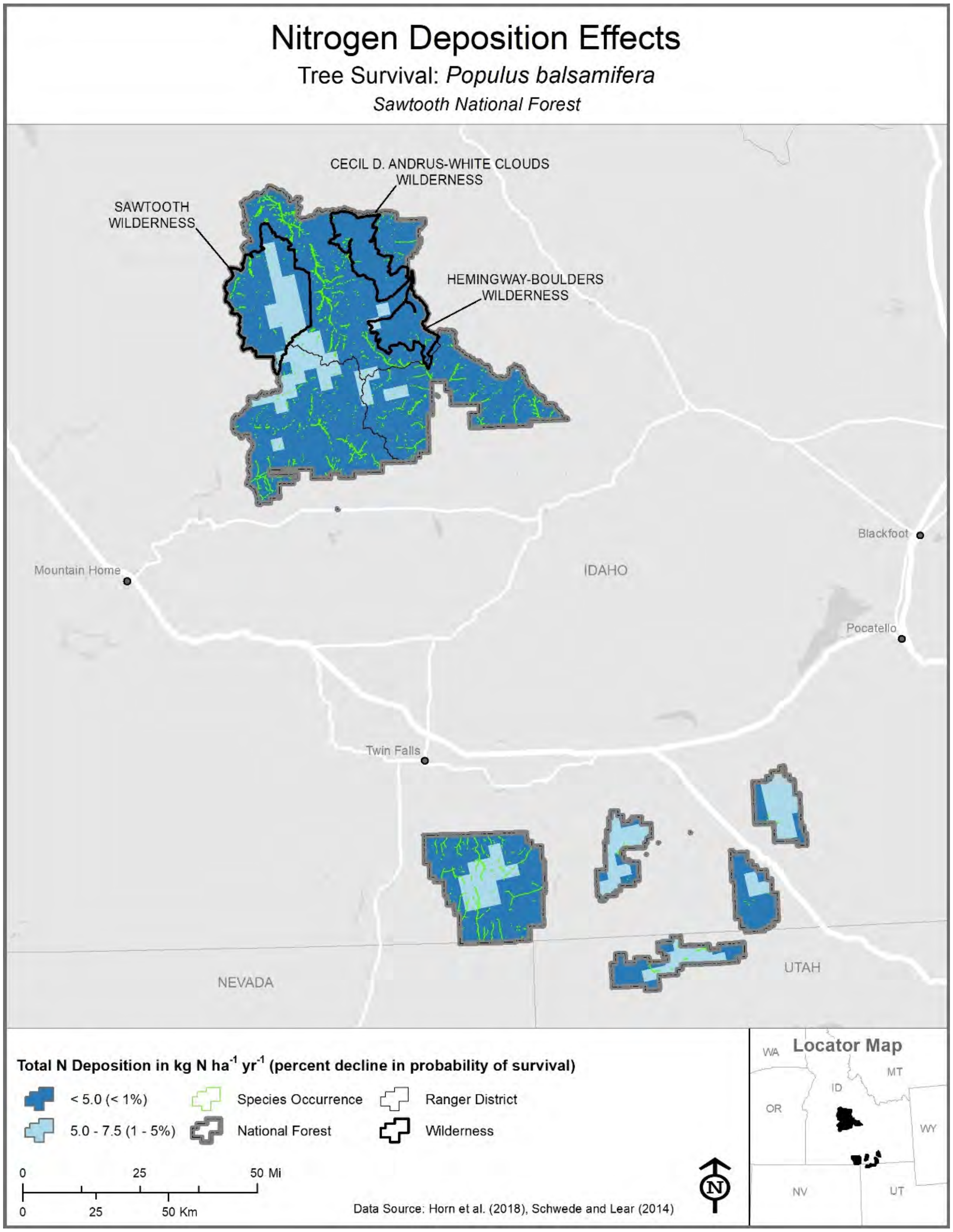

Figure 5-163. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

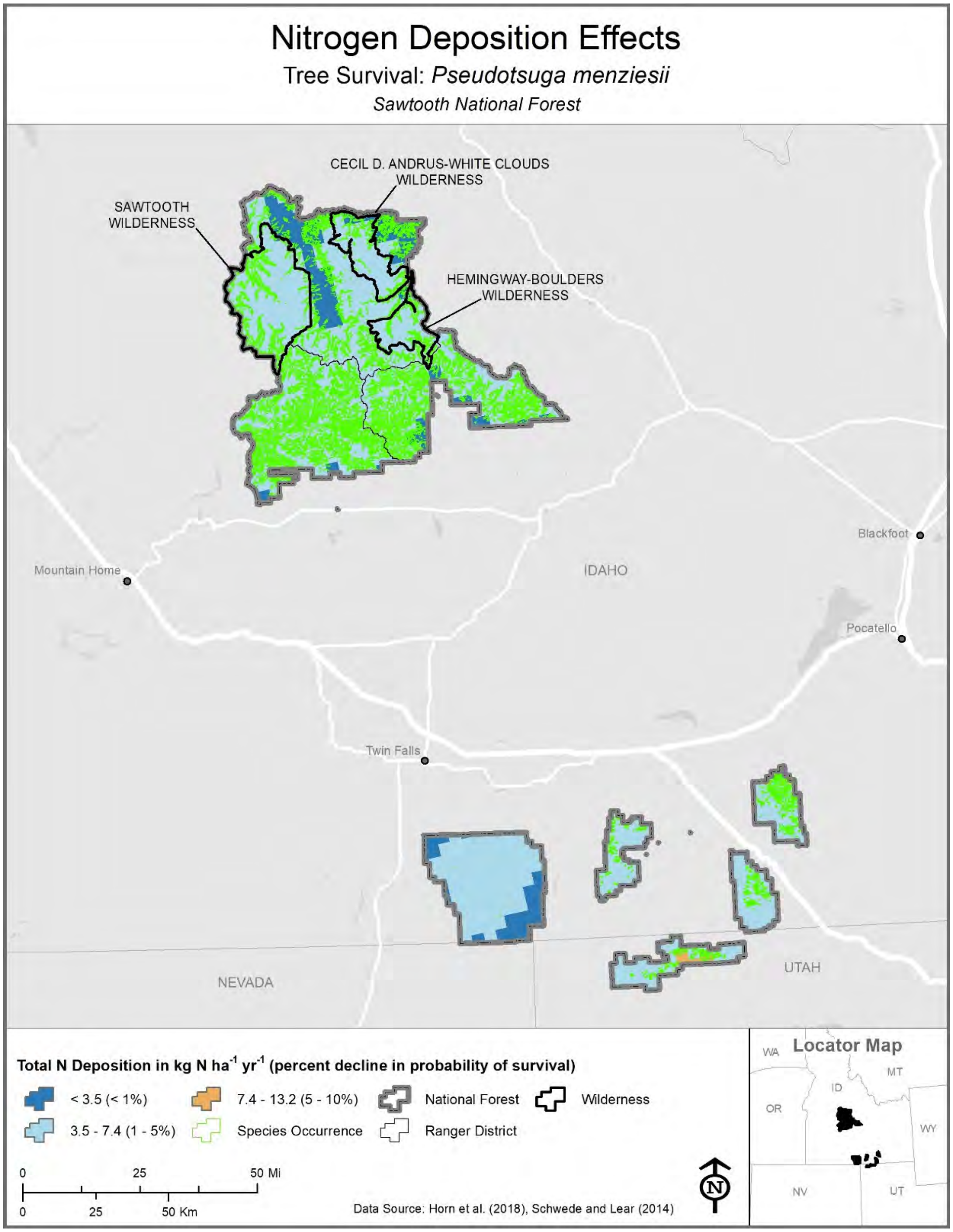

Figure 5-164. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

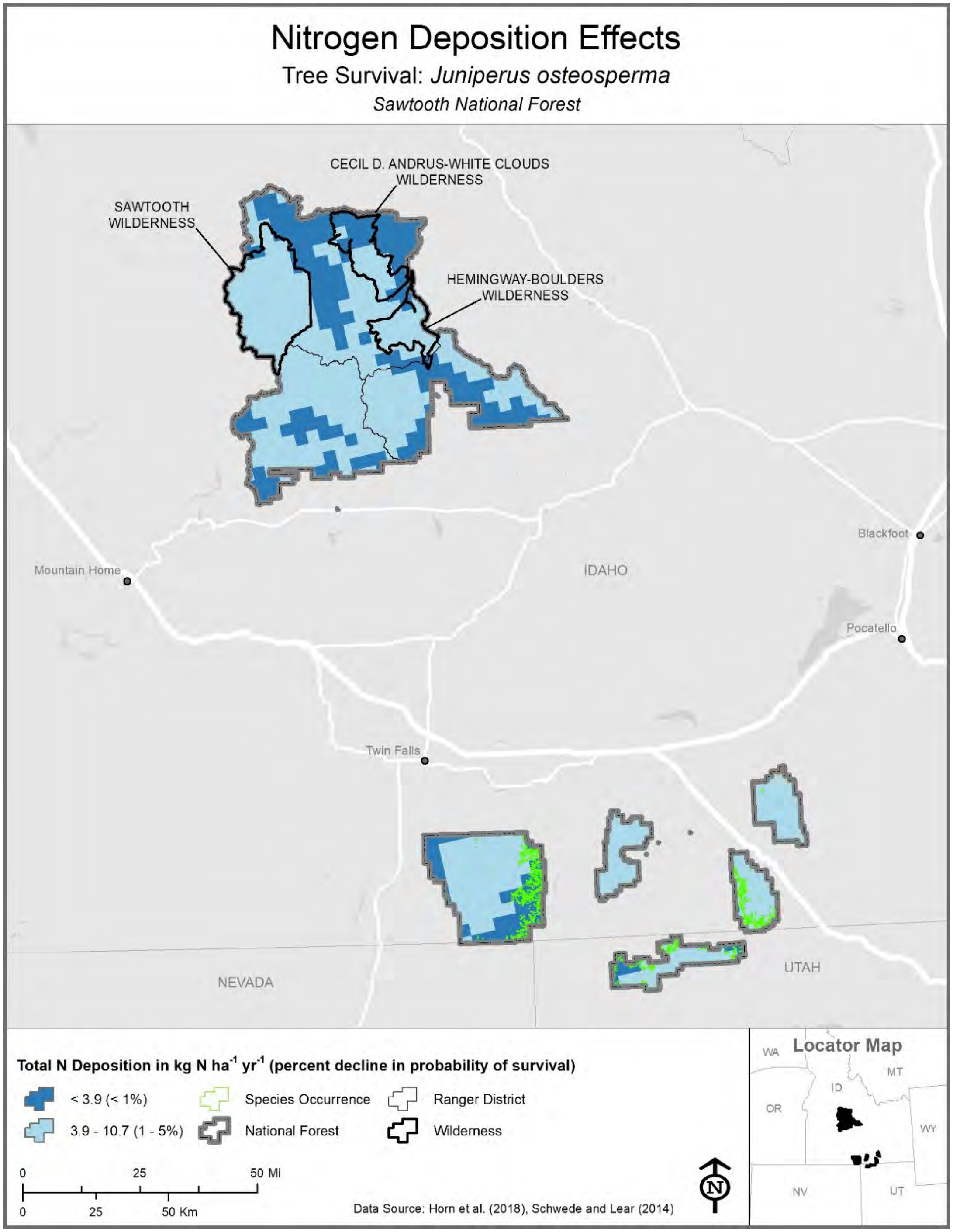

Figure 5-165. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

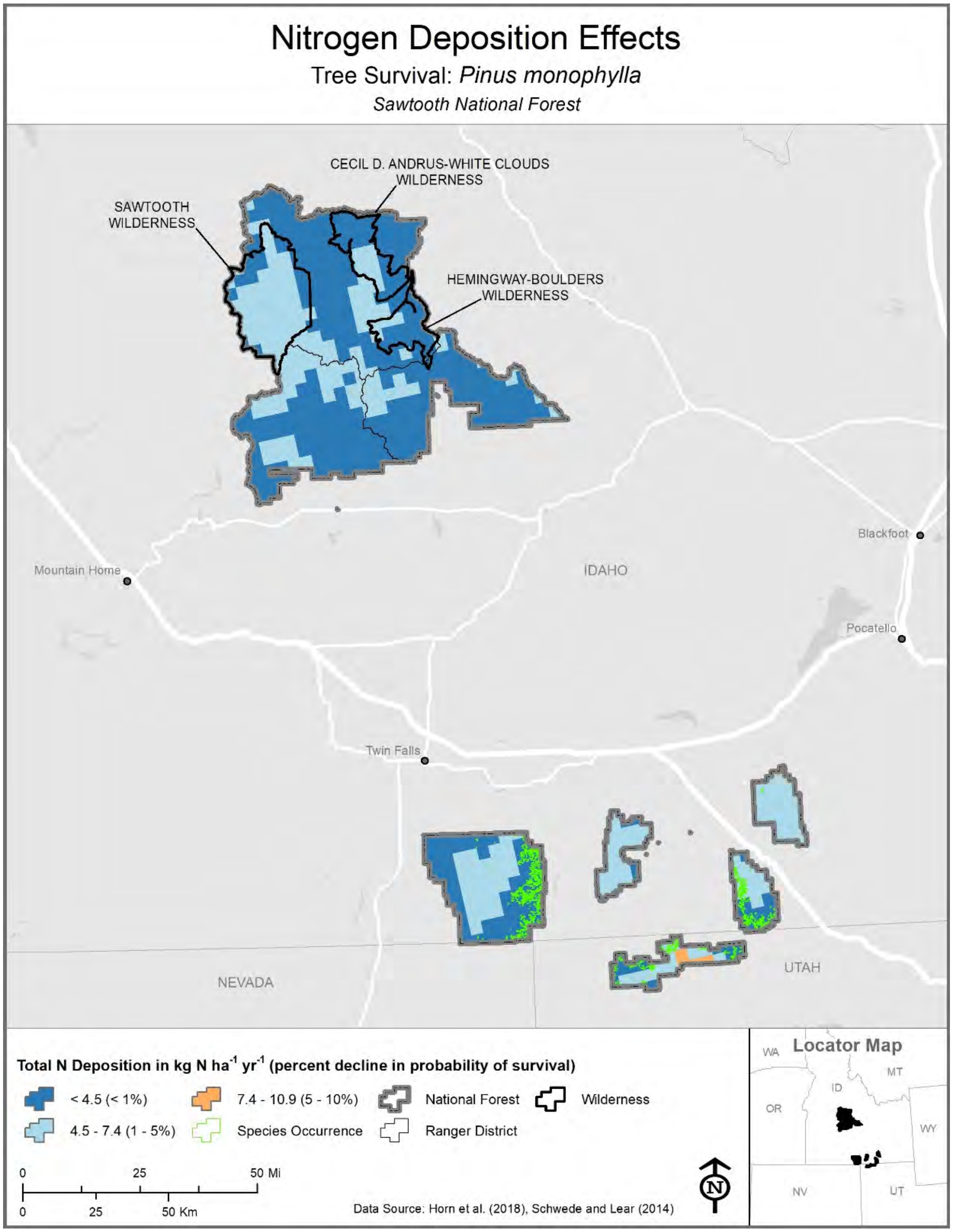

Figure 5-166. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Sawtooth National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

Other species of interest that occurred within the Sawtooth NF showed increasing growth response to N deposition and did not have high correlation between N deposition and any other variable in the model (bold species shown in **Table** 5-24). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

Table 5-24. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Sawtooth National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Pinus ponderosa	ponderosa pine	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.2.12 Uinta-Wasatch-Cache NF

5.2.12.1 Surface Water Acidification

Critical loads protective of effects from surface water acidification within the Uinta-Wasatch-Cache NF illustrated a range of sensitivity to acidification effects (**Figure** 5-167). Surface waters with relatively high and low risk of acidification effects (i.e., low and high CLs, respectively) occurred within and outside of wilderness areas. Ambient N deposition was high enough to exceed the CL at 27% (n = 9) of the sites (**Table** 5-2). This indicates that these locations are likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1} if N deposition (under ambient S deposition) were to persist at ambient levels until steady-state conditions are reached. Some of the waterbodies in exceedance were located within the Lone Peak Wilderness and High Uintas Wilderness (**Figure** 5-168). The highest magnitudes of exceedance were greater than 5 kg N ha^{-1} yr^{-1}. Given the low representation of sites where CLs are calculated in some portions of the Uinta-Wasatch-Cache NF, acid-sensitive waterbodies may occur elsewhere.

5.2.12.2 Surface Water Eutrophication

Low CLs (< 2 kg N ha^{-1} yr^{-1}) protective of surface water eutrophication were common throughout the Uinta-Wasatch-Cache NF and represented a total of nearly 3,990 km^2 (40%) of the forest (**Table** 5-3). Most of the wilderness area with available data was comprised of low CLs (**Figure** 5-169). Areas of exceedance followed a generally similar pattern as the CLs and included nearly 8100 km^2 (84%) of the forest (**Table** 5-4; **Figure** 5-170). The highest magnitudes of exceedance (5 – 10 kg N ha^{-1} yr^{-1}) were typically found within and in the vicinity of the wilderness areas. These areas of exceedance represent locations where increased abundance of algae are expected, among other potential effects associated with surface water eutrophication.

5.2.12.3 Lichen Species Richness and Abundance

Total N deposition exceeded CLs protective of lichen species richness and forage lichen abundance within 99% and 100%, respectively, of the Uinta-Wasatch-Cache NF (**Table**s 5-5 and 5-6). The full extent of all wilderness was in exceedance of both CLs and highest magnitudes (> 5 kg N ha^{-1} yr^{-1}) of exceedance were generally located in the northern and central portions of the

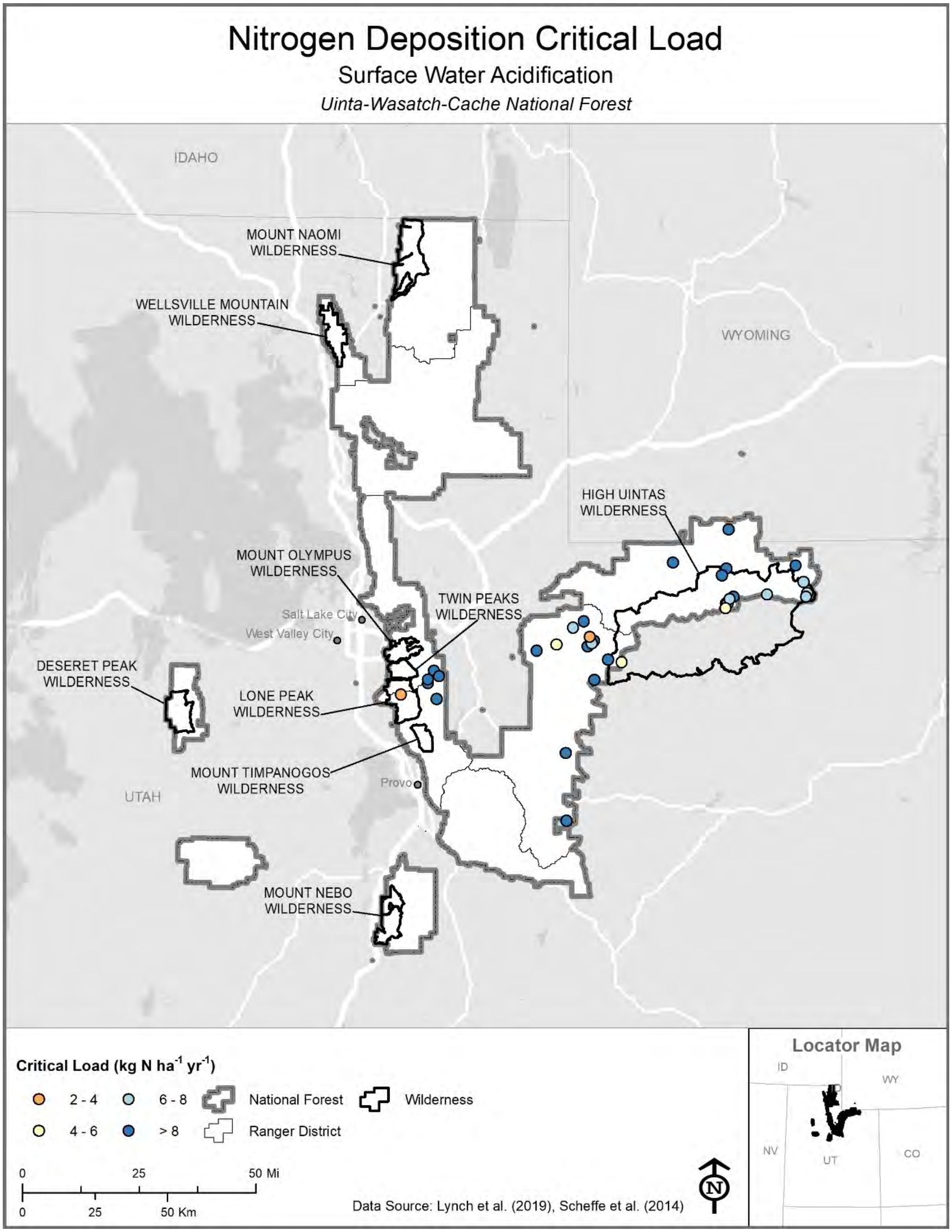

Figure 5-167. Critical loads of total nitrogen (N) deposition to protect against surface water acidification below 50 μeq L^{-1} at lake or stream sample sites located within the Uinta-Wasatch-Cache National Forest.

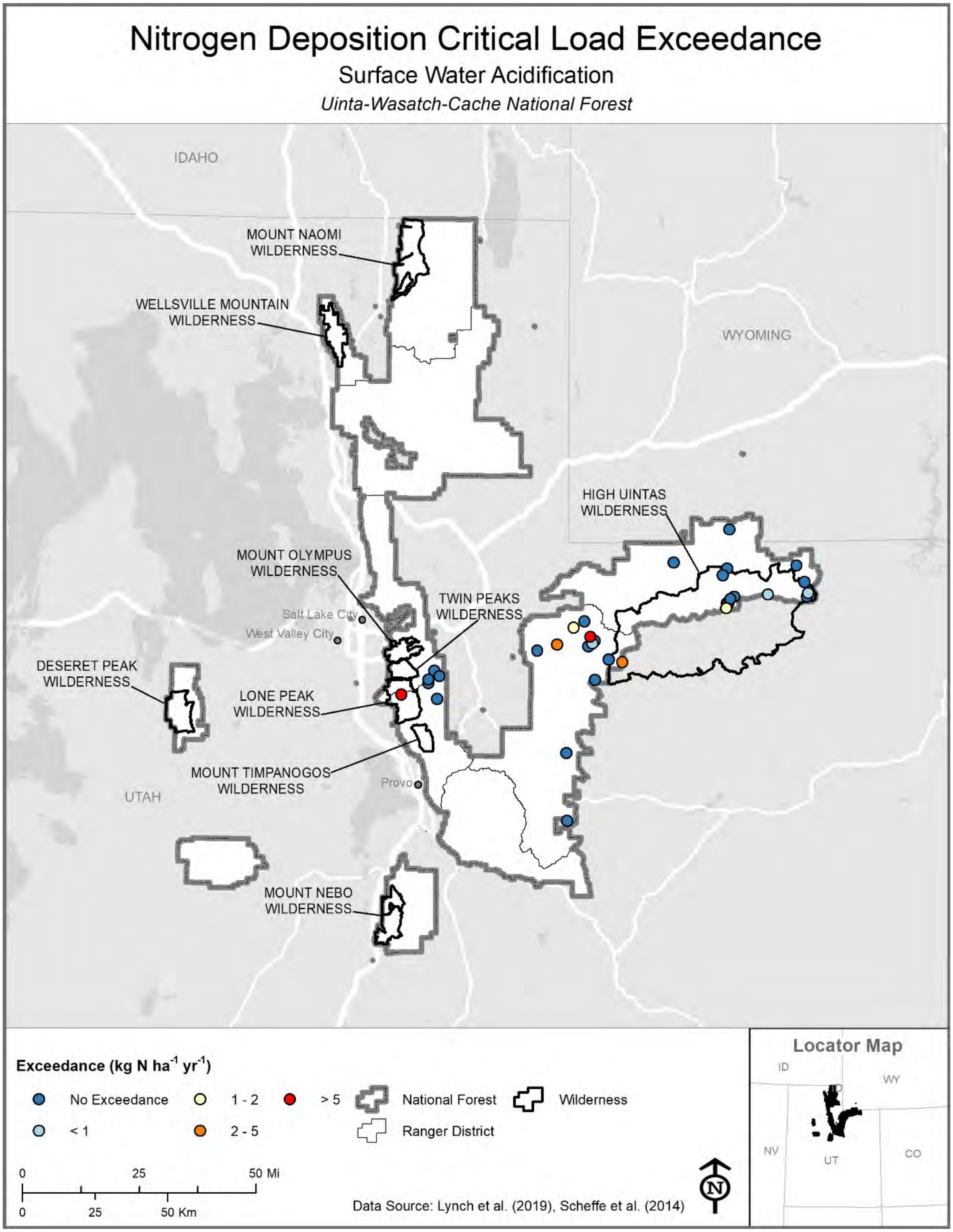

Figure 5-168. Exceedance of critical loads of nitrogen (N) for surface water acidification within the Uinta-Wasatch-Cache National Forest.

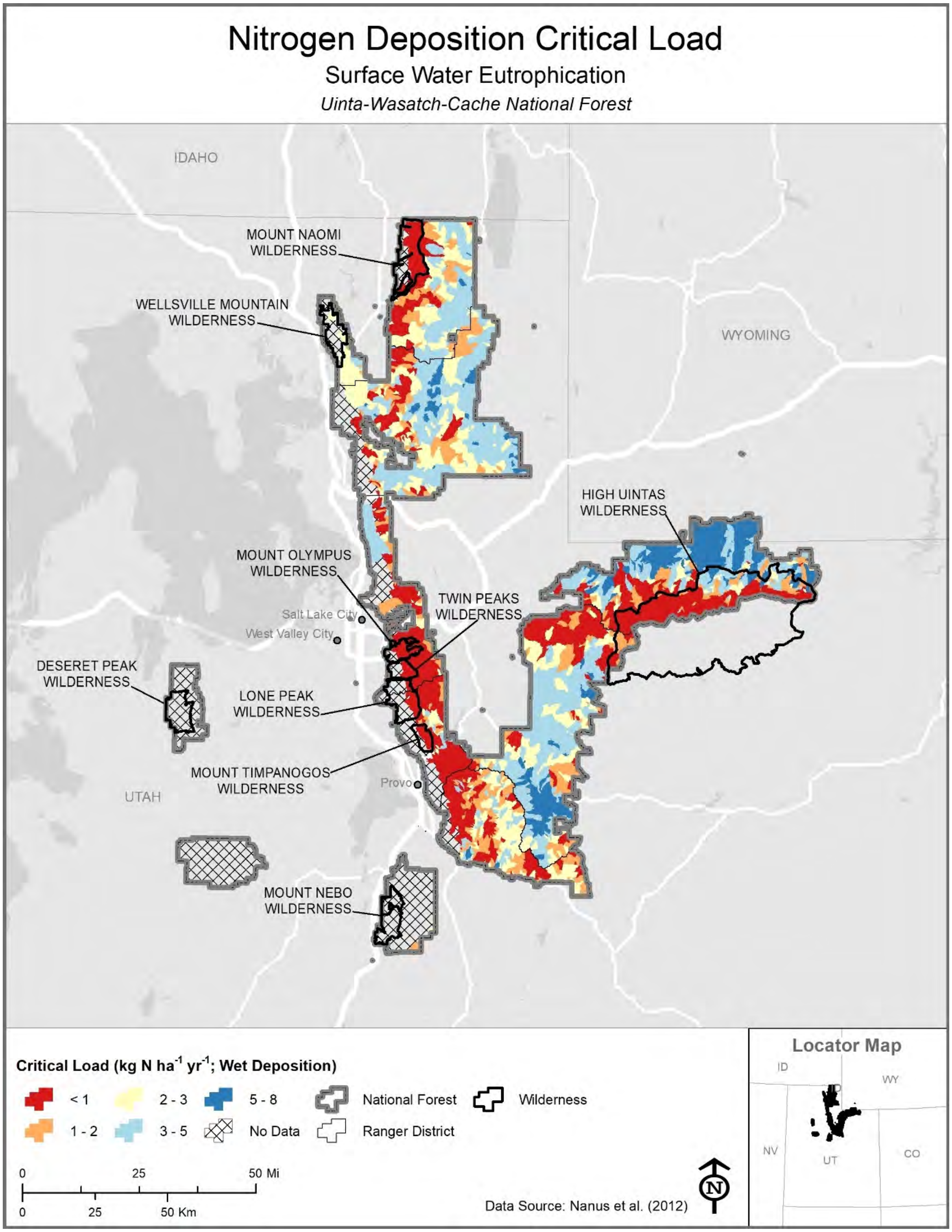

Figure 5-169. Critical loads of wet nitrogen (N) deposition to protect against surface water eutrophication within the Uinta-Wasatch-Cache National Forest based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

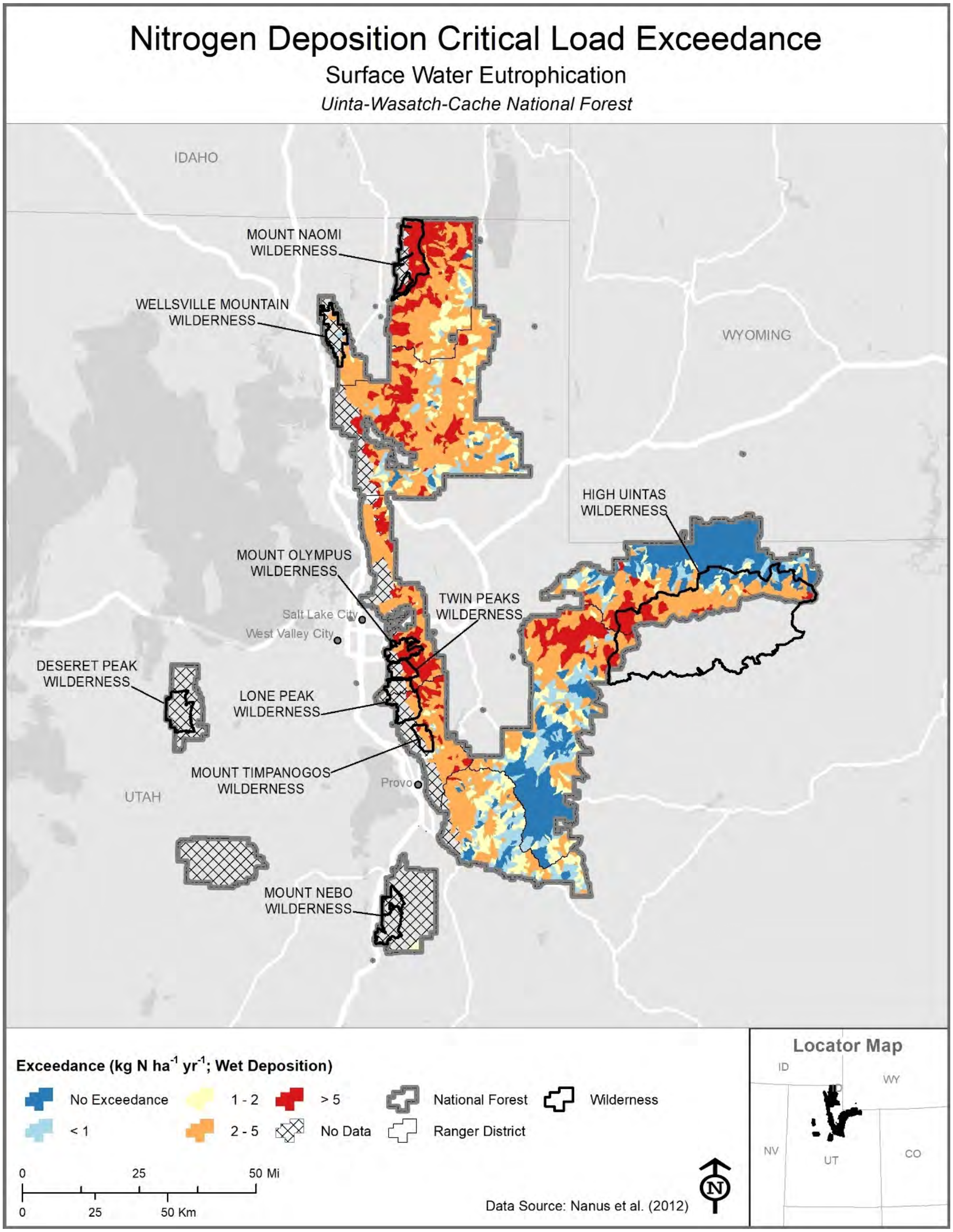

Figure 5-170. Exceedance of critical loads of nitrogen (N) for surface water eutrophication within the Uinta-Wasatch-Cache National Forest.

forest (**Figures** 5-171 and 5-172). Critical load exceedance associated with > 80% reductions in forage lichen abundance were common throughout the forest, including within wilderness areas.

5.2.12.4 Tree Growth and Survival

Total N deposition exceeded CLs protective of *P. tremuloides* growth and probability of survival (1%, 5%, or 10% reductions) within 0.2% and 63%, respectively, of the area in which this species is expected to occur within the Uinta-Wasatch-Cache NF (**Table**s 5-7 and 5-8). The very small area in exceedance for growth occurred in the northern portion of the forest (**Figure** 5-173). Expected reductions in probability of survival were common throughout the forest, including all wilderness areas, and were as high as 5 – 10% in the Mount Naomi Wilderness Area (**Figure** 5-174).

Total N deposition exceeded CLs protective of *P. balsamifera* growth and probability of survival (1%, 5%, or 10% reductions) within nearly 100% and 95%, respectively, of the area in which this species is expected to occur (**Table**s 5-9 and 5-10). Decreases in growth of >10% were common throughout the forest, particularly within the High Uintas Wilderness (**Figure** 5-175). Areas of reductions in probability of survival of 1 – 5% were also commonly found in the High Uintas Wilderness and other wilderness areas (**Figure** 5-176).

Total N deposition exceeded CLs protective of *P. menziesii* probability of survival (1%, 5%, or 10% reductions) within 71% of the area in which this species is expected to occur (**Table** 5-11). Areas of exceedance were common throughout the forest, including wilderness areas (**Figure** 5-177).

Total N deposition exceeded CLs protective of *J. osteosperma* probability of survival (1%, 5%, or 10% reductions) within 93% of the area in which this species is expected to occur (**Table** 5-12). Areas of exceedance were common throughout the forest, including wilderness areas (**Figure** 5-178).

Total N deposition exceeded CLs protective of *P. monophylla* probability of survival (1%, 5%, or 10% reductions) within 85% of the area in which this species is expected to occur (**Table** 5-13). Areas of exceedance were common throughout the forest, including wilderness areas (**Figure** 5-179).

Other species of interest that occurred within the Uinta-Wasatch-Cache NF showed increasing growth response to N deposition and did not have high correlation between N

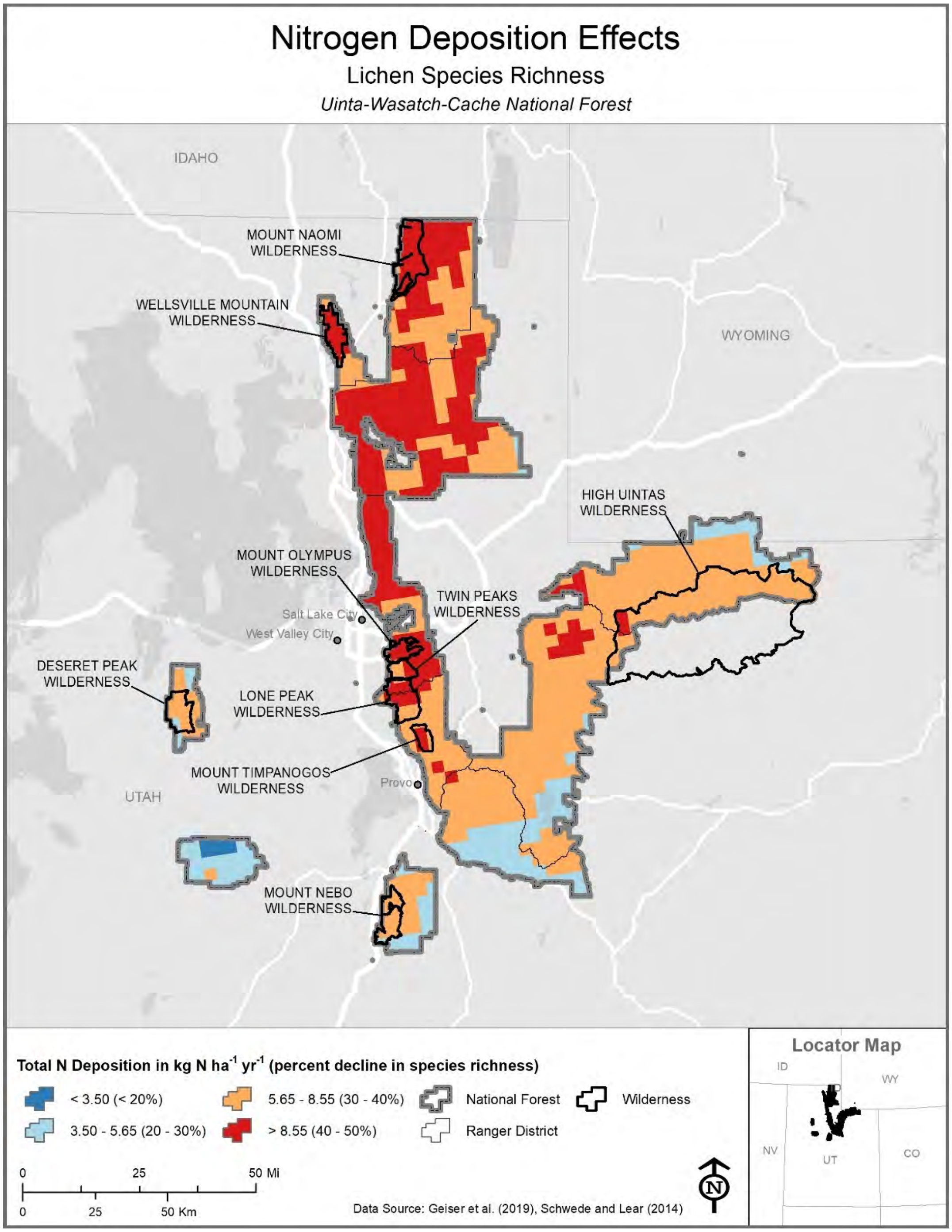

Figure 5-171. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to lichen species richness within the Uinta-Wasatch-Cache National Forest. The critical load for protecting against more than a 20% reduction in lichen species richness (3.5 kg N ha^{-1} yr^{-1}) is used to define the first category of total N deposition shown on the map. Areas with total N deposition above 3.5 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, and 50% reductions in lichen species richness.

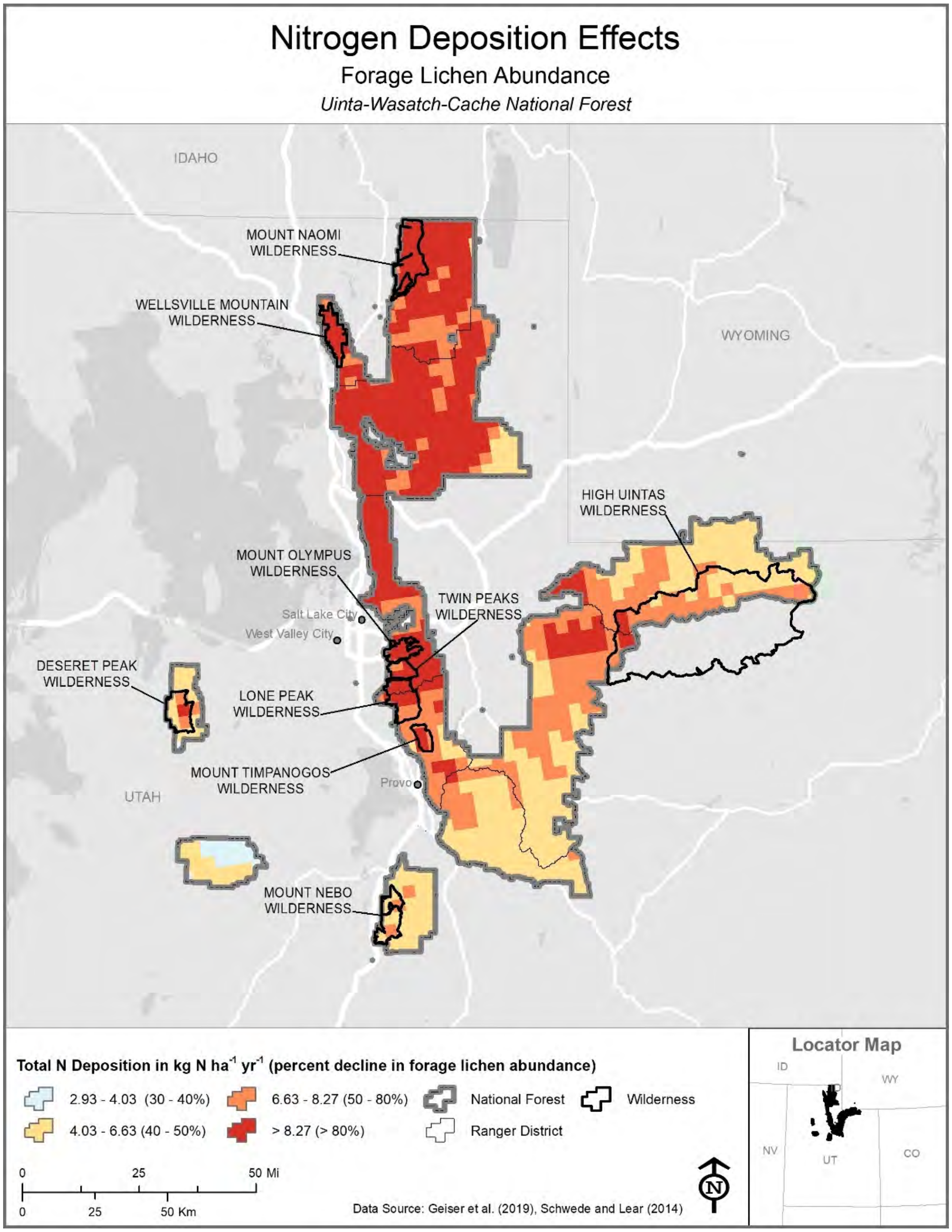

Figure 5-172. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to forage lichen abundance within the Uinta-Wasatch-Cache National Forest. The critical load for protecting against more than a 20% reduction in forage lichen abundance is 2.0 kg N ha^{-1} yr^{-1}. Areas with total N deposition above 2.0 kg N ha^{-1} yr^{-1} represent locations of critical load exceedance. Total N deposition is further categorized based on the level of total N deposition expected to be associated with 30%, 40%, 50%, and 80% reductions in forage lichen abundance.

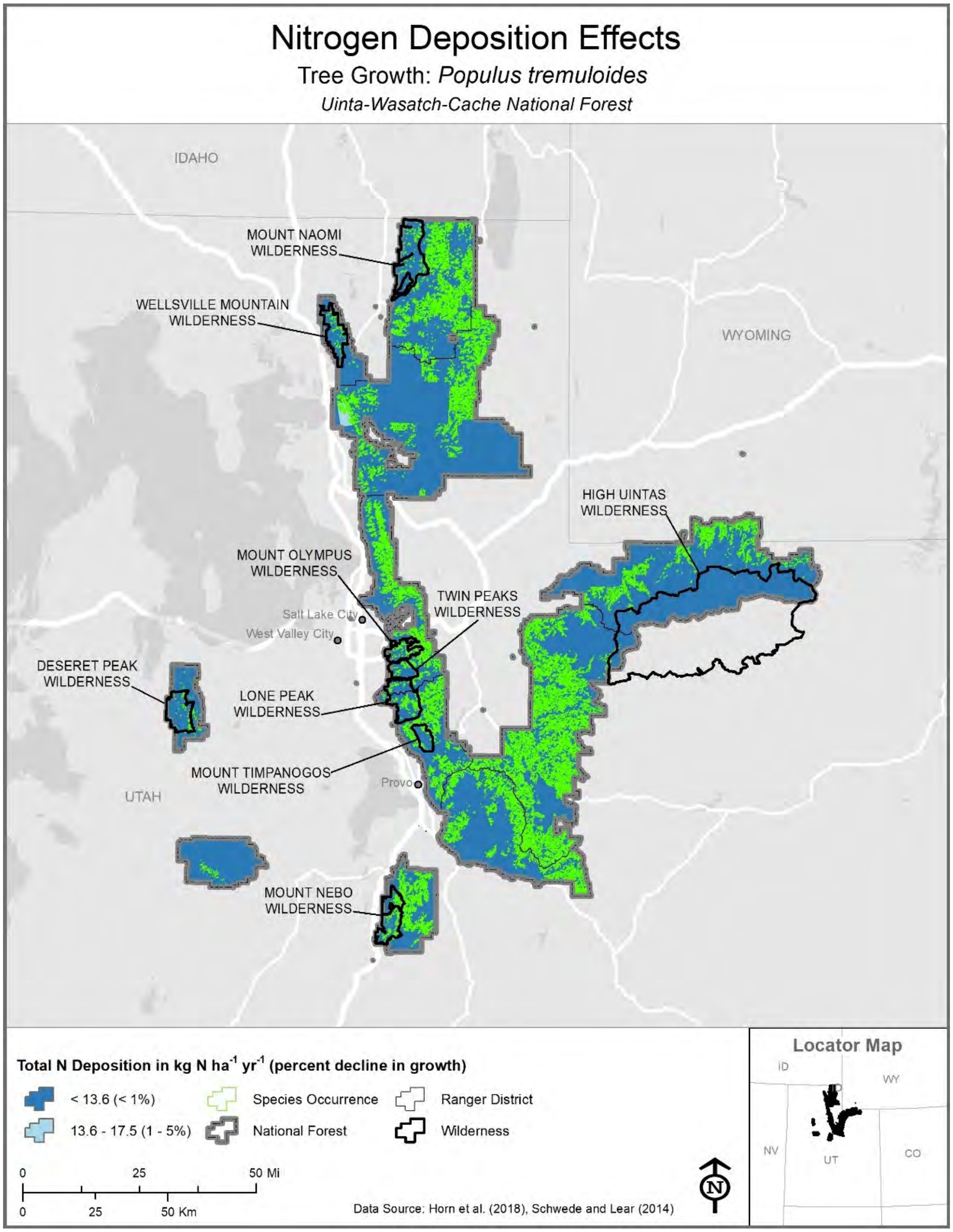

Figure 5-173. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* growth within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 13.6, 17.5, and 21.3 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

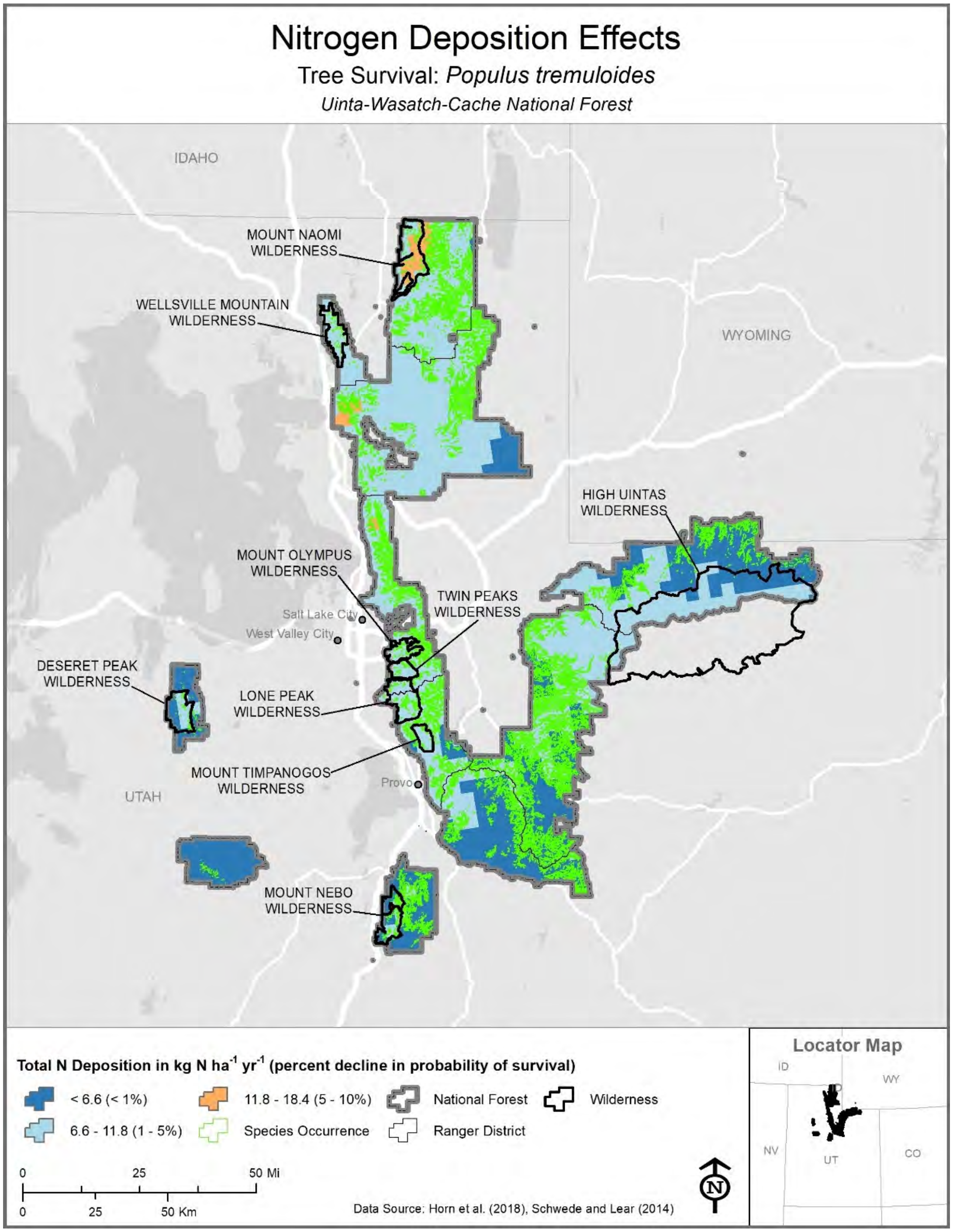

Figure 5-174. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus tremuloides* probability of survival over 10 years within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

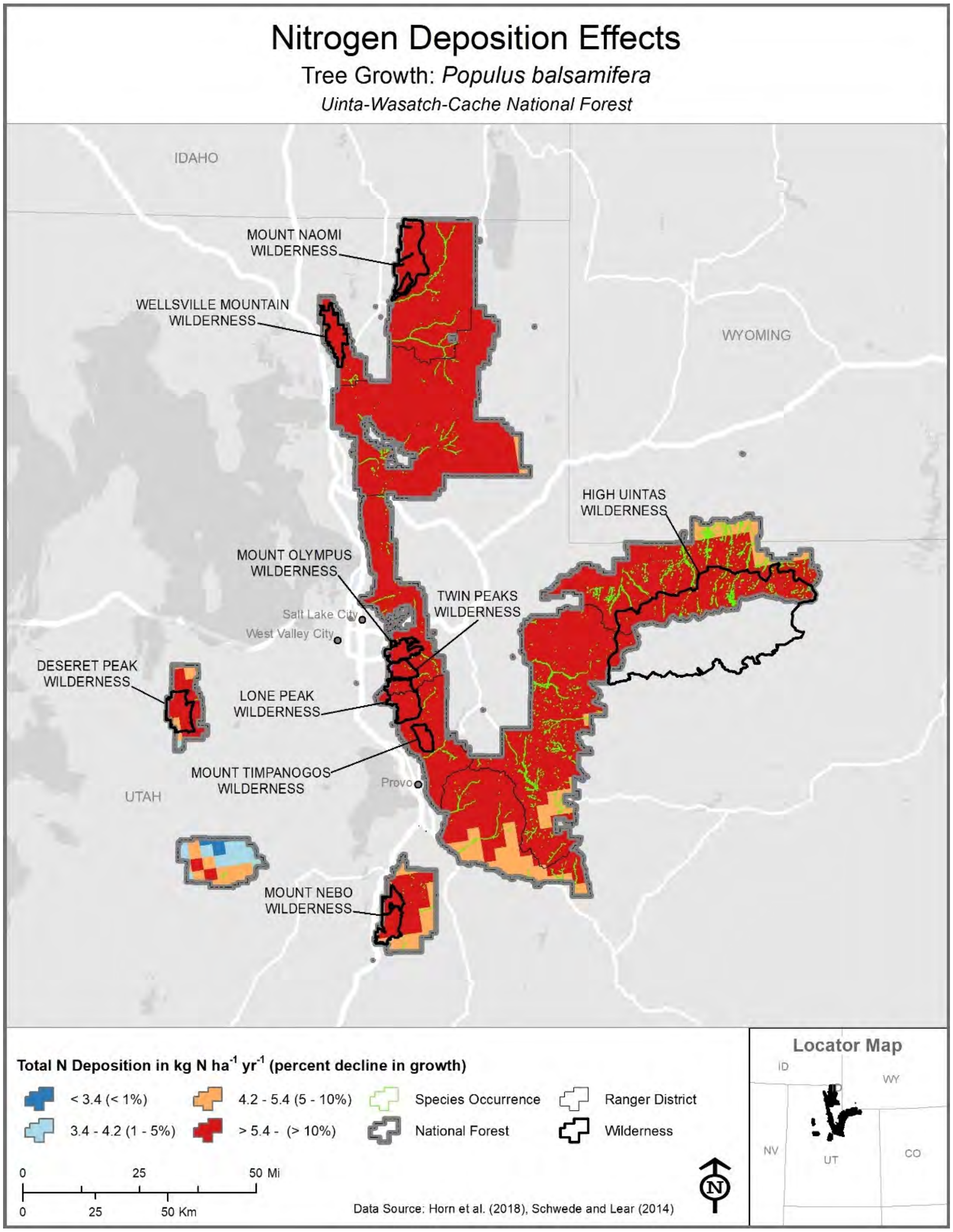

Figure 5-175. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* growth within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in growth are 3.4, 4.2, and 5.4 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories of total N deposition shown on the map. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

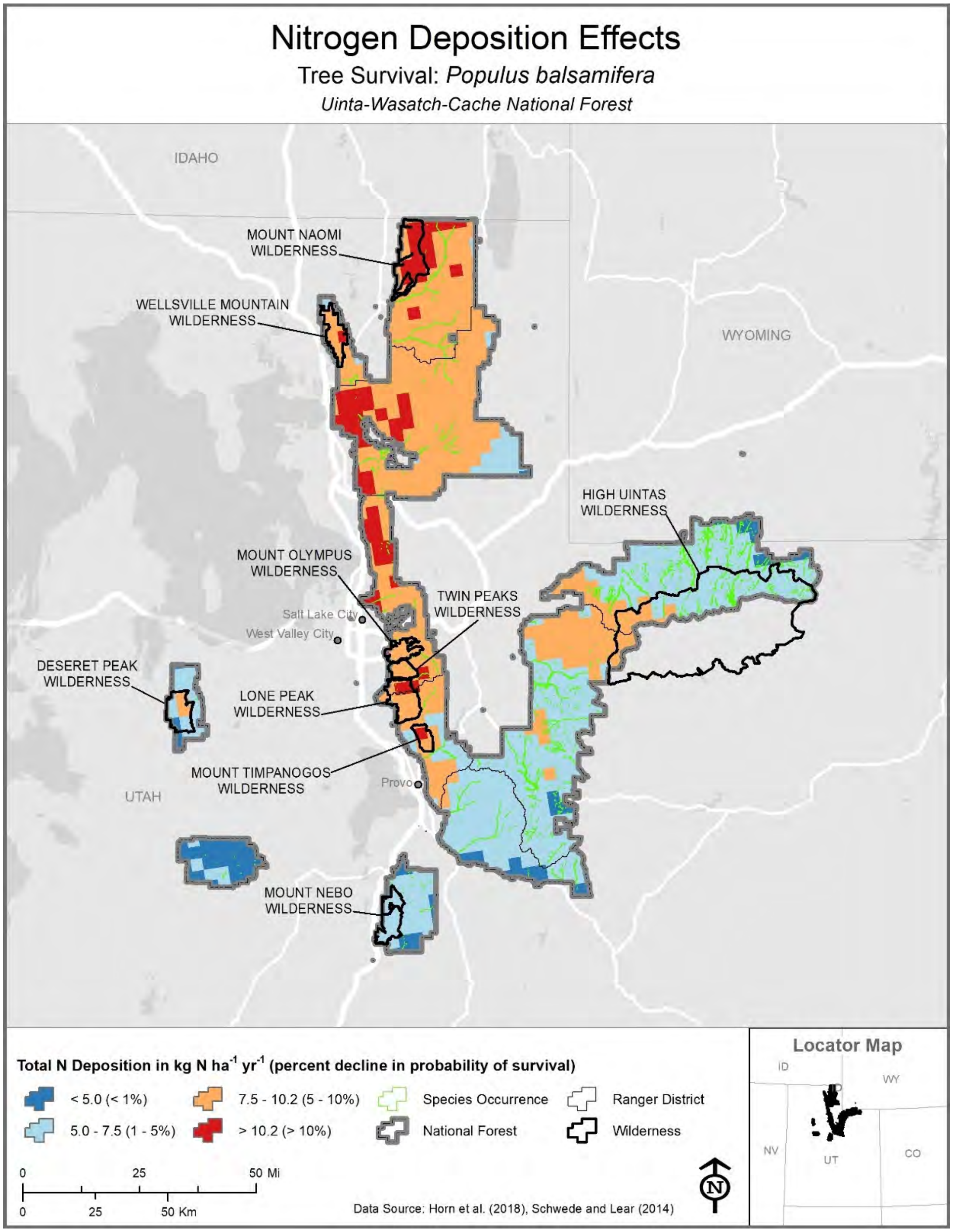

Figure 5-176. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Populus balsamifera* probability of survival over 10 years within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 5.0, 7.5, and 10.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

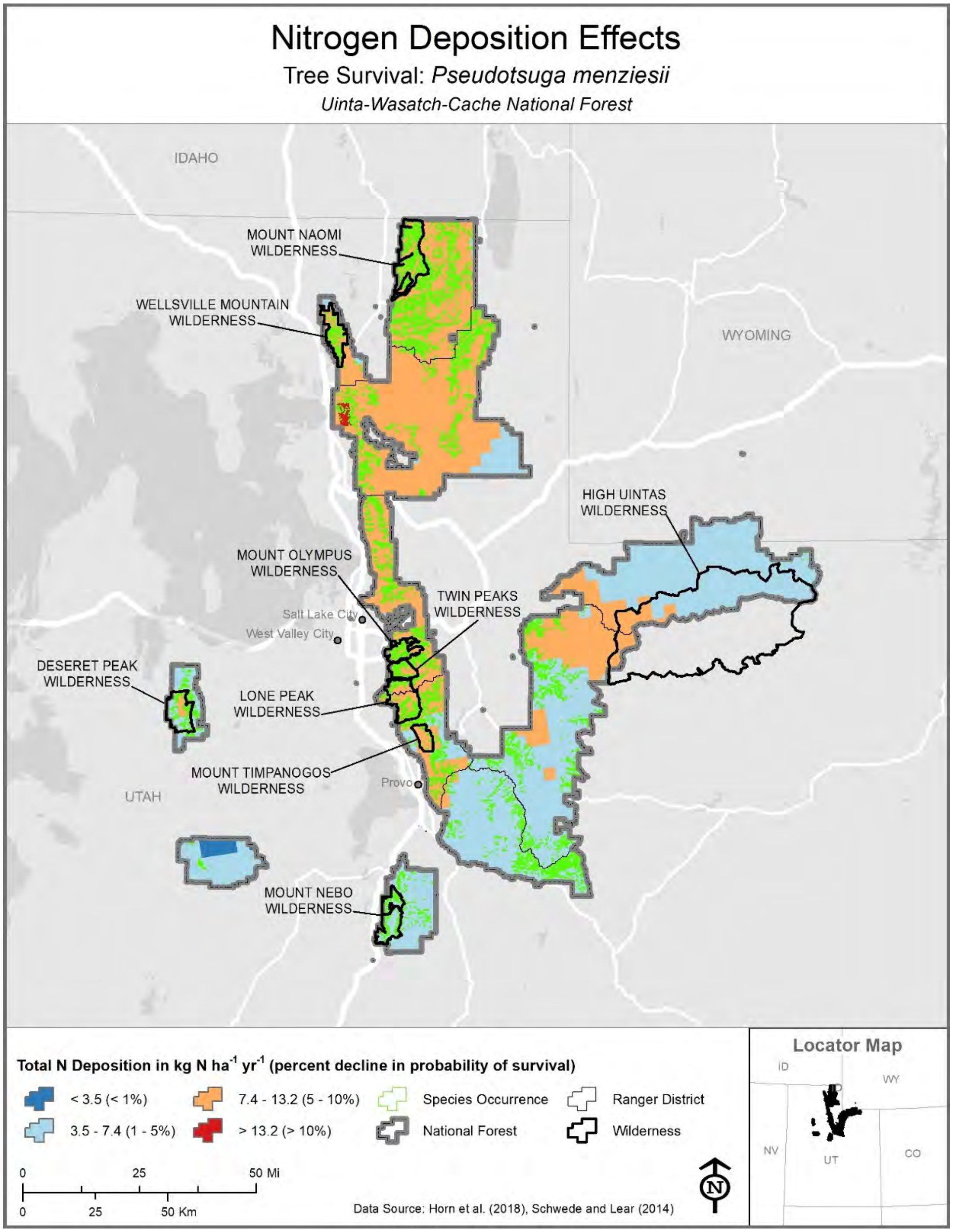

Figure 5-177. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pseudotsuga menziesii* probability of survival over 10 years within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.5, 7.4, and 13.2 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

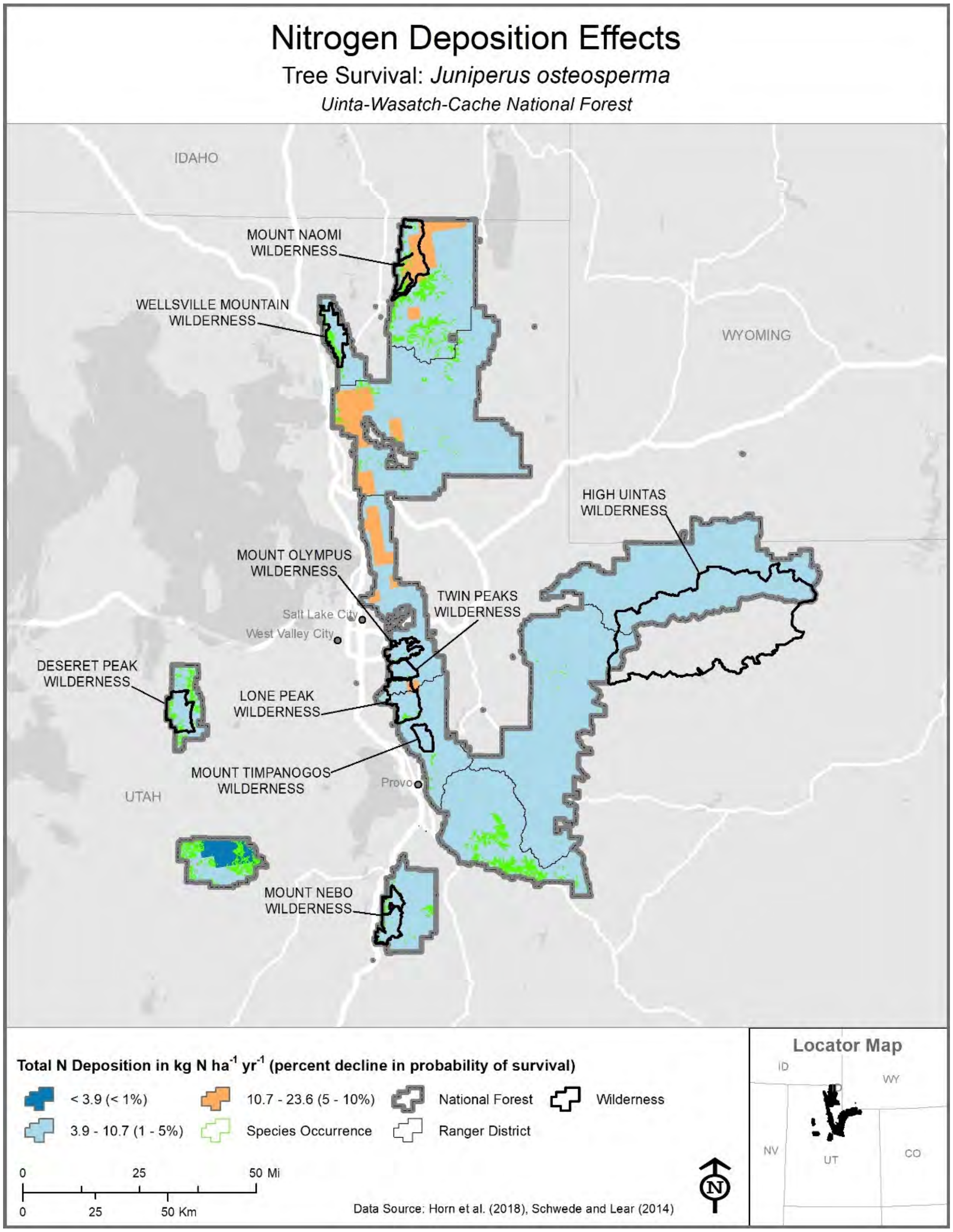

Figure 5-178. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Juniperus osteosperma* probability of survival over 10 years within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 3.9, 10.7, and 23.6 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

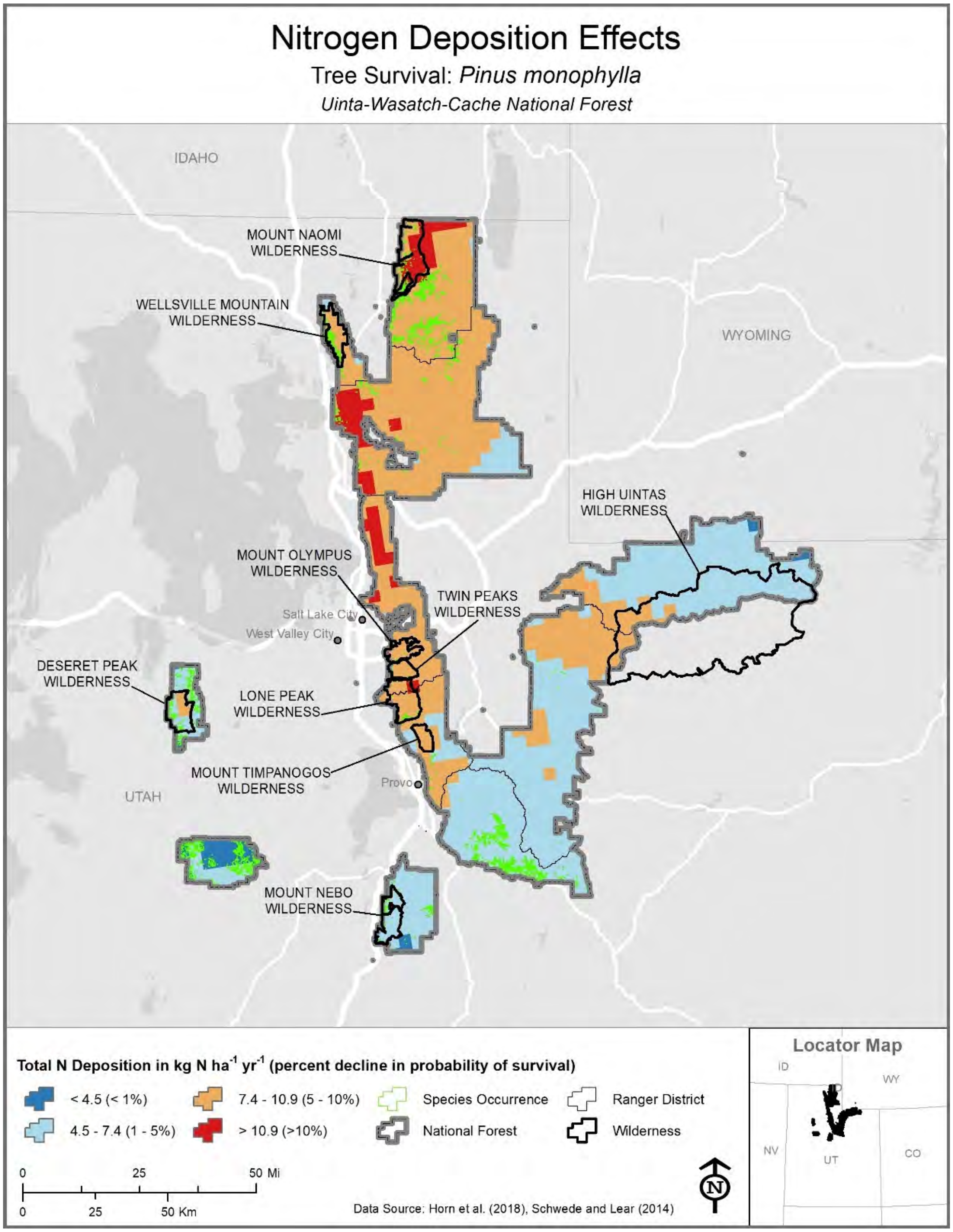

Figure 5-179. Total nitrogen (N) deposition (average 2015 – 2017) and associated extent of expected impact to *Pinus monophylla* probability of survival over 10 years within the Uinta-Wasatch-Cache National Forest. The critical loads for protecting against more than a 1%, 5%, and 10% reduction in probability of survival are 4.5, 7.4, and 10.9 kg N ha^{-1} yr^{-1}, respectively. These critical load values are used to define the categories for mapping total N deposition. Areas with total N deposition above a given critical load represent locations of critical load exceedance.

deposition and any other variable in the model (VIF N < 3; bold species shown in **Table** 5-25). Although CLs associated with decreased growth are not applicable to these species, increased growth as a result of N deposition would be expected to change the character of the forest.

Table 5-25. Critical loads (kg N ha^{-1} yr^{-1}) protective of decreases of 1%, 5% and 10% in tree growth and probability of survival (over 10 years) for species found within the Uinta-Wasatch-Cache National Forest.

Species Name	Common Name	Form of Response to N Deposition		Critical Load for Protecting Against Various Percent Decreases in Tree Growth and Survival		
				1%	5%	10%
Abies concolor	white fir	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Abies lasiocarpa	**subalpine fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Flat	N/A	N/A	N/A
Acer negundo	boxelder	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Juniperus osteosperma	**Utah juniper**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.9	10.7	23.6
Picea engelmannii	Engelmann spruce	Growth	Decreasing[1]	N/A	N/A	N/A
		Survival	Threshold[1]	N/A	N/A	N/A
Pinus contorta	lodgepole pine	Growth	Flat	N/A	N/A	N/A
		Survival	Flat	N/A	N/A	N/A
Pinus edulis	common or two-needle pinyon	Growth	Flat[1]	N/A	N/A	N/A
		Survival	Flat[1]	N/A	N/A	N/A
Pinus monophylla	**singleleaf pinyon**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	4.5	7.4	10.9
Populus balsamifera	balsam poplar	Growth	Decreasing	3.4	4.2	5.4
		Survival	Threshold	5.0	7.5	10.2
Populus tremuloides	quaking aspen	Growth	Threshold	13.6	17.5	21.3
		Survival	Threshold	6.6	11.8	18.4
Pseudotsuga menziesii	**Douglas fir**	**Growth**	**Increasing**	**N/A**	**N/A**	**N/A**
		Survival	Threshold	3.5	7.4	13.2

[1] Model not used because high correlation between variables increased uncertainty of deposition effects

5.3 Ranking

Critical loads were ranked based on expected usefulness and reliability for understanding expected effects from atmospheric N deposition for each forest (**Table** 5-26). The relative rankings were developed based mostly on data availability and the extent to which the CLs indicated resource sensitivity. Lichen-based CLs were often ranked as most useful due to full coverage for all forests and the ability to discern relative impacts for most forests. Surface water eutrophication effects were typically ranked second because not all areas of the forest were characterized and most forests were represented by surface water eutrophication CLs for wet N deposition only, rather than total N deposition. Tree growth and survival CLs were typically ranked third due to relative lack of coverage. Although CLs for surface water acidification were developed from site-level measurements, most forests had very few waterbodies characterized with surface water acidification CLs.

Exceptions to the above described ranking order included:

- Ashley NF – Surface water acidification CLs were generally widespread and indicated sensitivity to deposition, including within wilderness areas. Tree CLs generally showed low extent of exceedance throughout the forest. For these reasons, surface water acidification CLs were ranked third for this forest.

Table 5-26. Critical load usefulness ranking (1 = most useful) for Region 4 National Forests.

National Forest Name	Surface Water Acidification	Surface Water Eutrophication	Lichen Species Richness and Forage Lichen Abundance	Tree Growth and Survival
Ashley NF	3	2	1	
Boise NF		2	1	3
Bridger-Teton NF	3	1	2	
Caribou-Targhee NF		2	1	3
Dixie NF		2	1	3
Fishlake NF		2	1	3
Humboldt-Toiyabe NF	3		1	2
Manti-La Sal NF		2	1	
Payette NF		2	1	3
Salmon-Challis NF		2	1	3
Sawtooth NF	3	2	1	
Uinta-Wasatch-Cache NF		2	3	1

- Bridger-Teton NF – Surface water acidification CLs were generally widespread and indicated sensitivity to deposition, including within wilderness areas. Tree CLs generally showed low extent of exceedance throughout the forest. Also, the eutrophication CLs were based on total N deposition (rather than only wet N deposition). For these reasons, surface water acidification CLs were ranked third and surface water eutrophication CLs were ranked first for this forest.
- Humboldt-Toiyabe NF – Surface water eutrophication CLs were not available for this forest. For this reason, tree CLs were ranked second and surface water acidification CLs were ranked third for this forest.
- Sawtooth NF – Surface water acidification CLs were generally widespread and indicated sensitivity to deposition, including within wilderness areas. Tree CLs generally showed low extent of exceedance throughout the forest. For these reasons, surface water acidification CLs were ranked third for this forest.
- Uinta-Wasatch-Cache NF – Many of the tree species were widely distributed in this forest and showed varying levels of exceedance. High magnitudes of lichen CLs exceedance were ubiquitous. Although it is useful to know that lichens have likely been impacted throughout nearly all of the forest, it may be more useful to understand the more spatially varied pattern in the extent of CL exceedance for trees. For these reasons, tree CLs were ranked first and lichen CLs were ranked third for this forest.

6 CONCLUSIONS

6.1 Surface Water Acidification

Acid-sensitive surface waters of the Intermountain Region can be identified as those that have relatively low CLs. Wilderness areas often contained N and S deposition at levels high enough to exceed CLs for surface water acidification. Exceedances of the CLs reported here indicate areas with elevated risk of surface water acidification which can effect aquatic ecosystems, causing reductions in abundance and diversity of zooplankton, macroinvertebrates, and fish species.

6.2 Surface Water Eutrophication

Streams and lakes throughout large portions of the Intermountain Region are likely experiencing the onset of eutrophication impacts from elevated N concentrations in the form of increased abundance of N-limited algal species such as *A. formosa*. Wilderness areas often contained surface waters that were exceedance of the surface water eutrophication CL. Changes in algal abundance can alter competitive interactions among primary producers and have cascading effects on higher-tropic levels. Reductions in regional deposition to below the reported CLs protective of surface water eutrophication would be expected to largely prevent such adverse impacts in the region.

6.3 Lichen Species Richness and Abundance

Due to the relatively low CL to support lichen species, large portions of the Intermountain Region forests likely exceed the CL to protect against reductions in forage lichen abundance. Because the lichen CLs were based on deposition estimates known to underestimate N deposition, CL exceedance may be overestimated. Interpretation of these results based on patterns and relative magnitude of exceedance may be more useful than the absolute level of exceedance. Nonetheless, given the expected widespread impact to this functional group, cascading effects on other lifeforms such as ungulates, birds, rodents, lagomorphs, and invertebrates are also expected. Forage lichens provide critical winter forage for deer and elk in areas of deep snow and are the primary winter forage for flying squirrels, voles, and pikas as described by Geiser et al. (In preparation). Many bird species depend on forage lichens for nesting material. Mammals depend on forage lichens as food seasonally (winter) or year-round.

Lichens may serve as a mineral-rich dietary supplement, or as a dominant component of their diet. Lichen-dependent wildlife can be prey for other species. The lichen response models used as the basis for CLs in this assessment were developed from survey sites located throughout the United States and may not be fully reflective of lichen community conditions for a given location within the Intermountain Region.

6.4 Tree Growth and Survival

Based on the models used to evaluate the CLs for tree species considered in this assessment, reductions in growth of *P. balsamifera* and survival of *P. balsamifera*, *P. menziesii*, and *J. osteosperma* were expected to be widespread within the Intermountain Region. Potential impacts related to decreased growth and survival for these species include, but are not limited to, changes in tree species composition, riparian conditions, habitat for other plant and animal species, wilderness character, and fire regimes. Trees impacted by atmospheric N and S deposition may also be more susceptible to insect infestations, diseases, and drought. In addition to the ecological effects associated with reduced growth and survival of these species, decreased survival of *P. menziesii* may also have economic implications given its role as a timber species. The tree response models used as the basis for CLs in this assessment were developed from a set of trees spread throughout the range of distribution for a given species. Widespread species such as *P. tremuloides* or *P. menziesii* are subject to a broad range of ecological conditions and deposition rates. Regional response rates could be different than those developed from tree responses across the entire species range. Localized observations of tree growth and survival may differ from the modeled response based on nationally available data due to local impacts to tree growth and survival from disturbance agents such as insect infestations, fire, and seasonal drought.

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Appendix A. List of VCMQ map unit names used for mapping tree species with critical loads (from Horn et al. 2018).

Ashley NF

VCMQ Map Unit	Species Mapped with Critical Loads
Aspen	Aspen
Aspen/Conifer	Aspen
Douglas fir	Douglas fir
Douglas fir Mix	Douglas fir
Pinyon-Juniper	Singleleaf pinyon, Utah juniper

Boise NF

VCMQ Map Unit	Species Mapped with Critical Loads
Douglas Fir	Douglas fir
Douglas Fir/Ponderosa	Douglas fir
Riparian Shrubland/Deciduous Tree	Balsam poplar
Aspen	Aspen
Douglas Fir/Lodgepole	Douglas fir

Bridger NF

VCMQ Map Unit	Species Mapped with Critical Loads
Douglas fir Mix	Douglas fir
Aspen	Aspen
Aspen/Conifer Mix	Aspen
Cottonwood	Balsam poplar

Caribou NF

VCMQ Map Unit	Species Mapped with Critical Loads
Douglas fir	Douglas fir
Aspen	Aspen
Conifer/Aspen	Aspen
Aspen/Conifer	Aspen
Douglas fir/Lodgepole Pine	Douglas fir
Limber Pine/ Douglas fir	Douglas fir
Juniper Mix	Utah juniper

Dixie NF

VCMQ Map Unit	Species Mapped with Critical Loads
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Aspen/Conifer	Aspen
Ponderosa Pine/Woodland	Utah juniper, singleleaf pinyon

Douglas fir Mix	Douglas fir
Aspen	Aspen
Rocky Mountain Juniper Mix	Utah juniper, singleleaf pinyon

Fishlake NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Aspen/Conifer	Aspen
Aspen	Aspen
Douglas fir Mix	Douglas fir

VCMQ Map Unit	**Species Mapped with Critical Loads**
Pinyon/Juniper	Utah juniper, singleleaf pinyon
Aspen	Aspen
Riparian Aspen	Aspen
Pinyon	Singleleaf pinyon
Cottonwood	Balsam poplar
Mixed Aspen/Conifer	Aspen
Juniper	Utah juniper
Pinyon-Juniper/Montane Shrub	Utah juniper, singleleaf pinyon
Pinyon-Juniper/Desert Shrub	Utah juniper, singleleaf pinyon
Black Cottonwood	Balsam poplar
Cottonwood - Alder	Balsam poplar
Douglas fir - White Fir	Douglas fir
Quaking Aspen	Aspen
Singleleaf Pinyon Pine	Singleleaf pinyon
Willow - Aspen	Aspen
Utah Juniper	Utah juniper

MantiLaSal NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Aspen	Aspen
Aspen/Conifer	Aspen
Douglas fir Mix	Douglas fir
Ponderosa Pine/Woodland	Utah juniper, singleleaf pinyon
Rocky Mountain Juniper Mix	Utah juniper, singleleaf pinyon

Payette NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Douglas Fir	Douglas fir
Lodgepole Pine	Lodgepole pine
Douglas Fir/Ponderosa	Douglas fir

Riparian Shrubland/Deciduous Tree	Balsam poplar
Aspen	Aspen
Douglas Fir/Lodgepole	Douglas fir

Salmon NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Douglas fir	Douglas fir
Douglas fir/Lodgepole Pine	Douglas fir
Douglas fir/Ponderosa Pine	Douglas fir
Riparian Woody	Balsam poplar
Aspen/Conifer	Aspen
Aspen	Aspen

Sawtooth NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Douglas fir	Douglas fir
Aspen	Aspen
Subalpine Fir/ Douglas fir	Douglas fir
Aspen/Conifer	Aspen
Riparian Woody	Balsam poplar
Conifer/Aspen	Aspen
Douglas fir/Lodgepole Pine	Douglas fir
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Juniper Mix	Utah juniper, singleleaf pinyon

Uinta-Wasatch-Cache NF

VCMQ Map Unit	**Species Mapped with Critical Loads**
Aspen	Aspen
Aspen/Conifer	Aspen
Douglas fir Mix	Douglas fir
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Rocky Mountain Juniper Mix	Utah juniper, singleleaf pinyon