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Assessment of Atmospheric Nitrogen and Sulfur Deposition Critical Loads for Aquatic and Terrestrial Resources on National Forest System Lands in the Intermountain Region

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Abstract

A critical load (CL) is a science-based threshold that identifies the amount of pollutant deposition below which no significant ecological harm to an ecosystem component is expected. This report provides baseline critical load (CL) analyses for nitrogen (N) and sulfur (S) as required under the 2012 Planning Rule for forest plan assessments. The data also can be used to inform land management decisions where the effects of N and S deposition are relevant, including the evaluation of large projects through the National Environmental Policy Act, Prevention of Significant Deterioration (PSD) permitting program, wilderness monitoring, and watershed condition.

Significant portions of the USDA Forest Service system lands in the Intermountain Region are exposed to N deposition levels that exceed CLs. Areas in exceedance have an increased risk of negative ecological effects. Nine of the 12 National Forests within the Intermountain Region have areas that exceed CLs for surface water acidification and therefore are at higher risk for declines in abundance and diversity of aquatic species. All 12 National Forests have areas that exceed CLs for surface water eutrophication, lichen species richness, forage lichen abundance, and tree species growth rate and probability of survival (over 10 years). In areas with increased risk of surface water eutrophication, competitive interactions and community structure of primary producers can shift and cause compounding effects within the food web. Diversity and abundance of key aquatic species may decrease to the point of extirpation. Areas that exceed CLs for lichen species richness and forage lichen abundance have an increased risk to experience reduced diversity, occurrence, and abundance of lichen species which can negatively affect other biota such as mammals, birds, and invertebrates, that rely on lichens for food, shelter, and camouflage. Areas with an increased risk for declines in tree growth rate and probability of survival may experience a change in the composition of forest communities.

KEY WORDS: air quality, risk, eutrophication, acidification, air pollution, forest planning, forest management.

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Cover photos, from top: Jenny Lake, Boise National Forest, USDA Forest Service photo; Dark Canyon Wilderness on the Manti-La Sal National Forest, USDA Forest Service photo by Charity Parks; Wyoming paintbrush beside a creek, Bridger-Teton National Forest, USDA Forest Service photo; Emma Lake, Humboldt-Toiyabe National Forest, USDA Forest Service photo by Chris Africa; Midway Creek, Dixie National Forest, USDA Forest Service photo by Zack Taylor; White Clouds Wilderness Area, Sawtooth National Forest, USDA Forest Service photo by Mark Lisk.

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Mt. McDougal on Bridger-Teton National Forest. USDA Forest Service photo by Jill A. McMurray.

EXECUTIVE SUMMARY

Deposition of atmospheric nitrogen (N) and sulfur (S) can have widespread and important effects on natural ecosystems in the United States. 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 and composition of biological communities can change in response to acidifying and nutrient enriching effects from N and S deposition, including detrimental effects on tree growth rate and lifespan, lichen abundance and diversity, and the health and survival of aquatic ecosystems and species.

A critical load (CL) specifies the level of a pollutant deposition below which significant ecological harm to a specific ecosystem does not occur. Areas where pollution deposition is above the CL are in exceedance. These areas have an increased risk of negative ecological effects. The level of risk is affected by the magnitude and duration of the exceedance. For many years, CLs have been used in Europe and Canada to inform land management and policy decisions. Land managers and policy makers in the United States are following this lead and using CLs to inform key decisions. This report summarizes current N and S deposition levels, CLs, and areas of CL exceedance on USDA Forest Service System Lands in the Intermountain Region.

Information presented in this report was generated to provide baseline CLs analyses required under the 2012 Planning Rule for forest plan assessments. However, this information can also be used to inform land management decisions where the effects of N and S deposition are relevant, including, but not limited to the evaluation of large projects through the National Environmental Policy Act (NEPA), Prevention of Significant Deterioration permitting program (PSD), and wilderness character monitoring. Under the National Forest Management Act, the Forest Service 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).

To assess overall ecosystem effects and risk, the following CLs and exceedances are reported here for both terrestrial and aquatic environments:

1. Surface water acidification
2. Surface water eutrophication
3. Lichen species richness and forage lichen abundance
4. Tree growth rate and probability of survival over 10 years

Significant portions of the Forest Service system lands in the Intermountain Region are exposed to levels of N deposition that exceed CLs. Areas in exceedance have an increased risk of negative ecological effects. Nine of the 12 National Forests within the Intermountain Region have areas that exceed CLs for surface water acidification. Areas in exceedance are at higher risk for declines in abundance and diversity of aquatic species. All 12 National Forests have areas that exceed CLs for surface water eutrophication, lichen species richness, forage lichen abundance, tree species growth rate, and tree species probability of survival over 10 years. In areas with increased risk of surface water eutrophication, competitive interactions among primary producers can be altered. This may cause compounding effects within the food web reducing diversity and abundance of key aquatic species to the point of extirpation. Additionally, areas that exceed CLs for lichen species richness and forage lichen abundance are likely to experience reduced diversity, occurrence, and abundance of lichen species, particularly forage lichens. This reduction

in lichen species richness and abundance can then negatively affect other biota such as large mammals, birds, rodents, lagomorphs, and invertebrates that rely on lichens for food, shelter, and camouflage. Areas that exceed CLs for declines in tree growth rate and probability of survival are at greater risk to experience a change in the composition of forest communities.

Reductions in N emissions that result in decreases of N deposition may reduce detrimental effects to the terrestrial and aquatic ecosystem affected by excess N in the Intermountain Region. The Forest Service does not have the authority to regulate emissions outside of Forest Service system lands and thus must work cooperatively with the regulatory agencies to address any emission and deposition concerns.

All analyses in this report included N deposition. Deposition of S was incorporated into the CLs for surface water acidification and the CLs for tree growth rate and probability of survival. Sulfur deposition CLs were not assessed for lichens because the range in the S deposition gradient across lichen survey plots in the interior west was too narrow for these plots to be included in the national CL calculations. Thus, the uncertainty of the models was considered too high for evaluating CLs of S for lichens. Sulfur deposition was also not used in the calculations for surface water eutrophication because eutrophication is a response to N and phosphorus (P) enrichment.

The figures and tables presented in this report represent the risk for negative effects to occur and include spatial information about these risks and do not necessarily indicate that the specified effects have occurred. ArcGIS maps and shapefiles for all the figures presented in this report are also available by request.

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Wyoming paintbrush (*Castilleja linariifolia*) beside a creek, Bridger-Teton National Forest. USDA Forest Service photo.

1 BACKGROUND

1.1 Pollutants of Concern

Deposition of anthropogenic, or human-caused, air pollution containing nitrogen (N) and sulfur (S) can have widespread and detrimental acidifying and nutrient enrichment effects on natural ecosystems in the United States (US EPA 2008). Depending on its chemical composition, non-organic N pollution is classified as oxidized or reduced. Anthropogenic sources of oxidized N (NO_y) and S (SO_x) pollution include coal-fired electrical power generation, motor vehicles, and industrial combustion sources. Reduced N (NH_x) emissions often originate from agricultural sources such as feedlots, fertilizer production/use, and agricultural burning; NH_x can also originate from motor vehicles and industrial activities where NO_y emissions controls result in the production of NH_3. The gases and particles found in emissions from these sources can travel several hundred miles before they wash out of the air in the rain or snow (wet deposition), or fall directly on a surface such as a tree leaf or lake (dry deposition). The ability to travel long-distances means remote areas of the United States, including National Forests and Grasslands, are exposed to anthropogenic N and S deposition (McDonnell and Sullivan 2014).

Since the 1970 Clean Air Act and its amendments, emissions from stationary sources of SO_x (primarily SO_2) and NO_y have decreased significantly across much of the United States (US EPA 2016), resulting in a widespread decrease of NO_y and S deposition in precipitation (Du et al. 2014, Lehmann and Gay 2011). However, levels of N and S deposition remain above natural background conditions. In some western locations, emissions and deposition of N is increasing 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 (Ellis et al. 2015, Li et al. 2016, Lu et al. 2016, Neff et al. 2008, Weinhold 2012, Zhang et al. 2008).

1.2 Ecosystem Effects of Air Pollution

Atmospheric deposition within the USDA Forest Service Intermountain Region[1] contains, in part, a mixture of N and S compounds. Excess deposition can be acidifying or act as a nutrient (Sullivan and Jenkins 2014). When water below the ground (i.e., soil water) acidifies, base cations including calcium and magnesium, may be flushed out of the soil into drainage water (Lawrence et al. 2002). Increased acidity of soil and surface water can harm plant roots, fish, and other organisms (Driscoll et al. 2001, US EPA 2008). Soil organic matter and base cations, such as calcium and magnesium, help protect plants and aquatic biota from some of the effects of atmospheric N and S deposition. The various N compounds in atmospheric deposition can also serve as nutrients that are taken up by plant roots and canopies, stored in biomass, released by decay, and cycled into new growth. When N is in short supply, it is generally retained within the ecosystem in soil, vegetation, and microbial biomass. However, as N inputs increase, excess N leaches into soil water and moves to streams and lakes where it is used as a nutrient by algae to increase growth (Baron 2006, Greaver et al. 2012). High elevation areas, where most western USDA Forest Service managed Wilderness Areas occur, are often sensitive to acidification and nutrient enrichment effects caused by atmospheric N and S deposition, in part, because soils in these areas are often very thin or nonexistent and thus do not provide a buffering effect.

[1] The USDA Forest Service Intermountain Region, with regional headquarters in Ogden, Utah, includes 12 National Forests that are located in Utah, Nevada, western Wyoming, and southern and central Idaho. See Figure 4-1 for visual description. For more information, see https://www.fs.usda.gov/main/r4. The Intermountain Region is also referred to as Region 4.

When N supply is overly abundant, above ground biomass typically increases at a greater pace than below ground biomass. This can change the shoot to root biomass ratio, leading to an increased susceptibility to fires, drought, and wind damage (Greaver et al. 2012). When N accumulates in an ecosystem, the structure of the biological communities can change. Additional inputs of N can cause fast-growing invasive or new species to out-compete native species adapted to low N environments (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, Geiser et al. 2019, Sullivan and Jenkins 2014,).

Epiphytic lichen species grow above the ground on tree and shrub stems. These lichens absorb nutrients directly from the atmosphere and are sensitive to increases in atmospheric pollution. Elevated N and S pollution have been linked to biological responses in many epiphytic lichen species including decreases in community richness and abundance of ecologically important species (Geiser et al. 2019).

1.3 Critical Loads and Forest Planning

Critical loads are used to simplify complex scientific information and communicate the effects and risk of air pollution deposition to federal land managers, policy makers, and the public (Blett et al. 2014; Burns et al. 2008, 2011). The critical load (CL) is a science-based threshold that identifies the amount of pollutant deposition below which significant ecological harm to an ecosystem component is not expected to occur (Nilsson and Grennfelt 1988). Areas where pollution deposition is above the CL are in exceedance and have an increased risk of negative ecological effects (e.g., decreases in native species richness and abundance, decrease in tree growth rate and lifespan, increase in risk for eutrophication). The level of risk is affected by the magnitude and duration of the exceedance. The CL approach has been applied to N and S deposition to protect sensitive resources, including lakes, streams, lichens, plants, mycorrhizae, and forested ecosystems (Sullivan 2017). Critical loads have been used in Canada and Europe for many years (Dupont et al. 2005, Ouimet et al. 2006, Posch et al. 2001) and are increasingly incorporated across the United States to assess ecosystem or resource risk from air pollutants for land management, policy, and regulatory decision-making. To adequately address and respond to air pollution deposition effects on ecosystems and resources, it is important for land managers to:

1) Obtain knowledge of current pollutant loading on the landscape
2) Understand the effects of air pollution on sensitive resources and biota
3) Identify CLs for sensitive resources and biota
4) Locate areas at risk, typically areas with the highest CL exceedance, and, when applicable,
5) Develop mitigation, remediation, and management strategies

The various resources evaluated in this report have different sensitivities to N and S deposition and thus many National Forests will have multiple CLs. As part of CL assessments, land managers consider which CLs are best suited to guide protection of resources under their management. Quantifying the ecological effects and risk caused by N and S deposition can help land managers anticipate ecological changes due to air pollution and determine if current air quality conditions are sufficient to protect ecosystem integrity and natural resources sensitive to air pollution (Geiser et al., in preparation). Management actions and potential mitigation

strategies can then be considered to best protect the resource of concern. These actions and strategies are discussed in more detail within the results and discussion section of this report.

Regulation and permitting of major air pollutants and pollution sources falls under regulatory agency control. Land management agencies such as the USDA Forest Service (hereafter referred to as Forest Service) have little direct influence over emission sources beyond projects carried out or permitted within their agency boundaries. Land management agencies can, however, work with regulatory agencies and comment on projects outside agency boundaries in an effort to minimize additional pollution deposition to areas of concern.

The analysis in this report fulfills the CL requirements for the assessment phase of the Forest Service 2012 Forest Plan Revision Directives (Forest Service Handbook, FSH–1909.12, chapter 10; https://www.fs.fed.us/im/directives/dughtml/fsh_1.html). Information and results from this report may also be used in National Environmental Policy Act (NEPA) projects, wilderness monitoring and assessments, Prevention of Significant Deterioration permitting program (PSD), and other applications. The figures and tables presented in this report quantify the risk for negative effects to occur and include spatial information about these risks and do not necessarily indicate that the specified effects have occurred. ArcGIS (Environmental Systems Research Institute [ESRI], Redlands, CA) maps and shapefiles for all the figures presented in this report are available through the regional air program and the Intermountain Regional Office Information Management staff.[2]

2 OBJECTIVES

This report uses the most recent 3 year rolling average of N and S deposition estimates (2015 to 2017) and the best available scientific data to map and summarize CLs of N deposition and associated CL exceedance throughout all the National Forests in the Forest Service Intermountain Region. The purpose of this report is to inform forest plan assessments and management decisions related to ecosystem resources that are affected by N and S deposition. Resources were chosen based on availability of CL estimates and sensitivity to N and S deposition.

The following CLs and exceedances were assessed for terrestrial or aquatic environments:

- Surface water acidification
- Surface water eutrophication
- Lichen species richness and forage lichen abundance
- Tree growth rate and probability of survival over 10 years

The term "surface water" in this assessment refers to the following water above the earth's surface, lakes, ponds, streams, and rivers. The surface water eutrophication assessment includes all such water bodies. The surface water acidification assessment, however, was based on available water chemistry samples collected at individual sites, which were predominantly lakes and streams.

[2] ArcGIS maps and shapefiles for all the figures presented in this report are available through the regional air program and the Intermountain Regional Office Information Management staff, 324 25th Street, Ogden, UT 84401. Forest Service personnel can access the files at T:\FS\Reference\GIS\r04\Data\AirCriticalLoadAnalysis\Map_Data.

Deposition of S was incorporated into the CLs used for surface water acidification, tree species growth rate, and tree species probability of survival. Sulfur CLs for lichens were not used because the models used to derive S CLs were based on lichen plots located in Eastern US and this affected the reliability of the S CL estimates for the Interior West. Sulfur deposition was also not used in the calculations for surface water eutrophication, because eutrophication is primarily a response to nutrient N and phosphorus (P) enrichment.

3 CRITICAL LOAD DATA

This section includes background information on the different resources that were assessed in this study. Descriptions of the primary data sources used to map the CLs in this report are also included in this section.

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 that offer little buffering capacity. In the Eastern U.S. surface water acidification has been linked to species losses of fish, phytoplankton, and zooplankton, and changes in community composition, ecosystem structure and ecosystem function (US EPA 2009). An ANC of 50 $\mu eq\ L^{-1}$ or greater is recognized as providing general ecosystem protection even for surface waters susceptible to episodic dips in ANC during rainfall or snowmelt events (Baldigo et al. 2007, Robison et al. 2013). At ANC concentrations around or below 20 $\mu eq\ L^{-1}$, water acidity and/or concentrations of inorganic aluminum released from soils by increased acidity can be lethal to many aquatic species (US EPA 2009).

A national database has been compiled by EPA for surface water sites where nitrate and sulfate chemistry were available. This database includes CLs for N and S deposition calculated to protect surface waters from acidification (Lynch et al. 2019). The CL calculation 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. For sites with more than one year of data, the CL is representative of the average available water chemistry data at the site.

Uncertainty exists in the steady-state mass balance models used to estimate surface water acidification CLs, as they are based on an 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 related to the estimation of base cation (e.g., calcium and magnesium) weathering and from infrequently sampled sites where limited data were used to estimate the condition of the waterbody.

3.2 Surface Water Eutrophication

Nitrogen deposition has been shown to affect the nutrient status and function of high-elevation aquatic ecosystems in the western United States (Baron 2006). Such effects have included elevated surface water NO_3^- concentration and associated increases in algal abundance (Nanus et al. 2012). Aquatic ecosystems in mountainous 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).

Algae, such as *Asterionella formosa*, are among the first organisms to respond to nutrient changes in aquatic systems because of their diversity and short generation times. These qualities make *A. formosa* a useful sensitive indicator of N enrichment to surface waters (Saros et al. 2005, 2011; Slemmons et al. 2015). Exceedances of algae-based CLs for aquatic eutrophication can be used as early warning indicators of ecosystem change by resource managers. Managing for CLs of algae provides broad protection across both terrestrial and aquatic ecosystems (US EPA 2009).

Estimates of wet N deposition CLs calculated to protect aquatic ecosystems from nutrient enrichment effects were developed by Nanus et al. (2012) for a portion of the Intermountain Region. Critical load estimates were derived using statistical relationships between surface water nitrate measurements, the annual rate of wet N deposition received by the watershed, and watershed characteristics. Nanus et al. (2012) defined a surface water nitrate threshold by quantifying the growth rate of *A. formosa* in response to experimental N addition. The nitrate concentration that caused substantial change, in this case a maximum growth rate for *A. formosa*, occurred at 0.5 µmol L^{-1}. This nitrate concentration is used to mark the onset of surface water eutrophication (Nanus et al. 2012). A low CL indicates resource sensitivity, increases the likelihood of CL exceedance, and raises the risk of adverse effects to occur.

A later study by Nanus et al. (2017) followed a similar approach as the 2012 study. However, the 2017 study developed CLs of total (wet + dry) N deposition rather than only wet N deposition. The Bridger-Teton was the only National Forest in the Intermountain Region where full coverage of total N was available (Nanus et al. 2017). 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 modeled CL estimates generated by Nanus et al. (2017) were sensitive to differences in watershed characteristics, modeled deposition inputs, and changes in the selected surface water nitrate concentration value.

Uncertainty in the modeled wet and total N deposition estimates affects both the estimated CL values and the exceedances. Estimating total N deposition is difficult especially in complex terrain where land cover and deposition change dramatically over short distances (McDonnell et al. 2010). Any refinement to the NO_3^- threshold value would affect current CL estimates. Nanus et al. (2017) only included lake nitrate concentrations that were measured during the late growing season and did not incorporate seasonal variability; additional data would be needed to capture effects of seasonality.

3.3 Lichen Species Richness and Forage Lichen Abundance

Epiphytic macrolichens (non-crustose lichens growing on trees and shrubs) consist of one or more fungi (mycobiont) in symbiosis with algal and/or cyanobacterial photobiont(s). Lichens are sensitive to air pollutants, including N and S deposition, in part because they get most of their nutrients from the atmosphere, have a delicate nutritional balance among the symbionts, and lack many regulatory structures, such as guard cells, stomata, and root stele, which vascular plants can use to keep out or move unwanted contaminants (Munzi et al. 2010, Nash 2008). Because epiphytic macrolichens live under most forested canopies and are sensitive indicators, CLs that protect lichens can broadly protect other forest resources.

The Forest Service's Forest Inventory and Analysis (FIA) and Air Resource Management programs have used nationally standardized survey protocols to monitor the presence and

abundance of lichens across U.S. forests for over two decades (USDA FS 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 such as deer, birds, and various insects (Geiser et al., 2021). 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 surveys, based on FIA protocols, were used to identify the rates of decline in the functional groups at different levels of N and S deposition (kg ha^{-1} yr^{-1}; Geiser et al. 2019). With this method, one nationwide CL was defined for each functional group. Each CL corresponds to the N deposition level where 20 percent declines in each functional group was observed as this was the point identified as being ecologically significant. Critical loads were identified for the following functional groups: total species richness, sensitive species richness, forage lichen abundance, and cyanolichen abundance (**Table 3.1**; Geiser et al. 2019).

Two of the functional groups from Geiser et al. (2019), cyanolichens and sensitive lichen species, were excluded from this assessment because they are limited or absent in many parts of the Intermountain Region due to unfavorable climatic and ecological conditions. This report uses the CLs for total lichen species richness and forage lichen abundance. In the nationwide model, percent declines in lichen species richness of up to 50 percent were observed in response to N deposition. At this level of N deposition, an increase in the colonization of nitrogen tolerant species was observed and total species richness stopped decreasing (Geiser et al. 2019). Forage lichen abundance, however, continually declined as N deposition increased, with estimated declines >80 percent in some locations.

It is important to note that at the time of analysis for this report, the CL for forage lichen abundance was 2.0 kg N ha^{-1} yr^{-1}, it has since been revised and published as 1.9 kg N ha^{-1} yr^{-1} in Geiser et al. (2019). The risk evaluation and management implications are largely unaffected by this 0.1 kg N ha^{-1} yr^{-1} change.

The analyses reported by Geiser et al. (2019) were based on a very large data set (n=8855 plots) representing 362 lichen species and provides a foundation for understanding ecological risk. The main sources of uncertainty in the CL risk analysis stem from interactions between and among pollutants, the lack of high S deposition sites in the western United States, and uncertainties in deposition estimates, species recovery rates, and the percent of existing species collected within a

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[a]	2.6
Cyanolichen abundance	1.3	2.3

[a] 2.0 kg N ha^{-1} yr^{-1} was the CL for forage lichen abundance recommended and used at the time of the analysis for this report. The CL was revised and published in Geiser et al. (2019) as 1.9 kg N ha^{-1} yr^{-1}.

community (Geiser et al. 2019) . The level of uncertainty associated with a lack of high S deposition sites in the western United States resulted in the decision to exclude S CLs in this assessment. It should also be recognized that Geiser et al. (2019) was a broad-based empirical study, so while changes in lichen communities were statistically related to high N deposition levels, direct cause and effect relationship has not been established.

The lichen CLs developed by Geiser et al. (2019) were based on deposition data from the Community Multi-scale Air Quality Model (CMAQ), which has been shown to underestimate wet deposition for nitrate (-1.11 to -3.73 kg ha^{-1} yr^{-1}) and ammonia/ammonium (-0.26 to -0.81 kg ha^{-1} yr^{-1}) across 9 out of 10 ecological regions in the United States (Zhang et al. 2018). Underestimation of wet N deposition may cause calculations of lichen CLs to be low. To be consistent among all CL types included in this report, exceedance of the lichen CLs were calculated using deposition estimates from the total deposition (TDep) assessment of Schwede and Lear (2014). A study by McDonnell et al. (2020) compared TDep and CMAQ deposition estimates across the conterminous United States for the years 2003 and 2011. In the Intermountain Region, the 2011 CMAQ total N estimates were consistently lower than TDep. In some areas, including high elevations, the difference was between 1 and 4 kg N ha^{-1} yr^{-1} (McDonnell et al. 2020). Nitrogen deposition differences were driven by wet versus dry deposition. This assessment used average 2015–2017 TDep data which likely models N deposition higher than the CMAQ modelled N deposition estimates used to calculate lichen CLs. Thus, the magnitude and extent of lichen CL exceedance presented in this report may be conservative (estimating higher exceedances), regardless, this analysis provides an estimate of relative risk to lichens and maps areas of concern.

3.4 Tree Growth and Survival

Nitrogen and sulfur deposition can affect tree growth rate and probability of survival over 10 years (Horn et al. 2018). Both increasing and decreasing responses in growth rate or survival can lead to shifts in community composition and structure. Atmospheric N and S deposition can affect tree species and communities through soil acidification, increased aluminum mobility in soils, 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, Horn et al. 2018, McNulty and Boggs 2010, Pardo et al. 2011, US EPA 2009).

Horn et al. (2018) reported the variation in the rates of tree growth and probability of survival over 10 years for 71 species as functions of N and S deposition, among other variables, across the conterminous United States. The study analyzed nearly 1.5 million trees from forest plots inventoried by the FIA program between 2000 and 2016. Results suggested that the growth and/or survival of the majority of tree species in the analysis were significantly affected by atmospheric N or S deposition, or both.

Relationships between tree response (growth rate or probability of survival) and deposition were described as increasing, decreasing, threshold, or flat (**Figure 3-1**; Horn et al. 2018). U.S. Environmental Protection Agency gridded N and S deposition data between 2000 to 2013 were used for this study. The modeled responses to N deposition varied among tree species. For some species, growth rate and/or probability of survival declined consistently under very low levels of N and/or S deposition, while other species showed no effect (i.e., a flat response), a threshold response, or an increasing response to N deposition (Horn et al. 2018). A key assumption in the growth and survival models only allowed for flat or decreasing relationships with S deposition. An increasing growth response with low levels of S deposition may occur in some tree species (Fenn et al. 2020). Sulfur 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 United States.

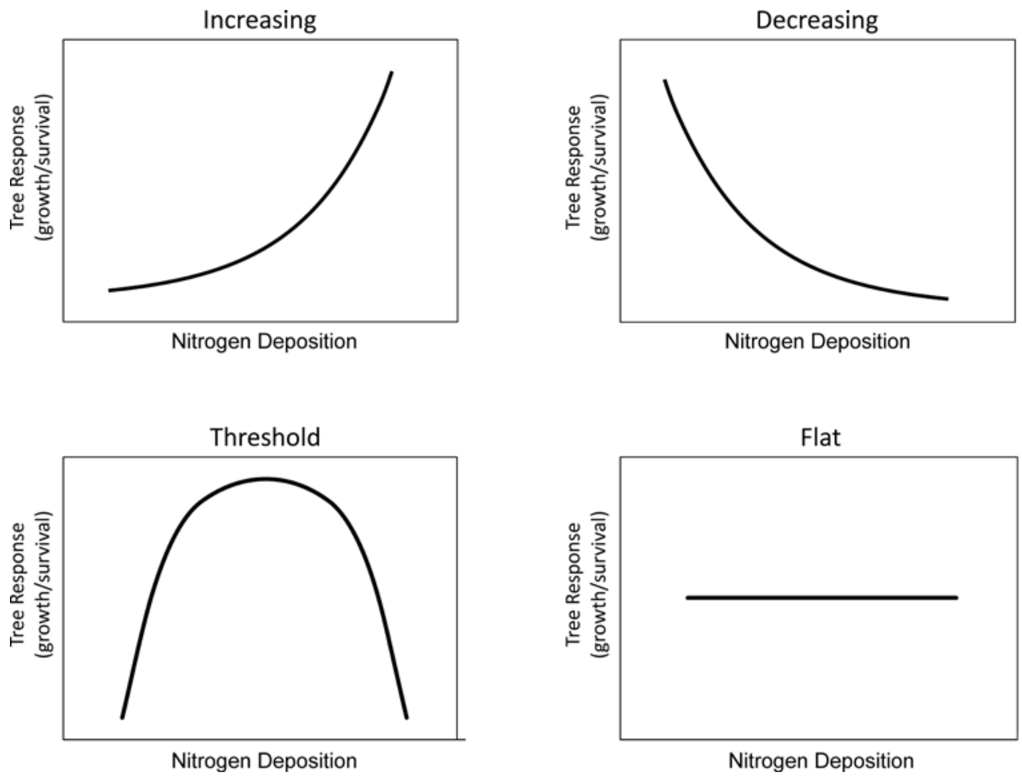


Figure 3-1.—Illustration of primary response types for tree growth and survival reported by Horn et al. (2018).

Although air temperature, precipitation, tree size, and competition were included as potential predictor variables (in addition to N and S deposition), other factors that influence tree growth rate and probability of survival were not considered in the analysis. These include ozone exposure, seasonal drought, insect infestation, and disease among other environmental or climatic factors. The exclusion of these other factors known to affect forest health increases uncertainty in the response functions and associated CLs.

3.5 Herbaceous Plants and Mycorrhizae

Published CLs for N deposition effects on herbaceous plants and mycorrhizae were developed for large geographic areas (i.e., "ecoregions") and varied widely, encompassing a range of species and responses (Pardo et al. 2011). These CLs were not used in this report because they were developed from data predominantly collected outside the Intermountain Region, the spatial resolution was coarser than the other datasets, and the confidence in the interpretation of the data for the Intermountain Region was low. Simkin et al. (2016) was also considered, but the coverage of data in the Intermountain Region was less complete than the other datasets used in this CL assessment.

4 APPROACH

The 12 National Forests and one National Grassland in the Intermountain Region were included in this CL assessment (**Figure 4-1**). The geographic area includes Nevada, Utah, western Wyoming, and central and southern Idaho. The references for identifying CLs used in this assessment are listed in **Table 4-1**.

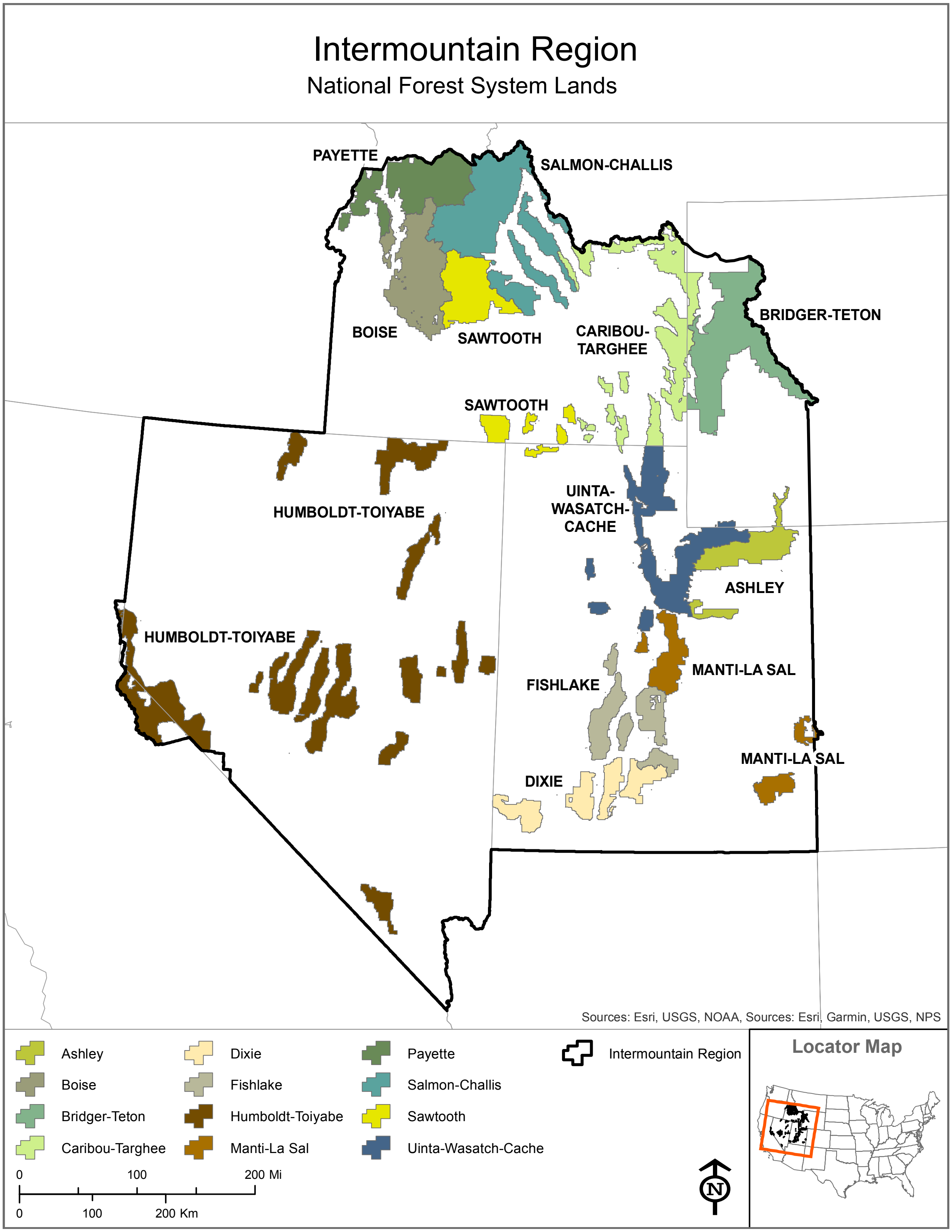


Figure 4-1.—National Forest System lands in the Intermountain Region of the USDA Forest Service.

Table 4-1.—The critical loads and references used for assessment

CLs	Reference(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)

Estimates of N and S deposition from TDep were used to calculate the CL for surface water acidification and eutrophication. Nationwide CLs for lichens and tree species were calculated prior to this assessment (Geiser et al. 2019, Horn et al. 2018). TDep was also used to evaluate exceedance of the CL for surface water acidification and eutrophication, lichen functional groups, and tree species growth rate and probability of survival. TDep uses a hybrid approach of measured and modeled data to produce deposition estimates (Schwede and Lear 2014, TDep v2018.02). The modeled N estimates for this report are calculated as the average of the three most recent years (2015–2017) available. Total N and S deposition within the Intermountain Region are shown in **Figures 4-2** and **4-3**.

4.1 Surface Water Acidification

To protect against acidification of surface waters, critical loads for N deposition were calculated for specific locations with known water chemistry data (Lynch et al. 2019). Within the Intermountain Region water chemistry data sites were primarily lakes and streams. Two CLs were calculated, one that protects ANC from decreasing below 50 µeq L^{-1} and one that protects ANC from decreasing below 20 µeq L^{-1}. This assessment focuses on and maps the CLs that protect ANC from decreasing below 50 µeq L^{-1} because this CL allows for earlier indication of shifts towards acidification and are more protective of the resource. Some surface waters in the Intermountain Region have ANC levels historically below 50 However, a small percentage of surface waters (<8 percent) had measured ANC values below 50 µeq L^{-1} (<8 percent) and therefore these surface waters were only included in the CL that protects ANC from decreasing below 20 µeq L^{-1}. It is important to note, for example, that if a given stream or lake currently has an ANC of 75 µeq L^{-1}, sustained deposition at the CL that protects an ANC decrease below 50 µeq L^{-1} would ultimately cause ANC to decline by 25 µeq L^{-1}, a loss of one-third of the acid neutralizing capacity. Thus, the CLs for these types of systems represent the maximum deposition that the system can tolerate without decreasing below 50 µeq L^{-1} and not the deposition that would maintain current water quality conditions (i.e., ANC = 75 µeq L^{-1} in this example).

Exceedances of acidification CLs were determined based on total (wet + dry) N deposition (2015–2017, average TDep version v2018.02). Exceedances were calculated as total N deposition minus the CL, with positive values resulting in exceedance of the CL. Because both N and S contribute to surface water acidification, acidification CLs for N deposition used current S deposition levels in the calculations. Critical loads of S deposition at current levels of N deposition were not calculated because S deposition is currently low throughout most of the Intermountain Region (**Figure 4-3**) and is not expected to increase significantly. However, if new sources of S emissions in the region are proposed, calculations for CLs of S deposition to protect against surface water acidification should be considered. Increases in S deposition would decrease the CLs of N reported and increase levels of exceedance.

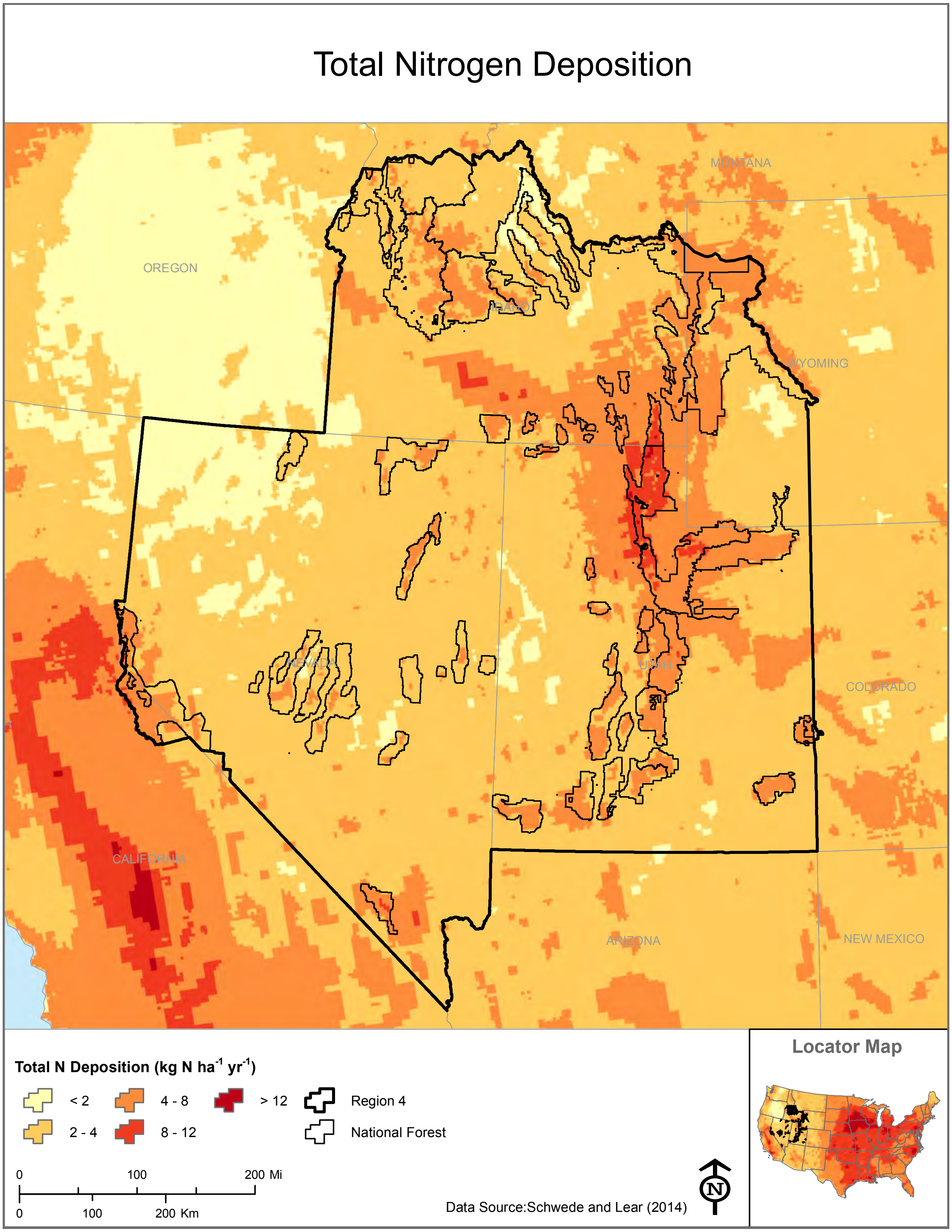


Figure 4-2.—Total (wet + dry) N deposition (average 2015–2017) from the Total Deposition model (TDep; Schwede and Lear 2014) for the Intermountain Region of the USDA Forest Service.

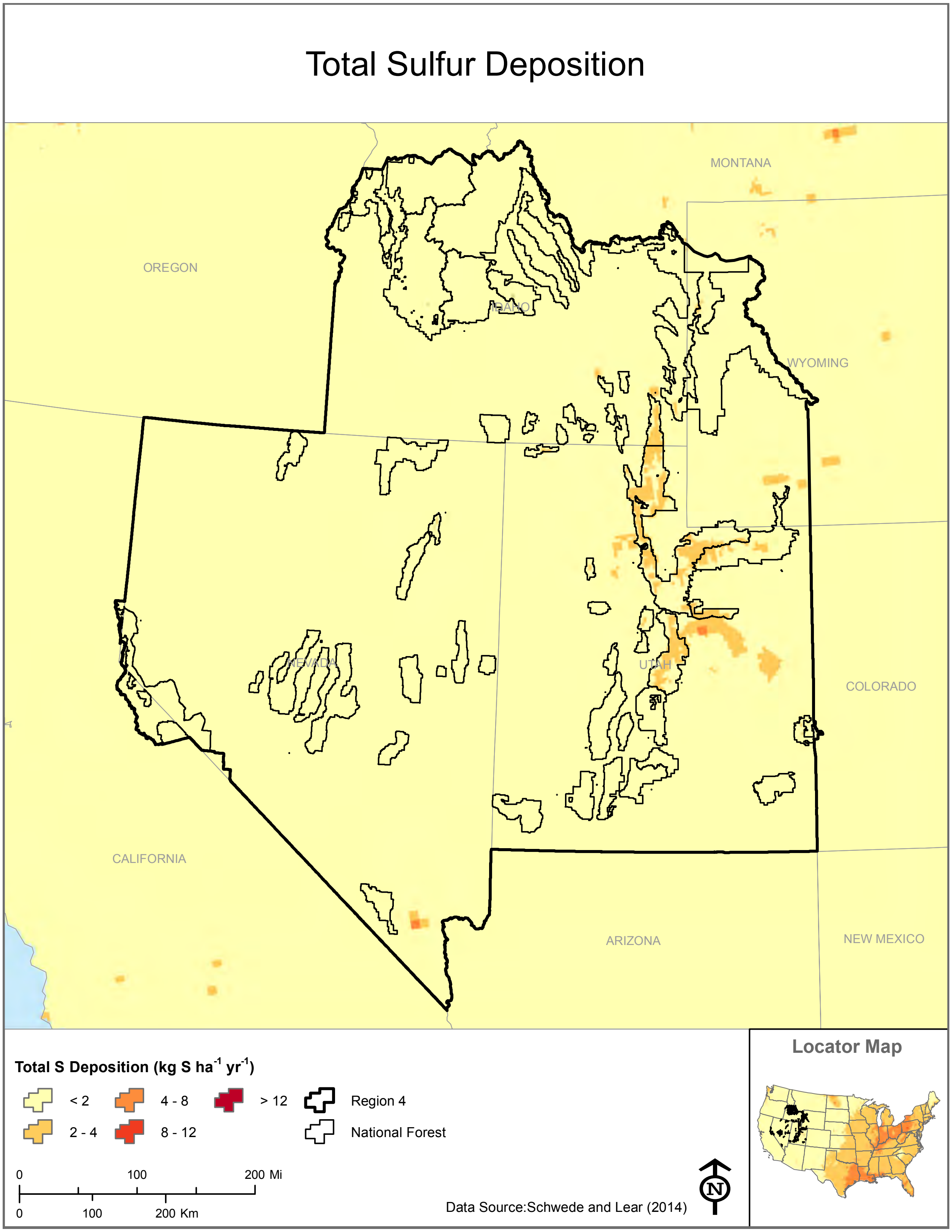


Figure 4-3.—Total (wet + dry) S deposition (average 2015–2017) from the Total Deposition model (TDep; Schwede and Lear 2014) for the Intermountain Region of the USDA Foerst Service.

4.2 Surface Water Eutrophication

The N deposition CLs that protect against surface water eutrophication and associated biological effects for the Bridger-Teton National Forest were calculated based on total N deposition (Nanus et al. 2017). Critical loads based on wet N deposition reported in Nanus et al. (2012) were used for the remainder of the National Forests in the Intermountain Region. Critical load exceedances were calculated with N deposition (total or wet) estimates from the TDep model (2015–2017, average TDep v2018.02). Surface water includes water bodies above the earth's surface, such as lakes, ponds, streams, and rivers. Surface water eutrophication CLs were based on a nitrate threshold ($NO_{3\ (threshold)}^{-}$) of 0.5 µmol L^{-1}. This low NO_3^- concentration (µmol L^{-1}) resulted in substantial change—maximum growth rate of the N-sensitive algal species *A. formosa* (Nanus et al. 2012)—and represents early onset of biological effects to surface waters. Changes in the abundance of primary producers such as *A. formosa* can affect higher trophic levels. Critical loads and exceedances for surface water eutrophication were calculated and mapped based on continuous polygon coverages representing incremental drainage areas (i.e., small catchments based on USGS NHDPlus) as provided by Nanus et al. (2012 and 2017). This means that the figures show the CL and CL exceedance for surface waters that occur at these locations. Some areas within the Intermountain Region were outside the bounds of the two studies used to calculate CLs (Nanus et al. 2012, 2017) and thus are marked as "No Data" in the figures.

4.3 Lichen Species Richness and Forage Lichen Abundance

The CLs of N deposition were calculated to protect lichen species richness and forage lichen abundance from decreasing by >20 percent. The CLs used in this assessment were 3.5 and 2.0 kg N ha^{-1} yr^{-1}, respectively (Geiser et al. 2019). It is important to note that at the time of analysis for this report the CL associated with a 20 percent decline in forage lichen abundance was 2.0 kg N ha^{-1} yr^{-1}, it has since been revised and published as 1.9 kg N ha^{-1} yr^{-1} in Geiser et al. (2019). The risk evaluation and management implications are grouped into ranges of percent decline to identify areas of risk, the 0.1 kg N ha^{-1} yr^{-1} change do not alter these ranges. In addition, modeled N deposition estimates for most forest system lands in the Intermountain West are above 2.0 kg ha^{-1} yr^{-1}. Geiser et al. (2019), showed that decreases in lichen species richness and forage lichen abundance were related to increased N deposition. Nitrogen deposition levels associated with different percent declines in lichen species richness and forage lichen abundance (**Table 4-2**) were used to define the classes for mapping various levels (magnitudes) of exceedance. For example, 4.03 to 6.63 (kg N ha^{-1} yr^{-1}) is associated with a 40 percent to 50 percent decline in forage lichen abundance. These levels of N deposition exceed the CL that protects forage lichen abundance from adverse effects (Geiser et al. 2019; **Table 4-2**).

Although Geiser et al. (2019) also generated CLs for S deposition, these CLs were calculated using plots mainly from the eastern United States due to the narrow S deposition gradient in the west. Because of this, uncertainty for the S CLs for western forests was increased and these CLs were excluded from this Intermountain Region assessment. It is important to note that while CL exceedances of lichens were mapped over the entirety of each National Forest administrative boundary, epiphytic lichens in these functional groups are not present throughout 100 percent of any given forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

Table 4-2.—Level of N deposition (kg N ha^{-1} yr^{-1}) associated with various magnitudes of decrease on lichen species richness and forage lichen abundance. The CL is set at 20 percent declines for both functional groups (bold).

Response	Magnitude of decrease (from maximum count or abundance)	N deposition (kg N ha^{-1} yr^{-1})
Lichen species richness	**20%**	**3.50**
	30%	5.65
	40%	8.55
Forage lichen abundance	**20%**	**2.00**[a]
	30%	2.93
	40%	4.03
	50%	6.63
	80%	8.27

[a] The CL associated with a 20 percent decline for forage lichen abundance has been revised since the analysis of this report to 1.9 kg N ha^{-1} yr^{-1}.

4.4 Tree Growth and Survival

Horn et al. (2018) used a minimum of 2,000 trees of each species to develop models for tree response in growth rate and probability of survival over 10 years to N and S deposition. Curves for the best fit model for each tree species was reported in Horn et al. (2018). The CL is defined here as the last point before a decline in growth rate or probability of survival over 10 years occurs. For species with a threshold (curved) response, the CL falls at the top or maximum point of the curve. For species with decreasing trends, the CL is at the first point of decline. There are five tree species in the Intermountain Region with threshold or declining response curves to N or both N + S deposition for growth rate and or probability of survival (**Table 4-3**). Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines beyond the estimated CLs for growth rate and probability of survival were assessed (**Table 4-3**). These percent declines were chosen as points of interest based on preliminary conversations with research agencies and forest land managers. Different N deposition levels or percent declines can be selected and assessed to address specific management goals and needs of individual National Forests. When the percent of change in probability of survival is low (e.g., 1 percent) it may be difficult to understand mortality effects due to N deposition because of uncertainty in both the modeling and in the deposition estimates.

Exceedances were mapped for individual tree species that showed a decrease or threshold response to N deposition (kg ha^{-1} yr^{-1}) associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival (**Table 4-3**). Additional tree species occur in the Intermountain Region but were not evaluated in this report because the response curves to N deposition were either flat or increasing (**Table 4-4**). Common names were used for tree species throughout the report; however, scientific names can be found in **Tables 4-3 and 4-4**.

The probability of survival model for balsam poplar was based on the second-best model because that model included N deposition as a driver of effects and was statistically equivalent to the best model, which did not include N deposition. Growth response models for western juniper (*Juniperus occidentalis*) and Engelmann spruce (*Picea engelmannii*) and survival models for grand fir (*Abies grandis*) and Engelmann spruce showed decreasing or threshold responses to N deposition (**Table 4-4**). However, CLs for these models were not included in this report because N deposition showed high correlations with other variables in the model. When correlations are high, the model is unable to separate changes in growth or survival related to N deposition from those related to other factors in the model such as climate variables.

Table 4-3.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against 1 percent, 5 percent, and 10 percent declines in tree growth rate and probability of survival (over 10 years) for tree species found in the Intermountain Region with available response curves. The critical load (CL) represents the point below which no decline has occurred. CLs were not calculated for species with an increasing or flat response to N deposition.

					N deposition levels that protect against various percent declines in tree growth and survival		
Common name	Scientific name	Form of response to N deposition		CL	1%	5%	10%
Utah juniper	*Juniperus osteosperma*	Survival	Threshold	1.7	3.9	10.7	23.6
Singleleaf pinyon	*Pinus monophylla*	Survival	Threshold	3.0	4.5	7.4	10.9
Balsam poplar	*Populus balsamifera*	Growth	Decreasing	3.3	3.4	4.2	5.4
		Survival	Threshold	3.7	5.0	7.5	10.2
Quaking aspen	*Populus tremuloides*	Growth	Threshold	11.1	13.6	17.5	21.3
		Survival	Threshold	4.2	6.6	11.8	18.4
Douglas-fir	*Pseudotsuga menziesii*	Survival	Threshold	2.0	3.5	7.4	13.2

Although Horn et al. (2018) 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 United States.

Data available through the Intermountain Region Vegetation Classification, Mapping, and Quantitative Inventory Program (VCMQ) were used for mapping the extent of species with either decreasing or threshold responses to N deposition. The VCMQ data provided modeled spatial datasets of existing vegetation at the mid-level scale (generally 1:100,000), this 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 and codominant vegetation. Some vegetation map units contain multiple species that could not be differentiated at this level of modeling (e.g., singleleaf pinyon and two-needle pinyon). 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 or codominant vegetation and other areas that may contain a species of interest that is not dominant or codominant in that area. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1. More information regarding VCMQ methods and products is available at: http://www.fs.usda.gov/goto/landmanagement/projects/VCMQ.

Table 4-4.—Tree species not used that had modeled dominant or codominant canopy cover and response curves within the National Forests of the Intermountain Region. These species were not used because the curves were either flat, increasing, or were correlated with climate variables.

Common name	Scientific name	Form of response to N deposition	
White fir	*Abies concolor*	Growth	Flat[a]
		Survival	Flat
Grand fir	*Abies grandis*	Growth	Increasing
		Survival	Threshold[a]
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing
		Survival	Flat
Boxelder	*Acer negundo*	Growth	Flat
		Survival	Flat
Oneseed juniper	*Juniperus monosperma*	Growth	Flat
		Survival	Flat[a]
Western juniper	*Juniperus occidentalis*	Growth	Threshold[a]
		Survival	Flat
Utah juniper	*Juniperus osteosperma*	Growth	Increasing
Western larch	*Larix occidentalis*	Growth	Increasing[a]
		Survival	Flat
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]
		Survival	Threshold[a]
White spruce	*Picea glauca*	Growth	Flat
		Survival	Flat
Lodgepole pine	*Pinus contorta*	Growth	Flat
		Survival	Flat
Common or two-needle pinyon	*Pinus edulis*	Growth	Flat[a]
		Survival	Flat[a]
Singleleaf pinyon	*Pinus monophylla*	Growth	Increasing
Ponderosa pine	Pinus ponderosa	Growth	Flat
		Survival	Flat
Douglas-fir	*Pseudotsuga menziesii*	Growth	Increasing

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

Wildflowers and sunrise in the Jedediah Smith Wilderness, Caribou-Targhee National Forest. USDA Forest Service photo by Mike Thom.

5 RESULTS AND DISCUSSION

The highest annual N deposition (average 2015–2017) occurred primarily on the Uinta-Wasatch-Cache and southern Caribou-Targhee National Forests, with ranges from 8 to 12 kg N ha^{-1} yr^{-1} (**Figure 4-2**). In contrast, total N deposition in other areas of the Intermountain Region, further from urban and agricultural development, were between 2 to 4 kg ha^{-1} yr^{-1} (**Figure 4-2**). In high N deposition areas, the dominant component of total N deposition was NH_x, such as that from ammonia (NH_3) emissions, primarily from concentrated animal husbandry, fertilized crops, and automobile emissions. The highest estimates of NH_x deposition, 4 to 8 kg ha^{-1} yr^{-1}, were also located on the Uinta-Wasatch-Cache and the southern portion of the Caribou-Targhee National Forests (**Figure 5-1**). Total oxidized N deposition (NO_y), typically a product of fossil fuel combustion, was generally less than 2 kg N ha^{-1} yr^{-1} within the Intermountain Region (**Figure 5-2**). The total S deposition for some National Forests in northern and central Utah and southern Idaho is estimated to be >2 kg S ha^{-1} yr^{-1}. This level of S deposition, considered high for the region, is likely influenced by the presence and location of coal-fired power plants and the density of mobile sources in urban areas (**Figure 4-3**).

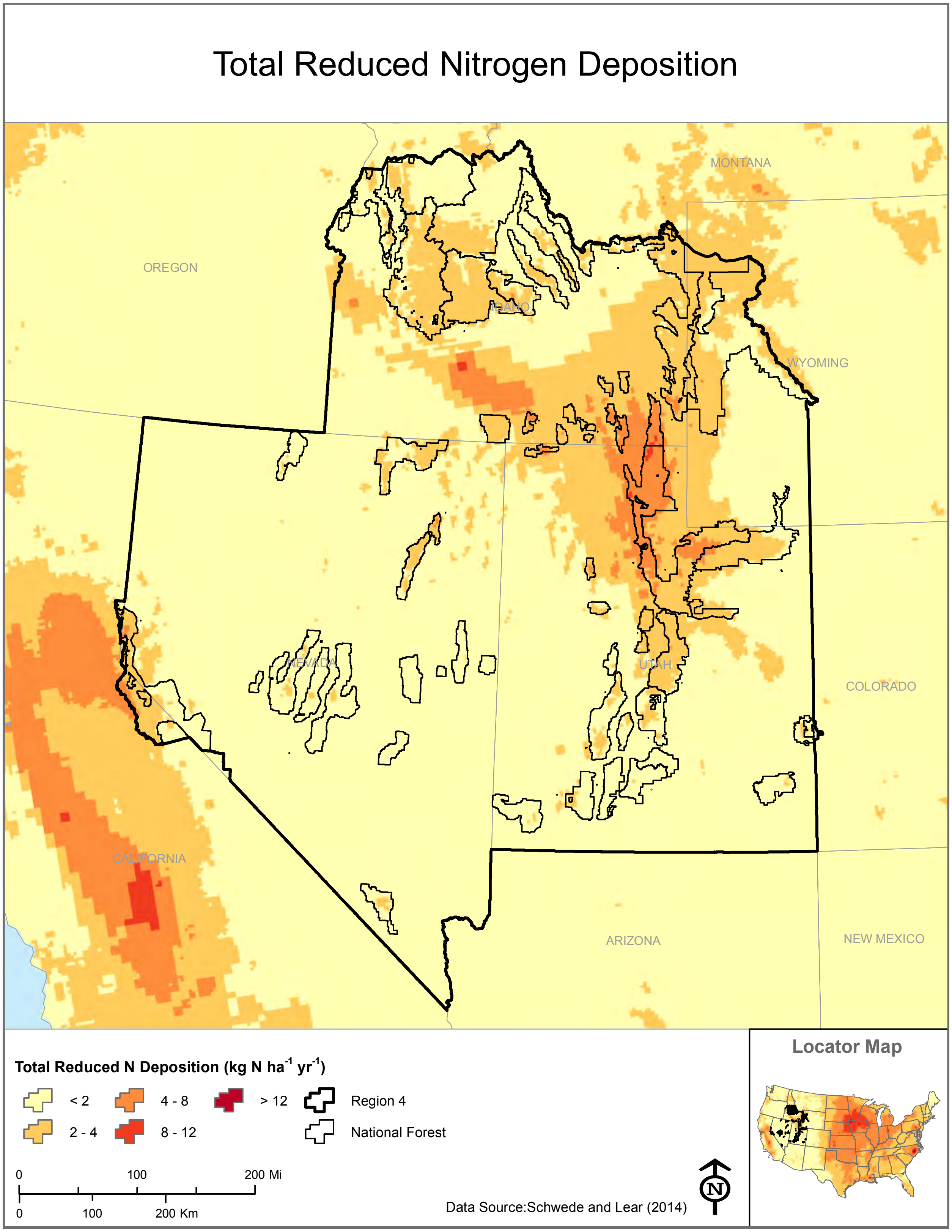


Figure 5-1.—Total (wet + dry) reduced nitrogen (NHx) deposition (average 2015–2017) from the Total Deposition model (TDep; Schwede and Lear 2014) for the Intermountain Region of the USDA Forest Service. Common sources of reduced N include agriculture such as feedlot operations, fertilizer use, agricultural burning, and, to a lesser degree, motor vehicle and industrial activities.

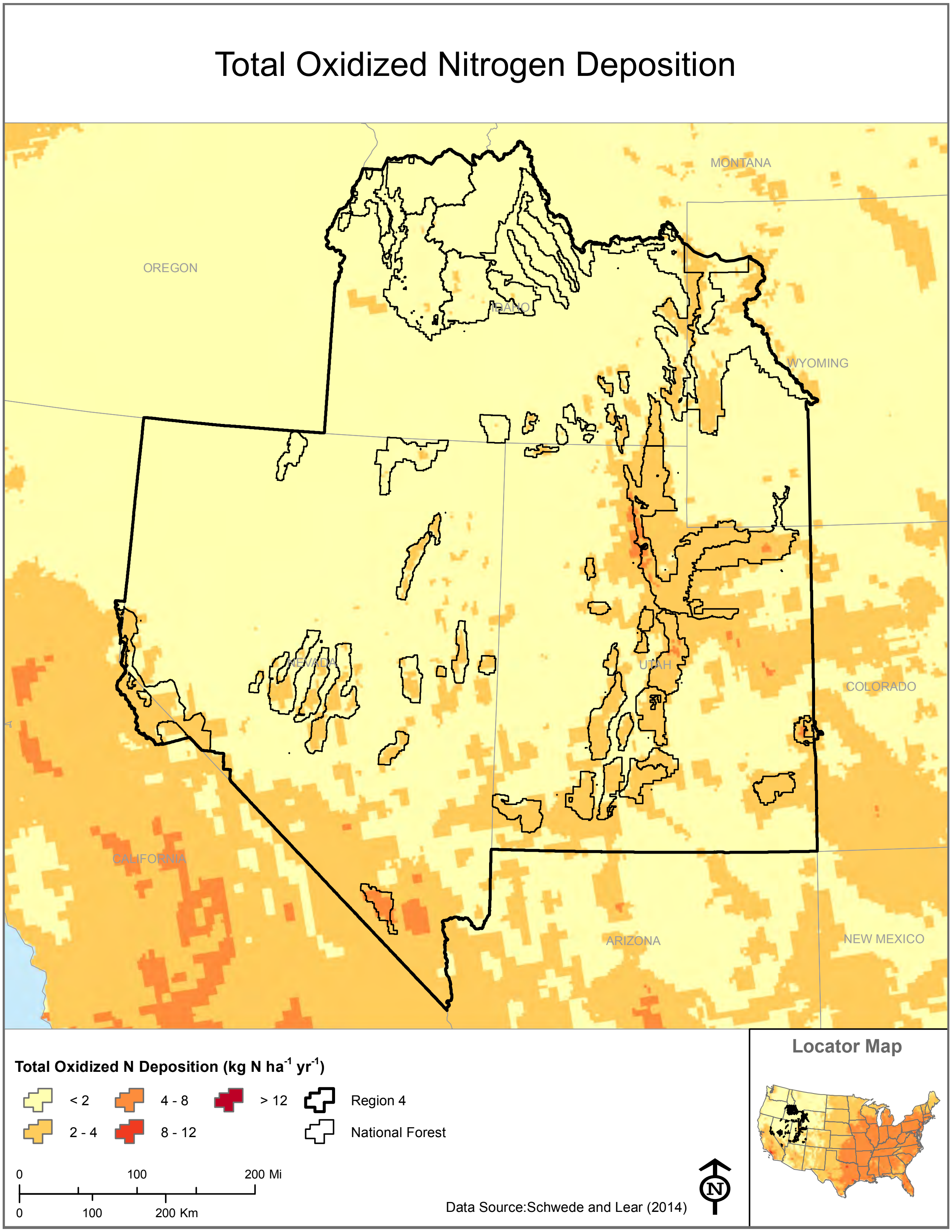


Figure 5-2.—Total (wet + dry) oxidized nitrogen (NOy) deposition (average 2015–2017) from the Total Deposition model (TDep; Schwede and Lear 2014) for the Intermountain Region of the USDA Forest Service. Common sources of NOy include coal-fired electrical power generation, motor vehicles, and industrial sources.

5.1 Summary Data Tables

5.1.1 Surface Water Acidification

Critical loads for N deposition were calculated only for waterbodies (e.g., lakes and streams) with available water chemistry data on each National Forest. Because of this, the number of waterbodies evaluated in this assessment varies between forests. The CL values were calculated to protect surface water ANC from decreasing below 50 μeq L^{-1} or 20 μeq L^{-1}. The figures in this assessment focus on CLs protective of decreases below 50 μeq L^{-1}ANC because it provides an earlier indication of potential acidification. Areas with low CLs (<4 kg N ha^{-1} yr^{-1}) were common on Ashley, Bridger-Teton, and Sawtooth National Forests; these Forests also contained the largest extent of surface water CL exceedance (**Tables 5-1** and **5-2**). The low CLs and numerous CL exceedances on these three National Forests were influenced by the number of sites sampled and the sample location. Most sample sites were lakes in high alpine basins with little buffering capacity due to thin soils and sparse vegetation. These characteristics are associated with sensitivity to changes in surface water acid-base chemistry (Sullivan 2012).

The CL that protects ANC from decreasing below 50 μeq L^{-1} was high (>8 kg N ha^{-1} yr^{-1}) at over half (54 percent) of the sites sampled. The Boise, Dixie, and Manti-La Sal had no exceedances for the CLs that would protect against ANC from decreasing below 50 μeq L^{-1}. The Ashley, Bridger-Teton, and Sawtooth National Forests had the highest number of surface water sites in exceedance due primarily to the high number of sites sampled. The Ashley and Uinta-Wasatch-Cache National Forests had the highest magnitudes (>5 kg N ha^{-1} yr^{-1}) of CL exceedance to protect against ANC from decreasing below 50 μeq L^{-1} (**Tables 5-1** and **5-2**).

Low CLs and high N deposition are two factors that increase the risk for surface water acidification and associated biological effects. Waterbodies with low ANC typically have low CLs, these sensitive waterbodies are more likely to experience changes in chemistry from deposition. Historically, surface water monitoring within the Air Resource program of the Forest Service have focused on waterbodies with low ANC. Thus, sample sites are not random nor representative of all waterbodies on any given forest.

Table 5-1.—The number and percent of sampled waterbodies on each National Forest by the critical load (CL) category (kg N ha^{-1} yr^{-1}) that would protect surface water ANC from decreasing below 50 µeq L^{-1} or 20 µeq L^{-1}.

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

Table 5-2.—The number and percent of sampled waterbodies on each National Forest by the magnitude of critical load (CL) exceedance (kg N ha^{-1} yr^{-1}). The CL is designed to protect surface water ANC from decreasing below 50 µeq L^{-1} or 20 µeq L^{-1}.

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

5.1.2 Surface Water Eutrophication

The CLs that protect against surface water eutrophication were based on a threshold NO_3^- concentration of 0.5 µmol L^{-1}. Surface waters used for this assessment include lakes, ponds, streams, and rivers. The CL calculations used wet N deposition on all National Forests except for the Bridger-Teton which had data available to use total N deposition (Nanus et al. 2012, 2017). Areas with low CLs have a higher likelihood of CL exceedances and associated biological effects. Low CLs of (<2 kg wet N ha^{-1} yr^{-1}) were mapped across at least 25 percent of each National Forest except for the Bridger-Teton National Forest (**Table 5-3**). The highest CL, which is representative of the least sensitive waterbody, was 7.9 kg wet N ha^{-1} yr^{-1}. Nine National Forests exceeded the surface water eutrophication CL on >50 percent of administered lands where data was available (**Table 5-4**). Some National Forests had areas where data was not available because these areas were outside the bounds of the two studies used to calculate CLs for this assessment (Nanus et al. 2012, 2017). The extent of CL exceedance was particularly high (72 to 90 percent) within the Bridger-Teton, Salmon-Challis, Sawtooth, and Uinta-Wasatch-Cache National Forests.

Table 5-3.—Area[a] (km^2) and percent of area in surface water eutrophication critical load categories (kg N ha^{-1} yr^{-1}) for each National Forest using a water nitrate concentration of 0.5 µmol L^{-1}. "Area" represents National Forest System lands where surface waters may exist and not total area of surface water. Areas without data were excluded from the total area for each National Forest where data coverage was incomplete.

National Forest	Forest area	Critical load category (kg wet N ha^{-1} yr^{-1})[b]											
		<1		1–2		2–3		3–4		4–5		>5	
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley	5670.7	2008.3	35.4	589.0	10.4	670.1	11.8	695.6	12.3	689.6	12.2	1018.2	18.0
Boise	9767.7	4101.5	42.0	2067.2	21.2	1708.8	17.5	1116.7	11.4	550.7	5.6	222.9	2.3
Bridger-Teton[b]	14029.6	363.5	2.6	1040.6	7.4	7220.8	51.5	5402.4	38.5	1.9	0	0.0	0
Caribou-Targhee	9286.4	2419.2	26.1	1144.4	12.3	1770.9	19.1	1591.7	17.1	1021.0	11.0	1339.1	14.4
Dixie	4978.8	703.3	14.1	590.3	11.9	784.1	15.7	990.4	19.9	1091.5	21.9	819.1	16.5
Fishlake	6271.9	1320.3	21.1	676.8	10.8	964.2	15.4	1579.5	25.2	1010	16.1	721.3	11.5
Humboldt-Toiyabe	NA												
Manti-La Sal	5620.1	1560.9	27.8	833.4	14.8	1272.4	22.6	1064.1	18.9	564.2	10.0	325.3	5.8
Payette	8533.9	3793.7	44.5	1265.3	14.8	1547.0	18.1	1360	15.9	487.5	5.7	80.3	0.9
Salmon-Challis	17790.7	11405.6	64.1	3069.7	17.3	1821.7	10.2	927.9	5.2	471.0	2.6	94.9	0.5
Sawtooth	6303.0	4505.6	71.5	886.3	14.1	486.8	7.7	245.5	3.9	121.2	1.9	57.6	0.9
Uinta-Wasatch-Cache	9673.9	2587.1	26.7	1295.1	13.4	1884.4	19.5	1723.8	17.8	1192.9	12.3	990.6	10.2

[a] Determined by administrative boundary.
[b] Surface water eutrophication CL for the Bridger-Teton National Forest was based on total N deposition and not only wet N deposition.

Table 5-4.—Area[a] (km^2) and percent of area in each National Forest by the magnitude of surface water eutrophication exceedance. "Area" represents National Forest System lands where surface waters may exist and not total area of surface water. Areas without data were excluded from the total km^2 for each Forest where data coverage was incomplete.

				Magnitude of exceedance (kg wet N ha^{-1} yr^{-1})[b]										Total area and percent in exceedance	
	Forest area	No exceedance		<1		1–2		2–3		3–4		>4			
National Forest	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley	5670.7	2280.4	40.2	631.7	11.1	808.9	14.3	808.2	14.3	748.3	13.2	393.2	6.9	3390.3	59.8
Boise	9767.7	3121.7	32.0	1943.8	19.9	2285.8	23.4	1794.0	18.4	622.6	6.4	0.0	0.0	6646.1	68.0
Bridger-Teton[b]	14029.6	1347.9	9.6	3164.0	22.6	4498.3	32.1	3230.2	23.0	1434.6	10.2	354.6	2.5	12681.7	90.4
Caribou-Targhee	9286.4	3967.6	42.7	1346.1	14.5	1563.5	16.8	1349.5	14.5	523.7	5.6	536.0	5.8	5318.8	57.3
Dixie	4978.8	4009.0	80.5	386.2	7.8	538.0	10.8	45.6	0.9	0.0	0.0	0.0	0.0	969.8	19.5
Fishlake	6271.9	4367.2	69.6	528.7	8.4	808.1	12.9	428.7	6.8	139.2	2.2	0.0	0.0	1904.7	30.3
Humboldt-Toiyabe	NA														
Manti-La Sal	5620.1	2182.7	38.8	1077.5	19.2	1291.5	23.0	626.8	11.2	287.5	5.1	154.2	2.7	3437.4	61.2
Payette	8533.9	3867.6	45.3	1594.3	18.7	2529.4	29.6	542.6	6.4	0.0	0.0	0.0	0.0	4666.3	54.7
Salmon-Challis	17790.7	4861.3	27.3	5277.9	29.7	5115.7	28.8	2535.8	14.3	0.0	0.0	0.0	0.0	12929.4	72.8
Sawtooth	6303.0	663.7	10.5	691.3	11.0	1098.6	17.4	2270.5	36.0	1441.8	22.9	137.0	2.2	5639.2	89.5
Uinta-Wasatch-Cache	9673.9	1599.7	16.5	979.4	10.1	1252.0	12.9	1324.1	13.7	1722.7	17.8	2796.1	28.9	8074.3	83.4

[a] Determined by administrative boundary.

[b] Surface water eutrophication CL for the Bridger-Teton National Forest was based on total N deposition and not only wet N deposition.

5.1.3 Lichen Species Richness and Abundance

The N deposition CL that protects against >20 percent decline in lichen species richness was exceeded on all National Forests in the Intermountain Region, with exceedances ranging from 25 percent to 99 percent (**Table 5-5**). Nearly all of the Manti-La Sal and Uinta-Wasatch-Cache National Forests were in exceedance of the N CL for lichen species richness and, along with the Ashley National Forests, had the highest magnitude of exceedances associated with >30 percent declines.

The N deposition CL that protects against >20 percent decline in forage lichen abundance was exceeded on all National Forests in the Intermountain Region, with exceedances ranging from 97 percent to 100 percent of each forest (**Table 5-6**). Most areas in exceedance experienced N deposition associated with 30 percent to 50 percent declines in forage lichen abundance (**Table 5-6**). The Uinta-Wasatch-Cache National Forest contained the highest magnitudes of exceedance, with 65 percent of the Forest above the CL for N deposition associated with >50 percent declines in forage lichen abundance.

The ecological risk of declines in lichen species richness increases with the magnitude of exceedance. Lichen CL values were calculated using estimates of N deposition from the CMAQ model and the TDep model was used to evaluate exceedances. Due to differences in N deposition estimates between the two models, the CLs reported here are likely conservative causing exceedances and magnitudes to be over-represented. It is important to note that CL exceedances of lichens were mapped across the entirety of each National Forest, while epiphytic lichens used in these functional groups will be absent from many areas, particularly high alpine, shrubland, and grasslands with little to no tree cover and areas where the climatic conditions are not suitable.

Table 5-5.—Area[a] (km^2) and percent of each National Forest by critical load (CL) exceedance category that results in various percent declines of lichen species richness. The CL, 3.5 kg N ha^{-1} yr^{-1}, is associated with a 20 percent decline in lichen species richness.

National Forest	Forest area	Exceedance category (decline 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	5670.3	738.2	13.0	1929.0	34.0	2991.0	52.7	12.1	0.2	4932.1	87.0
Boise	10225.6	3060.0	29.9	7095.8	69.4	69.7	0.7	0.0	0.0	7165.6	70.1
Bridger-Teton	14029.0	2832.8	20.2	10387.4	74.0	808.8	5.8	0.0	0.0	11196.2	79.8
Caribou-Targhee	12454.5	1278.4	10.3	8303.7	66.7	2328.9	18.7	543.4	4.4	11176.1	89.7
Dixie	6925.1	1648.5	23.8	5128.8	74.1	147.8	2.1	0.0	0.0	5276.6	76.2
Fishlake	7236.4	1318.9	18.2	5420.0	74.9	497.5	6.9	0.0	0.0	5917.5	81.8
Humboldt-Toiyabe	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	5722.8	93.0	1.6	3404.3	59.5	2207.9	38.6	17.6	0.3	5629.8	98.4
Payette	9748.1	7362.7	75.5	2385.4	24.5	0.0	0.0	0.0	0.0	2385.4	24.5
Salmon-Challis	17789.8	12050.6	67.7	5708.4	32.1	30.9	0.2	0.0	0.0	5739.3	32.3
Sawtooth	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	11789.2	80.6	0.7	1622.5	13.8	6662.3	56.5	3423.8	29.0	11708.6	99.3

[a] Determined by administrative boundary.

Table 5-6.—Area[a] (km^2) and percent of each National Forest by critical load (CL) exceedance category that results in various percent declines of forage lichen abundance. The CL, 2.0 kg N ha^{-1} yr^{-1}, is associated with 20 percent declines in forage lichen abundance.

National Forest	Forest area	Exceedance category (decline in forage lichen abundance)												Total area and percent in exceedance	
		No exceedance		20–30%		30–40%		40–50%		50–80%		>80%			
	km^2	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Ashley	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	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	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	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	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	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	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	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	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	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	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	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

[a] Determined by administrative boundary.

[b] CL associated with a 20 percent decline for forage lichen abundance has been revised since the analysis of this report to 1.9 kg N $ha^{-1}yr^{-1}$.

5.1.4 Tree Growth and Survival

The CLs for tree growth rate and probability of survival over 10 years were based on national research that defines separate CLs for growth and probability of survival of individual tree species (**Table 4-4**). Critical loads for tree species are associated with the N deposition level right before the percent decline in growth and survival increases above zero. When the percent change in growth rate or probability of survival is low (e.g., <1 percent) it may be difficult to understand effects due to N deposition because of uncertainty in both the modeling and in the deposition estimates. Due to discussions with land managers and uncertainties in both modeling and the deposition estimates, declines >1 percent for growth rate and probability of survival over 10 years were assessed. A forest may choose different percent declines (e.g., 15 percent declines) based on forest management and resource objectives. Exceedances of N deposition levels associated with 1, 5, and 10 percent declines were assessed and mapped for growth rate and probability of survival for each tree species on each National Forest within the Intermountain Region that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance have a greater risk of experiencing declines (e.g., >10 percent) in tree species growth rate and probability of survival. Tree species are mapped for each National Forest based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level that protects against a >1 percent decline in probability of survival over 10 years for Douglas-fir was exceeded on portions of all 12 National Forests in the Intermountain Region (**Table 5-7**). On nine of these National Forests, >1 percent declines in survival was mapped over 80 percent of the area that Douglas-fir is modeled to be a dominant or codominant species. Most declines associated with N deposition levels in Douglas-fir survival were between 1 and 5 percent. Nitrogen deposition on the Uinta-Wasatch-Cache, however, was mostly associated with 5 to 10 percent declines in Douglas-fir survival. The response curve to N deposition for Douglas-fir growth rate was increasing and thus no CLs were calculated.

Utah juniper. All eight National Forests where Utah juniper is modeled to be dominant or codominant exceeded the N deposition level that protects against a >1 percent decline in probability of survival over 10 years (**Table 5-8**). Three National Forests—the Caribou-Targhee, Manti-La Sal, and Uinta-Wasatch-Cache—mapped >1 percent declines in probability of survival over 80 percent of the range Utah juniper is modeled to have dominant or codominant canopy cover (127 km^2, 1056 km^2, and 287 km^2, respectively). The Humboldt-Toiyabe National Forest contained the most area (1318 km^2) in exceedance, 18 percent of the modeled range (**Table 5-8**). Only the Uinta-Wasatch-Cache National Forest contained areas where 5 to 10 percent declines in probability of survival for Utah juniper were mapped. The response curve to N deposition for Utah juniper growth rate was increasing and thus no CLs were calculated.

Singleleaf pinyon. All seven National Forests where singleleaf pinyon was modeled to be dominant or codominant had some area (8 percent to 85 percent) where the N deposition level that protects against a >1 percent decline in probability of survival over 10 years was exceeded (**Table 5-9**). The Humboldt-Toiyabe National Forest contains the largest area of modeled singleleaf pinyon, covering 8704 km^2, and the largest portion of any forest in exceedance of >1 percent decline in probability of survival over 10 years (1,146 km^2, 13 percent of the range). The Uinta-Wasatch-Cache had the highest percent of area in exceedance (85 percent) with 28 percent of the modeled range associated with a 5 to 10 percent decline in probability of survival

(**Table 5-9**). The response curve to N deposition for singleleaf pinyon growth rate was increasing and thus no CLs were calculated. The mapping technique for VCMQ is mid-level and does not distinguish species (e.g., single leaf pinyon and two-needle pinyon (*Pinus edulis*)) in the pinyon/juniper mapping unit. We present information for singleleaf pinyon on all forests where the pinyon/juniper mapping unit is present (**appendix 1**).

Quaking aspen was modeled as either dominant or codominant on all National Forests in the Intermountain Region. The N deposition level associated with a >1 percent decline in probability of survival was exceeded on five National Forests (**Table 5-11**). The Uinta-Wasatch-Cache and Caribou-Targhee National Forests had small areas (4 and 18 km^2, respectively) of exceedance associated with a 5 to 10 percent decline in probability of survival. The Uinta-Wasatch-Cache was the only National Forest where the N deposition level associated with a >1 percent decline in growth rate for quaking aspen was exceeded. This exceedance covered a small area of the Forest (4 km^2 or 0.2 percent of the range; **Table 5-10**).

Balsam poplar is not widespread throughout the Intermountain Region but is commonly found in riparian areas. The Boise National Forest had the most modeled balsam poplar dominant areas with 149 km^2. On nine National Forests, the N deposition level that protects against a >1 percent decline in growth rate of balsam poplar was exceeded on over 50 percent of the area where balsam poplar is modelled to be dominant (**Table 5-12**). The magnitude of exceedances was high, eight National Forests had exceedances associated with >10 percent decline in growth rate. Nearly 100 percent of the modeled balsam poplar range on the Manti-La Sal and Uinta-Wasatch-Cache National Forests were in exceedance of the N deposition levels associated with a >1 percent decline in growth rate with the majority of exceedances associated with >10 percent declines (**Table 5-12**). On eight National Forests, the N deposition level that protects against a >1 percent decline in probability of survival was exceeded. The Manti-La Sal and Uinta-Wasatch-Cache National Forests had the largest areas (both percentage and total area) in exceedance (**Table 5-13**). The Uinta-Wasatch-Cache was the only forest that had exceedances associated with a >10 percent decline in probability of survival.

Table 5-7. —Douglas-fir vegetation mapped area (km²) and percent of National Forest within different percent decline categories. Categories represent the percent decline in probability of survival of Douglas-fir over 10 years. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 3.5, 7.4, and 13.2 kg N ha[1] yr^{-1}, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where Douglas-fir has a dominant/codominant canopy cover on each National Forest.

National Forest	Vegetation mapped area	Percent decline in probability of survival category								Total area and percent in exceedance	
		No exceedance <1%		1-–5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	197.9	13.6	6.9	184.4	93.1	0.0	0.0	0.0	0.0	184.4	93.1
Boise	2087.2	331.0	15.9	1756.2	84.1	0.0	0.0	0.0	0.0	1756.2	84.1
Bridger-Teton	1010.8	184.0	18.2	826.8	81.8	0.0	0.0	0.0	0.0	826.8	81.8
Caribou-Targhee	2805.0	439.0	15.7	2242.8	80.0	123.2	4.4	0.0	0.0	2365.9	84.3
Dixie	273.4	26.8	9.8	246.6	90.2	0.0	0.0	0.0	0.0	246.6	90.2
Fishlake	111.7	9.5	8.5	102.2	91.5	0.0	0.0	0.0	0.0	102.2	91.5
Humboldt-Toiyabe	0.04	0.0	0.0	.04	100.0	0.0	0.0	0.0	0.0	0.04	100.0
Manti-La Sal	314.9	2.1	0.7	311.1	98.8	1.7	0.5	0.0	0.0	312.8	99.3
Payette	2431.2	2084.0	85.7	347.2	14.3	0.0	0.0	0.0	0.0	347.2	14.3
Salmon-Challis	5711.2	4251.4	74.4	1459.8	25.6	0.0	0.0	0.0	0.0	1459.8	25.6
Sawtooth	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	862.3	0.0	0.0	251.5	29.2	607.2	70.4	3.6	0.4	862.3	100.0

Table 5-8.—Utah juniper vegetation mapped area (km²) and percent of National Forest within different percent decline categories. Categories represent the percent decline in probability of survival of Utah juniper over 10 years. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 3.9, 10.7, and 23.6 kg N $ha^{-1}yr^{-1}$, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where Utah juniper canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in probability of survival category								Total area and percent in exceedance	
		No exceedance <1%		1–5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	395.8	124.1	31.3	271.7	68.7	0.0	0.0	0.0	0.0	271.7	68.7
Boise	NA										
Bridger-Teton	NA										
Caribou-Targhee	141.2	14.0	9.9	127.2	90.1	0.0	0.0	0.0	0.0	127.2	90.1
Dixie	1834.3	1066.2	58.1	768.0	41.9	0.0	0.0	0.0	0.0	768.0	41.9
Fishlake	1549.2	991.5	64.0	557.7	36.0	0.0	0.0	0.0	0.0	557.7	36.0
Humboldt-Toiyabe	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	1319.0	262.7	19.9	1056.3	80.1	0.0	0.0	0.0	0.0	1056.3	80.1
Payette	NA										
Salmon-Challis	NA										
Sawtooth	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	308.9	22.3	7.2	281.9	91.2	4.8	1.5	0.0	0.0	286.6	92.8

Table 5-9.—Singleleaf pinyon vegetation mapped area (km²) and percent of National Forest within percent decline categories. Categories represent the percent decline in probability of survival of singleleaf pinyon over 10 years. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 4.5, 7.4 and 10.9 kg N $ha^{-1}yr^{-1}$, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where singleleaf pinyon canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in probability of survival category								Total area and percent in exceedance	
		No exceedance <1%		1--5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	395.8	175.0	44.2	220.8	55.8	0.0	0.0	0.0	0.0	220.8	55.8
Boise	NA										
Bridger-Teton	NA										
Caribou-Targhee	NA										
Dixie	1834.3	1547.4	84.4	286.9	15.6	0.0	0.0	0.0	0.0	286.9	15.6
Fishlake	1549.2	1427.0	92.1	122.2	7.9	0.0	0.0	0.0	0.0	122.2	7.9
Humboldt-Toiyabe	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	1319.0	825.2	62.6	493.4	37.4	0.4	0.0	0.0	0.0	493.8	37.4
Payette	NA										
Salmon-Challis	NA										
Sawtooth	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	308.9	45.5	14.7	172.2	55.8	87.0	28.2	4.2	1.3	263.4	85.3

Table 5-10.—Quaking aspen vegetation mapped area (km²) and percent of National Forest area within percent decline categories. Categories represent the percent decline in growth rate of quaking aspen. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 13.6, 17.5, and 21.3 kg N $ha^{-1}yr^{-1}$ respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where quaking aspen canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in growth rate category								Total area and percent in exceedance	
		No exceedance <1%		1–5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	754.5	754.5	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Boise	120.4	120.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Bridger-Teton	698.4	698.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Caribou-Targhee	1740.2	1740.2	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Dixie	698.5	698.5	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Fishlake	915.1	915.1	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Humboldt-Toiyabe	860.4	860.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Manti-La Sal	976.3	976.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Payette	33.3	33.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Salmon-Challis	102.4	102.4	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Sawtooth	445.2	445.2	100.0	0	0.0	0	0.0	0	0.0	0	0.0
Uinta-Wasatch-Cache	1879.7	1875.8	99.8	3.9	0.2	0	0.0	0	0.0	3.9	0.2

Table 5-11.—Quaking aspen vegetation mapped area (km²) and percent of National Forest area within percent decline categories. Categories represent the percent decline in probability of survival of quaking aspen over 10 years. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 6.6, 11.8, and 18.4 kg N ha^{-1} yr^{-1}, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where quaking aspen canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in probability of survival category								Total area and percent in exceedance	
		No exceedance <1%		1-–5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	754.5	712.9	94.5	41.6	5.5	0.0	0.0	0.0	0.0	41.6	5.5
Boise	120.4	120.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bridger-Teton	698.4	698.3	100.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Caribou-Targhee	1740.2	1411.2	81.1	324.6	18.7	4.4	0.3	0.0	0.0	329.1	18.9
Dixie	698.5	698.5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fishlake	915.1	914.9	100.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Humboldt-Toiyabe	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	976.3	677.1	69.4	299.2	30.6	0.0	0.0	0.0	0.0	299.2	30.6
Payette	33.3	33.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmon-Challis	102.4	102.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sawtooth	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	1879.7	694.5	36.9	1166.8	62.1	18.4	1.0	0.0	0.0	1185.2	63.1

Table 5-12.—Balsam poplar vegetation mapped area (km²) and percent of National Forest area within percent decline categories. Categories represent the percent decline in growth rate of balsam poplar. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 3.4, 4.2, and 5.4 kg N $ha^{-1}yr^{-1}$, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where balsam poplar canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in growth rate category								Total area and percent in exceedance	
		No exceedance <1%		1–5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	NA										
Boise	148.9	31.8	21.4	72.9	48.9	42.7	28.7	1.5	1.0	117.1	78.6
Bridger-Teton	1.5	0.8	50.0	0.6	36.8	0.2	13.2	0.0	0.0	0.8	50.0
Caribou-Targhee	NA										
Dixie	34.1	5.0	14.8	11.9	34.9	15.6	45.7	1.6	4.7	29.0	85.2
Fishlake	45.6	8.2	18.0	16.6	36.5	17.3	37.9	3.5	7.6	37.4	82.0
Humboldt-Toiyabe	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	28.4	0.1	0.4	2.4	8.5	9.3	32.7	16.6	58.5	28.3	99.6
Payette	48.2	41.1	85.2	7.0	14.5	0.2	0.3	0.0	0.0	7.2	14.8
Salmon-Challis	131.7	77.4	58.7	29.1	22.1	24.8	18.8	0.4	0.3	54.3	41.2
Sawtooth	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	118.0	0.1	0.1	0.2	0.1	15.0	12.7	102.8	87.1	118.0	99.9

Table 5-13.—Balsam poplar vegetation mapped area (km²) and percent of National Forest area within percent decline categories. Categories represent the percent decline in probability of survival of balsam poplar over 10 years. Nitrogen deposition levels associated with 1 percent, 5 percent, and 10 percent declines are 5.0, 7.5 and 10.2 kg N $ha^{-1}yr^{-1}$, respectively. Categories >1 percent are in exceedance, while the <1 percent category is not in exceedance. The "vegetation mapped area" represents the area where balsam poplar canopy cover is modelled as dominant/codominant on each National Forest.

National Forest	Vegetation mapped area	Percent decline in probability of survival category								Total area and percent in exceedance	
		No exceedance <1%		1–-5%		5–10%		>10%			
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Ashley	NA										
Boise	148.9	145.4	97.6	3.6	2.4	0.0	0.0	0.0	0.0	3.6	2.4
Bridger-Teton	1.5	1.5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caribou-Targhee	NA										
Dixie	34.1	30.4	89.1	3.7	10.9	0.0	0.0	0.0	0.0	3.7	10.9
Fishlake	45.6	36.8	80.8	8.8	19.2	0.0	0.0	0.0	0.0	8.8	19.2
Humboldt-Toiyabe	14.9	13.6	91.4	1.2	8.3	.04	0.3	0.0	0.0	1.3	8.6
Manti-La Sal	28.4	9.3	32.7	18.6	65.5	0.5	1.8	0.0	0.0	19.1	67.3
Payette	48.2	48.2	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmon-Challis	131.8	129.8	98.5	2.0	1.5	0.0	0.0	0.0	0.0	2.0	1.5
Sawtooth	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	118.0	6.0	5.1	80.3	68.0	29.6	25.0	2.2	1.8	112.0	94.9

5.2 Management Implications

Nitrogen and sulfur CLs are a tool to provide managers with information about the level or threshold of atmospheric deposition at which change, or negative effects may occur on the lands they are tasked to manage. Once CLs for a given resource are identified, N and S deposition estimates are used to identify areas where current deposition exceeds the CL. In addition, the magnitude of exceedance should also be evaluated. Considering the type of resource protected by a given CL, N and S deposition levels on the National Forest, and the magnitude of exceedance, a manager can recognize the level of risk (low, medium, high) for adverse effects to result from N and S deposition. If N deposition is reduced below a specific CL, negative effects may be mitigated or prevented. Depending on the level, location, and distribution of risk, various resource management actions are possible.

1. A manager may choose to make decisions about on-forest projects to minimize further N or S deposition to resources already at risk. However, except for large projects such as mining or oil and gas development—the reality for most National Forests is the majority of atmospheric N and S deposition is from air pollution originating off-forest.

2. A manager may choose to make decisions that minimize additional impacts to areas where resources are already at risk for adverse effects from air pollution deposition.

3. The Forest Service has the opportunity to comment on off-forest emissions that affect Class I Wilderness Areas through PSD, NEPA, led by other federal agencies, and state implementation plans. If reductions in off-forest emissions are needed beyond these programs to protect a resource or multiple resources, concerns should be communicated to the regulatory agencies—the states and U.S Environmental Protection Agency.

4. When regulatory and on-forest mitigation actions are not viable or adequate options to protect an affected resource, collaborative or voluntary efforts that involve stakeholders may be an additional tool. The Rocky Mountain National Park (RMNP) Initiative is a good working example of a collaborative response that successfully decreased N deposition to RMNP. This collaborative effort provided agricultural producers with an early warning system to help voluntarily limit or postpone activities that produce large amounts of nitrogen emissions when weather conditions would carry the emissions to RMNP. More information can be found at: https://www.colorado.gov/pacific/cdphe/rocky-mountain-national-park-initiative.

5. Monitoring and supporting on-the-ground research of at-risk resources with low CLs and resources in locations of CL exceedance is important for tracking the health, status, and any adverse effects to the resource. These data and the interpretation are important for protecting resources and communicating trends and conditions to air regulators, project proponents, and the public, especially if off-forest mitigation is needed.

6. Air pollution and deposition in the form of reduced N (NH_x) is increasing in many western locations, supporting monitoring efforts to measure ammonium or ammonia (e.g., via the Ammonia Monitoring Network [AMoN]) will validate modeled N deposition and help National Forests track trends in this pollutant.

7. Mitigation of N-saturated environments by using tools such as prescribed fire, thinning, certain harvesting techniques, moderate grazing, seasonal mowing, and late spring burns in grasslands may help to reduce excess N retained in the environment (Fenn et al. 2011).

Moon Lake on the Ashley National Forest. USDA Forest Service photo.

5.3 Results by National Forest

5.3.1 Ashley National Forest

5.3.1.1 Surface Water Acidification

Low critical loads (CLs) and high N deposition are two factors that increase the risk of surface water acidification and associated biological effects. Surface waters with the lowest CLs that protect ANC from decreasing below 50 µeq L^{-1}, were located in the High Uintas Wilderness (**Figure 5-3**). Less sensitive waterbodies with higher CLs mostly occurred outside of this Wilderness Area at lower elevations. Nitrogen deposition was high enough to exceed the CL at 24 (60 percent) of the sites (**Table 5-2**). There is an increased risk that these locations are experiencing biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}, and that risk rises if current N and S deposition rates continue or increase. The risk of effects from acidification also increases as the magnitude of exceedance increases, the highest magnitudes of exceedance (2 to 5 and >5 kg N ha^{-1} yr^{-1}) occurred predominantly within the High Uintas Wilderness (**Figure 5-4**). There may be additional acid-sensitive water bodies on the Ashley National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

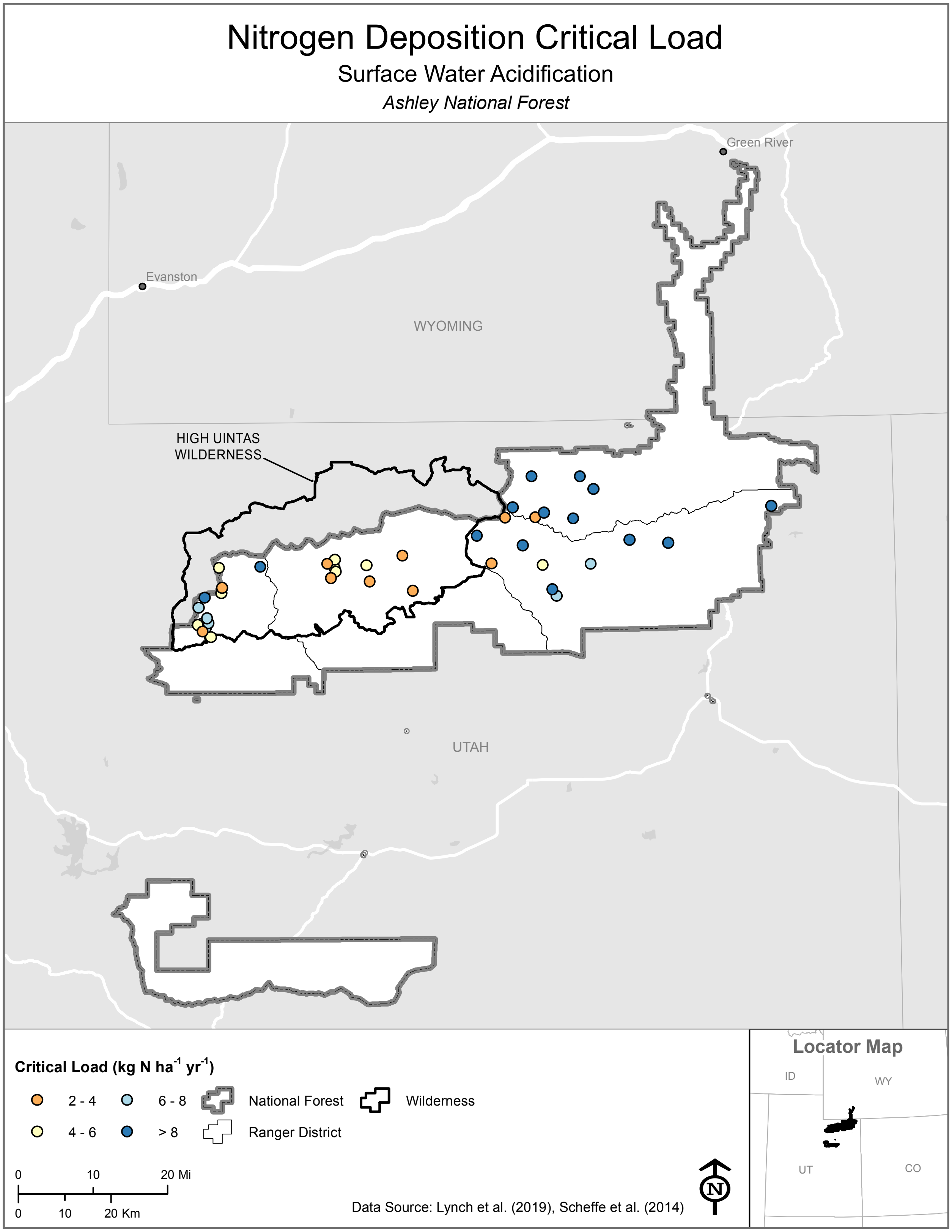


Figure 5-3.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below an ANC of 50 µeq L^{-1} at lake or stream sample sites located within the Ashley National Forest.

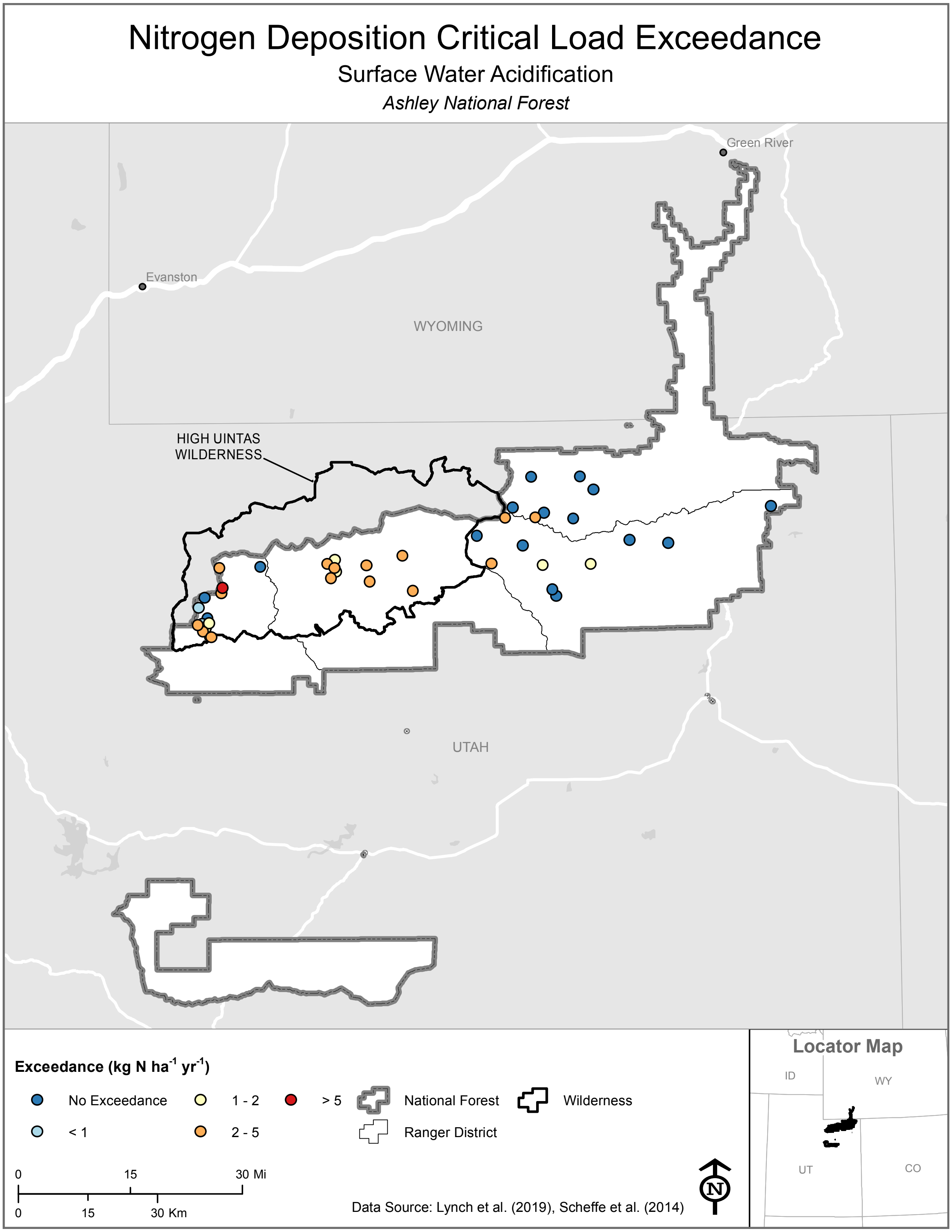


Figure 5-4.—Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below an ANC of 50 μeq L^{-1} at lake or stream sample sites located within the Ashley National Forest.

View of Flaming Gorge along the Flaming Gorge-Uintas National Scenic Byway, Ashley National Forest. USDA Forest Service photo by Martina C. Barnes.

5.3.1.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Ashley National Forest were calculated using wet N deposition. The higher the CL, the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across approximately 2,600 km^2 (46 percent) of the Forest, including most of the High Uintas Wilderness (**Table 5-3**, **Figure 5-5**). Areas with low CLs were more likely to have CL exceedances. Nitrogen CLs were exceeded on 3,400 km^2 (60 percent) of the Forest (**Table 5-4**, **Figure 5-6**). Critical load exceedances >4 kg N ha^{-1} yr^{-1} were mapped across 393 km^2 (7 percent) of the Forest including portions of the High Uintas Wilderness (**Figure 5-6** and **Table 5-4**). Exceedances of 2 to 4 kg N ha^{-1} yr^{-1} were mapped across 1,557 km^2 (28 percent) of the Forest (**Figure 5-6** and **Table 5-4**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Areas with no exceedance were mapped across 2,280 km^2 (40 percent) of the Forest, primarily in the eastern and northeastern portions (**Figure 5-6** and **Table 5-4**). These areas are considered at low risk to experience effects associated with surface water eutrophication.

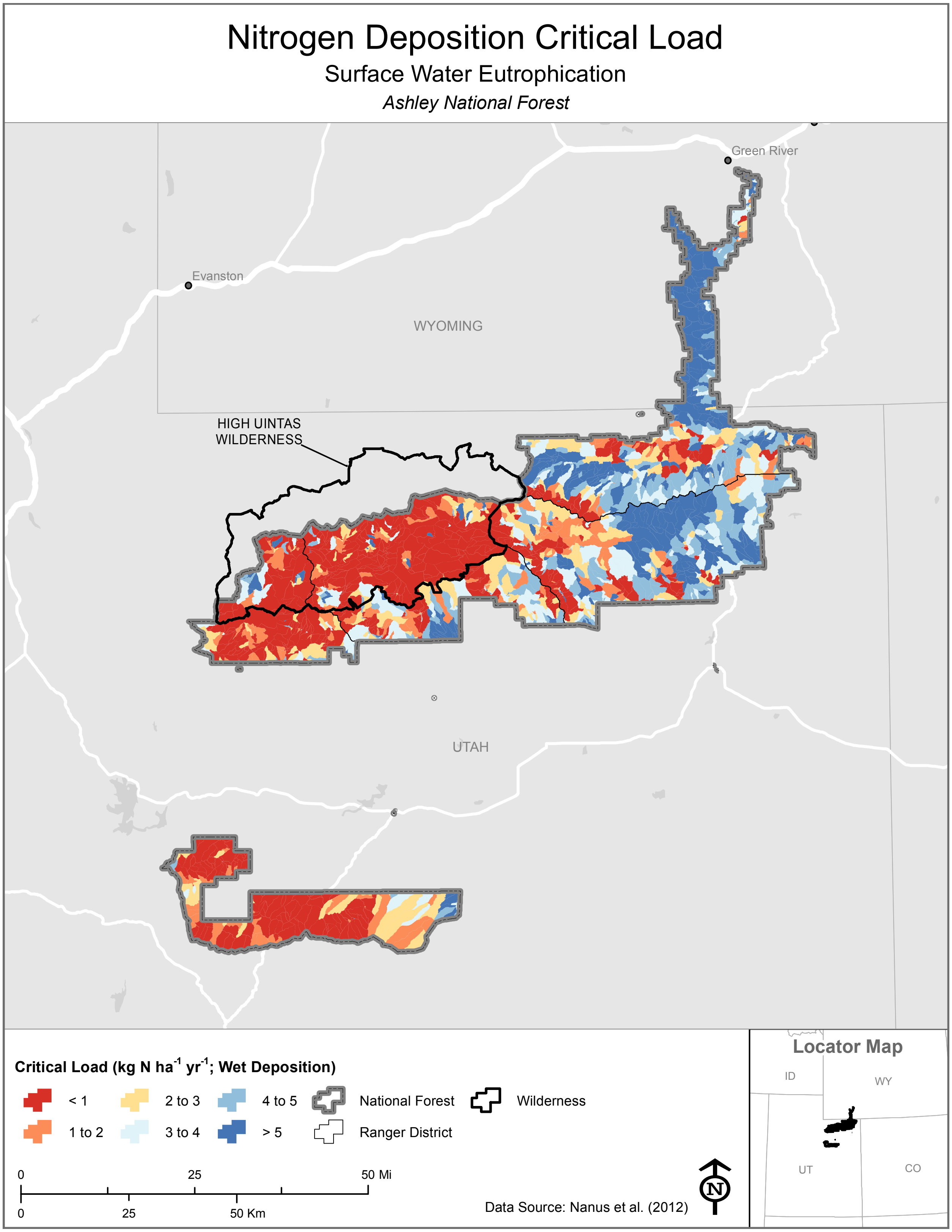


Figure 5-5.—Wet N deposition CLs that protect against surface water eutrophication within the Ashley National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

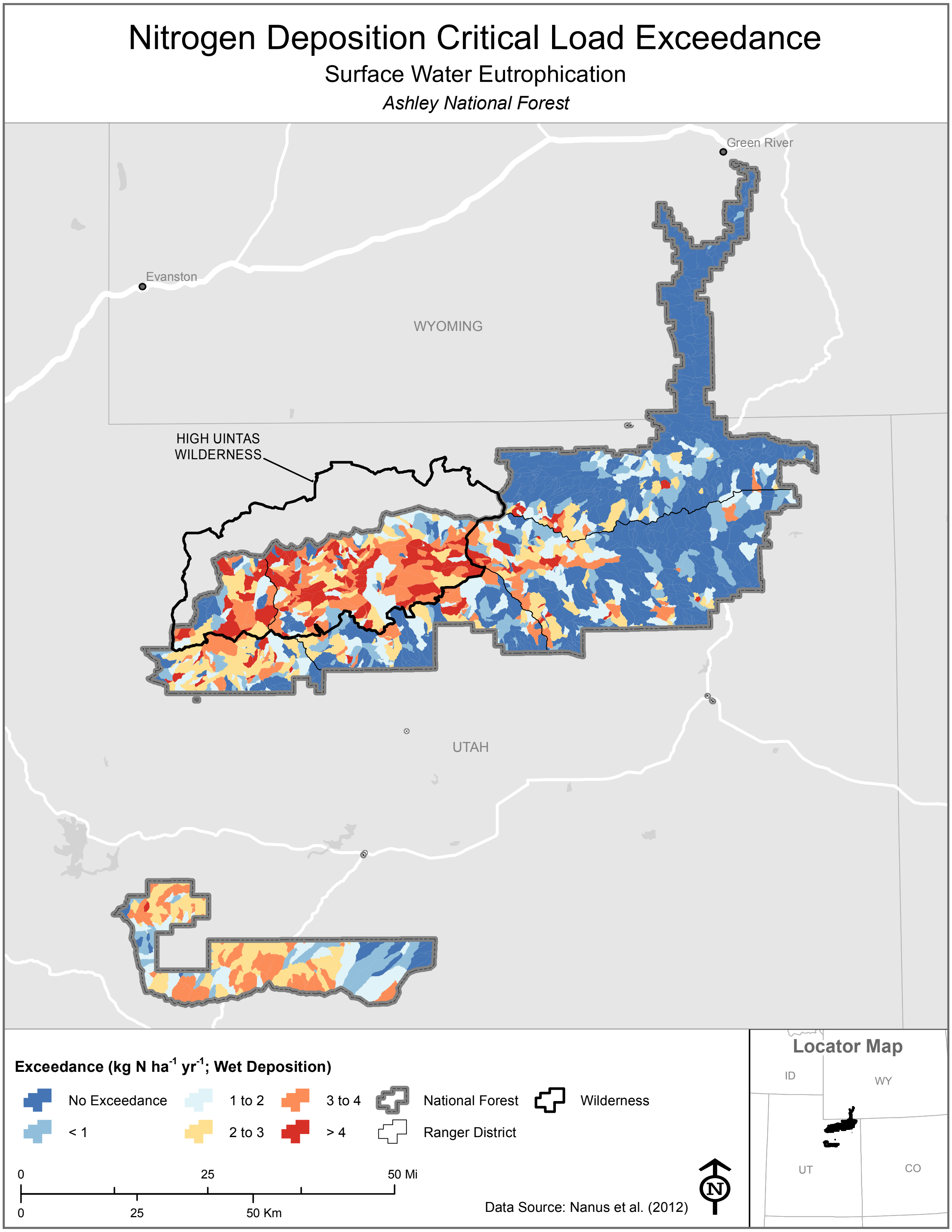


Figure 5-6.—Exceedances of wet N CLs that protect against surface water eutrophication within the Ashley National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

Grandaddy Basin on the Ashley National Forest Wilderness. USDA Forest Service photo.

5.3.1.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against >20 percent declines in lichen species richness and forage lichen abundance throughout 87 percent (4,932 km^2) and 100 percent (5,670 km^2), respectively, of the Ashley National Forest (**Tables 5-5** and **5-6**). Exceedances of the CL for lichen species richness were associated with significant declines (30 to 50 percent) on over half of the Forest (53 percent, 3,003 km^2), including most of the High Uintas Wilderness (**Table 5-5** and **Figure 5-7**). Critical loads for lichen species richness were not exceeded on the northeastern portion of the Forest. Portions of the High Uintas Wilderness contained high magnitudes of exceedance (>5 kg N ha^{-1} yr^{-1}) for both lichen CLs (**Figures 5-7** and **5-8**). High magnitude of CL exceedances for forage lichen abundance were associated with declines >50 percent on 17 percent (987 km^2) of the Forest and declines 30 to 50 percent on nearly 72 percent (4,061 km^2) of the Forest (**Table 5-6**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

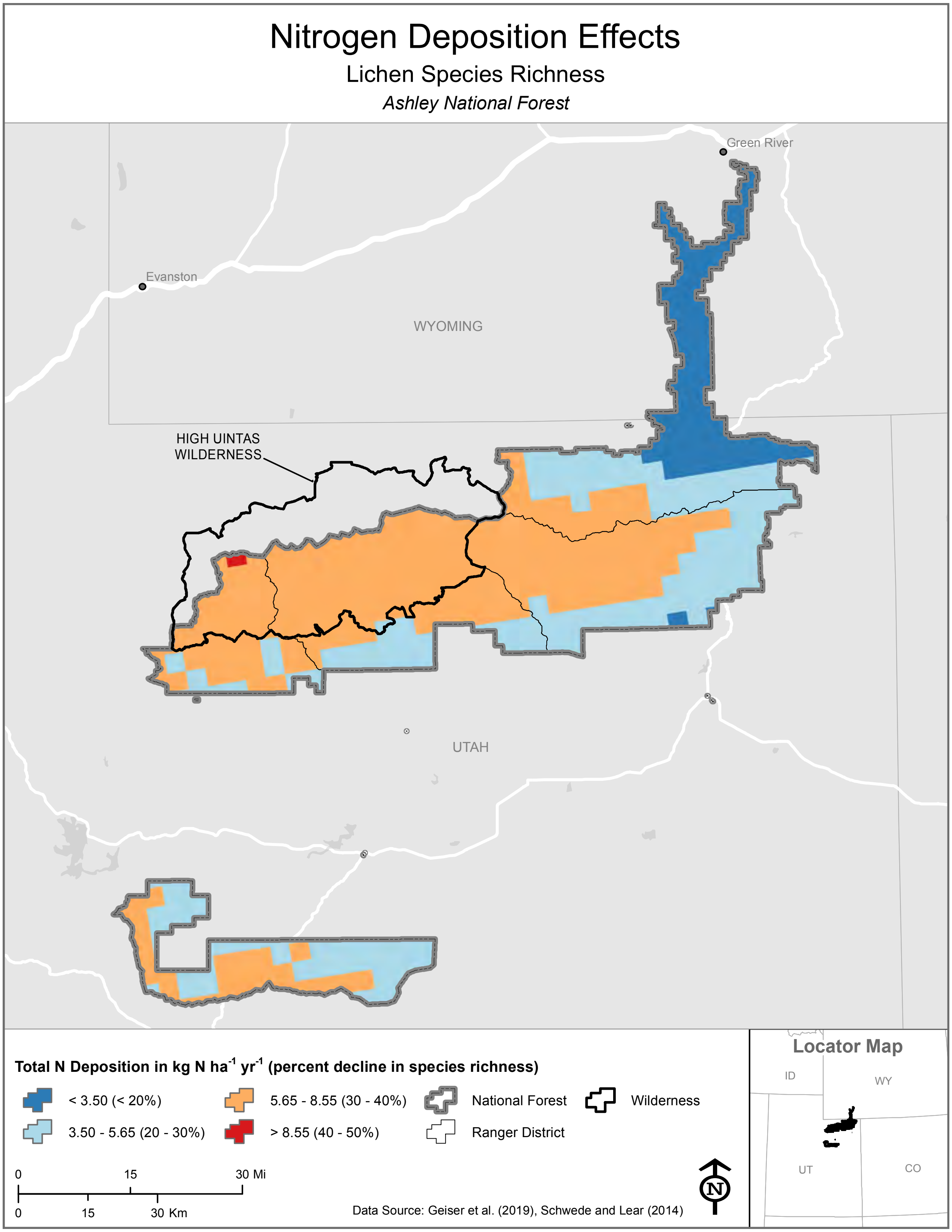


Figure 5-7.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Ashley National Forest.

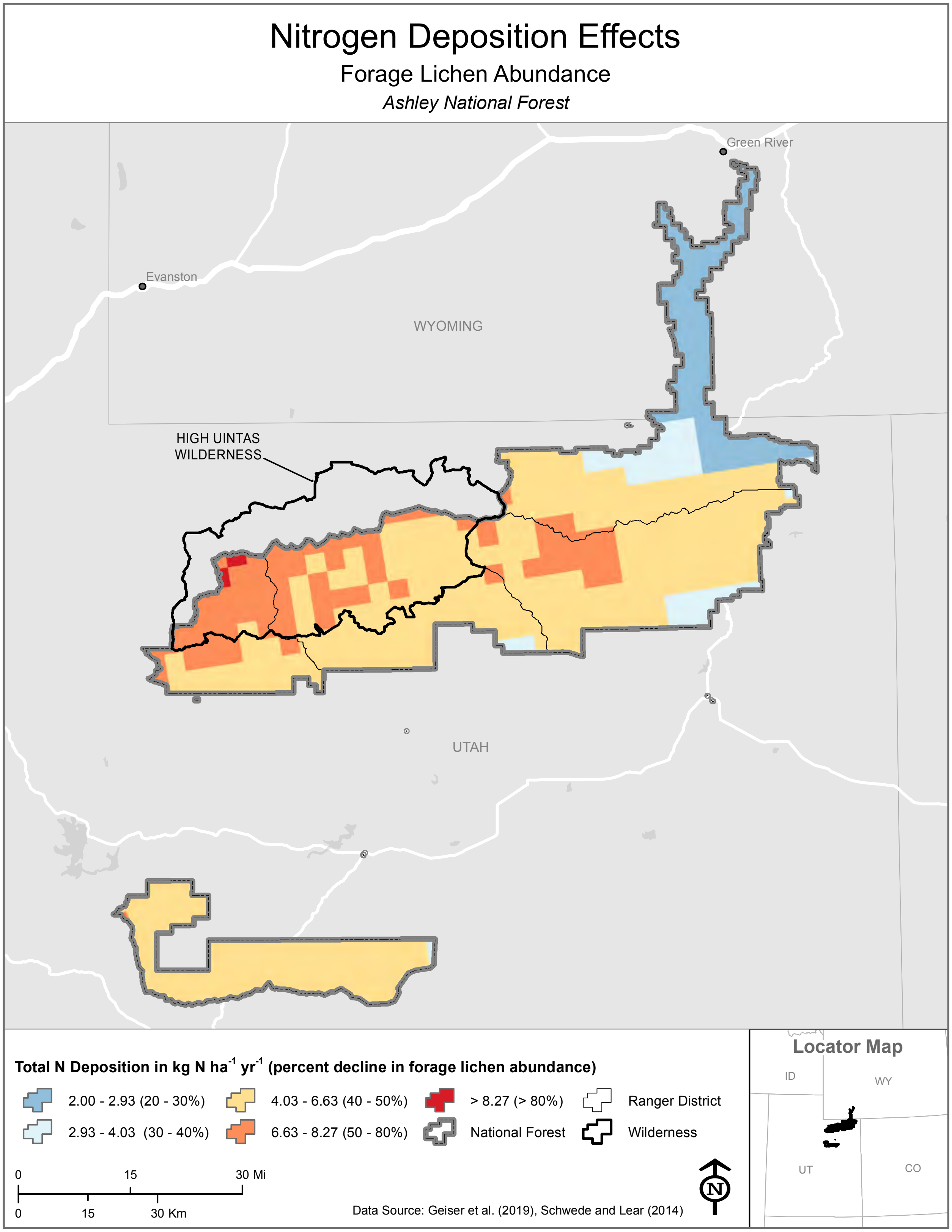


Figure 5-8.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Ashley National Forest.

5.3.1.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival (over 10 years) of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and exceedances for each tree species on the Ashley National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 69 percent (272 km^2) of the area on the Ashley National Forest where this species is modeled as dominant or codominant (**Table 5-8**). No exceedances were associated with a >5 percent decline in probability of survival. Areas of exceedance occurred primarily in the southern half of the Forest (**Figure 5-9**).

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 56 percent (221 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). Areas of exceedance occurred throughout the Forest, except in the northeast portion where no exceedances were mapped (**Figure 5-10**).

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 93 percent (184 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-7**). Areas of exceedance occurred throughout the Forest, except in the northeast portion where no exceedances were mapped (**Figure 5-11**).

Quaking aspen. There were no exceedances of N deposition associated with declines in growth rate for quaking aspen (**Figure 5-12)**. The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceeded within 6 percent (42 km^2) of the area where this species is modeled as dominant or codominant, including a small area within the High Uinta Wilderness (**Table**s **5-10** and **5-11**, **Figure 5-13**). Although exceedance generally occurred within and in the vicinity of the High Uintas Wilderness, most of the population of this species occurred outside the Wilderness Area (**Figure 5-13**).

Other tree species on the Ashley National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-14**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-14.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Ashley National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

					N levels that protects against various percent declines in tree growth and survival		
Common name	Species name	Form of response to N deposition		CL	1%	5%	10%
Subalpine fir	Abies lasiocarpa	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Boxelder	Acer negundo	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	Picea engelmannii	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	Pinus contorta	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Common or two-needle pinyon	Pinus edulis	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	Pinus ponderosa	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

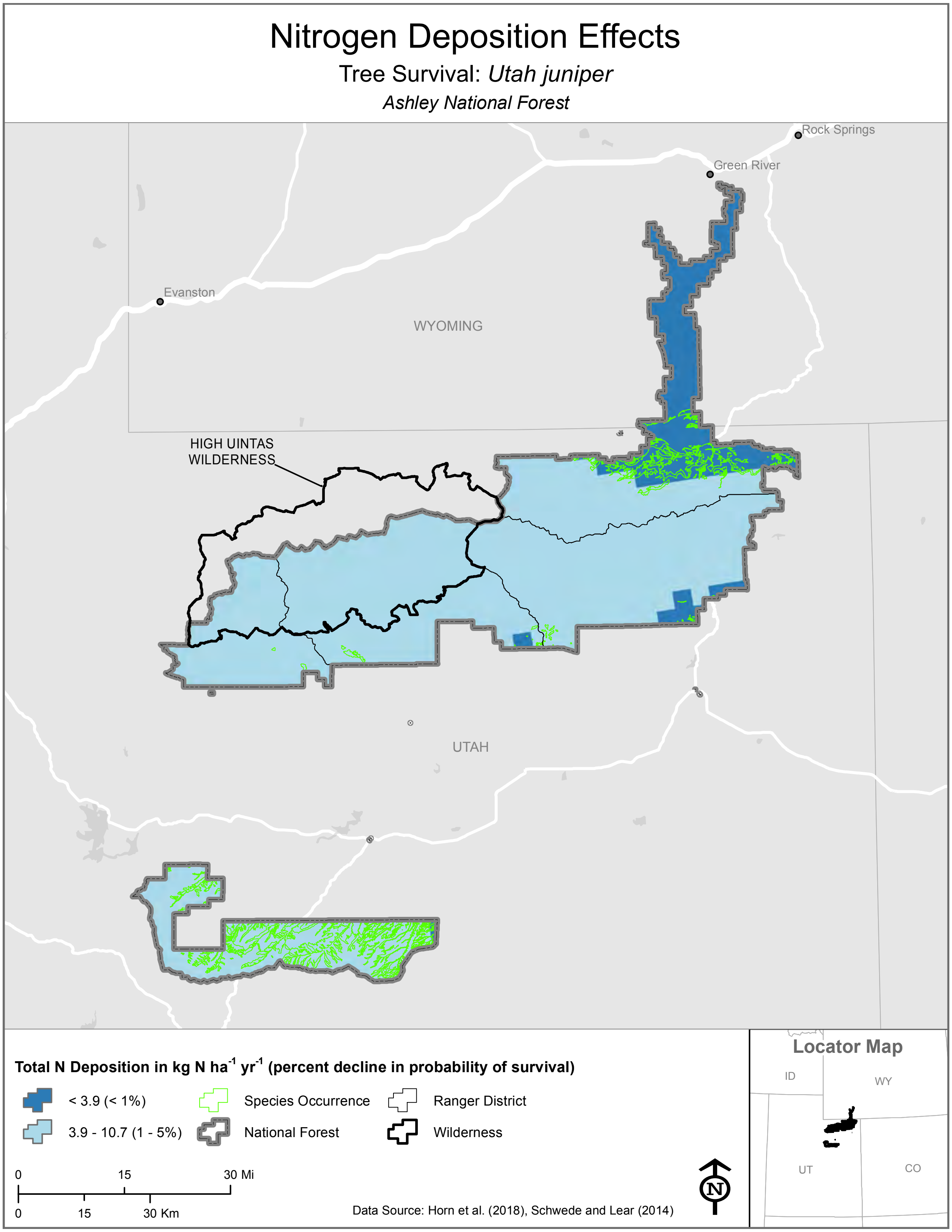


Figure 5-9.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Ashley National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

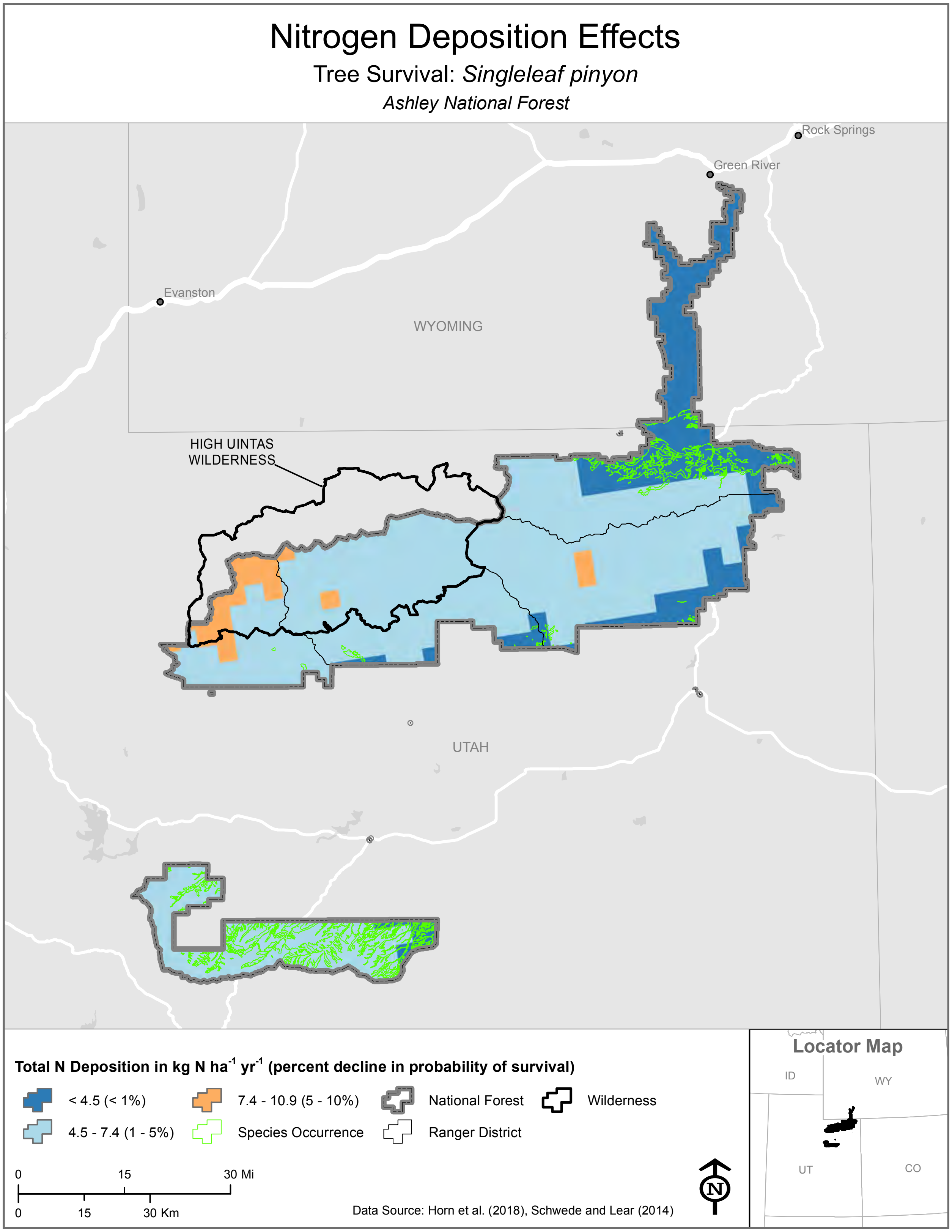


Figure 5-10.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Ashley National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

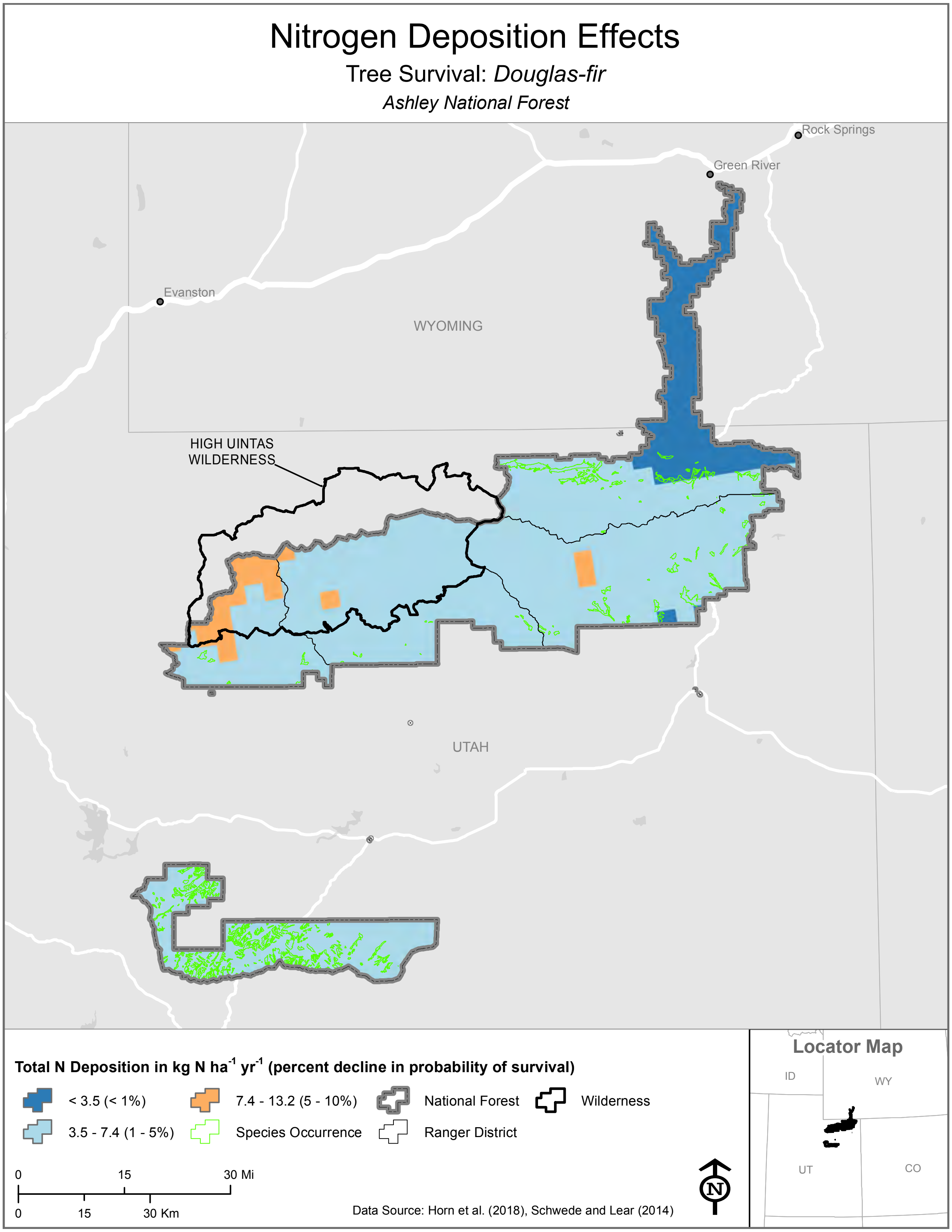


Figure 5-11.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Ashley National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest

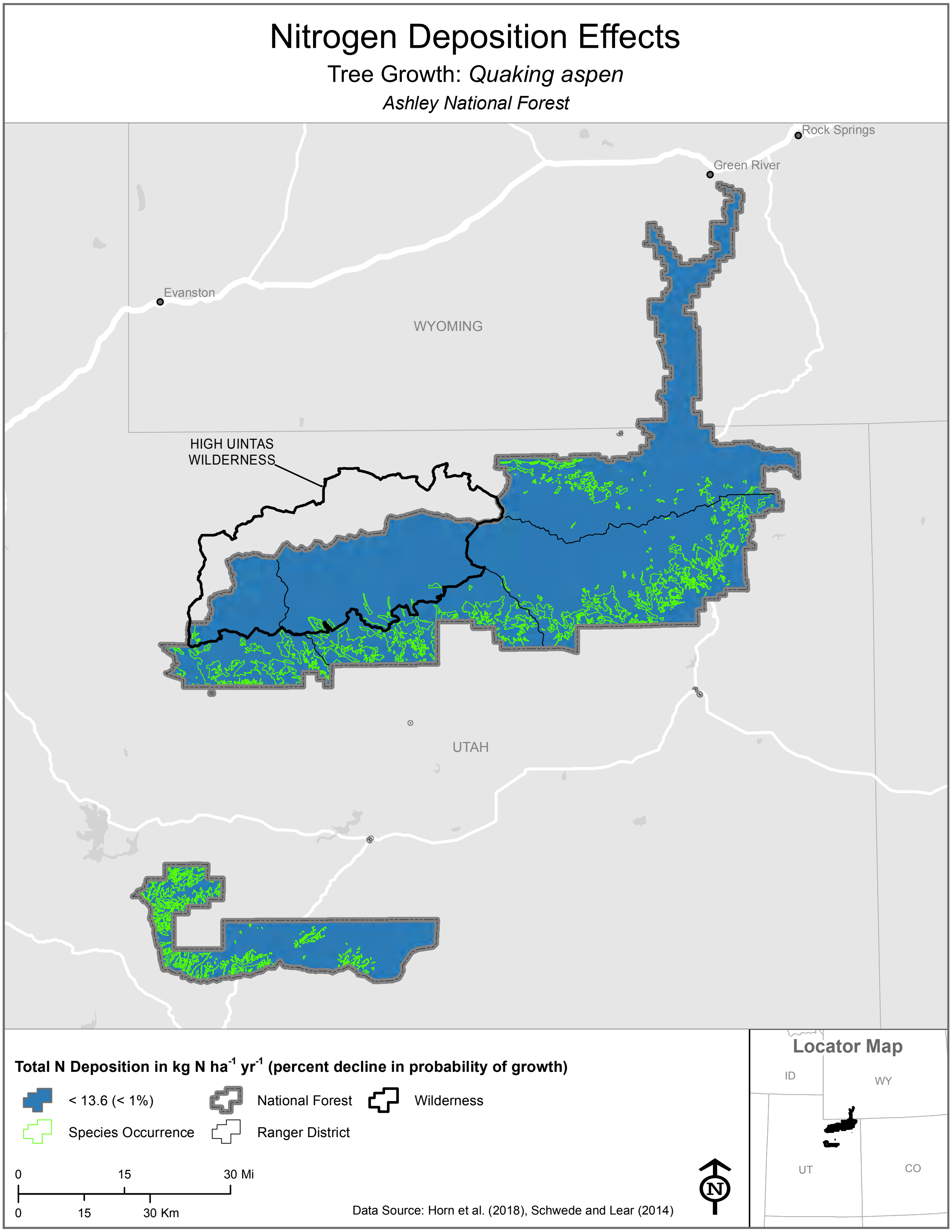


Figure 5-12.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Ashley National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

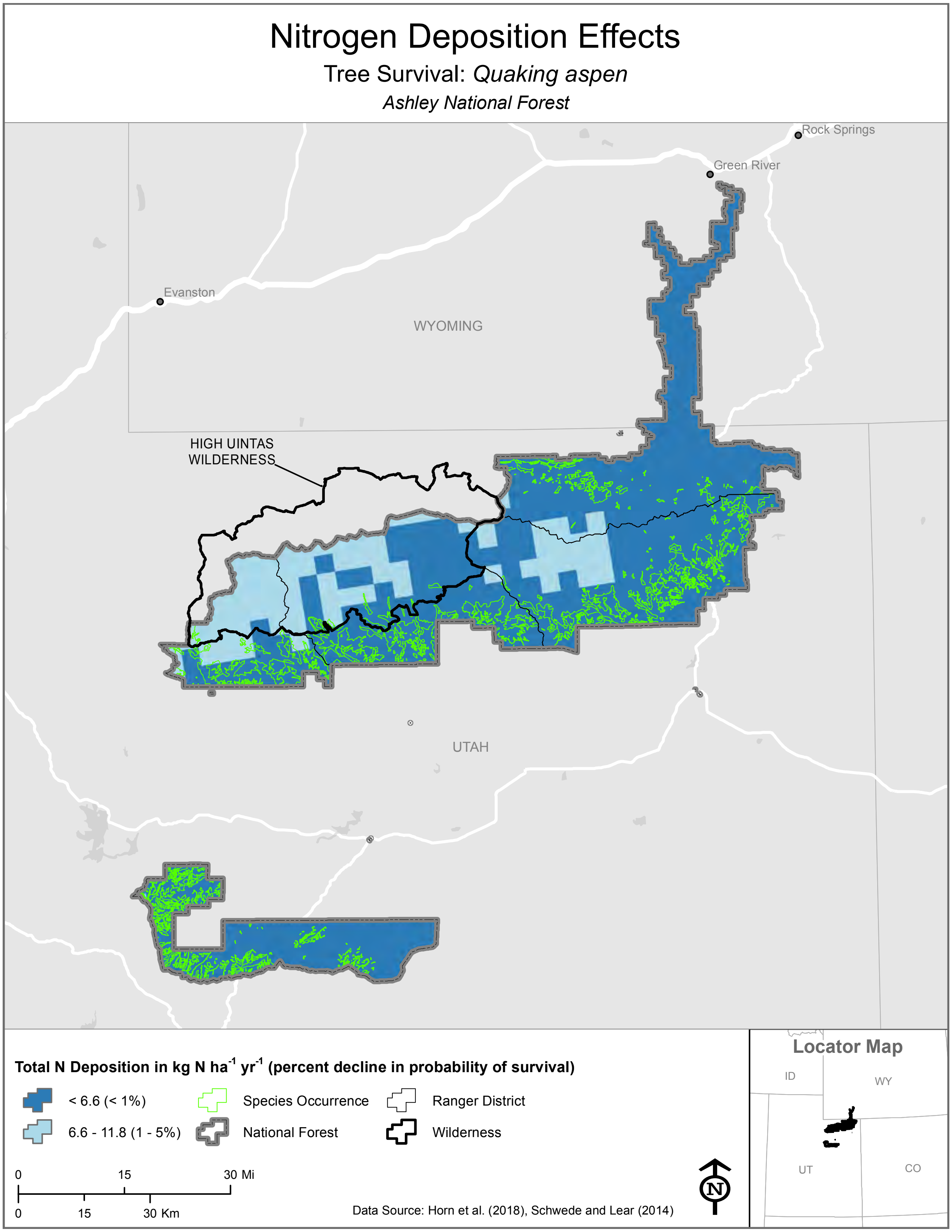


Figure 5-13.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Ashley National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Stream in the Johnson's Bridge area, Boise National Forest. USDA Forest Service photo by Kate Loveless.

5.3.2 Boise National Forest

5.3.2.1 Surface Water Acidification

Low critical loads (CLs) and high N deposition are two factors that increase the risk of surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 μeq L^{-1} were calculated for eight locations throughout the Boise National Forest (**Figure 5-14**). The N deposition at each of these locations did not exceed the CLs (>8 kg N ha^{-1} yr^{-1}; **Table 5-2**, **Figure 5-15**). These surface waters have a low risk to experience biological effects associated with surface water ANC decreasing below 50 μeq L^{-1}. There may be additional acid-sensitive water bodies on the Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

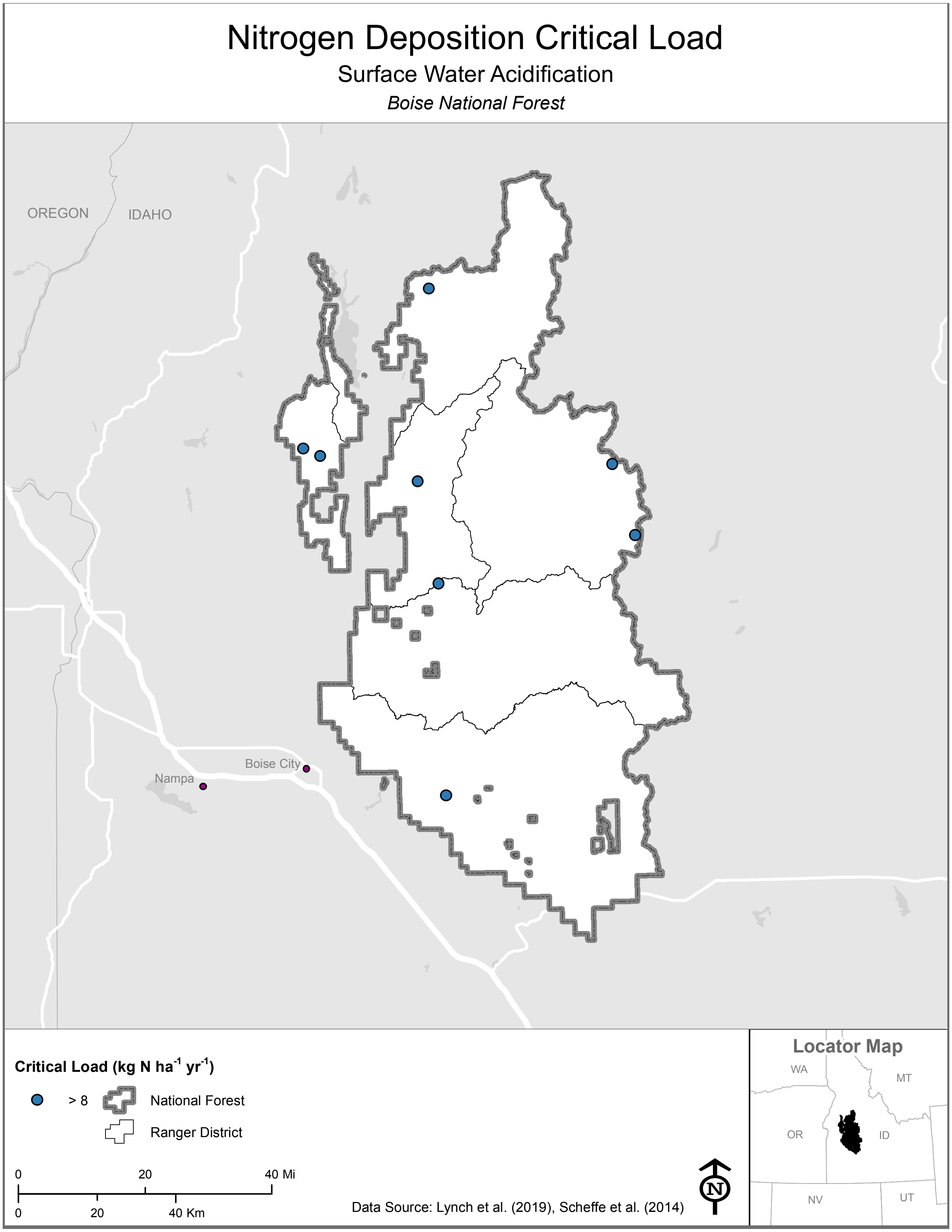


Figure 5-14.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Boise National Forest.

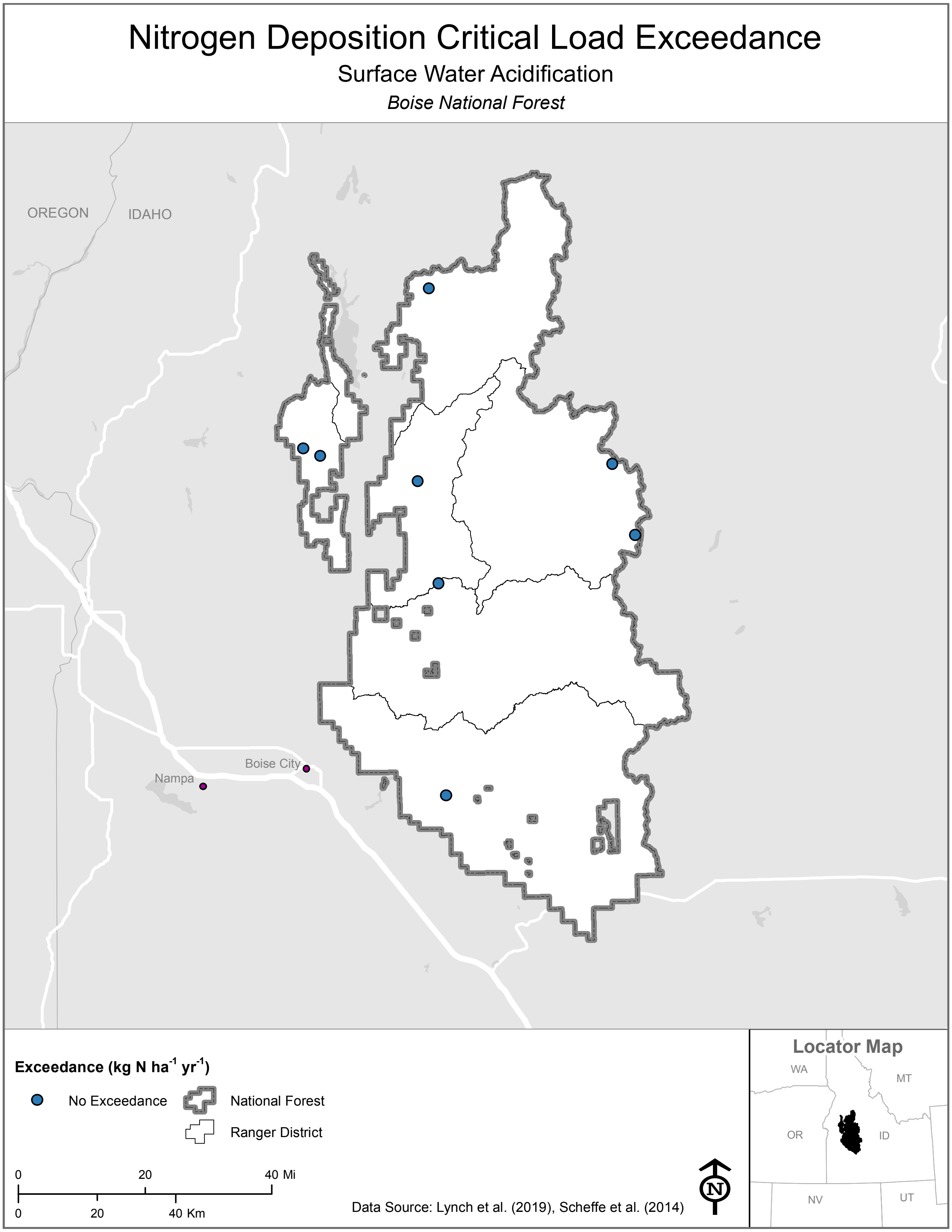


Figure 5-15.—The Boise National Forest has no exceedances of the total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites.

Jenny Lake and mountain on the Boise National Forest. USDA Forest Service photo.

5.3.2.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Boise National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 6,170 km^2 (63 percent) of the Forest (**Table 5-3**, **Figure 5-16**). Areas of exceedance followed a similar pattern as the CLs and included 6,650 km^2 (68 percent) of the Forest (**Table 5-4**, **Figure 5-17**). The highest magnitudes of exceedance, 3 to 4 kg wet N ha^{-1} yr^{-1}, were mapped across 623 km^2 (6 percent) of the Forest. Exceedances of 2 to 4 kg wet N ha^{-1} yr^{-1} were mapped across 2417 km^2 (25 percent) of the Forest (**Table 5-4**, **Figure 5-17**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of Boise National Forest are outside the geographic bounds of this study. These areas were marked as “No Data” in **Figure 5-16** and **Figure 5-17**.

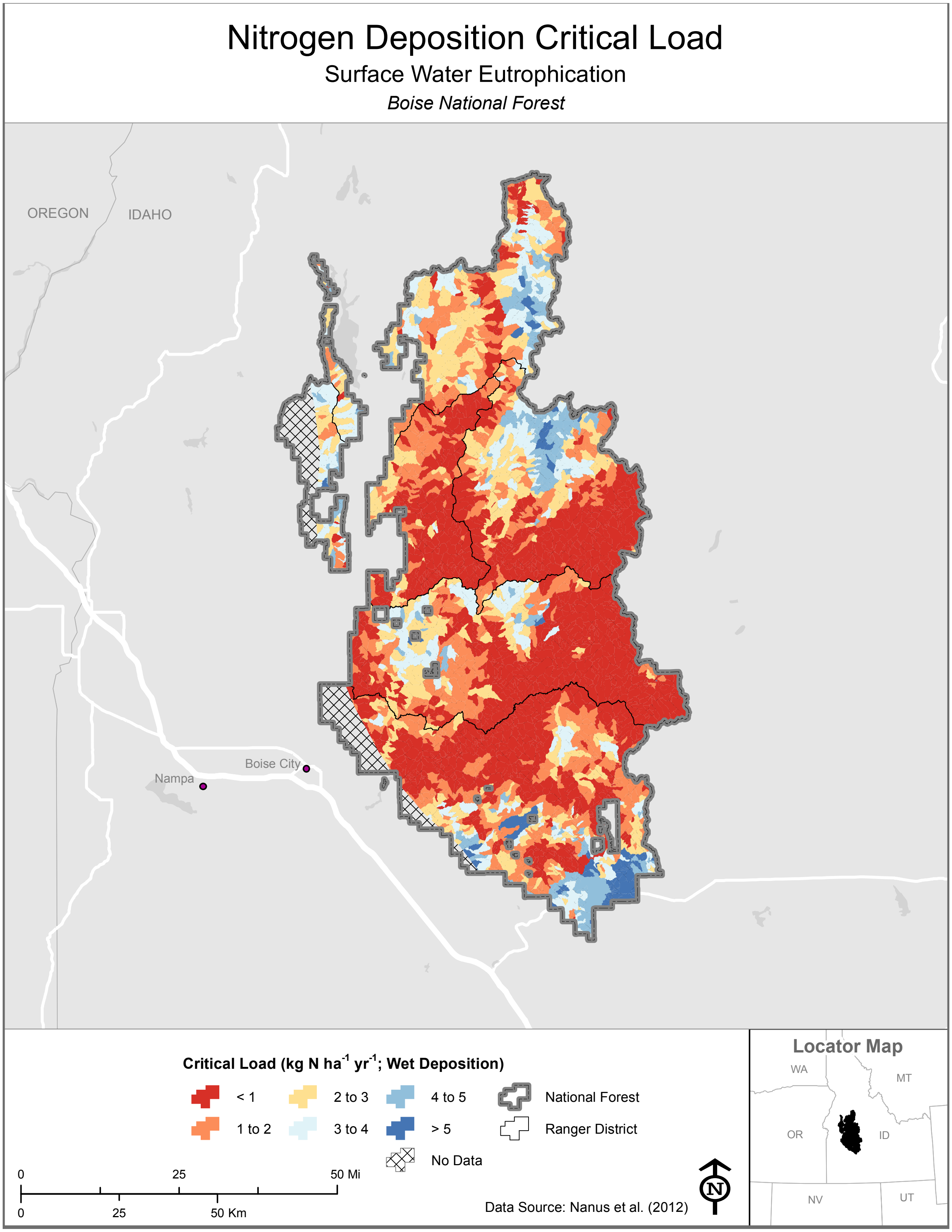


Figure 5-16.—Wet N deposition CLs that protect against surface water eutrophication within the Boise National Forest. Based on a threshold nitrate concentration of 0.5 µmol L-1. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

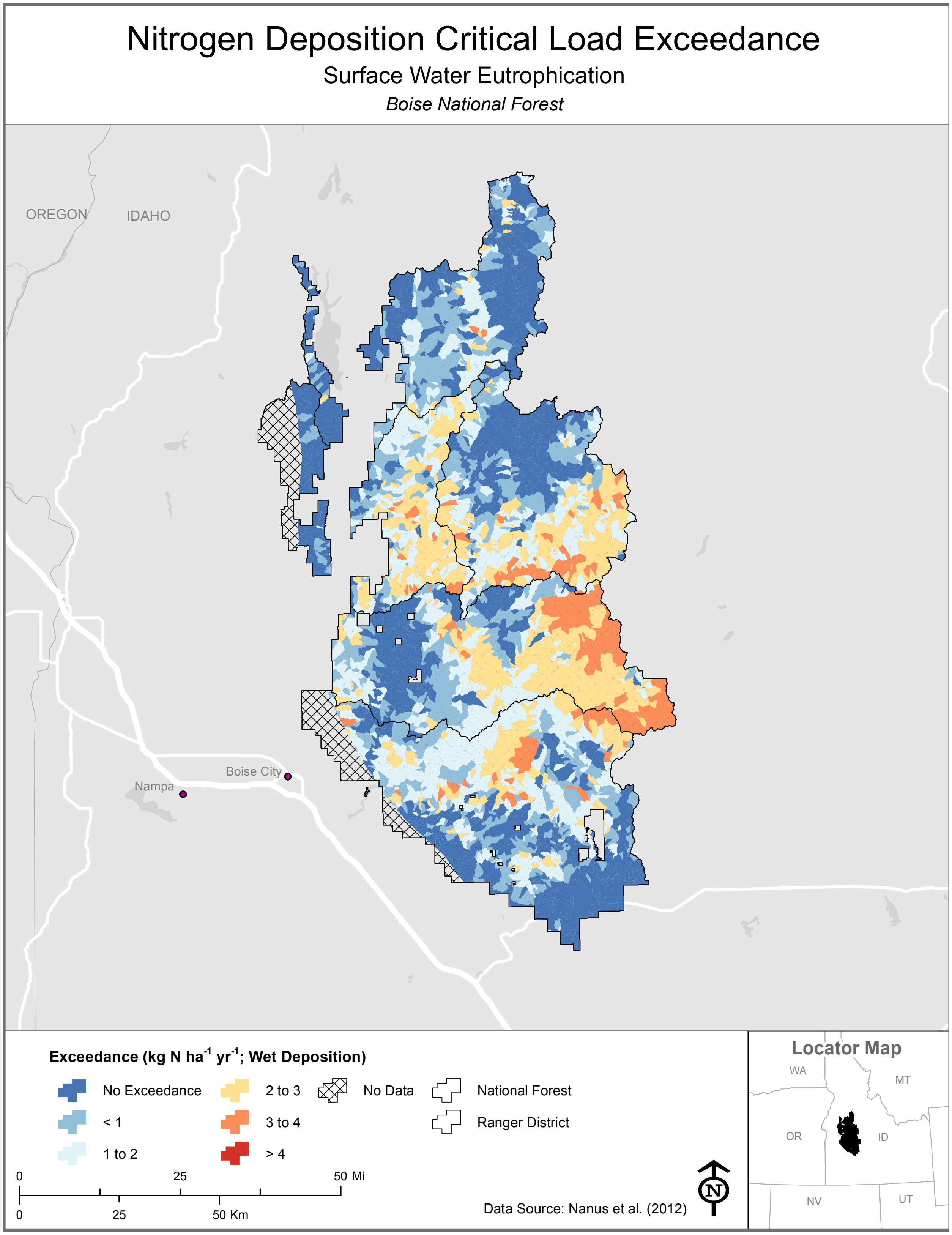


Figure 5-17.—Exceedances of the wet N CLs that protect against surface water eutrophication within the Boise National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

Little Lookout Lake in front of Trinity Mountain, Boise National Forest. USDA Forest Service photo by Joshua Newman.

5.3.2.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applied one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 70 percent (7,166 km^2) and 100 percent (10,226 km^2), respectively, of Boise National Forest (**Tabl**e**s 5-5** and **5-6**). Most of the western portion of the Forest was not in exceedance of the CL for lichen species richness while the eastern portion of the Forest showed the highest magnitudes of CL exceedance (>2 kg N ha^{-1} yr^{-1}) for both lichen species richness and forage lichen abundance (**Figures 5-18** and **5-19**). Critical load exceedance associated with 30 to 50 percent declines in forage lichen abundance were common throughout the Forest. The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

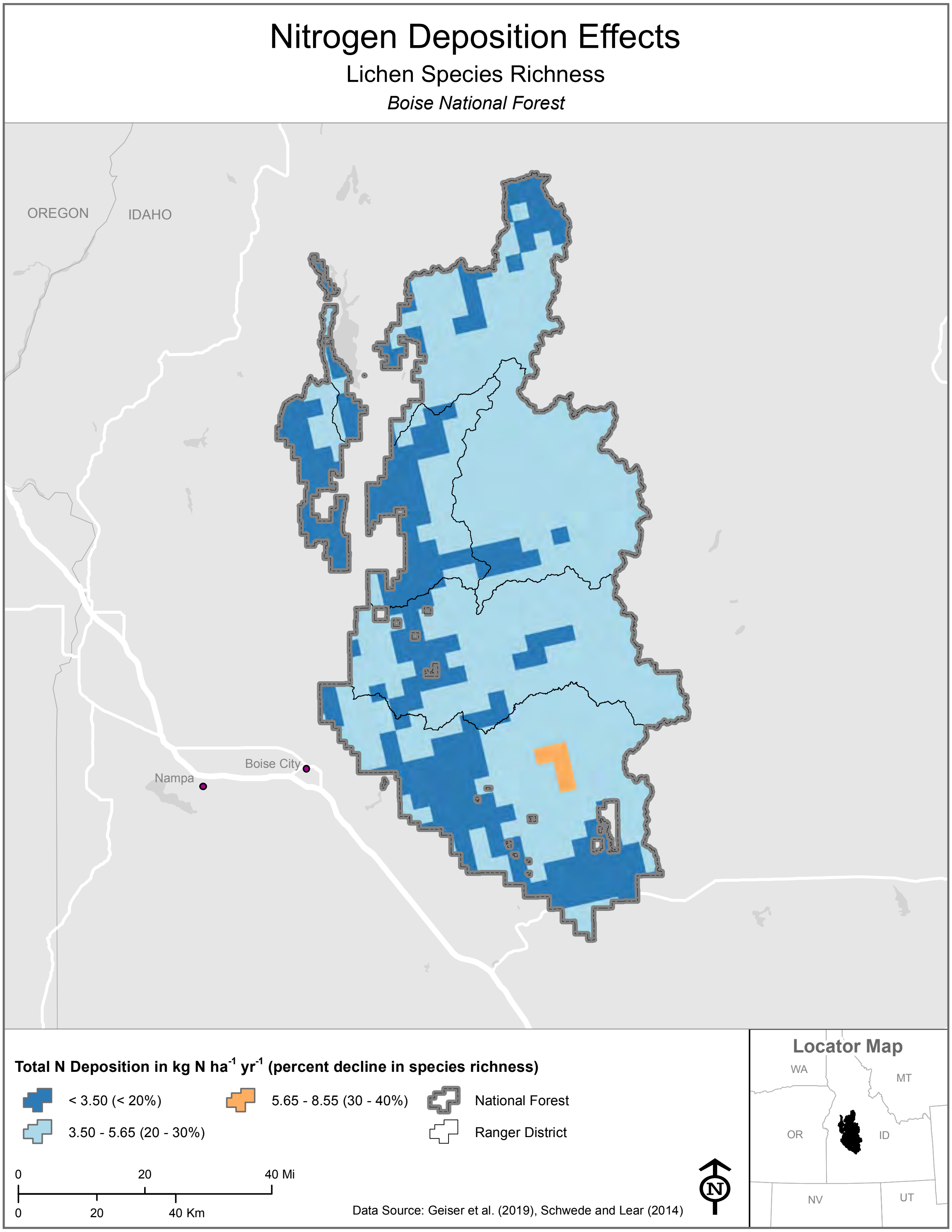


Figure 5-18.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Boise National Forest.

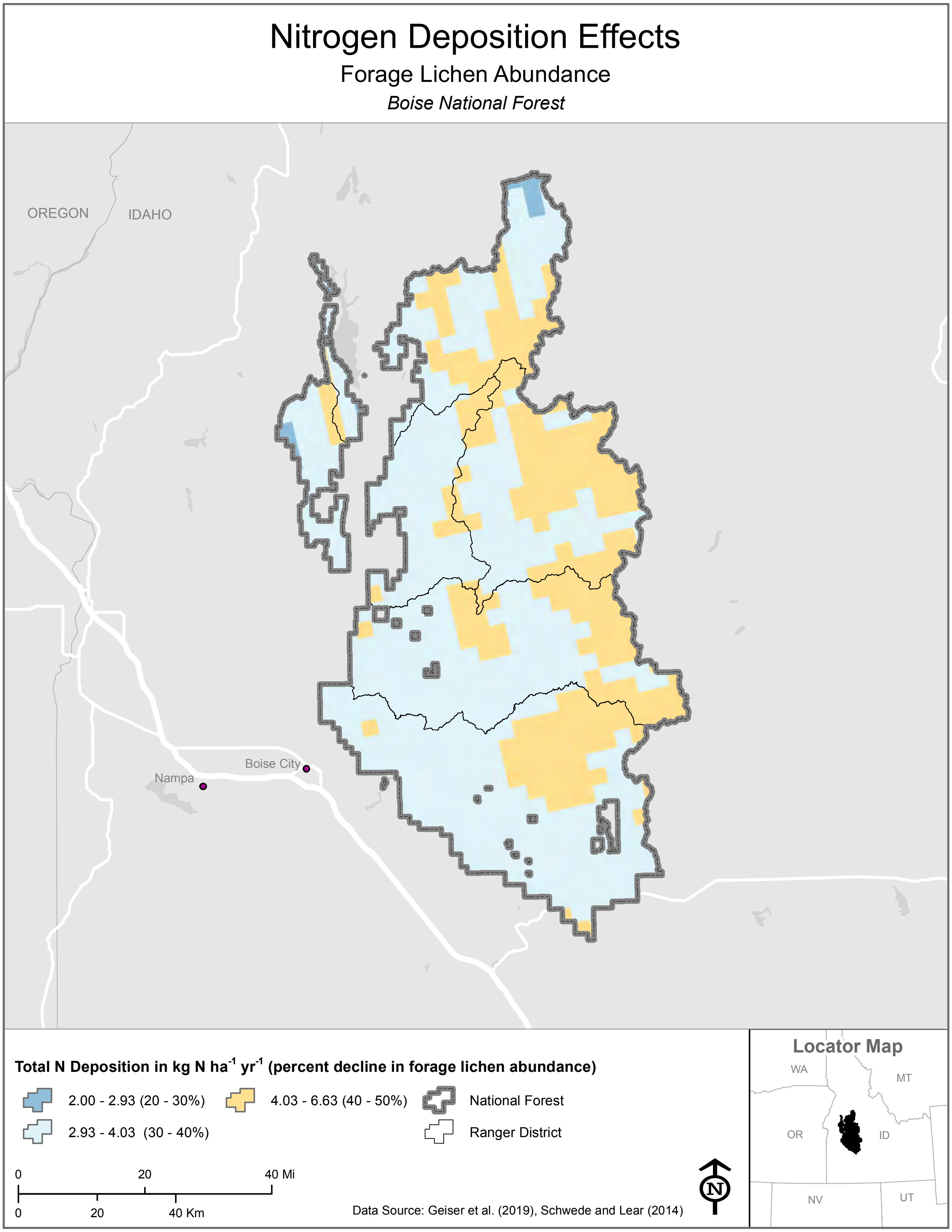


Figure 5-19.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Boise National Forest.

5.3.2.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national analysis that defined one CL each for growth and survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Boise National Forest that had a declining response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 1,756 km^2 (84 percent) of the Boise National Forest where this species is modeled as dominant or codominant (**Table 5-7**). Areas of exceedance were common throughout the Forest (**Figure 5-20**). The N deposition level that protects against a >5 percent decline (7.5 kg N ha^{-1} yr^{-1}) in probability of survival was not exceeded.

Balsam poplar. The N deposition level (3.4 kg N ha^{-1} yr^{-1}) that protects balsam poplar against a >1 percent decline in growth rate was exceeded within 79 percent (117 km^2) of the Forest where this species is modeled as dominant or codominant (**Table**s **5-12 and 5-13**). Exceedance of the N deposition level (>4.2 kg N ha^{-1} yr^{-1}) that protects against a >5 percent decline in growth rate occurred over 43 km^2, largely in the eastern portion of the Forest. In the southern part of the Forest, a small portion of balsam poplar range (1.5 km^2 or 1 percent) exceeded the N deposition level (5.4 kg N ha^{-1} yr^{-1}) that protects against declines in growth rate >10 percent (**Figure 5-21**). The N deposition level (5.0 kg N ha^{-1} yr^{-1}) that protects against a >1 percent decline in probability of survival over 10 years was exceeded in small areas (3 km^2 or 2 percent) of the eastern and southern portions of the Forest where this species is modeled as dominant or codominant (**Figure 5-22**).

Quaking aspen. Total N deposition levels that protects against >1 percent decline in quaking aspen growth rate (13.6 kg N ha^{-1} yr^{-1}) or probability of survival over 10 years (6.6 kg N ha^{-1} yr^{-1}) were not exceeded within any part of the Forest where this species is modeled as dominant or codominant (**Table**s **5-10** and **5-11**, **Figures 5-23** and **5-24**).

Other tree species on the Boise National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-15**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-15.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Boise National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
		Survival	Threshold[a]	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Western larch	*Larix occidentalis*	Growth	Increasing	---	---	---	---
		Survival	Flat[a]	---	---	---	---
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

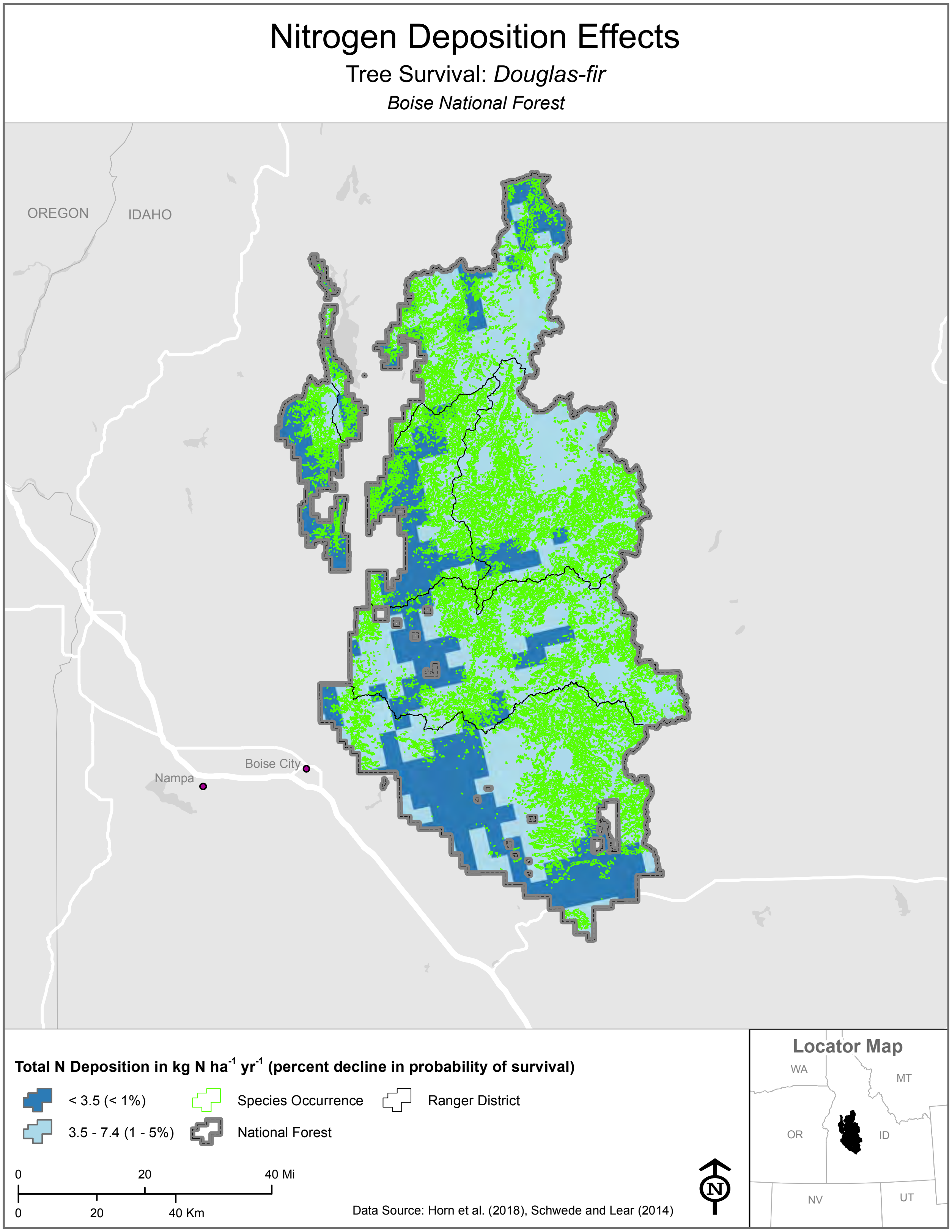


Figure 5-20.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Boise National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

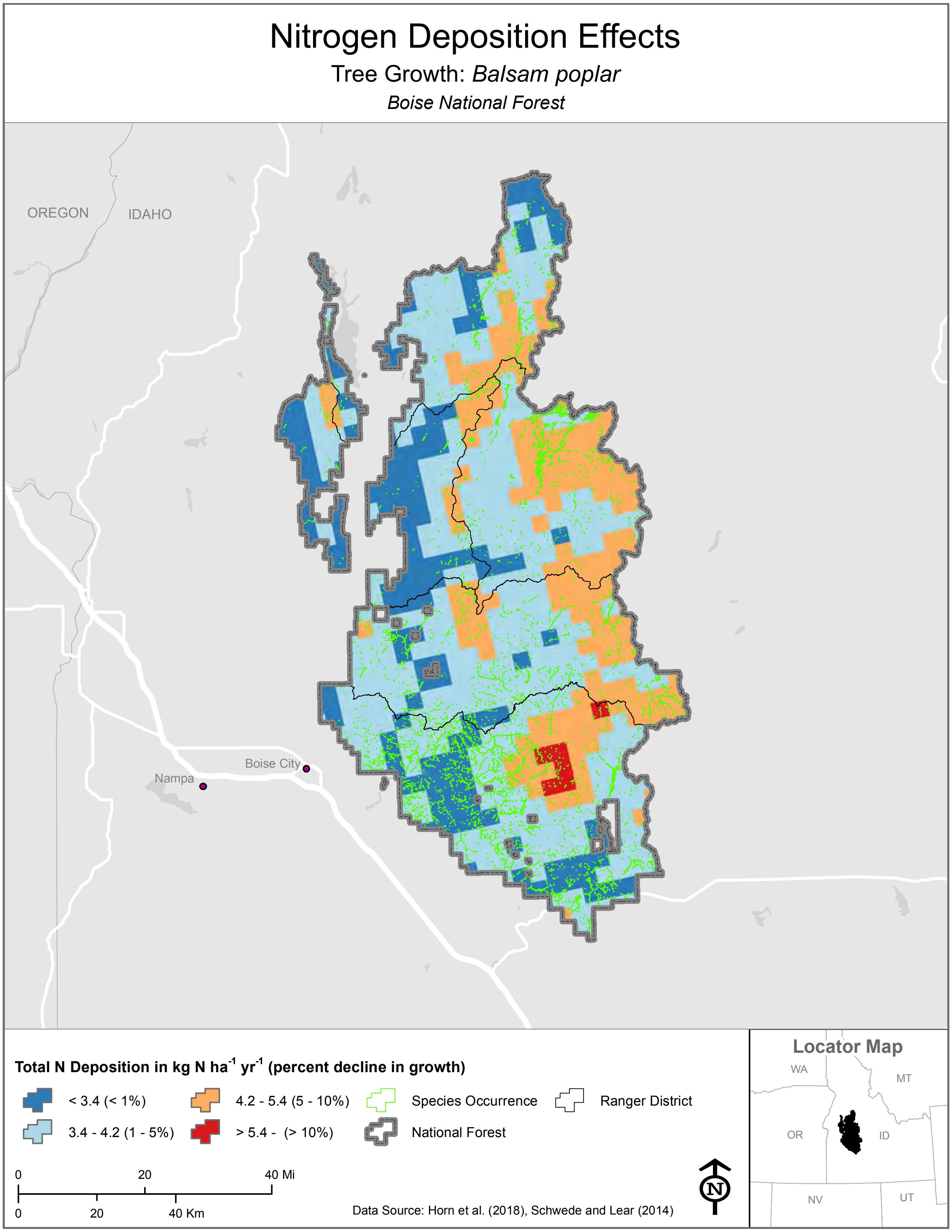


Figure 5-21.—Total (wet + dry) N deposition and percent of decline in growth rate of balsam poplar within the Boise National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

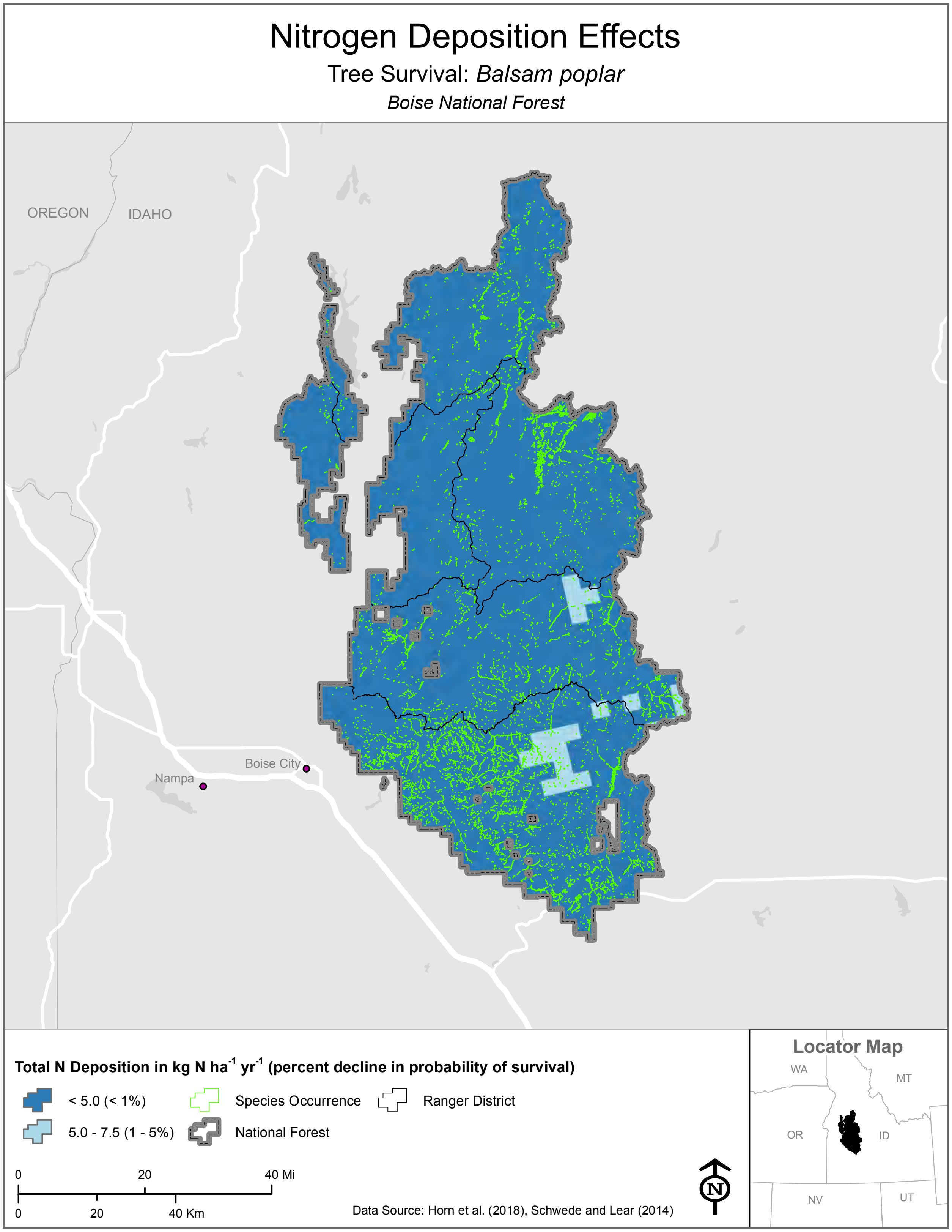


Figure 5-22.—Total (wet + dry) N deposition and percent of decline in the probability of survival over 10 years for balsam poplar within the Boise National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

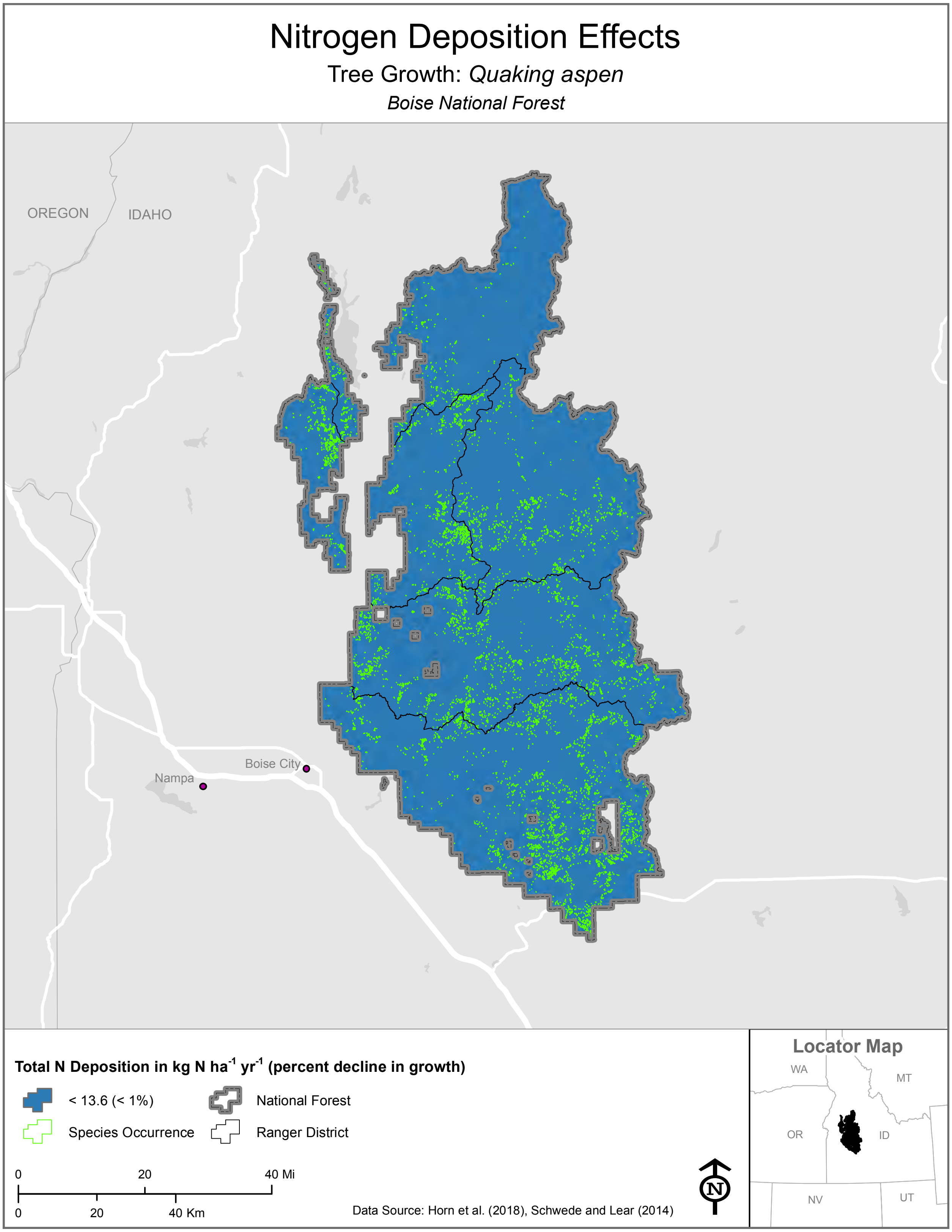


Figure 5-23.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Boise National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

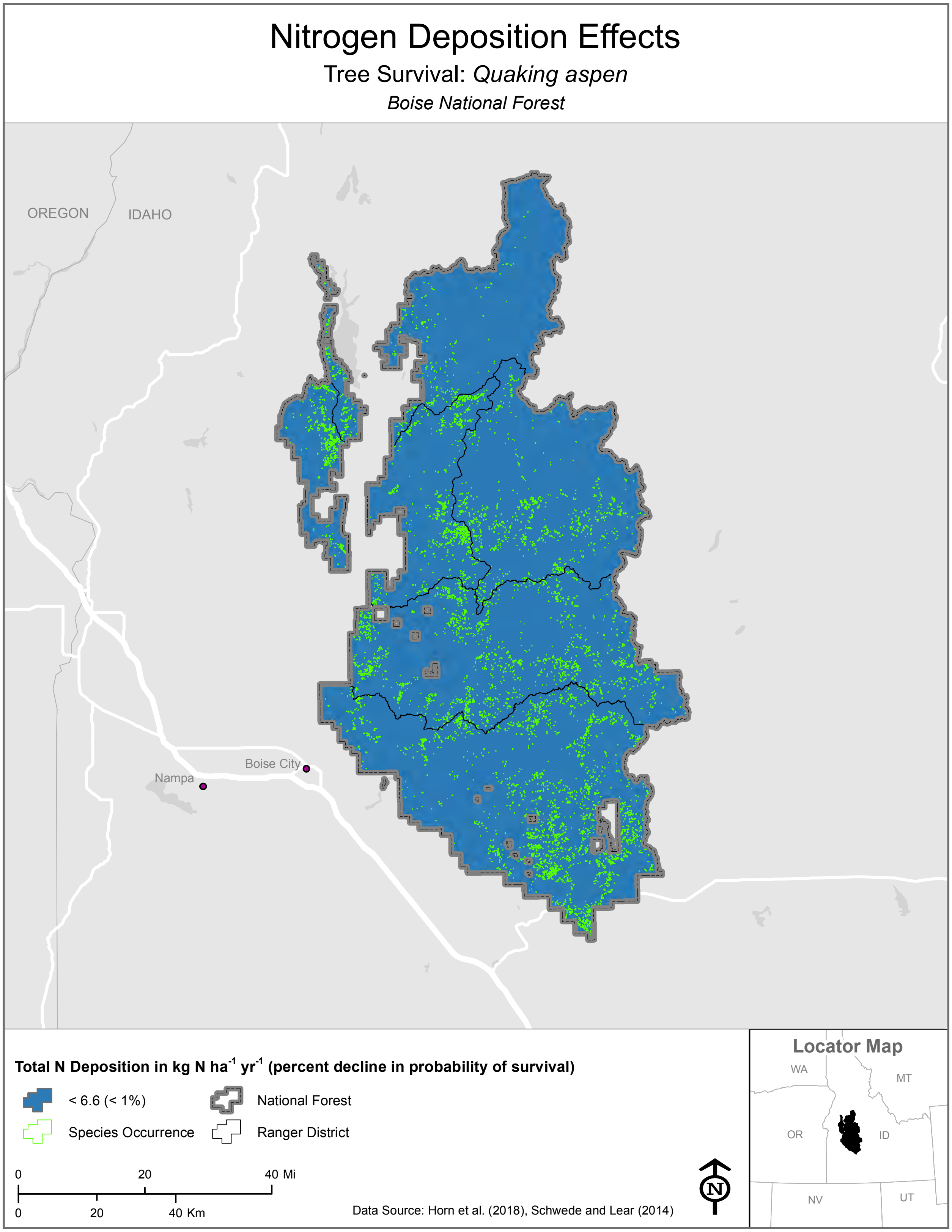


Figure 5-24.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Boise National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Fish Creek at the Upper Green River on the Bridger-Teton National Forest. USDA Forest Service photo by A.Cohen.

5.3.3 Bridger-Teton National Forest

5.3.3.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 and 20 µeq L^{-1} were calculated for 203 lakes throughout the Bridger-Teton National Forest (**Figure 5-25**). Of these lakes analyzed, 20, or 10 percent, had low CLs (<2 kg N ha^{-1} yr^{-1}) to protect ANC from decreasing below 50 µeq L^{-1}. Lakes with the lowest CLs were found in the Teton and Bridger Wilderness Areas. Nitrogen deposition was high enough to exceed the CL at 30 percent (n = 61) of the sites (**Table 5-2**). The highest magnitudes of CL exceedance (2 to 5 kg N ha^{-1} yr^{-1}) occurred at 11 percent (n = 23) of the sites, mostly within the Bridger Wilderness (**Figure 5-26**). These locations have a higher risk to experience biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}, especially if N deposition (under current S deposition) is constant or increases. Due to the density of sites in the Bridger Wilderness, expanded views of these CLs and CL exceedances are shown in **Figures 5-27** and **5-28**, respectively. There may be additional acid-sensitive water bodies on the Bridger-Teton National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

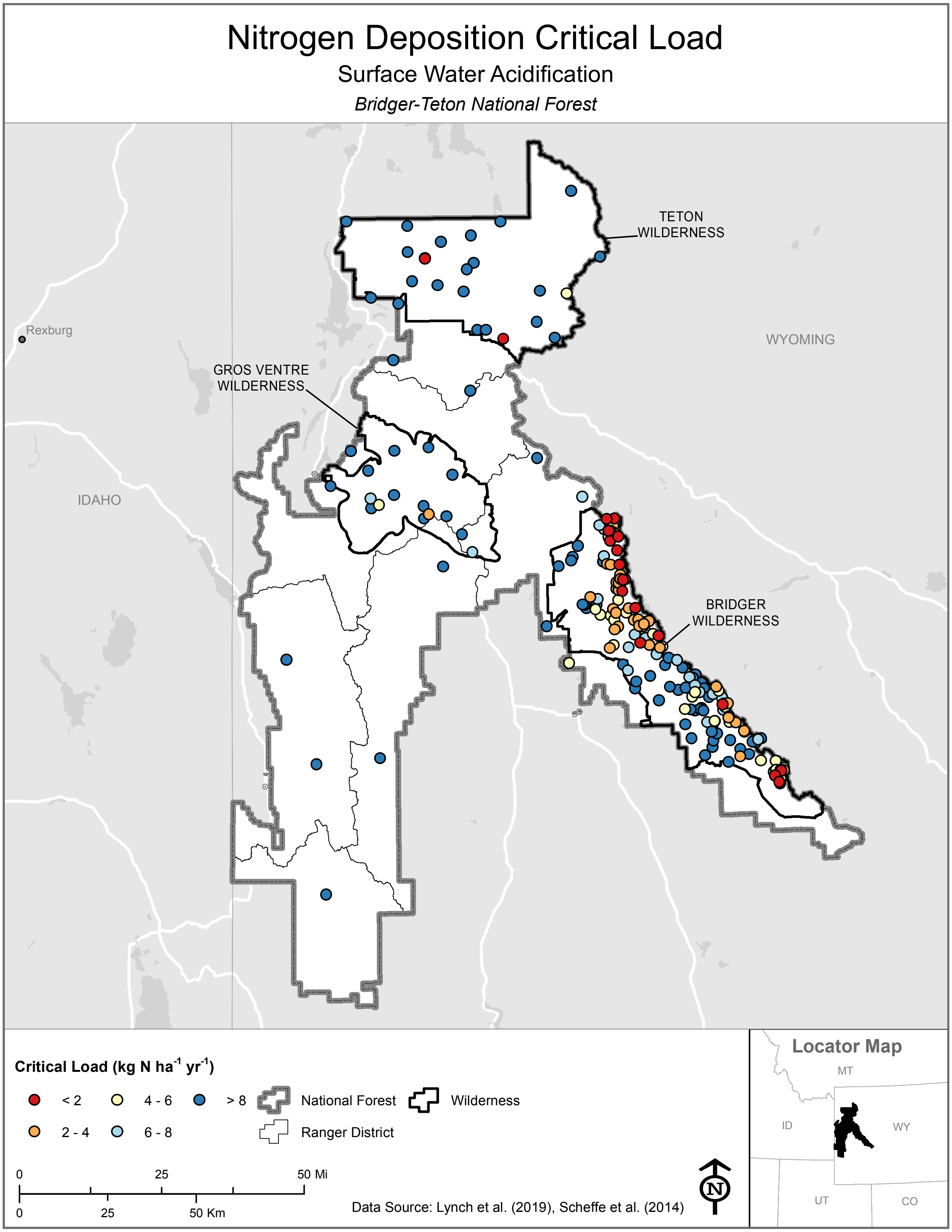


Figure 5-25.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Bridger-Teton National Forest.

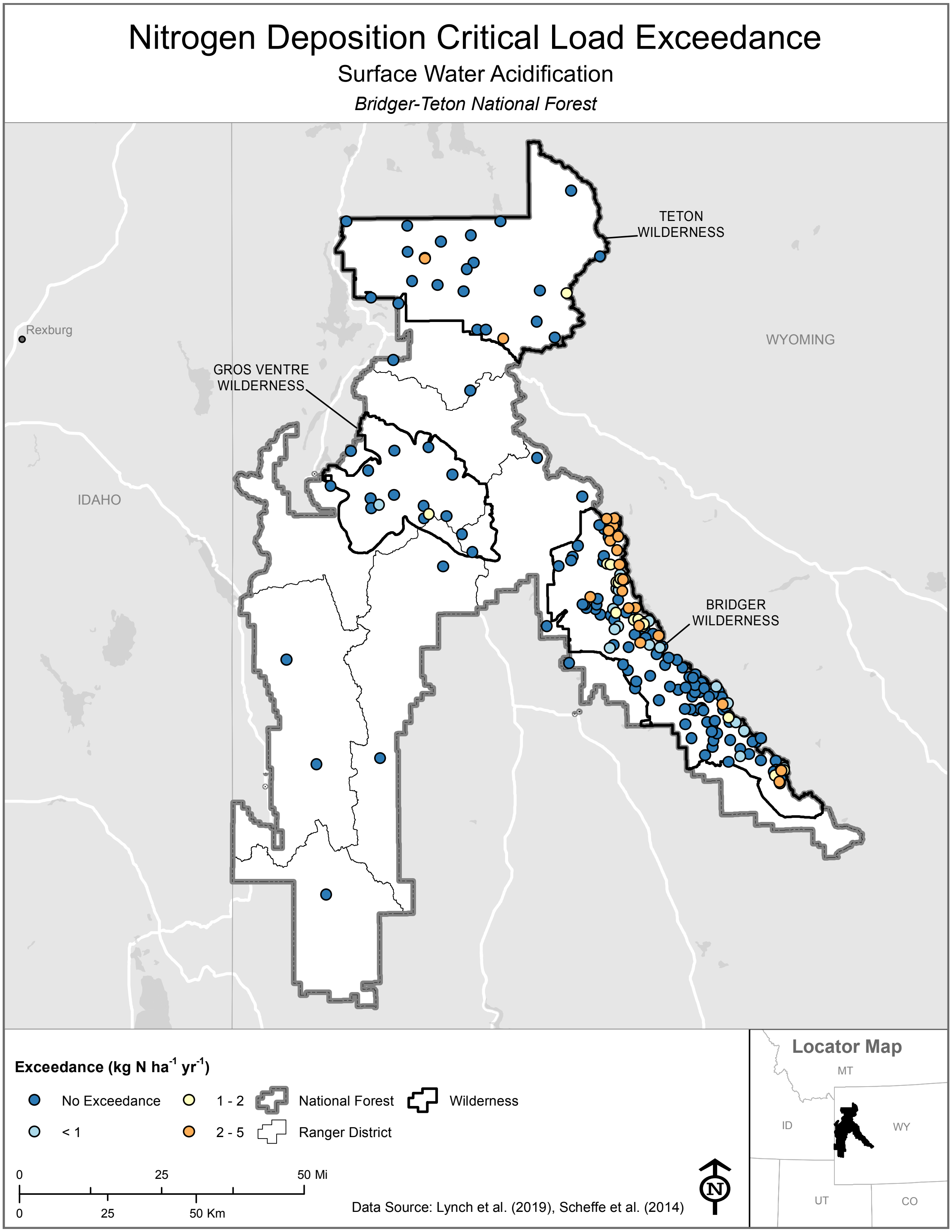


Figure 5-26.—Exceedances of the CLs for total (wet + dry) N deposition that protect surface water acidification decreasing below 50 µeq L^{-1} at lake or stream sample sites on the Bridger-Teton National Forest.

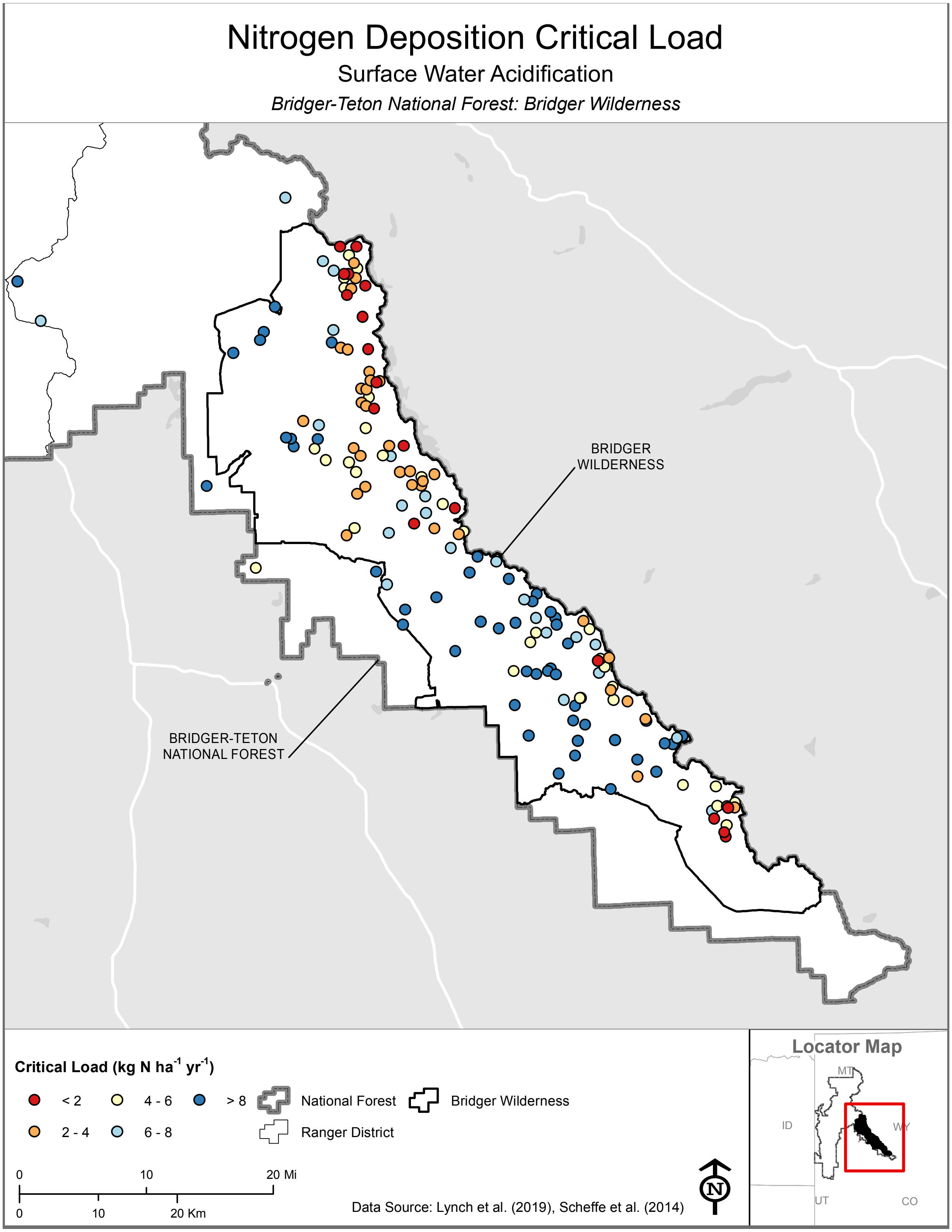


Figure 5-27.—Total (wet + dry) N deposition CLs that protect surface water acidification decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Bridger Wilderness of the Bridger-Teton National Forest.

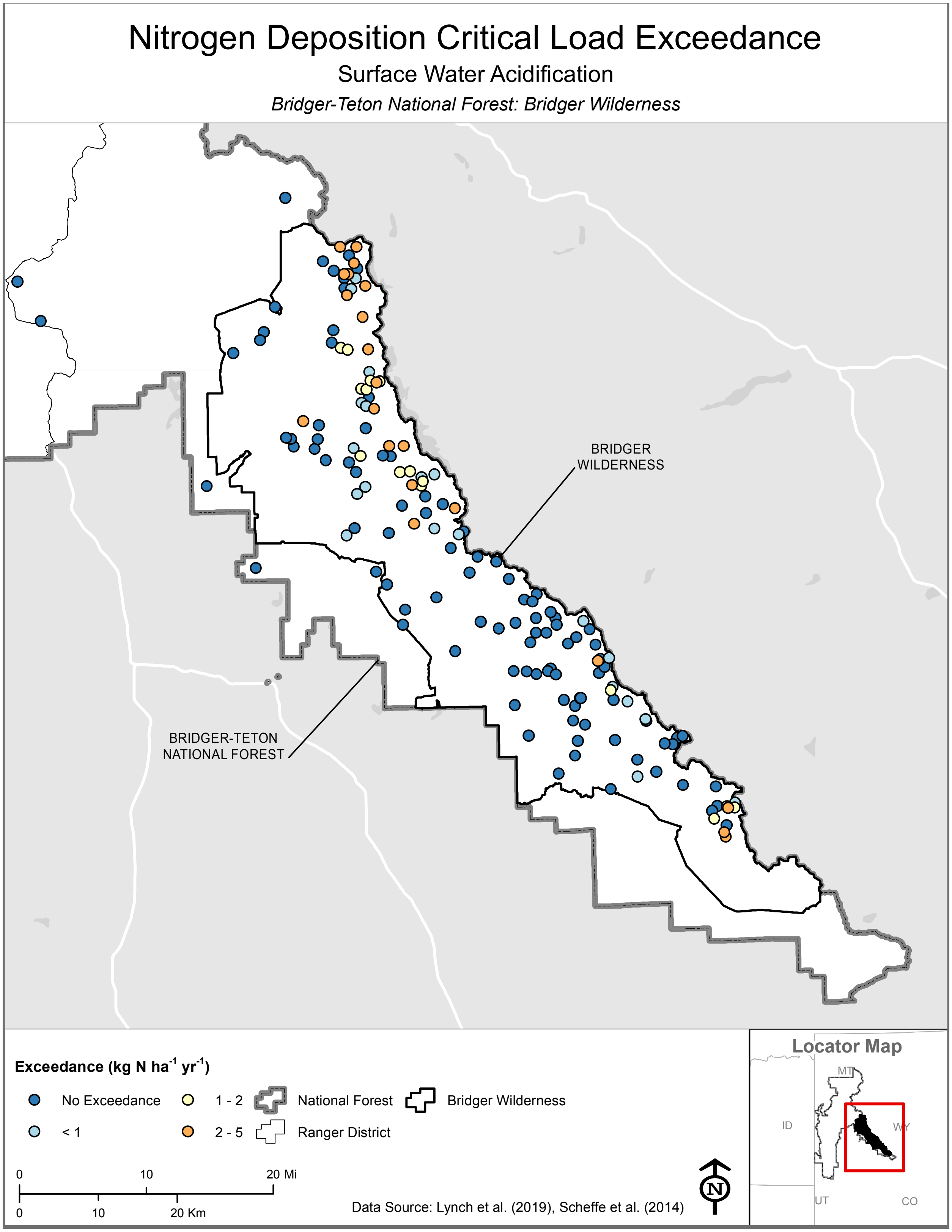


Figure 5-28.—Exceedances of the CLs for N deposition that protect surface water acidification from decreasing below 50 μeq L^{-1} on the within the Bridger Wilderness area of the Bridger-Teton National Forest at lake or stream sample sites.

Canoeing on Murphy Lake, Bridger-Teton National Forest. USDA Forest Service photo.

5.3.3.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Bridger-Teton National Forest were calculated using total (wet + dry) N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg N ha^{-1} yr^{-1}) were mapped across 1,400 km^2 (10 percent) of the Forest. These low CLs were concentrated in the Teton and Bridger Wilderness Areas (**Table 5-3**, **Figure 5-29**). Nitrogen deposition was high enough to exceed the CLs for eutrophication on 12,682 km^2 (90.5 percent) of the Forest (**Table 5-4**). The highest magnitudes of exceedance, >4 kg N ha^{-1} yr^{-1}, were mapped in the high alpine zones of the Teton and Bridger Wilderness Areas and in the southwest portion of the Forest (355 km^2 total or 2.5 percent of the Forest). Exceedances of 2 to 4 kg N ha^{-1} yr^{-1} were mapped across 4,665 km^2 (33 percent) of the Forest, including large portions of the Teton, Gros, Ventre, and Bridger Wilderness Areas (**Figure 5-30** and **Table 5-4**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities.

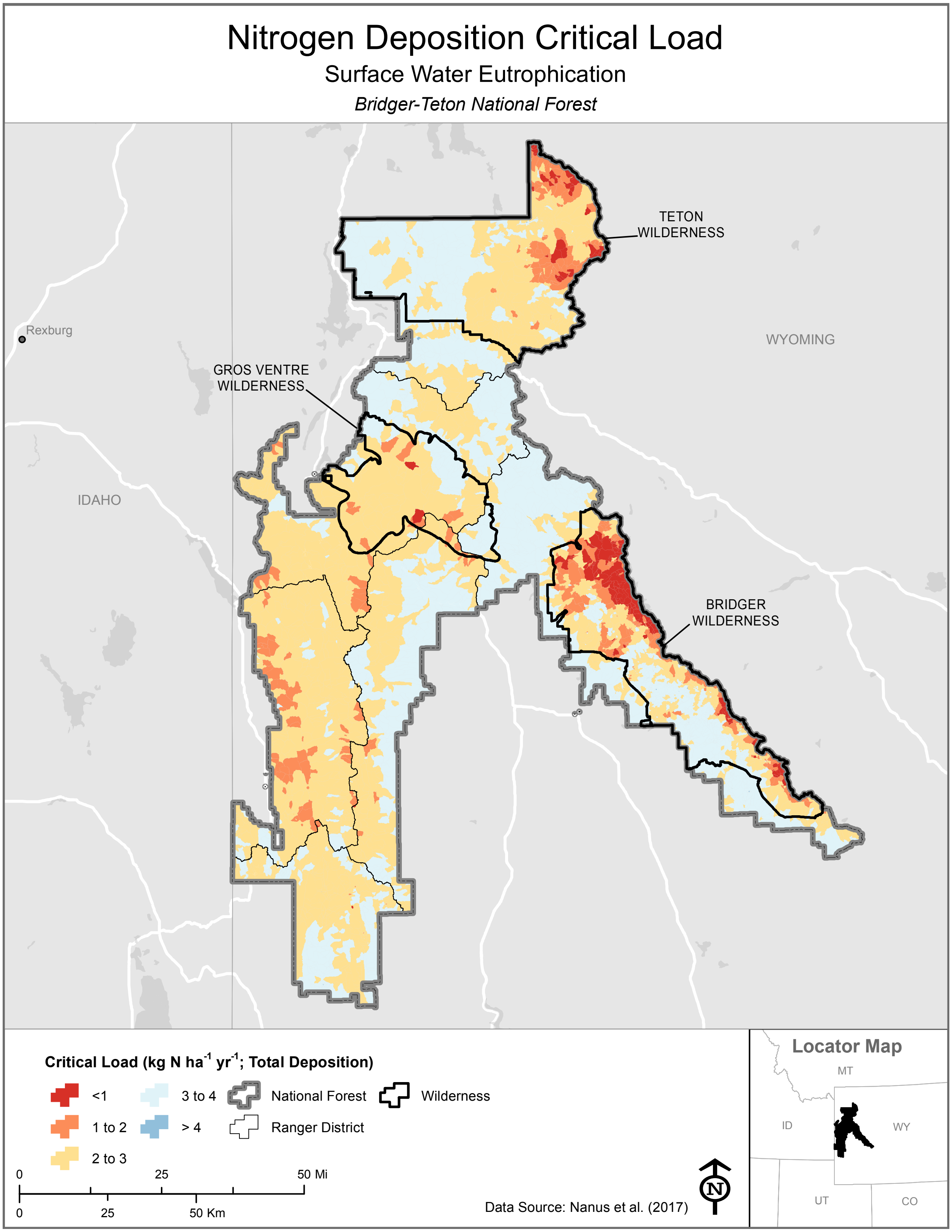


Figure 5-29.—Total (wet + dry) N deposition critical loads that protect against surface water eutrophication within the Bridger-Teton National Forest. Based on a threshold nitrate concentration of 0.5 μmol L^{-1}.

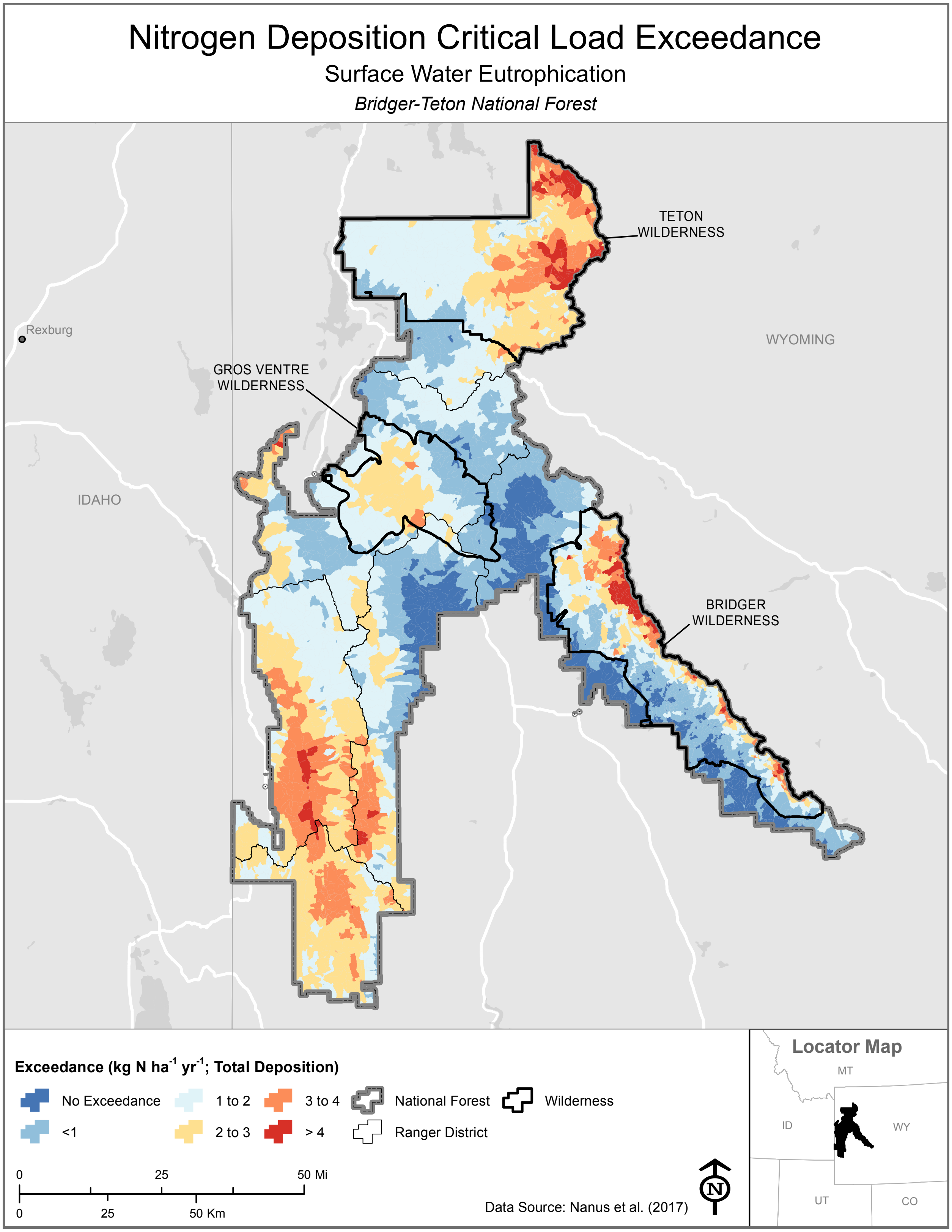


Figure 5-30.—Exceedances of CLs for total (wet + dry) N that protect against surface water eutrophication within the Bridger-Teton National Forest. Based on a threshold nitrate concentration of 0.5 μmol L^{-1}.

Sunset view from Shadow Lake, Bridger Wilderness, Bridger-Teton National Forest. USDA Forest Service photo by Greg Bevenger.

5.3.3.3 Lichen Species Richness and Abundance

Lichen CLs for species richness (3.5 kg N ha^{-1} yr^{-1}) and forage lichen abundance (2.0 kg N ha^{-1} yr^{-1}) were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance on 80 percent (11,196 km^2) and 100 percent (14,029 km^2), respectively, of the Bridger-Teton National Forest (**Tables 5-5** and **5-6**). The highest magnitudes of CL exceedances (associated with a 30 to 40 percent decline) for lichen species richness were widespread in the Teton Wilderness and the southwest portion of the Forest (**Figure 5-31**). CL exceedances associated with 40 to 50 percent declines in forage lichen abundance were widespread throughout the Teton Wilderness, the high elevation portions of the Gros Ventre and Bridger Wilderness Areas, and the southwestern portion of the Forest (**Figure 5-32**). A small area (17 km^2) in the southwest portion of the Forest had CL exceedances associated with a 50 to 80 percent decline in forage lichen abundance. The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

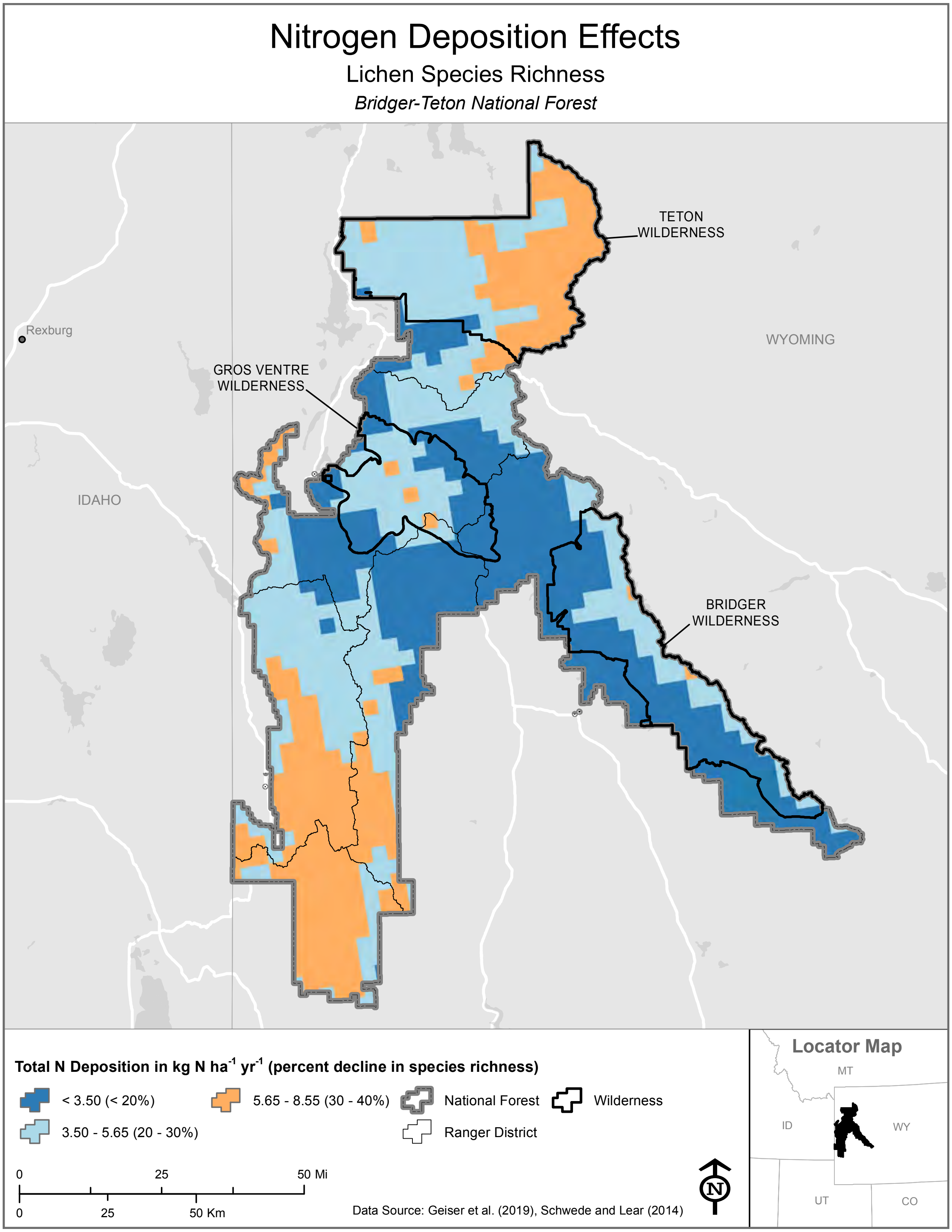


Figure 5-31.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Bridger-Teton National Forest.

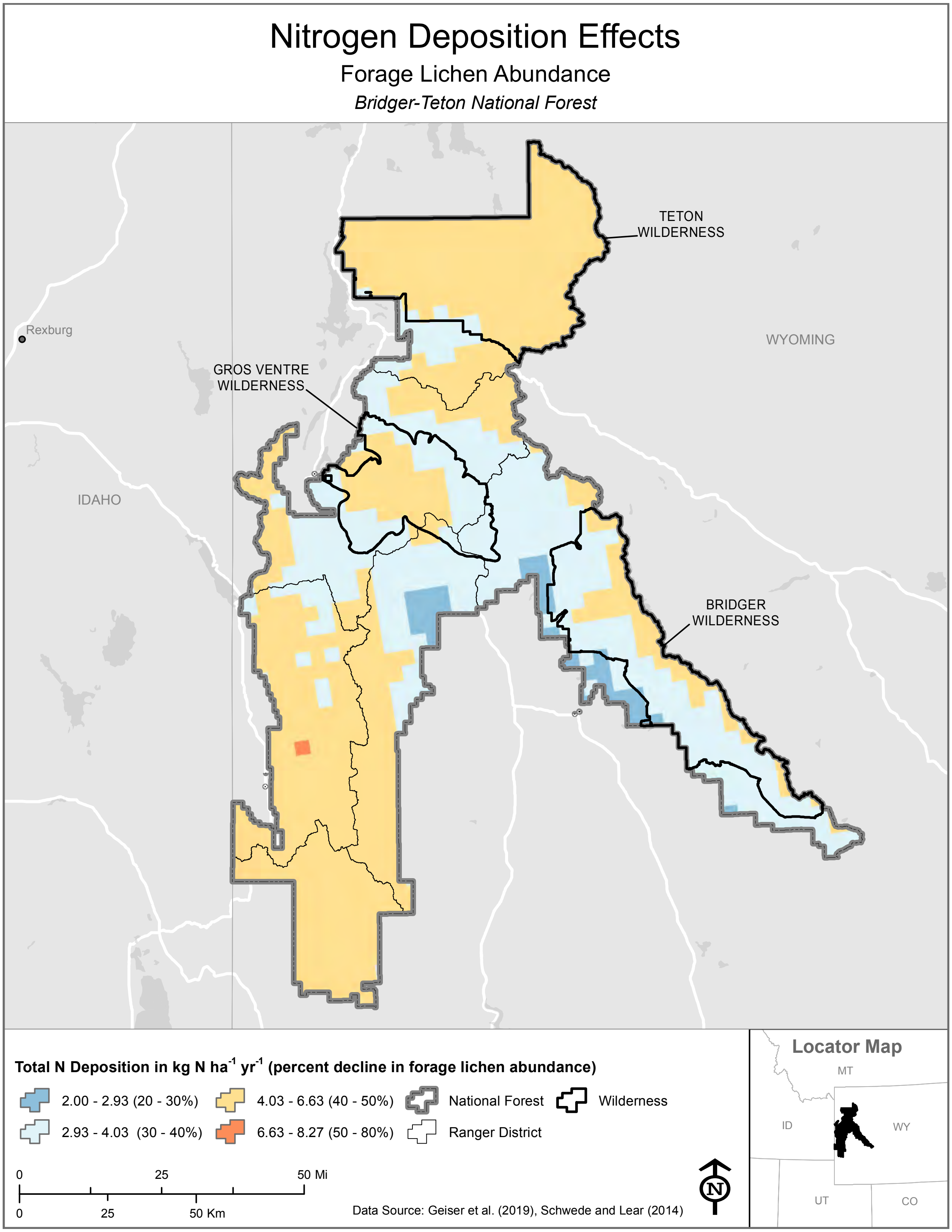


Figure 5-32.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Bridger-Teton National Forest.

5.3.3.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Bridger-Teton National Forest that had a declining or threshold response to N deposition. Areas with high magnitudes of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 82 percent (827 km^2) of the area that this species is modeled as dominant or codominant on the Bridger-Teton National Forest (**Table 5-7**). Exceedances were associated with declines in survival between 1 and 5 percent and were common throughout the forest, including portions of the Bridger, Teton, and Gros Ventre Wilderness Areas (**Figure 5-33**).

Balsam poplar. Balsam poplar is modeled as dominant or codominant in small pockets that total only 1.5 km^2, primarily in the northern half of the Bridger-Teton National Forest. The N deposition level (3.4 kg N ha^{-1} yr^{-1}) that protects balsam poplar against a >1 percent decline in growth rate was exceeded within 0.8 km^2 (50 percent) of the area that this species is modeled as dominant or codominant (**Table 5-12**). The exceedances were predominantly associated with 1 to 5 percent declines in growth rate, with the exception of 0.2 km^2 that was associated with 5 to 10 percent declines (**Table 5-12**). Exceedances occurred mainly in the northern portion of the Forest (**Figure 5-34**). There were no exceedances of the N deposition level (5.0 kg N ha^{-1} yr^{-1}) associated with declines in probability of survival for balsam poplar (**Table 5-13** and **Figure 5-35**).

Quaking aspen. There were no exceedances of the N deposition level that protects quaking aspen against declines in growth rate (**Table 5-10** and **Figure 5-36**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceeded on only 0.1 km^2 of the 698 km^2 where this species is modeled as dominant or codominant (**Table 5-11**). This rare pocket of exceedance was associated with a 1 to 5 percent decline in probability of survival and occurred in the southwestern portion of the Forest (**Figure 5-37**).

Other species of interest that occurred within the Bridger-Teton National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-16**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-16.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Bridger-Teton National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival 1%	5%	10%
Subalpine fir	Abies lasiocarpa	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Engelmann spruce	Picea engelmannii	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	Pinus contorta	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	**Populus balsamifera**	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	**Populus tremuloides**	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	**Pseudotsuga menziesii**	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

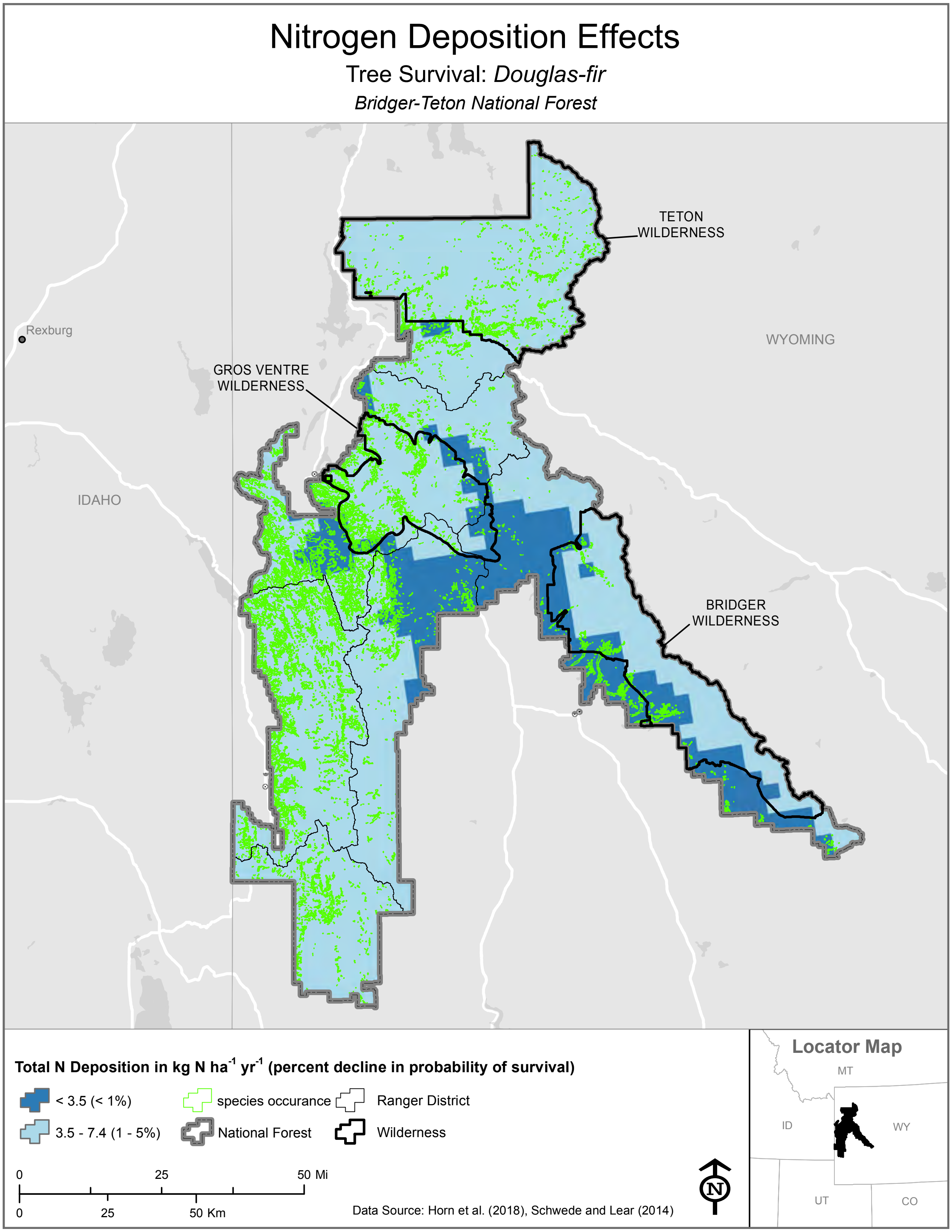


Figure 5-33.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Bridger-Teton National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

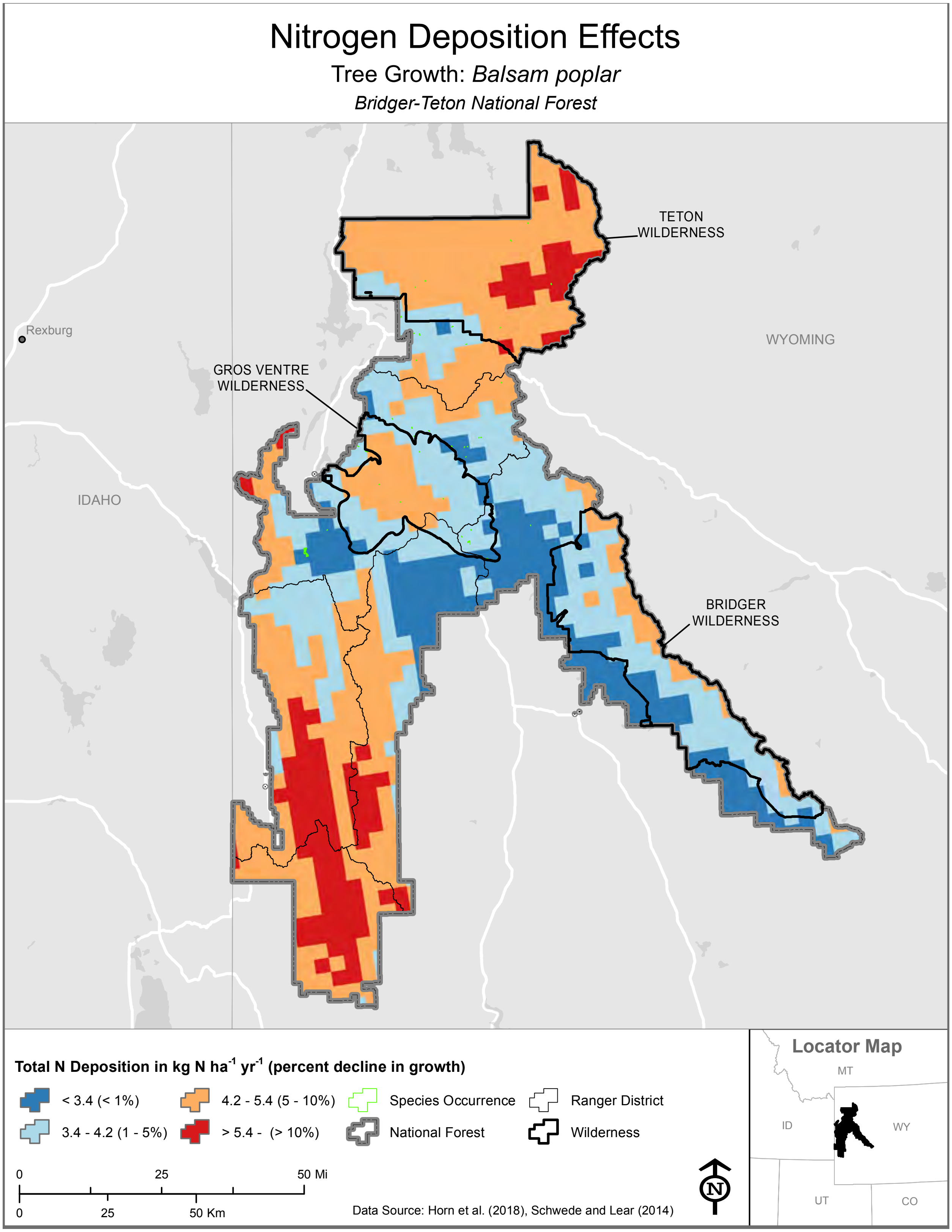


Figure 5-34.—Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Bridger-Teton National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest

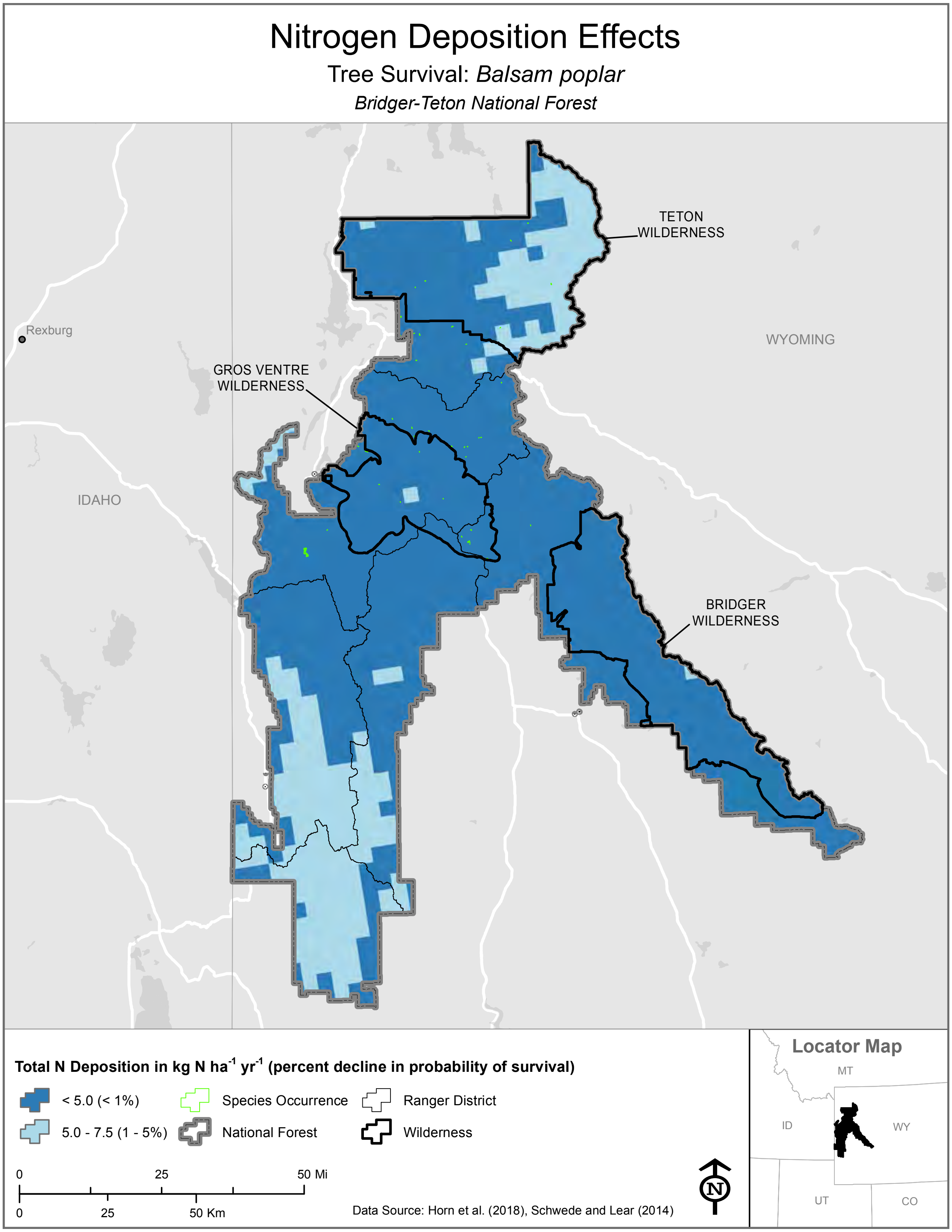


Figure 5-35.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Bridger-Teton National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

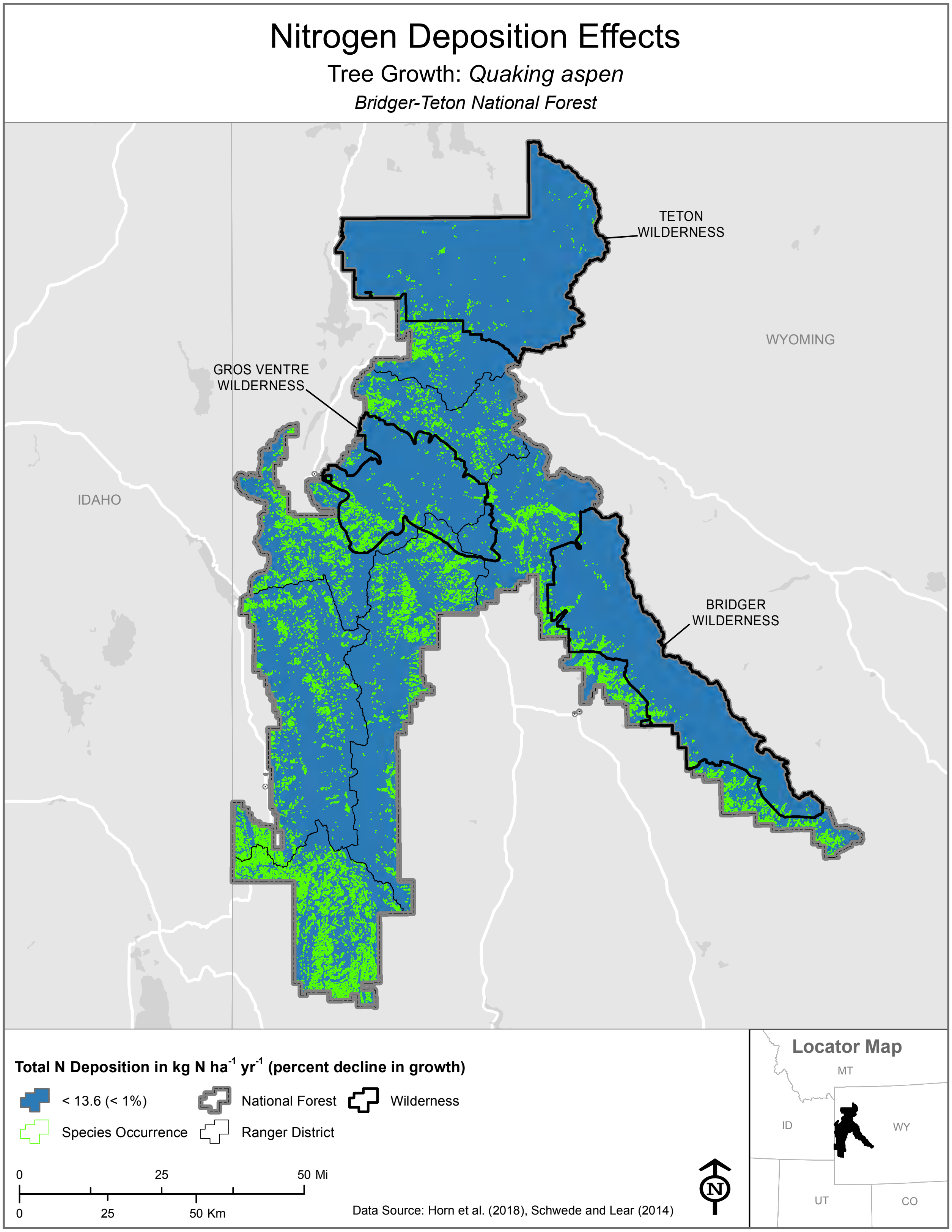


Figure 5-36.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Bridger-Teton National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

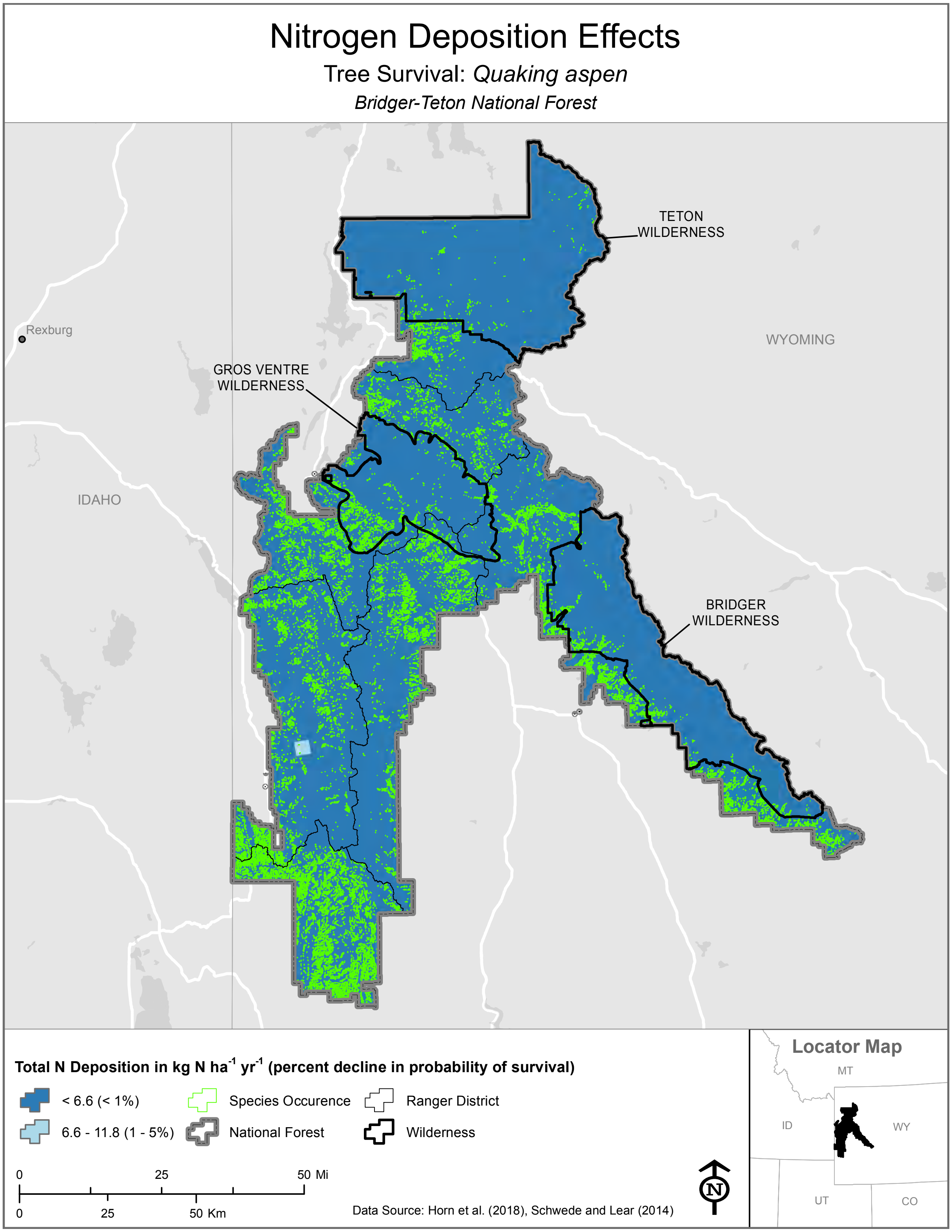


Figure 5-37.—Total (wet + dry) N deposition percent of decline in probability of survival over 10 years for quaking aspen within the Bridger-Teton National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Looking east toward Table Mountain in the Jedediah Smith Wilderness Area, Caribou-Targhee National Forest. USDA Forest Service photo by Rose Lehman.

5.3.4 Caribou-Targhee National Forest

5.3.4.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 $\mu eq\ L^{-1}$ were calculated for 17 water bodies on Caribou-Targhee National Forest. Fourteen water bodies (82 percent), had a low risk for surface water acidification with high CLs (>8 kg N $ha^{-1}\ yr^{-1}$; **Figure 5-38**) and no CL exceedances (**Table 5-1**, **Figure 5-39)**. N deposition levels were high enough at two lakes in the Jedediah Smith Wilderness to exceed the CLs that protect against ANC from decreasing below 50 $\mu eq\ L^{-1}$ (**Figure 5-39**). There were no exceedances for the CLs that protect ANC from decreasing below 20 $\mu eq\ L^{-1}$ (**Table 5-1)**. There may be additional acid-sensitive water bodies on the Caribou-Targhee National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

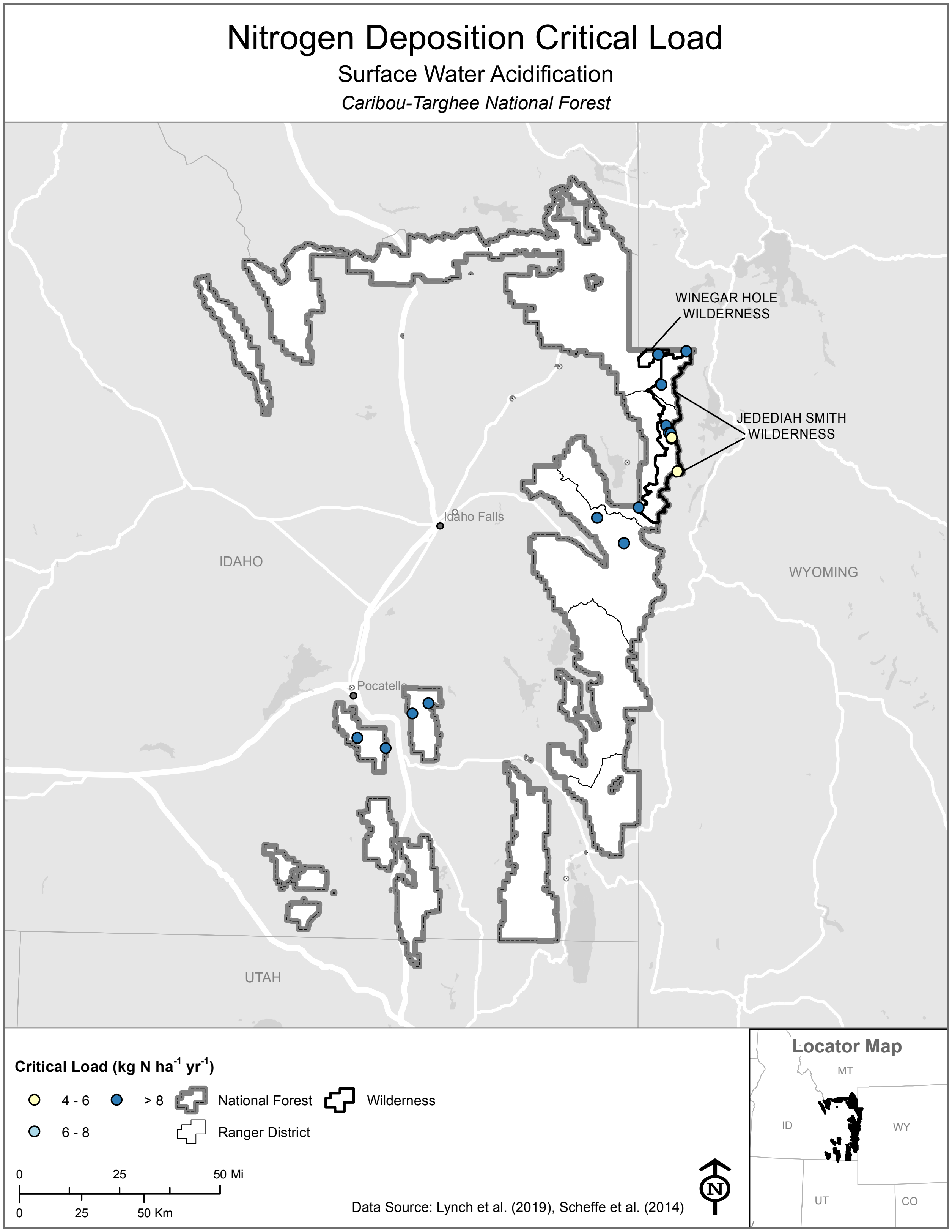


Figure 5-38.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Caribou-Targhee National Forest.

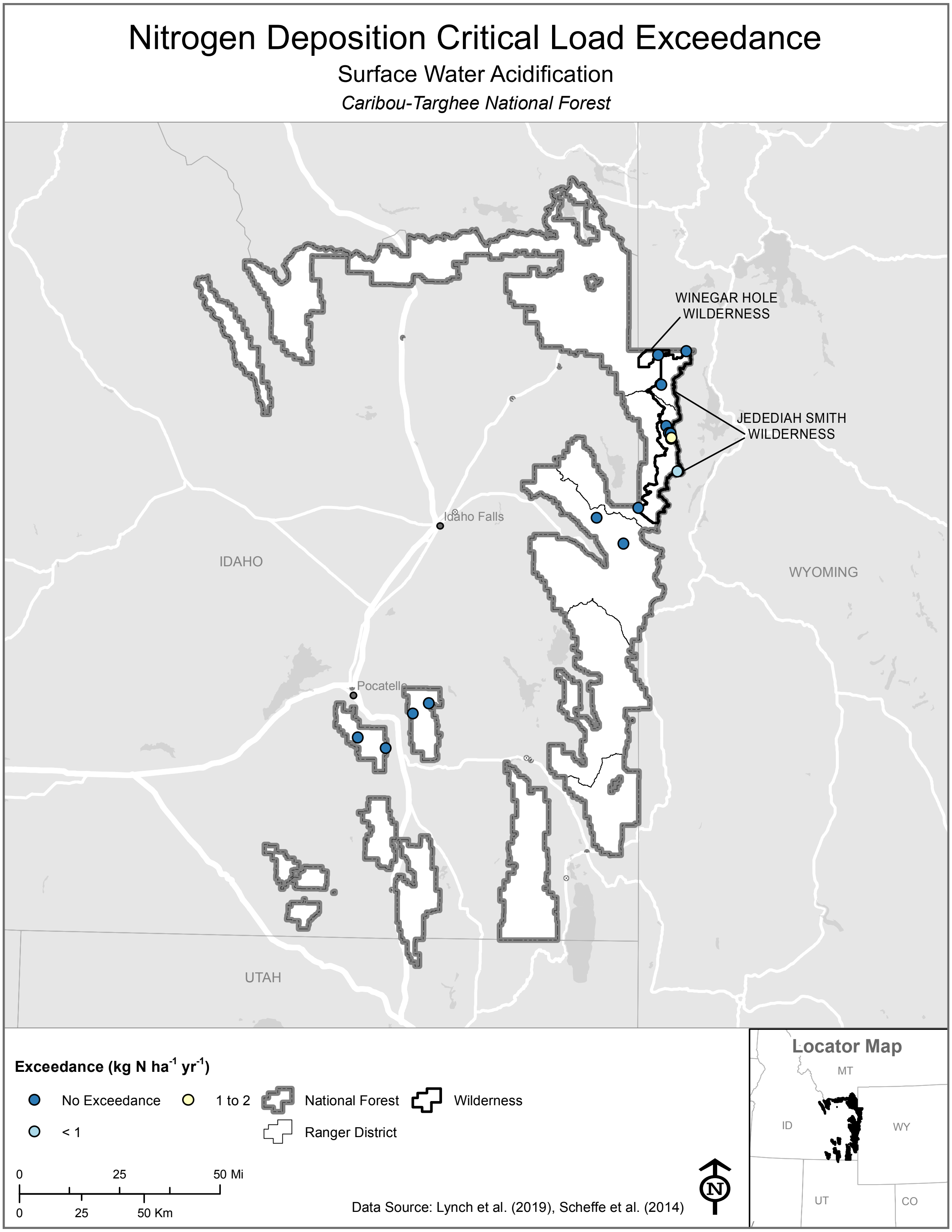


Figure 5-39.—Exceedance of total (wet + dry) N CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Caribou-Targhee National Forest.

South fork of the Snake River Caribou-Targhee National Forest. USDA Forest Service photo.

5.3.4.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Caribou-Targhee National Forest were calculated using wet N deposition. The higher the CL, the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 3,564 km^2 (38.5 percent) of the Forest (**Table 5-3**, **Figure 5-40**). The largest magnitudes of exceedance were typically found in areas with low CLs. Exceedances of CLs occurred over 5,319 km^2 (57 percent) of the Forest (**Table 5-4**, **Figure 5-41**). The highest magnitudes of exceedance, >4 kg wet N ha^{-1} yr^{-1}, were mapped over 536 km^2 (6 percent) of the Forest (**Figure 5-41** and **Table 5-4)**. Exceedances of 2 to 4 kg wet N ha^{-1} yr^{-1} were mapped across 1,873 km^2 (20 percent) of the Forest (**Figure 5-41** and **Table 5-4)**. Areas with high magnitudes of exceedance, including most of the Jedediah Smith Wilderness, are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Caribou-Targhee National Forest are outside the geographic bounds of this study. These areas are marked as “No Data” in **Figure 5-40** and **Figure 5-41**.

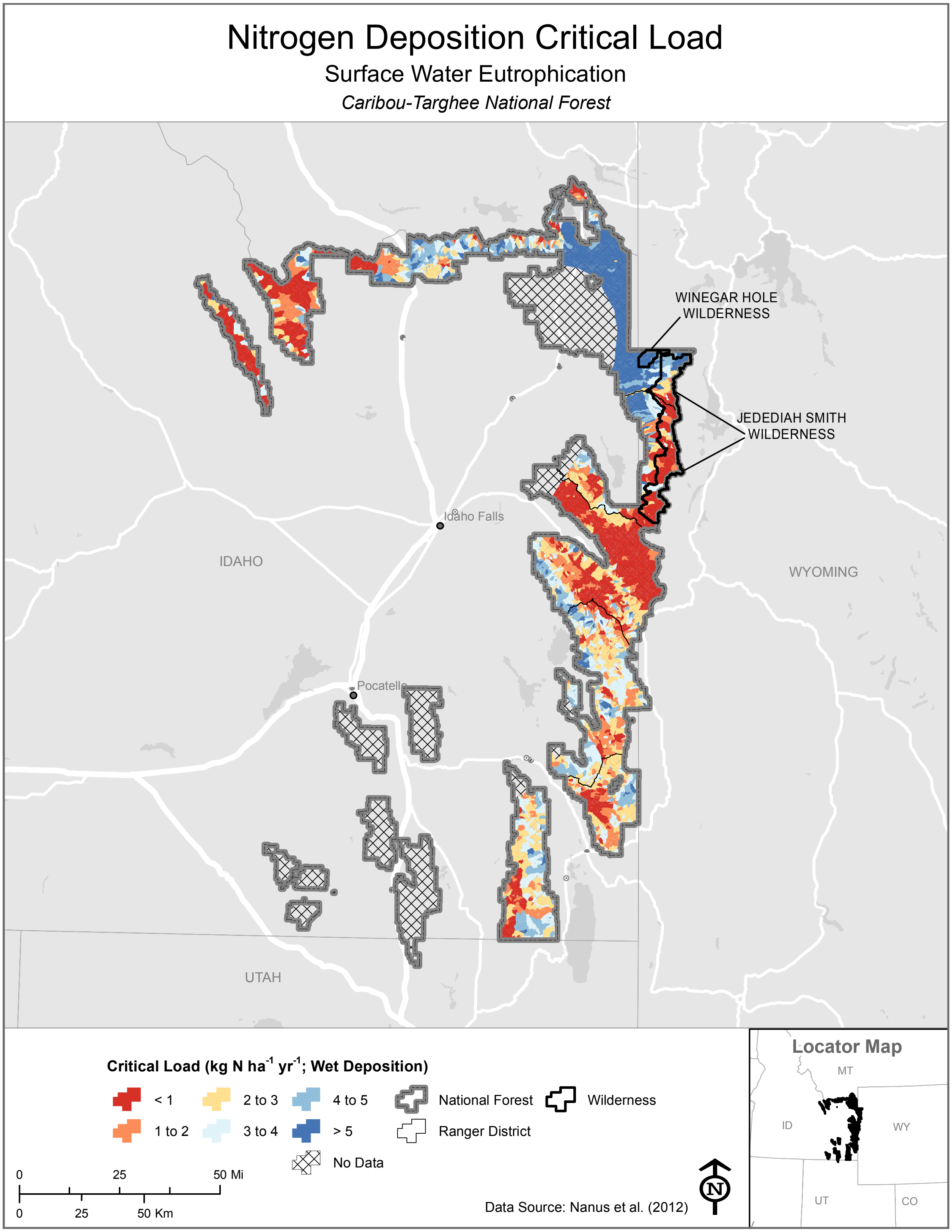


Figure 5-40.—Wet N deposition CLs that protect against surface water eutrophication within the Caribou-Targhee National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

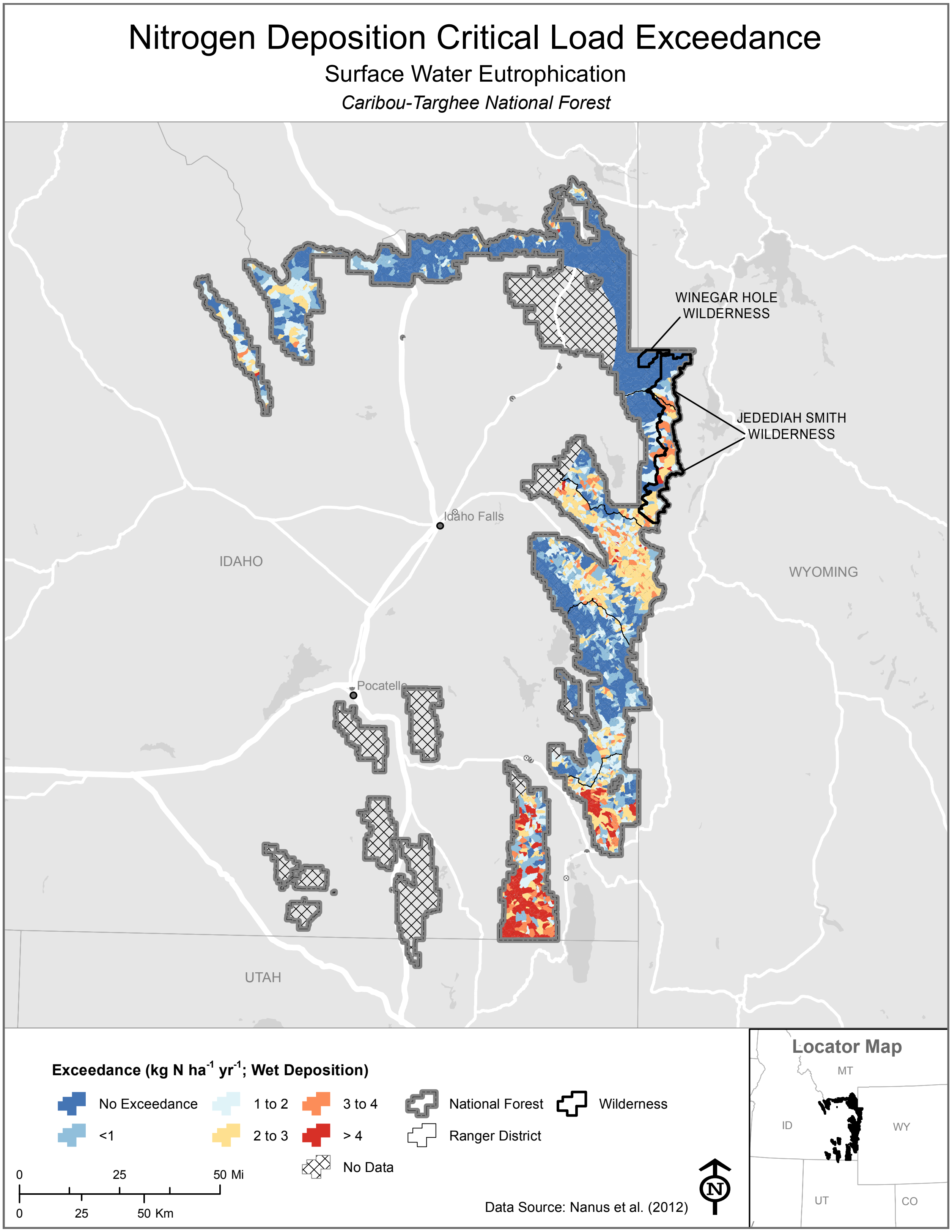


Figure 5-41.—Exceedance of wet N CLs that protect against surface water eutrophication within the Caribou-Targhee National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

Fall Creek falls, Caribou-Targhee National Forest. USDA Forest Service photo.

5.3.4.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 90 percent (11,176 km^2) and 100 percent (12,455 km^2), respectively, of the Caribou-Targhee National Forest (**Table**s **5-5** and **5-6**). The northwestern portion of the Forest had no exceedances of the CL that protects against declines (>20 percent) in lichen species richness and low magnitude of exceedances (associated with 20 to 30 percent declines) of the CL that protects against declines (>20 percent) in forage lichen abundance (**Figures 5-42** and **5-43**). The southern portion of the Forest had the highest magnitudes of exceedance (>5 kg N ha^{-1} yr^{-1} for both CLs) associated with 40 to 50 percent declines in lichen species richness and >80 percent declines in forage lichen abundance (**Figures 5-42** and **5-43**). The Winegar Hole Wilderness and Jedediah Smith Wilderness were in exceedance for both CLs with a higher magnitude of exceedance associated with declines in forage lichen abundance. The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover, or areas where the climatic conditions are not suitable.

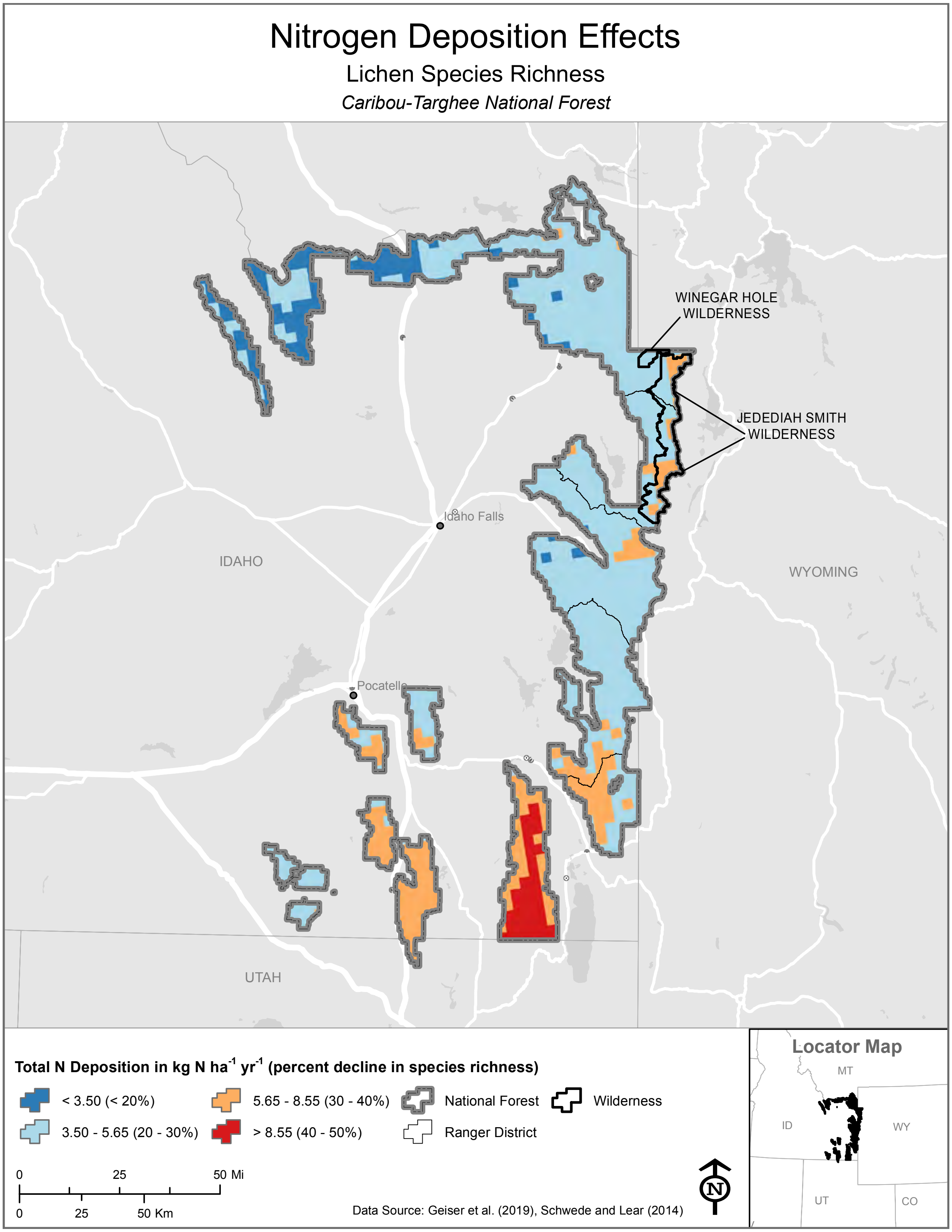


Figure 5-42.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Caribou-Targhee National Forest.

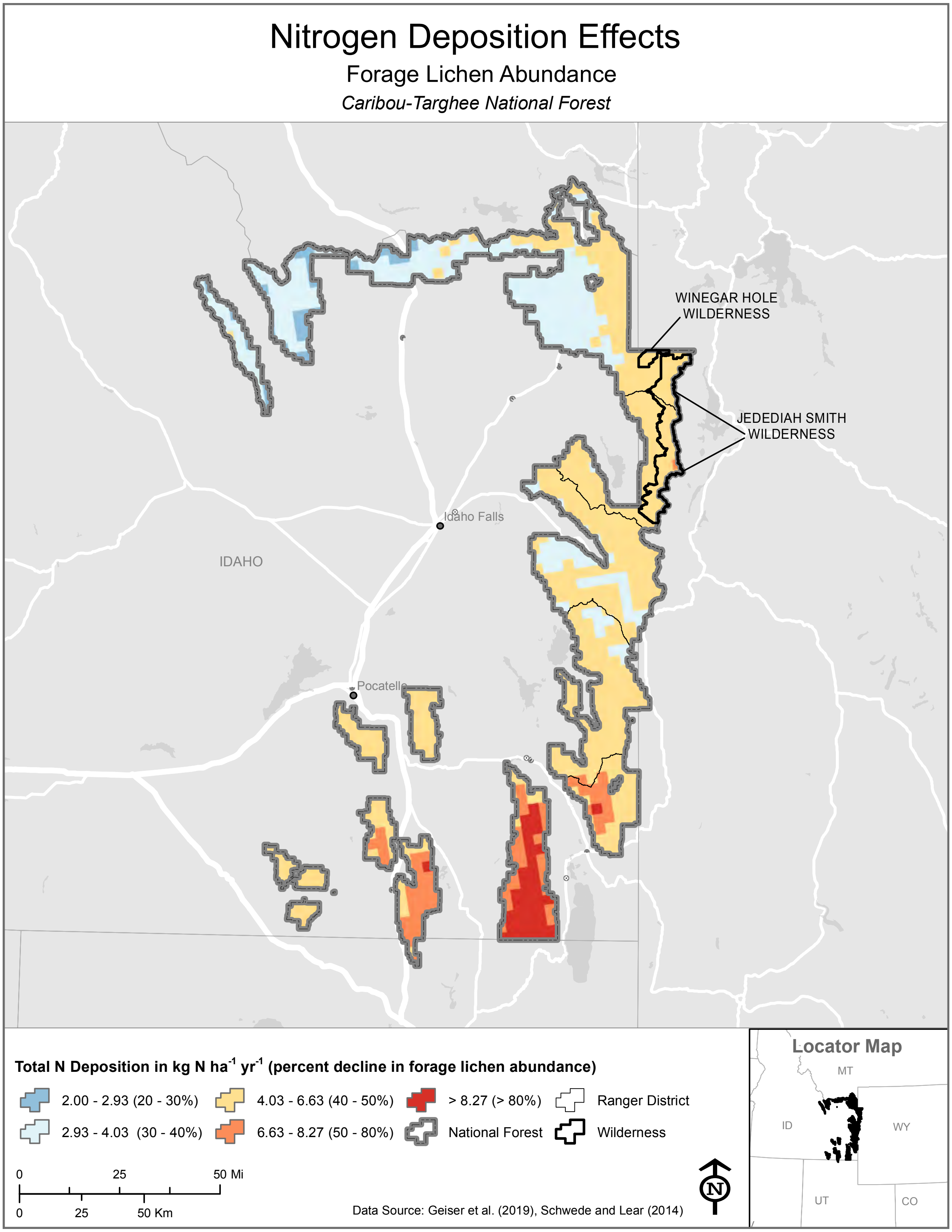


Figure 5-43.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Caribou-Targhee National Forest.

5.3.4.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Caribou-Targhee National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 84 percent (2,366 km^2) of the area where this species is modeled as dominant or codominant on the Caribou-Targhee National Forest (**Table 5-7**). Exceedances were associated with 1 to 5 percent declines in probability of survival over 2,243 km^2 (80 percent) and with 5 to 10 percent declines over 123 km^2 (4 percent) of the range where Douglas-fir is modelled as dominant or codominant (**Table 5-7, Figure 5-44**). Exceedances were common throughout the Douglas-fir range, including portions of the Winegar Hole and Jedediah Smith Wilderness Areas. The highest magnitudes of exceedance (associated with 5 to 10 percent declines in probability of survival) occurred in the southern portion of the Forest (**Figure 5-44**).

Quaking aspen. There were no exceedances for N deposition levels associated with declines in growth rate of quaking aspen (**Table 5-10** and **Figure 5-45**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceeded within 19 percent (329 km^2) of the Forest where this species is modeled as dominant or codominant (**Tables 5-10** and **5-11**, **Figure 5-46**). Only 4.4 km^2 (0.3 percent) of the Forest exceeded the N deposition level associated with 5 to 10 percent declines in probability of survival (**Tables 5-11**). Exceedances occurred primarily in the southern portion of the Caribou-Targhee National Forest (**Figure 5-46**).

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 90 percent (127 km^2) of the Caribou-Targhee National Forest where this species is modeled as dominant or codominant (**Table 5-8**). Exceedances were associated with 1 to 5 percent declines in probability of survival and occurred throughout the whole Forest except the northwestern portion (**Table 5-8**, **Figure 5-47**).

Other species of interest that occurred within the Caribou-Targhee National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-17**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-17.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for tree species (in bold font) found within the Caribou-Targhee National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

					N levels that protects against various percent declines in tree growth and survival		
Common name	Species name	Form of response to N deposition		CL	1%	5%	10%
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Boxelder	*Acer negundo*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

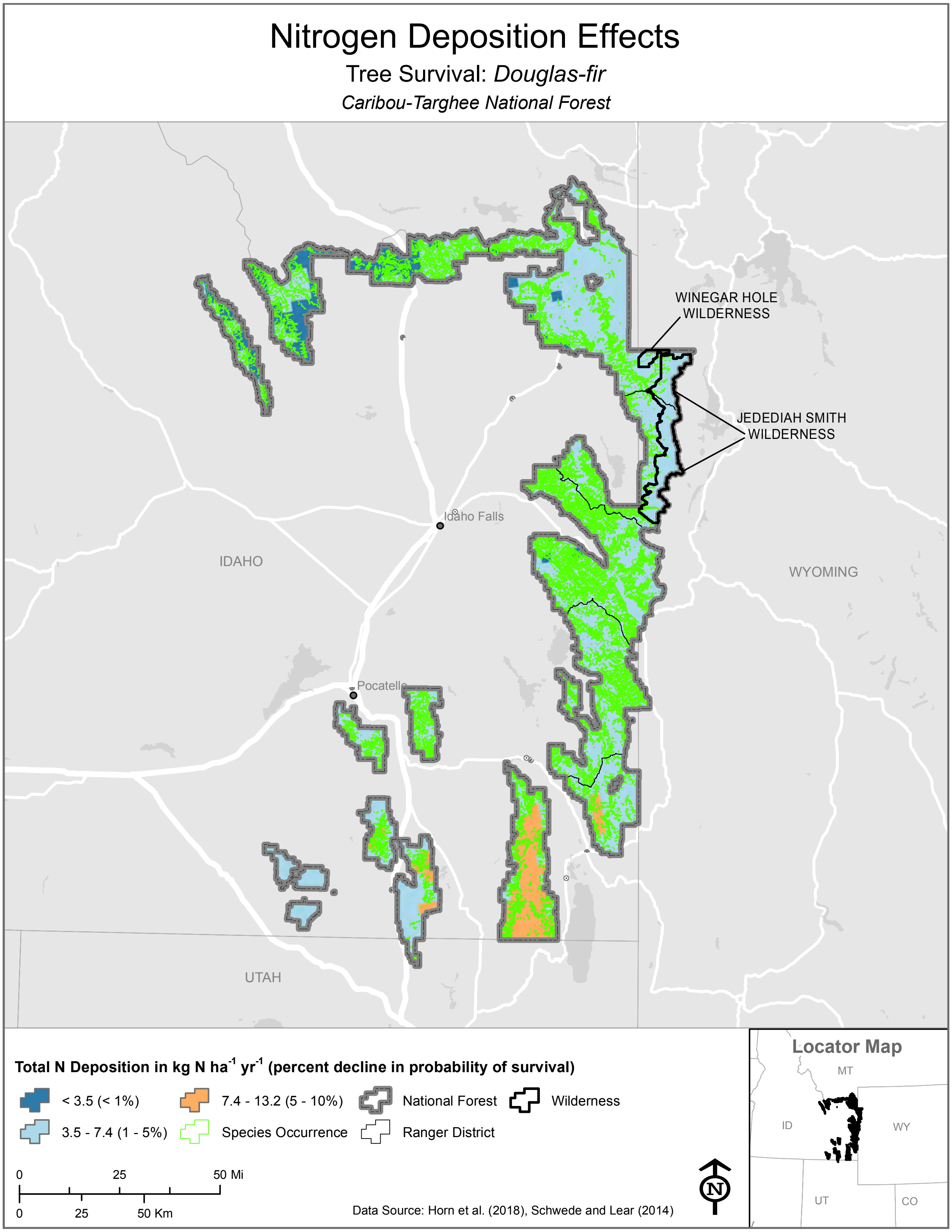


Figure 5-44.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Caribou-Targhee National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

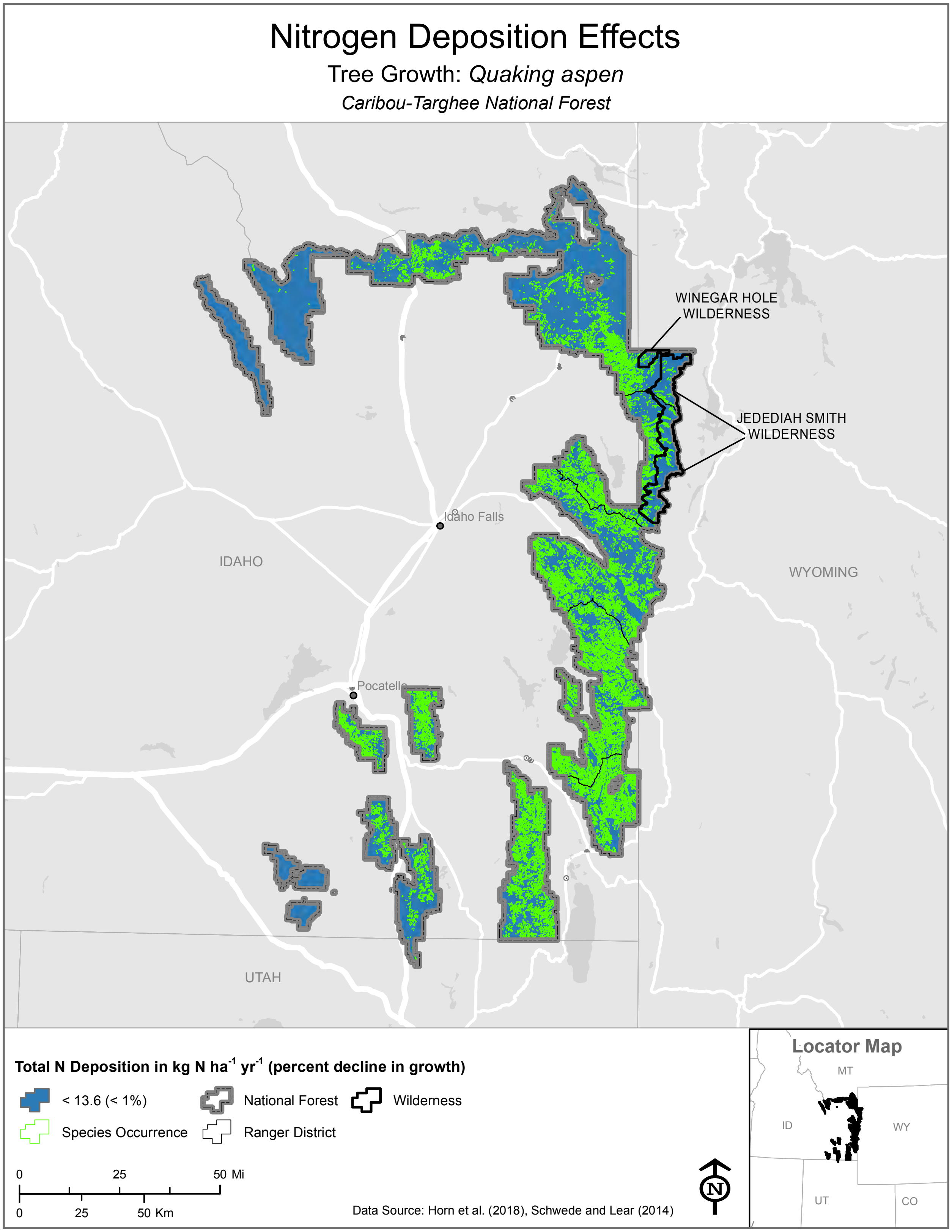


Figure 5-45.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Caribou-Targhee National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

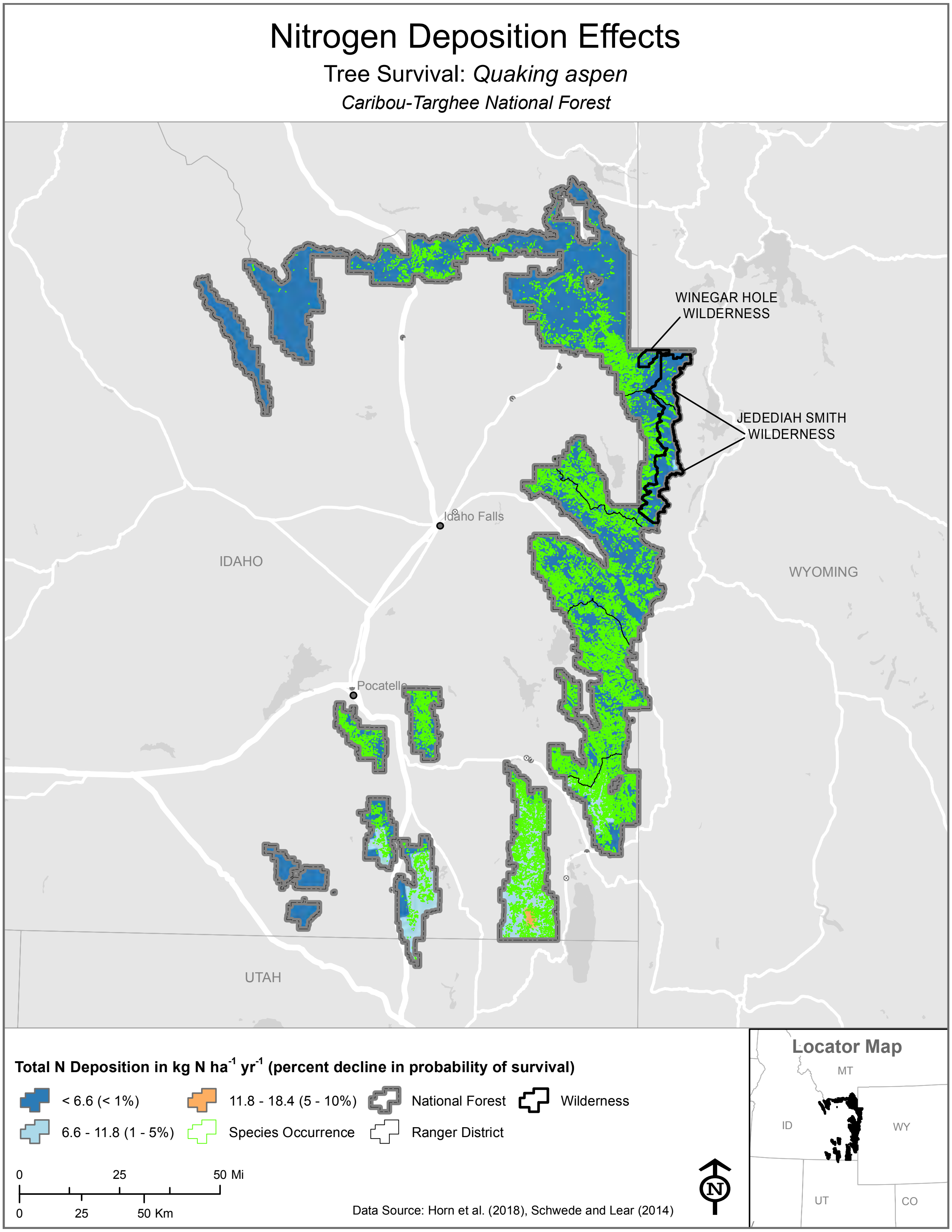


Figure 5-46.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Caribou-Targhee National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

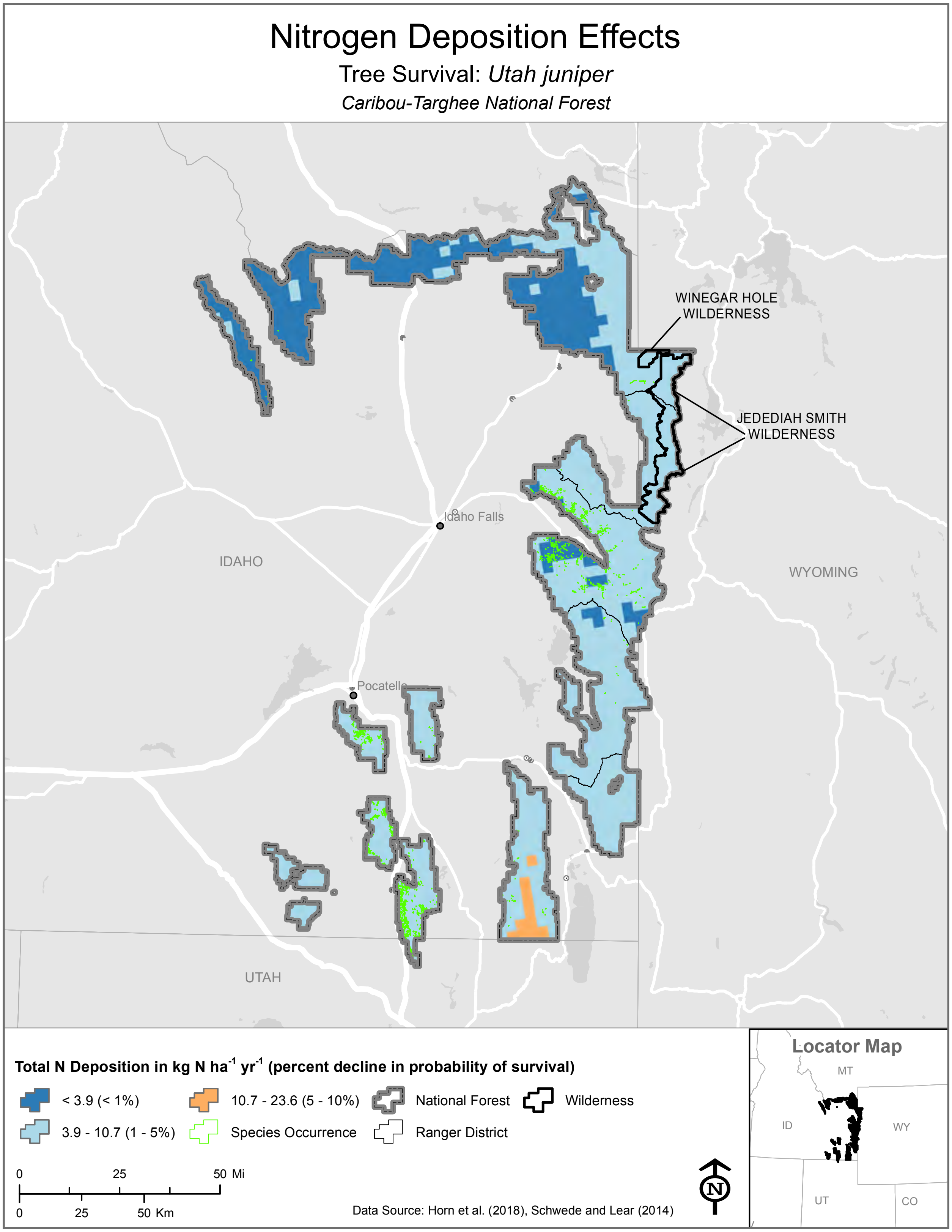


Figure 5-47.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Caribou-Targhee National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

View of Pink Cliffs off Powell Point and Table Cliff Plateau, Dixie National Forest. USDA Forest Service photo.

5.3.5 Dixie National Forest

5.3.5.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Only three sites on the Dixie National Forest had data to calculate CLs that protect surface water ANC from decreasing below 50 µeq L^{-1}. These waterbodies had high CLs (>8 kg N ha^{-1} yr^{-1}) and N deposition did not exceed the CLs (**Table 5-2, Figure 5-48** and **5-49**). The risk is low for these waterbodies to experience biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}. There may be additional acid-sensitive water bodies on the Dixie National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

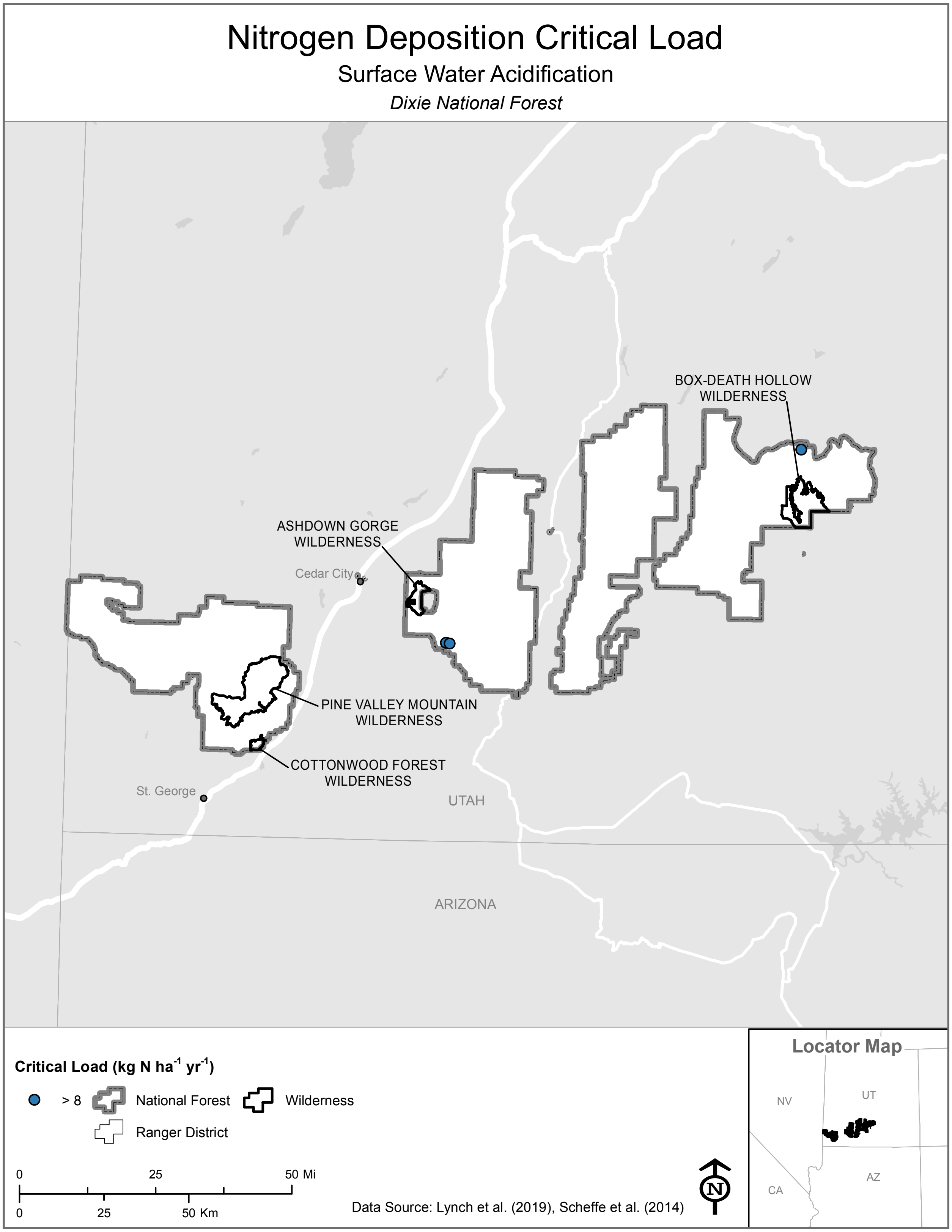


Figure 5-48.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Dixie National Forest.

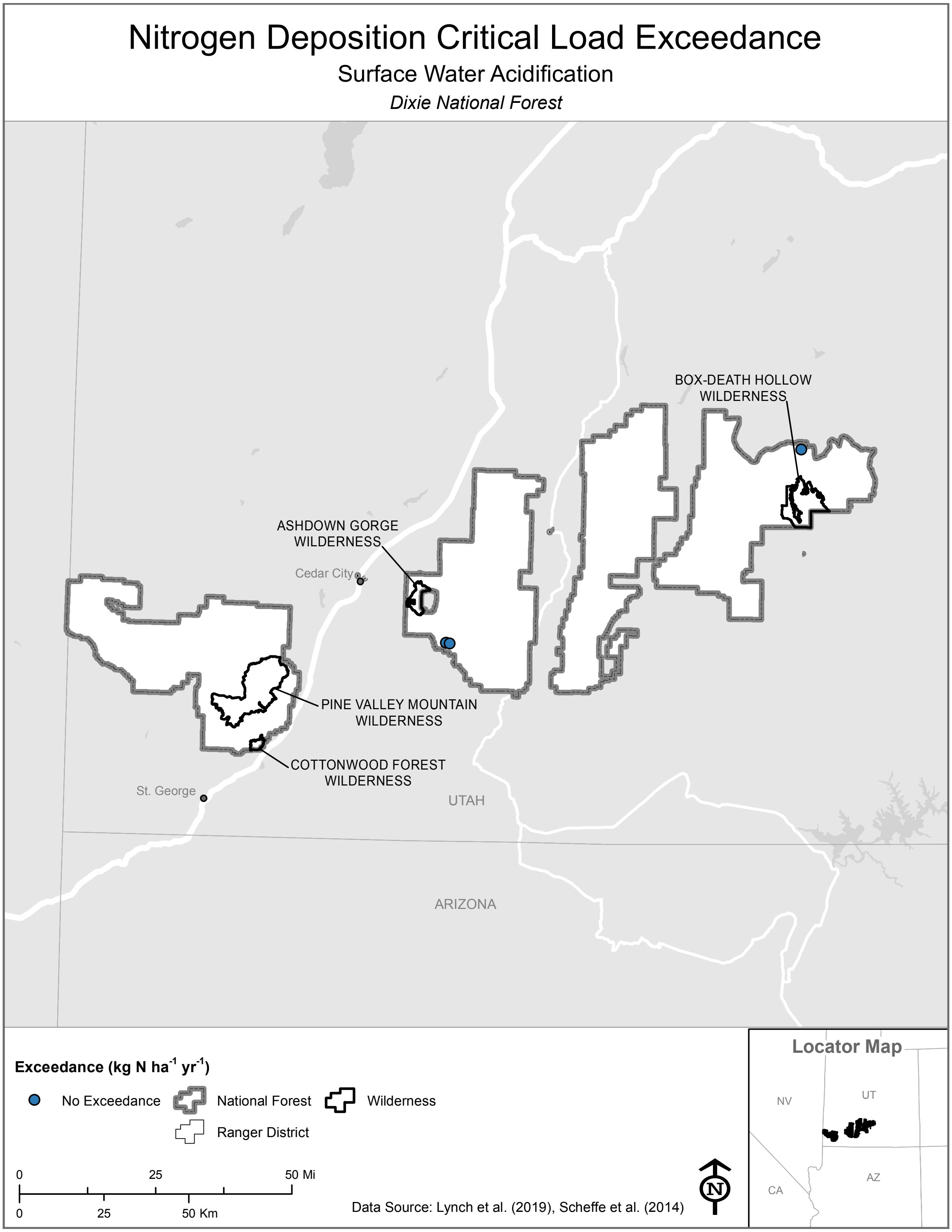


Figure 5-49.—The Dixie National Forest has no exceedances of the total (wet + dry) N CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Dixie National Forest.

Mammoth Creek, Dixie National Forest. USDA Forest Service photo.

5.3.5.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Dixie National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 1,294 km^2 (26 percent) of the Forest (**Table 5-3**, **Figure 5-50**). Even with low CLs, only 970 km^2 (<20 percent) of the Forest was in exceedance of the CLs. Large portions of the Ashdown Gorge and Box-Death Hollow Wilderness Areas exceeded CLs, primarily in the range of 1 to 2 kg wet N ha^{-1} yr^{-1} (**Table 5-4**, **Figure 5-51**). The highest magnitudes of exceedance (2 to 3 kg wet N ha^{-1} yr^{-1}) were rare, covering 46 km^2 (<1 percent) of the Forest. Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Dixie National Forest are outside the geographic bounds of this study. These areas were marked as "No Data" in **Figure 5-50** and **Figure 5-51**.

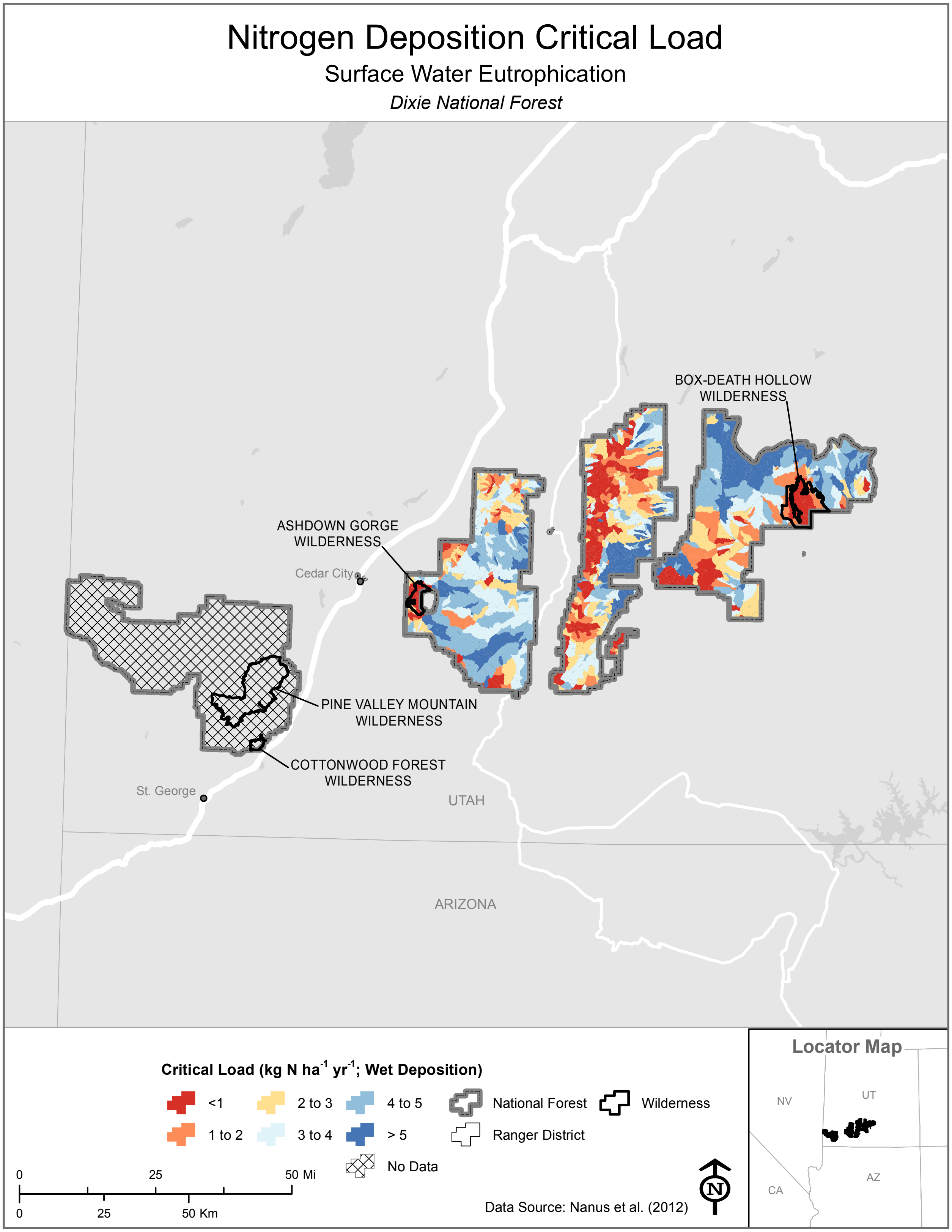


Figure 5-50.—Wet N deposition CLs that protect against surface water eutrophication within the Dixie National Forest. Based on a threshold nitrate concentration of 0.5 µmol L-1. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

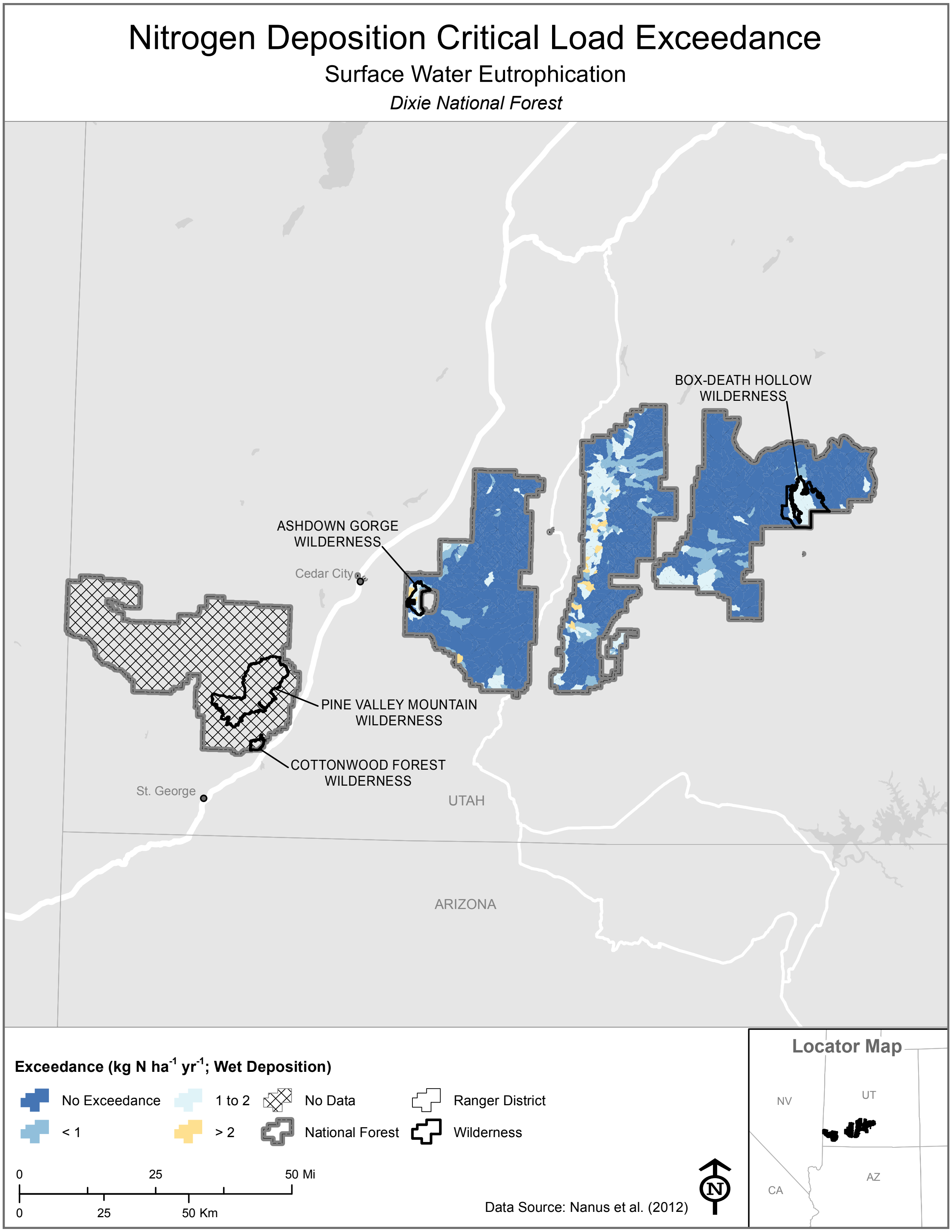


Figure 5-51.—Exceedance of wet N CLs that protect against surface water eutrophication within the Dixie National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

Red Canyon, Dixie National Forest. USDA Forest Service photo by Doug Wewer.

5.3.5.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 76 percent (5,277 km^2) and 100 percent (6,925 km^2), respectively, of the Dixie National Forest (**Table**s **5-5** and **5-6**). The majority of the CL exceedances for lichen species richness (74 percent of the Forest) were associated with 20 to 30 percent declines. Critical load exceedances associated with 30 to 40 percent declines in lichen species richness were uncommon (2 percent of the Forest) and scattered throughout the Forest (**Table**s **5-5** and **Figures 5-52**). The majority (97 percent) of CL exceedances for forage lichen abundance were associated with 30 to 50 percent declines, including Ashdown Gorge and Box-Death Hollow Wilderness Areas (**Table**s **5-6** and **Figures 5-53**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

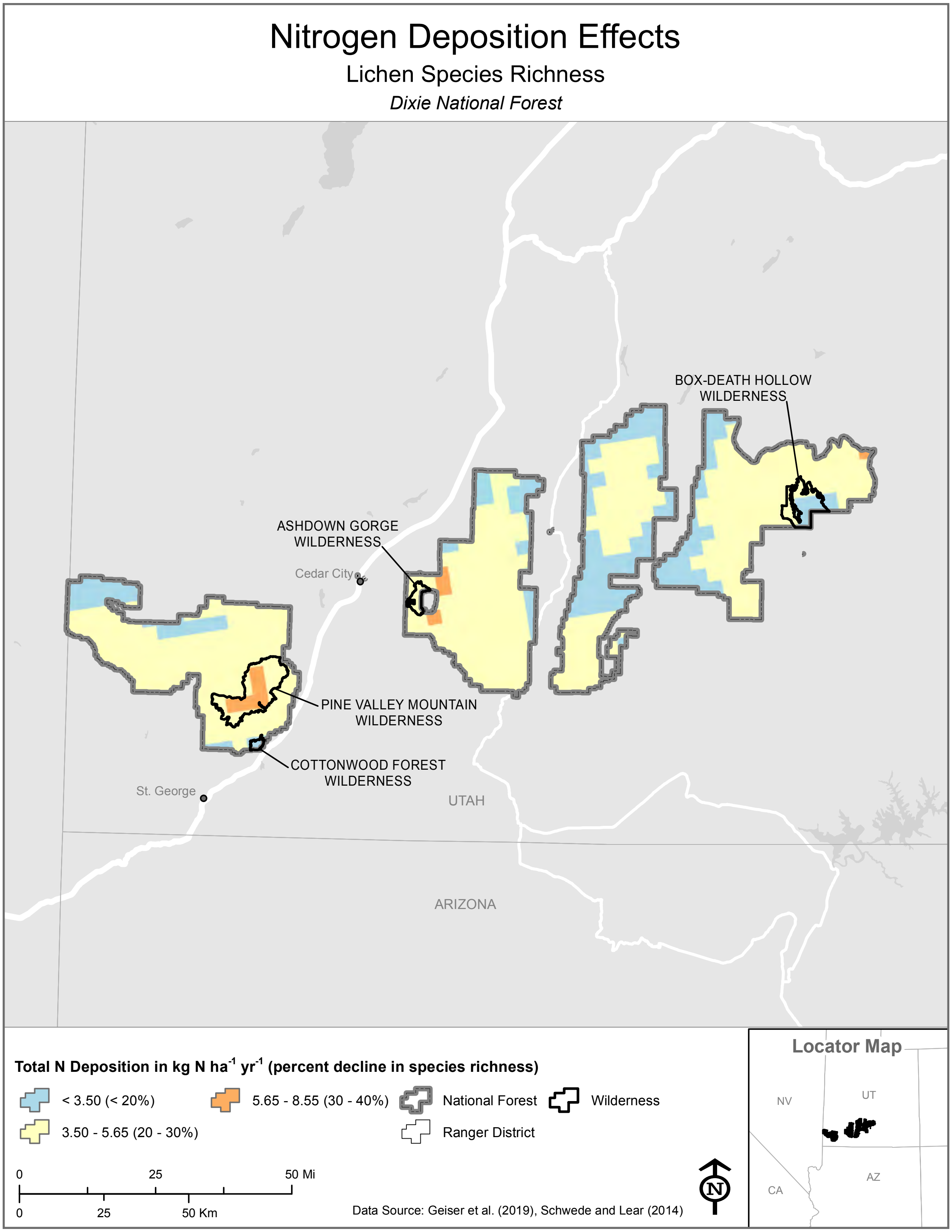


Figure 5-52.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Dixie National Forest.

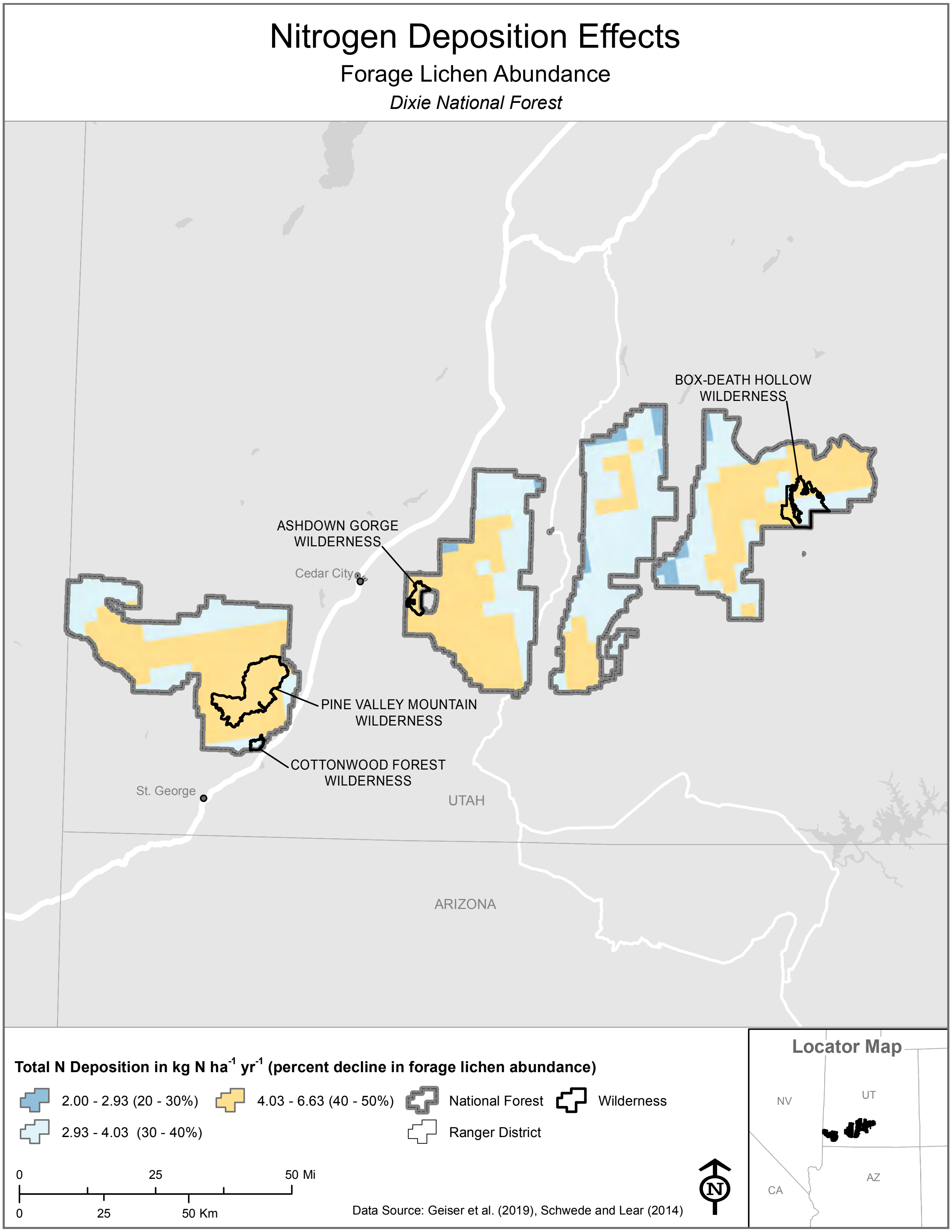


Figure 5-53.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Dixie National Forest.

5.3.5.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Dixie National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 90 percent (247 km^2) of the total area (273 km^2) where this species is modeled as dominant or codominant on the Dixie National Forest (**Table 5-7**). Areas of exceedance were common throughout the Forest (**Figure 5-54**). There were no exceedances associated with a >5 percent decline in probability of survival.

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 42 percent (768 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-8**). The western portion of the Forest had the largest area in exceedance (**Figure 5-55**). There were no exceedances associated with a >5 percent decline in probability of survival.

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 15.6 percent (287 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). The western portion of the Forest had the largest area in exceedance (**Figure 5-56**). There were no exceedances associated with a >5 percent decline in probability of survival.

Balsam poplar. The N deposition level that protect balsam poplar against >1 percent decline in growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) was exceeded within 85 percent (29 km^2) and 11 percent (4 km^2), respectively, of the total area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). A small portion of the balsam poplar-dominant area (2 km^2 or 5 percent) exceeded N deposition levels associated with >10 percent declines in growth rate (**Figure 5-57)**. There were no exceedances associated with a >5 percent decline in probability of survival (**Figure 5-58**).

Quaking aspen. The N deposition level that protects quaking aspen against a >1 percent decline in growth rate (13.6 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (6.6 kg N ha^{-1} yr^{-1}) was not exceeded within any of the 699 km^2 area where this species is modeled as dominant or codominant (**Tables 5-10** and **5-11**; **Figures 5-59** and **5-60**).

Other species of interest that occurred within the Dixie National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-18**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-18. —Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Dixie National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
White fir	*Abies concolor*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Boxelder	*Acer negundo*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Common or two-needle pinyon	*Pinus edulis*	Growth	Flat[a]	---	---	---	---
		Survival	Flat[a]	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

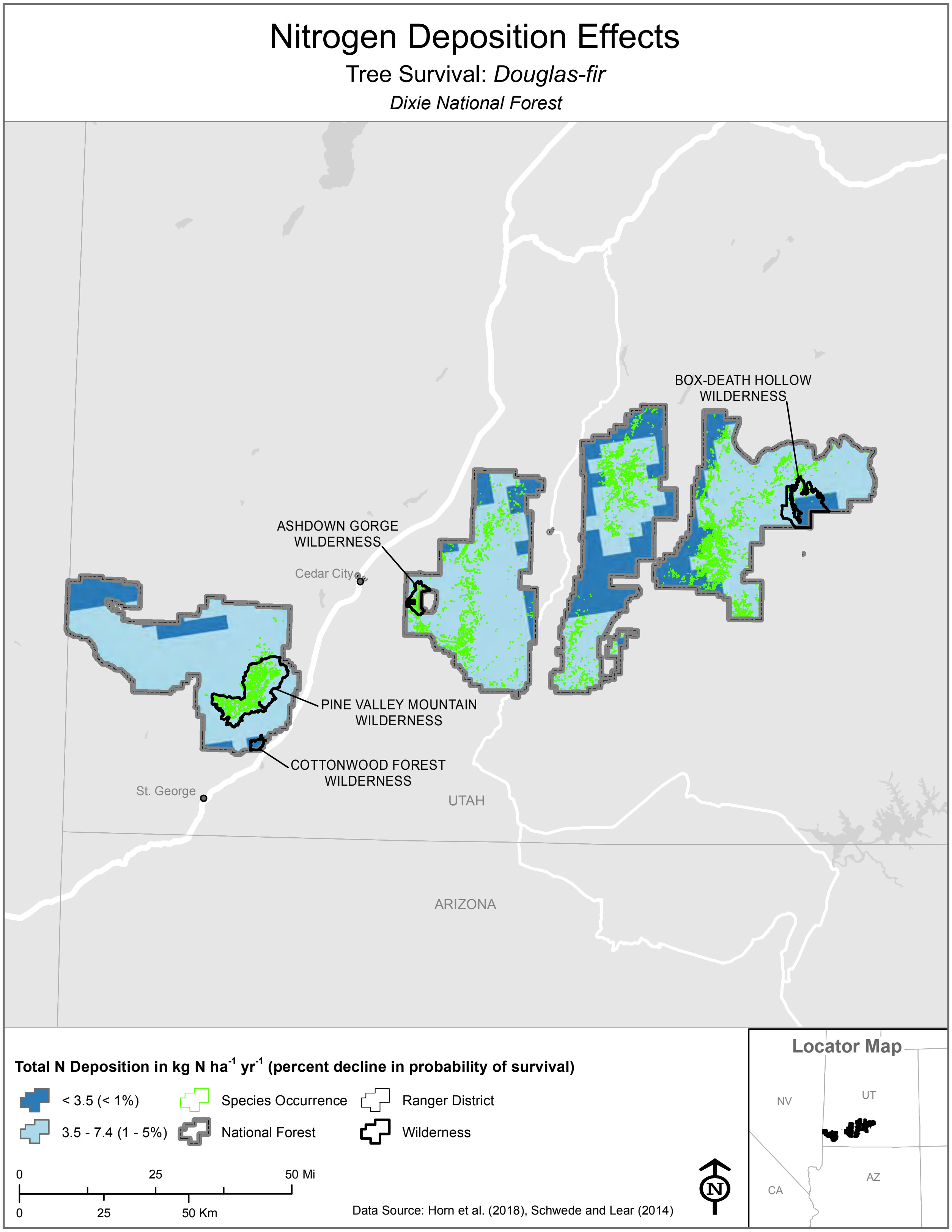


Figure 5-54.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

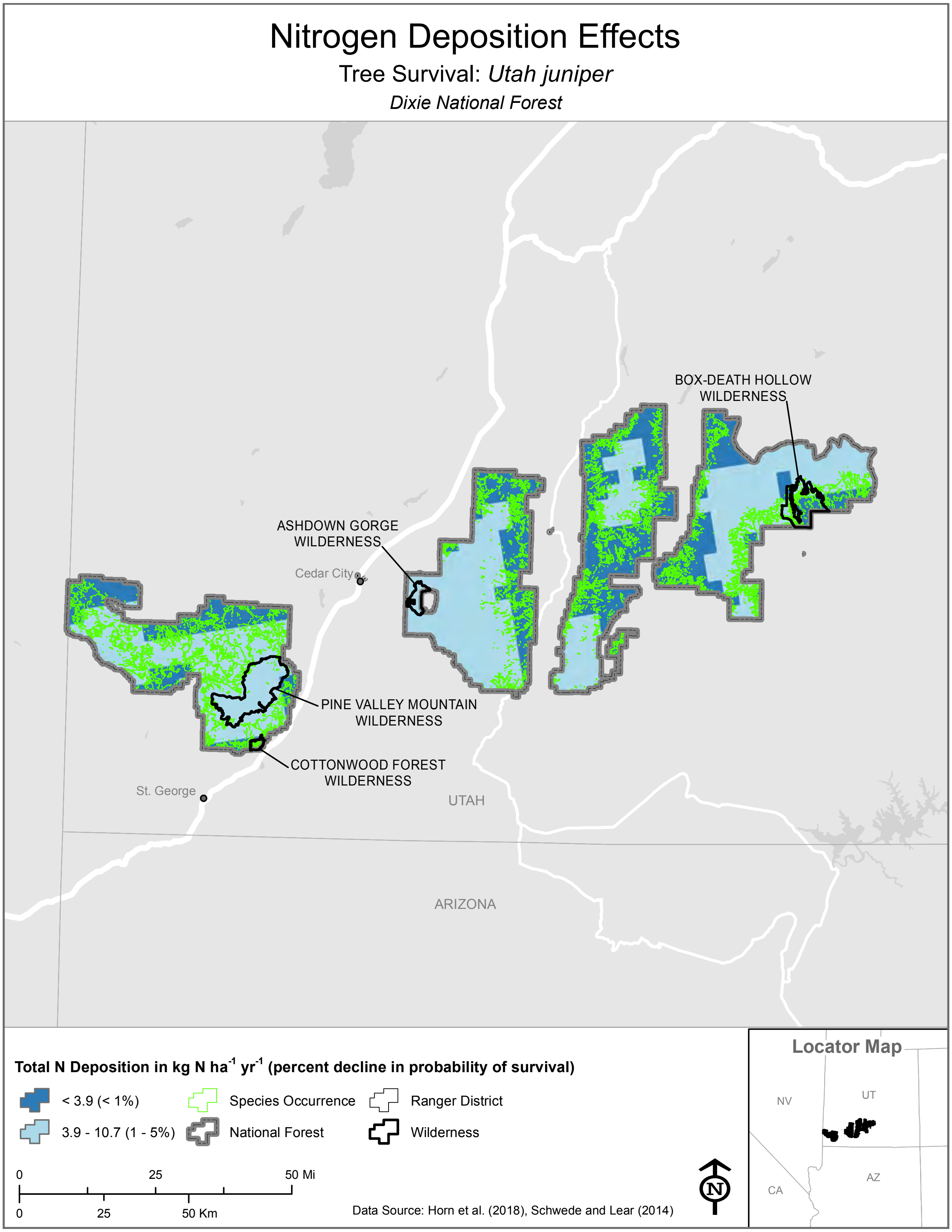


Figure 5-55.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

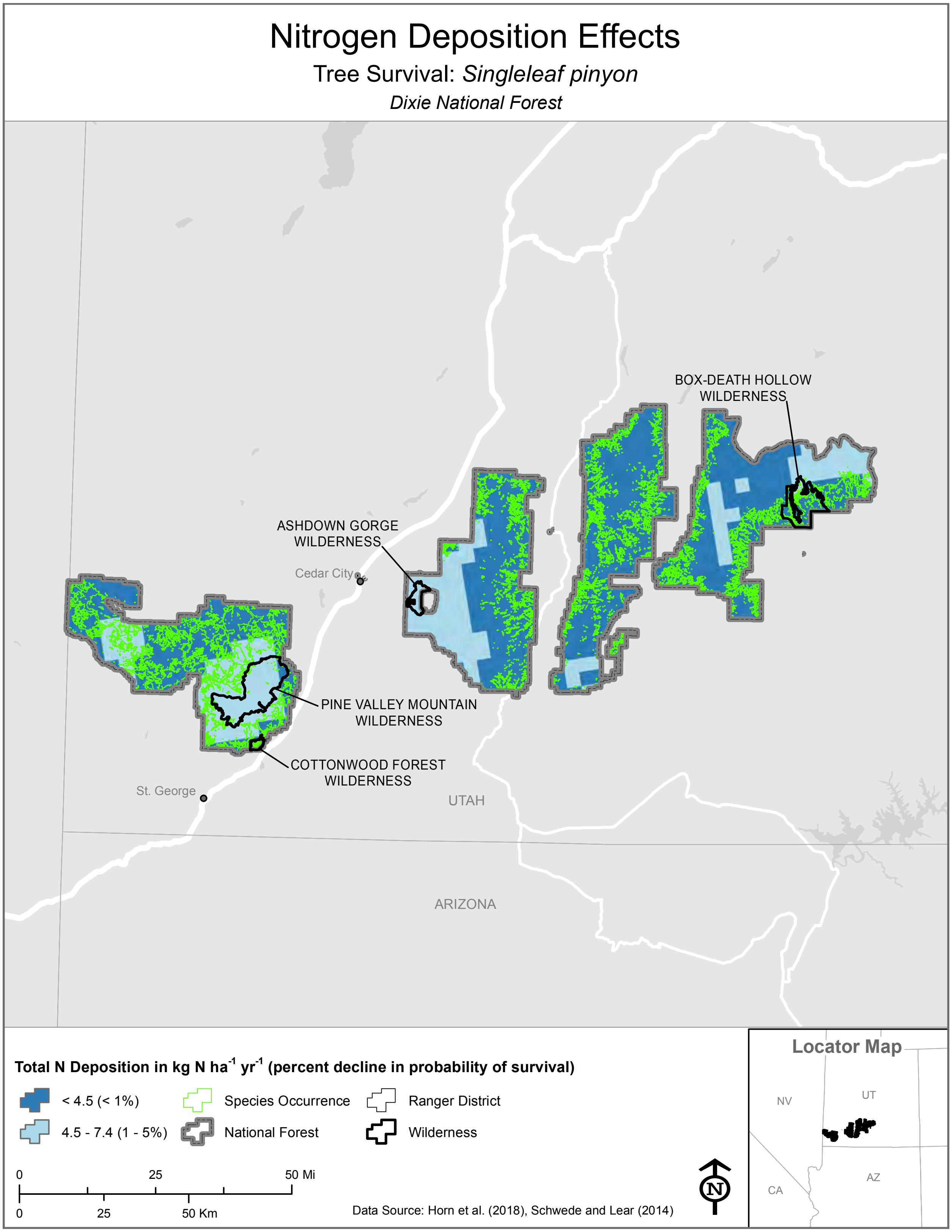


Figure 5-56.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

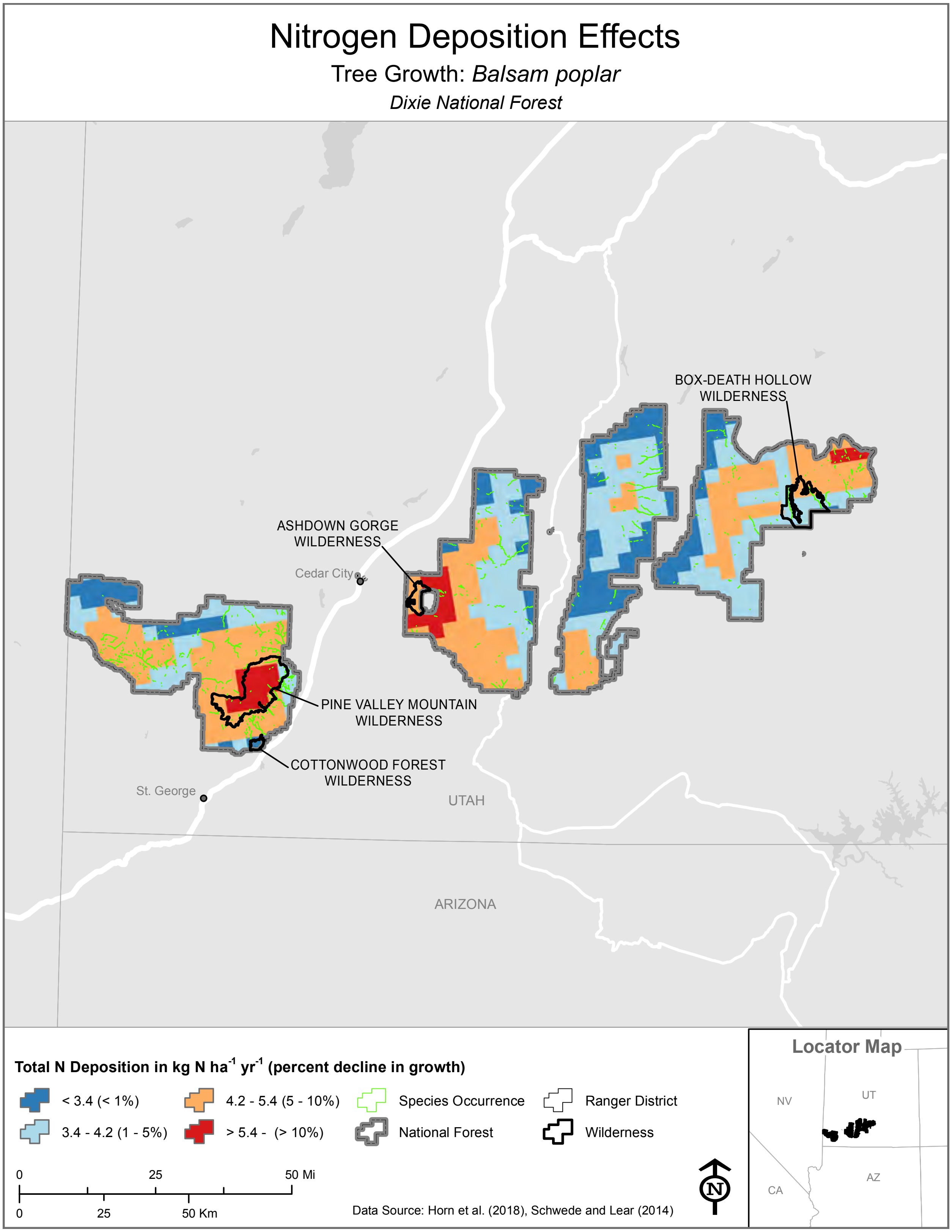


Figure 5-57.—Total (wet + dry) nitrogen (N) deposition and percent of decline in growth rate for balsam poplar within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

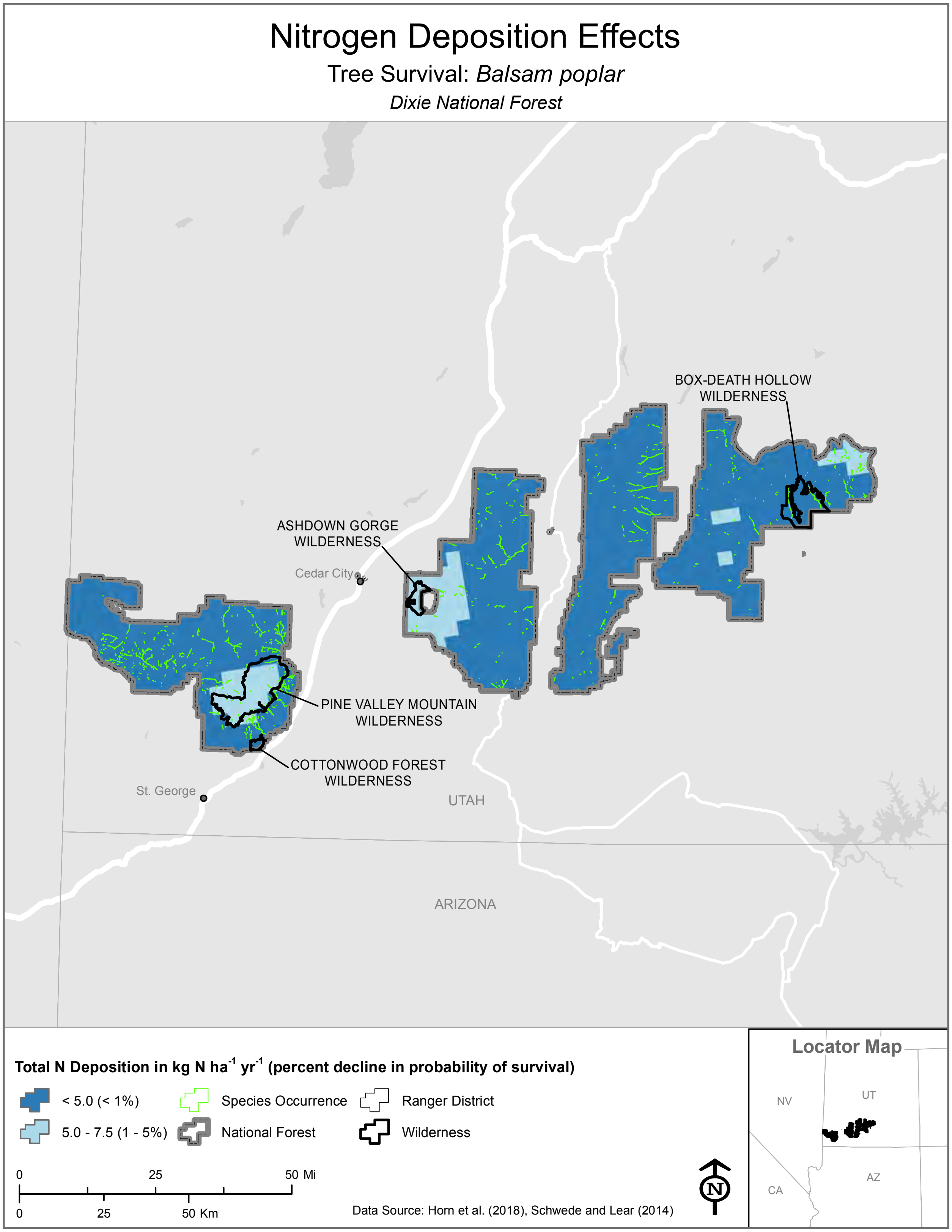


Figure 5-58.—Total (wet + dry) nitrogen (N) deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

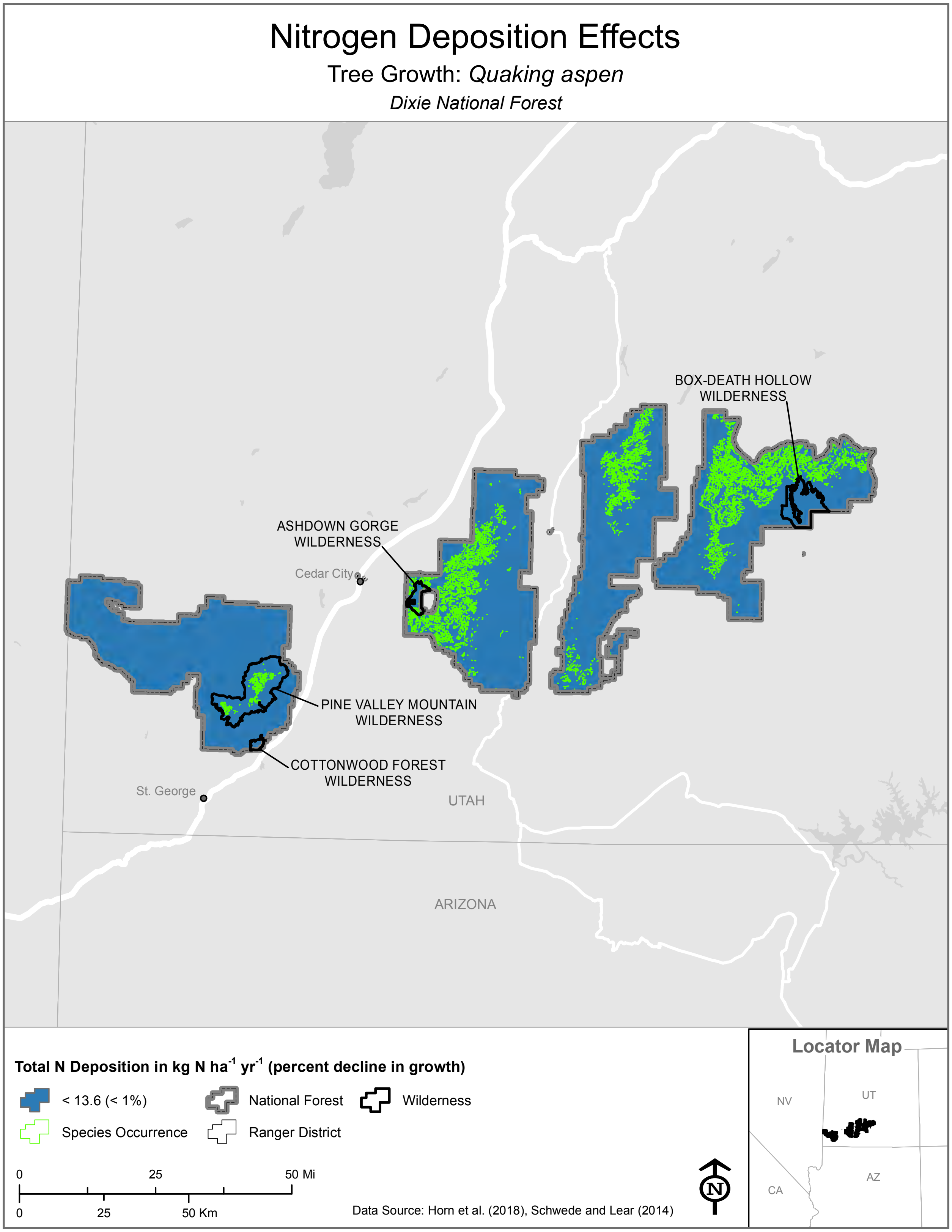


Figure 5-59.—Total (wet + dry) nitrogen (N)deposition and percent of decline in growth rate for quaking aspen within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

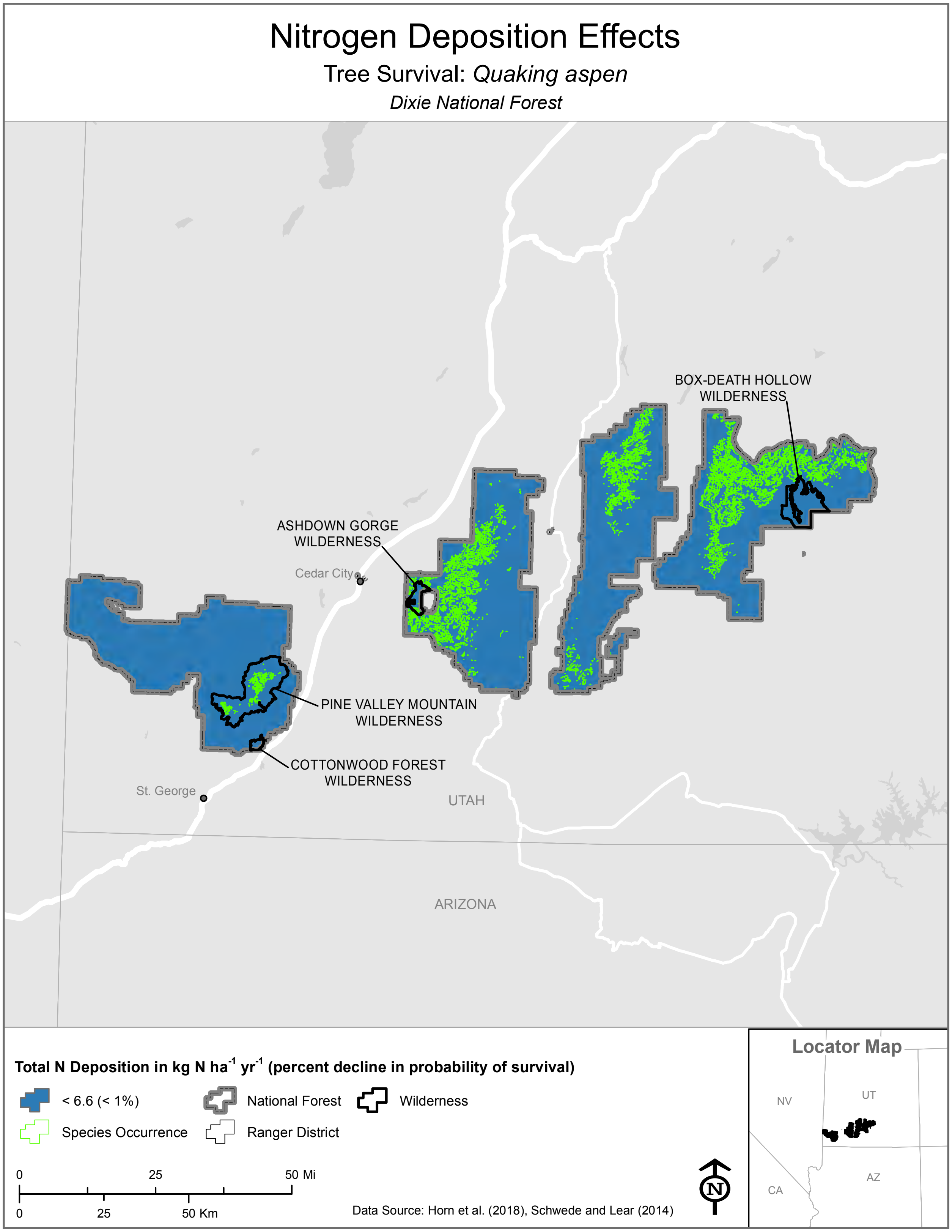


Figure 5-60.—Total (wet + dry) nitrogen (N) deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Dixie National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Aspens overlooking Kents Lake, Fishlake National Forest. USDA Forest Service photo by Wende Wilding.

5.3.6 Fishlake National Forest

5.3.6.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 µeq L^{-1} were calculated for eight waterbodies that had water chemistry data available. Most sites were within the southeastern portion of the Fishlake National Forest (**Table 5-1** and **Figure 5-61**). Five of the waterbodies had high CLs (>8 kg N ha^{-1} yr^{-1}) and no CL exceedances. These waterbodies were at low risk to experience effects of acidification associated with surface water ANC decreasing below 50 µeq L^{-1} (**Table 5-1**, **Figure 5-61** and **5-62**). Three waterbodies located in the southeastern part of the Forest exceeded CLs (ANC below 50 µeq L^{-1}), the magnitudes of exceedances for two of the waterbodies were in the 2 to 5 kg N ha^{-1} yr^{-1} range (**Table 5-2** and **Figure 5-62**). These three waterbodies have a higher risk to experience biological effects associated with surface water ANC decreasing below 50 µeq L^{-1} if N deposition (under ambient S deposition) persists or increases. There were no exceedances of CLs that protect ANC from decreasing below 20 µeq L^{-1}. There may be additional acid-sensitive water bodies on the Fishlake National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

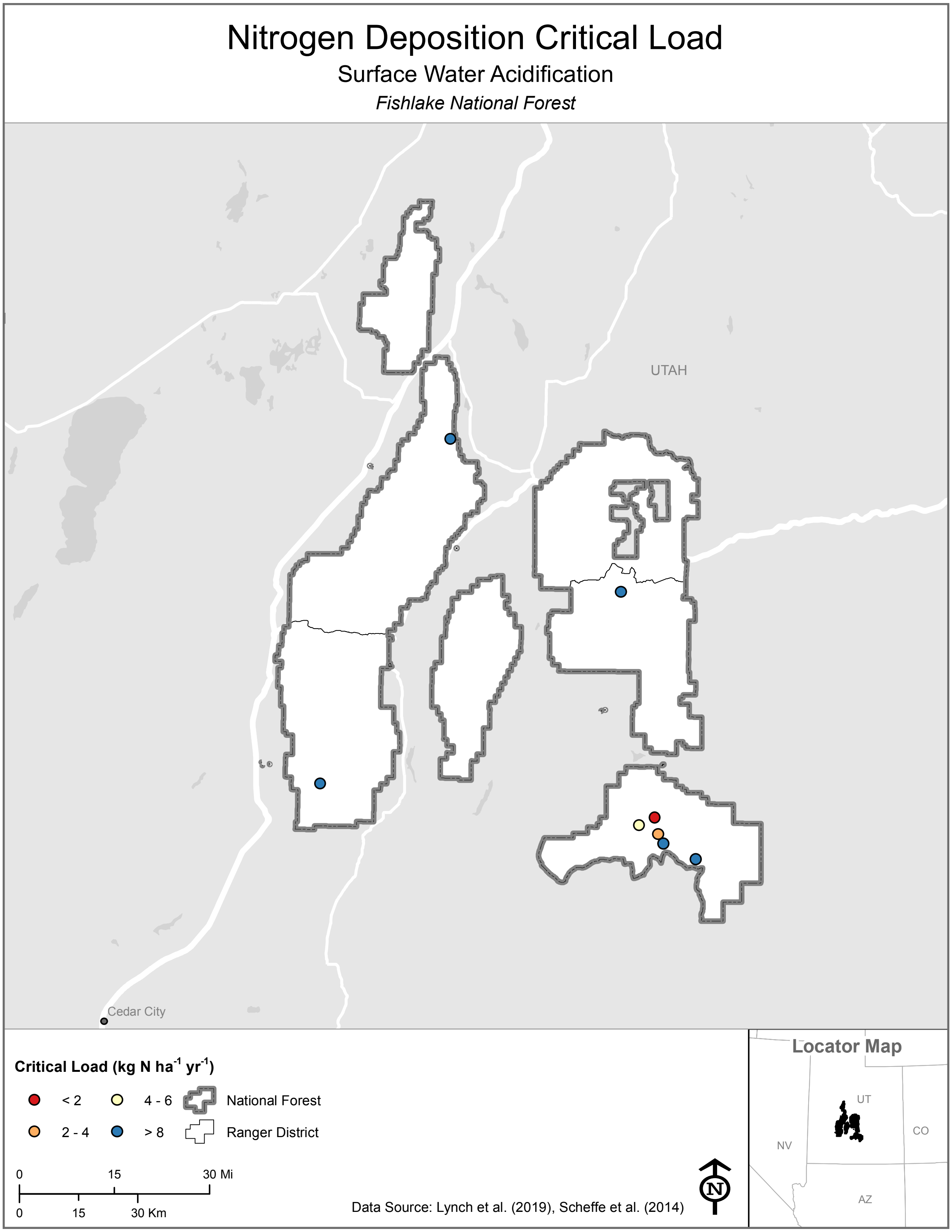


Figure 5-61.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Fishlake National Forest.

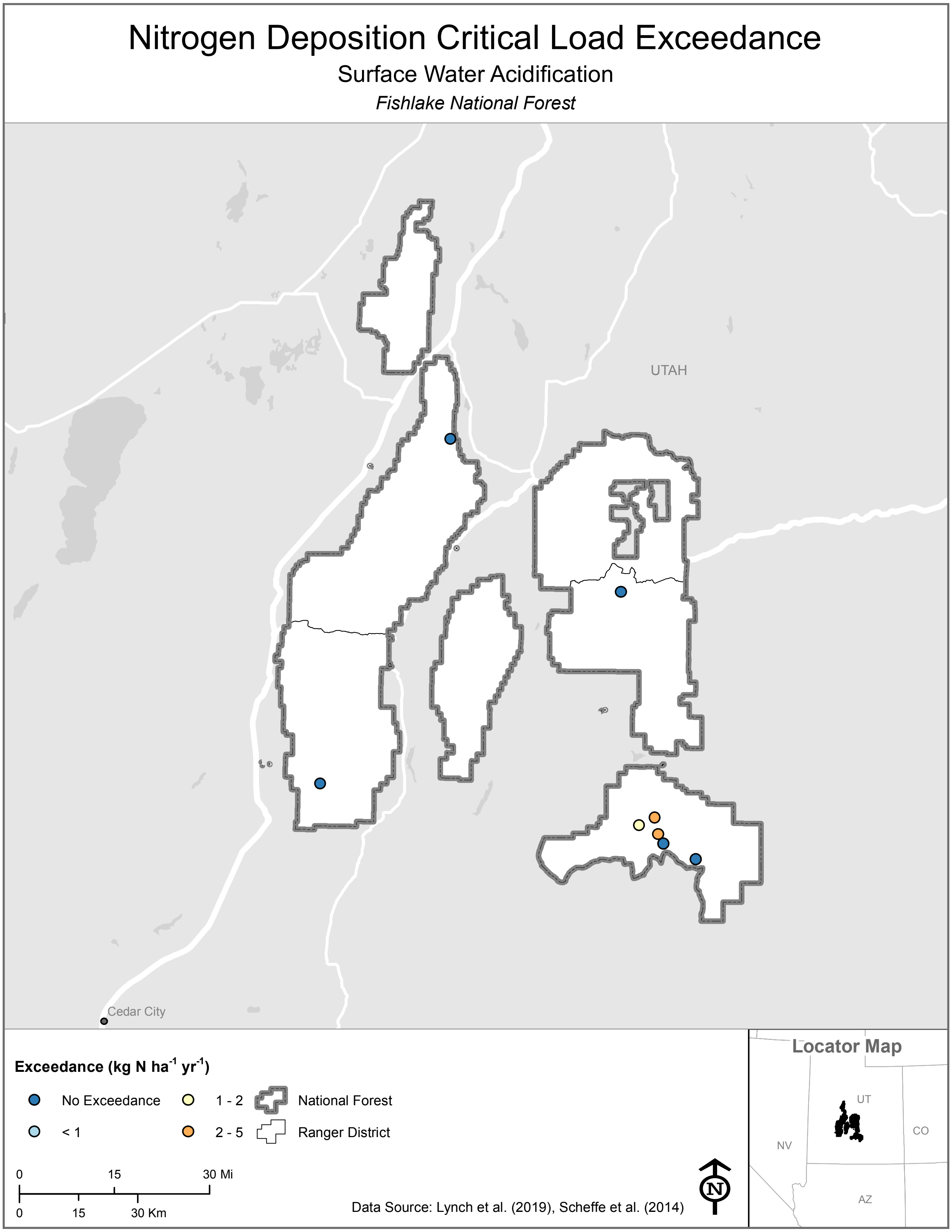


Figure 5-62.—Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Fishlake National Forest.

Zedds Meadow adjacent to Fremont River, Fishlake National Forest. USDA Forest Service photo.

5.3.6.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Fishlake National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 2,000 km^2 (32 percent) of the Forest (**Table 5-3** and **Figure 5-63**). Areas of CL exceedance followed a similar pattern to CLs sensitivity and included just over 1,900 km^2 (30 percent) of the Forest (**Table 5-4**, **Figure 5-64**). The highest magnitudes of exceedance (>3 kg wet N ha^{-1} yr^{-1}) were mapped across 139 km^2, about 2 percent of the Forest. The largest areas of exceedance were in the western portion of the Forest (**Table 5-4** and **Figure 5-64)**. Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Fishlake National Forest are outside the geographic bounds of this study. These areas were marked as “No Data” in **Figure 5-63** and **Figure 5-64**.

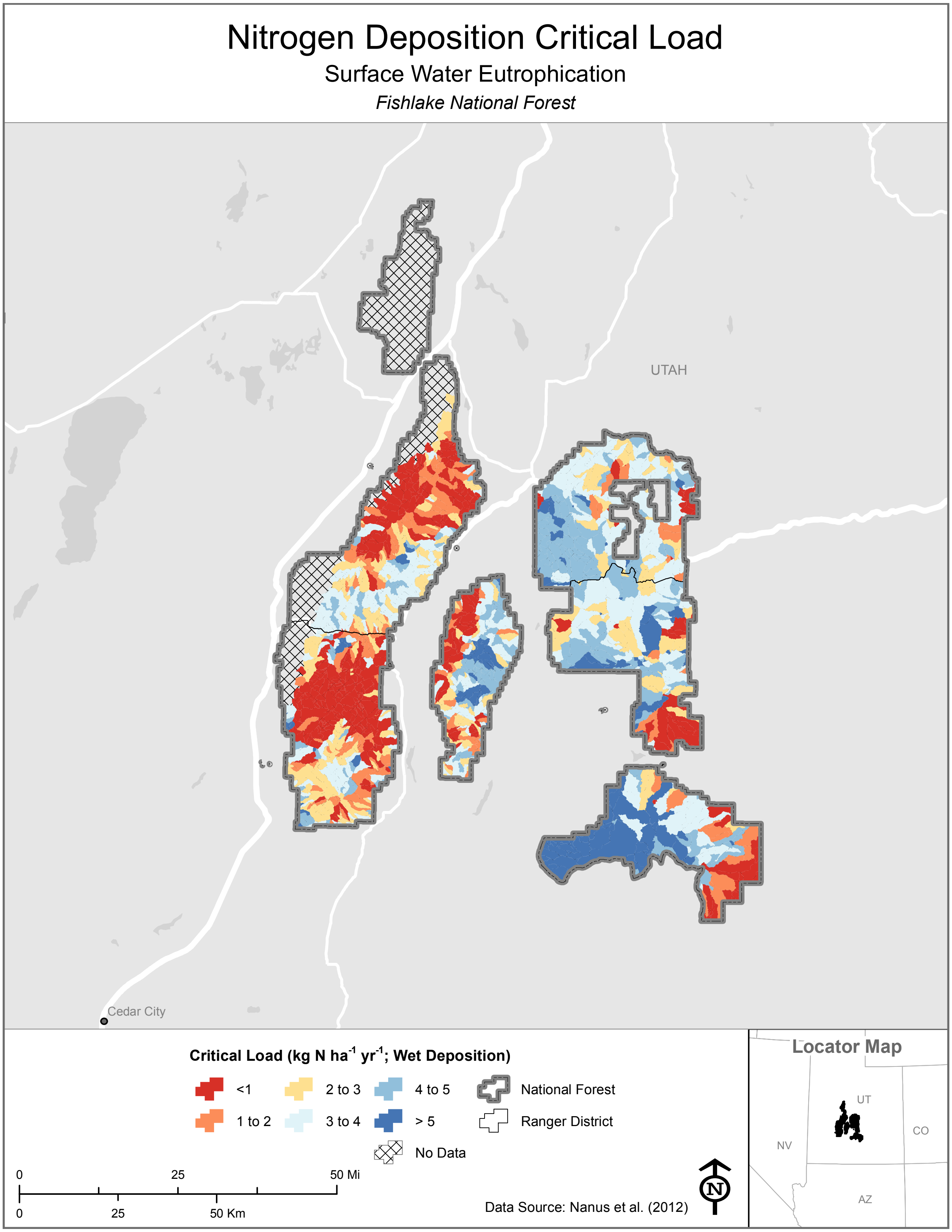


Figure 5-63.—Wet N deposition CLs that protect against surface water eutrophication within the Fishlake National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated “No Data” are outside the bounds of the dataset used to calculate CLs.

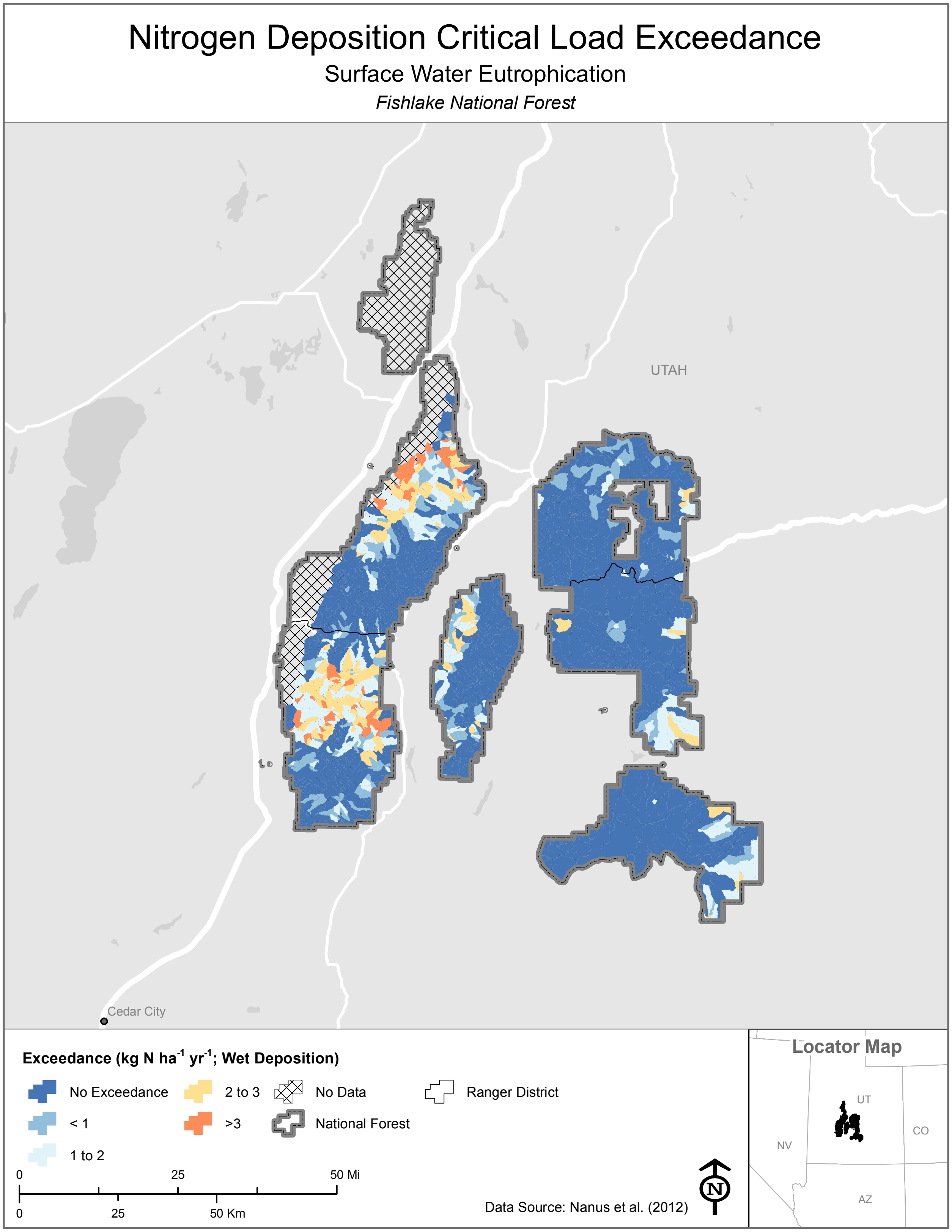


Figure 5-64.—Exceedances of wet N CLs that protect against surface water eutrophication within the Fishlake National Forest. Based on a threshold nitrate concentration of 0.5 μmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

Pelican Point at Fish Lake in Utah on the Fishlake National Forest. USDA Forest Service photo.

5.3.6.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 82 percent (5,918 km^2) and 100 percent (7,236 km^2), respectively, of the Fishlake National Forest (**Tables 5-5** and **5-6**). Critical load exceedances on 75 percent of the Forest (5,420 km^2) were associated with 20 to 30 percent declines in lichen species richness (**Table 5-5**). Higher magnitudes of exceedance (2 to 5 kg N ha^{-1} yr^{-1}) were associated with 30 to 40 percent declines in lichen species richness and were scattered throughout nearly 500 km^2 (7 percent) of the Forest (**Figure 5-65**). The majority of exceedances for forage lichen abundance (60 percent) were associated with 40 to 50 percent declines and were common throughout the Forest including the Pine Valley Mountain and Ashdown Gorge Wilderness Areas (**Table 5-6**, **Figure 5-66**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout the entire Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

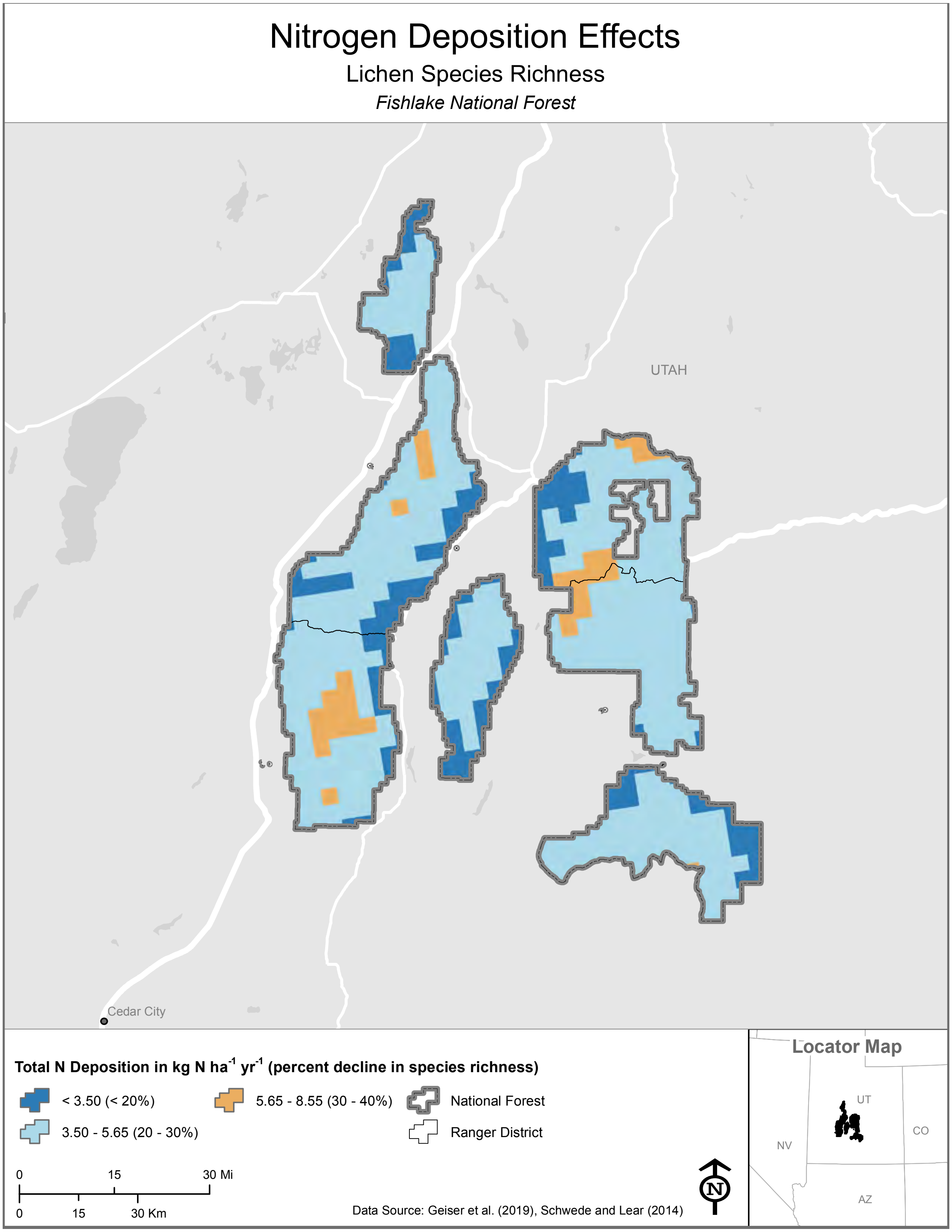


Figure 5-65.—Total nitrogen (N) deposition (average 2015–2017) and the estimated effect to lichen species richness within the Fishlake National Forest.

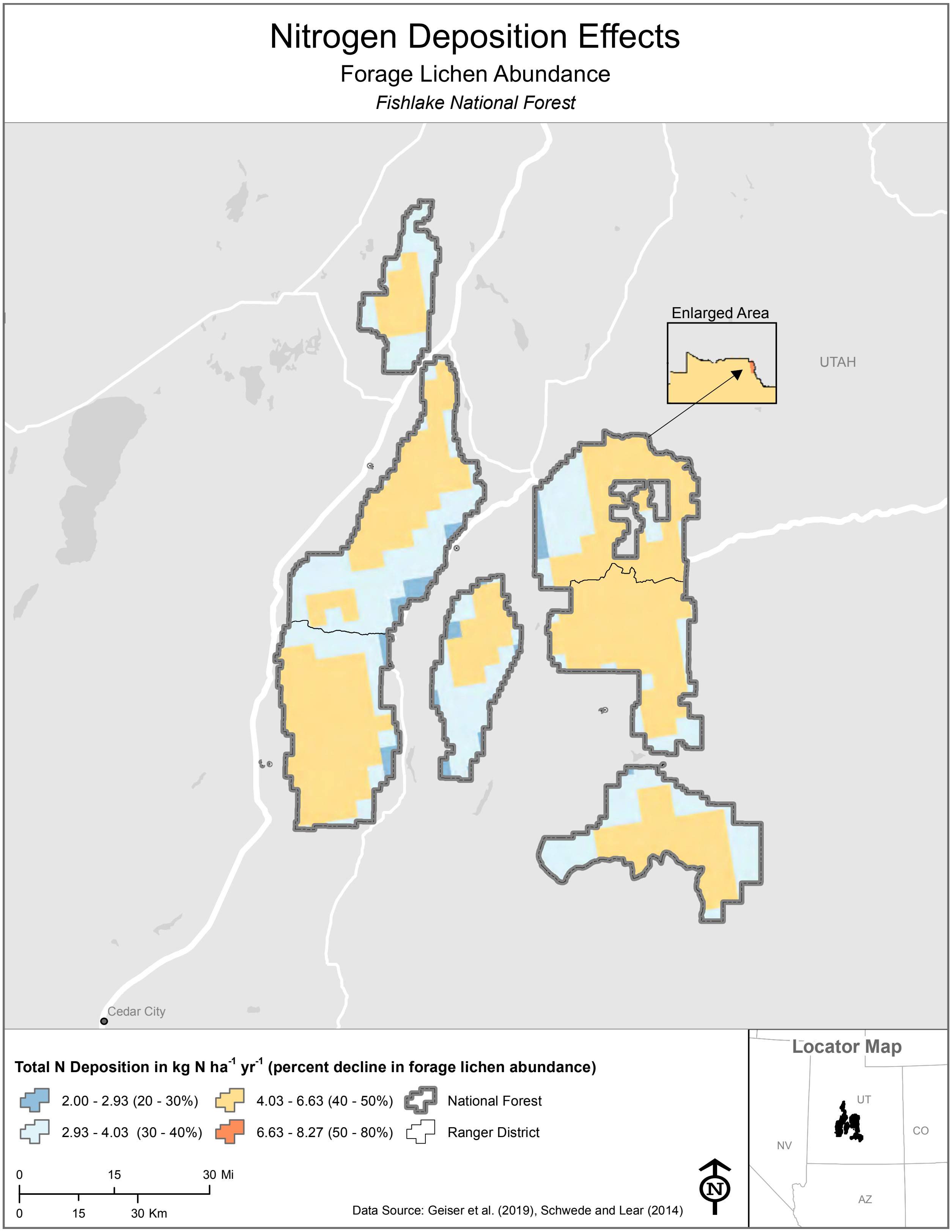


Figure 5-66.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Fishlake National Forest.

Autumn view of the Fremont River meandering through Zedds Meadow, Fishlake National Forest. USDA Forest Service photo.

5.3.6.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedance of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Fishlake National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 36 percent (558 km^2) of the 1,549 km^2 area where this species is modeled as dominant or codominant on the Fishlake National Forest (**Table 5-8**). Exceedances were associated with declines in survival between 1 and 5 percent and were found throughout the Forest (**Table 5-8** and **Figure 5-67**).

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 8 percent (122 km^2) of the 1,549 km^2 area that this species is modeled as dominant or codominant (**Table 5-9**). Exceedances were associated with declines in survival between 1 and 5 percent and were found spread throughout the Forest (**Figure 5-68**).

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 92 percent (102 km^2) of the 112 km^2 area where this species is modeled as dominant or codominant (**Table 5-7**). Exceedances were associated with declines in survival between 1 and 5 percent and were found spread throughout the Forest (**Figure 5-69**).

Balsam poplar. The N deposition levels that protect against declines in balsam poplar growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) were exceeded within 82 percent (37 km^2) and 19 percent (9 km^2), respectively, of the 46 km^2 area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). Exceedances were associated with >10 percent decline in growth rate for 8 percent (4 km^2) and 5 to 10 percent decline in growth rate for 38 percent (17 km^2) of the area that this species is modeled as dominant or codominant (**Tables 5-12** and **Figure 5-70**). Exceedances associated with >1 percent decline in probability of survival were infrequent throughout the Forest (**Figure 5-71**).

Quaking aspen. There were no exceedances of N deposition levels associated with declines in growth rate of quaking aspen **(Table 5-10** and **Figure 5-72**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects against declines in quaking aspen probability of survival over 10 years was exceeded within less than 0.2 km^2 of the total area (915 km^2) that this species is modeled as dominant or codominant (**Tabl**es **5-11**, **Figure 5-73**). This small area of exceedance occurred in the northeastern portion of the Forest (**Figure 5-73**).

Other species of interest that occurred within the Fishlake National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-19**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-19.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Fishlake National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
White fir	*Abies concolor*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Boxelder	*Acer negundo*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Common or two-needle pinyon	Pinus edulis	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

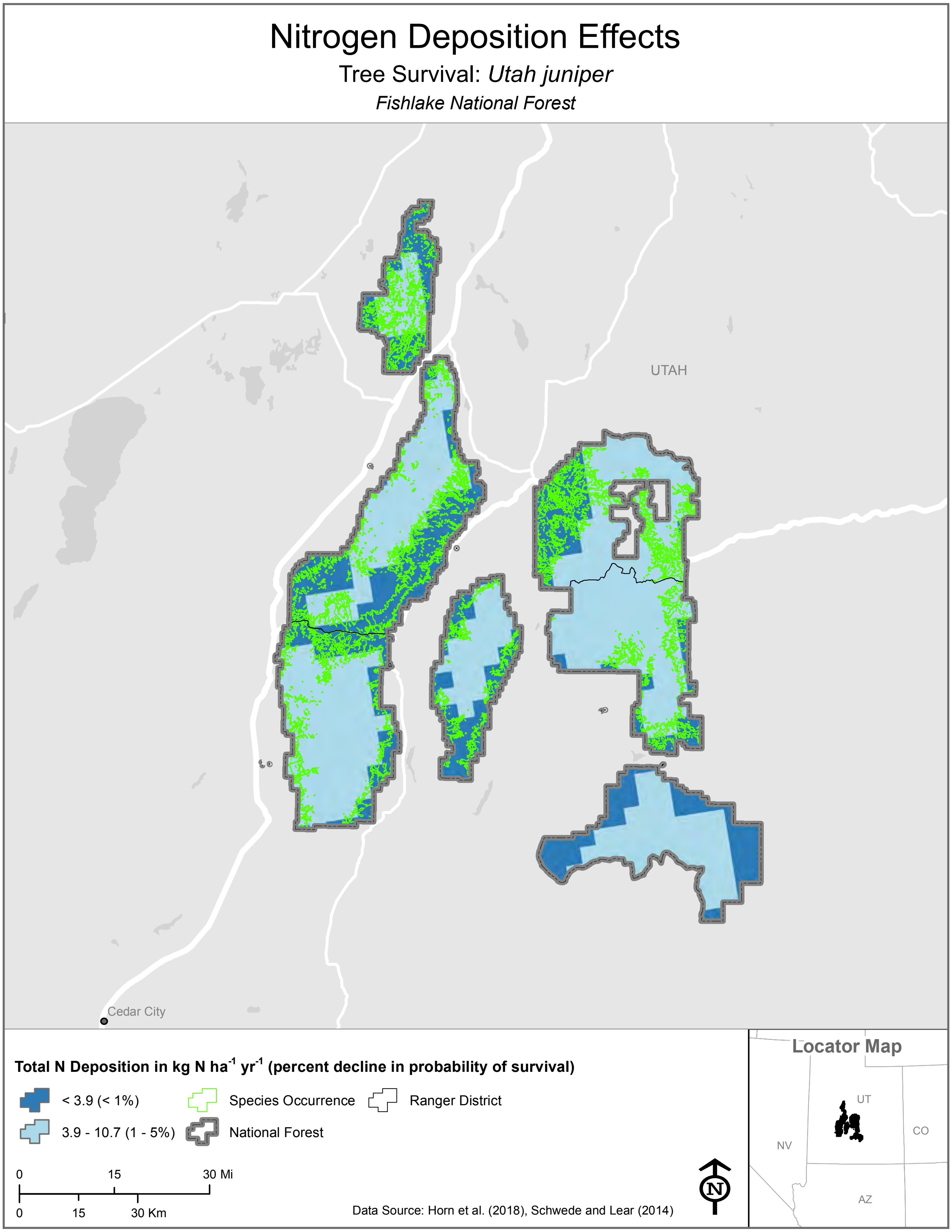


Figure 5-67.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

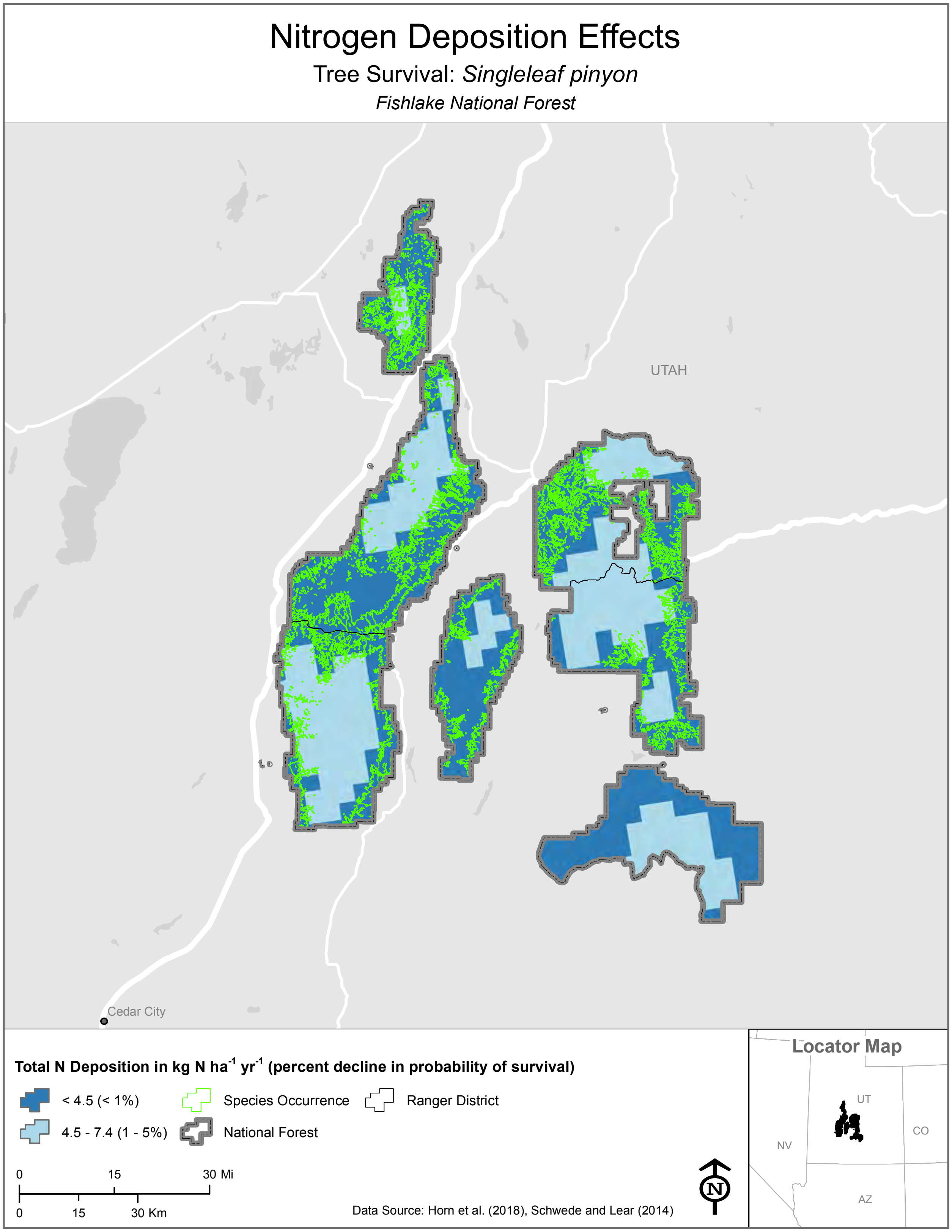


Figure 5-68.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

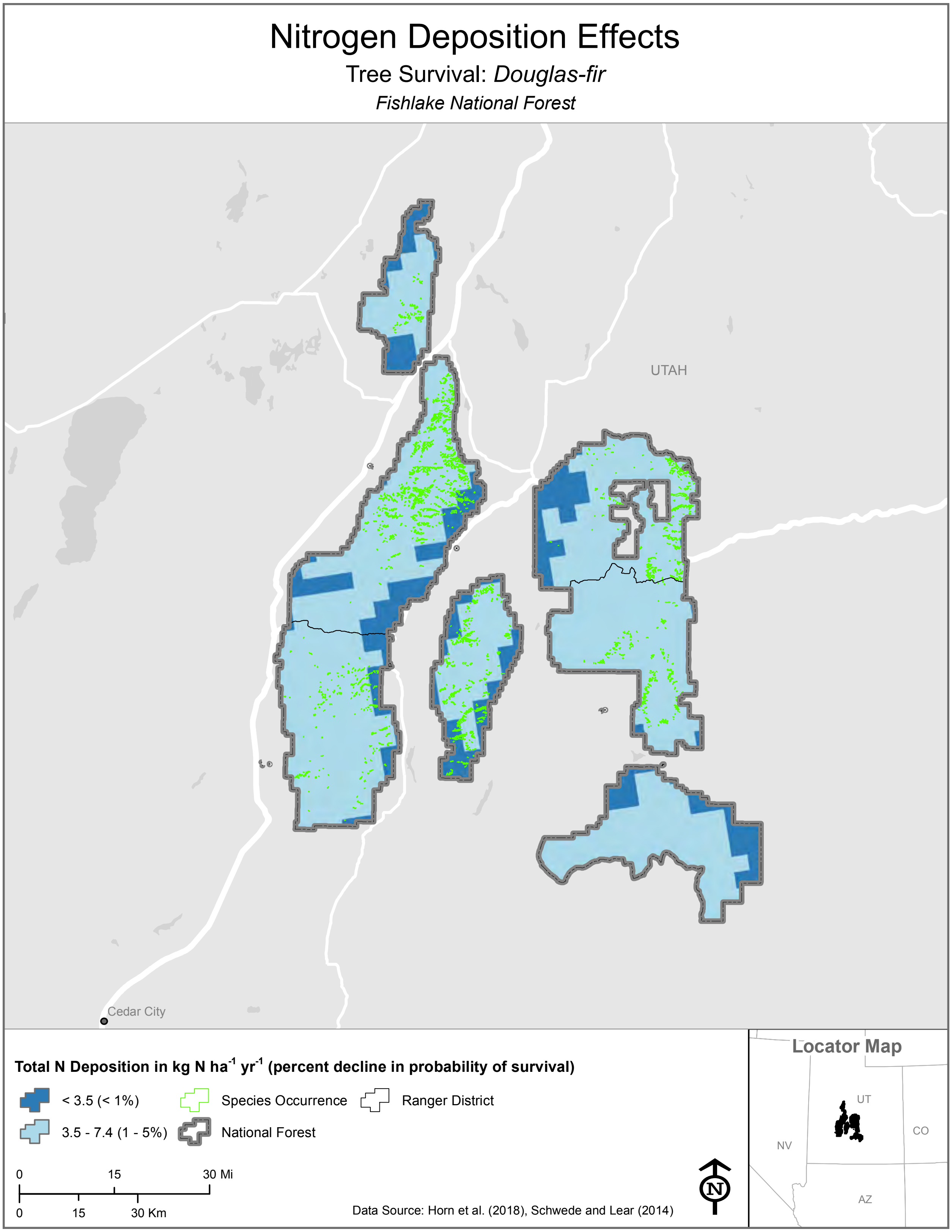


Figure 5-69.—Total (wet + dry) N and percent of decline in probability of survival over 10 years for Douglas-fir within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

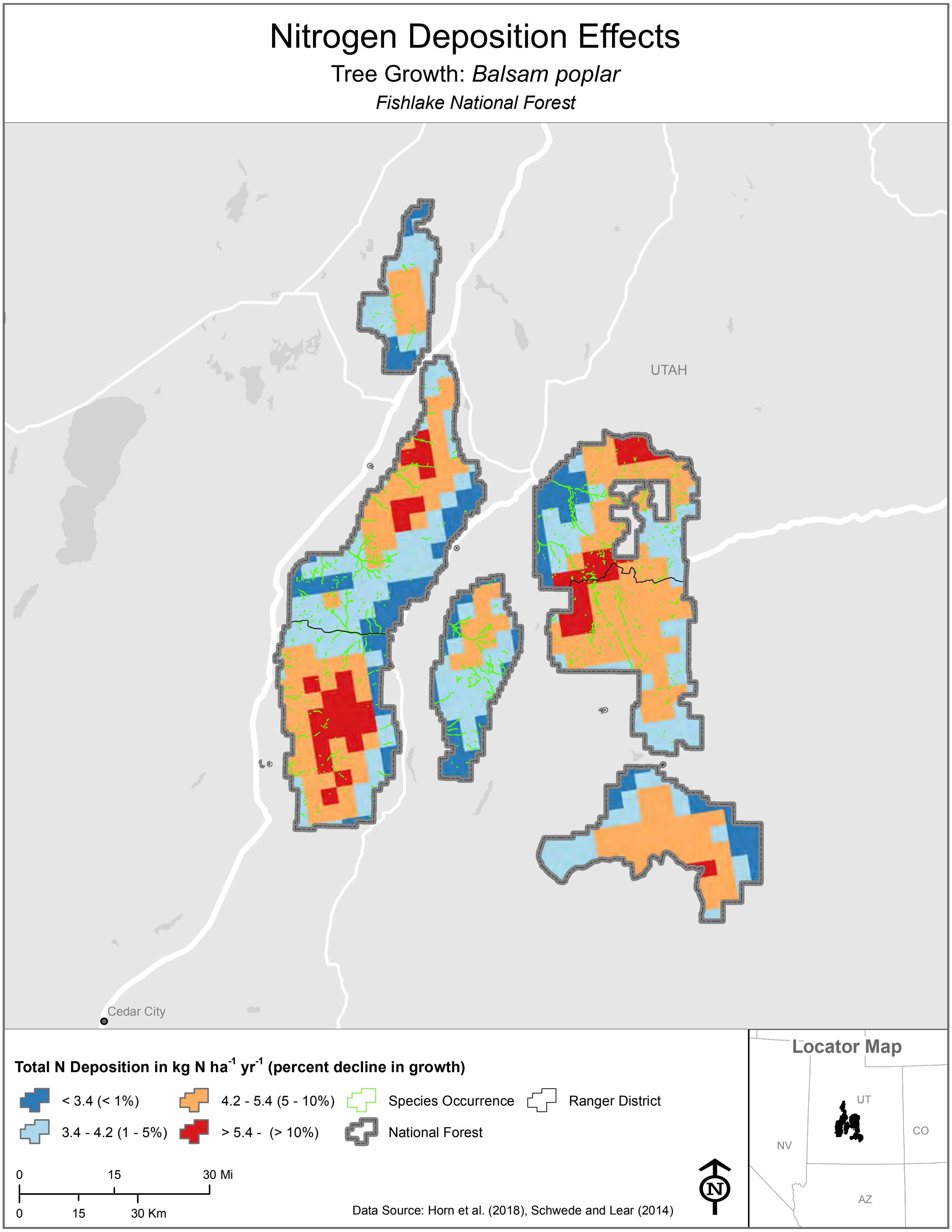


Figure 5-70.—Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

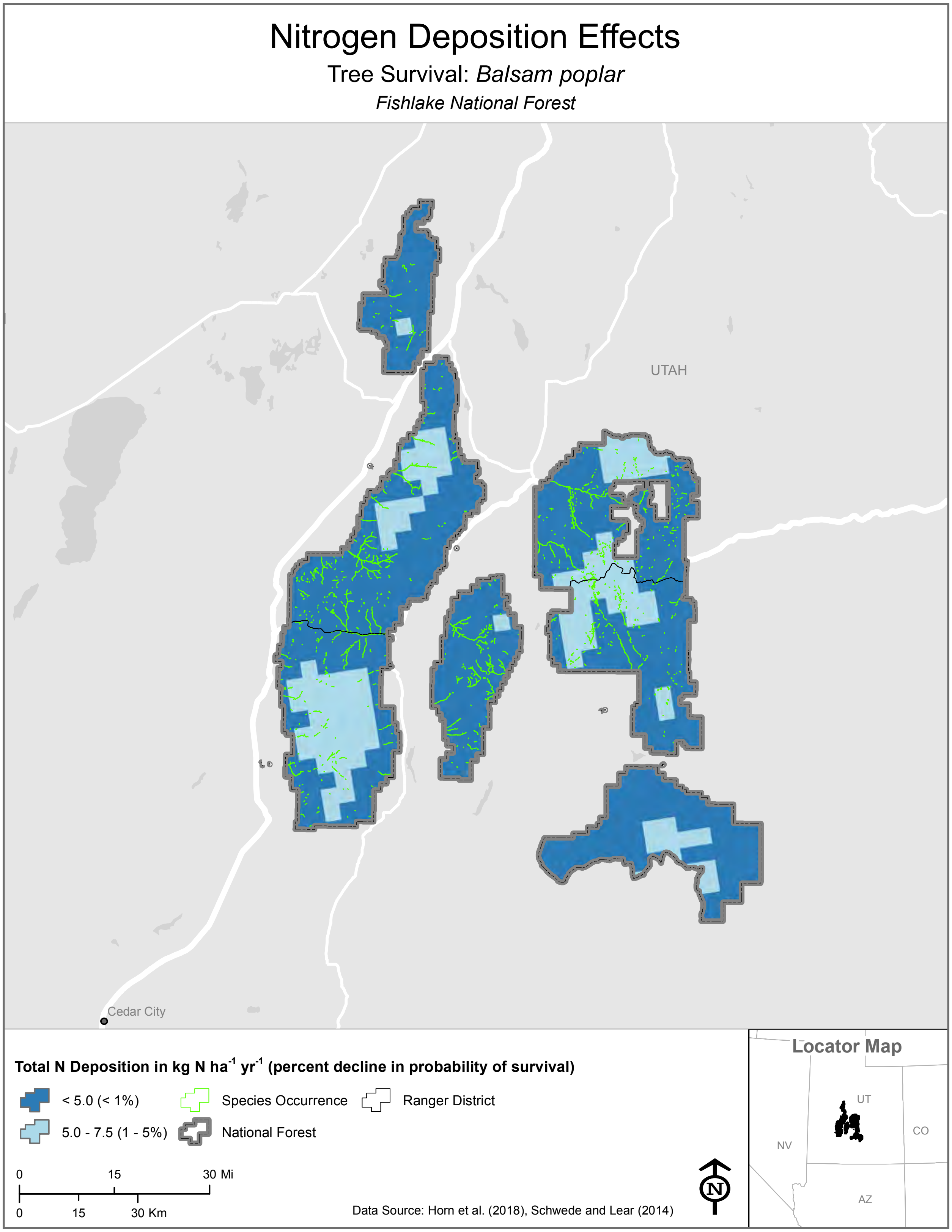


Figure 5-71.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

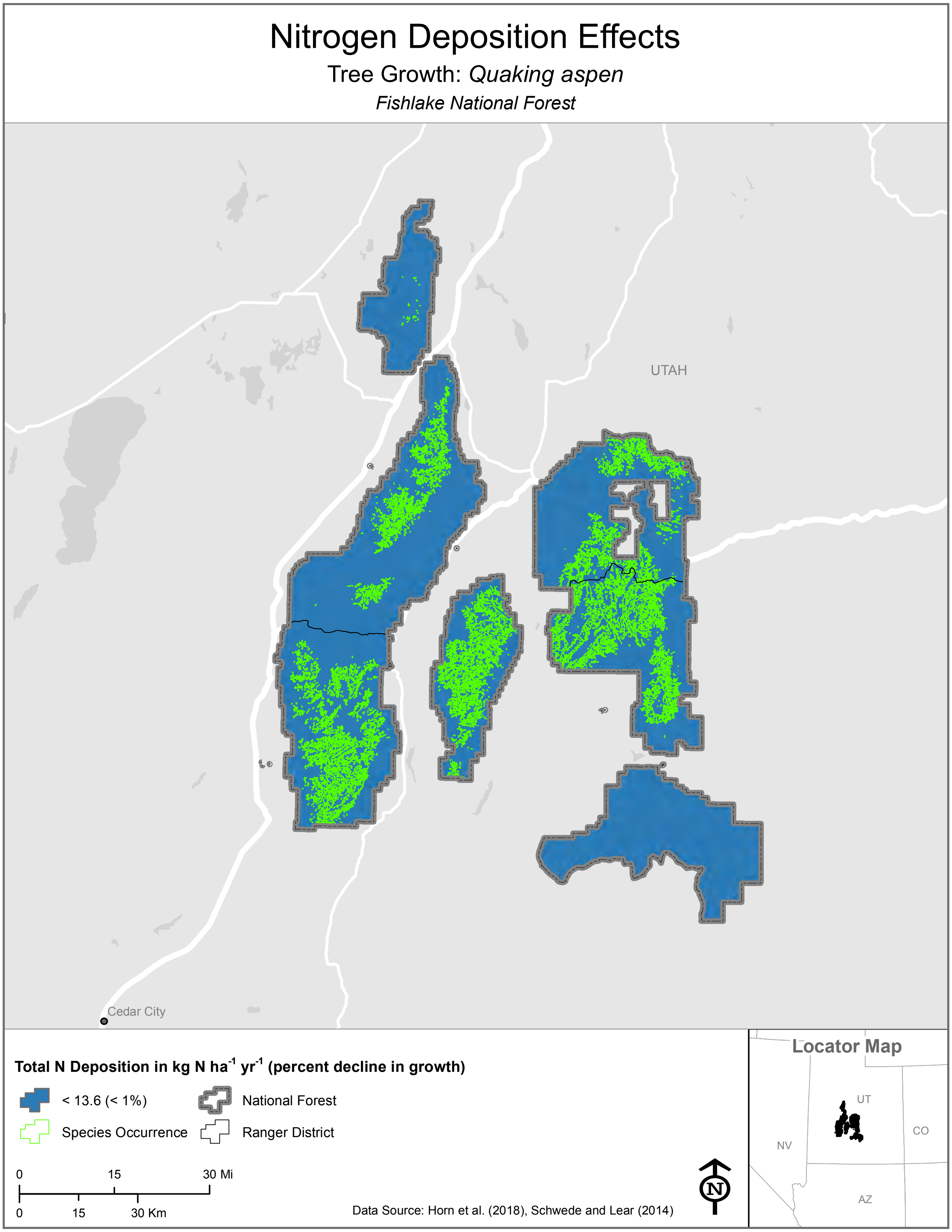


Figure 5-72.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

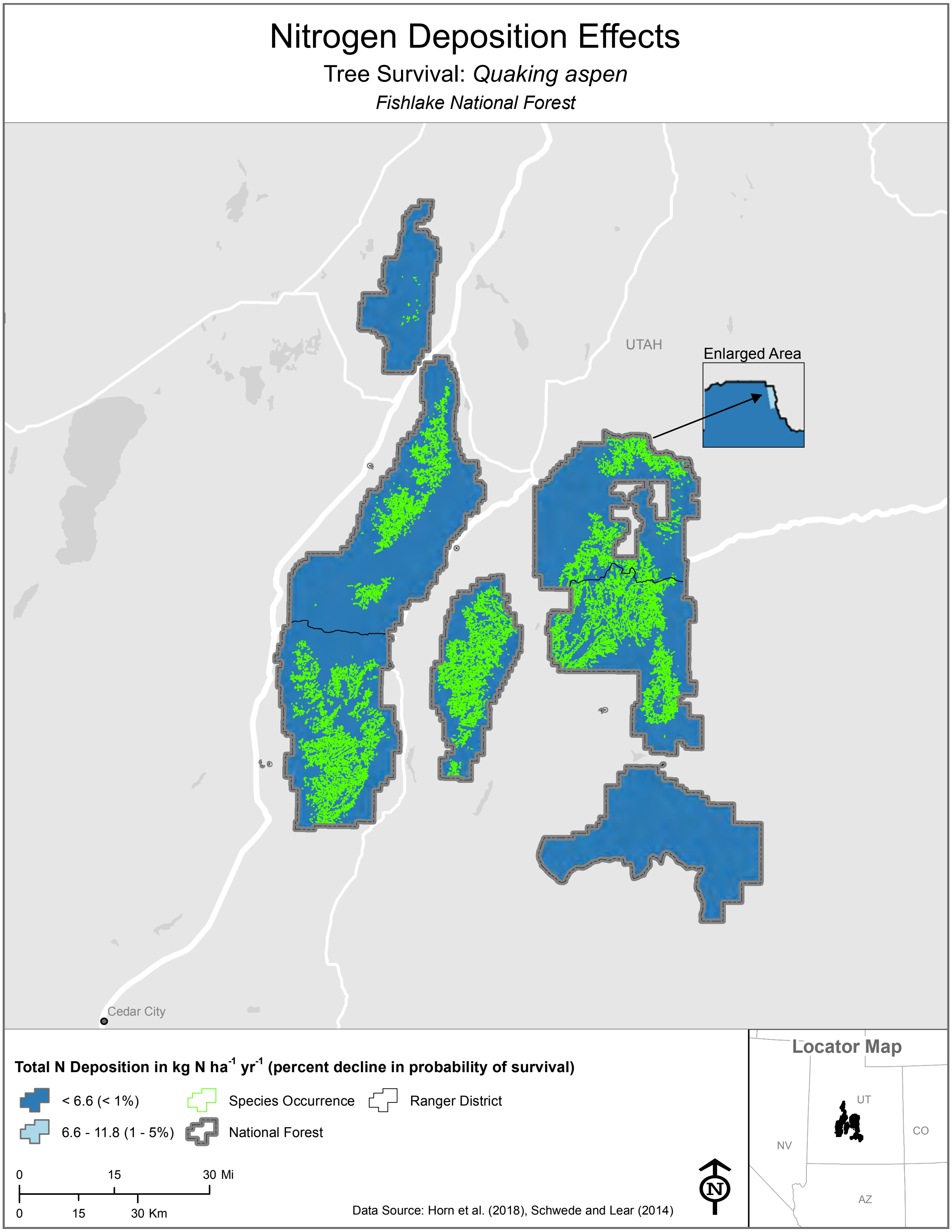


Figure 5-73.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Fishlake National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Perennial snow water melt feeds this unique alpine ring, on the Mountain City Ranger District of the Humboldt-Toiyabe Natonal Forest. USDA Forest Service photo by Susan Elliott.

5.3.7 Humboldt-Toiyabe National Forest

5.3.7.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 μeq L^{-1} were calculated for 34 locations throughout the Humboldt-Toiyabe National Forest (**Table 5-1**, **Figures 5-74** through **5-76**). Thirty-one of the water bodies had a low risk to experience biological effects associated with surface water acidification because N deposition did not exceed the high CLs (27 waterbodies with CL >8 kg N ha^{-1} yr^{-1}, **Figures 5-77** through **5-79**). Three waterbodies, one near the Mokelumne Wilderness Area and two within the Hoover Wilderness Area exceeded the CLs that protect surface water ANC from decreasing below 50 μeq L^{-1} (**Table 5-2** and **Figure 5-79**). The highest magnitude of exceedance was between 2 and 5 kg N ha^{-1} yr^{-1}. These three waterbodies have a higher risk to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}, particularly if N deposition (under ambient S deposition) persists or increases. Surface water CLs were not available for the Ely Ranger District and the Spring Mountains National Recreation Area. There may be additional acid-sensitive water bodies on the Humboldt-Toiyabe National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

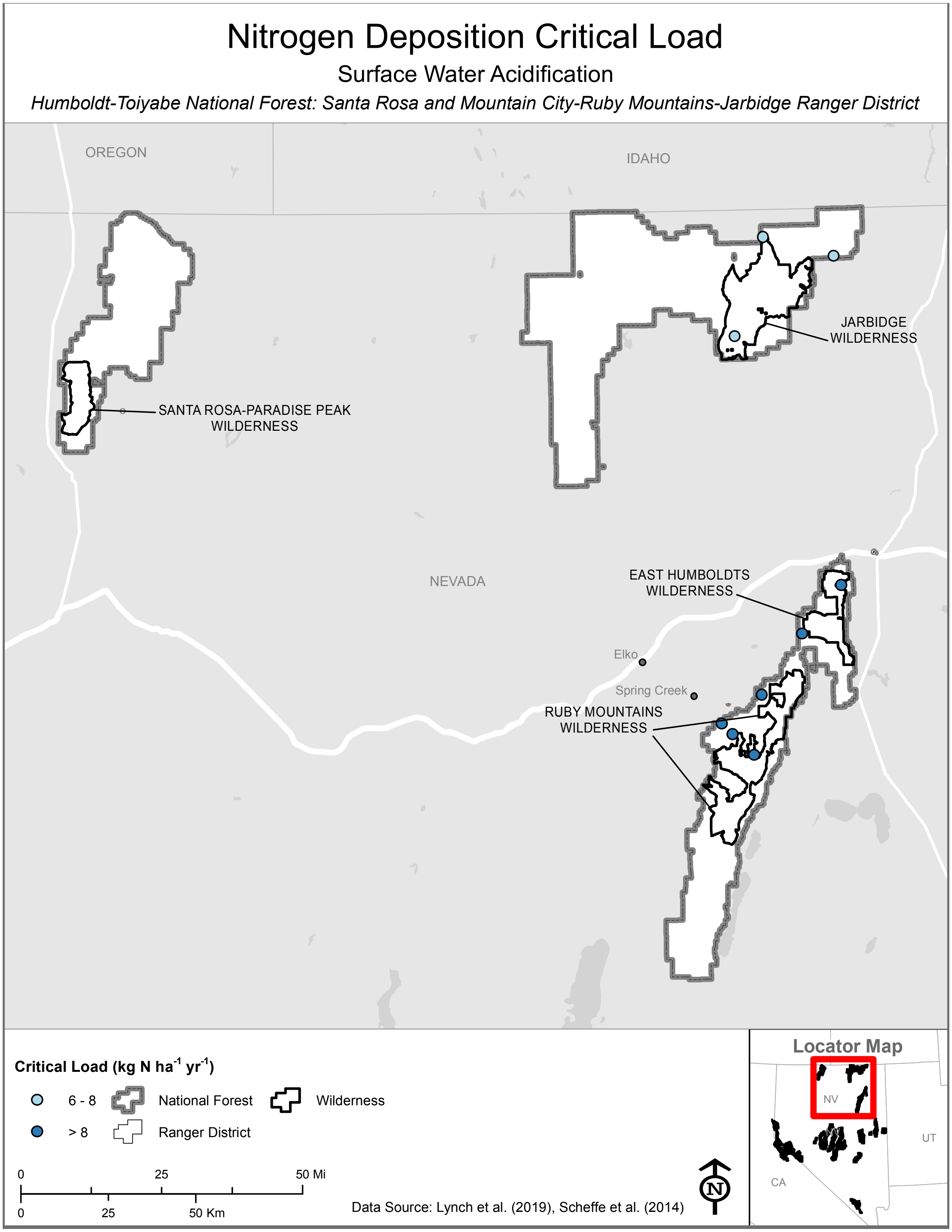


Figure 5-74.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest.

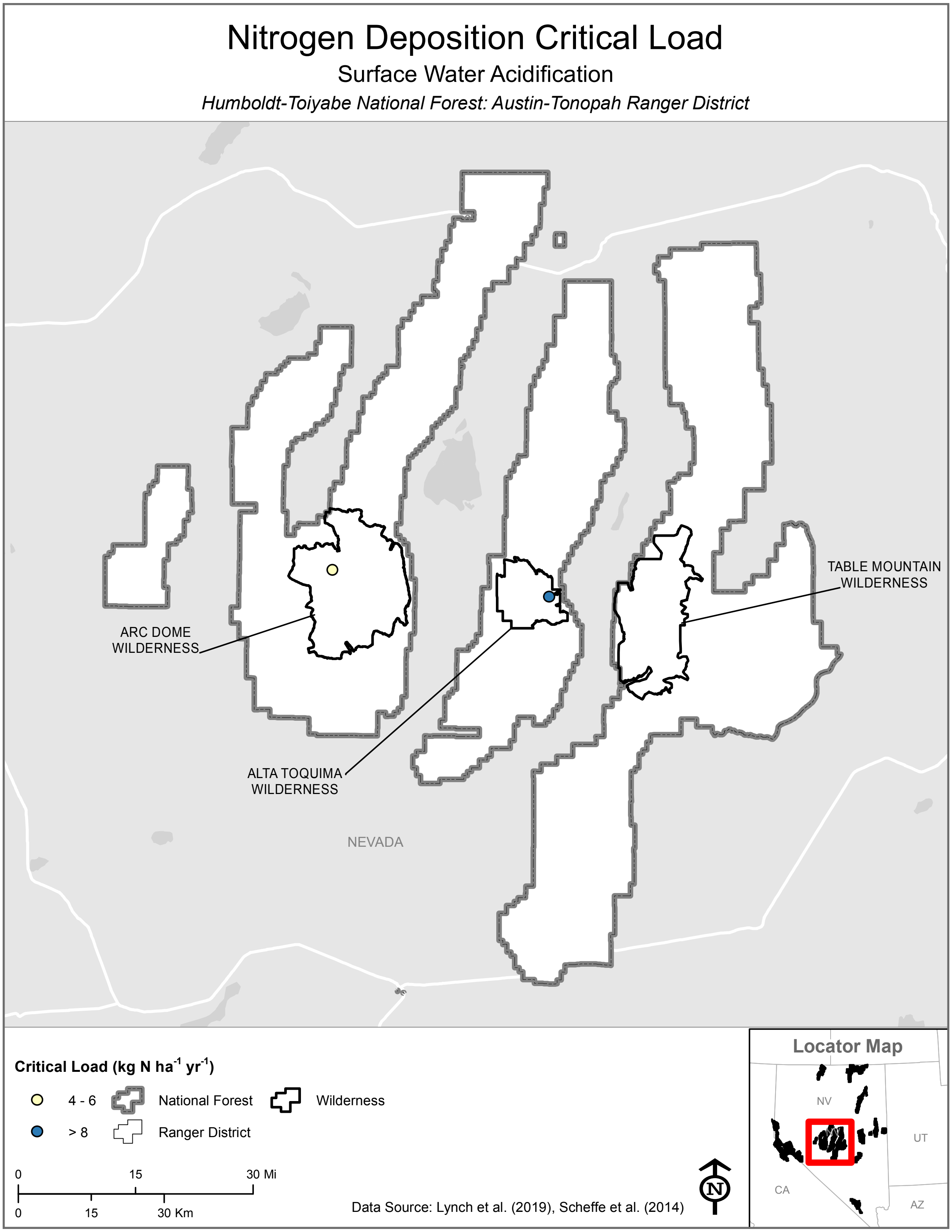


Figure 5-75.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest.

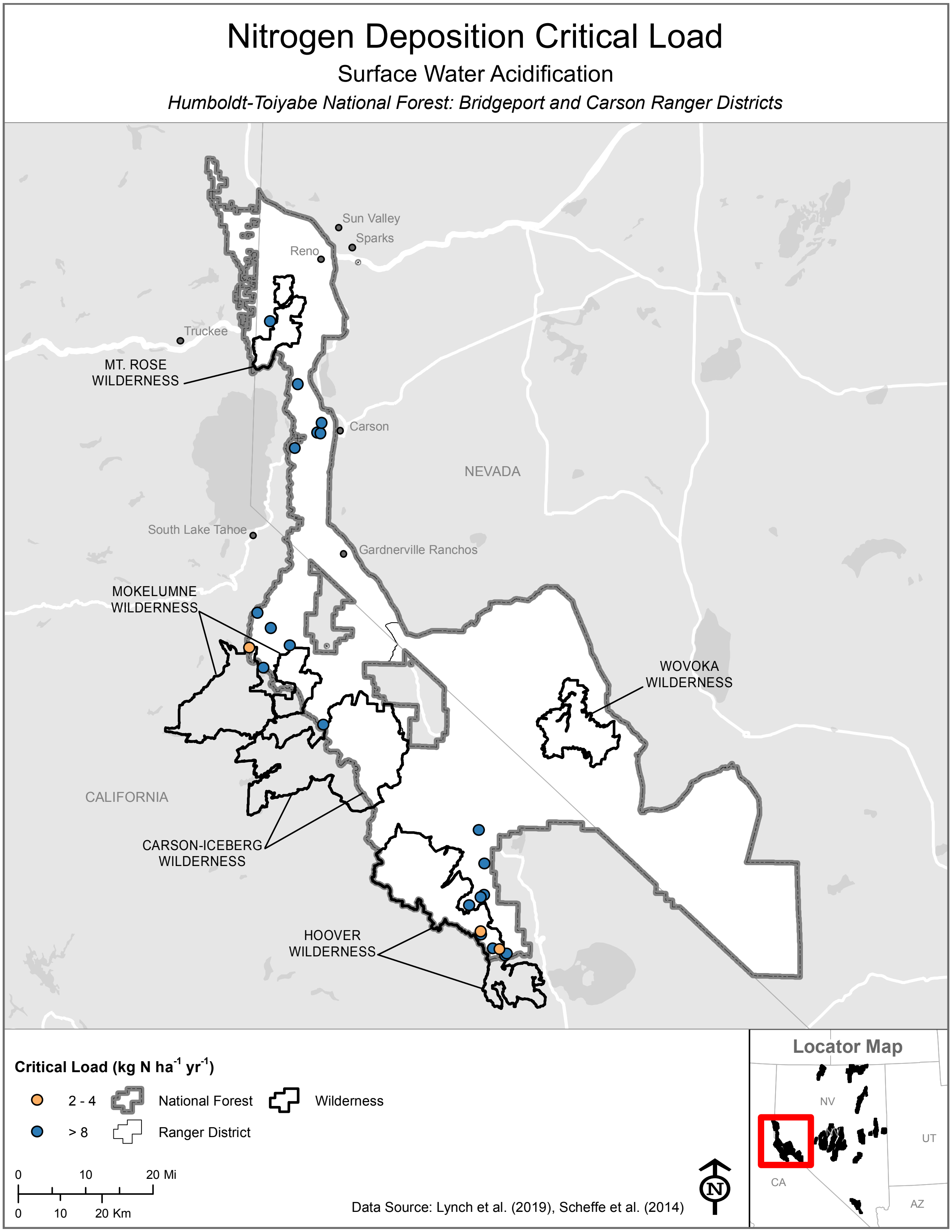


Figure 5-76.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest.

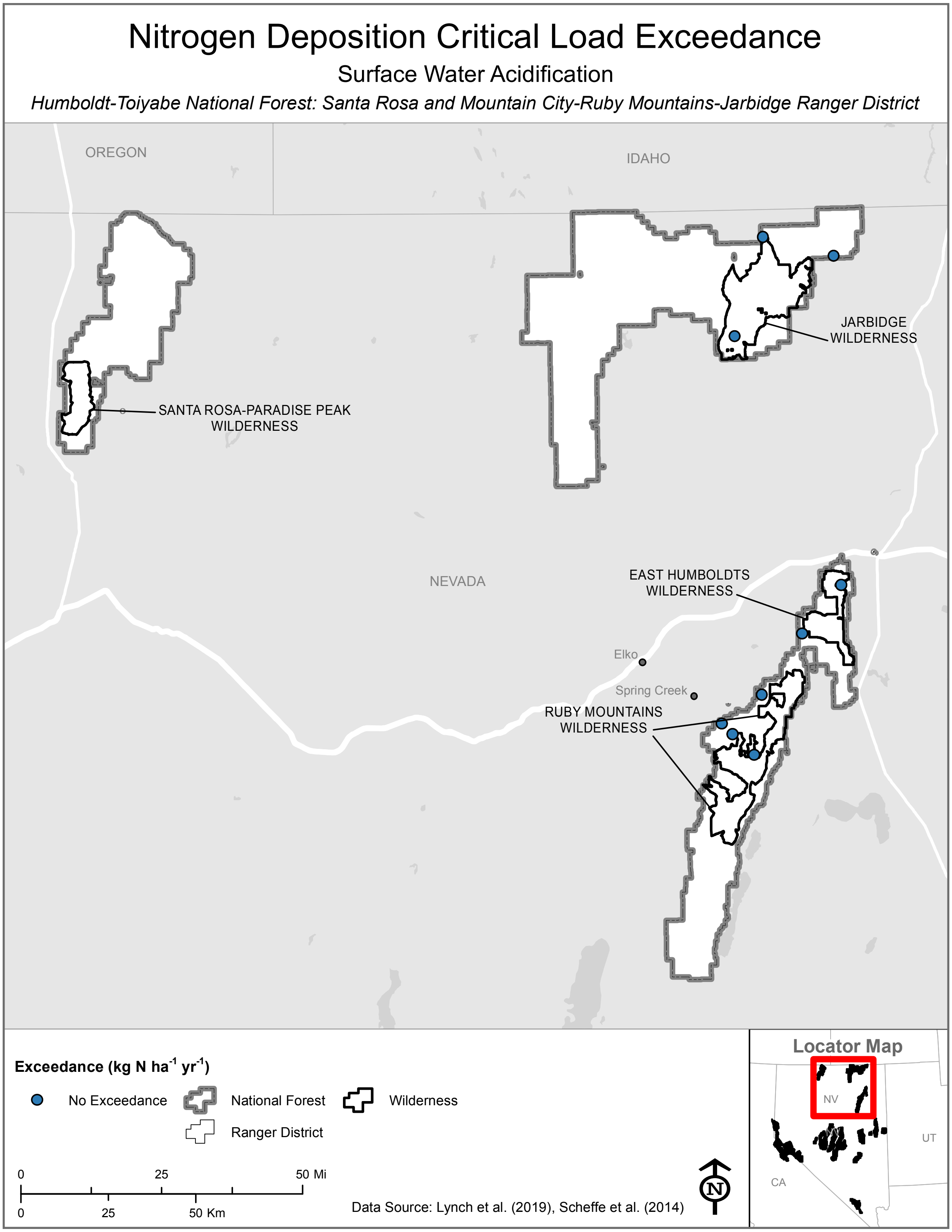


Figure 5-77.—Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest have no exceedances of total (wet + dry) N CLs that protect surface water acidification from decreasing below 50 µeq L^{-1}.

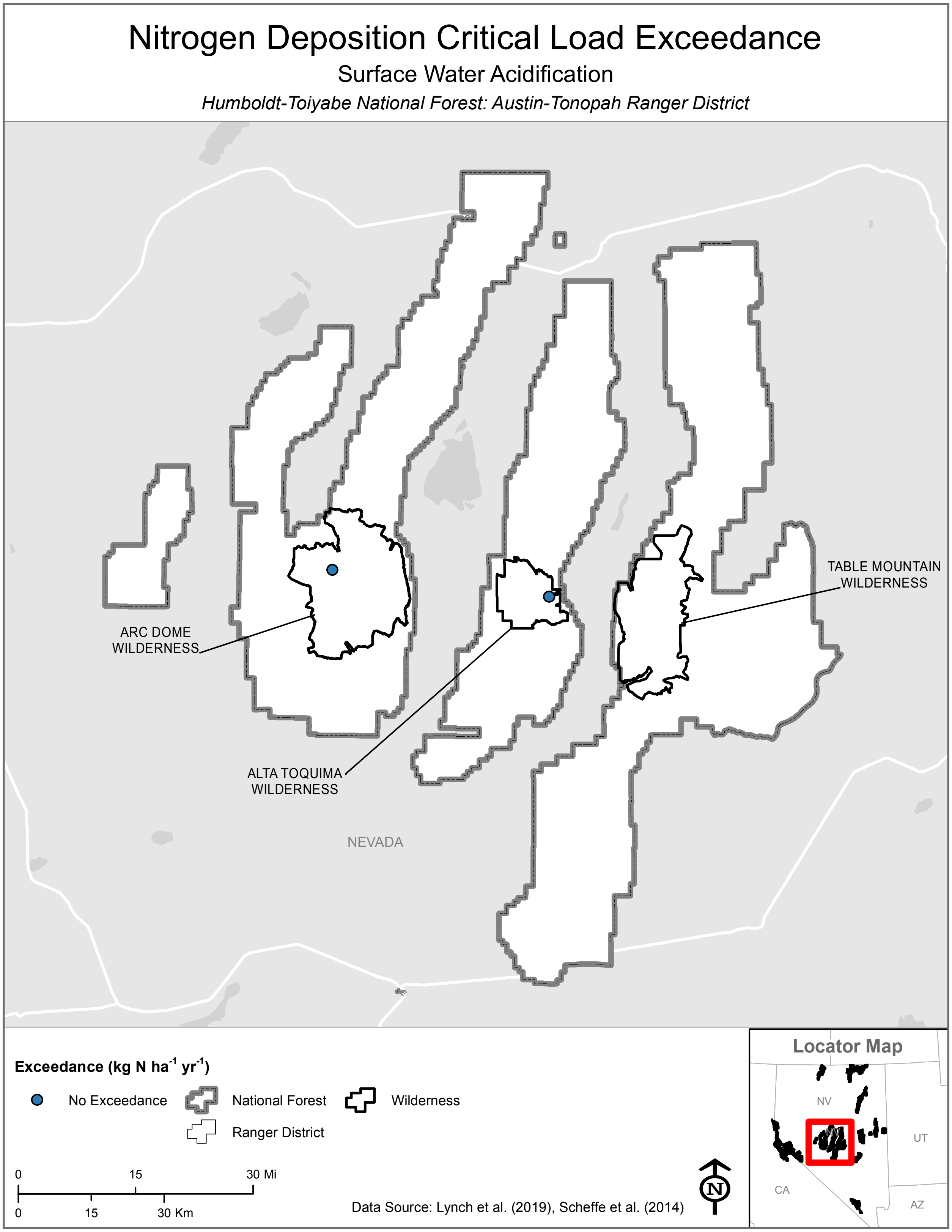


Figure 5-78.—Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest has no exceedances of the total (wet + dry) N CLs that protect surface water acidification from decreasing below 50 µeq L^{-1}.

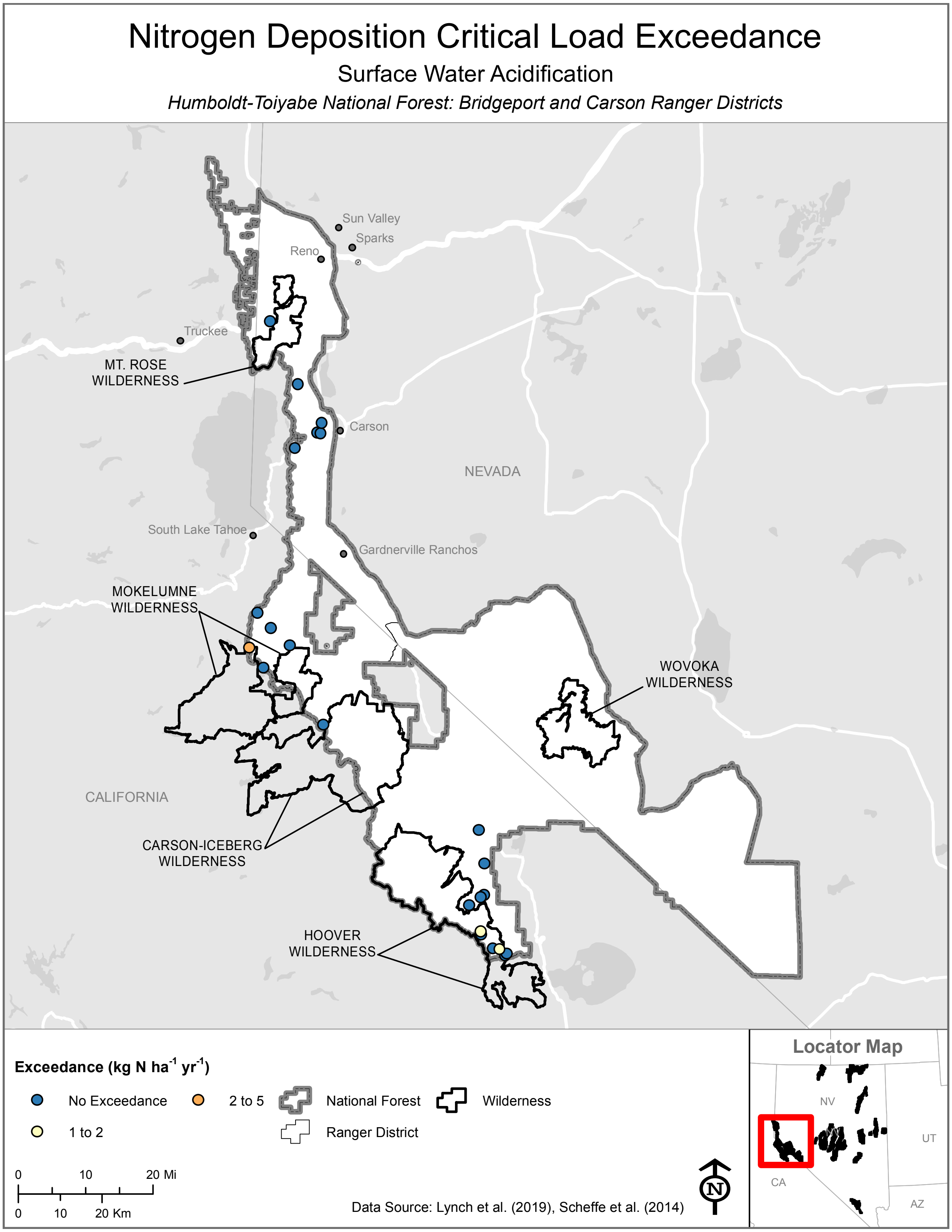


Figure 5-79.—Exceedances for wet N CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest.

Granite Peak as viewed from Buttermilk Meadows on the Santa Rosa Ranger District of the Humboldt-Toiyabe National Forest. USDA Forest Service photo by Mark Dallon.

5.3.7.2 Surface Water Eutrophication

Spatial data for CLs that protect against surface water eutrophication were not available for the Humboldt-Toiyabe National Forest because this area was outside the geographic bounds of the study used to assess eutrophication CLs for the other National Forests in the Intermountain Region (Nanus et al. 2012).

Emma Lake, Humboldt-Toiyabe National Forest. USDA Forest Service photo by Chris Africa.

5.3.7.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance.

Total N deposition exceeded CLs that protect against declines (>20 percent) of lichen species richness and forage lichen abundance within 57 percent (15,570 km^2) and nearly 100 percent (27,093 km^2), respectively, of the Humboldt-Toiyabe National Forest (**Table**s **5-5** and **5-6**). Critical load exceedances associated with 30 to 40 percent declines in lichen species richness covered nearly 3,000 km^2 (11 percent) of the Forest with magnitudes of exceedance greater than 6 kg N ha^{-1} yr^{-1} in some areas. The Wilderness Areas with the highest magnitude of exceedances associated with 30 to 40 percent declines in lichen species richness included the East Humboldts, Mt. Charleston, La Madre Mountain, Rainbow Mountain, Mokelumne, Carson-Iceberg, and Mt. Rose (**Figures 5-80** through **5-84**). The Humboldt-Toiyabe is a large, diverse forest with low N deposition in many areas. Forty-three percent (11,567 km^2) of the Forest had no exceedances of the CL protects against declines in lichen species richness (**Table 5-5)**. The Austin-Tonopah and Ely Ranger Districts had the lowest magnitudes of CL exceedance associated with declines in lichen species richness (**Figures 5-81** and **5-82**).

Significantly more area was in exceedance of the CL that protects against declines in forage lichen abundance, mainly because the CL is low. The patterns of exceedance were similar to lichen species richness (**Figures 5-85** through **5-89**). The Wilderness Areas with the highest magnitudes of exceedance associated with >50 percent declines in forage lichen abundance included Mt. Charleston, La Madre Mountain, Mt. Rose, Mokelumne, Carson-Iceberg, and Hoover. The Wilderness Areas with the lowest magnitudes of exceedance, associated with <40 percent declines included Shellback, Bald Mountain, Red Mountain, Quinn Canyon, and Santa Rosa Paradise (**Figures 5-85** and **5-86**).

The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

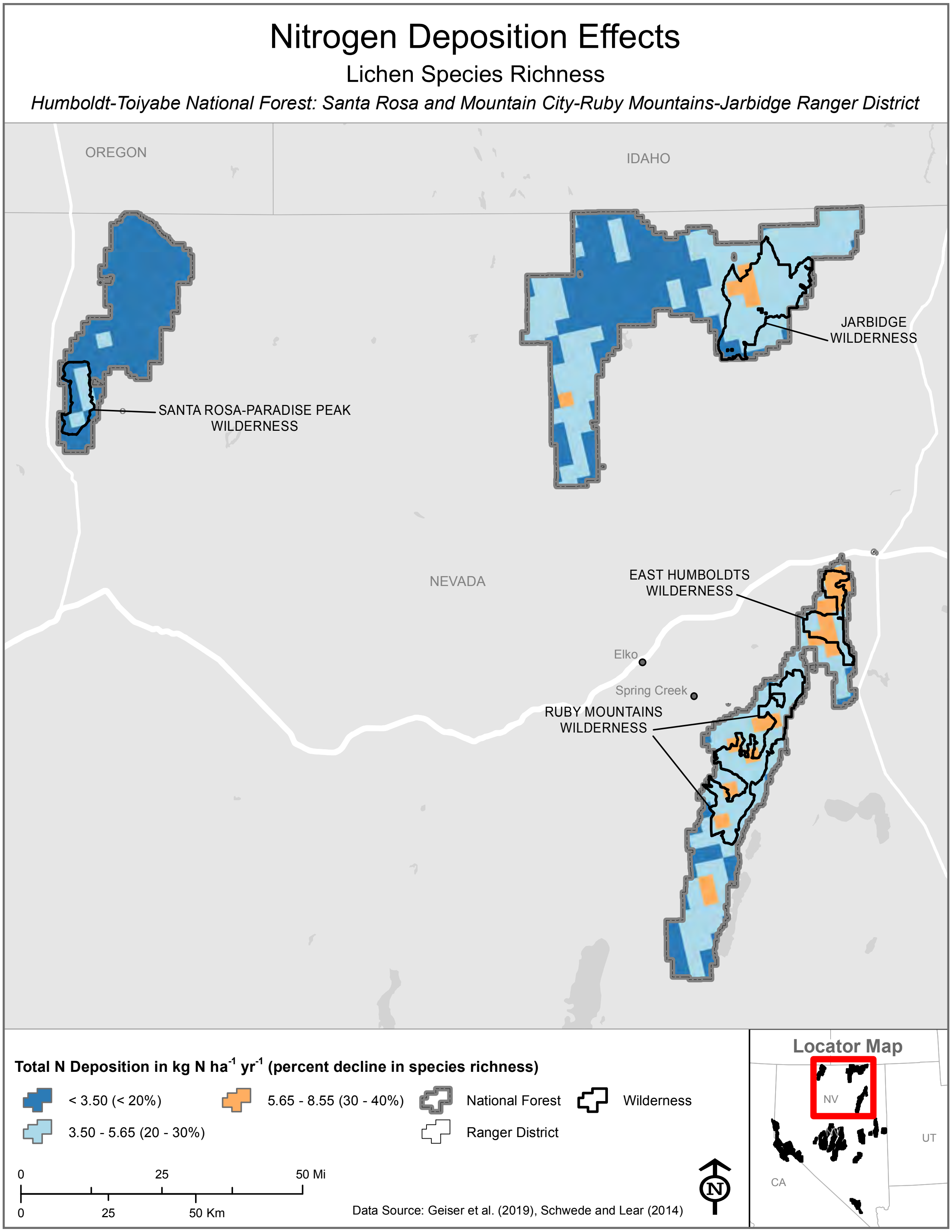


Figure 5-80.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest.

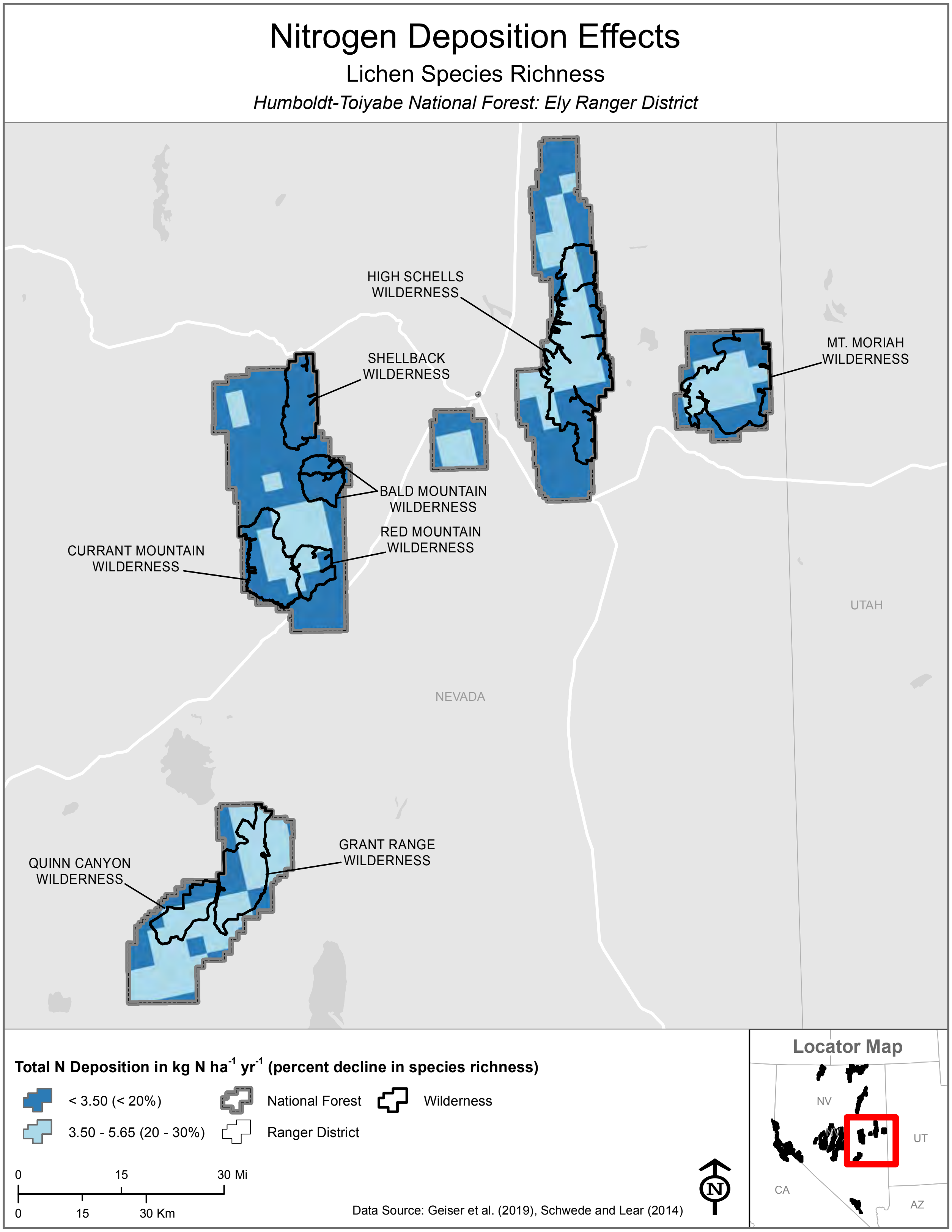


Figure 5-81.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Ely Ranger District on the Humboldt-Toiyabe National Forest.

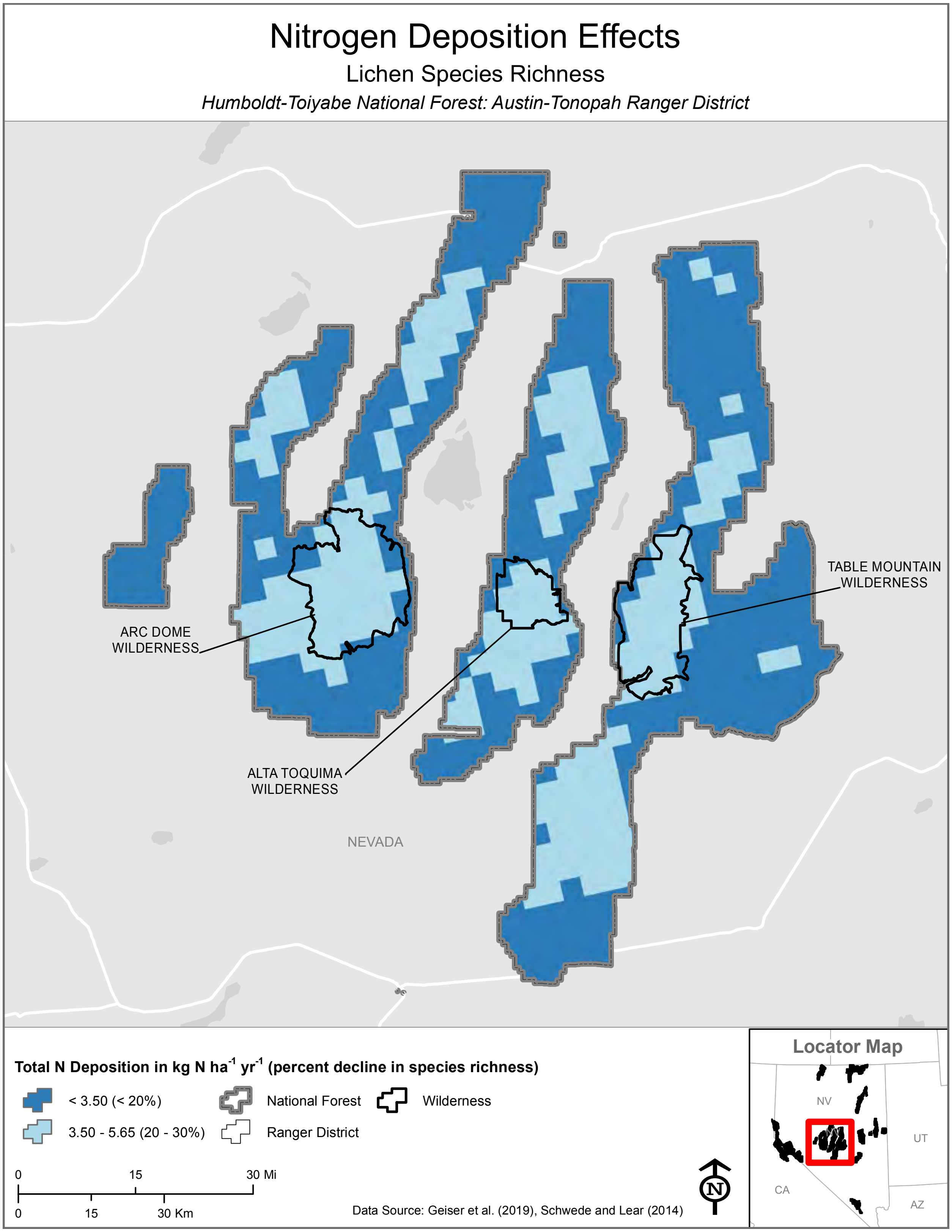


Figure 5-82.—Total (wet + dry) N deposition (average 2015–2017) the estimated effect to lichen species richness within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest.

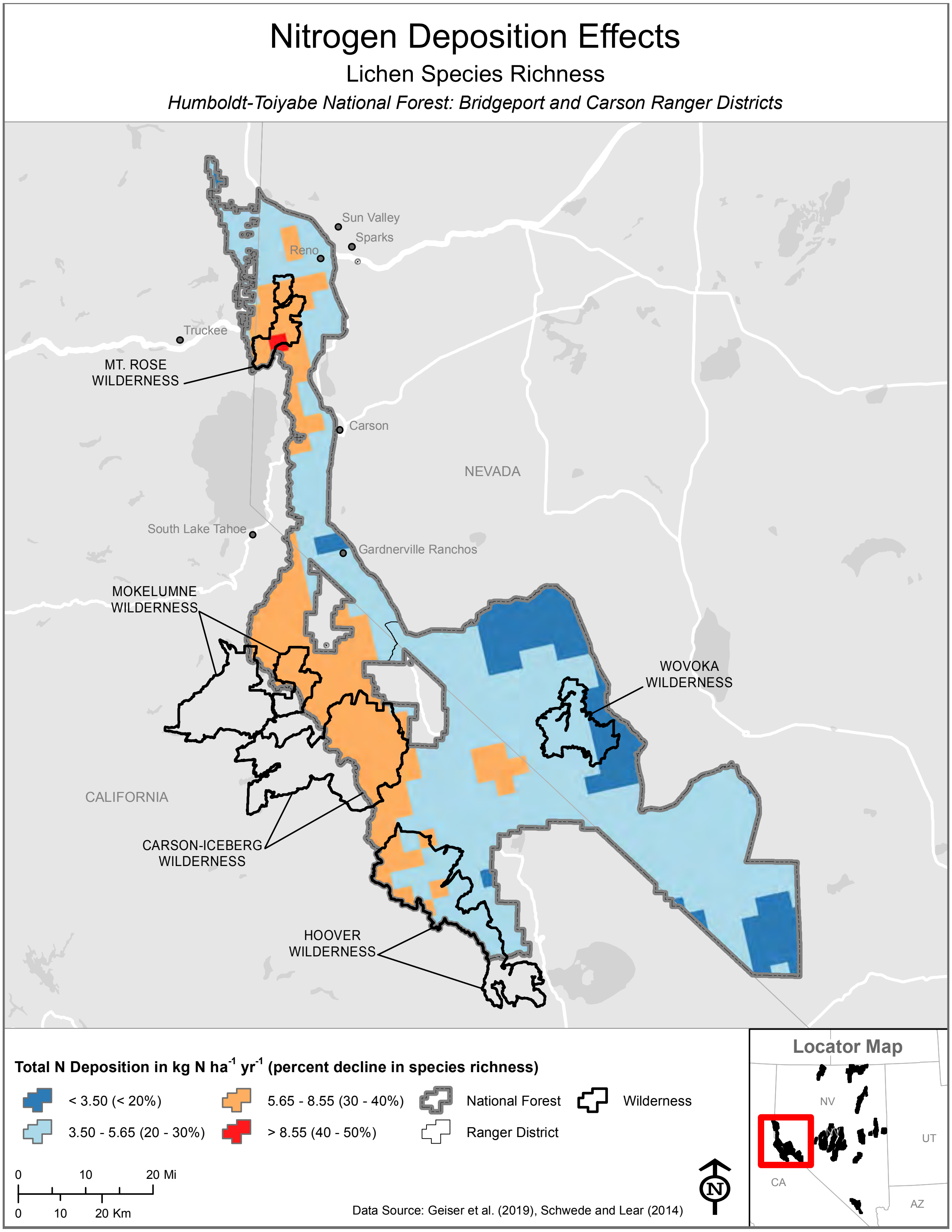


Figure 5-83.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest.

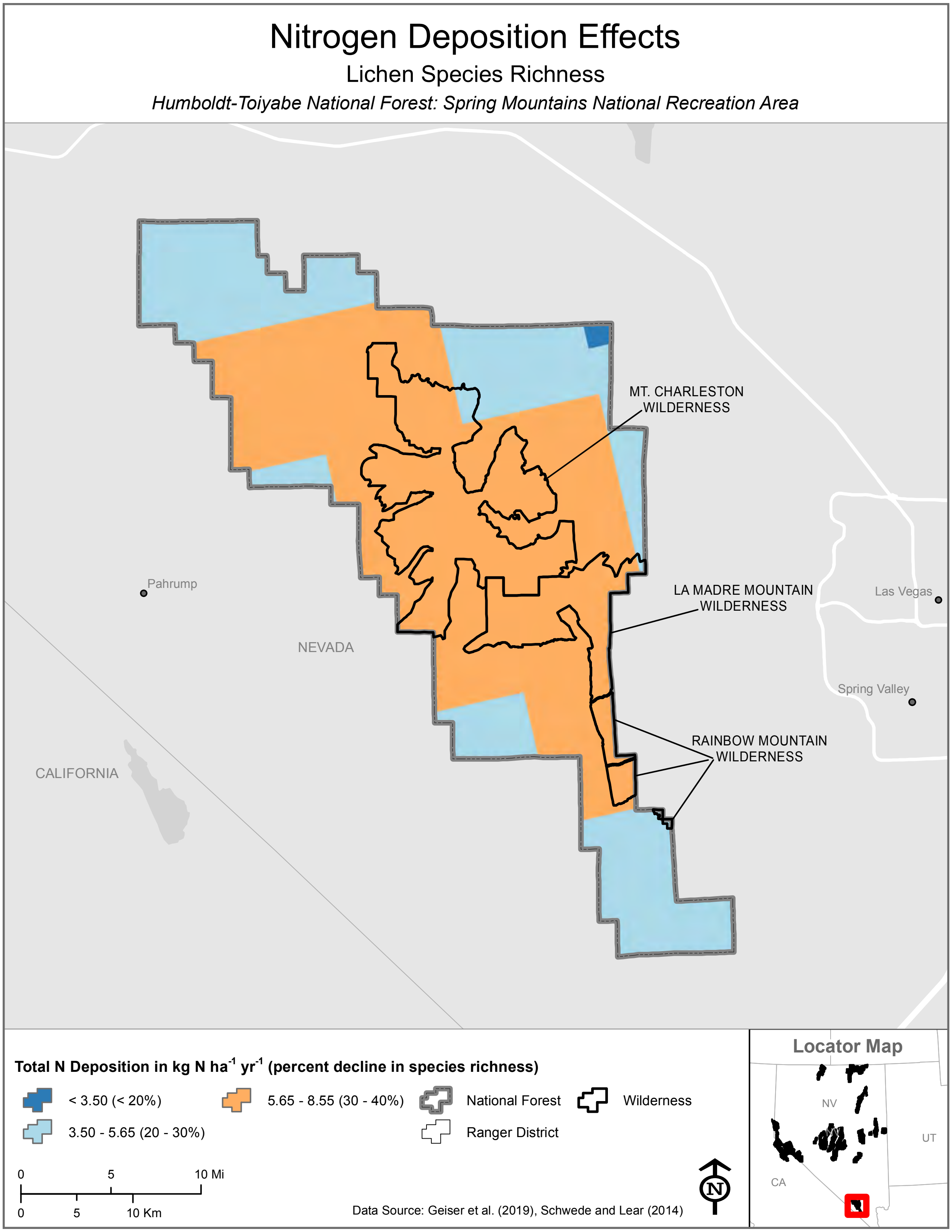


Figure 5-84.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest.

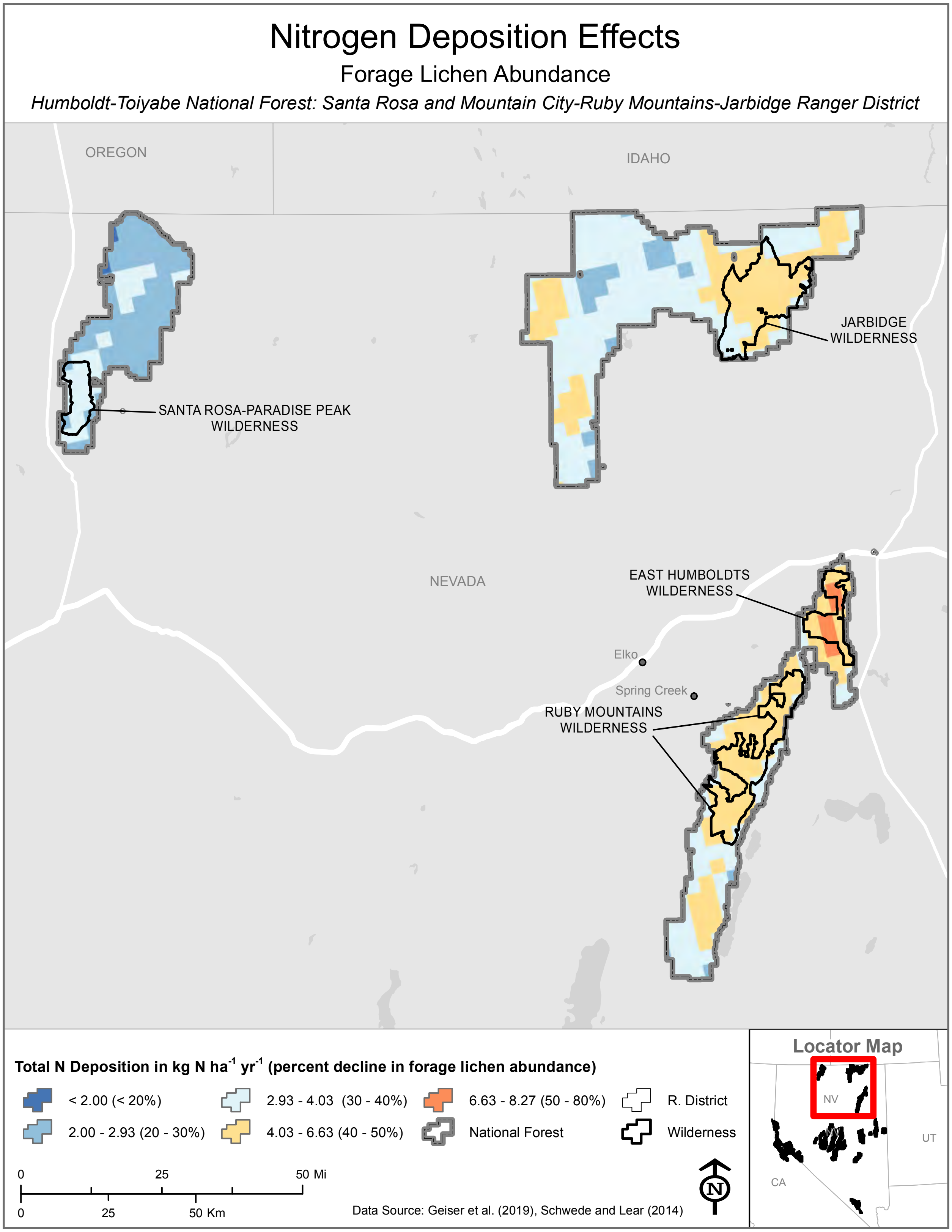


Figure 5-85.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest.

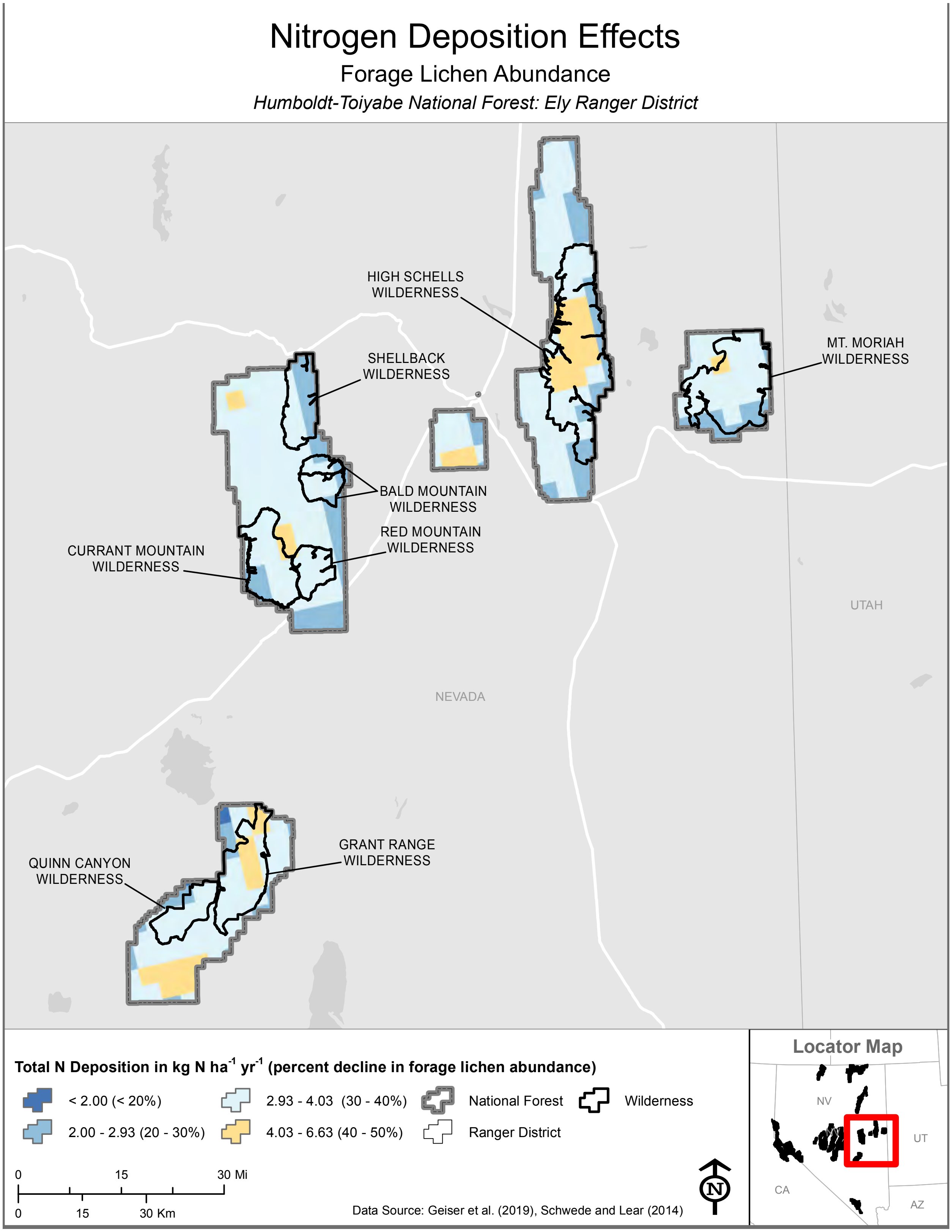


Figure 5-86.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Ely Ranger District on the Humboldt-Toiyabe National Forest.

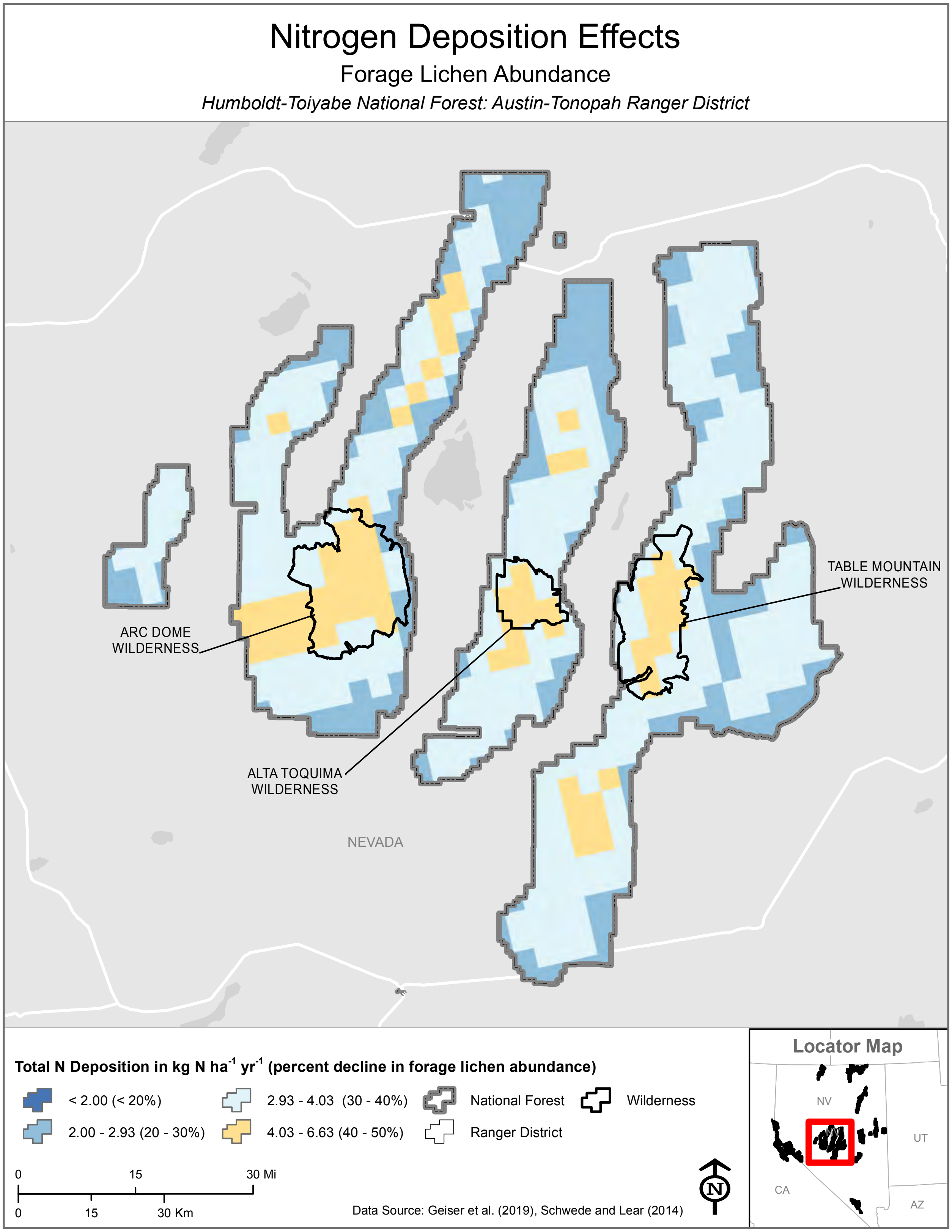


Figure 5-87.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest.

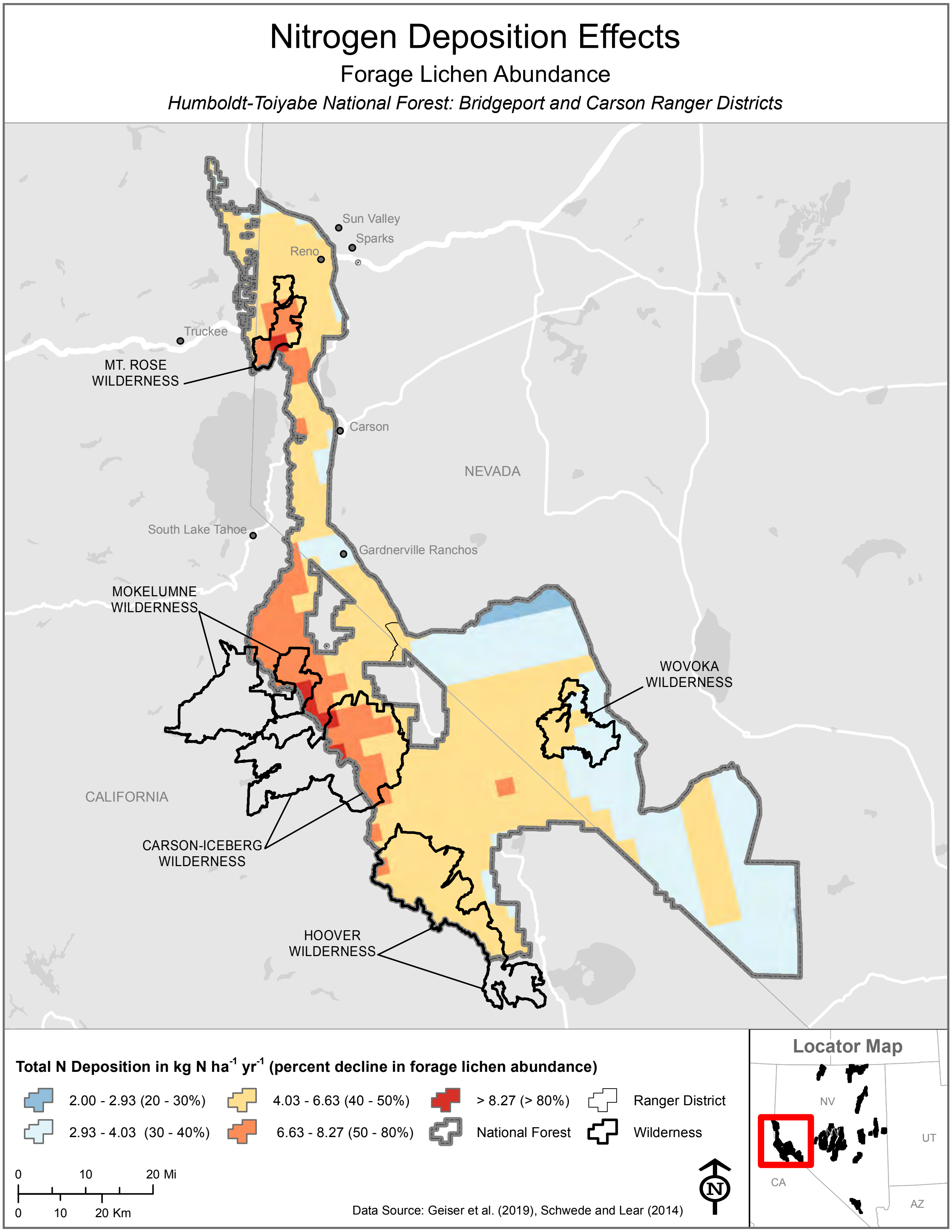


Figure 5-88.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest.

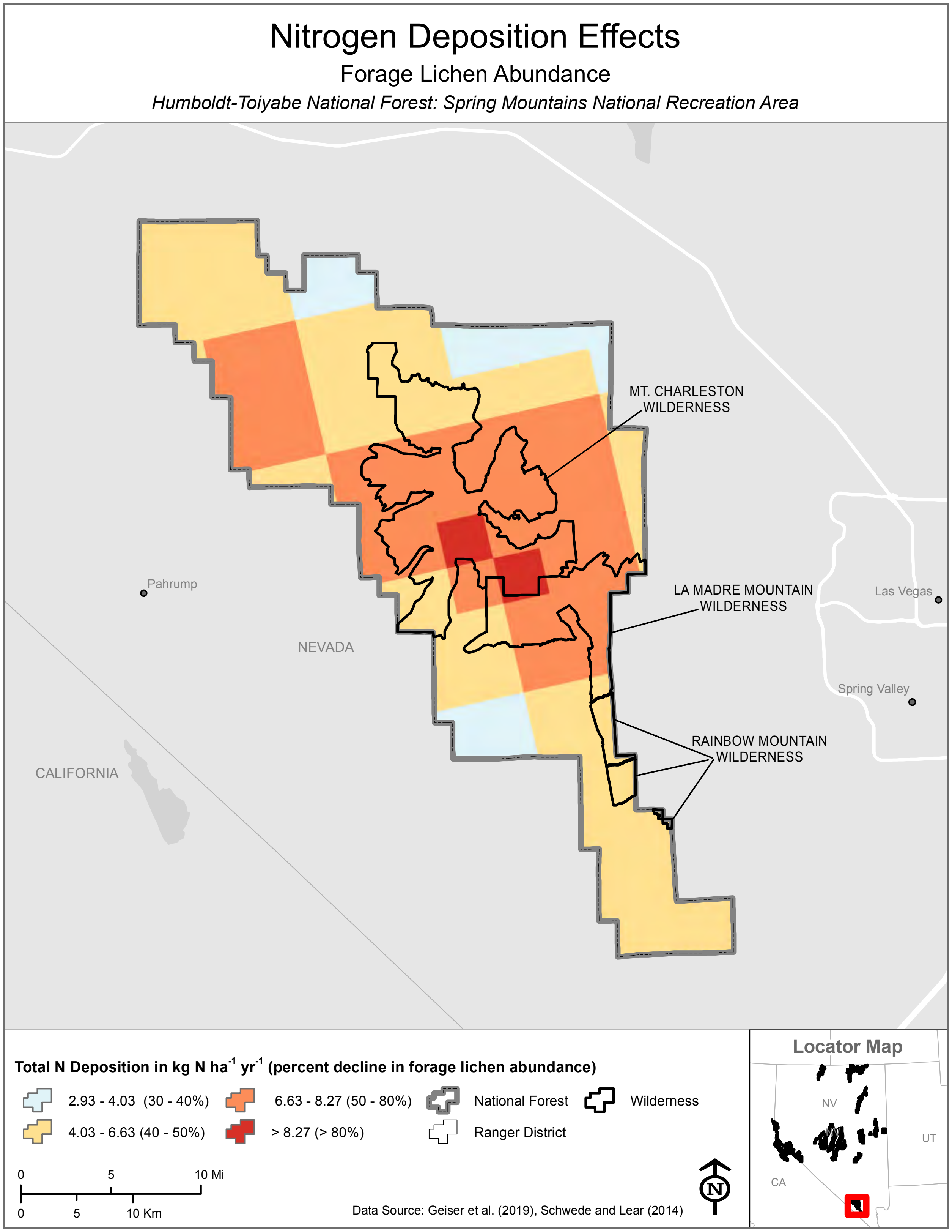


Figure 5-89.—Total (wet + dry) N (average 2015–2017) and the estimated effect to forage lichen abundance within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest.

Aspens in the Spring Mountains National Recreation Area, Humboldt-Toiyabe National Forest. USDA Forest Service Photo.

5.3.7.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Humboldt-Toiyabe National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 18 percent (1,318 km^2) of the area where this species is modeled as dominant or codominant on the Humboldt-

Toiyabe National Forest (**Table 5-8**). Exceedances were associated with 1 to 5 percent declines in probability of survival and were common throughout the Forest including many Wilderness Areas (**Figures 5-90** through **5-94**).

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 13 percent (1,146 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). Most exceedances were associated with 1 to 5 percent declines in probability of survival, with 2 percent (164 km^2) associated with 5 to 10 percent declines. Exceedances were common within the Bridgeport and Carson Ranger Districts and Spring Mountains National Recreation Area, including the Mt. Charleston Wilderness and several other Wilderness Areas (**Figures 5-95** through **5-99**).

Quaking aspen. There were no exceedances of N deposition levels associated with declines in growth rate for quaking aspen (**Table 5-10** and **Figures 5-100** through **5-104**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceeded within 4 percent (34 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-11**, **Figures 5-105 through 5-109**). Exceedances were associated with declines in survival between 1 and 5 percent and occurred within and near the East Humboldt, Mt. Rose, Mokelumne, Carson-Iceberg, and Mt. Charleston Wilderness Areas (**Figures 5-105** through **5-109)**.

Balsam poplar. The N deposition levels that protect against > 1 percent declines in balsam poplar growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) were exceeded within 53 percent (8 km^2) and 9 percent (1.3 km^2), respectively, of the area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). Exceedances were associated with a greater than 1, 5, and 10 percent declines in growth rate and a greater than 1 and 5 percent declines in probability of survival (**Table 5-12** and **5-13**). Exceedances associated with declines in growth rate occurred in small areas throughout the Forest including some of the Wilderness Areas, particularly the Jarbidge Wilderness (**Figures 5-110** through **5-113**). Exceedances associated with declines in probability of survival were limited to small pockets throughout the Forest (**Figures 5-114** through **5-117**). Maps of balsam poplar exceedance were not included for the Spring Mountains National Recreation Area because this species was not modeled as having any dominant or co dominant cover in this area.

Douglas-fir. Dominant or codominant canopy cover of Douglas-fir were rare, with a total area of 0.04 km^2 between the Bridgeport and Carson Ranger Districts. The N deposition level associated with >1 percent declines in probability of survival over 10 years was exceed over the entire modeled area (**Table 5-7** and **Figure 5-118**).

Other species of interest that occurred within the Humboldt-Toiyabe National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-20**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-20. —Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent and 10 percent in tree growth and probability of survival (over 10 years) for species (in bold font) found within the Humboldt-Toiyabe National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

					N levels that protects against various percent declines in tree growth and survival		
Common name	Species name	Form of response to N deposition		CL	1%	5%	10%
White fir	*Abies concolor*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Western juniper	*Juniperus occidentalis*	Growth	Threshold[a]	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

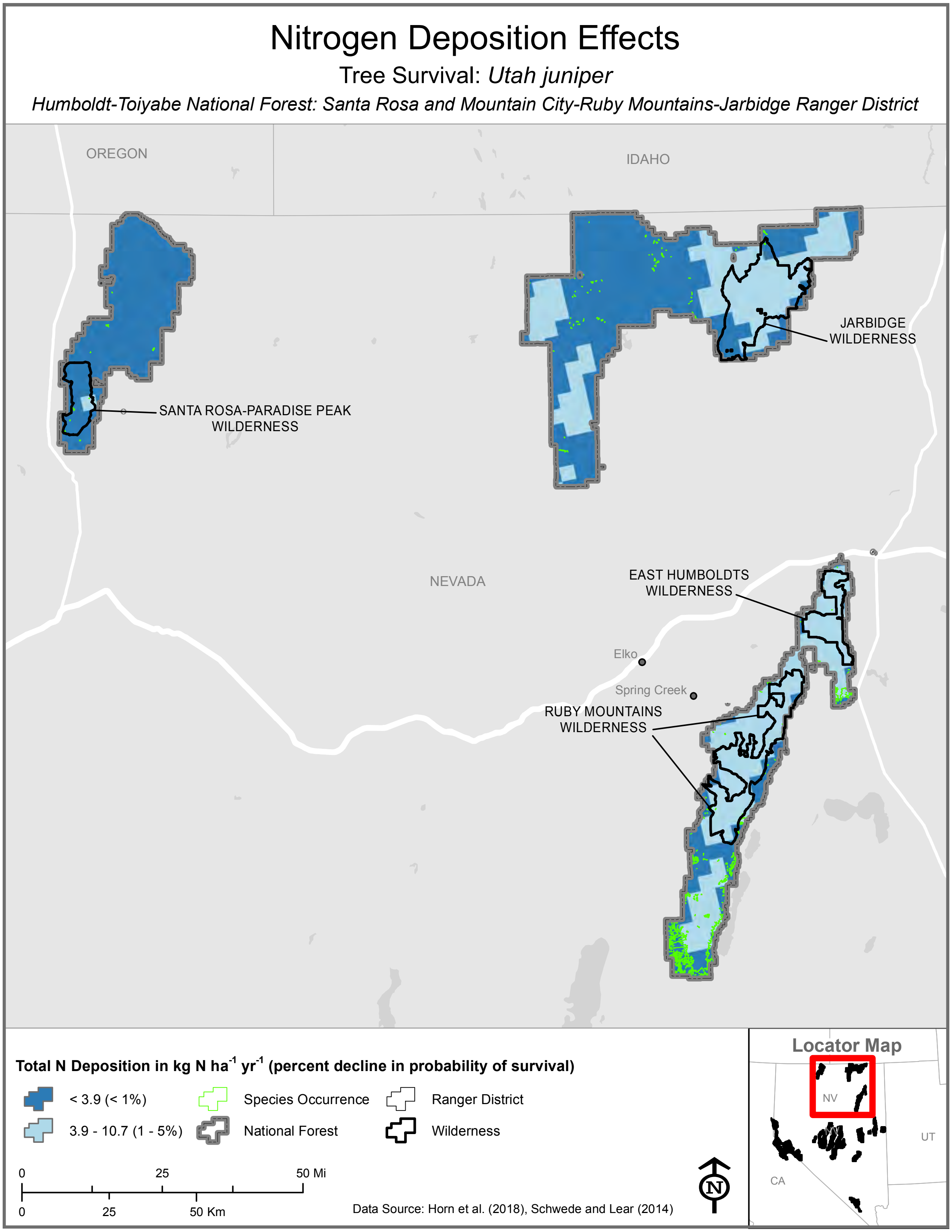


Figure 5-90.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

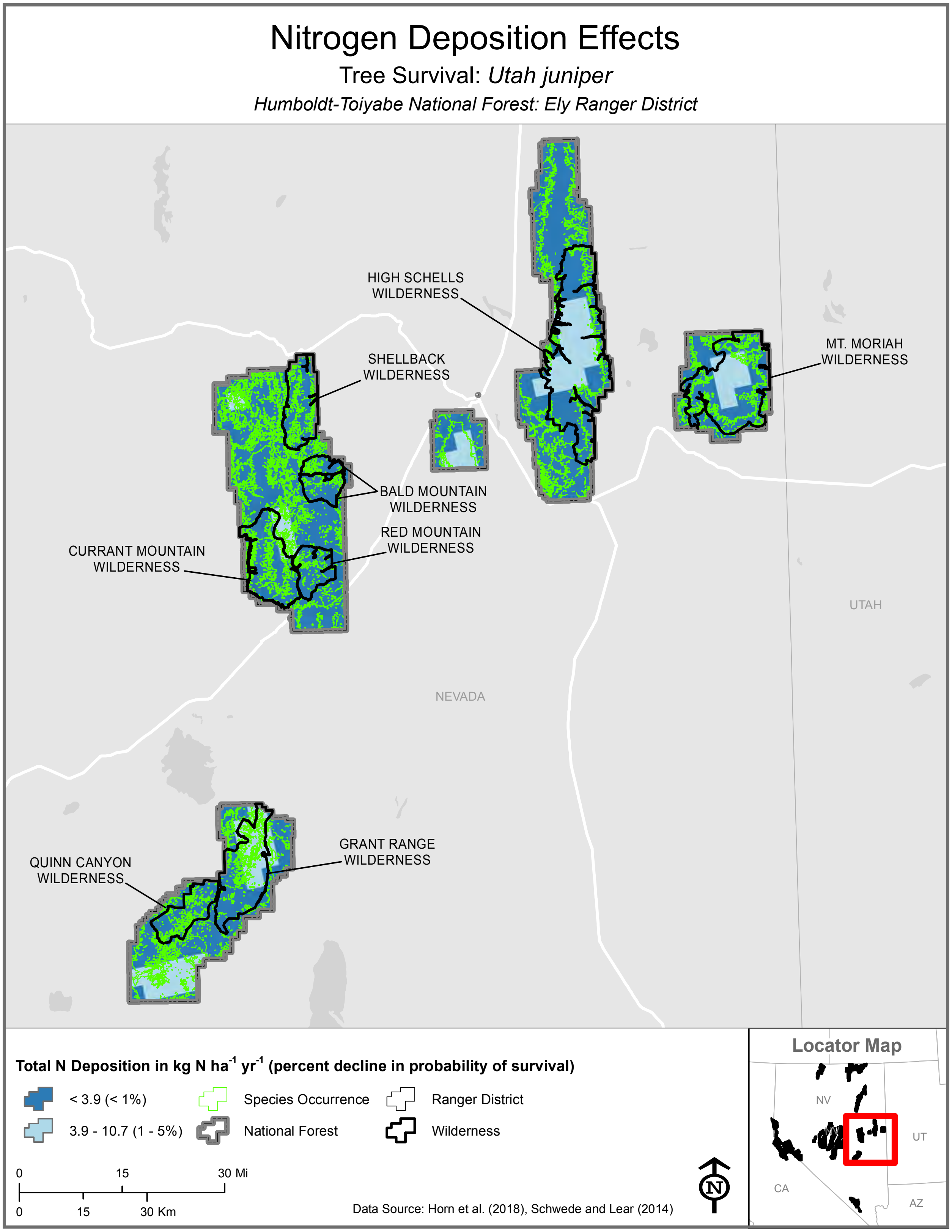


Figure 5-91.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

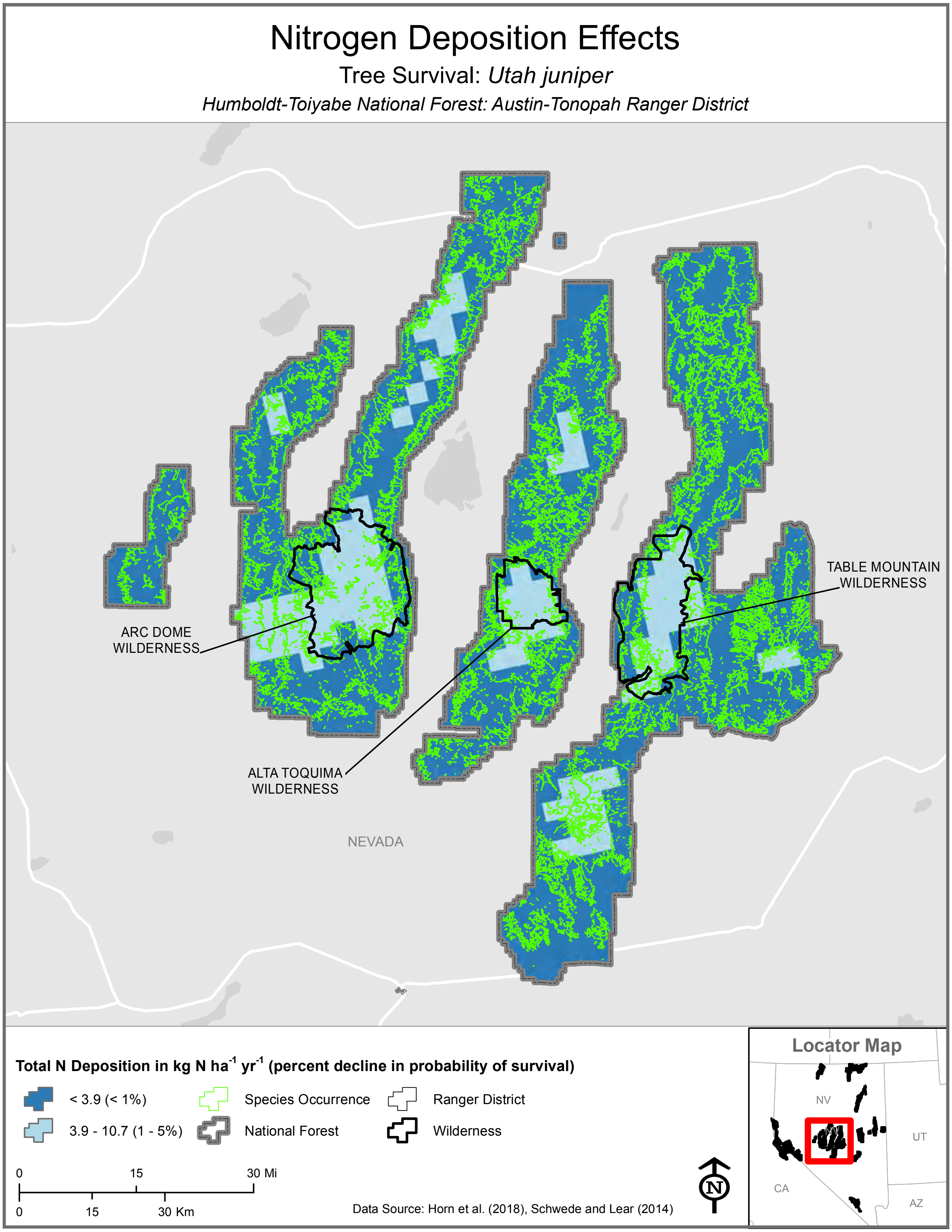


Figure 5-92.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

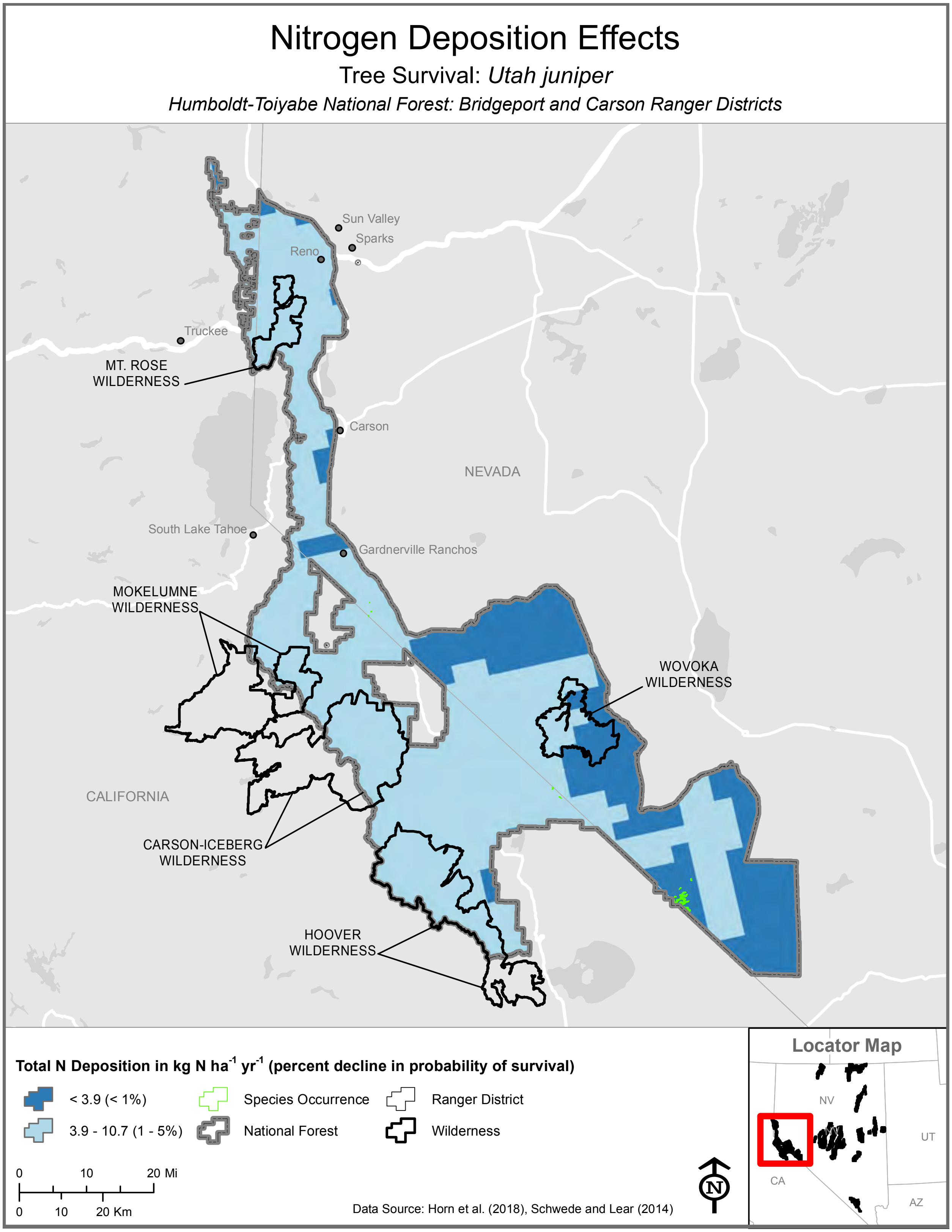


Figure 5-93.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

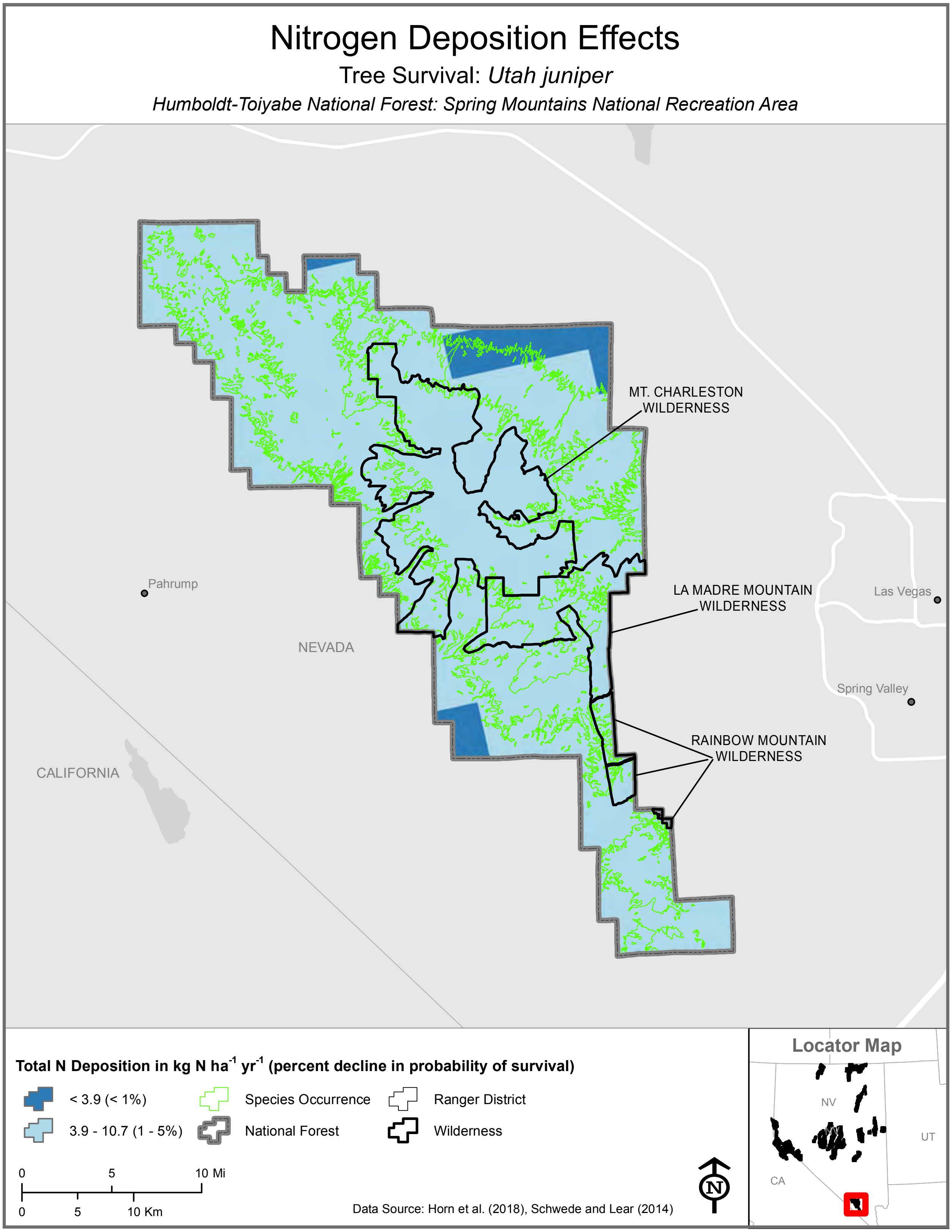


Figure 5-94.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

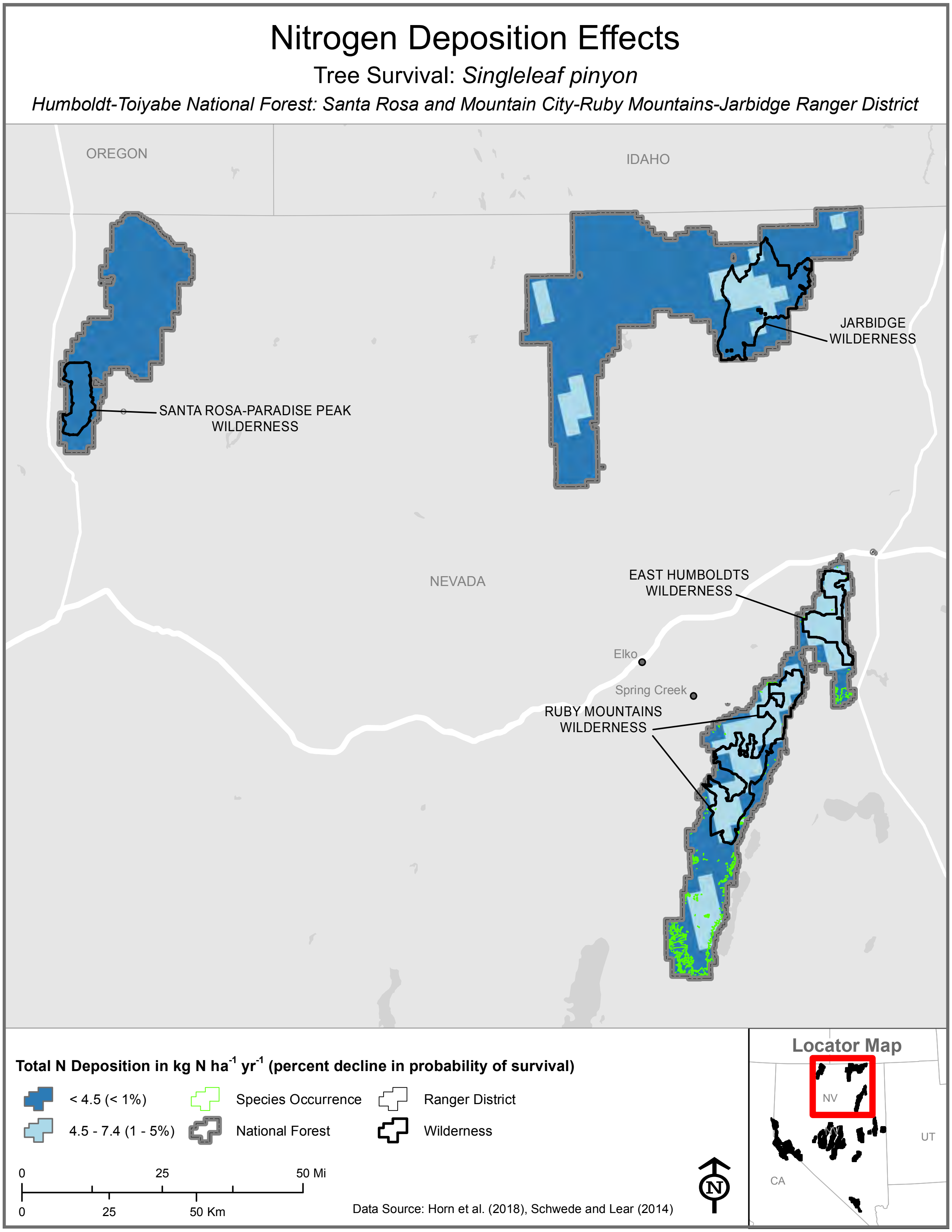


Figure 5-95.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

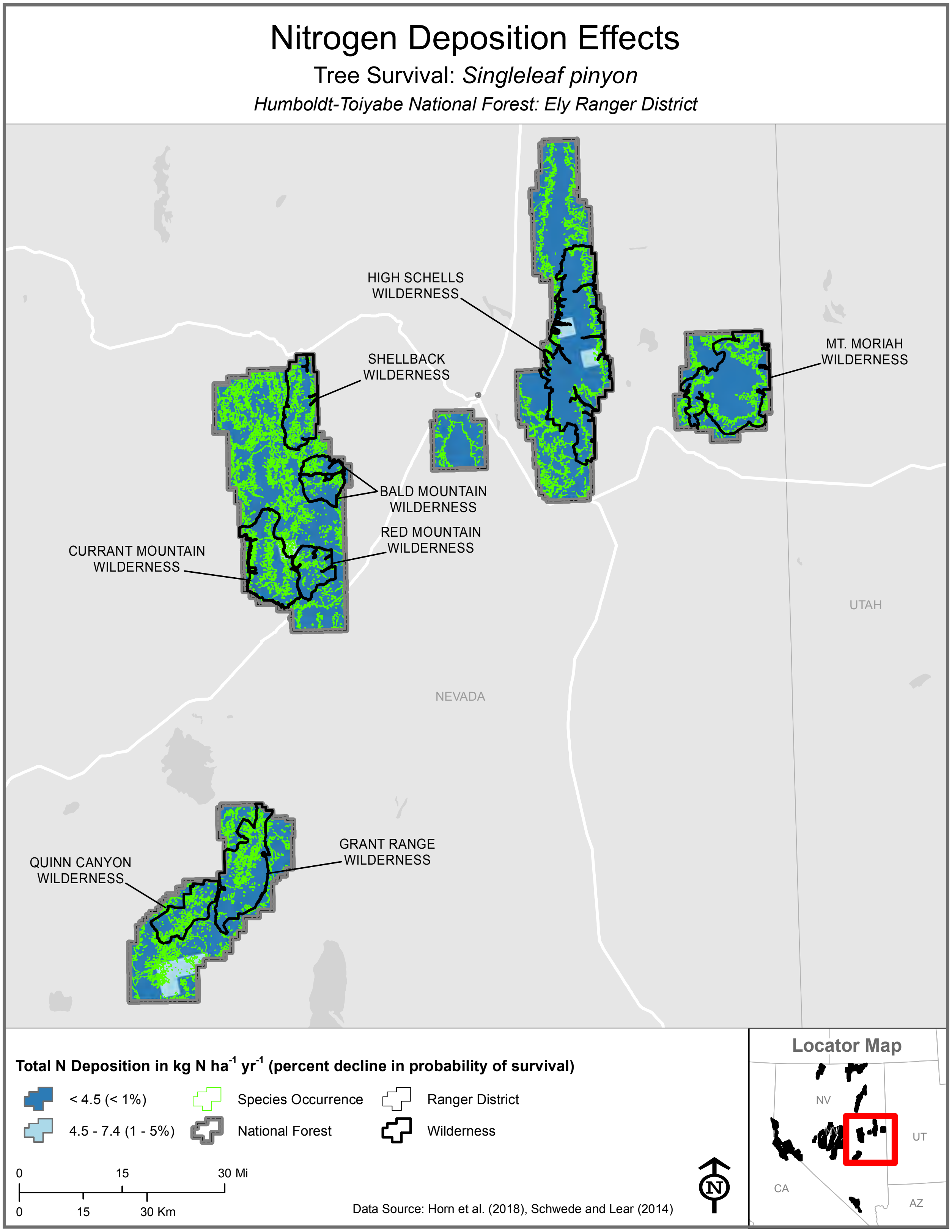


Figure 5-96.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

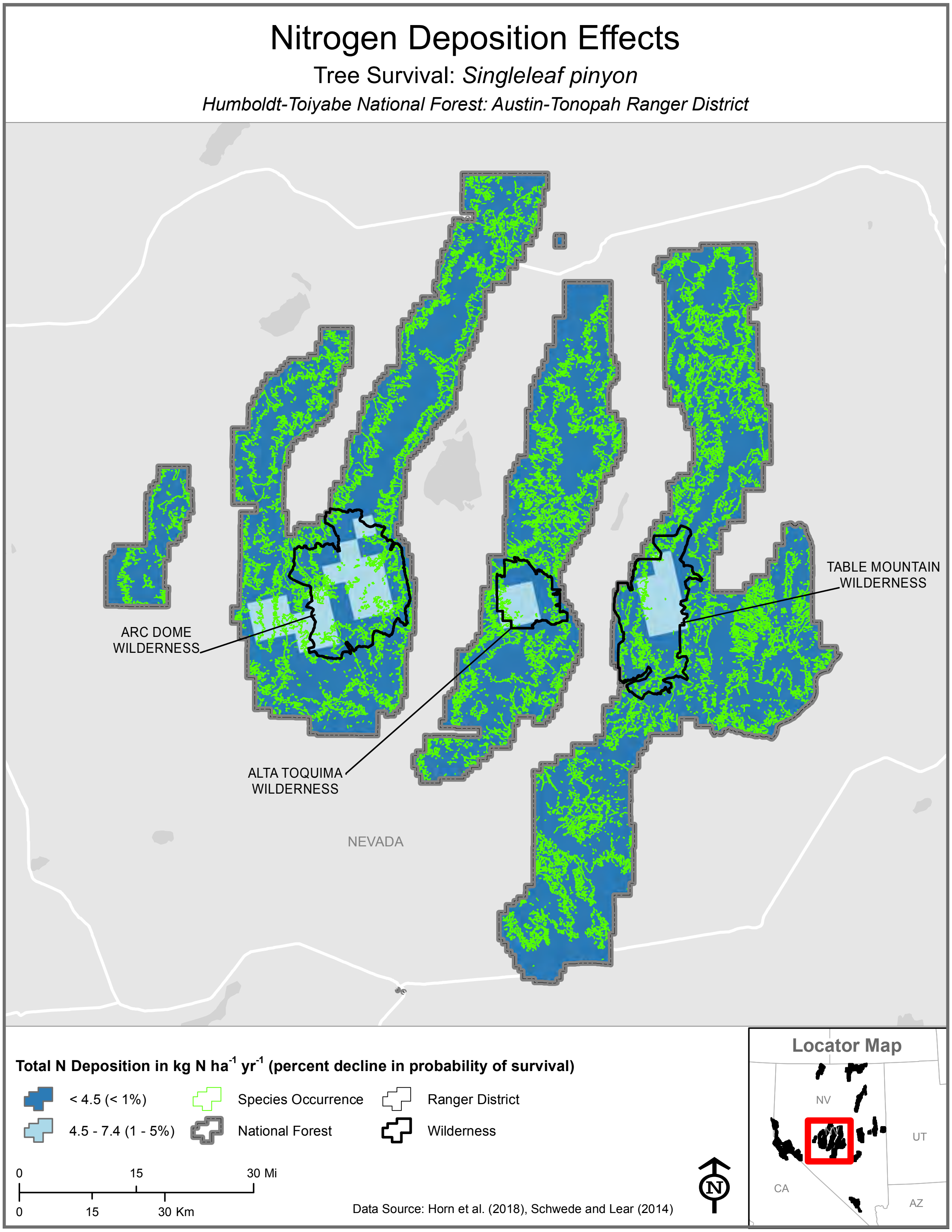


Figure 5-97.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

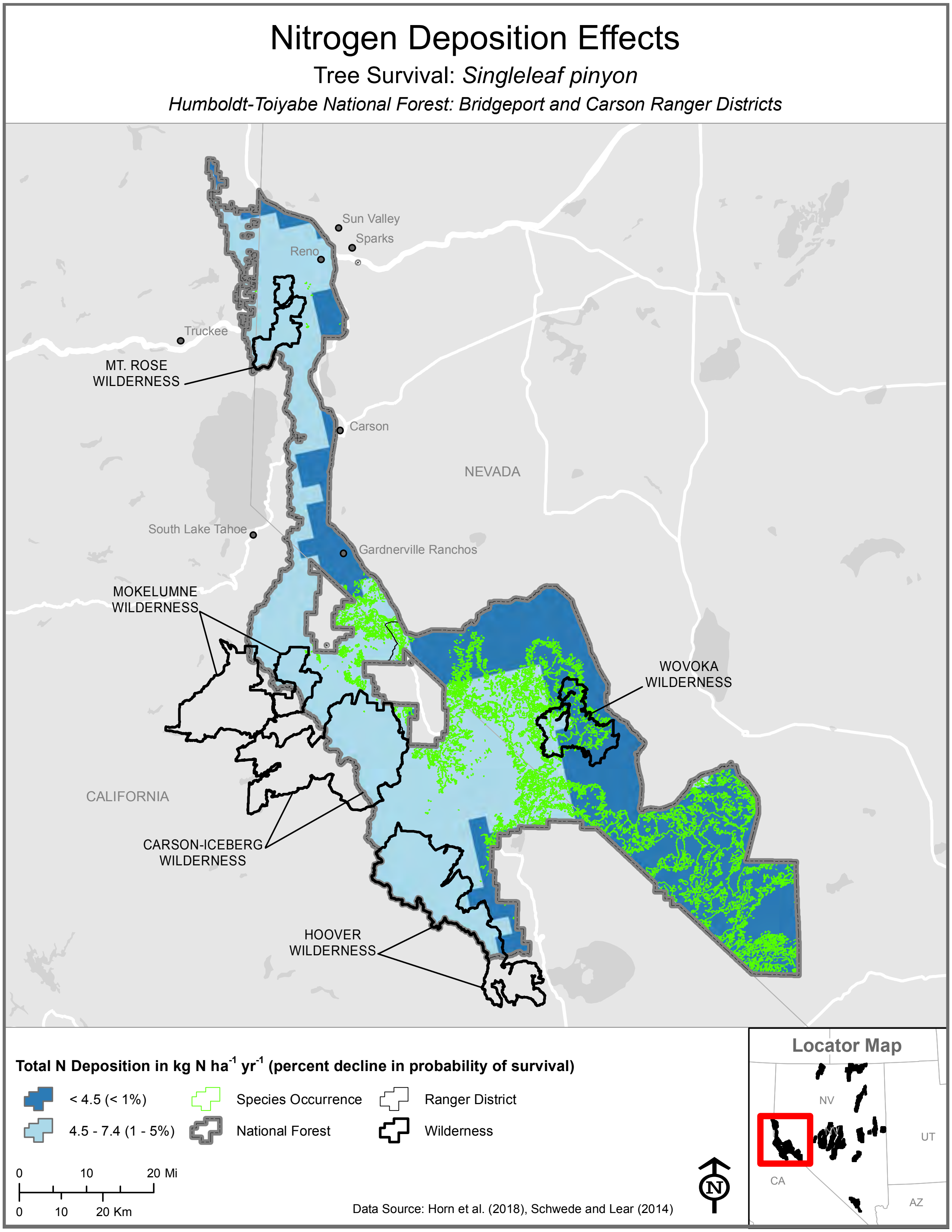


Figure 5-98.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

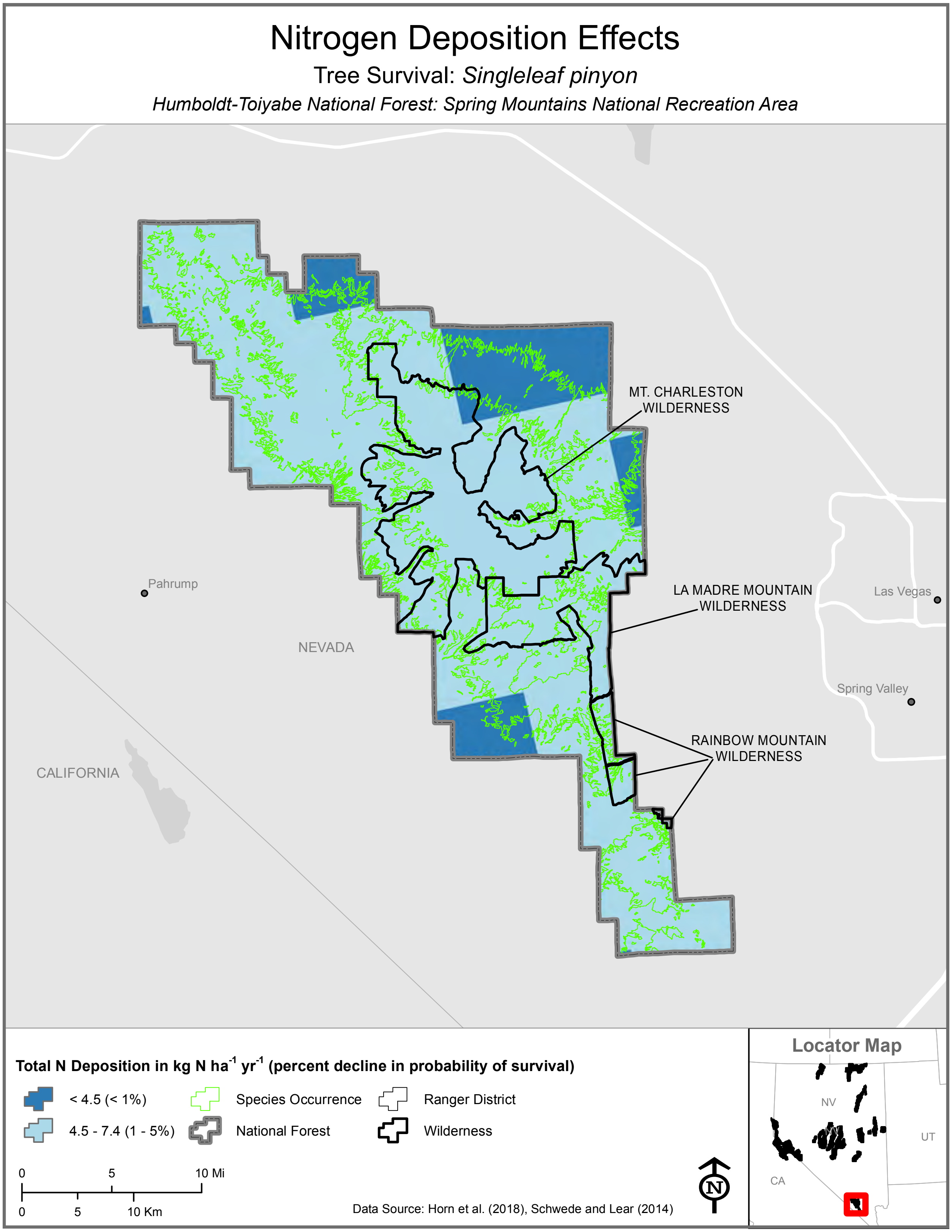


Figure 5-99.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

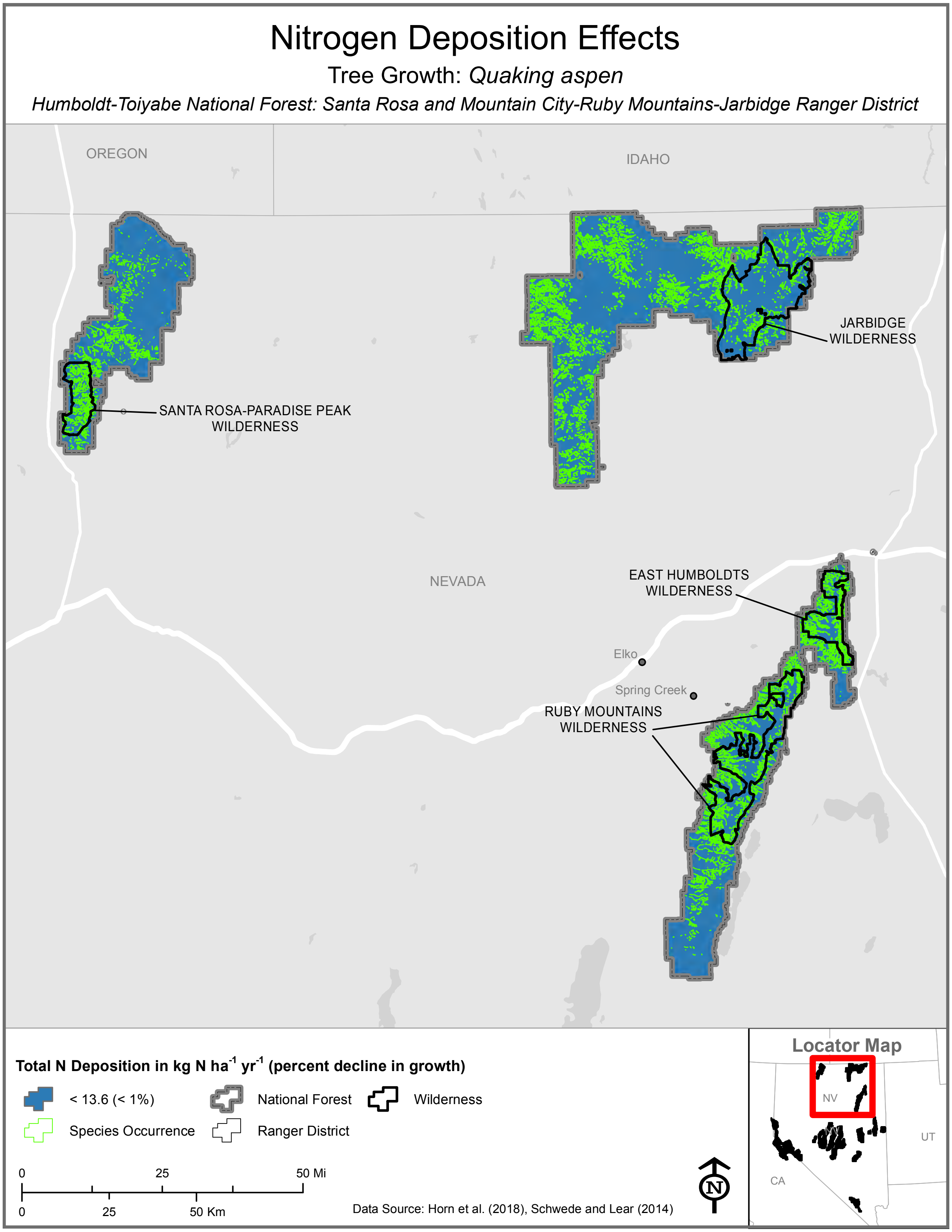


Figure 5-100.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

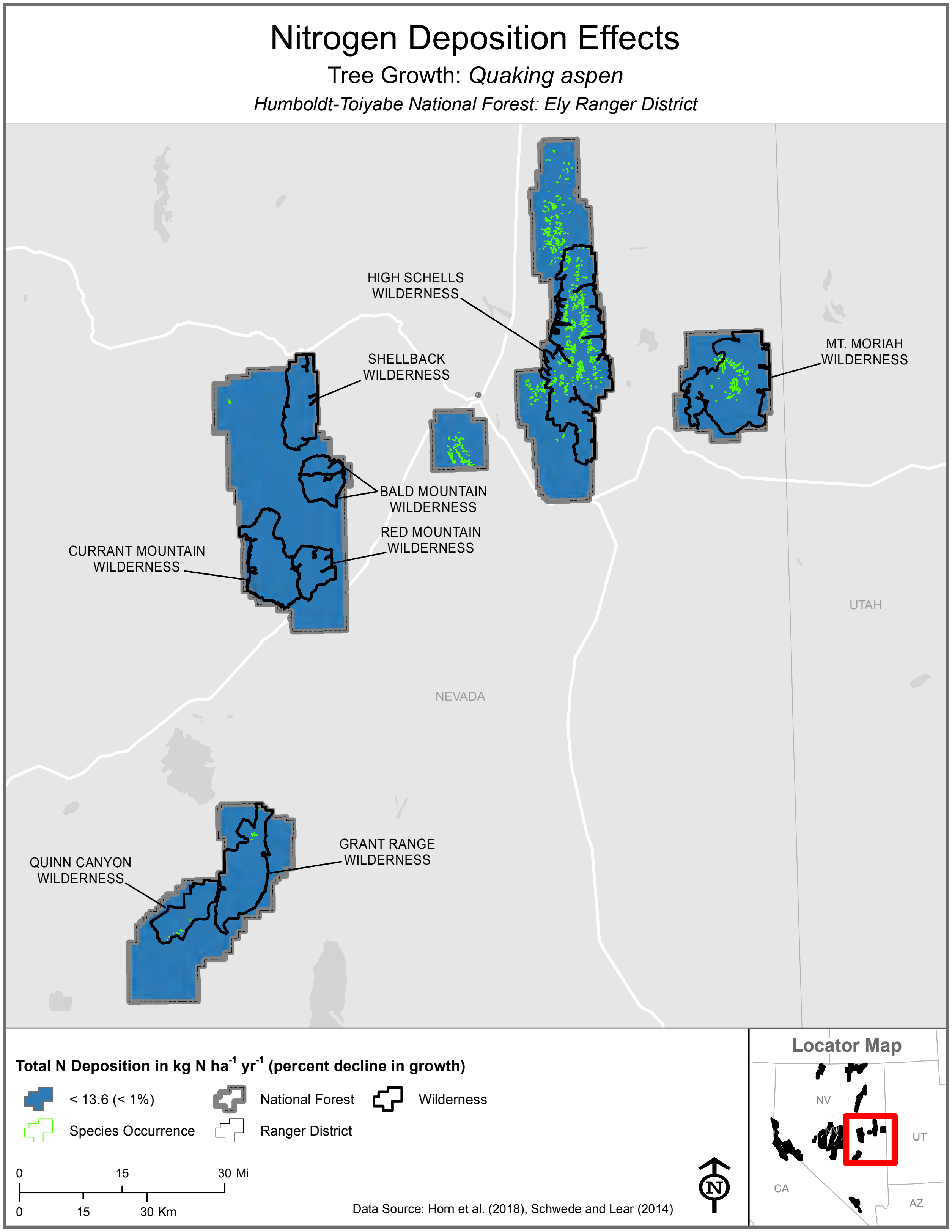


Figure 5-101.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

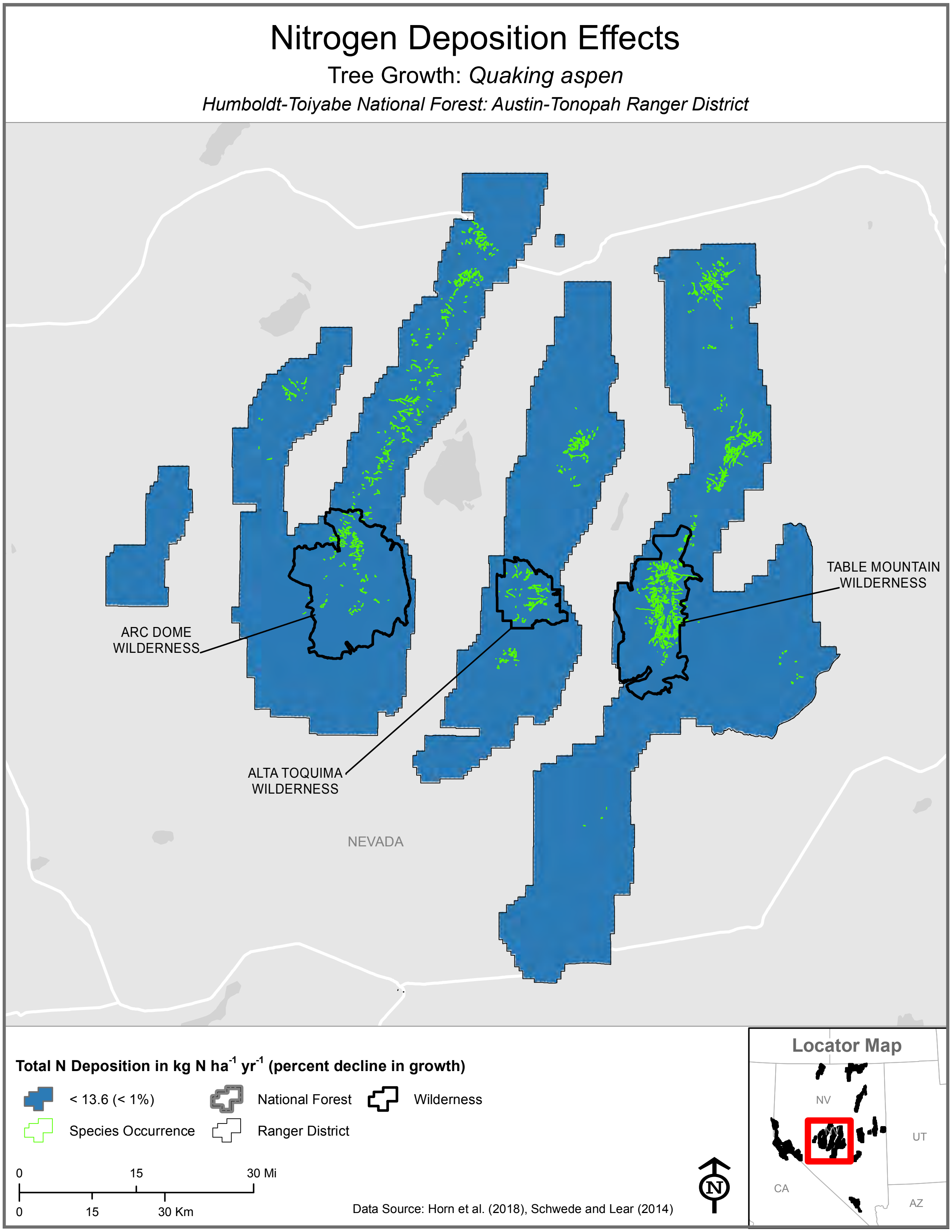


Figure 5-102.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

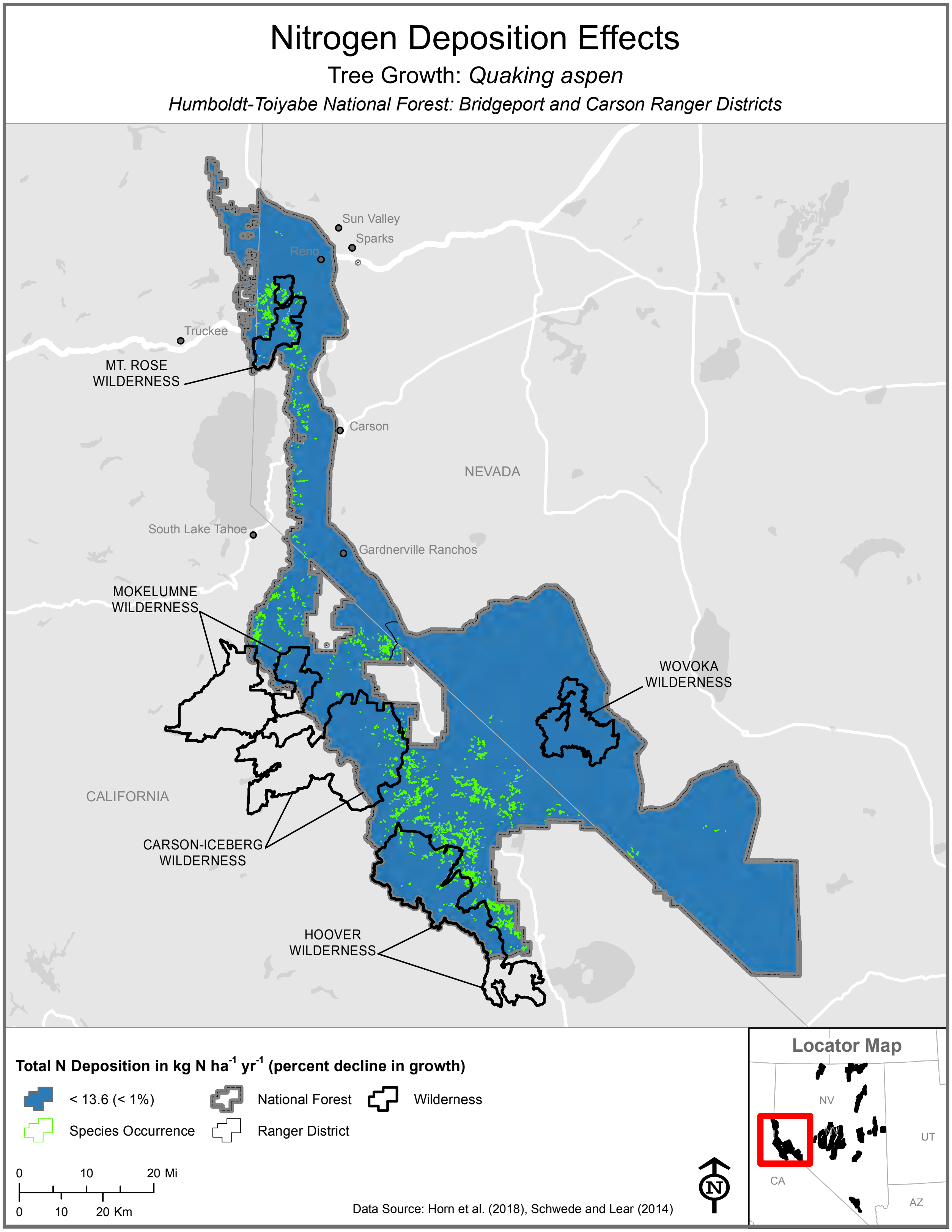


Figure 5-103.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

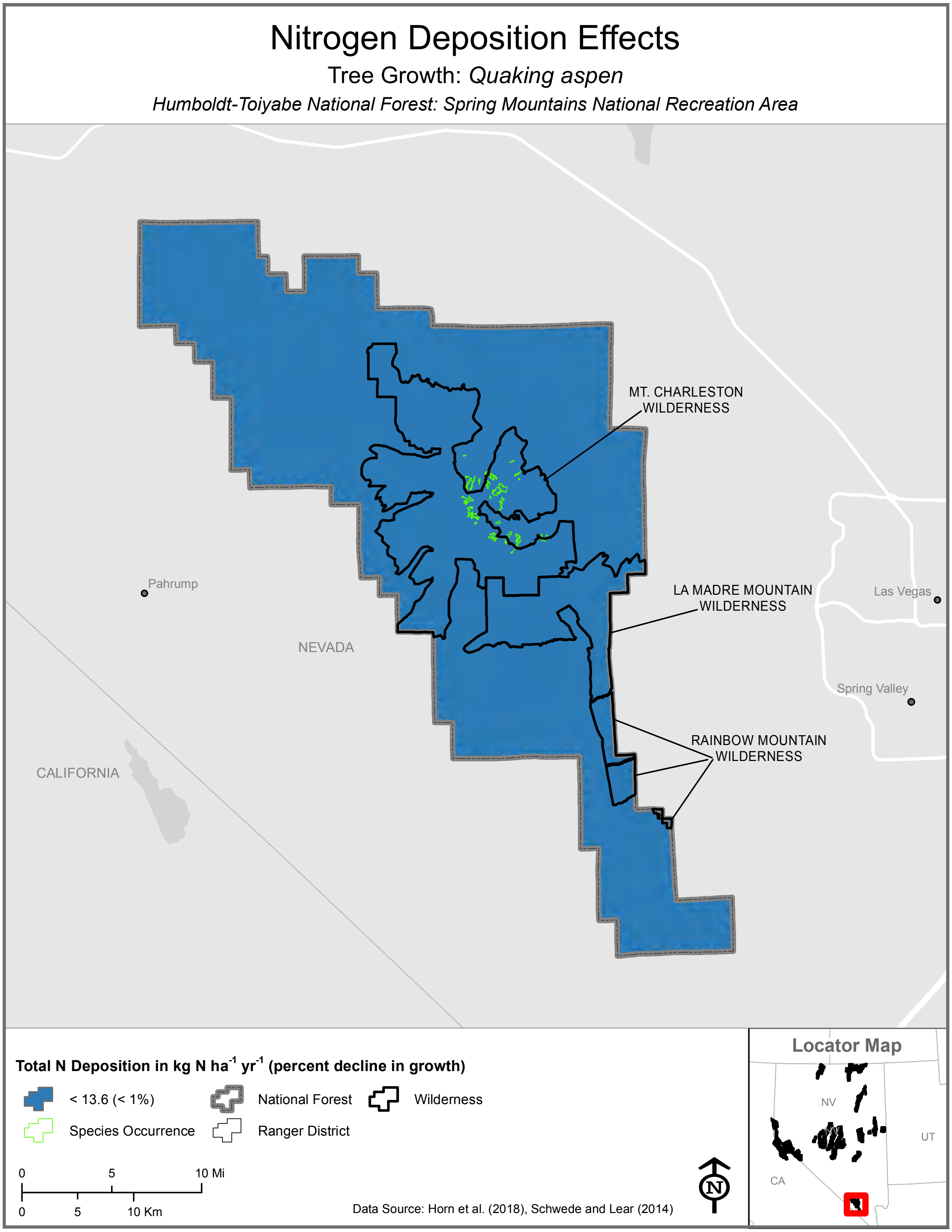


Figure 5-104.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

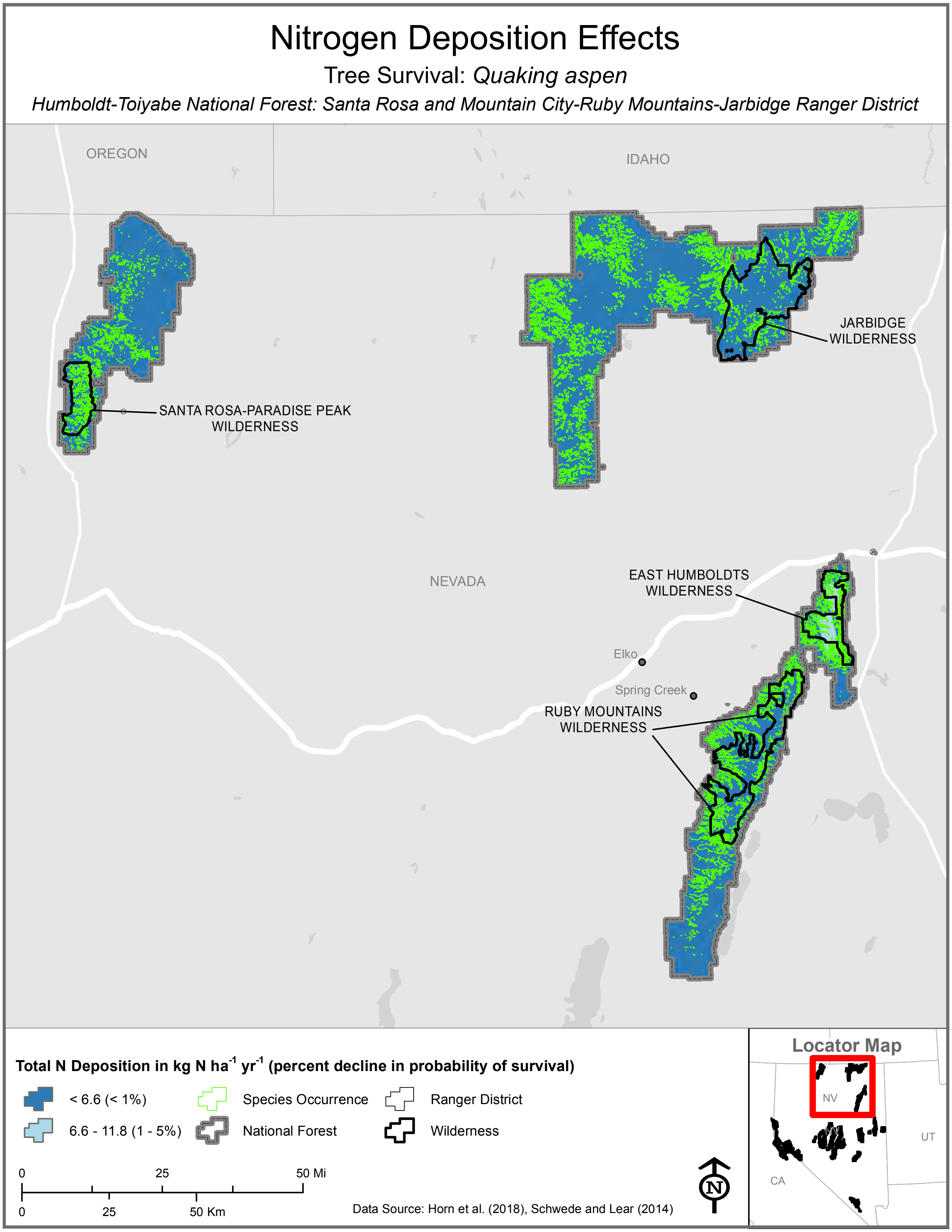


Figure 5-105.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

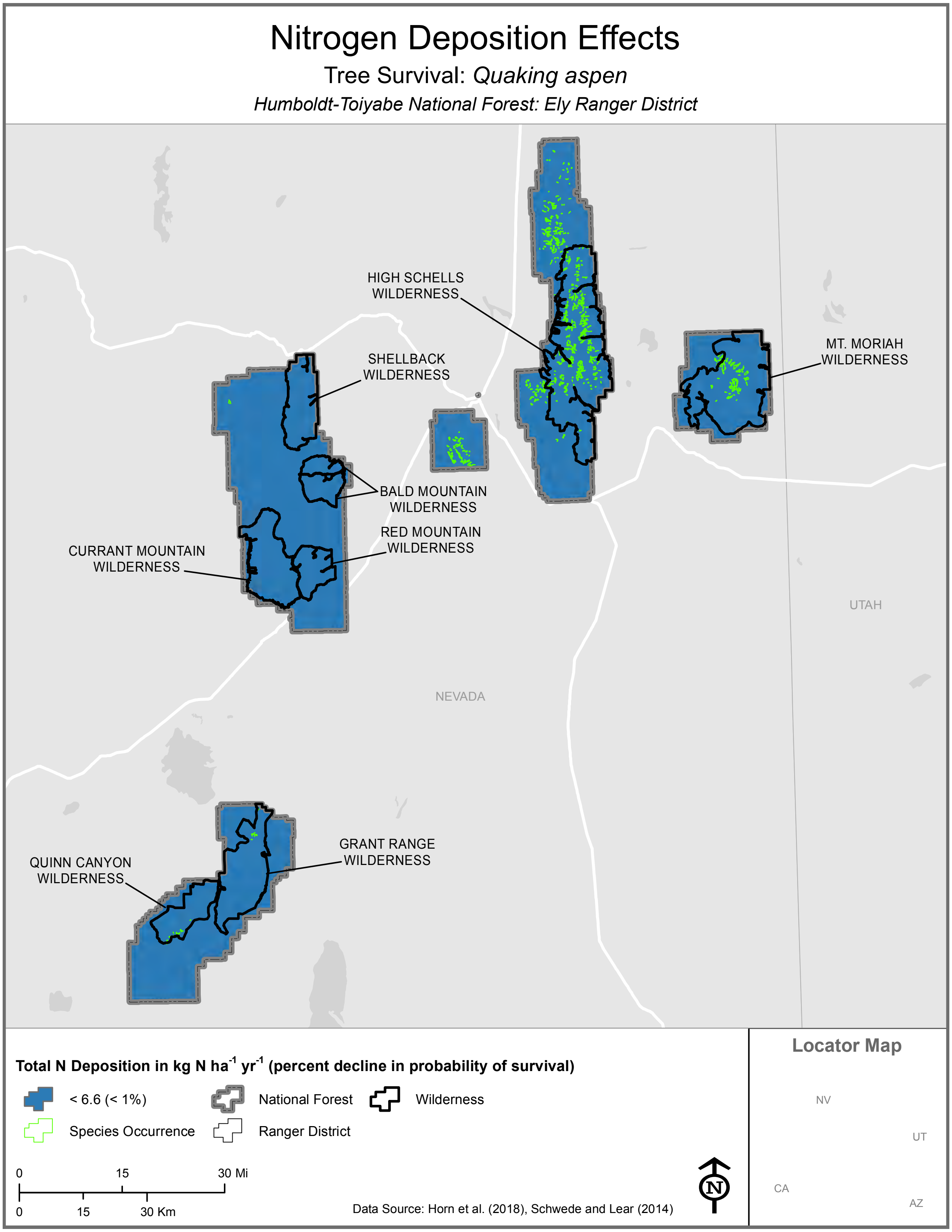


Figure 5-106.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

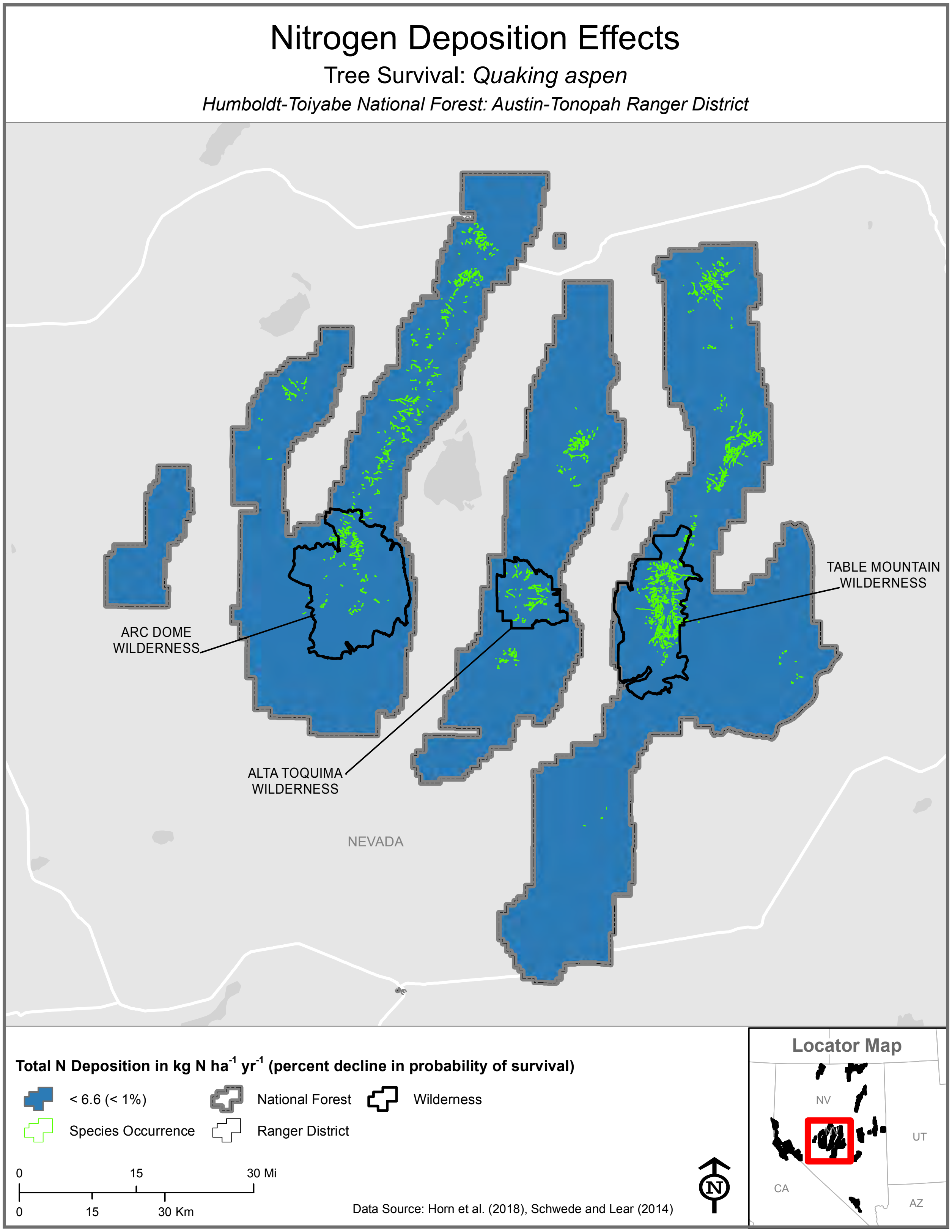


Figure 5-107.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

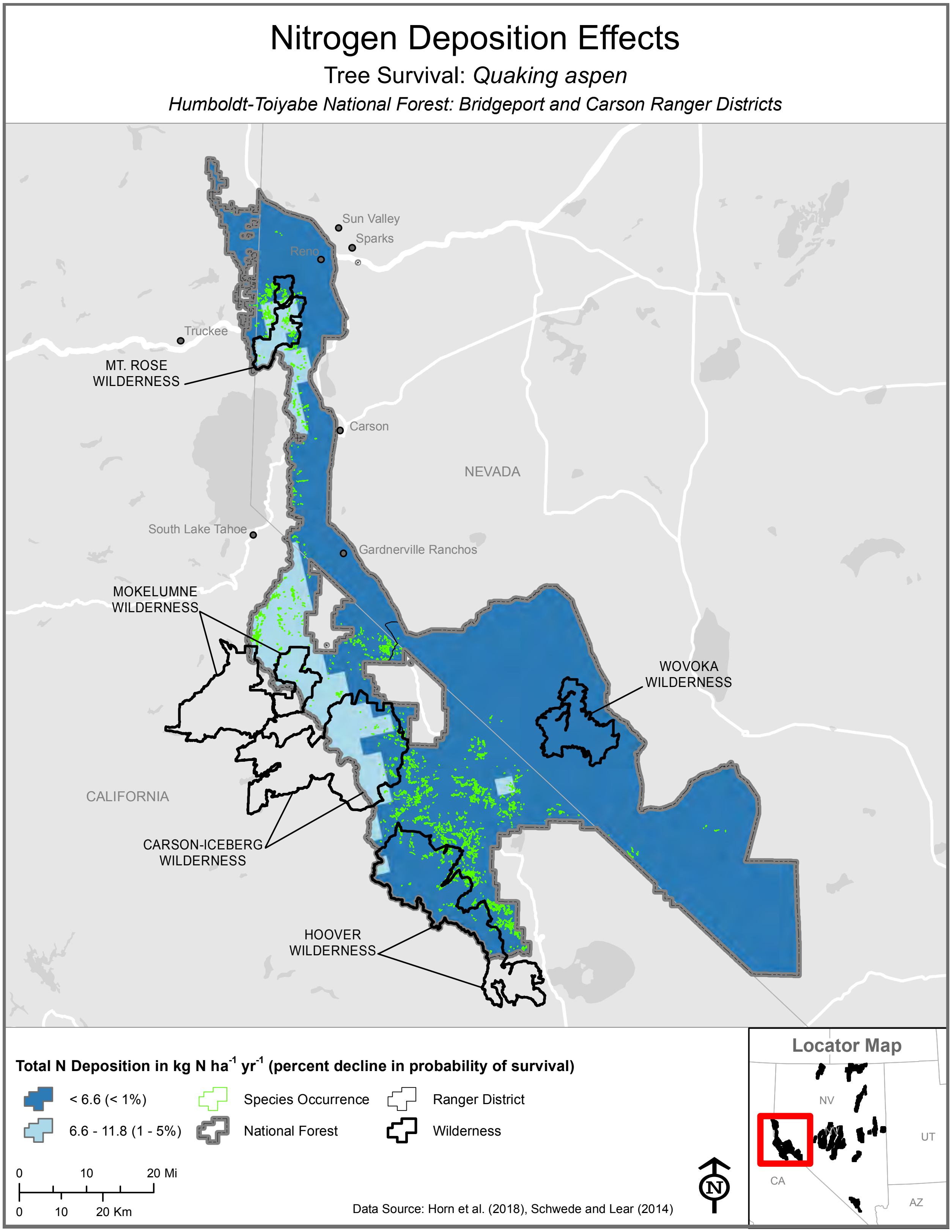


Figure 5-108.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

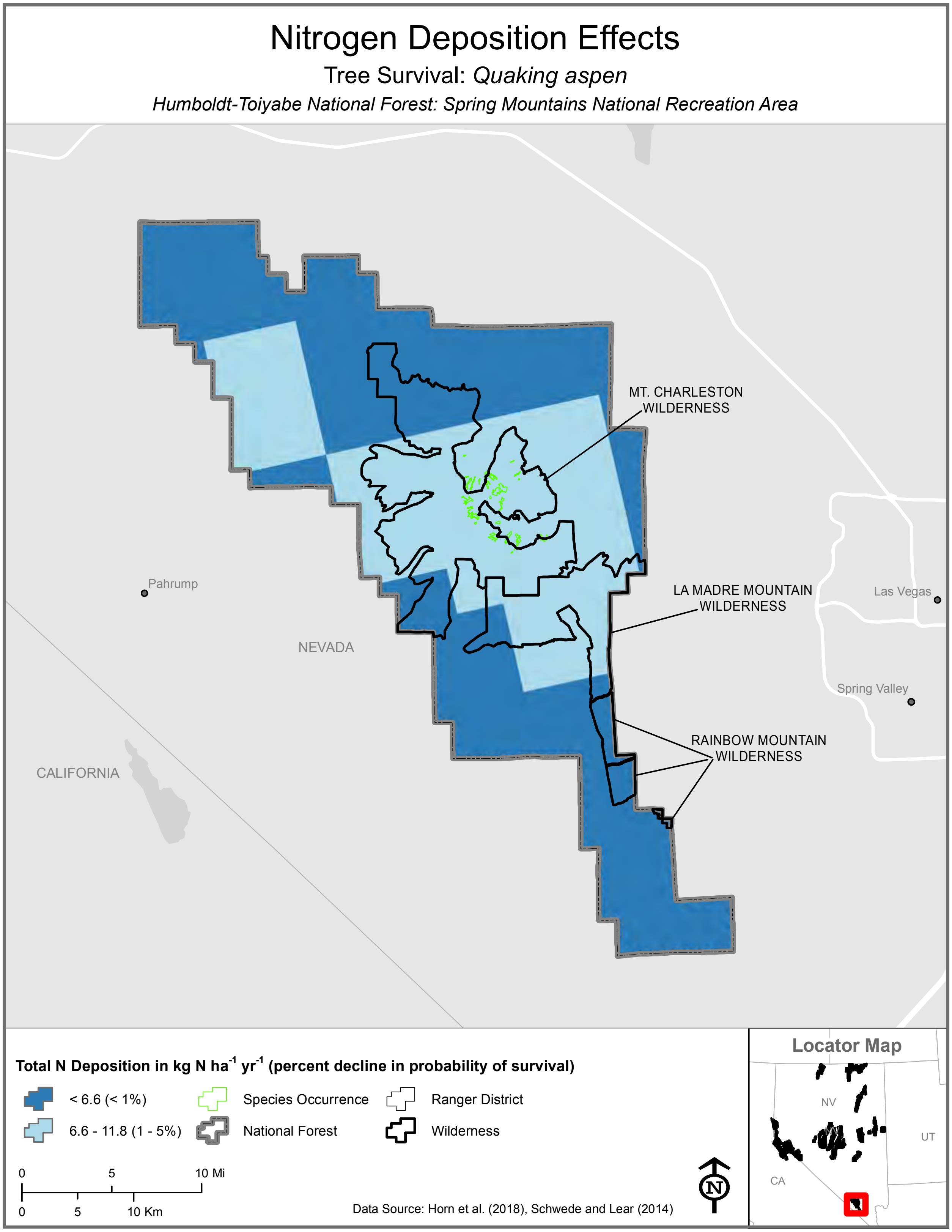


Figure 5-109.— Total (wet + dry) N deposition and percent of decline in survival over 10 years for quaking aspen within the Spring Mountains National Recreation Area on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

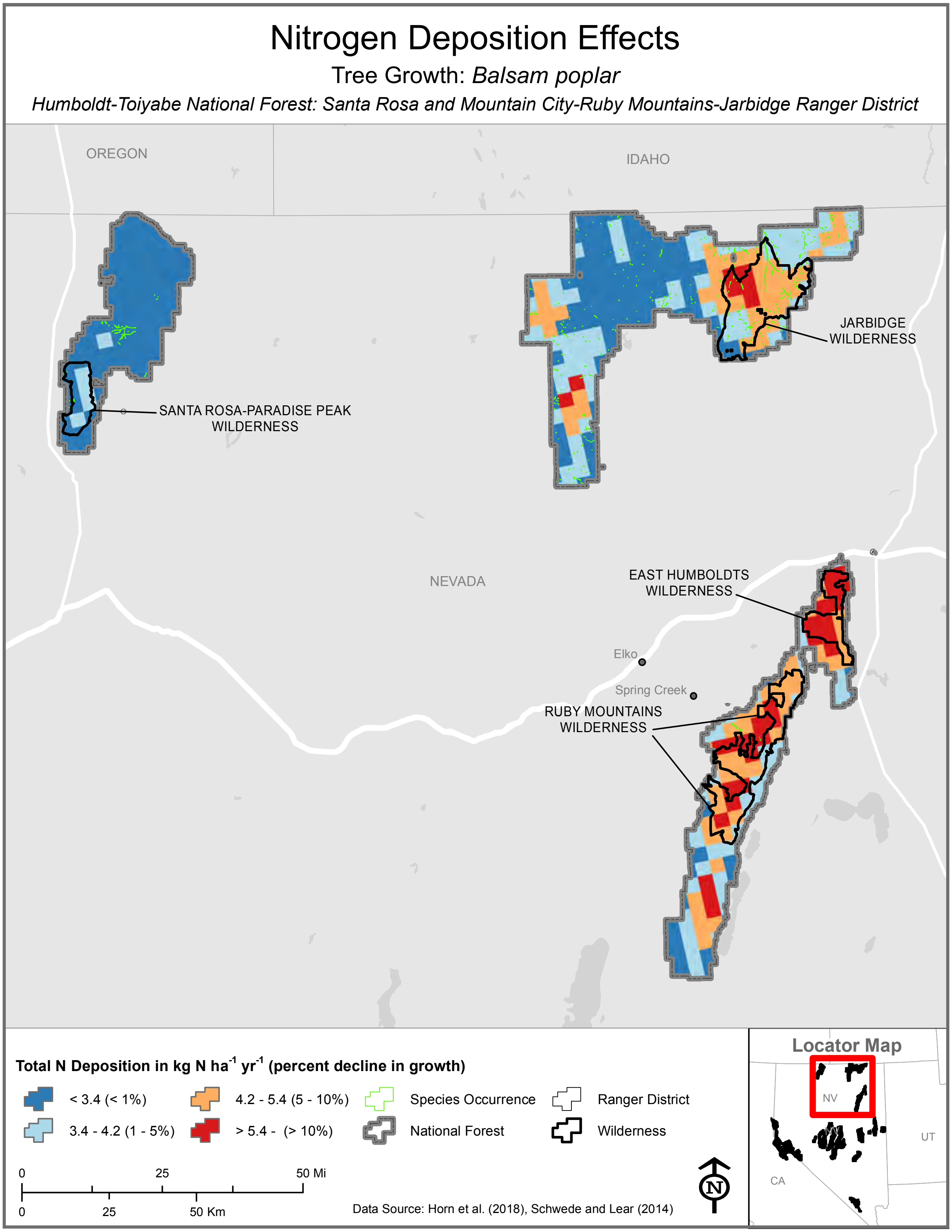


Figure 5-110.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

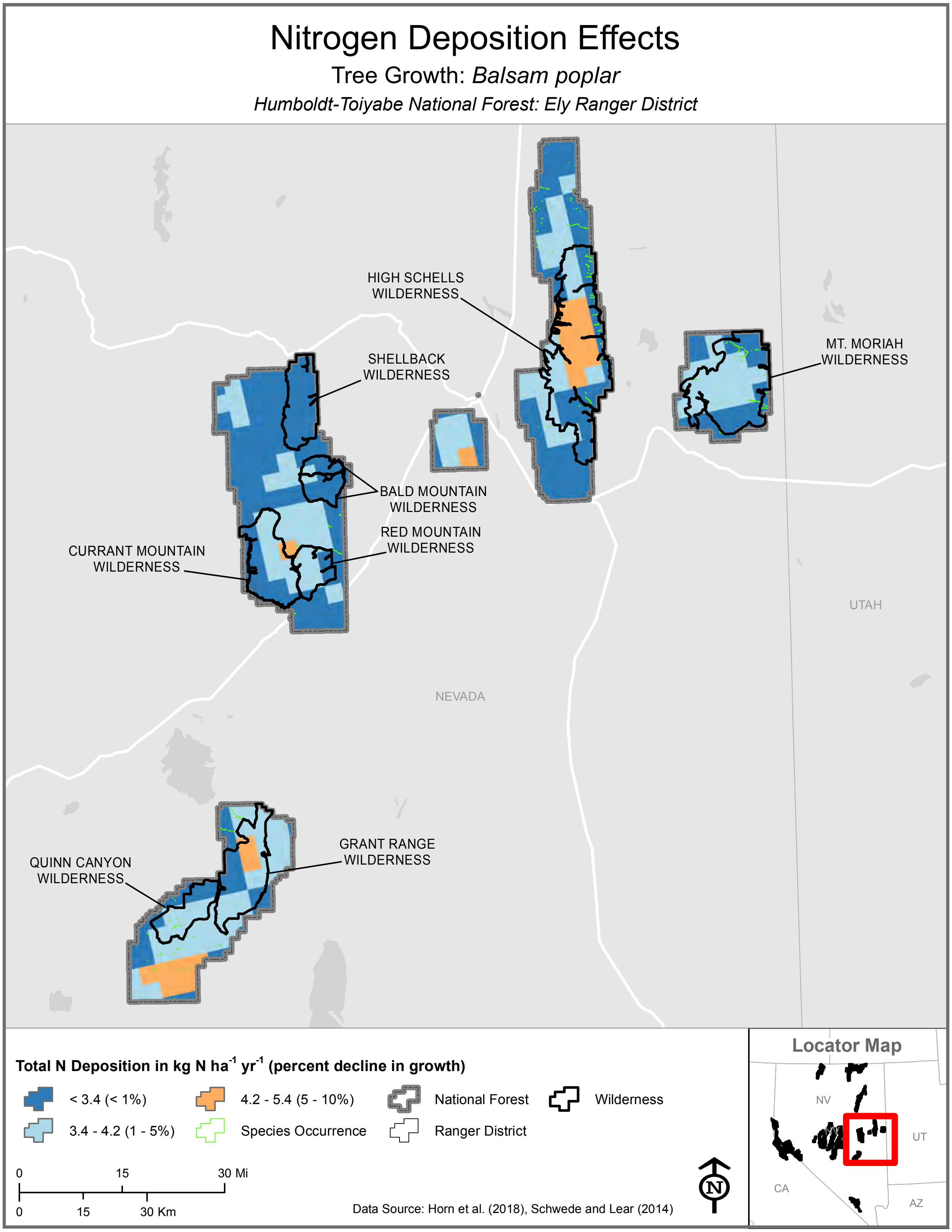


Figure 5-111.—Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

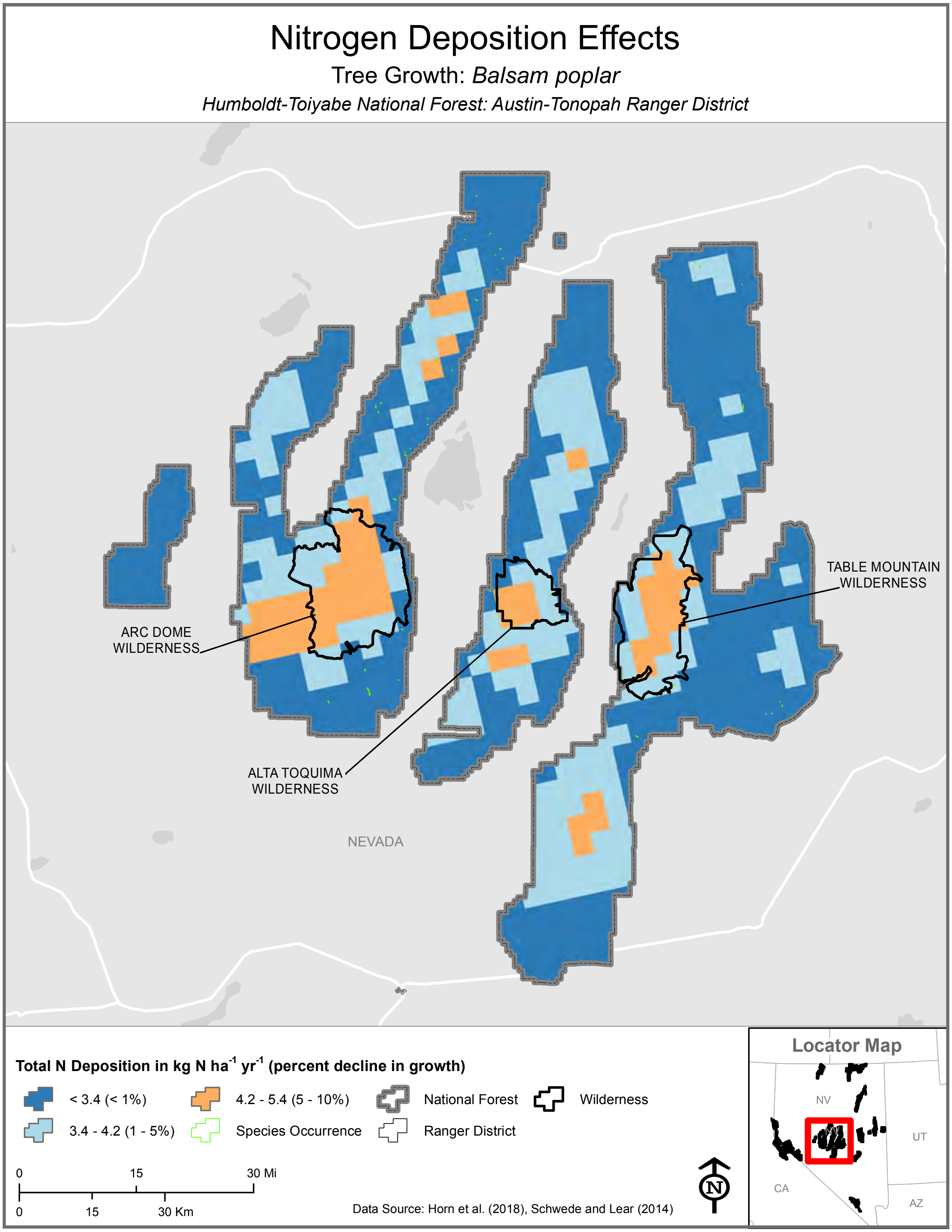


Figure 5-112.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

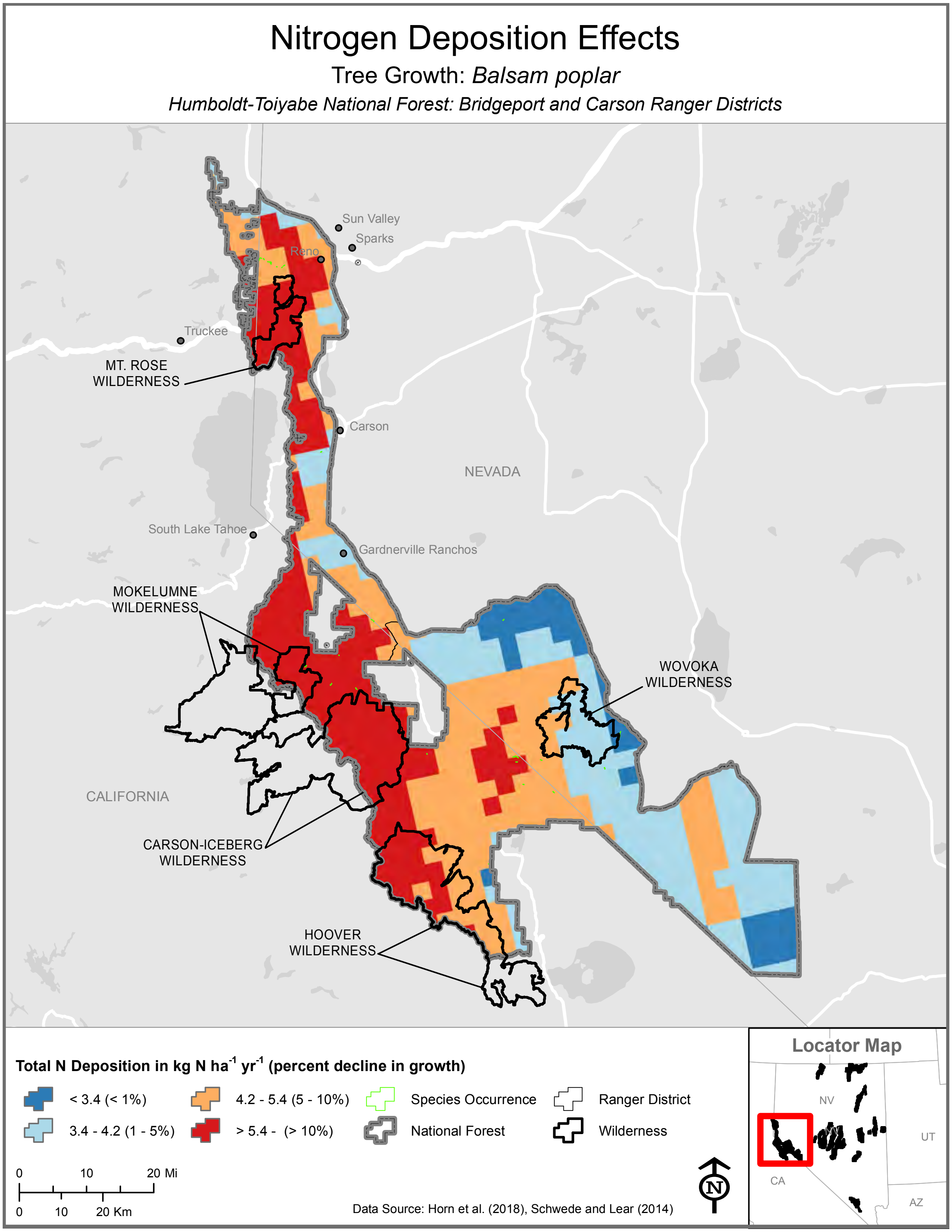


Figure 5-113.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest.

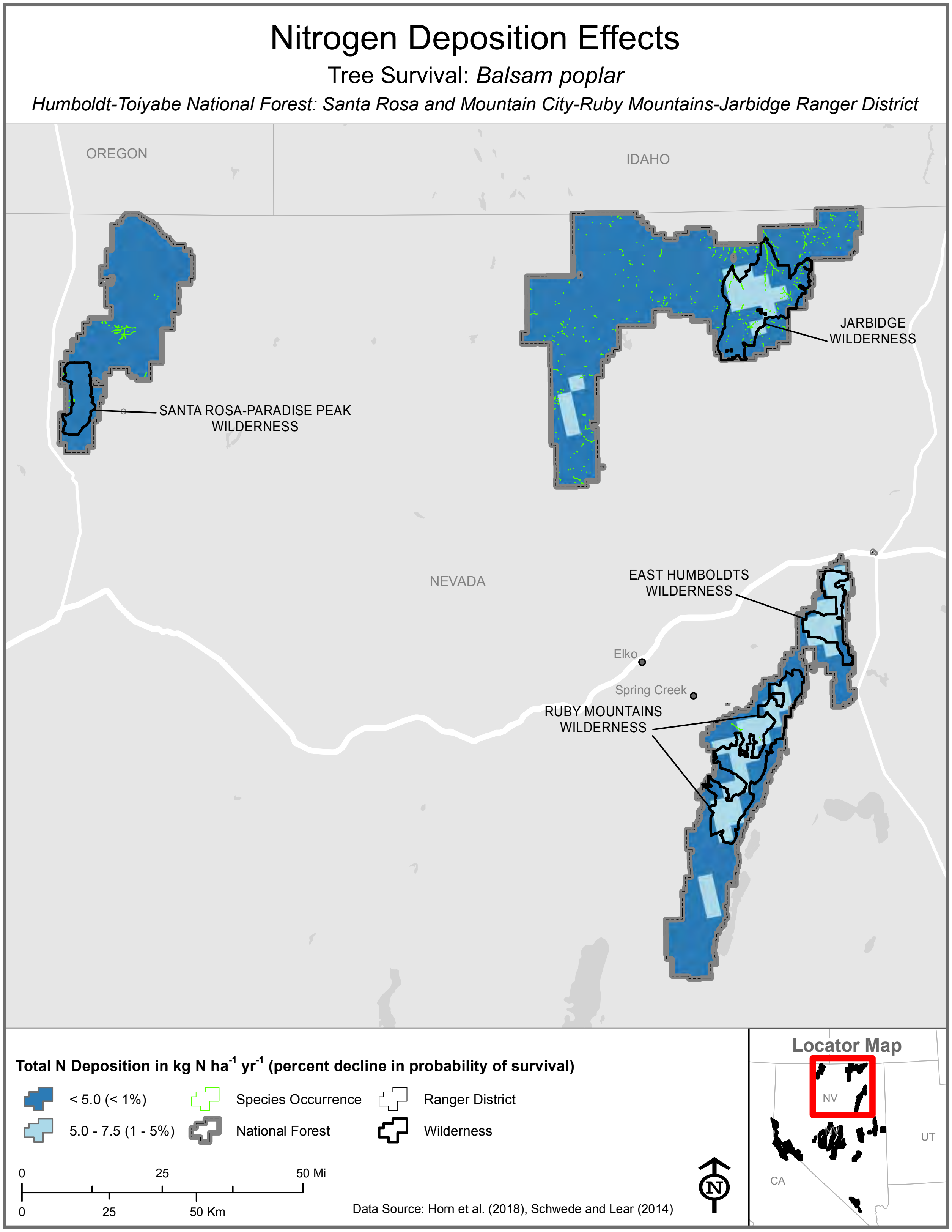


Figure 5-114.— Total (wet + dry) N deposition and percent of decline in probability of survival for balsam poplar over 10 years within the Santa Rosa and Mountain City-Ruby Mountains-Jarbidge Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

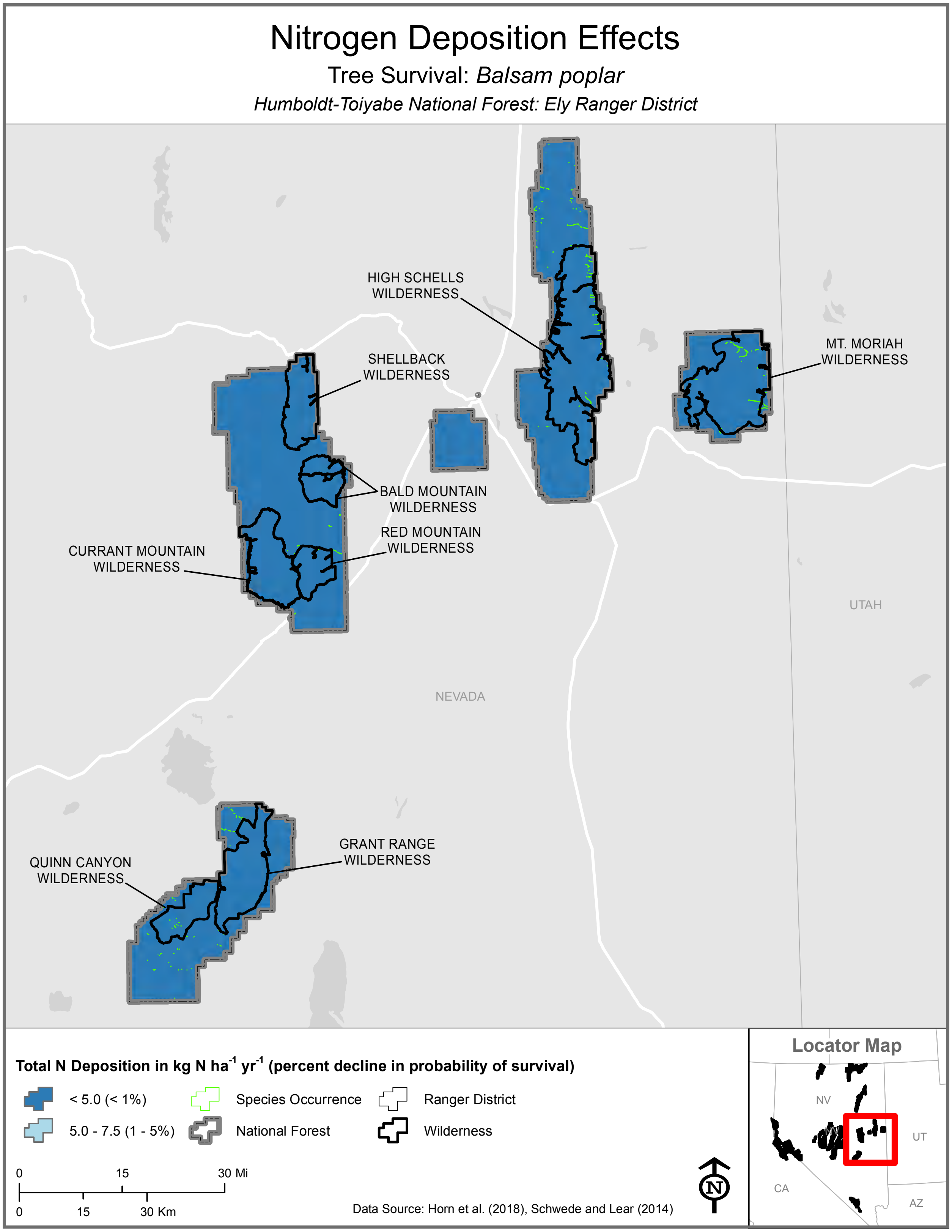


Figure 5-115.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Ely Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

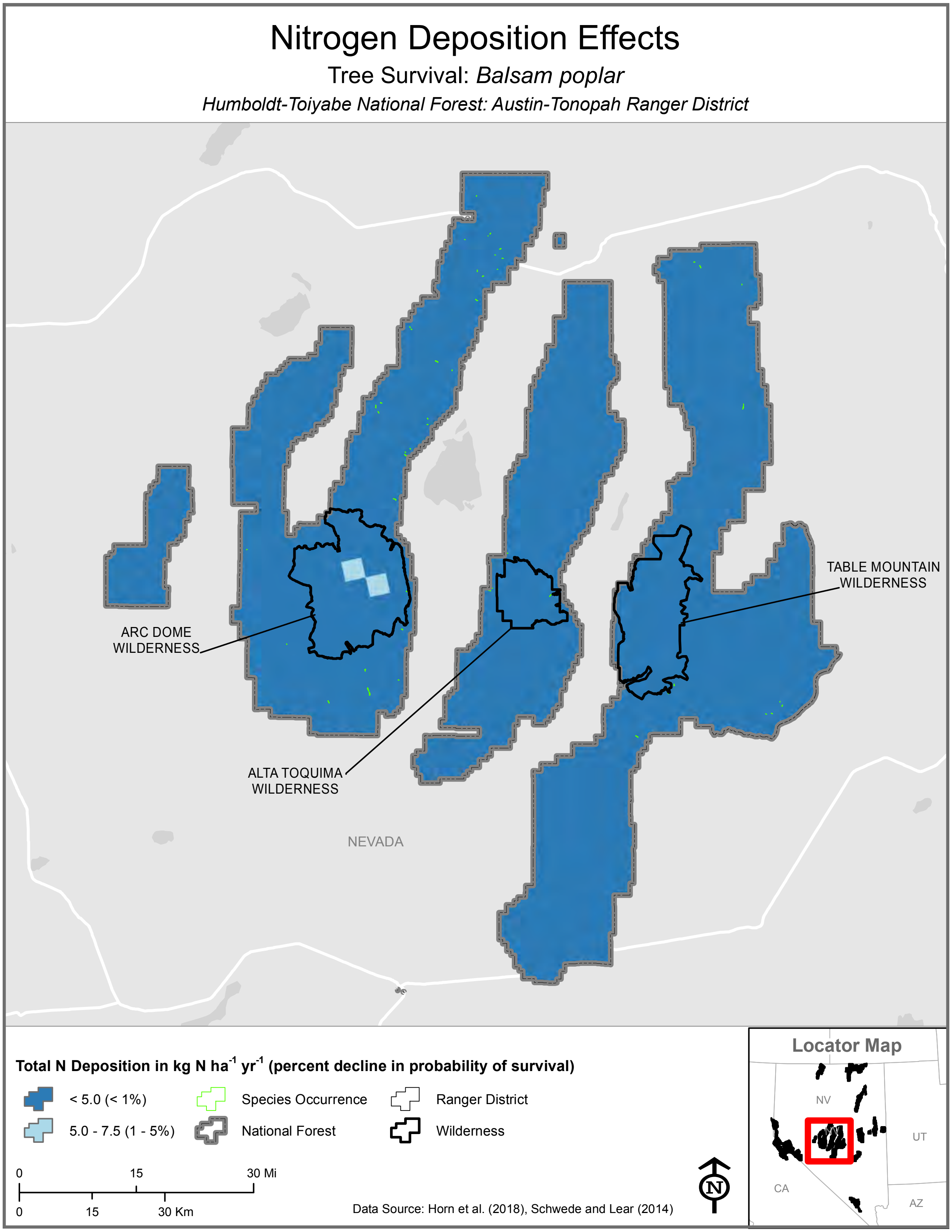


Figure 5-116.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Austin-Tonopah Ranger District on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

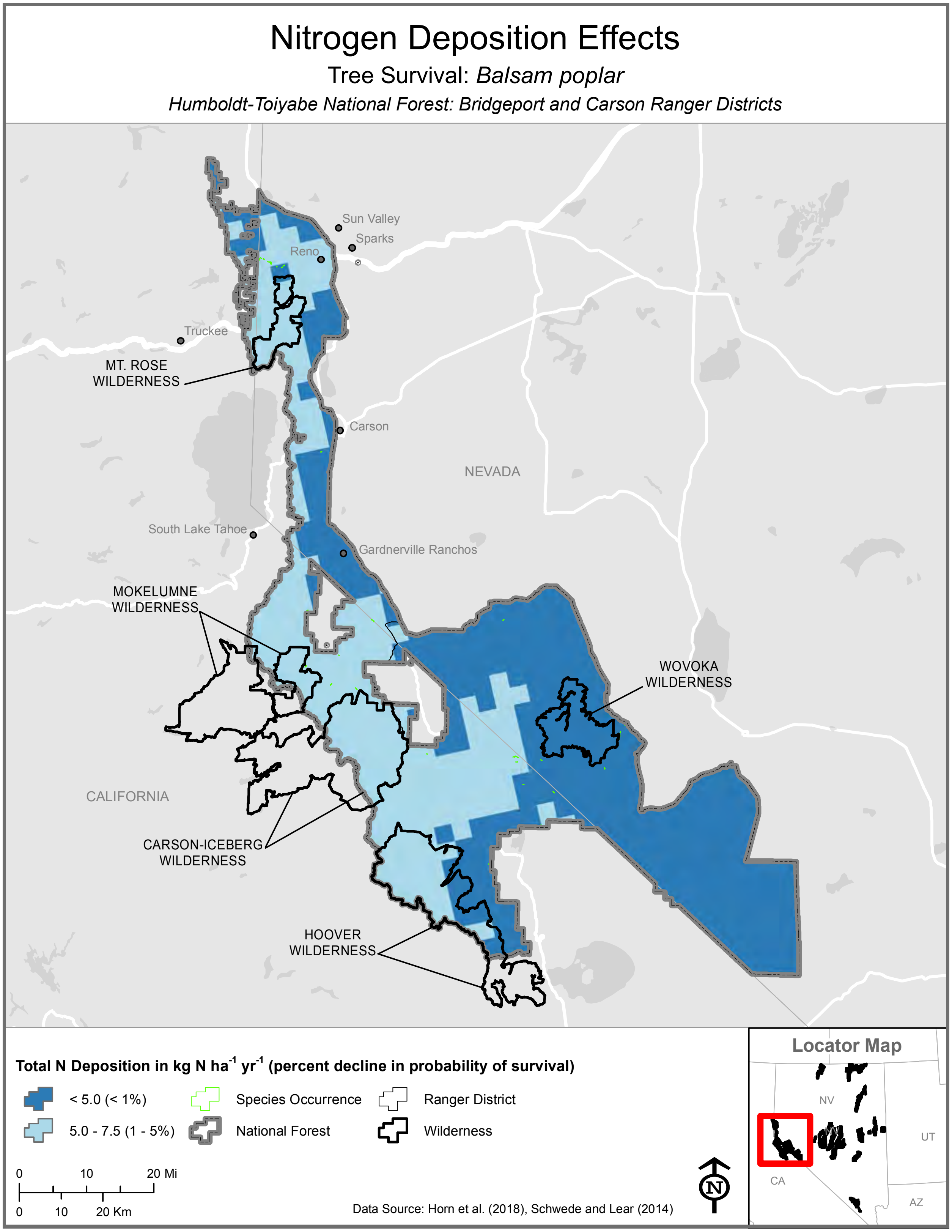


Figure 5-117.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

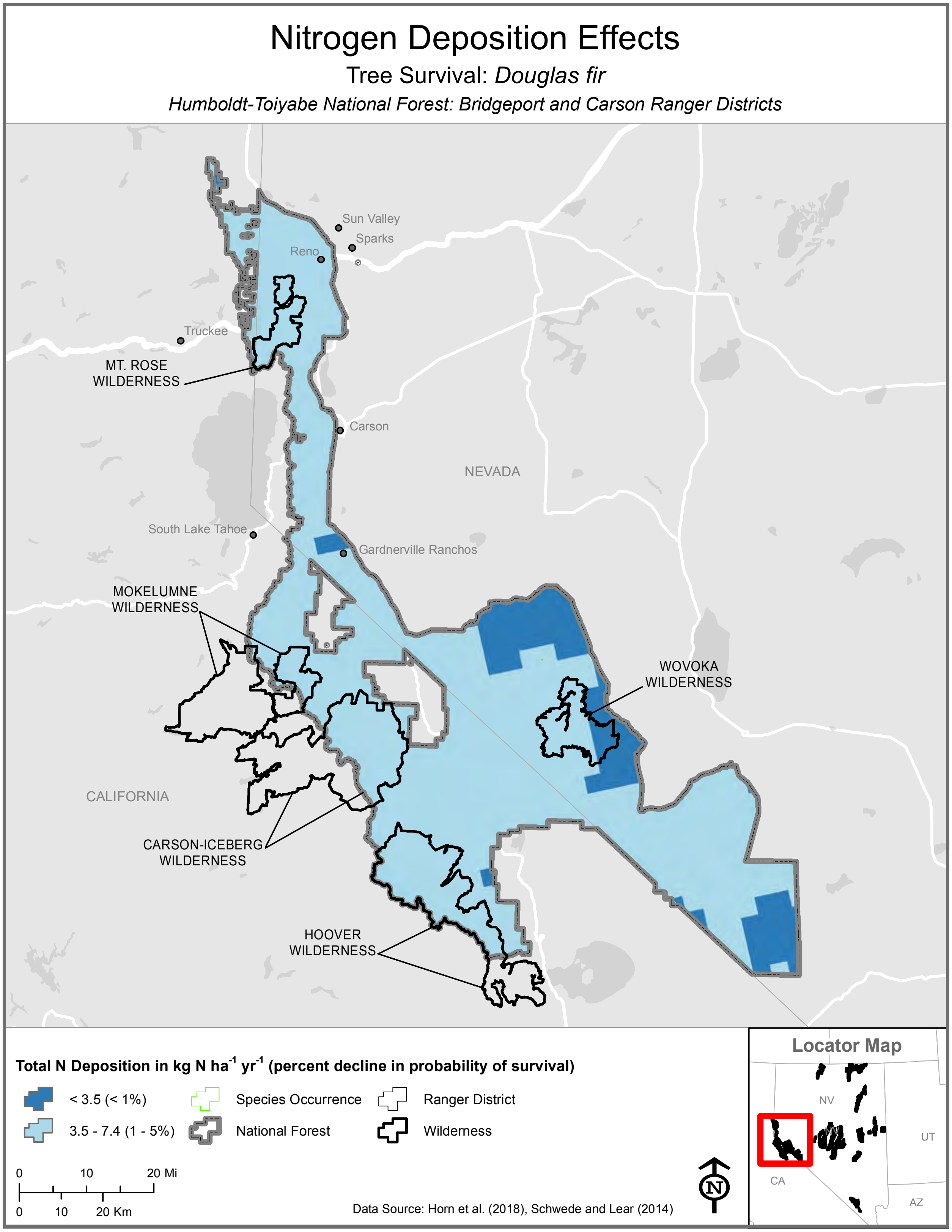


Figure 5-118.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Bridgeport and Carson Ranger Districts on the Humboldt-Toiyabe National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Cleveland Reservoir at the top of Huntington Canyon on the Manti-La Sal National Forest. USDA Forest Service photo.

5.3.8 Manti-La Sal National Forest

5.3.8.1 Surface Water Acidification

Low critical loads (CLs and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 μeq L^{-1} were calculated for three waterbodies with available water chemistry data within the Manti-La Sal National Forest. All three waterbodies were found to have low risk for effects associated with surface water acidification due to high CLs (>8 kg N ha^{-1} yr^{-1}) and N deposition levels that did not exceed the CLs (**Table 5-1** and **5-2**, **Figure 5-119** and **5-120**). These locations are not likely to experience biological effects associated with decreases in ANC below 50 μeq L^{-1}. There may be additional acid-sensitive water bodies on the Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

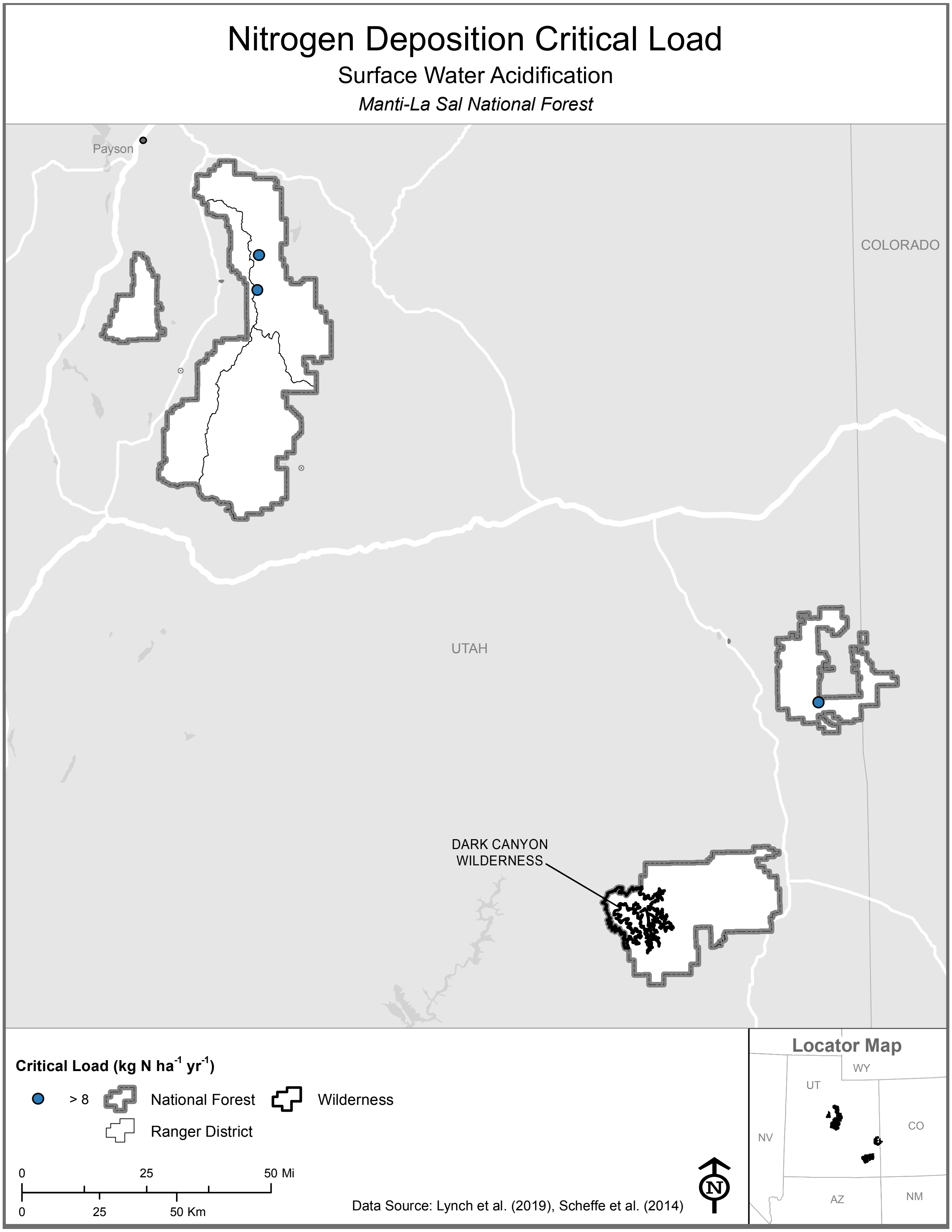


Figure 5-119.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Manti-La Sal National Forest.

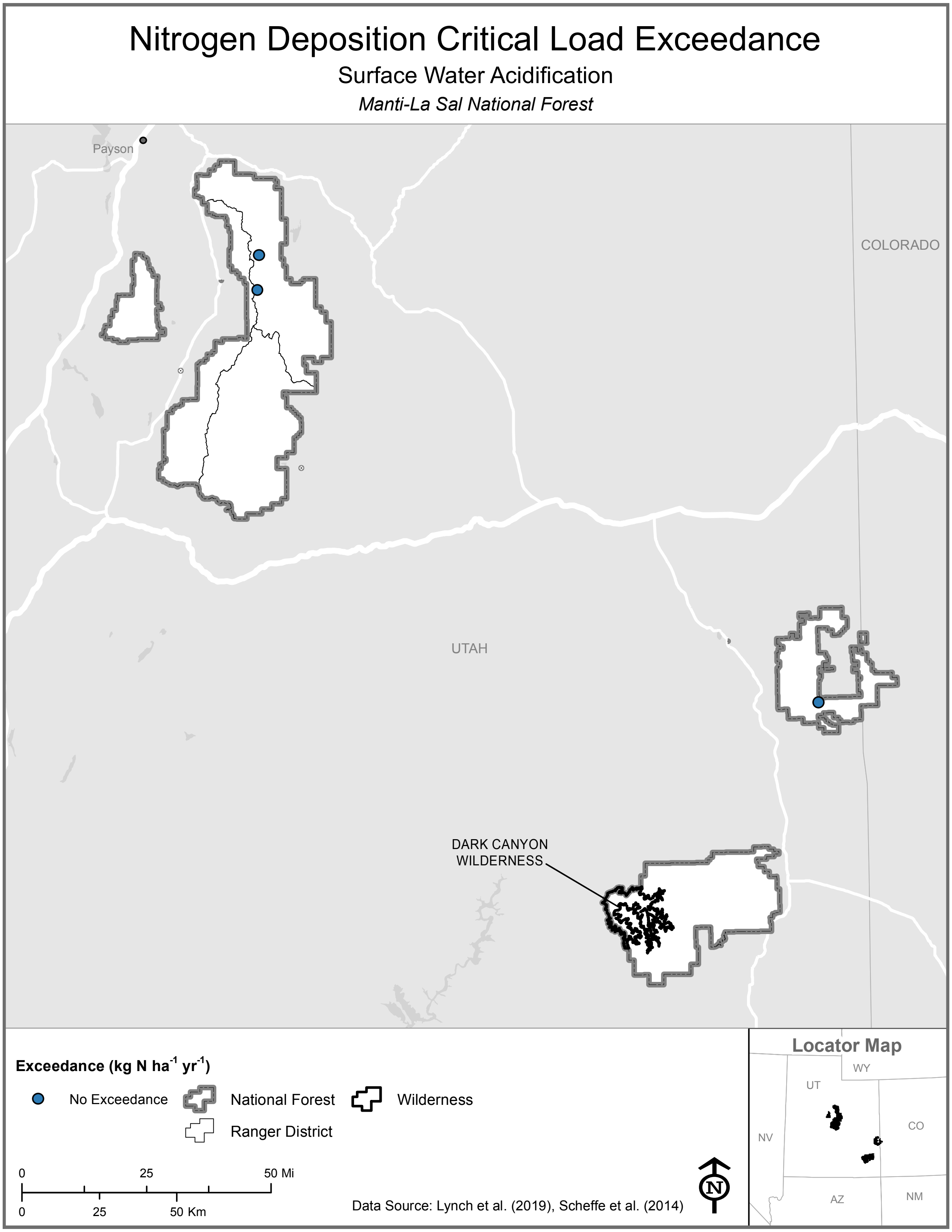


Figure 5-120.— The Manti-La Sal National Forest has no exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites.

Fall Colors mirrored on Electric Lake, Manti-La Sal National Forest. USDA Forest Service photo by Corinne Dalton.

5.3.8.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Manti-La Sal National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 2,394 km^2 (43 percent) of the Forest, including most of Dark Canyon Wilderness (**Table 5-3**, **Figure 5-121**). Areas of exceedance followed a similar pattern as the CLs and included 3,438 km^2 (61 percent) of the Forest (**Table 5-4**, **Figure 5-122**). The highest magnitudes of exceedance (>4 kg wet N ha^{-1} yr^{-1}) were mapped across 154 km^2 (3 percent) of the Forest. Exceedances between 2 and 4 kg wet N ha^{-1} yr^{-1} were mapped across 914 km^2 (16 percent) of the Forest, including portions of Dark Canyon Wilderness (**Table 5-4**, **Figure 5-122**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Manti-La Sal National Forest are outside the geographic bounds of this study. These areas were marked as "No Data" in **Figure 5-121** and **Figure 5-122**.

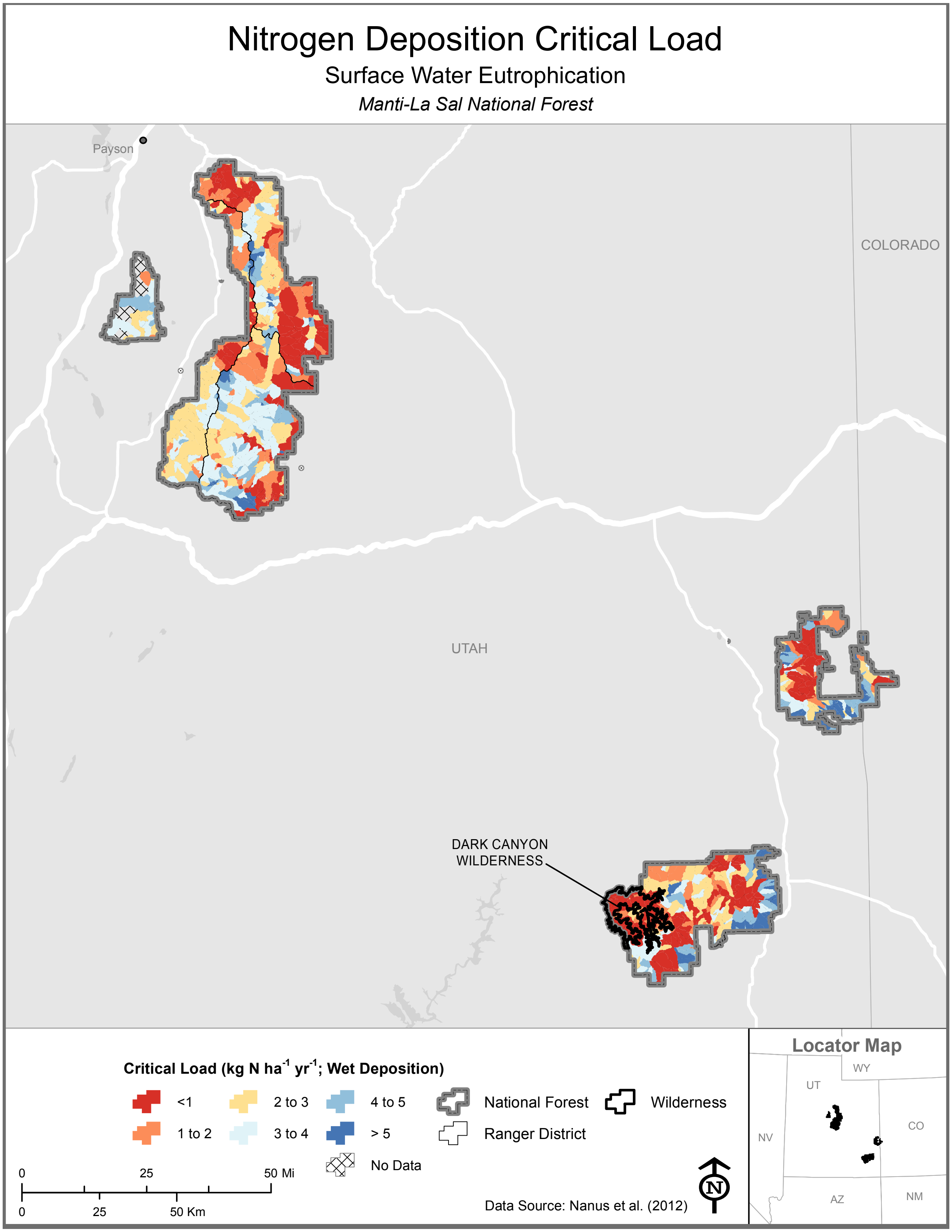


Figure 5-121.—Wet N deposition CLs that protect against surface water eutrophication within the Manti-La Sal National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

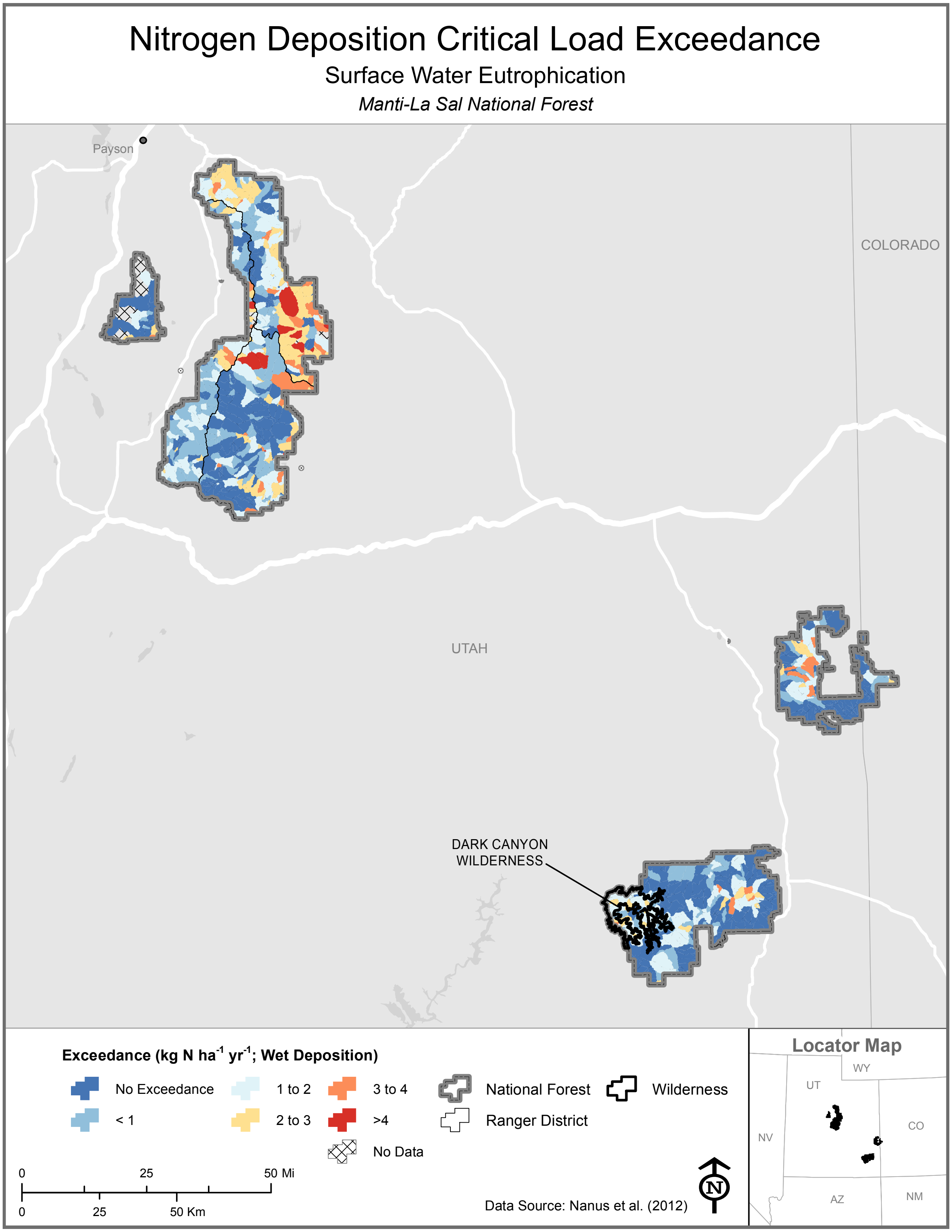


Figure 5-122.—Exceedances of wet N CLs that protect against surface water eutrophication within the Manti-La Sal National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

Rock and cliff formations seen from Horse Pasture Trail in Dark Canyon Wilderness on the Manti-La Sal National Forest. USDA Forest Service photo by Charity Parks.

5.3.8.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 98 percent (5,630 km^2) and 100 percent (5,723 km^2), respectively, of the Manti-La Sal National Forest (**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 5-123** and **5-124**). Critical load exceedances in the Dark Canyon Wilderness were associated with <30 percent declines in lichen species richness and <50 percent declines in forage lichen abundance (**Figures 5-123** and **5-124**). Critical load exceedance associated with at least 40 to 50 percent declines in forage lichen abundance were common throughout the Forest. The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout the entire Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

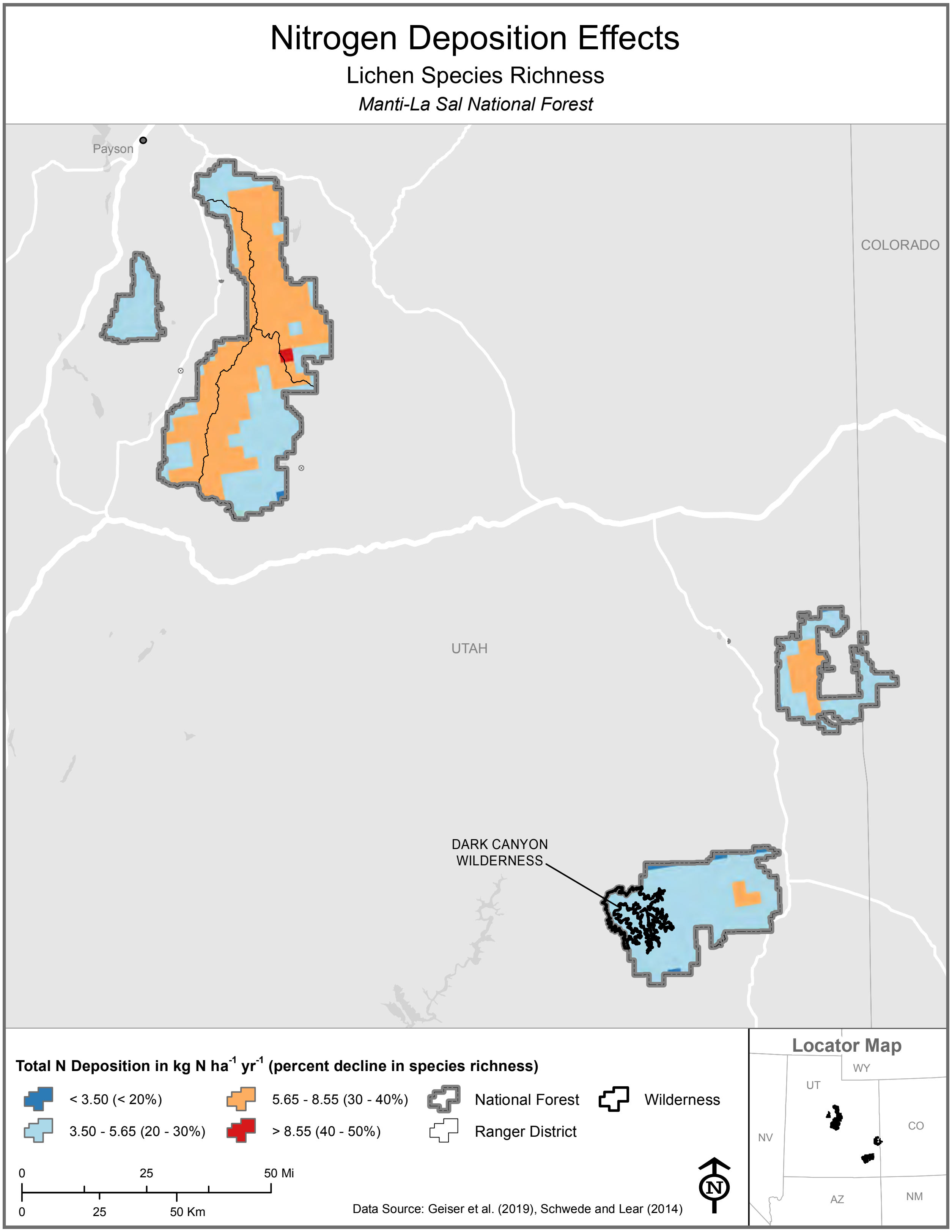


Figure 5-123.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Manti-La Sal National Forest.

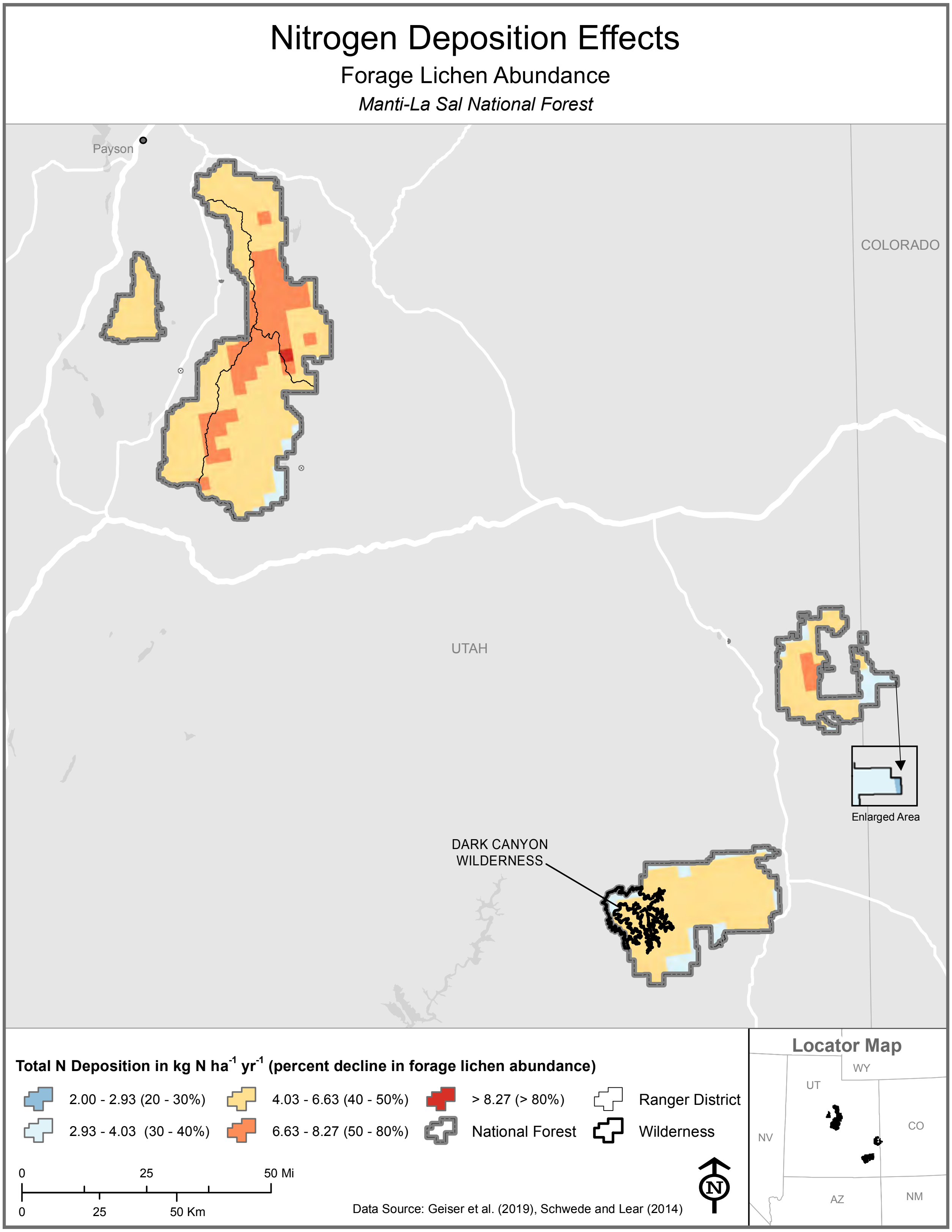


Figure 5-124.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effects to forage lichen abundance within the Manti-La Sal National Forest.

The La Sal mountains, Manti- La Sal National Forest. USDA Forest Service by Charity Parks.

5.3.8.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and for each tree species on the Manti-La Sal National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 80 percent (1,056 km^2) of the area where this species is modeled as dominant or codominant on the Manti-La Sal National Forest (**Table 5-8**). Exceedances were associated with 1 to 5 percent declines in probability of survival and occurred throughout the Forest, including within Dark Canyon Wilderness (**Figure 5-125**).

Singleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 37 percent (494 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). All exceedances were associated with 1 to 5 percent declines in probability of survival, except for 0.4 km^2 (associated with 5 to 10 percent declines), and occurred throughout the Forest, including within Dark Canyon Wilderness (**Figure 5-126**).

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 99 percent (313 km^2) of the area that this species is modeled as dominant or codominant (**Table 5-7**). Nearly all exceedances were associated with 1 to 5 percent declines in probability of survival, except for 1.7 km^2 (associated with 5 to 10 percent declines), and occurred throughout the Forest, including within Dark Canyon Wilderness (**Figure 5-127**).

Quaking aspen. There were no exceedances of N deposition levels associated with declines in growth rate for quaking aspen (**Tables 5-10**, **Figure 5-128**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceeded within 31 percent (299 km^2) of the area where this species is modeled as dominant or codominant (**Tables 5-11**, **Figure 5-129**). All exceedances were associated with 1 to 5 percent declines in probability of survival and occurred predominantly in the northwestern portion of the Forest (**Figure 5-129**).

Balsam poplar. The N deposition levels that protect balsam poplar against a >1 percent decline in growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) were exceeded within nearly 100 percent (28 km^2) and 67 percent (19 km^2), respectively, of the area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). For growth rate, most exceedances (59 percent, 17 km^2) were associated with >10 percent declines and occurred predominantly in the northern half of the Forest (**Table 5-12** and **Figure 5-130**). For probability of survival, CL exceedances were associated with 1 to 5 percent declines, except for 0.5 km^2 (associated with 5 to 10 percent declines) and occurred infrequently throughout the Forest (**Table 5-13** and **Figure 5-131**).

Other tree species of interest that occurred within the Manti-La Sal Nationl Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-21**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-21.—Nitrogen deposition level (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Manti-La Sal National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
White fir	*Abies concolor*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Western juniper	*Juniperus occidentalis*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Common or two-needle pinyon	*Pinus edulis*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

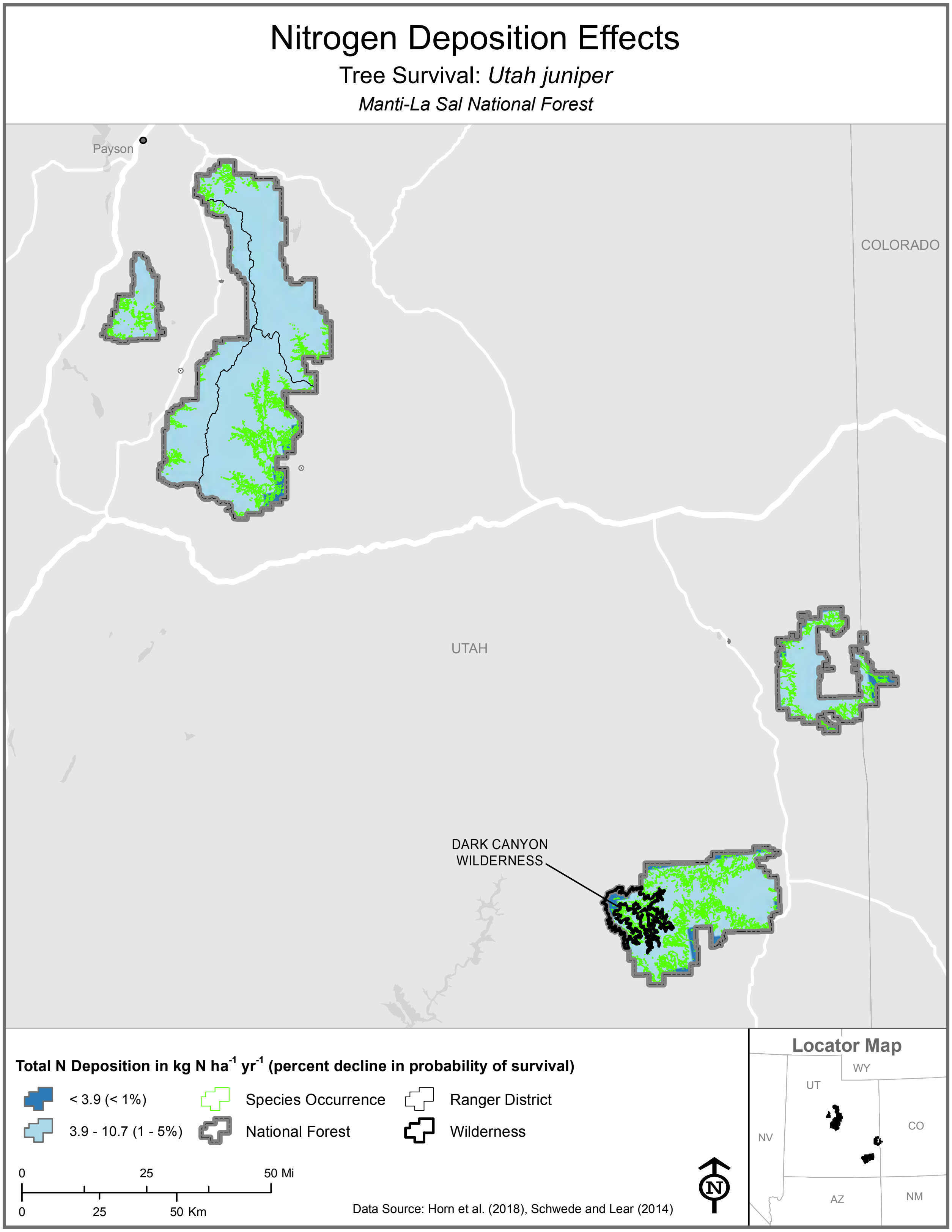


Figure 5-125.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

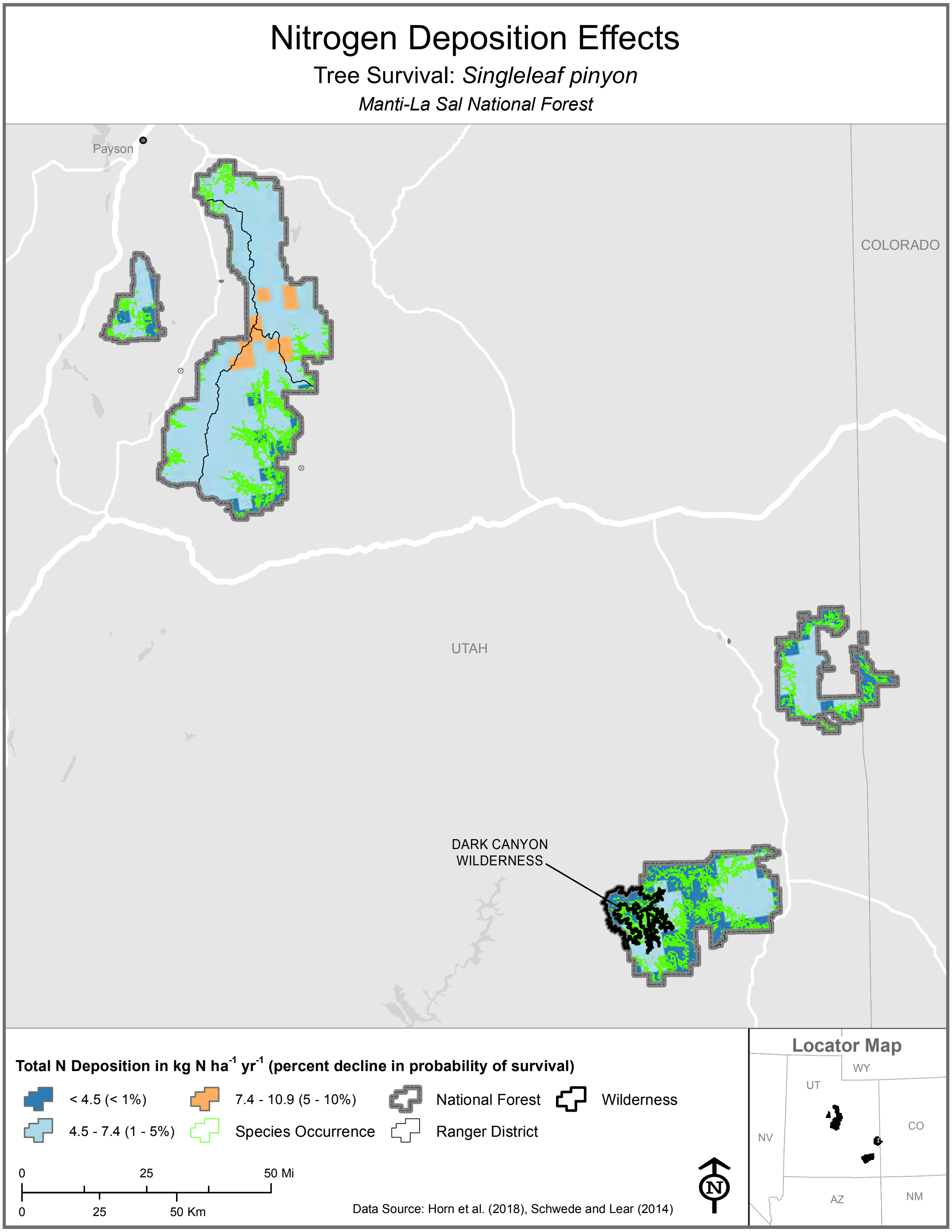


Figure 5-126.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

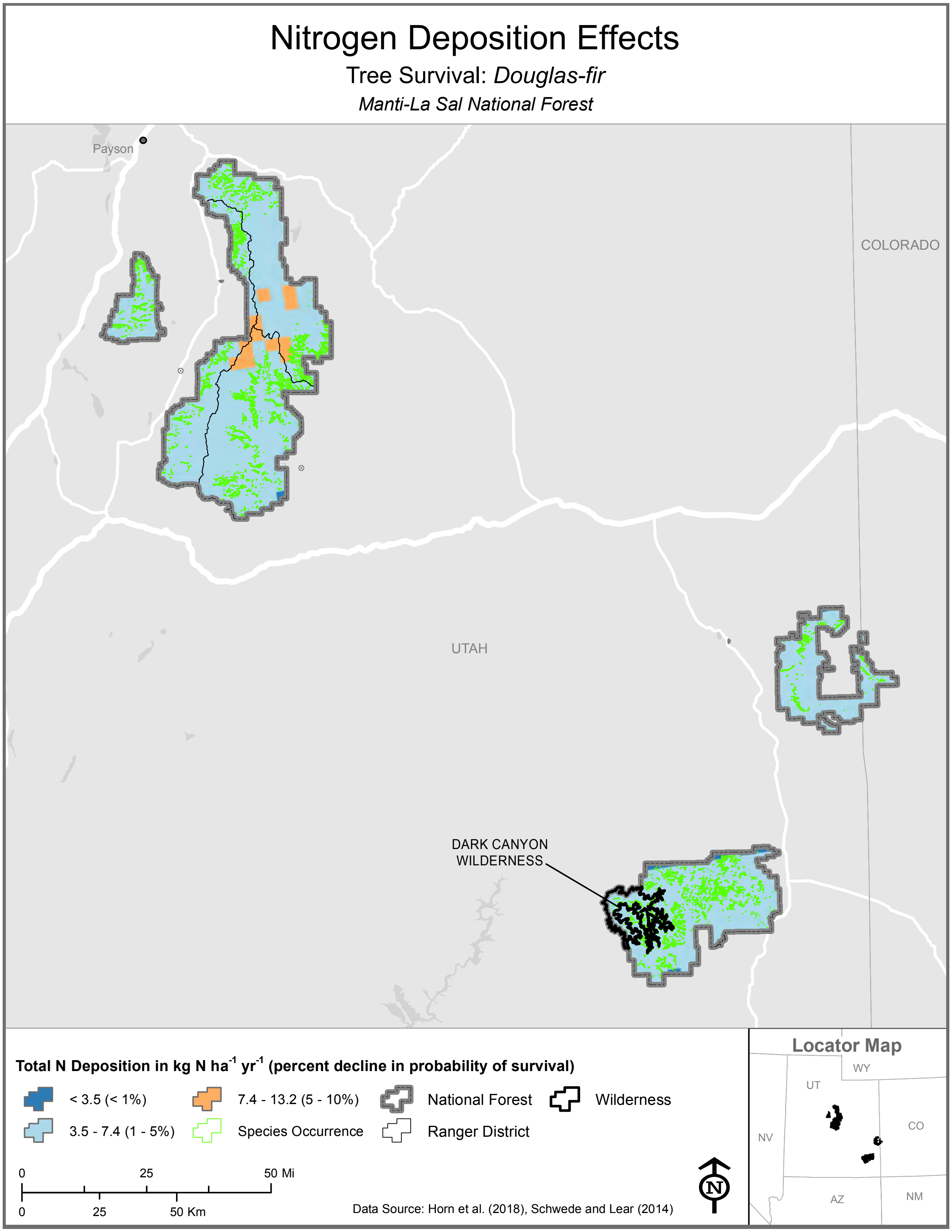


Figure 5-127.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

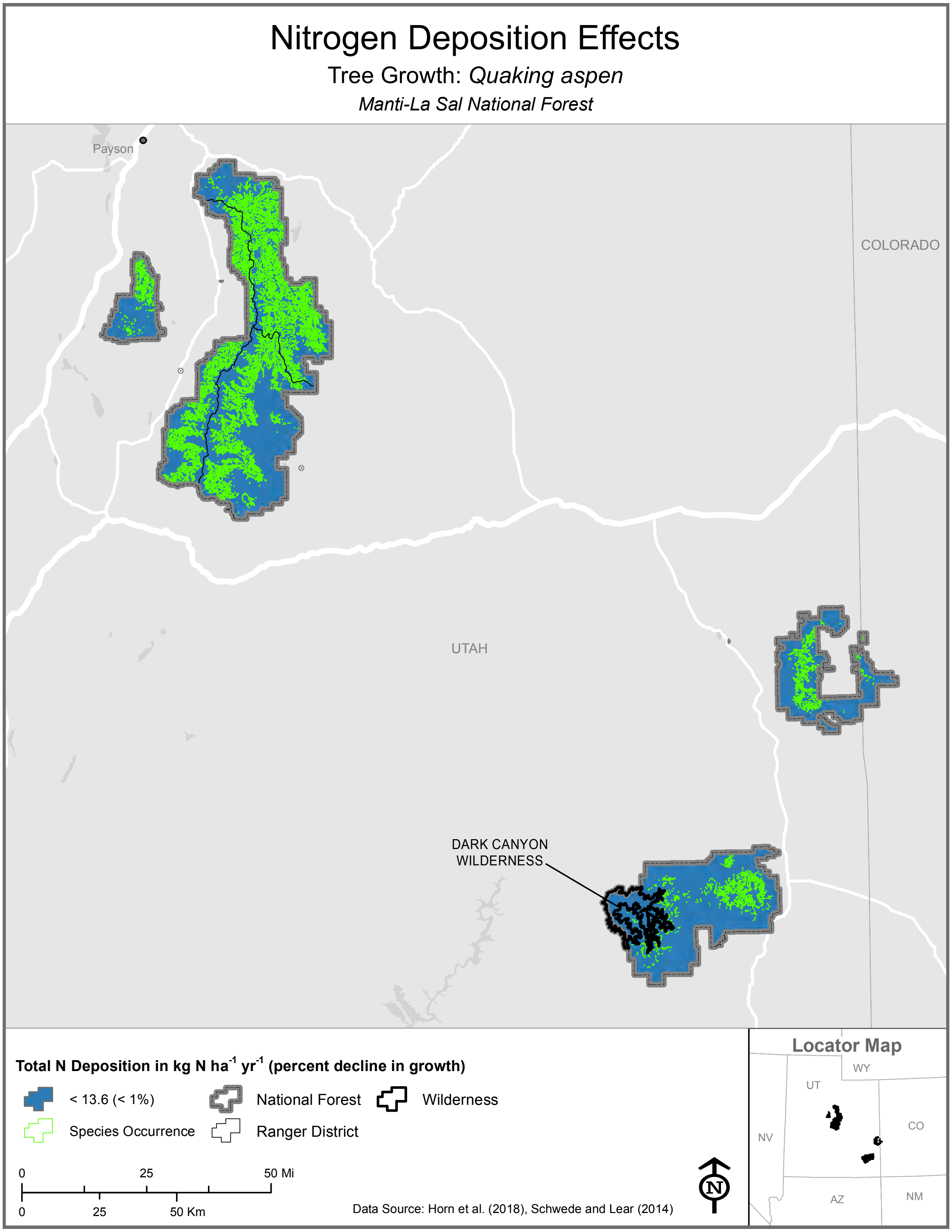


Figure 5-128.— Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

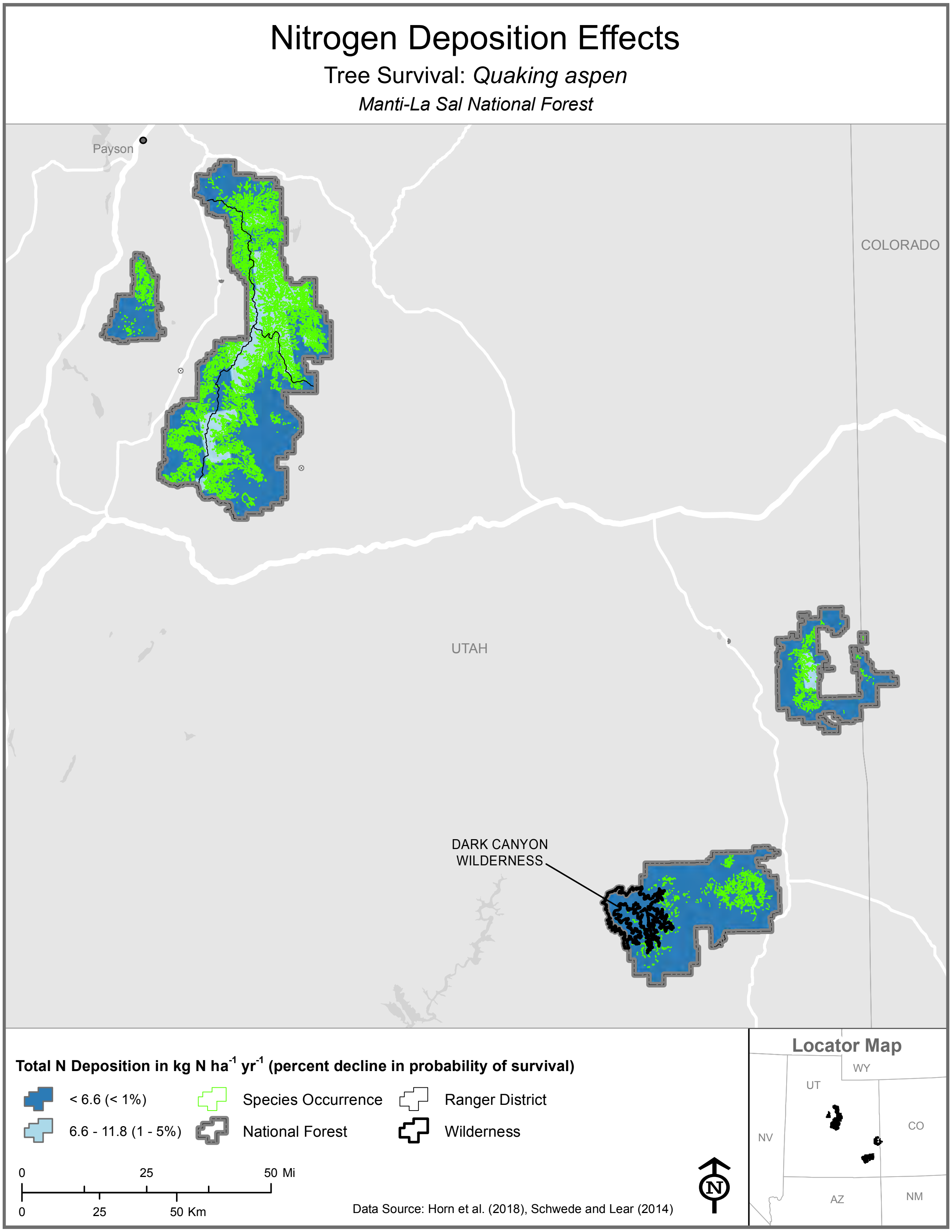


Figure 5-129.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

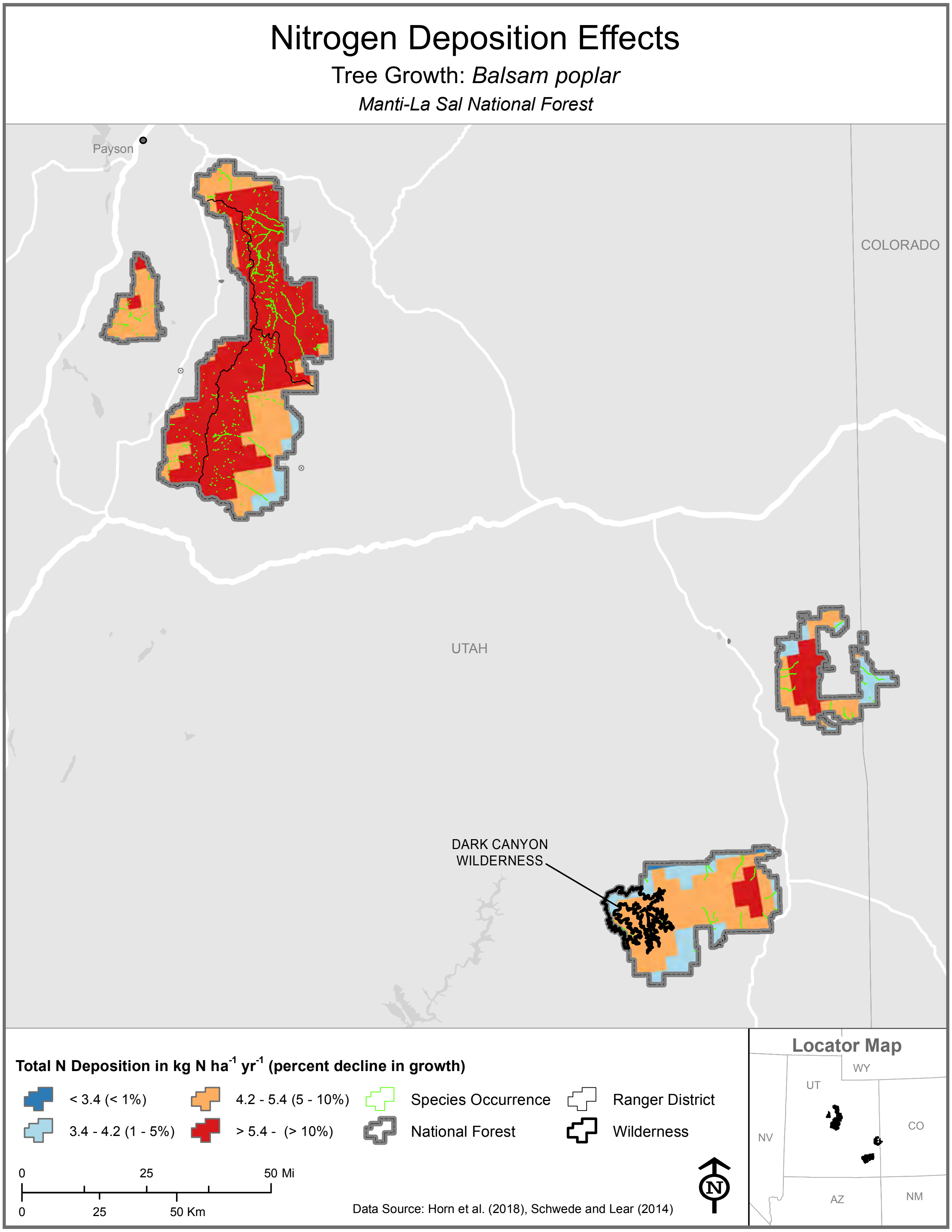


Figure 5-130.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

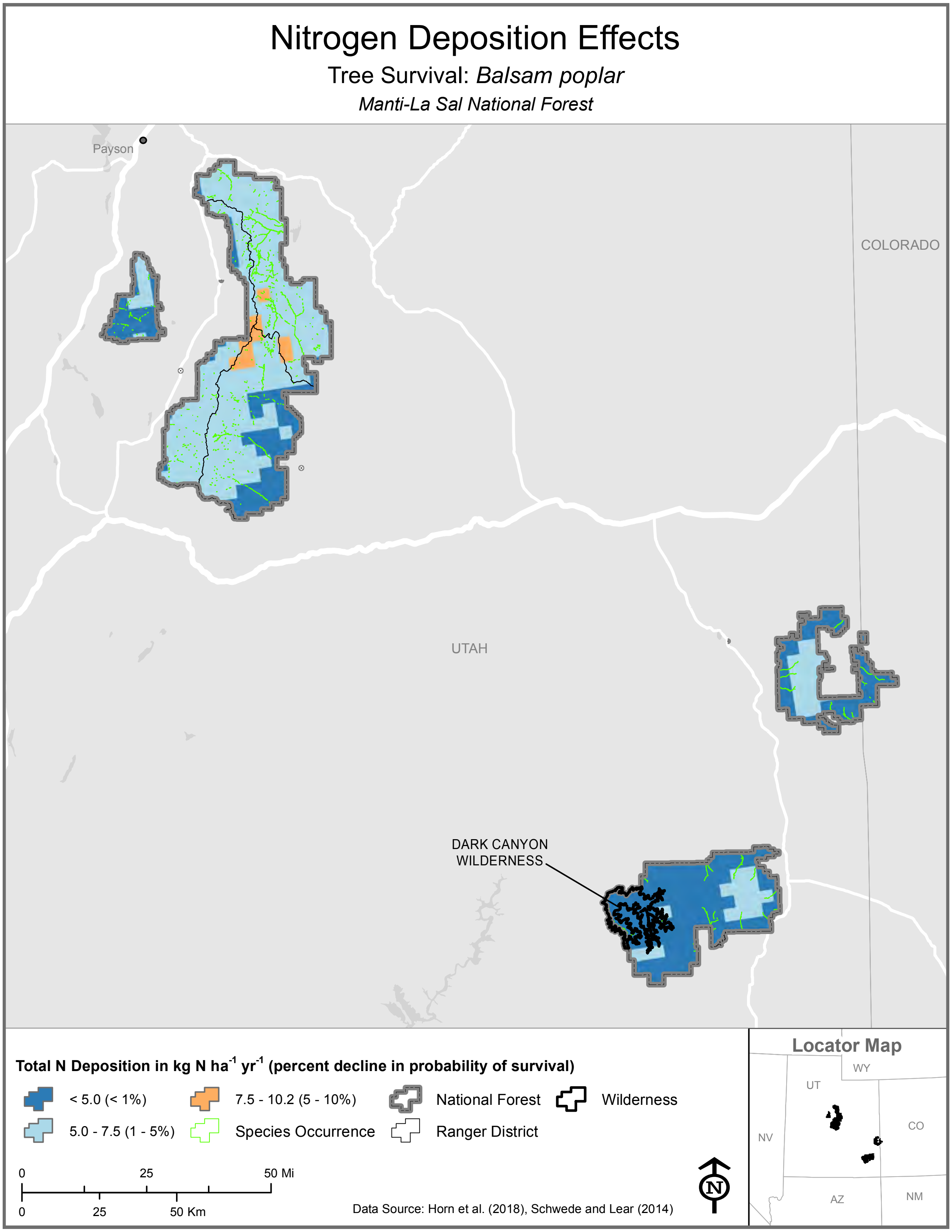


Figure 5-131.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Manti-La Sal National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Early fall snow and aspen trees along the Lick Creek Road in the Payette National Forest. USDA Forest Service photo by Todd Leeds.

5.3.9 Payette National Forest

5.3.9.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 µeq L^{-1} were calculated for 51 waterbodies, mostly within the central portion, of the Payette National Forest (**Table 5-1**, **Figure 5-132**). One waterbody had a low CL (<2 kg N ha^{-1} yr^{-1}) and 34 waterbodies had high CLs (>8 kg N ha^{-1} yr^{-1}, **Table 5-1**). Nitrogen deposition was high enough to exceed the CL for six waterbodies (12 percent, **Table 5-2**). The magnitude of exceedance was <2 kg N ha^{-1} yr^{-1} at five sites and between 2 and 5 kg N ha^{-1} yr^{-1} at one site (**Table 5-2** and **Figure 5-133**). Waterbodies exceeding CLs have a higher risk of experiencing biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}, particularly if N deposition (under ambient S deposition) persists or increases. The risk of effects also increases as the magnitude of exceedance increases. No waterbodies exceeded the CLs that protect surface water ANC from decreasing below 20 µeq L^{-1}. There may be additional acid-sensitive water bodies on the Payette National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

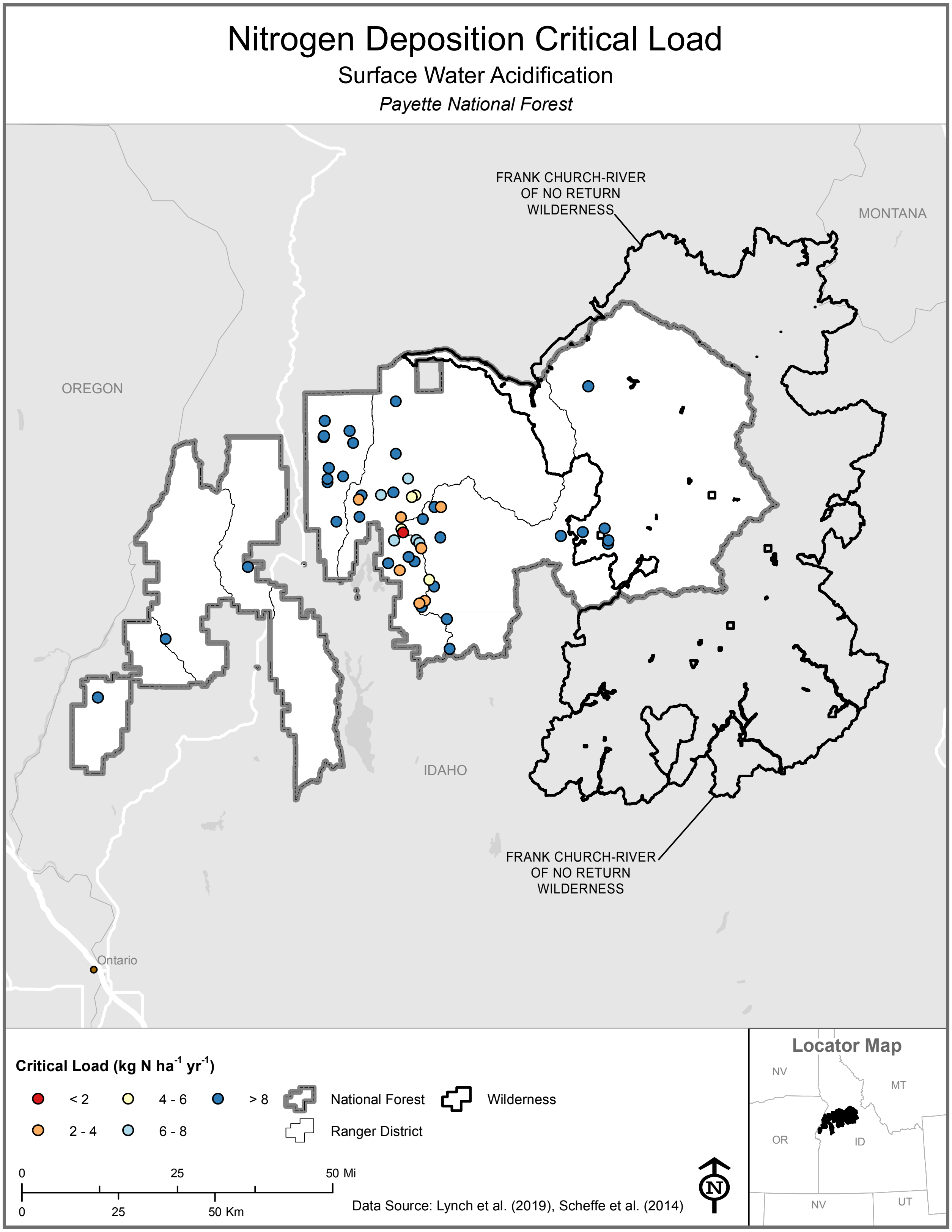


Figure 5-132.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Payette National Forest.

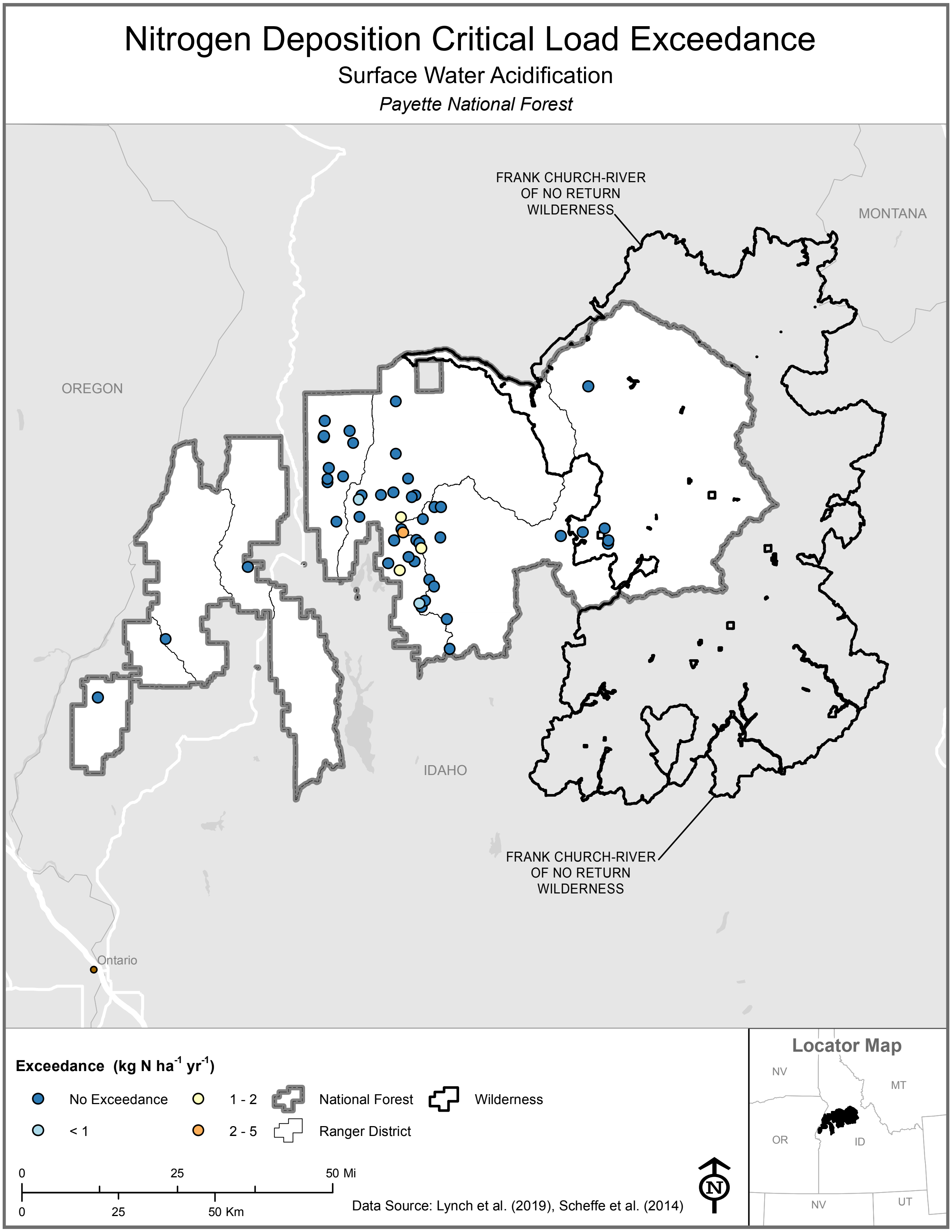


Figure 5-133.—Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Payette National Forest.

Big Bar in Hells Canyon, located on the Payette National Forest. USDA Forest Service photo by Jascha Zeitlin.

5.3.9.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Payette National Forest were calculated using wet N deposition. The higher the CL, the lower the likelihood that a given surface water will experience eutrophication and associated biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 5,059 km^2 (59 percent) of the Forest including the western and southern parts of the Frank Church–River of No Return Wilderness that is administered by the Payette National Forest (**Table 5-3**, **Figure 5-134**). Areas of exceedance followed a similar pattern as the CLs and included 4,666 km^2 (55 percent) of the Forest (**Table 5-4**, **Figure 5-135**). The highest magnitudes of exceedance (2 to 3 kg wet N ha^{-1} yr^{-1}) were mapped across 543 km^2 (6 percent) scattered throughout the Forest, including parts of the Frank Church–River of No Return Wilderness[3] (**Table 5-4**, **Figure 5-135**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Payette National Forest are outside the geographic bounds of this study. These areas were marked as “No Data” in **Figure 5-134** and **Figure 5-135**.

[3] The Frank Church—River of No Return Wilderness is located in four different National Forests, plus a relatively small portion of land administered by the Bureau of Land Management. In this report, Frank Church—River of No Return Wilderness is included in sections covering both the Payette National Forest and Salmon-Challis National Forest.

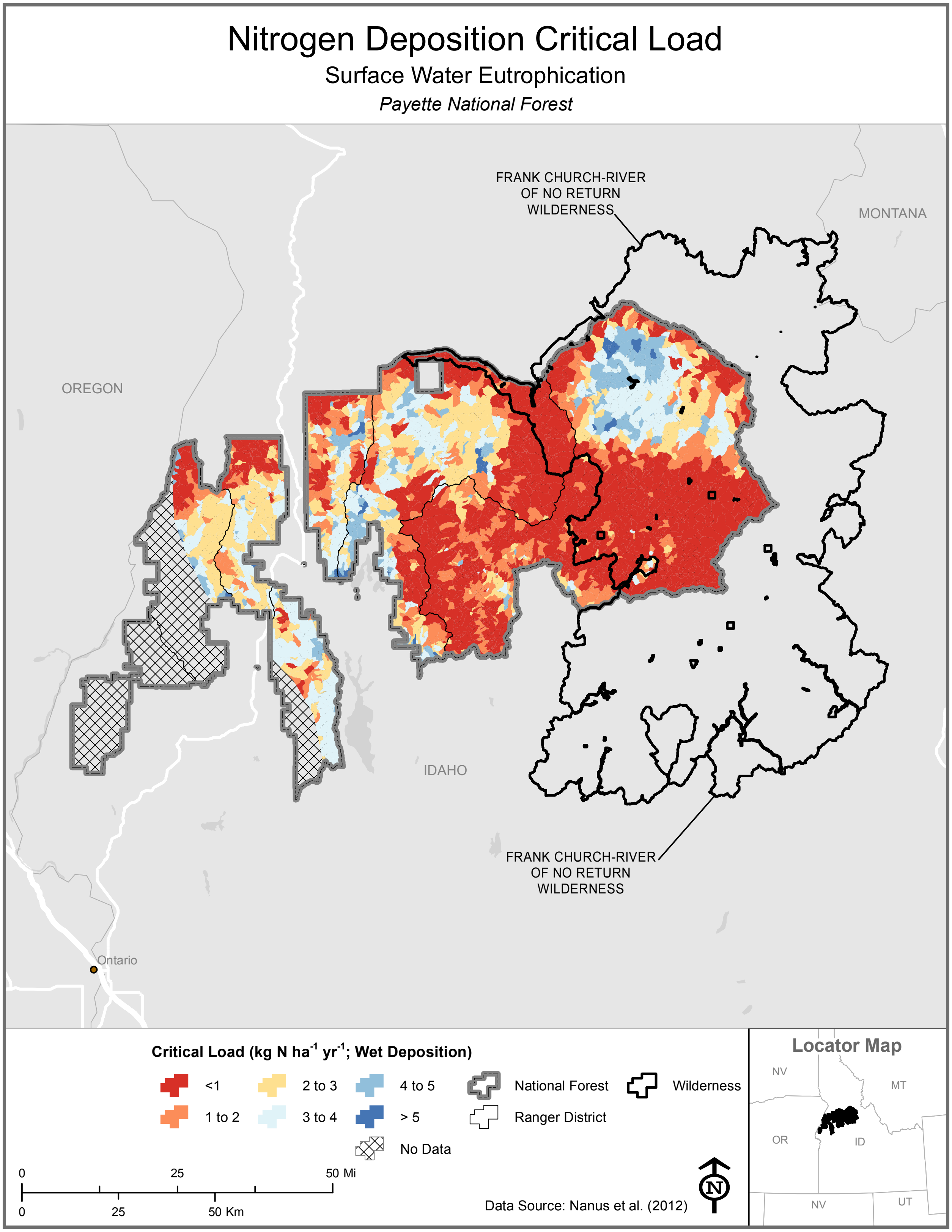


Figure 5-134.—Wet N deposition CLs that protect against surface water eutrophication within the Payette National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

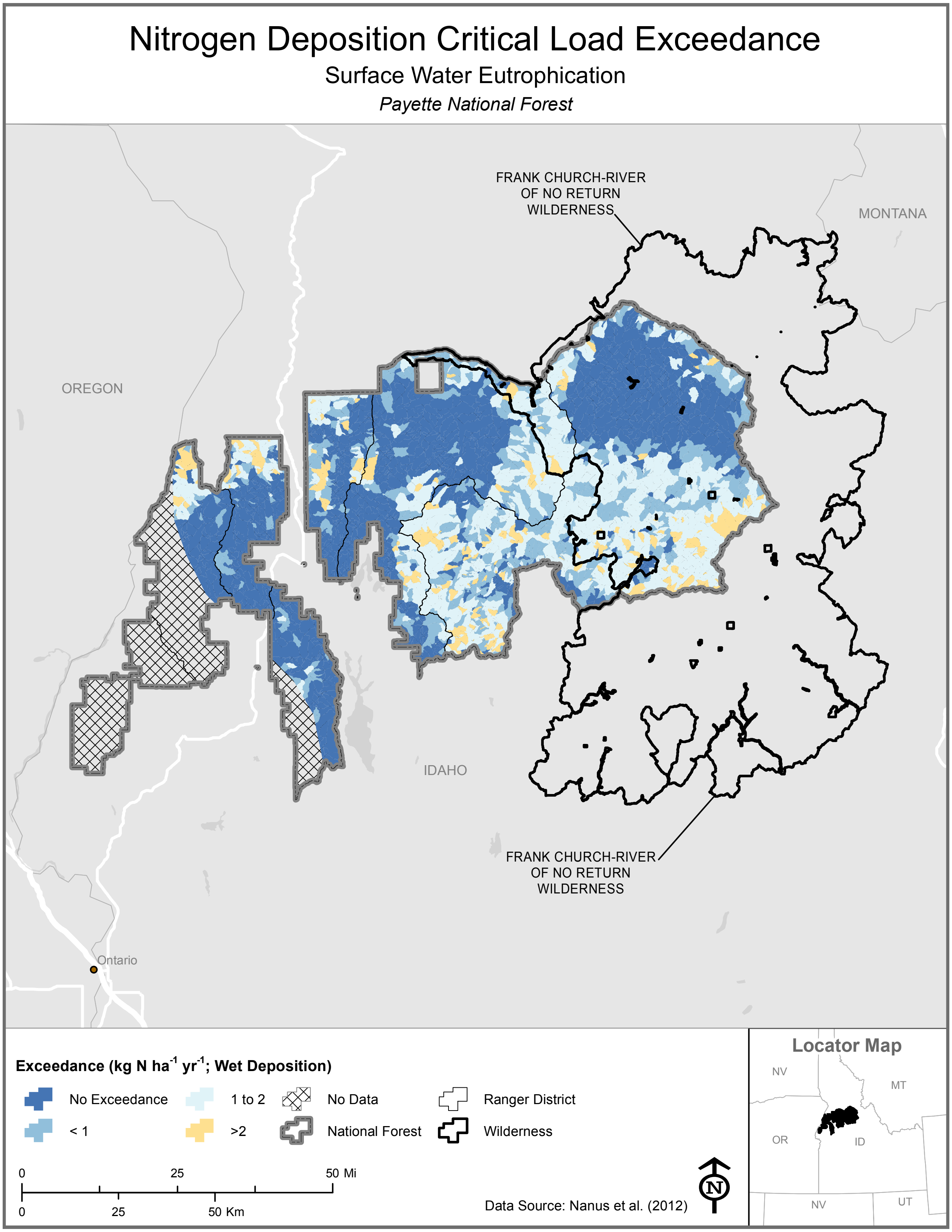


Figure 5-135.— Exceedances of wet N CLs that protect against surface water eutrophication within the Payette National Forest. Based on a threshold nitrate concentration of 0.5 µmol L-1. Areas designated "No Data" are outside the bounds of the dataset used to calculate CLs.

A stream on the Payette National Forest in the fall of 2020, USDA Forest Service photo by Todd Leeds.

5.3.9.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 25 percent (2,385 km^2) and nearly 100 percent (9,703 km^2), respectively, of the Payette National Forest (**Table**s **5-5** and **5-6**). Most of the Forest (75 percent) did not exceed the CL to protect against declines (>20 percent) in lichen species richness. All exceedances were associated with 20 to 30 percent declines (**Table 5-5**). Only a small section (southwest) of the Frank Church–River of No Return Wilderness administered by the Payette National Forest was in exceedance of the lichen species richness CL (**Figure 5-136**). Most CL exceedances for forage lichen abundance were associated with 30 to 50 percent declines, including portions of the Frank Church–River of No Return Wilderness (**Table 5-6** and **Figure 5-137**). The highest magnitudes of CL exceedance (>2 kg N ha^{-1} yr^{-1}) for forage lichen abundance were primarily located in the central portion of the Forest (**Figures 5-137**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

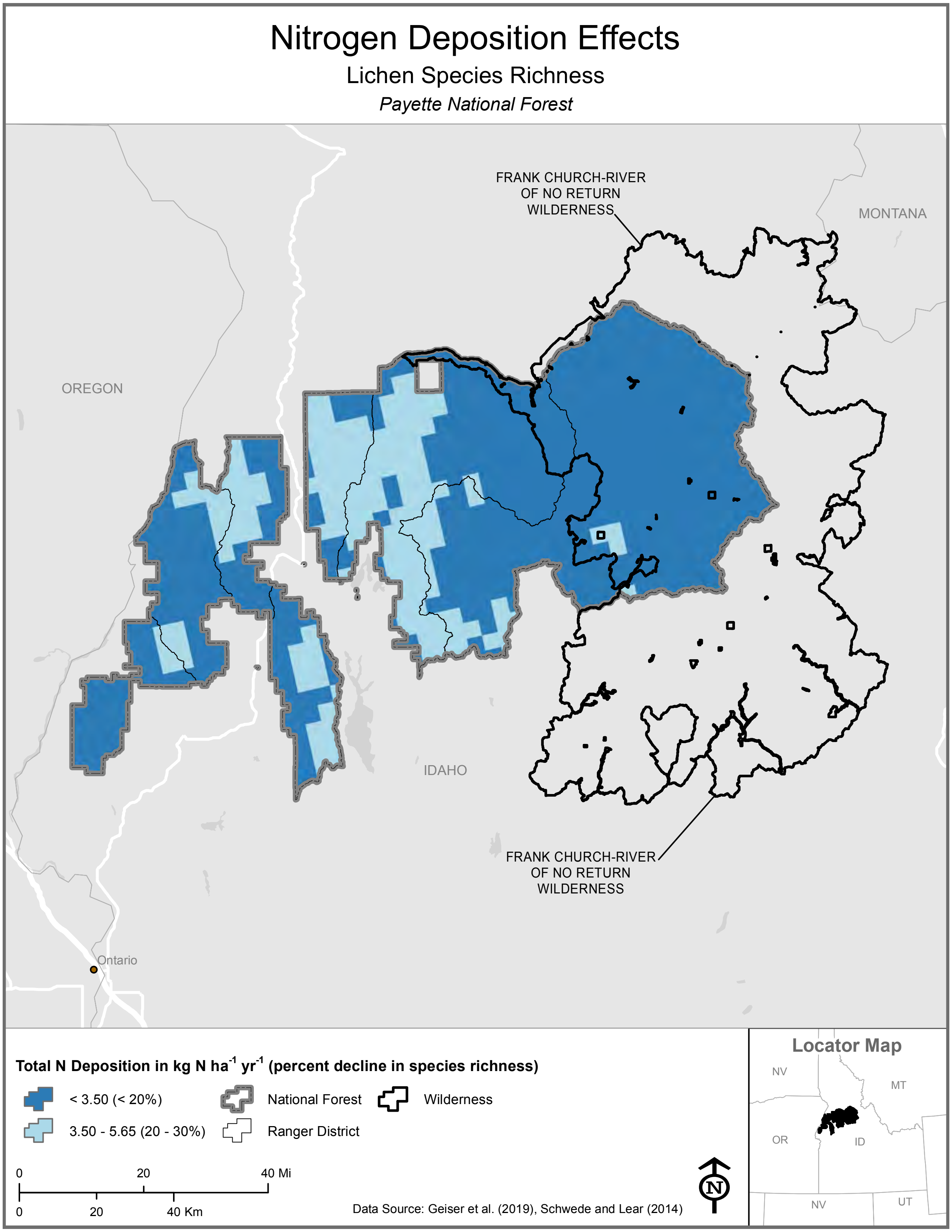


Figure 5-136.— Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Payette National Forest.

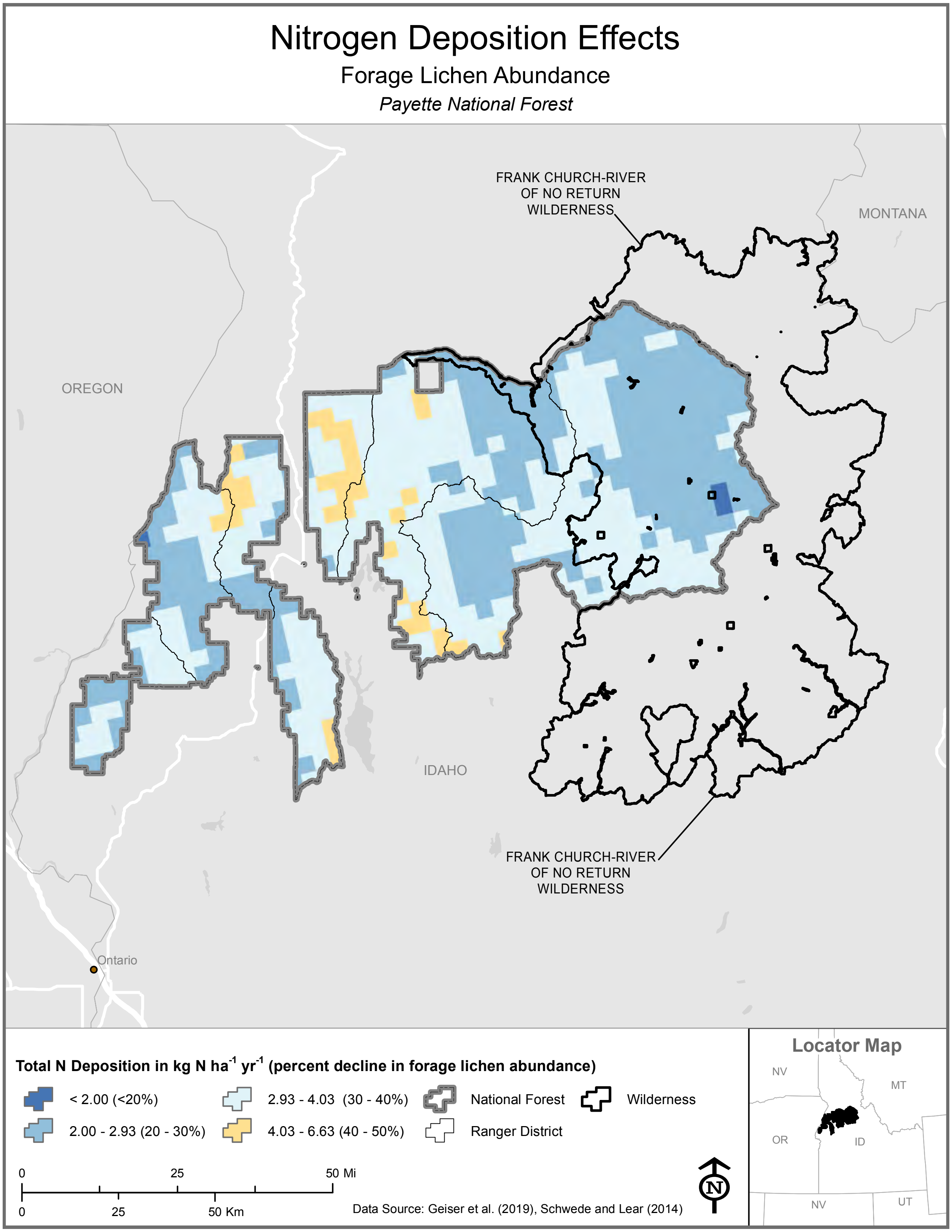
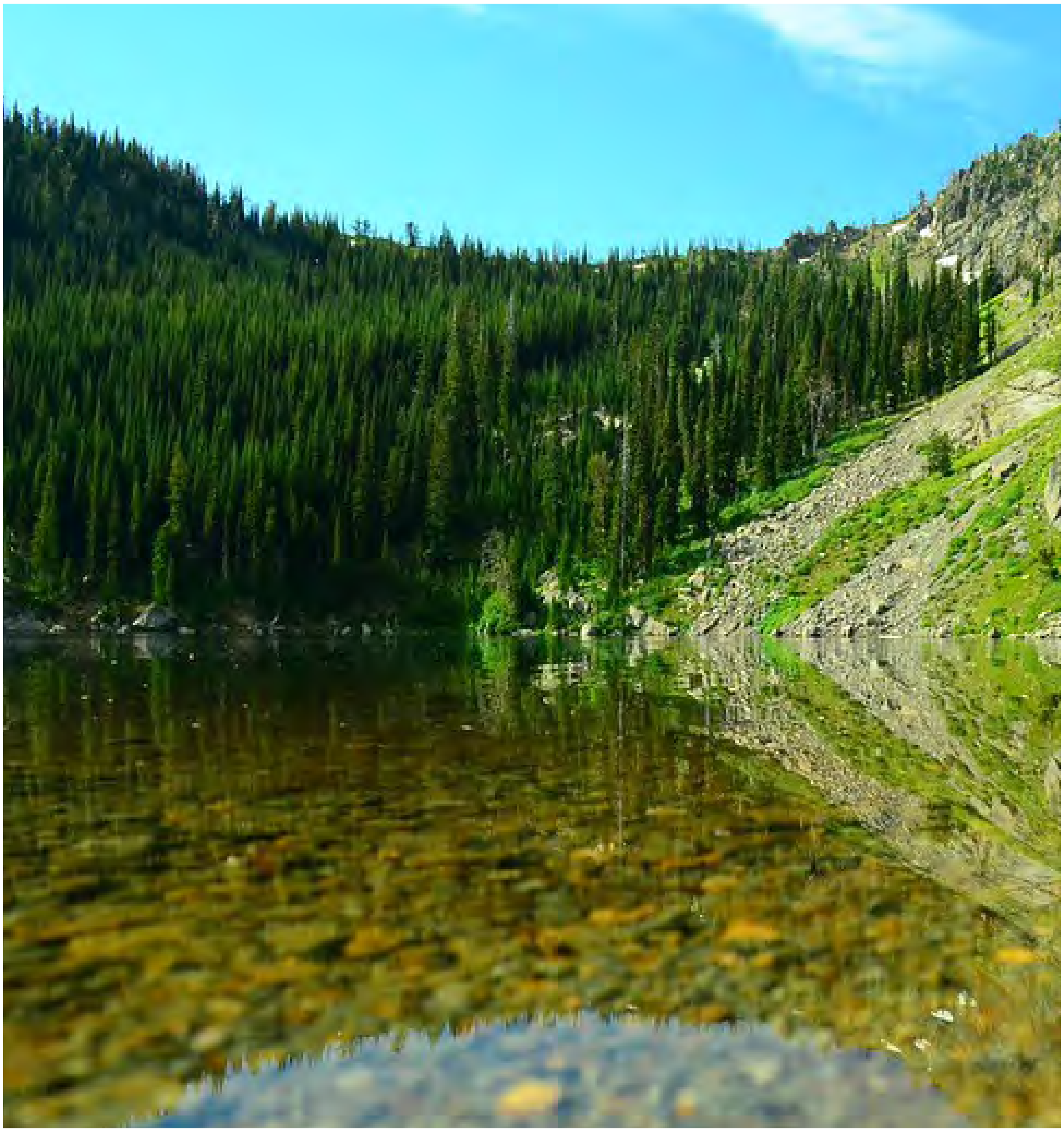


Figure 5-137.— Total (wet + dry) N deposition (average 2015–2017) and estimated effects to forage lichen abundance within the Payette National Forest.



Black Lake on the Payette USDA Forest Service photo by Cody Allred.

5.3.9.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Payette National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL

exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 14 percent (347 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-7**). Exceedances were associated with 1 to 5 percent declines in probability of survival and occurred primarily in the central and western portions of the Forest and within a small section of the Frank Church–River of No Return Wilderness (**Figure 5-138**).

Balsam poplar. The N deposition level that protects balsam poplar against a >1 percent decline in growth rate (3.4 kg N ha^{-1} yr^{-1}) was exceeded within 15 percent (7 km^2) of the area where this species is modeled as dominant or codominant (**Tabl**es **5-12** and **5-13**). All exceedances were associated with 1 to 5 percent declines in growth rate, except for 0.2 km^2 that was associated with 5 to 10 percent declines in growth rate (**Tabl**es **5-12**). Most exceedances occurred in the central and western portions of the Forest (**Figure 5-139**). There were no exceedances of N deposition levels (5.0 kg N ha^{-1} yr^{-1}) associated with declines in probability of survival over 10 years (**Figure 5-140**).

Quaking aspen. There were no exceedances of the N deposition levels that protect quaking aspen against declines in growth rate (13.6 kg N ha^{-1} yr^{-1}) or probability of survival over 10 years (6.6 kg N ha^{-1} yr^{-1}) within any of the area where this species is modeled as dominant or codominant (**Tables 5-10** and **5-11**, **Figures 5-141** and **5-142**).

Other species of interest that occurred within the Payette National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-22**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-22.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Payette National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
Grand fir	*Abies grandis*	Growth	Increasing	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Western larch	*Larix occidentalis*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

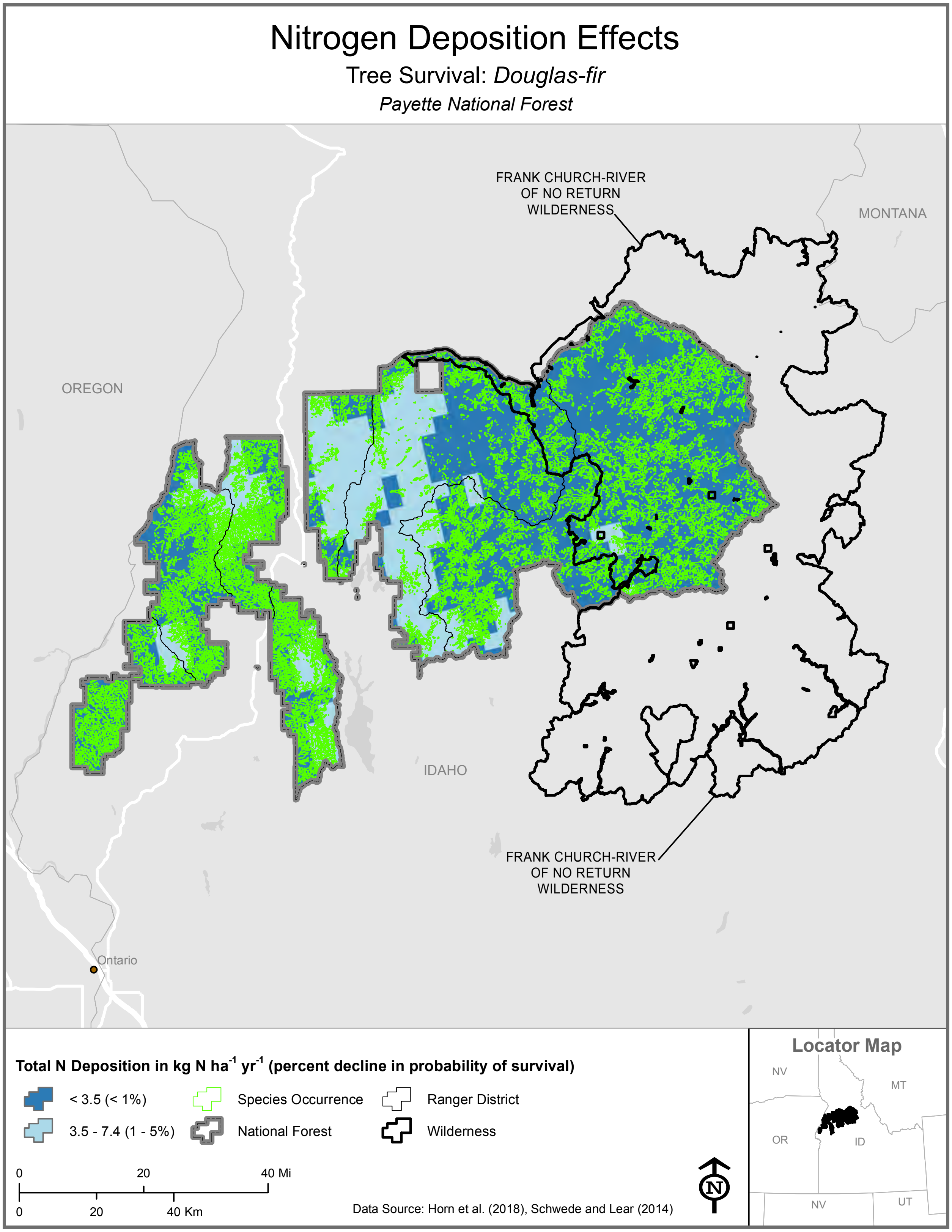


Figure 5-138.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Payette National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

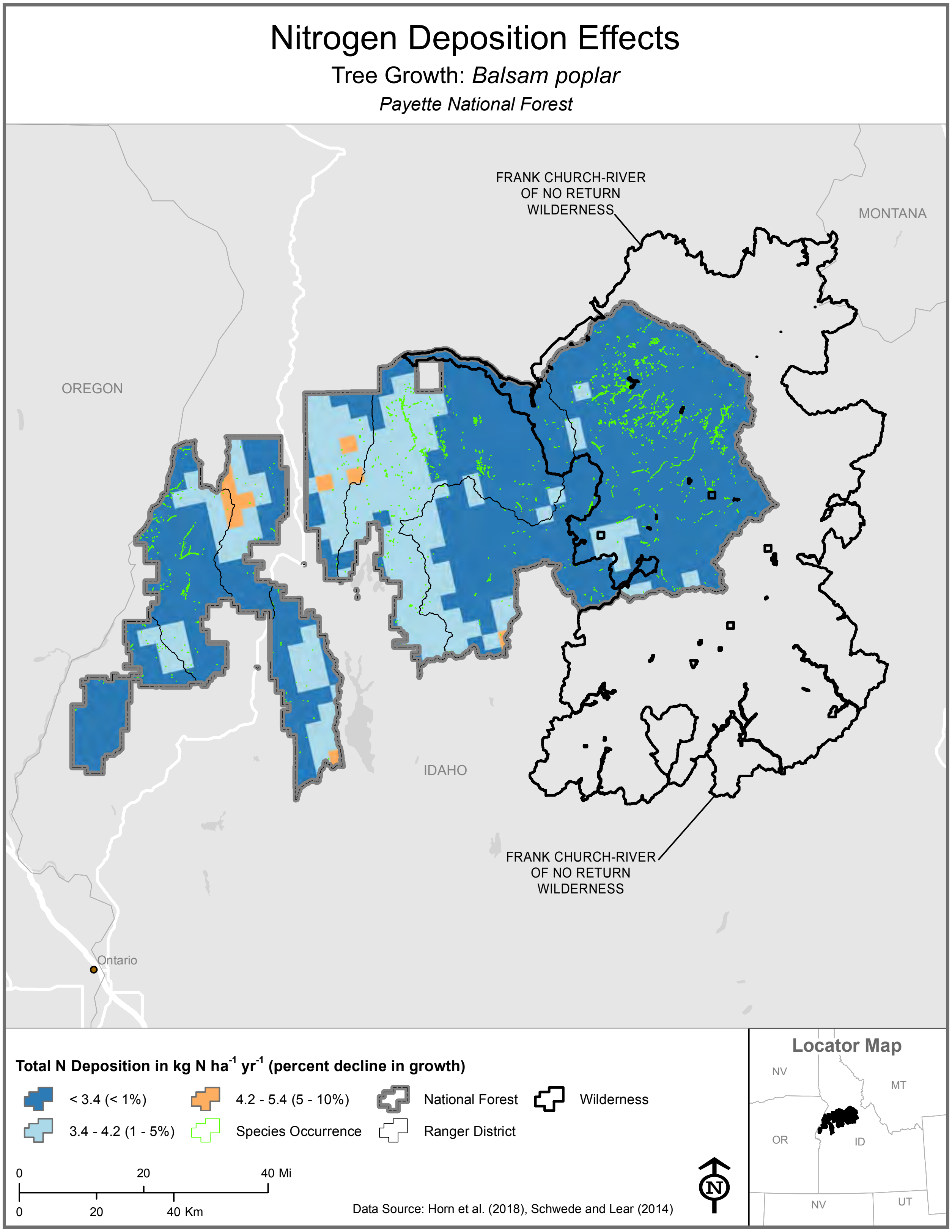


Figure 5-139.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Payette National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

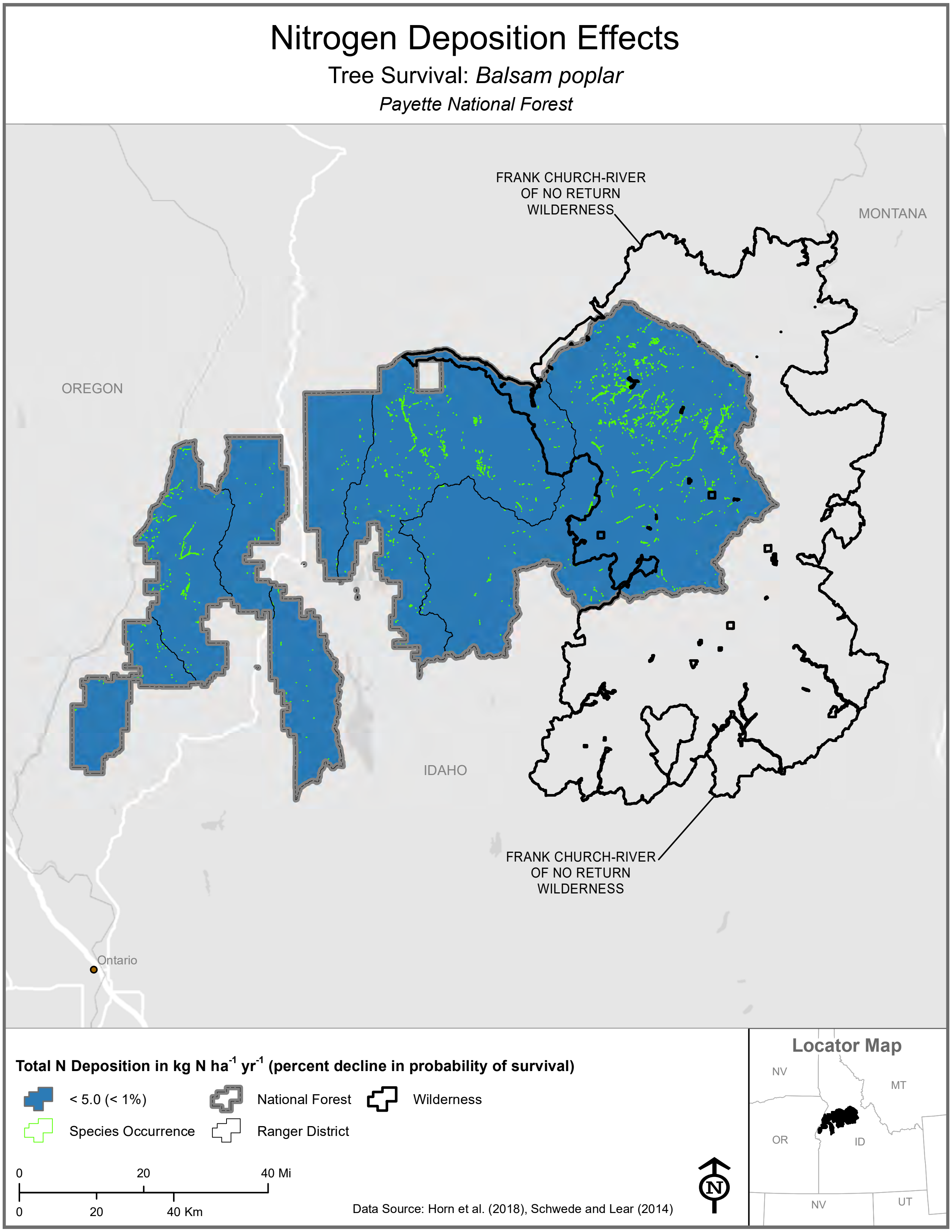


Figure 5-140.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Payette National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

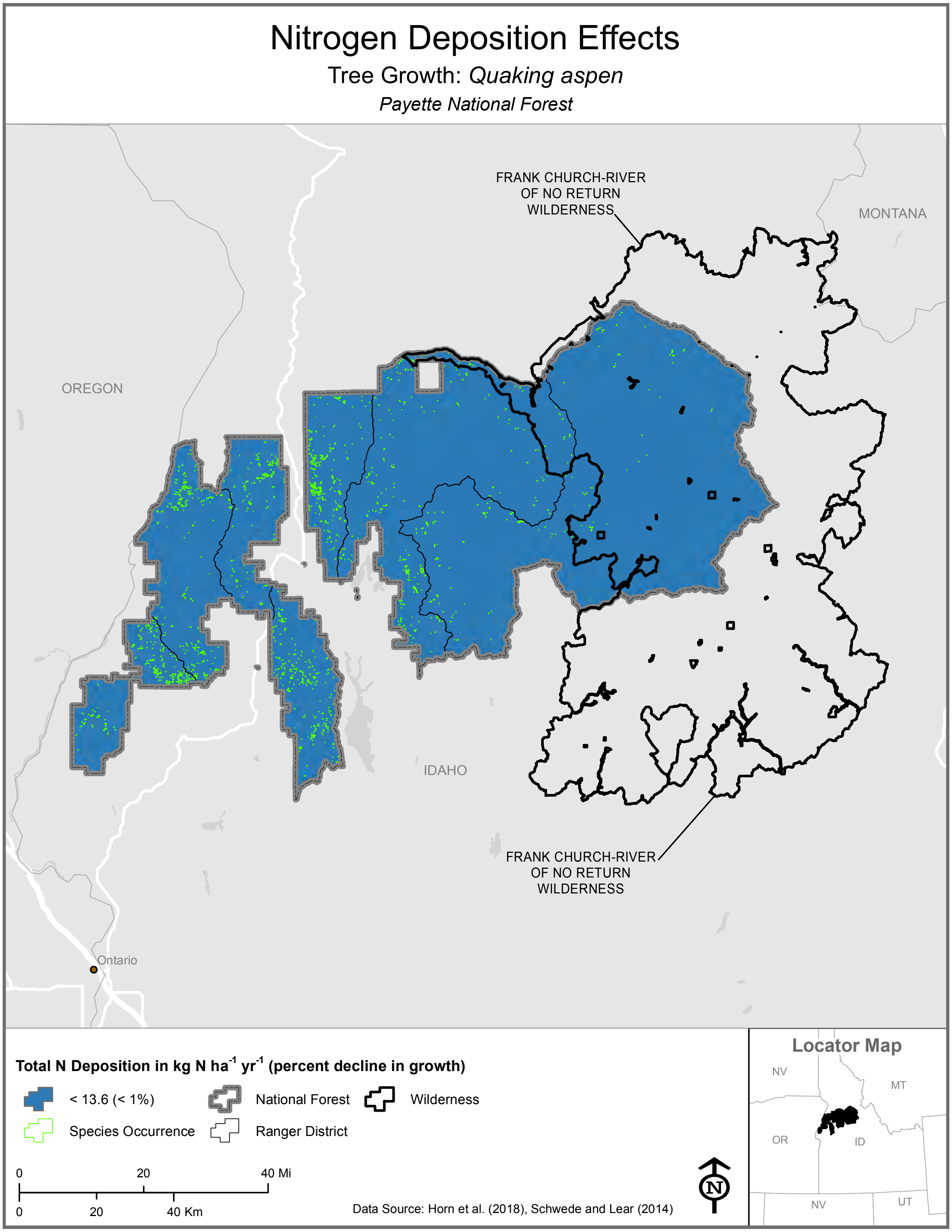


Figure 5-141.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Payette National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

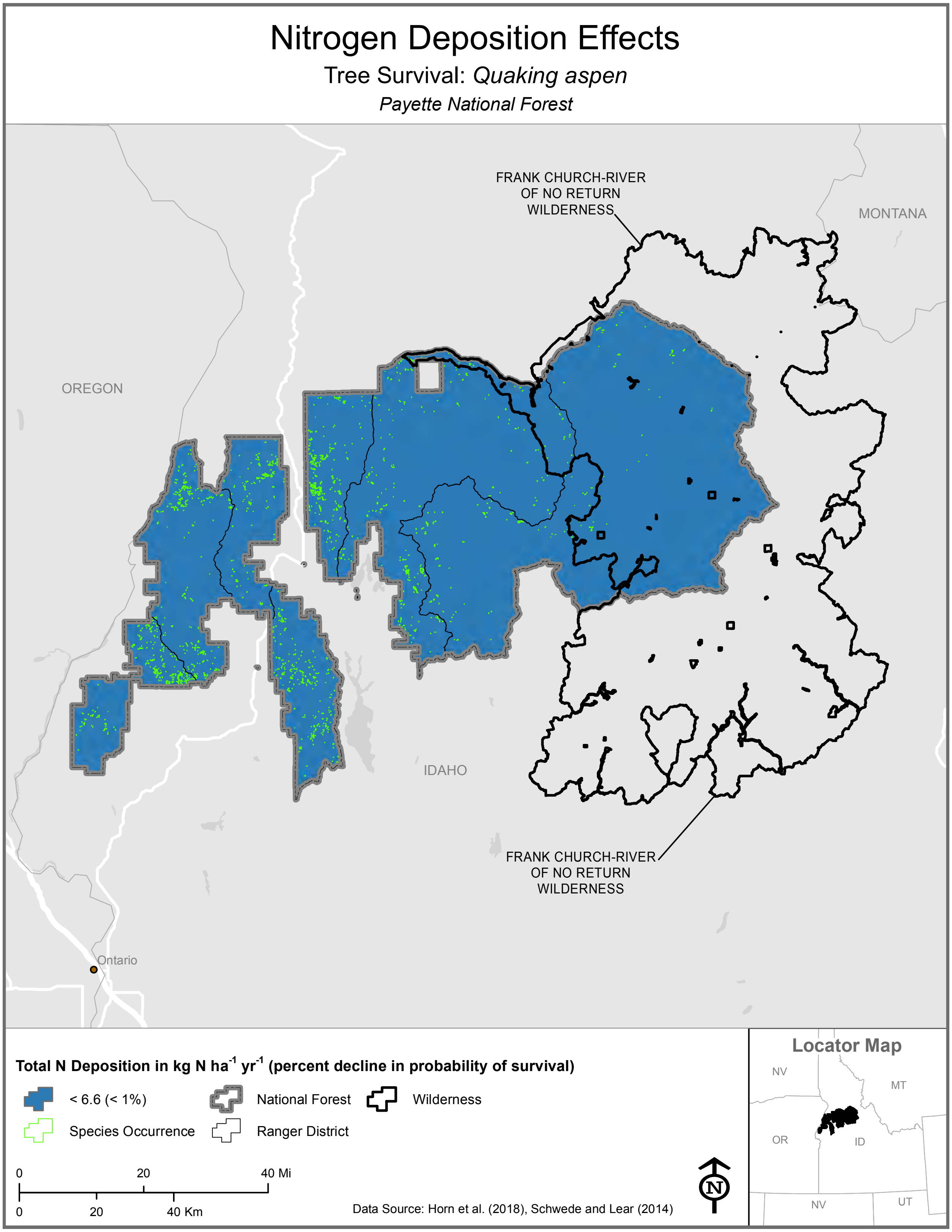


Figure 5-142.—T Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Payette National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Middle Fork of the Salmon River, Salmon-Challis National Forest. USDA Forest Service photo by Charity Parks.

5.3.10 Salmon-Challis National Forest

5.3.10.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water acidification from decreasing below an ANC of 50 µeq L^{-1} were calculated for 18 water bodies on Salmon-Challis National Forest (**Table 5-1** and **Figure 5-143**). Sixteen (89 percent) of the waterbodies were not in exceedances of the CL (**Table 5-2** and **Figure 5-144**). Two waterbodies had low CLs (<2 kg N ha^{-1} yr^{-1}) with N deposition rates that exceeded the CLs (ANC below 50 µeq L^{-1}) by a magnitude of 1 to 2 kg N ha^{-1} yr^{-1} (**Table 5-1** and **5-2**). One of these waterbodies was within the Frank Church–River of No Return Wilderness Area administered by the Salmon-Challis National Forest (**Figure 5-144**). These two waterbodies have a higher risk to experience biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}, especially if N deposition (under ambient S deposition) persists or increases. No sites were located within the Jim McClure–Jerry Peak Wilderness. There may be additional acid-sensitive water bodies on the Salmon-Challis National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

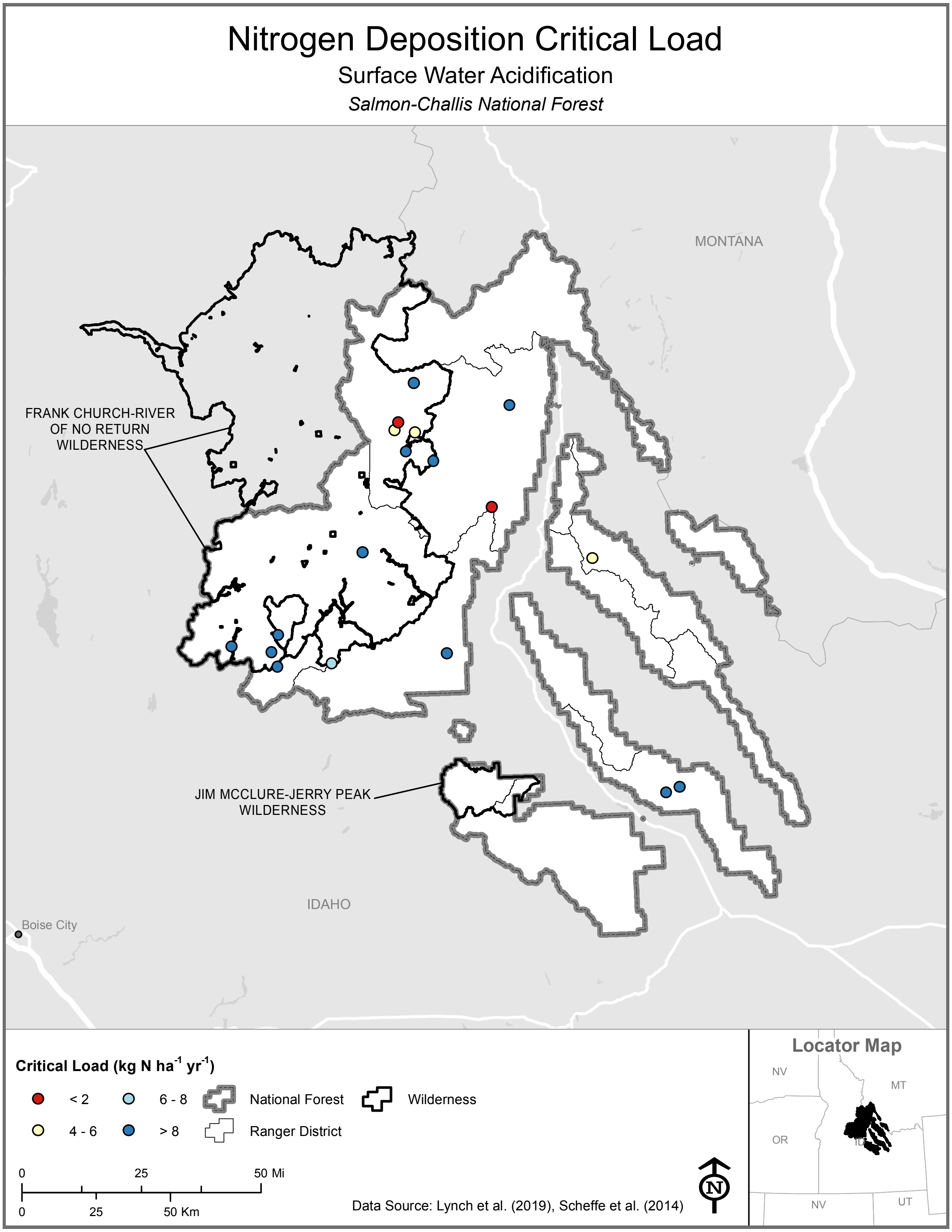


Figure 5-143.—Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Salmon-Challis National Forest.

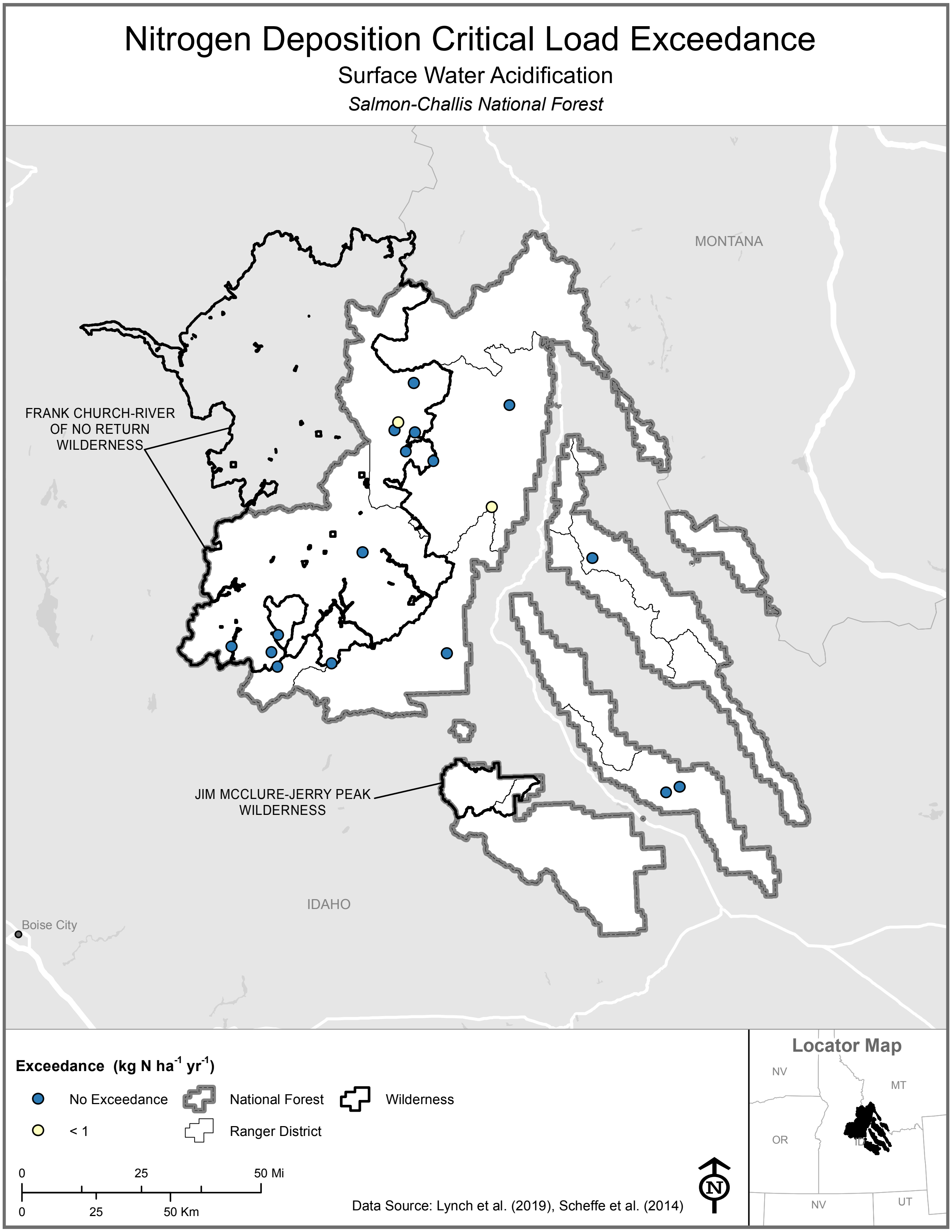


Figure 5-144.—Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Salmon-Challis National Forest.

Merriam Lake in the Lost River Range on the Salmon-Challis National Forest. USDA Forest Service photo.

5.3.10.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Salmon-Challis National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 14,475 km^2 (81 percent) of the Forest, including most of the Jim McClure–Jerry Peak Wilderness and the portion of the Frank Church–River of No Return Wilderness within the Salmon-Challis National Forest (**Table 5-3**, **Figure 5-145**). Areas of exceedance followed a similar pattern as the CLs and included 12,929 km^2 (73 percent) of the Forest (**Table 5-4**, **Figure 5-146**). The highest magnitudes of exceedance, 2 to 3 kg wet N ha^{-1} yr^{-1}, were mapped across 2,536 km^2 (14 percent) of the Forest, including parts of the Jim McClure–Jerry Peak and Frank Church–River of No Return Wilderness Areas (**Table 5-4**, **Figure 5-146**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities.

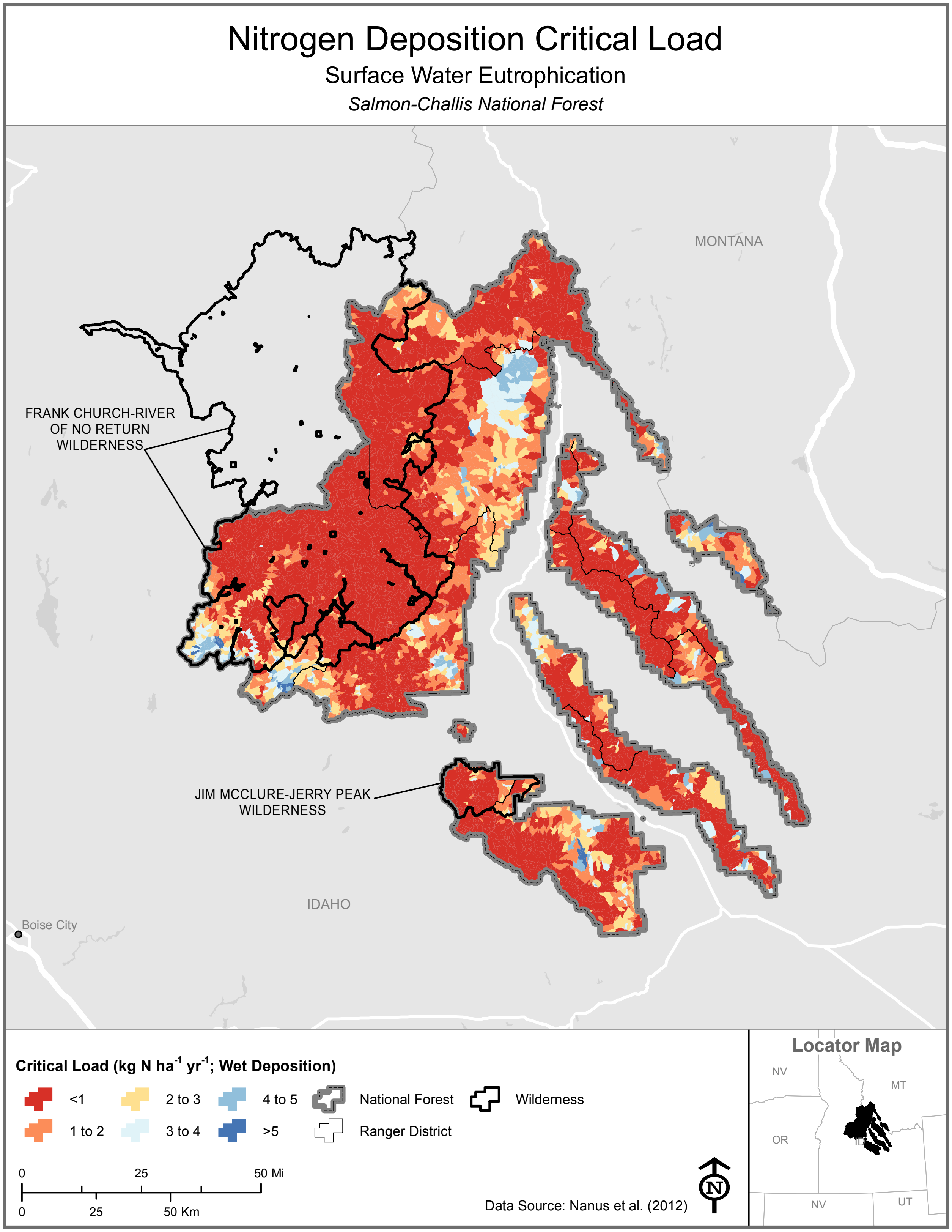


Figure 5-145.—Wet N deposition CLs that protect against surface water eutrophication within the Salmon-Challis National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

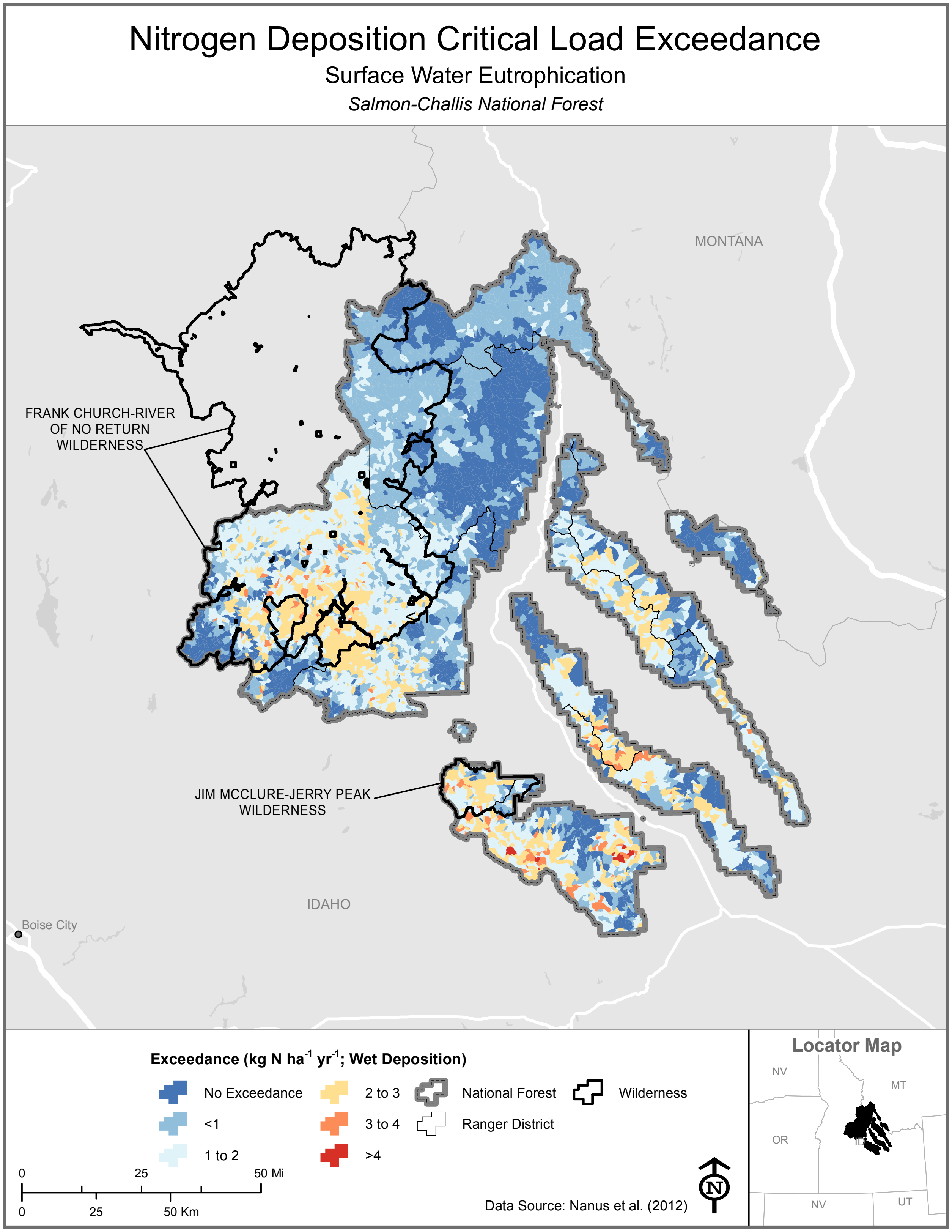


Figure 5-146.—Exceedance of wet N CLs that protect against surface water eutrophication within the Salmon-Challis National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}.

Taking in the view on approach to a young mountaineer's first summit of Freeman Peak in the Beaverhead Mountains on the Salmon-Challis National Forest USDA Forest Service photo by David Deschaine.

5.3.10.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applies one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 32 percent (5,739 km^2) and 97 percent (17,215 km^2), respectively, of the Salmon-Challis National Forest (**Table**s **5-5** and **5-6**). Most of the Forest, particularly in the northern areas, did not exceed the CL that protects against declines in lichen species richness (**Figure 5-147**). The areas in exceedance (5,708 km^2, 32 percent) were associated with 20 to 30 declines in lichen species richness, except for an isolated 31 km^2 (0.2 percent) of the Forest associated with 30 to 40 percent declines in lichen species richness (**Table 5-5** and **Figure 5-147**). Magnitudes of exceedance associated with 30 to 50 percent declines in forage lichen abundance were common (9,664 km^2, 54 percent) throughout the southern half of the Forest including portions of the Jim McClure–Jerry Peak and Frank Church–River of No Return Wilderness Areas (**Table 5-6** and **Figure 5-148**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

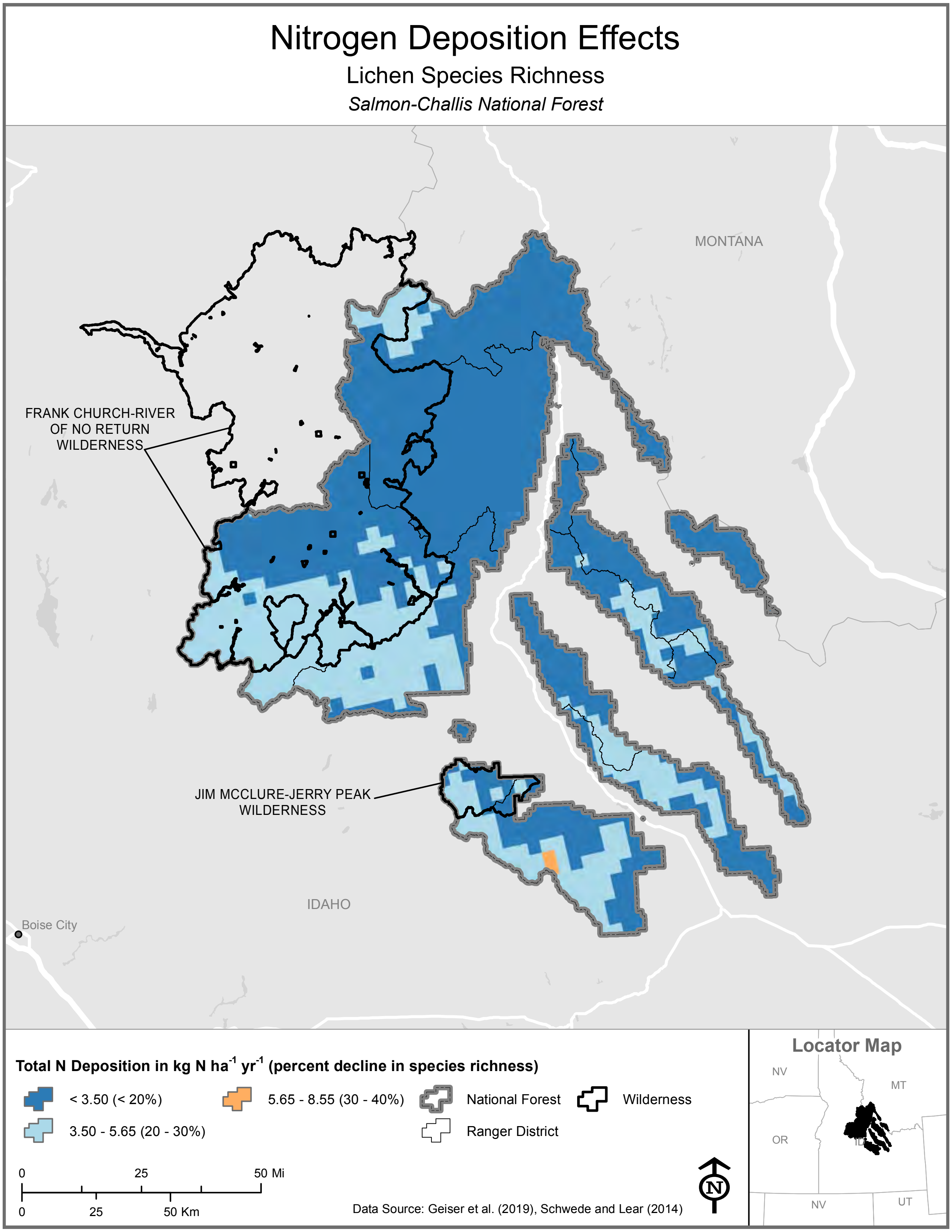


Figure 5-147.— Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Salmon-Challis National Forest.

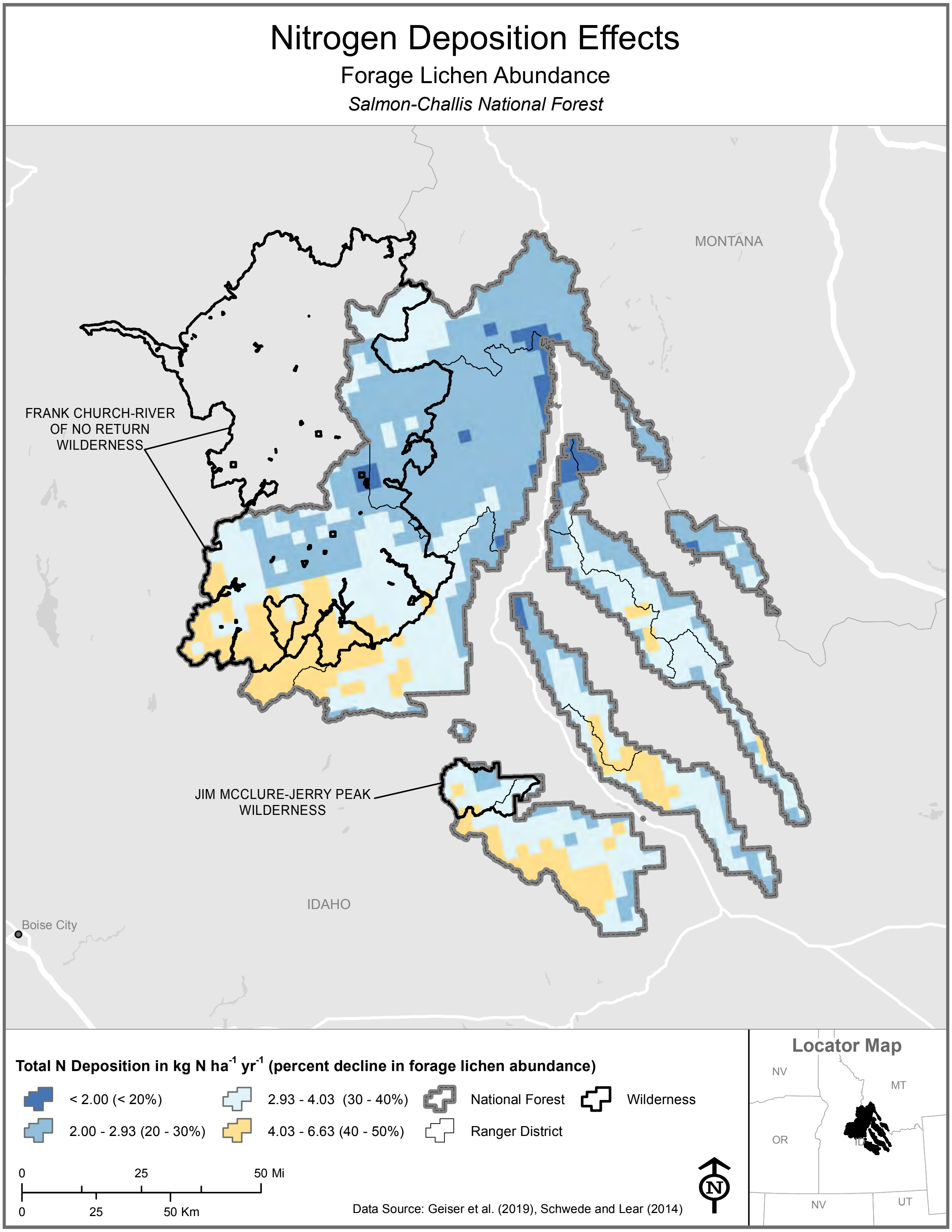


Figure 5-148.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effects to forage lichen abundance within the Salmon-Challis National Forest.

Rafts lined up along the Salmon River, on the Salmon-Challis National Forest. USDA Forest Service photo.

5.3.10.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Salmon-Challis National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL

exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 26 percent (1,460 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-7**). All exceedances were associated with 1 to 5 percent declines in probability of survival and occurred primarily in the central and southern portions of the Forest, including both the Frank Church—River of no Return and Jim McClure—Jerry Peak Wilderness Areas (**Figure 5-149**).

Balsam poplar. The N deposition levels that protect balsam poplar against a >1 percent decline in growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) were exceeded within 41 percent (54 km^2) and 1.5 percent (2 km^2), respectively, of the area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). Exceedances associated with a 1 to 5 percent decline (22 percent, 29 km^2) and a 5 to 10 percent decline in growth rate (19 percent, 25 km^2) were found throughout the southern half of the Forest, including within the Frank Church–River of No Return Wilderness (**Figure 5-150**). The highest magnitudes of exceedance associated with >10 percent declines in growth rate occurred on 0.4 km^2 in the southern portion of the Forest (**Figure 5-150**). The small area (1.5 percent, 2 km^2) of exceedance associated with >1 percent decline in probability of survival occurred within the southern portion of the Forest (**Figure 5-151**). No exceedances were associated with >5 percent decline in probability of survival.

Quaking aspen. There were no exceedances of the N deposition levels that protect quaking aspen against declines in growth rate (13.6 kg N ha^{-1} yr^{-1}) or probability of survival over 10 years (6.6 kg N ha^{-1} yr^{-1}) within any of the area (102 km^2) where this species is modeled as dominant or codominant (**Tables 5-10** and **5-11**, **Figures 5-152** and **5-153**).

Other species of interest that occurred within the Salmon-Challis National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-23**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-23.—Nitrogen deposition level (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Salmon-Challis National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

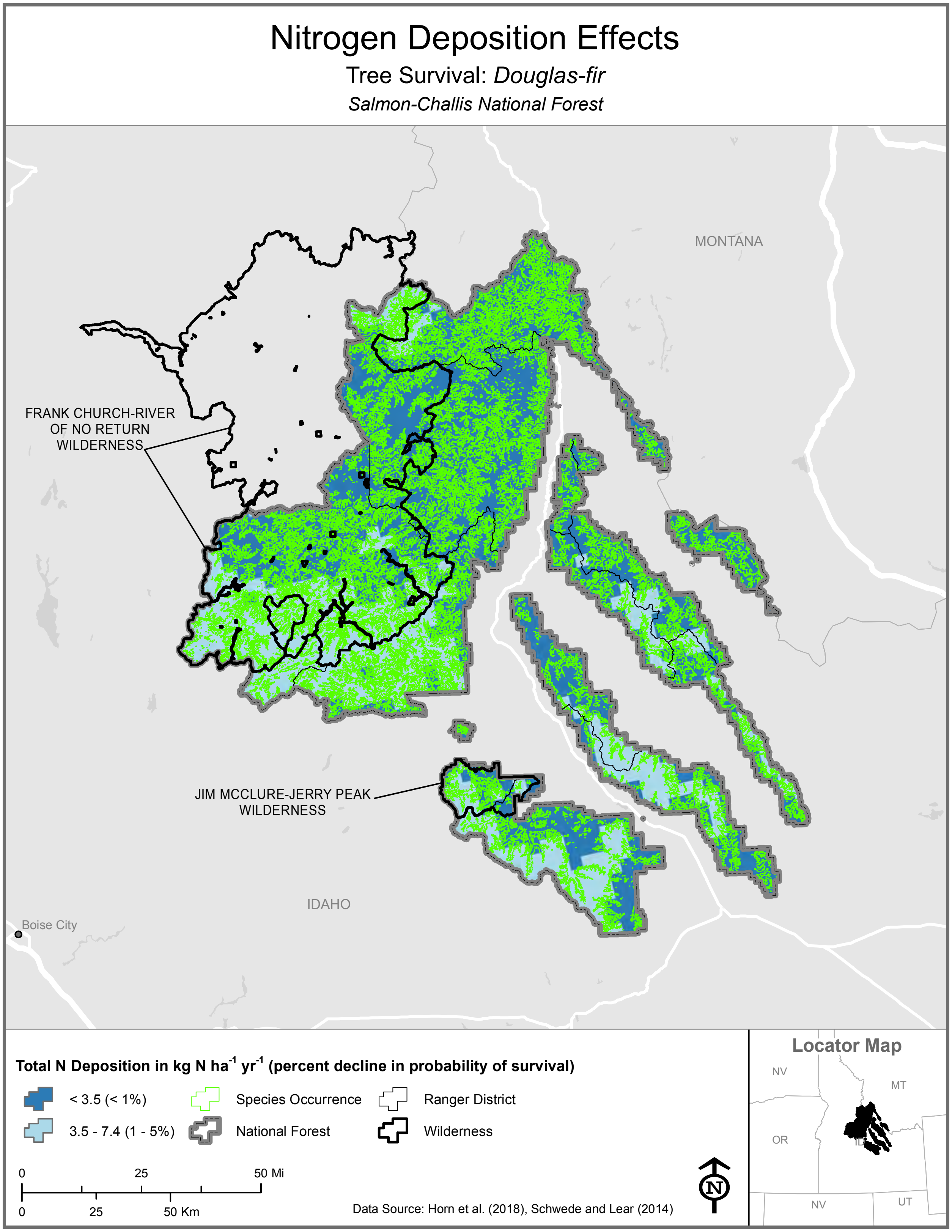


Figure 5-149.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Salmon-Challis National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

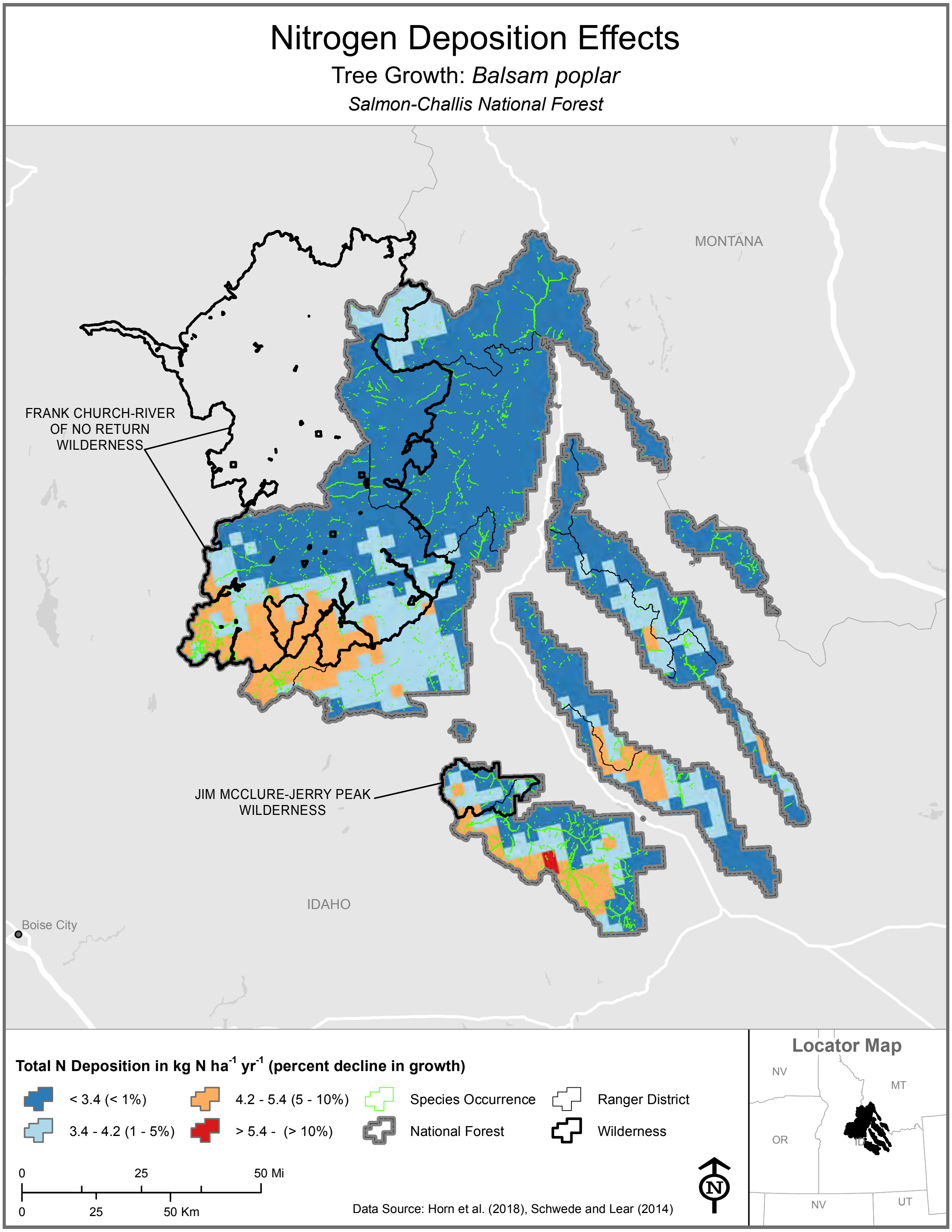


Figure 5-150.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Salmon-Challis National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

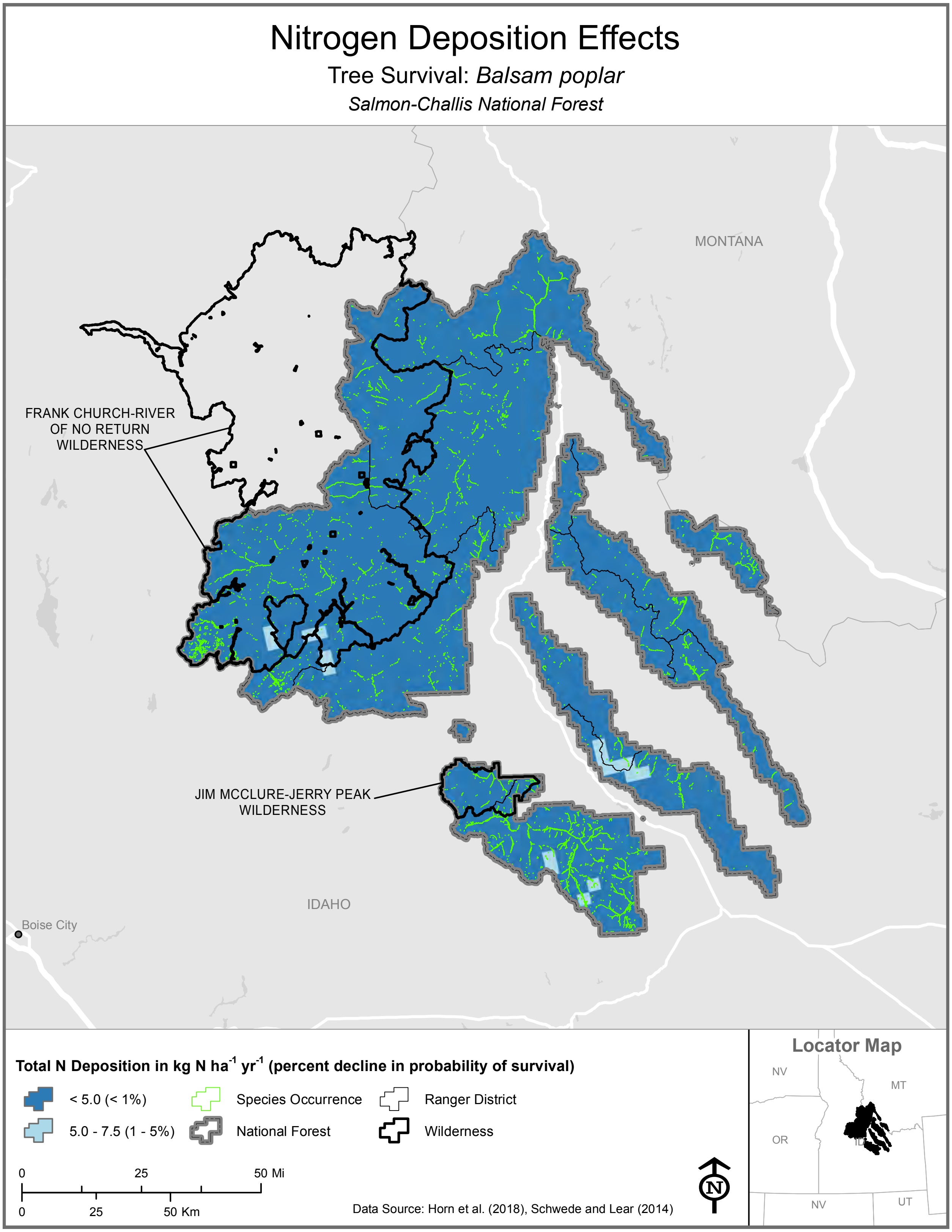


Figure 5-151.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Salmon-Challis National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

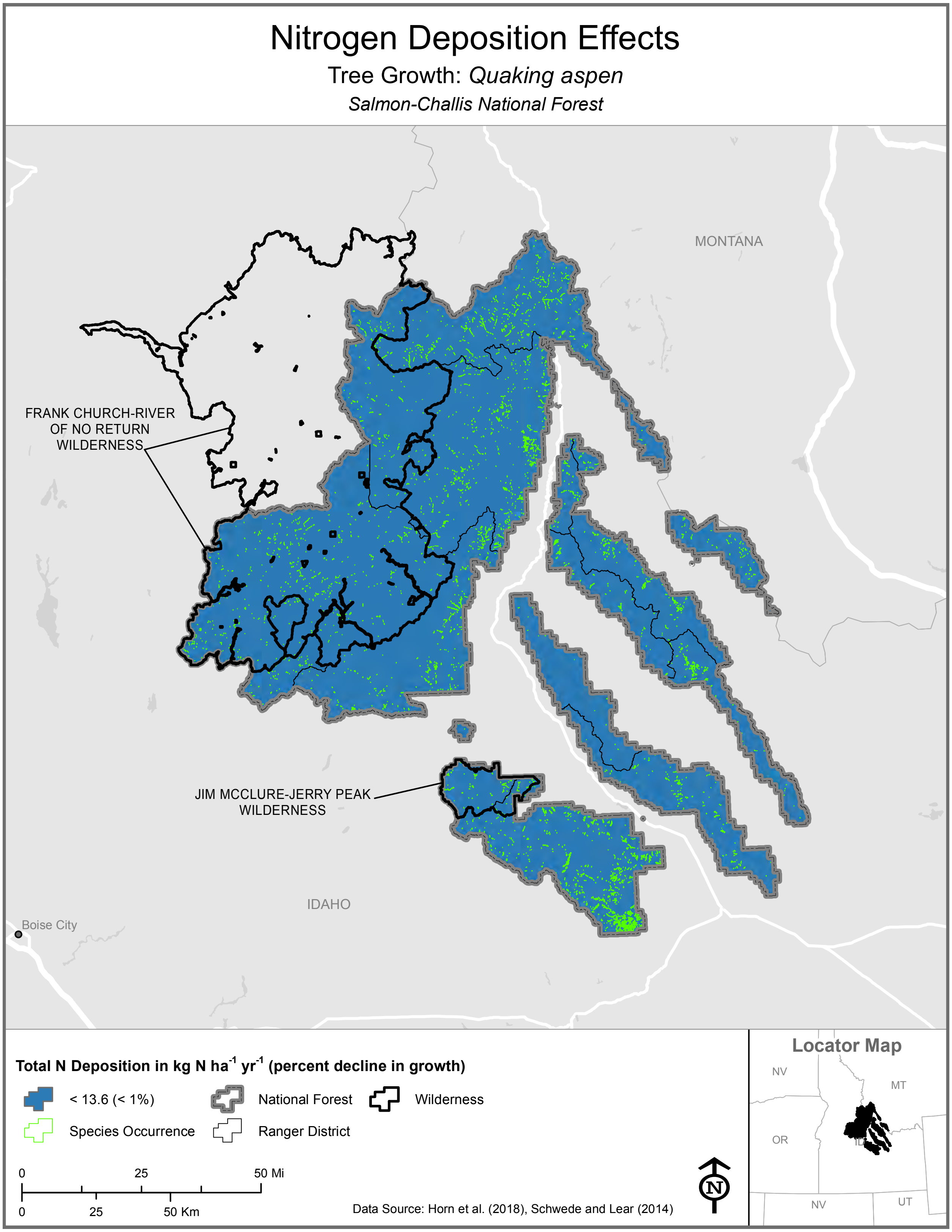


Figure 5-152.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Salmon-Challis National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

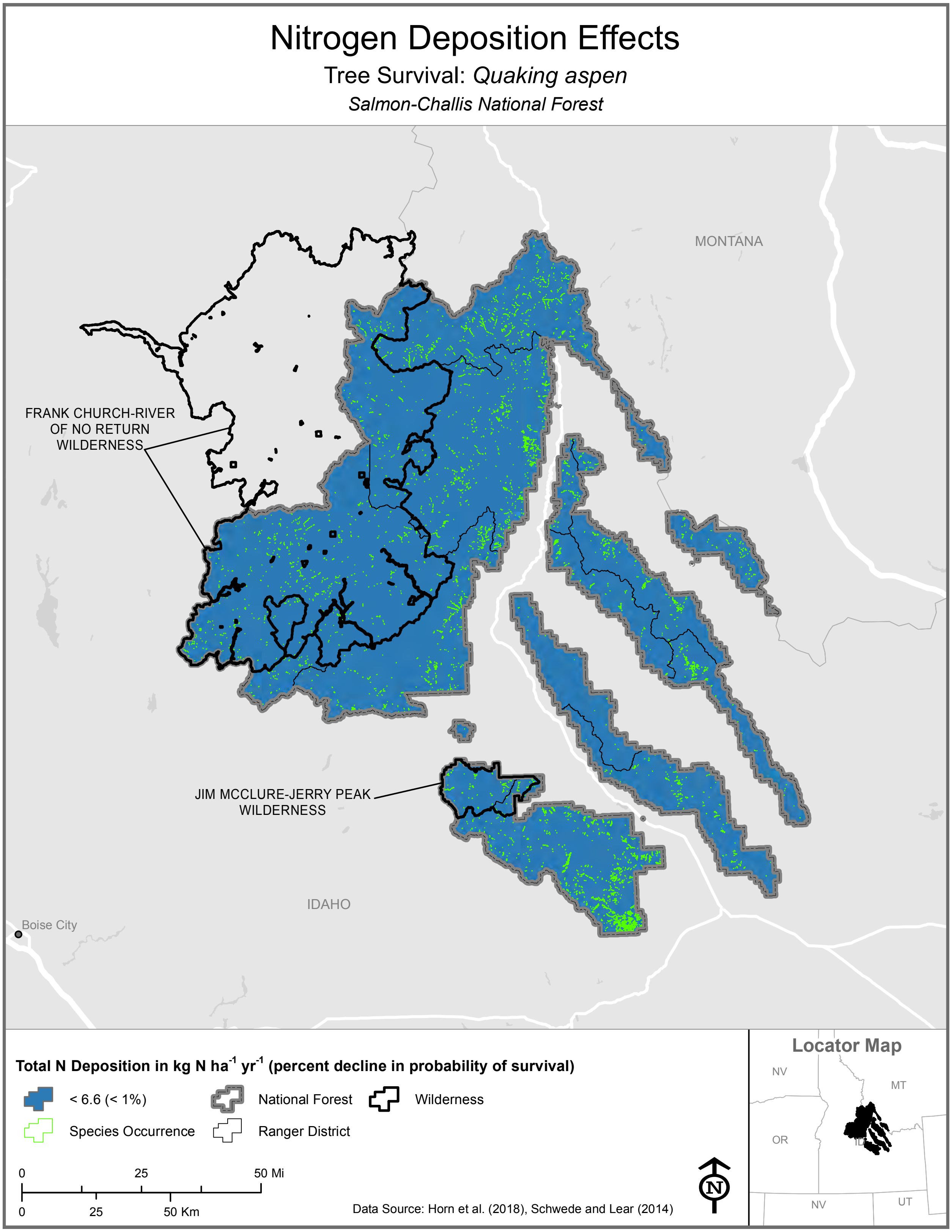


Figure 5-153.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Salmon-Challis National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

The high lakes of the Four Lakes basin hold ice and snow well into July, White Clouds Wilderness area, Sawtooth National Forest. USDA Forest Service photo by Mark Lisk.

5.3.11 Sawtooth National Forest

5.3.11.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 µeq L^{-1} were calculated for 56 waterbodies in the Sawtooth National Forest, with the majority located within the Sawtooth Wilderness (**Table 5-1** and **Figure 5-154**). The 13 waterbodies with the lowest CLs (<2 kg N ha^{-1} yr^{-1}) were located within the Sawtooth Wilderness. The 25 waterbodies with the highest CLs (>8 kg N ha^{-1} yr^{-1}) were located throughout the Forest (**Figure 5-154** and **Figure 5-156**). Nitrogen deposition was high enough to exceed surface water acidification CLs for 27 (48 percent) of waterbodies, all in the Sawtooth Wilderness (**Table 5-2**, **Figure 5-155,** and **Figure 5-157**). Nineteen waterbodies had magnitudes of exceedance that ranged from 2 to 5 kg N ha^{-1} yr^{-1}. These waterbodies have a higher risk to experience biological effects associated with surface water ANC decreasing below 50 µeq L^{-1}, especially if N deposition (under ambient S deposition) persists or increases. Due to the density of sites in the Sawtooth Wilderness, an expanded view of these CLs and CL exceedances are shown in **Figures 5-156** and **5-157**, respectively. There may be additional acid-sensitive water bodies on the Sawtooth National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

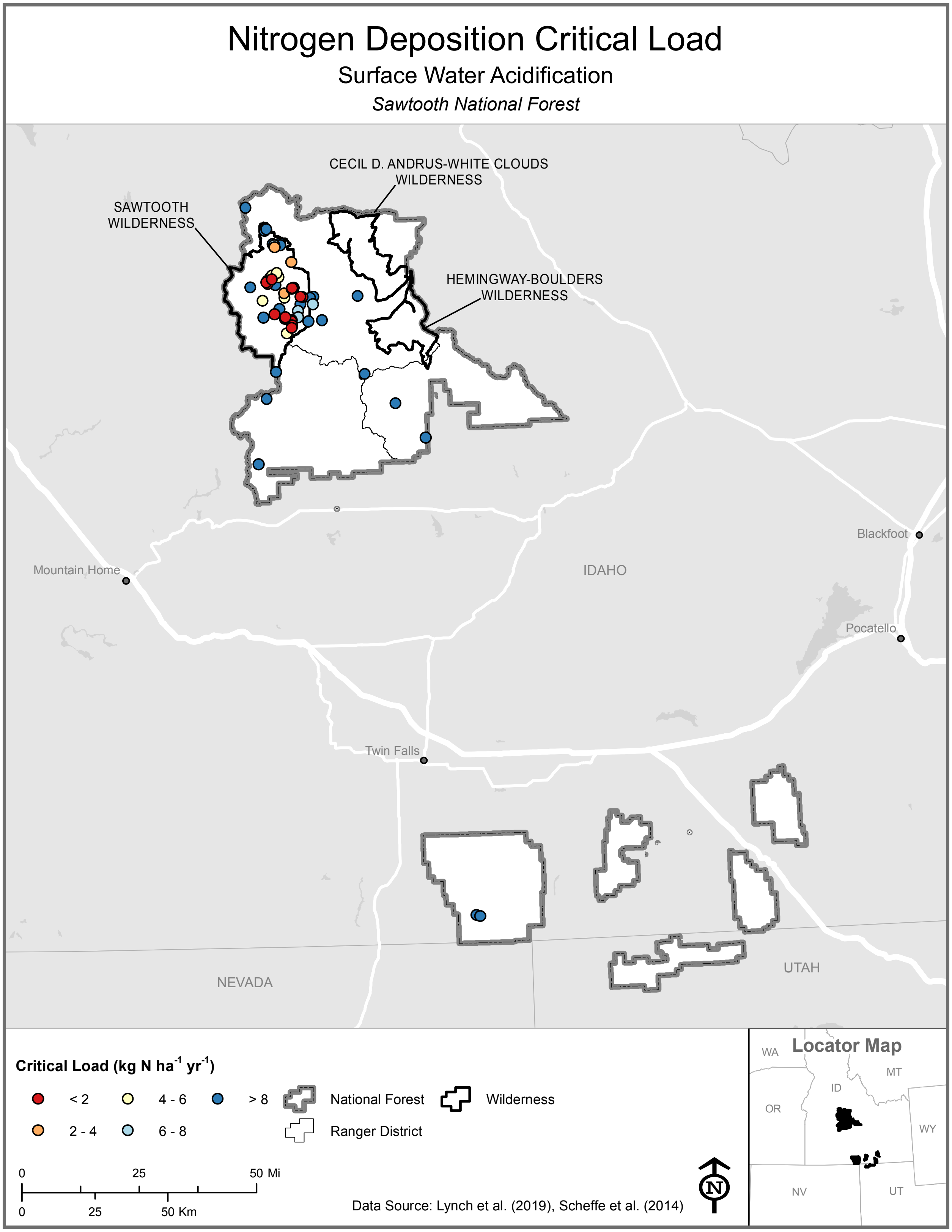


Figure 5-154.— Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Sawtooth National Forest.

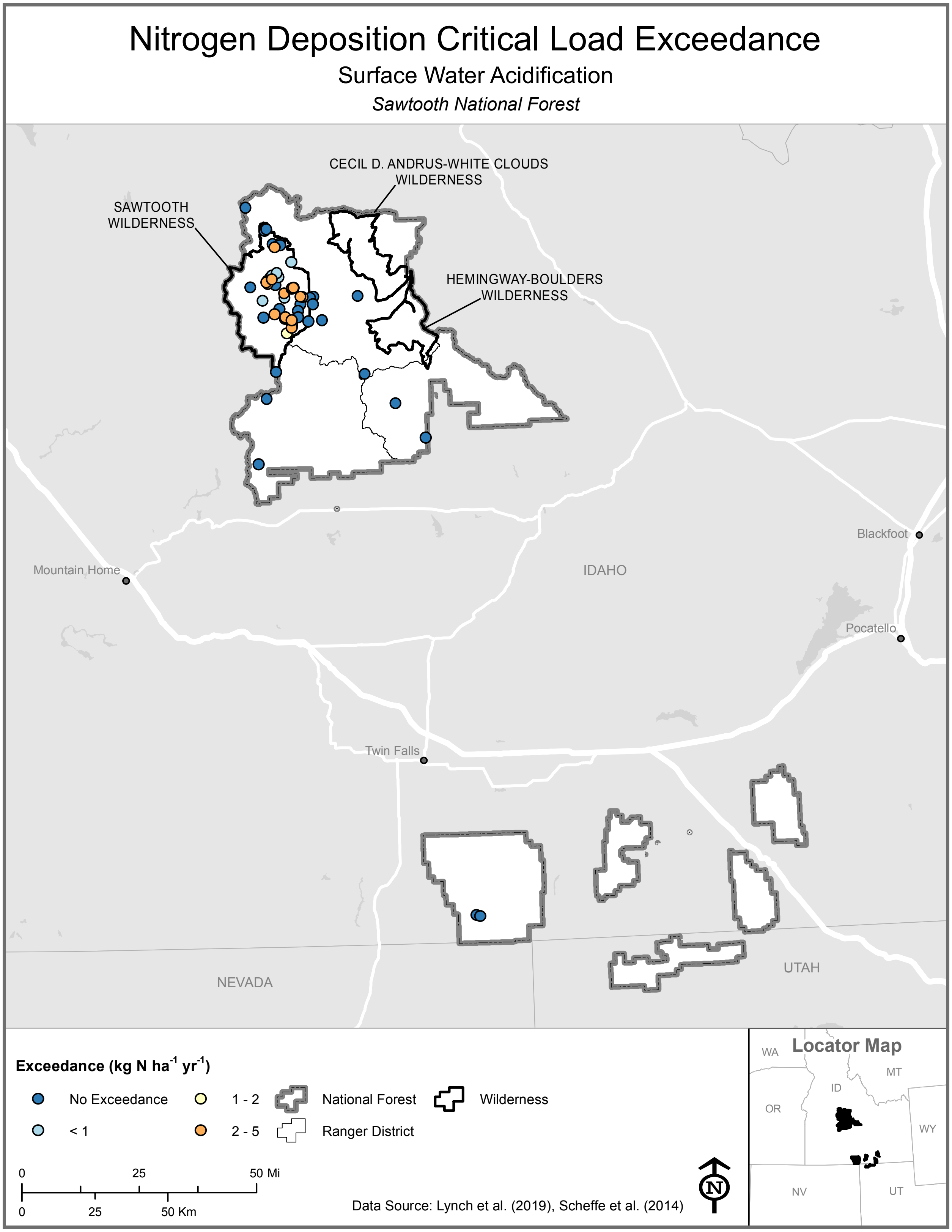


Figure 5-155.— Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Sawtooth National Forest.

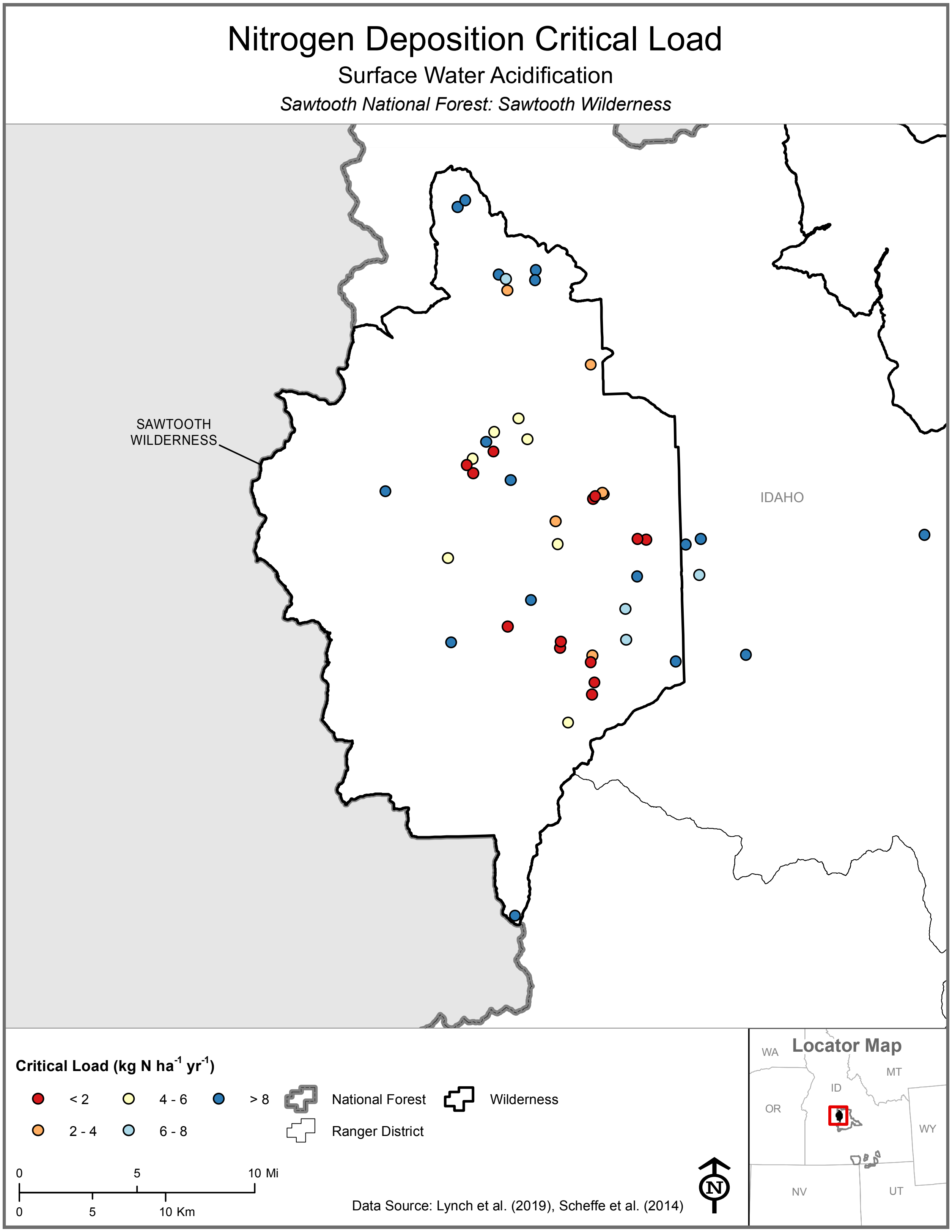


Figure 5-156.— Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Sawtooth Wilderness of the Sawtooth National Forest.

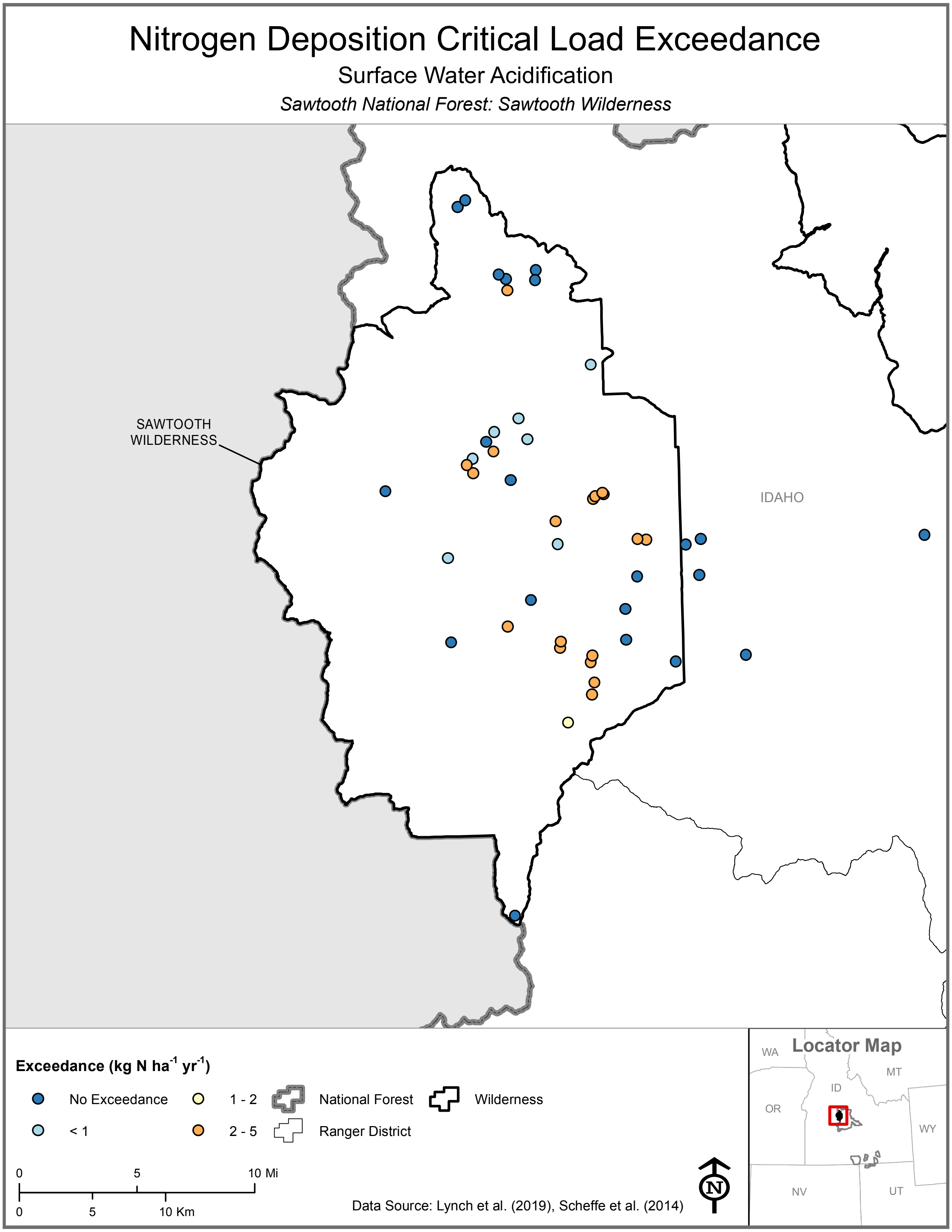


Figure 5-157.—Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 µeq L^{-1} at lake or stream sample sites located within the Sawtooth Wilderness of the Sawtooth National Forest.

White Cloud peaks reflect into a small lake on the Windy Devil Pass in the Sawtooth National Forest. Courtesy photo by Mark Lisk.

5.3.11.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Sawtooth National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 5,937 km^2 (86 percent) of the Forest including the Sawtooth, Cecil D. Andrus-White Clouds, and Hemingway–Boulders Wilderness Areas (**Table 5-3**, **Figure 5-158**). Areas of exceedance followed a generally similar pattern as the CLs and included 5,639 km^2 (90 percent) of the Forest, including all three Wilderness Areas (**Table 5-4**, **Figure 5-159**). The highest magnitudes of exceedance (>4 kg wet N ha^{-1} yr^{-1}) were mapped across 137 km^2 (2.2 percent) of the Forest, including parts of the Sawtooth Wilderness (**Table 5-4**, **Figure 5-159**). Exceedances of 2 to 4 kg wet N ha^{-1} yr^{-1} were mapped across 3,712 km^2 (59 percent) of the Forest (**Table 5-4**, **Figure 5-159**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Sawtooth National Forest are outside the geographic bounds of this study. These areas were marked as “No Data” in **Figure 5-158** and **Figure 5-159**.

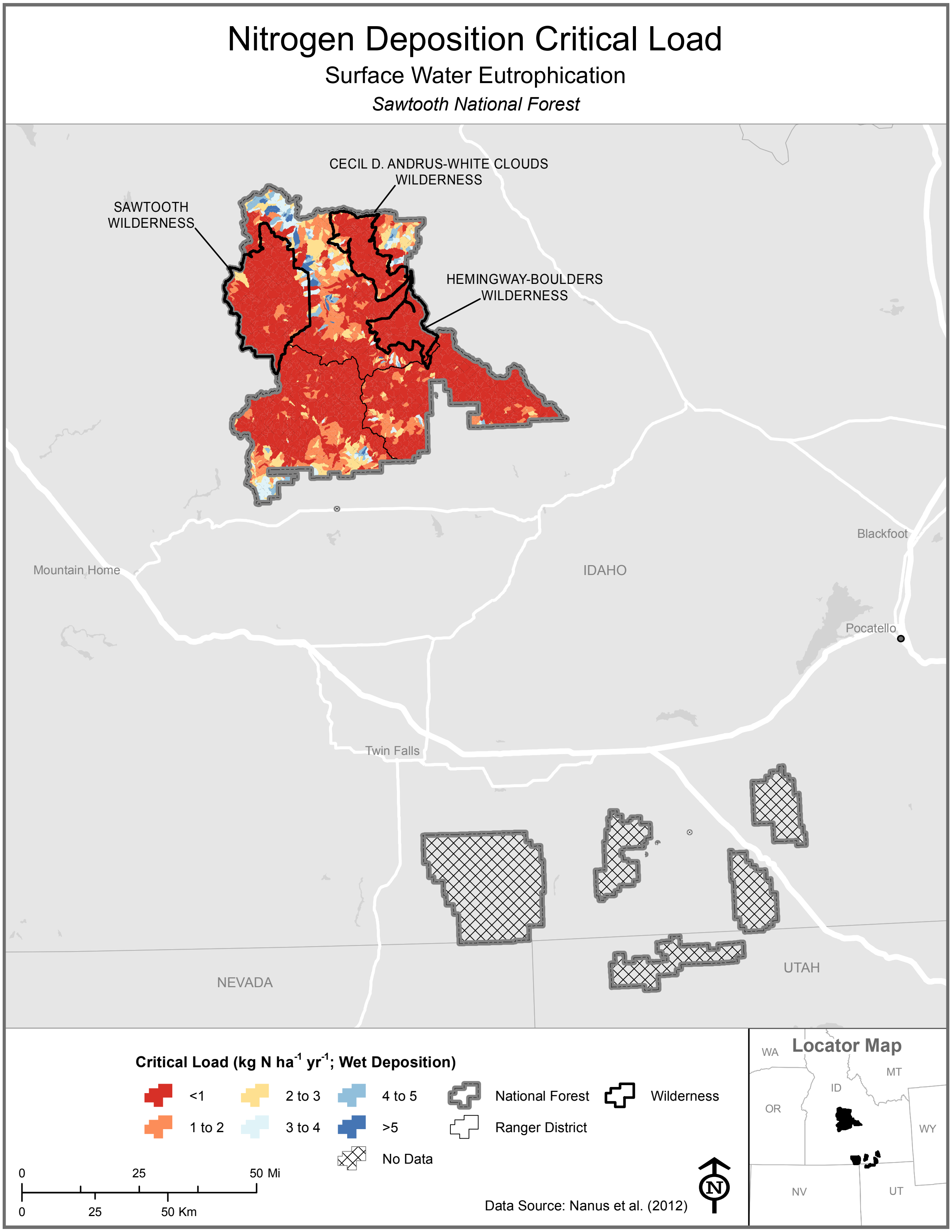


Figure 5-158.—Wet N deposition CLs that protect against surface water eutrophication within the Sawtooth National Forest. Based on a threshold nitrate concentration of 0.5 μmol L^{-1}. Areas designated “No Data” are outside the bounds of the dataset used to calculate CLs.

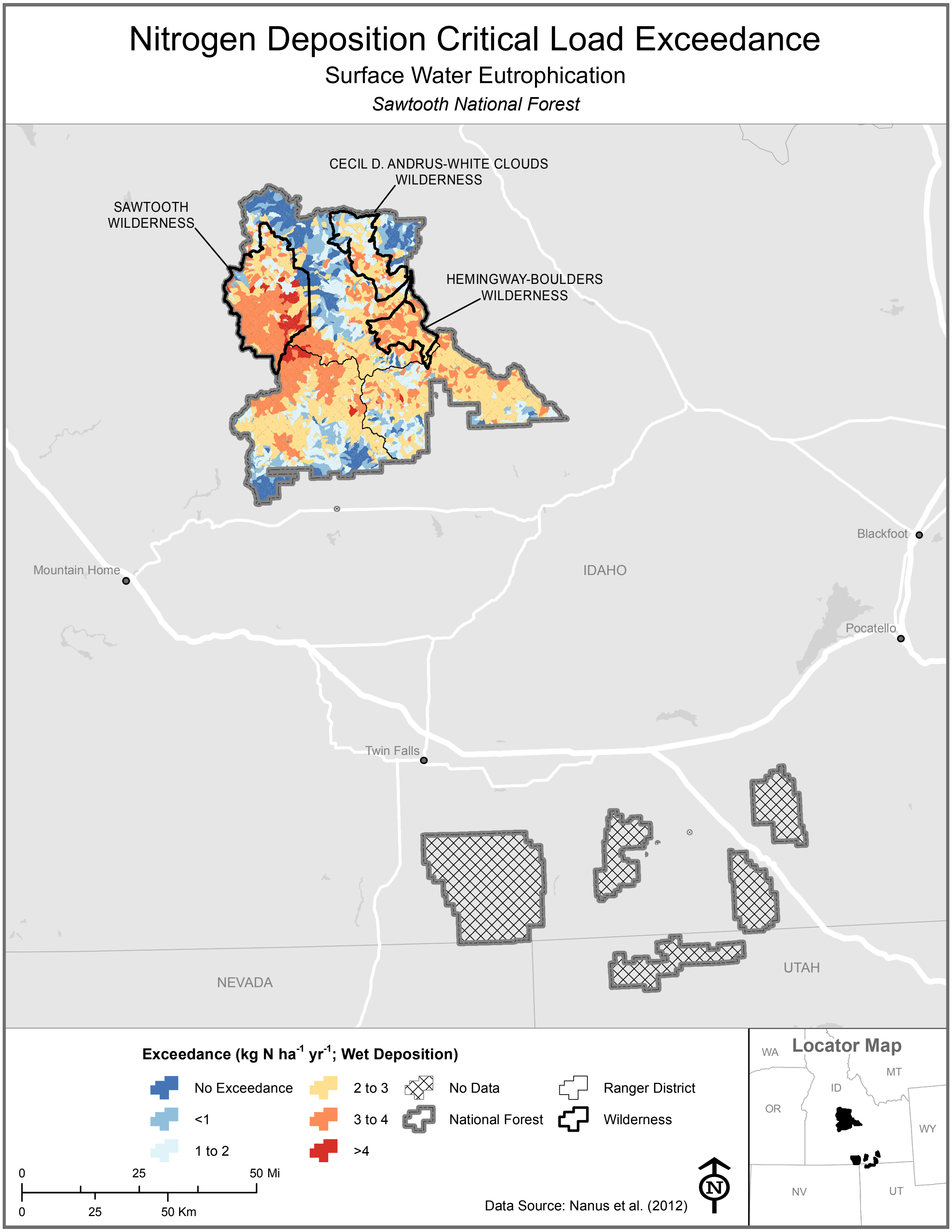


Figure 5-159.— Exceedances for wet N CLs that protect against surface water eutrophication within the Sawtooth National Forest. Based on a threshold nitrate concentration of 0.5 µmol L^{-1}. Areas designated “No Data” are outside the bounds of the dataset used to calculate CLs.

View across Little Redfish Lake, Sawtooth National Forest. USDA Forest Service photo by Nancy Brunswick.

5.3.11.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applied one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 87 percent (7,675 km^2) and 100 percent (8864 km^2), respectively, of the Sawtooth National Forest (**Tables 5-5** and **5-6**). Most of the CL exceedances (82 percent, 7303 km^2) for declines in lichen species richness on the Forest were associated with 20 to 30 percent declines (**Table 5-5** and **Figure 5-160**). The highest magnitudes of CL exceedances, associated with 30 to 50 percent declines in lichen species richness, were located in or near the Sawtooth Wilderness and the southern portion of the Forest (**Table 5-5** and **Figure 5-160**). Ninety-eight percent of the Forest and all three Wilderness Areas had CL exceedances associated with 30 to 50 percent declines in forage lichen abundance. Small portions (1 percent) of the southern part of the Forest had CL exceedances associated with >50 percent declines in forage lichen abundance (**Table 5-6** and **Figure 5-161**). Total N deposition was high enough to exceed both lichen CLs by >5 kg N ha^{-1} yr^{-1} in the southern portion of the Forest (**Figures 5-160** and **5-161**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

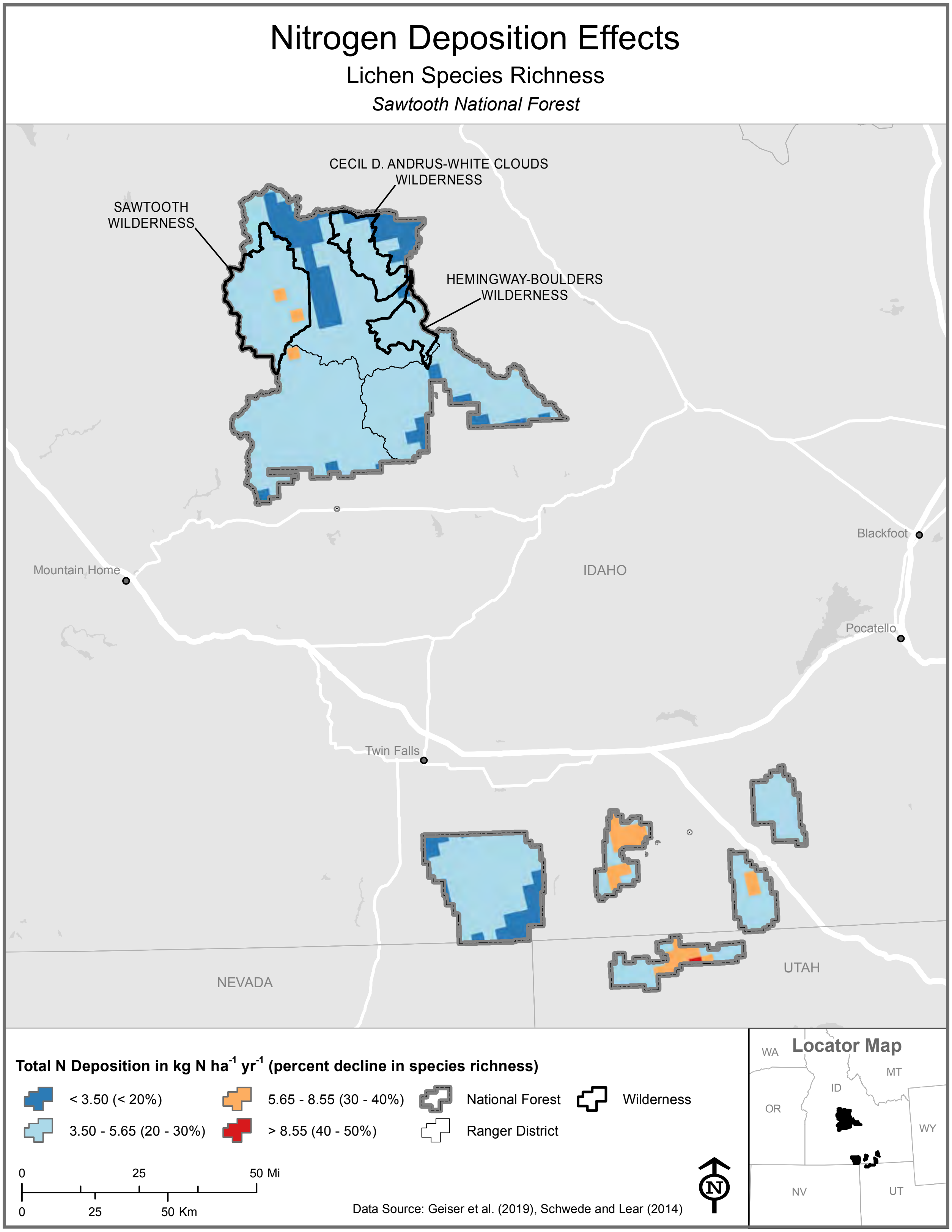


Figure 5-160.— Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Sawtooth National Forest.

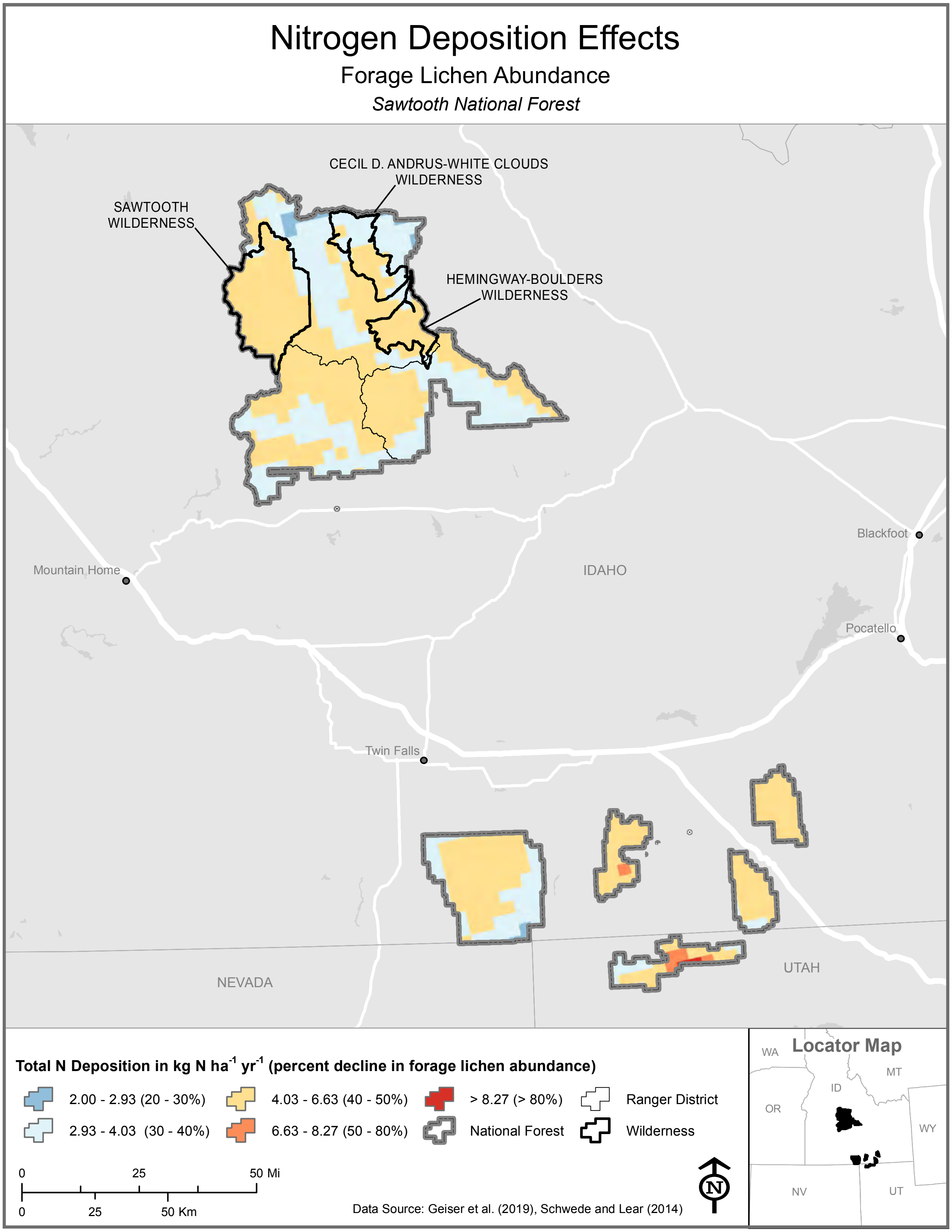


Figure 5-161.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Sawtooth National Forest.

McGowan Peak, Sawtooth National Forest. USDA Forest Service photo by Beckie Nourse.

5.3.11.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national research that defines one CL each for growth rate and probability of survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Sawtooth National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 88 percent (1,792 km^2) of the area where this species is modeled as dominant or codominant on the Sawtooth National Forest. Exceedances occurred in all three Wilderness Areas (**Table 5-7** and **Figure 5-162**). Nearly all exceedances were associated with a 1 to 5 percent decline in probability of

survival with only 4 km^2 (0.4 percent) in the southern part of the Forest associated with a 5 to 10 percent decline (**Table 5-7**). The highest magnitude of exceedance occurred in the southern part of the Forest outside any Wilderness Area (**Figure 5-162**).

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival over 10 years was exceeded within 50 percent (125 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-8**). All exceedances were associated with a 1 to 5 percent decline in probability of survival and occurred throughout the Forest (**Figure 5-163**).

Balsam poplar. The N deposition levels that protects against a balsam poplar against a >1 percent decline in growth rate (3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (5.0 kg N ha^{-1} yr^{-1}) was exceeded within 75 percent (61 km^2) and 5 percent (4 km^2), respectively, of the area where this species is modeled as dominant or codominant (**Tables 5-12** and **5-13**). Fifty-two percent (42 km^2) of exceedances were associated with 1 to 5 percent declines in growth rate. Exceedances associated with 5 to 10 percent declines in growth rate occurred over 21 percent (17 km^2) of the modelled range with only 1.7 percent (1.4 km^2) associated with >10 percent declines in growth rate (**Figure 5-164**). The highest magnitudes of exceedance occurred in the southern portion of the Forest. Exceedances associated with 5 to 10 percent declines in growth rate occurred in all three Wilderness Areas (**Figure 5-164**). Exceedances associated with a > 1 percent declines in probability of survival were infrequent and mostly occurred in the southern portion of the Forest (**Figure 5-165**).

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival over 10 years was exceeded within 17 percent (43 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). Most exceedances were associated with 1 to 5 percent decline in probability of survival and occurred in the southern portion of the Forest where singleleaf pinyon is modeled to occur (**Figure 5-166**).

Quaking aspen. There were no exceedances of N deposition levels associated with declines in growth rate for quaking aspen (**Table 5-10** and **Figure 5-167**). The N deposition level (6.6 kg N ha^{-1} yr^{-1}) that protects quaking aspen against a >1 percent decline in probability of survival over 10 years was exceed within 1.4 percent (6 km^2) of the area where this species is modeled as dominant or codominant (**Table**s **5-11**, **Figure 5-168**). Exceedances were associated with 1 to 5 percent declines in probability of survival and occurred in the southern portion of the Forest (**Figure 5-168**).

Other tree species on the Sawtooth National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-24**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-24.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Sawtooth National Forest. Critical loads (CLs) were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Ponderosa pine	*Pinus ponderosa*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Balsam poplar	**Populus balsamifera**	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	**Populus tremuloides**	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

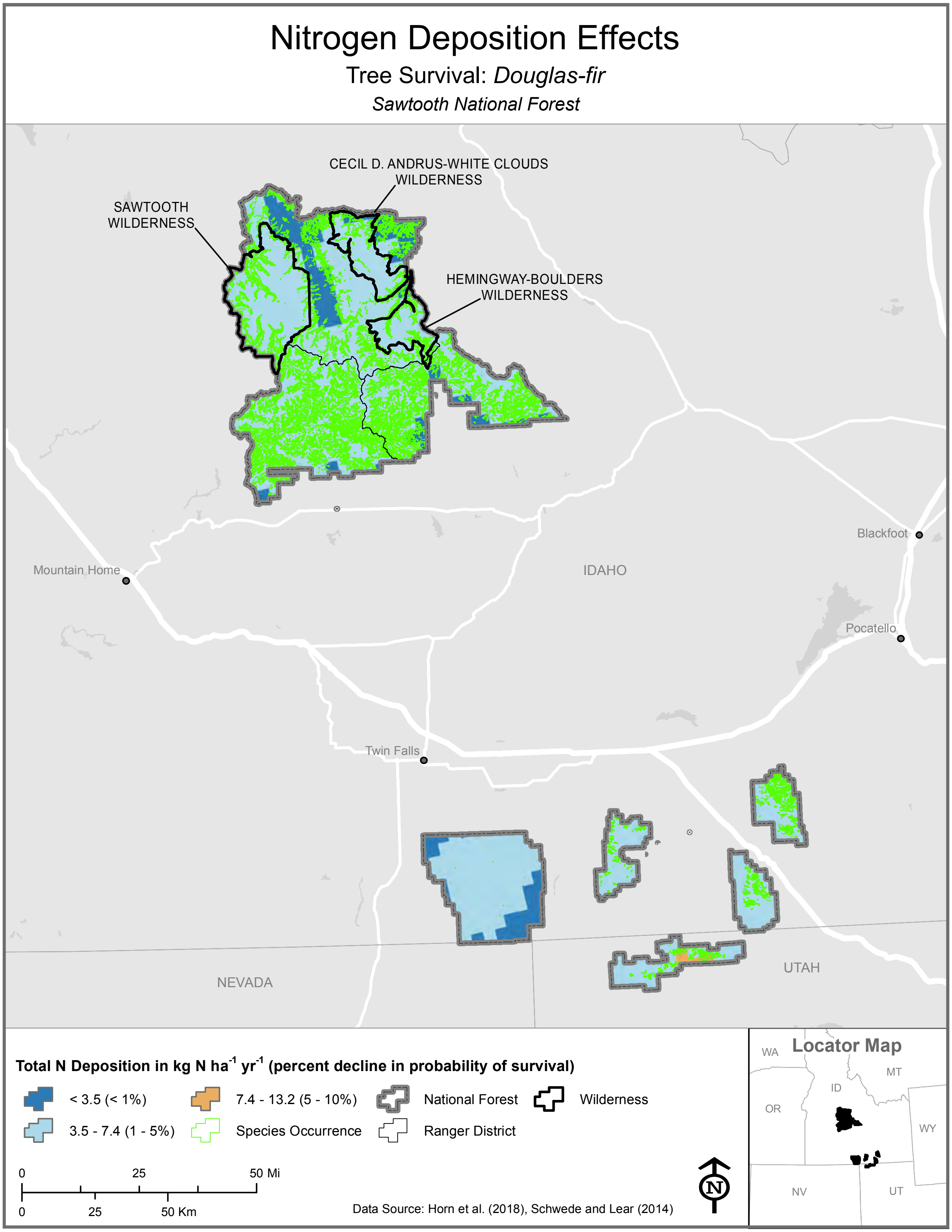


Figure 5-162.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

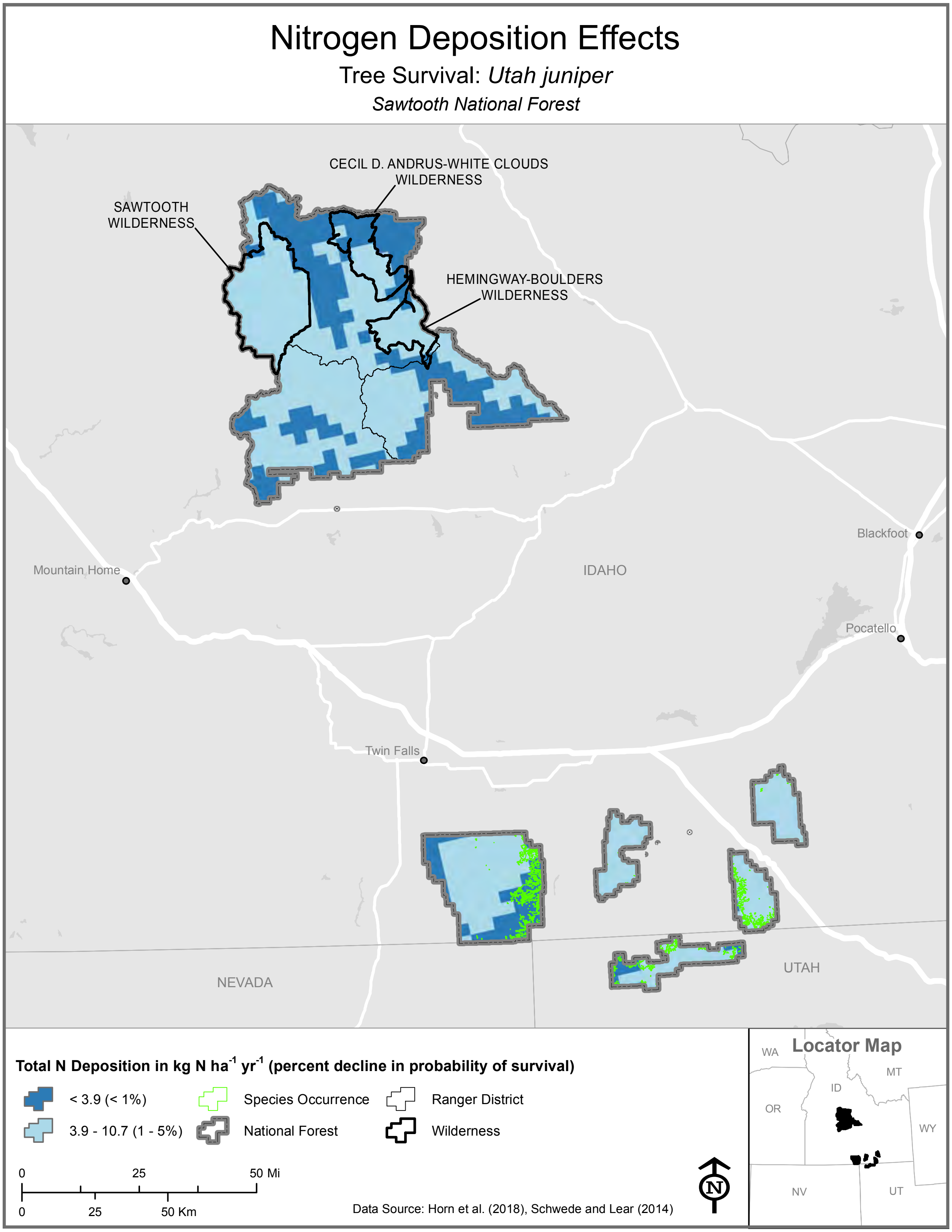


Figure 5-163.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

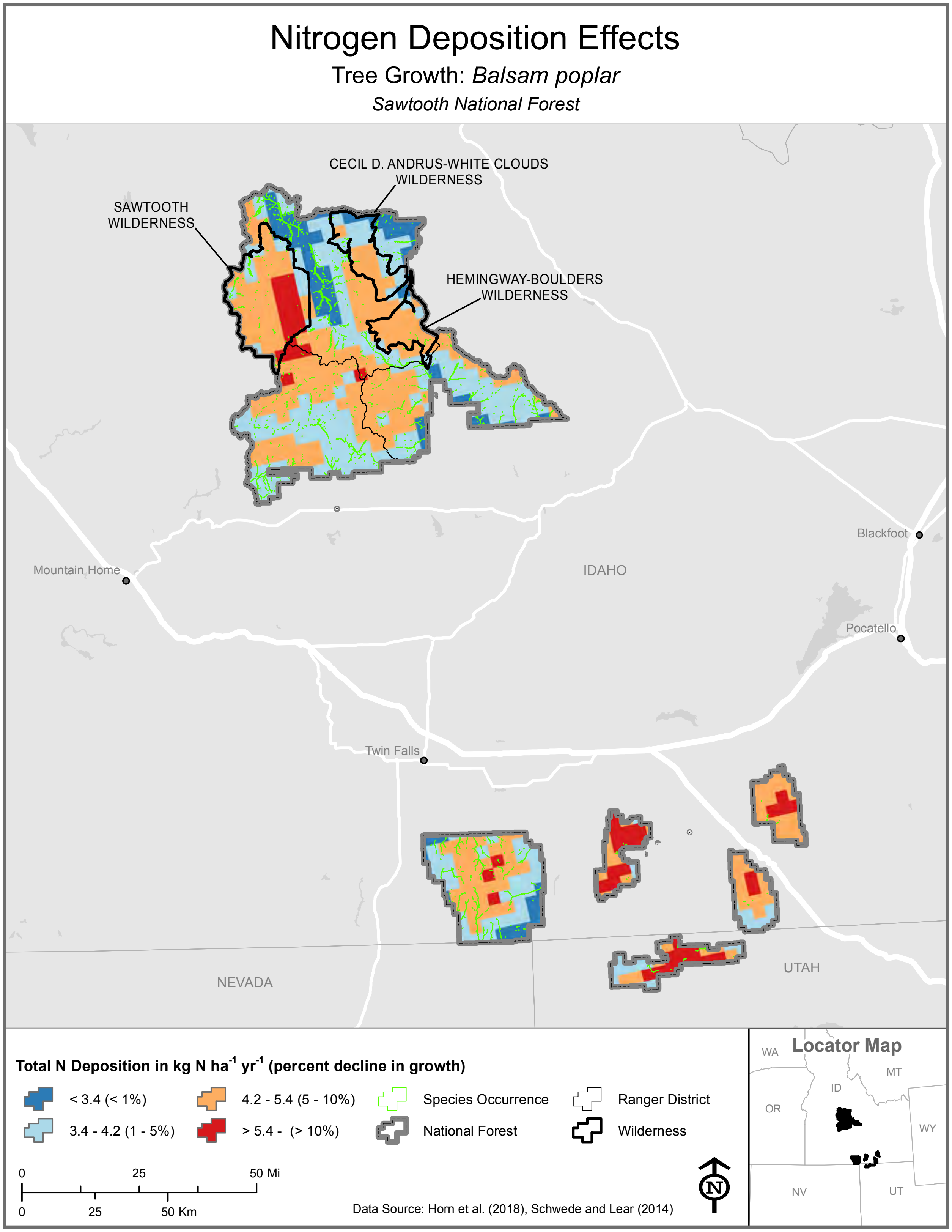


Figure 5-164.—Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

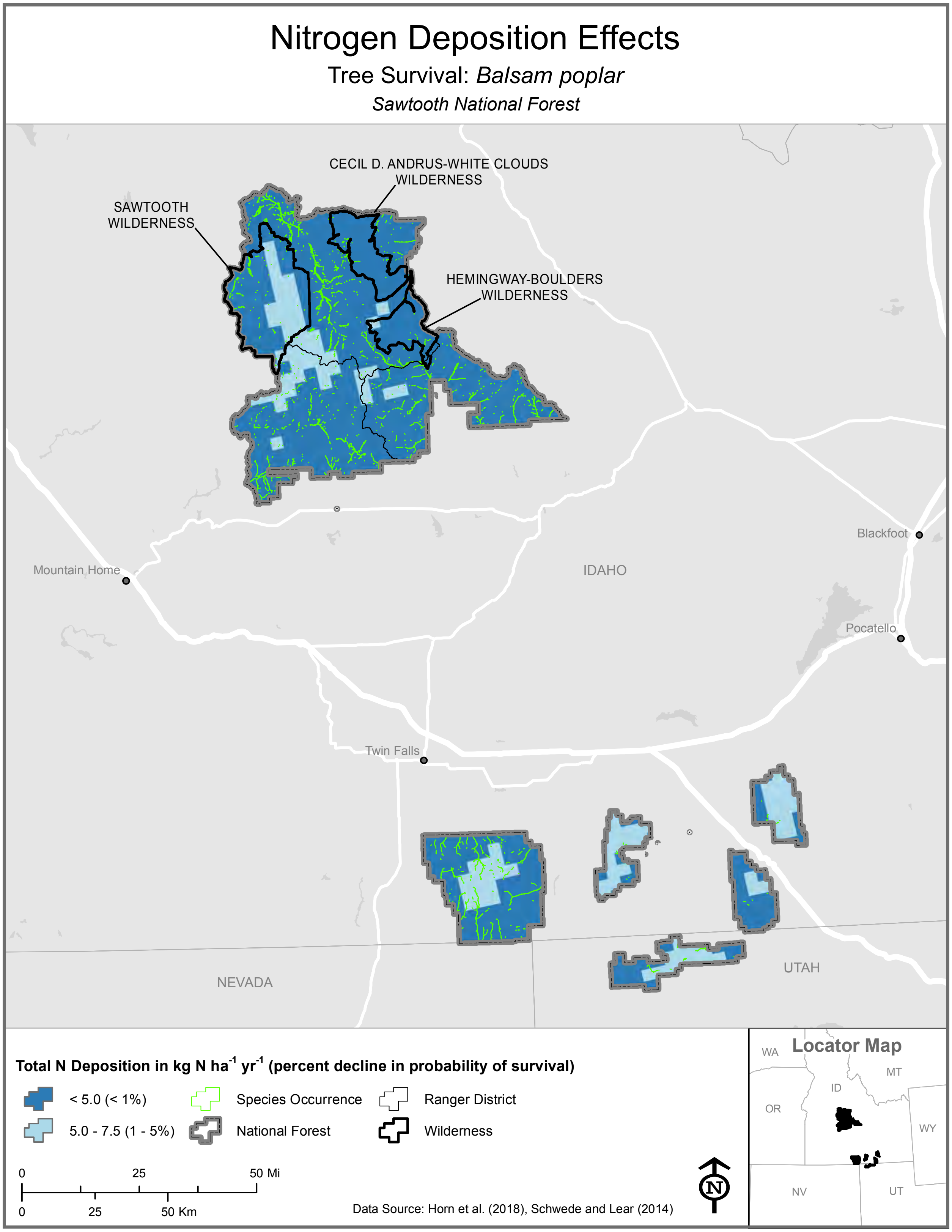


Figure 5-165.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

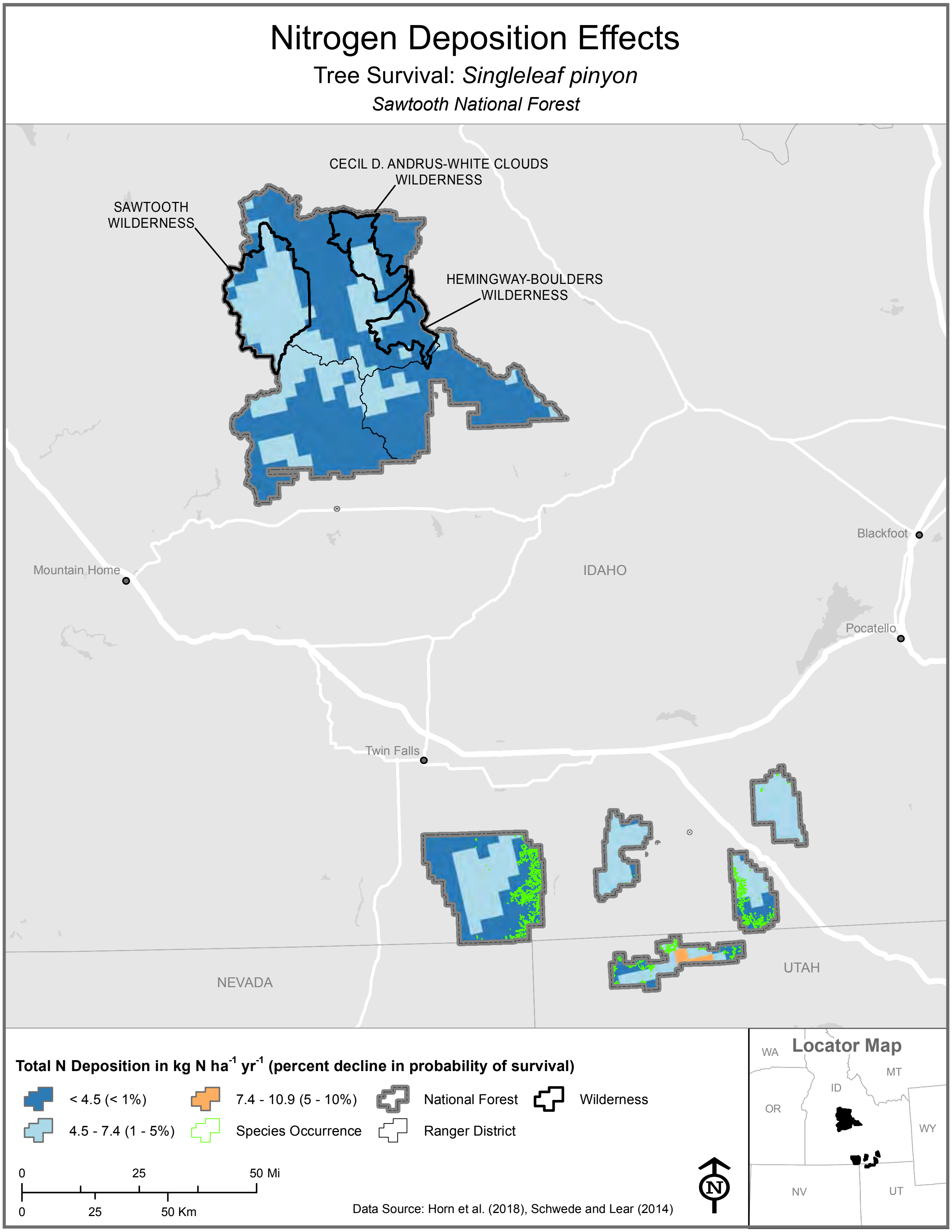


Figure 5-166.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for singleleaf pinyon within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

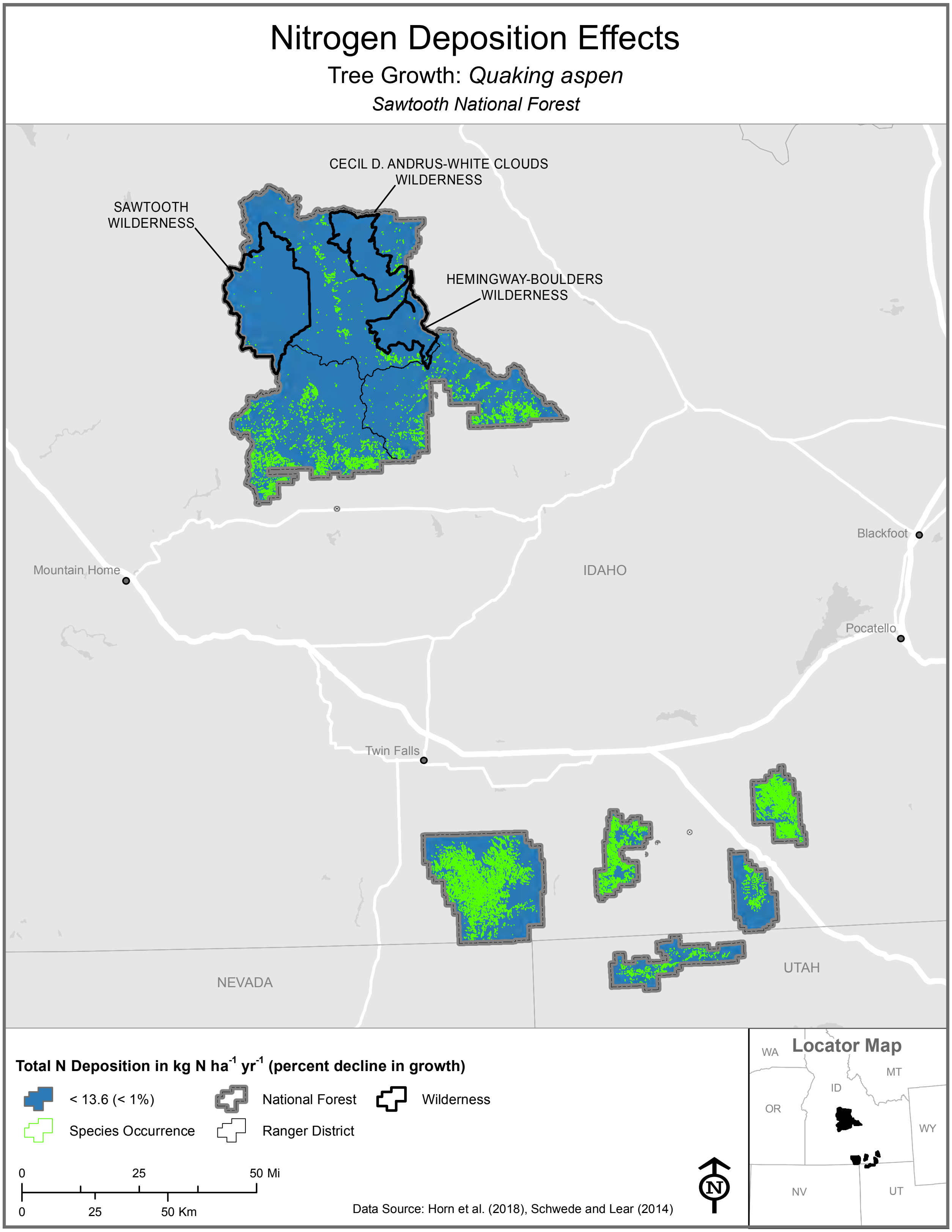


Figure 5-167.— Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

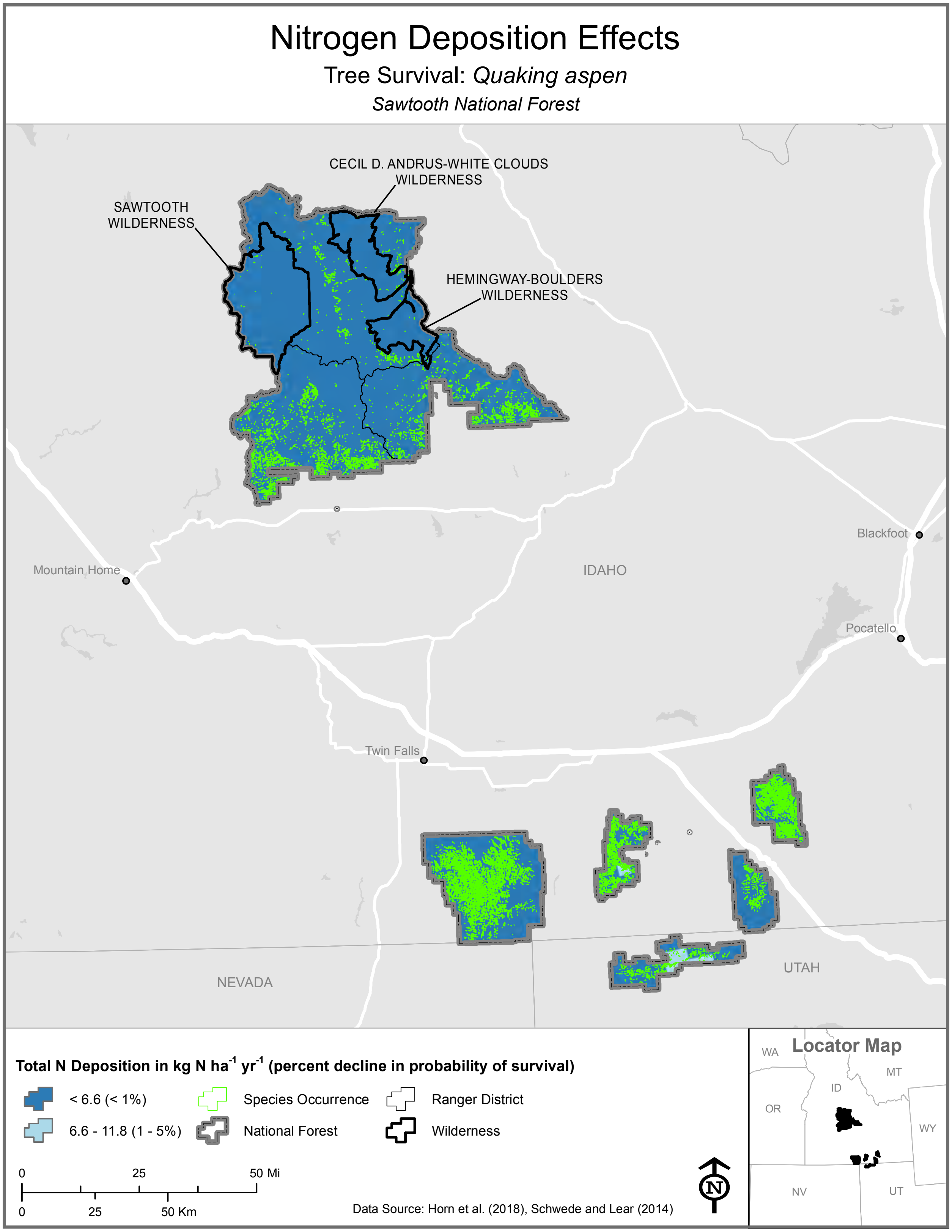


Figure 5-168.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Sawtooth National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Tony Grove on the Uinta-Wasatch-Cache National Forest. USDA Forest Service photo by Kelly Wickens

5.3.12 Uinta-Wasatch-Cache National Forest

5.3.12.1 Surface Water Acidification

Low critical loads (CLs) and high nitrogen (N) deposition are two factors that increase the risk for surface water acidification and associated biological effects. Critical loads that protect surface water ANC from decreasing below 50 μeq L^{-1} were calculated for 33 waterbodies on the Uinta-Wasatch-Cache National Forest. Twenty-four of the waterbodies had high CLs (19 had CLs >8 kg N $ha^{-1}yr^{-1}$) and no exceedances of the CLs. These waterbodies are at low risk to experience effects of acidification associated with an ANC below 50 μeq L^{-1} (**Table 5-1** and **Table 5-2**). Of the two waterbodies that had low CLs (2 to 4 kg N ha^{-1} yr^{-1}), one was in Lone Peak Wilderness (**Table 5-1** and **Figure 5-169**). Nitrogen deposition was high enough to exceed the CLs for nine waterbodies (27 percent), including three exceedances in the High Uinta Wilderness and one exceedance in the Lone Peak Wilderness (**Table 5-2** and **Figure 5-170**). The highest magnitudes of exceedance (>5 kg N ha^{-1} yr^{-1}) occurred at the two waterbodies with the lowest CLs (**Figure 5-169** and **Figure 5-170**). These waterbodies have a higher risk to experience biological effects associated with surface water ANC decreasing below 50 μeq L^{-1} if N deposition (under ambient S deposition) persists or increases. There may be additional acid-sensitive water bodies on the Uinta-Wasatch-Cache National Forest, where water chemistry data were not available, that are experiencing CL exceedances and effects associated with acidification.

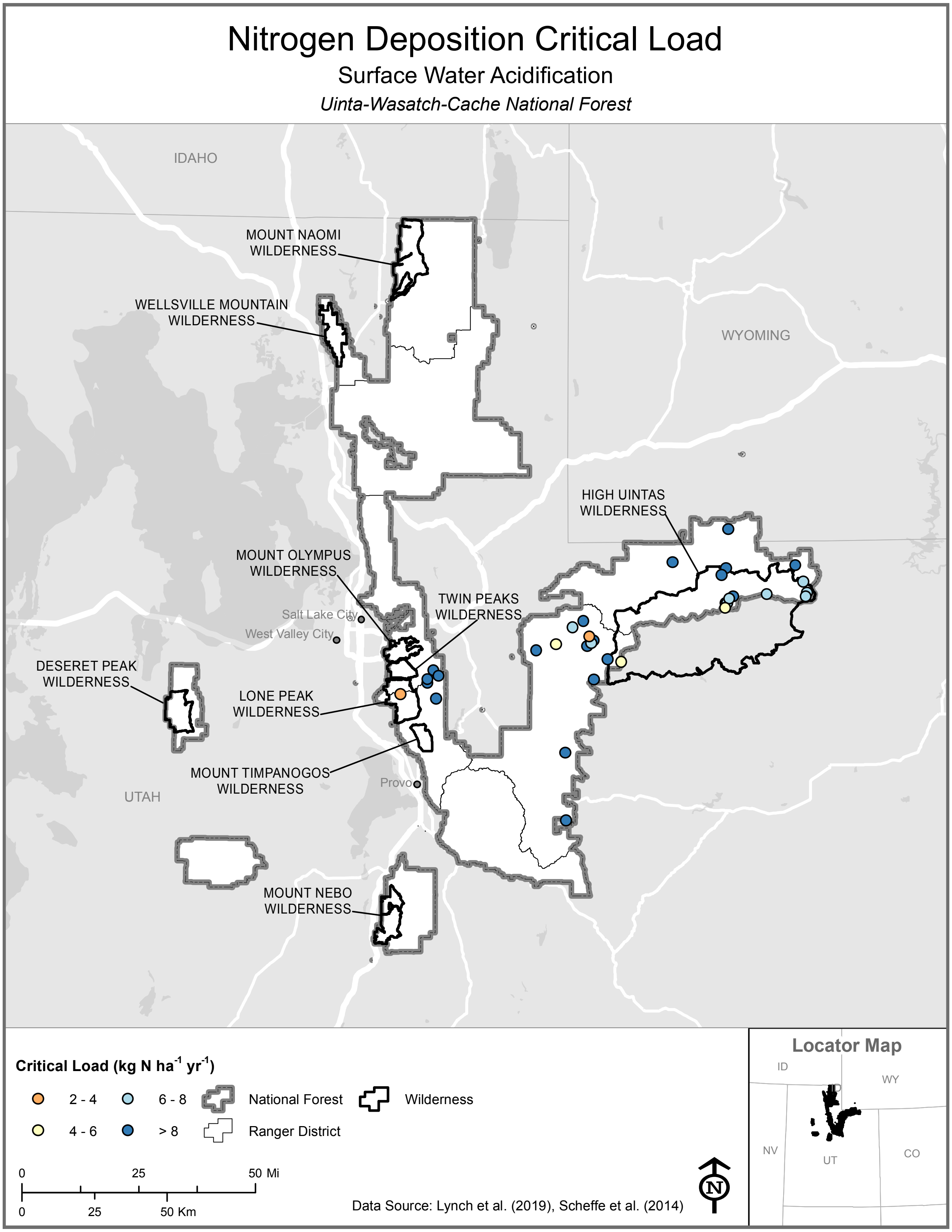


Figure 5-169.— Total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Uinta-Wasatch-Cache National Forest.

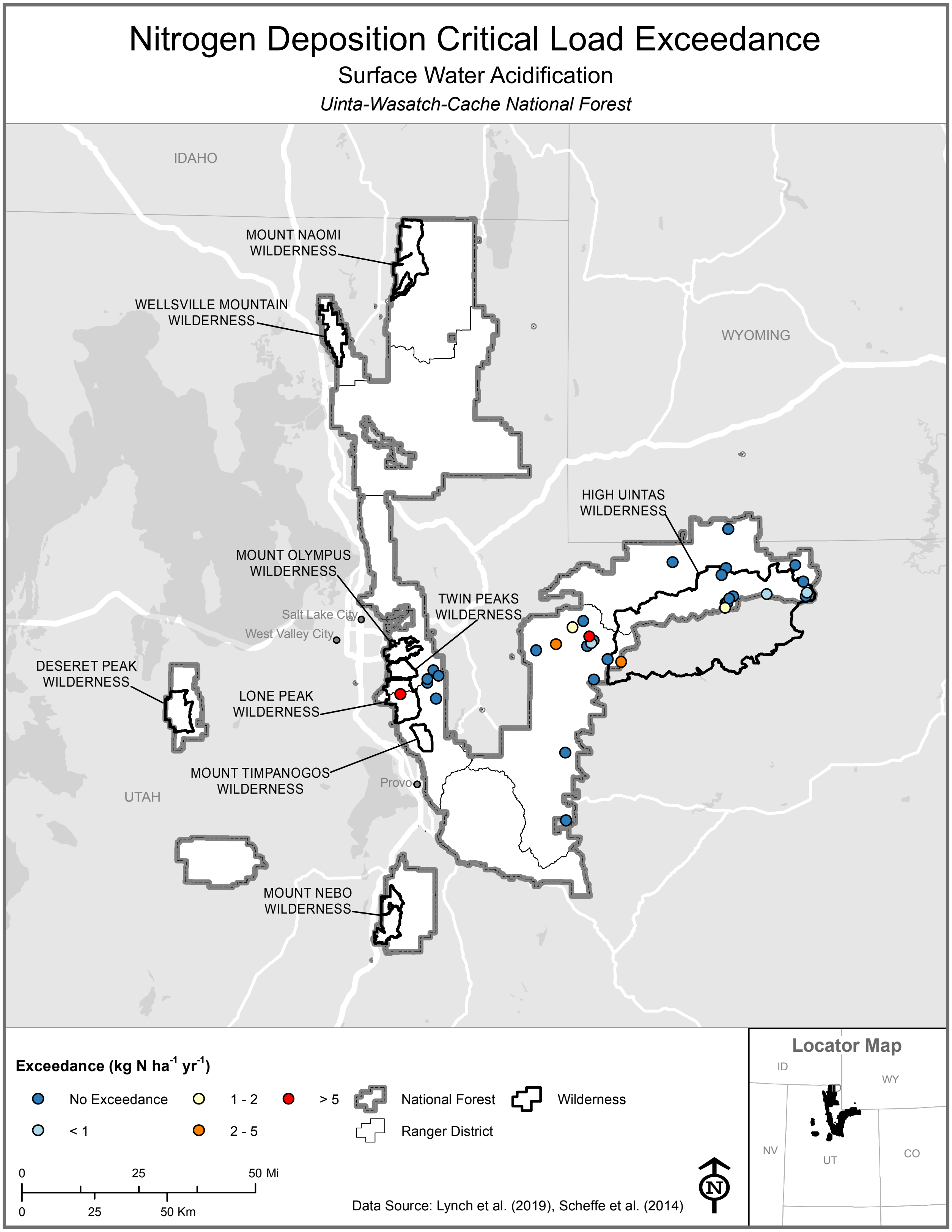


Figure 5-170.— Exceedances of total (wet + dry) N deposition CLs that protect surface water acidification from decreasing below 50 μeq L^{-1} at lake or stream sample sites located within the Uinta-Wasatch-Cache National Forest.

Spring run-off creates this waterfall in Little Cottonwood Canyon on the Uinta-Wasatch-Cache National Forest. USDA Forest Service photo by Bekee Hotze.

5.3.12.2 Surface Water Eutrophication

Nitrogen-based CLs that protect against surface water eutrophication on the Uinta-Wasatch-Cache National Forest were calculated using wet N deposition. The higher the CL the lower the likelihood that a given surface water will experience eutrophication and associated negative biological effects in response to wet N deposition loading. Low CLs (<2 kg wet N ha^{-1} yr^{-1}) were mapped across 3,882 km^2 (40 percent) of the Forest (**Table 5-3**). Most Wilderness Areas where data were available contained low CLs; this included Mount Naomi, Mount Olympus, Twin Peaks, Lone Peak, Mount Timpanogos, and the High Uinta Wilderness Areas (**Figure 5-171**). Areas of exceedance followed a similar pattern as the CLs and included 8,075 km^2 (83 percent) of the Forest (**Table 5-4** and **Figure 5-172**). The highest magnitudes of exceedance (>4 kg wet N ha^{-1} yr^{-1}) were mapped across 2,796 km^2 (29 percent) of the Forest including sections of the previously mentioned Wilderness Areas. Exceedances of 2 to 4 kg wet N ha^{-1} yr^{-1} were mapped across 3047 km^2 (32 percent) throughout the Forest (**Table 5-4** and **Figure 5-172**). Areas with a high magnitude of exceedance are at an increased risk to experience effects associated with surface water eutrophication, including an increase in algae abundance and shifts in diatom communities. Nearly 1,600 km^2 (16.5 percent), primarily in the eastern portion of the Forest, did not exceed CLs for surface water eutrophication. Data from Nanus et al. (2012) were used to assess eutrophication CLs and exceedances. Parts of the Uinta-Wasatch-Cache National Forest are outside the geographic bounds of this study. These areas were marked as “No Data” in **Figure 5-171** and **Figure 5-172**.

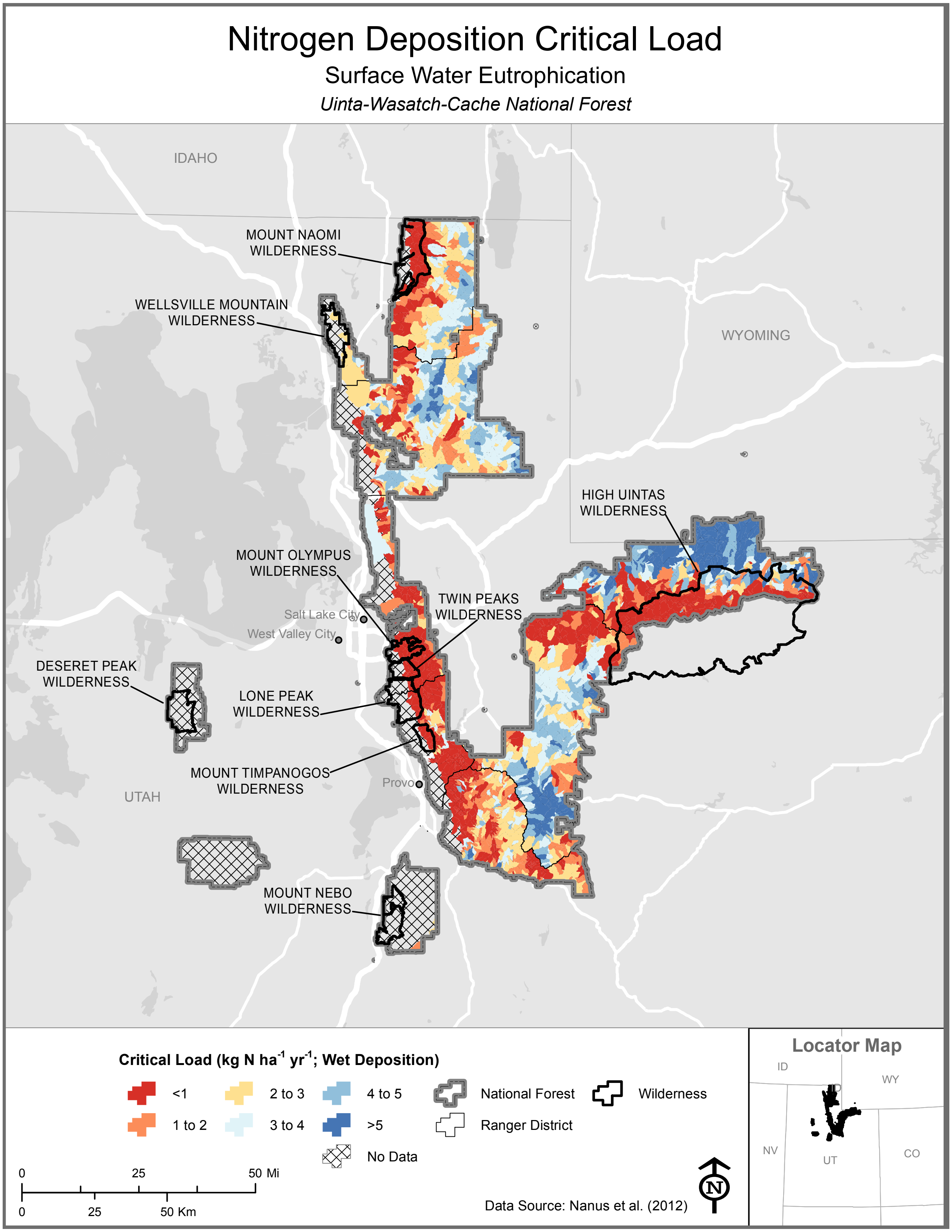


Figure 5-171.— Wet N deposition CLs that protect against surface water eutrophication within the Uinta-Wasatch-Cache National Forest. Based on a threshold nitrate concentration of 0.5 μmol L^{-1}. Areas designated “No Data” are outside the bounds of the dataset used to calculate CLs.

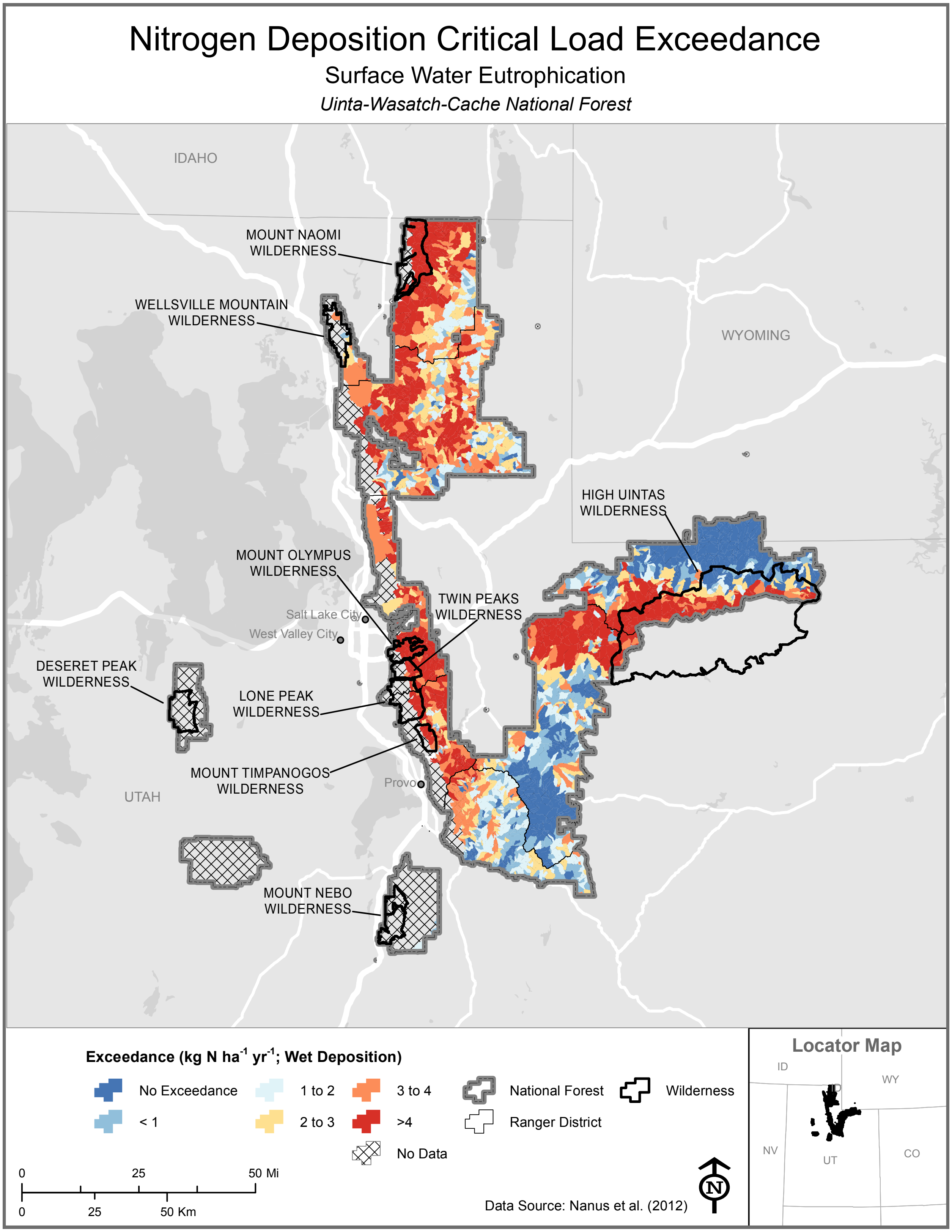


Figure 5-172.— Exceedances of wet N CLs that protect against surface water eutrophication within the Uinta-Wasatch-Cache National Forest based on a threshold nitrate concentration of 0.5 μmol L^{-1}. Areas designated “No Data” are outside the bounds of the dataset used to calculate CLs.

Looking north along the Wasatch Mountains from the summit of the Squaw Peak Road on the Uinta-Wasatch-Cache National Forest USDA Forest Service photo by Nate Lowe.

5.3.12.3 Lichen Species Richness and Abundance

Lichen CLs for species richness and forage lichen abundance were based on national research that applied one CL to each functional group, unlike surface water CLs which were dynamic across the landscape. Because the CL is static, only the CL exceedances were mapped for lichen species richness and forage lichen abundance. Total N deposition exceeded CLs that protect against declines (>20 percent) in lichen species richness and forage lichen abundance within 99 percent and 100 percent (11,789 km^2), respectively, of the Uinta-Wasatch-Cache National Forest (**Table**s **5-5** and **5-6**). Exceedances of the CL on 85 percent of the Forest (10,086 km^2) was associated with 30 to 50 per declines in lichen species richness, including all Wilderness Areas (**Table 5-5** and **Figure 5-173**). Exceedances of the CL on 65 percent of the Forest, including all Wilderness Areas, was associated with >50 percent (**Table 5-6** and **Figure 5-174**). The highest magnitudes (>5 kg N ha^{-1} yr^{-1}) of exceedance were predominantly located in the northern and central portions of the Forest (**Figures 5-173** and **5-174**). The greater the magnitude of exceedance, the higher the risk for declines in lichen species richness and forage lichen abundance and associated adverse impacts. Epiphytic macrolichens are integral parts of forested ecosystems and support various ecosystem functions and services including provisions of food and habitat for deer, birds, insects, and other wildlife. It is important to note that CL exceedances of lichens were mapped for the whole Forest while epiphytic lichens used in these functional groups will not be present throughout 100 percent of the Forest, particularly in high alpine, shrubland, and grassland areas with little to no tree cover or areas where the climatic conditions are not suitable.

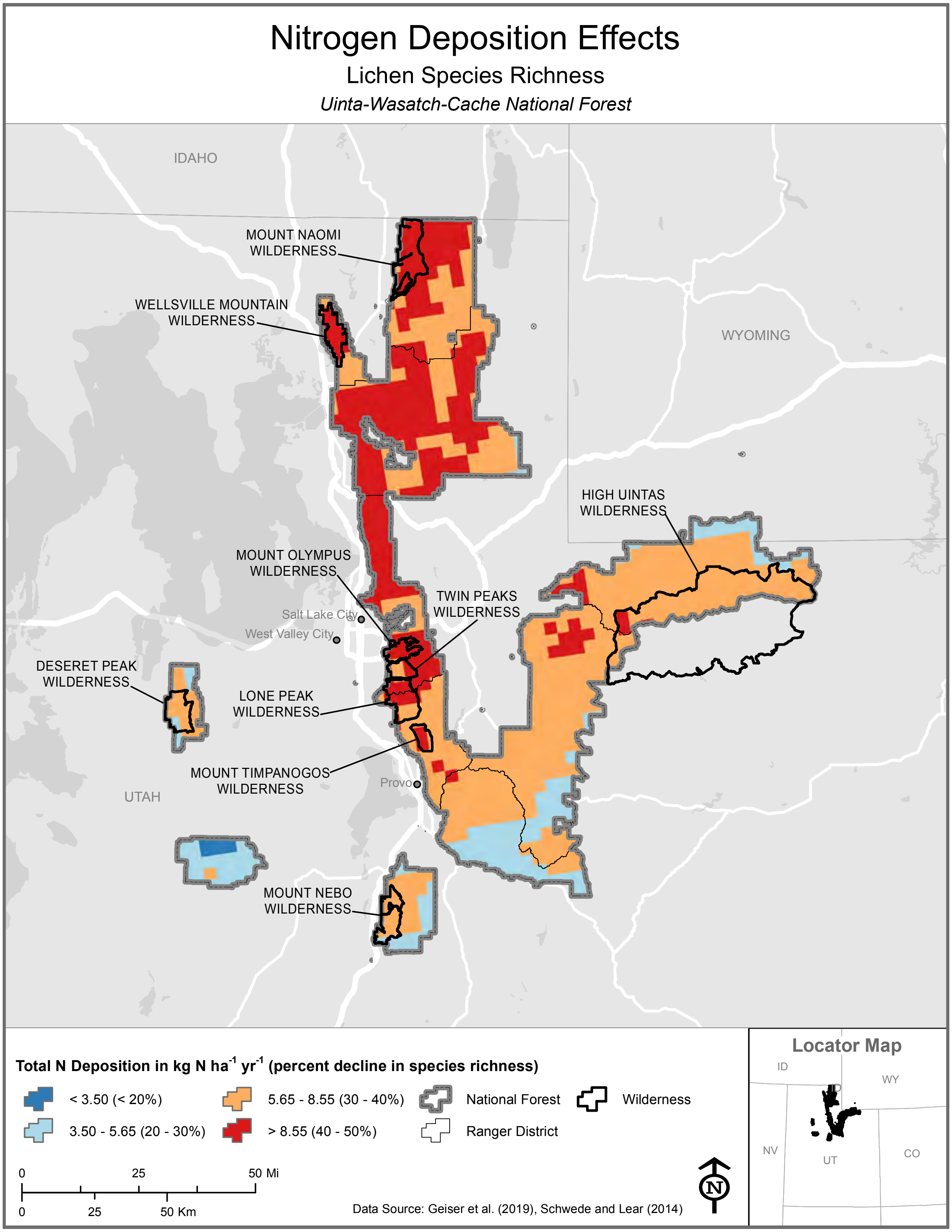


Figure 5-173.—Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to lichen species richness within the Uinta-Wasatch-Cache National Forest.

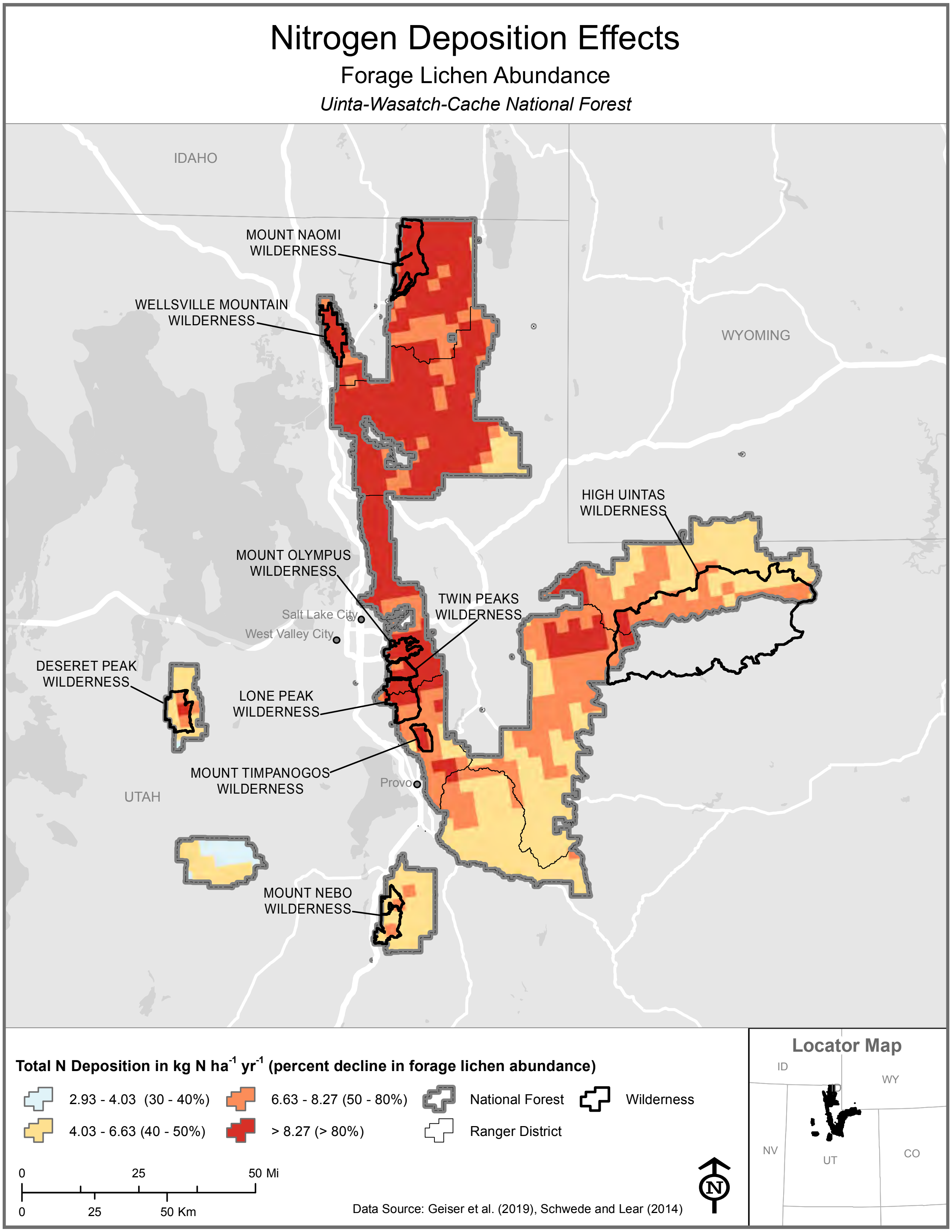


Figure 5-174.— Total (wet + dry) N deposition (average 2015–2017) and the estimated effect to forage lichen abundance within the Uinta-Wasatch-Cache National Forest.

Mid-summer wildflowers along the Mt. Superior trail with Pfeifferhorn Peak in the distance on the Uinta-Wasatch-Cache National Forest. USDA Forest Service photo by Bekee Hotze.

5.3.12.4 Tree Growth and Survival

The CLs for growth rate and probability of survival over 10 years for tree species were based on national analysis that defined one CL each for growth and survival of individual tree species (**Table 4-4**). Exceedances of N deposition levels associated with 1 percent, 5 percent, and 10 percent declines in growth rate and probability of survival were assessed and mapped for each tree species on the Uinta-Wasatch-Cache National Forest that had a declining or threshold response to N deposition. Areas with high magnitude of exceedance are at greater risk to experience declines in tree species growth rate and probability of survival over 10 years. Tree species were mapped based on modeled data of dominant or codominant canopy cover. The modeled canopy cover is a mid-level mapping product. Some vegetation map units contain multiple dominant or codominant species that are indistinguishable at this mapping level such as singleleaf pinon and two-needle pinyon. Therefore, some National Forests may have CL exceedance maps for species which are not actually dominant or even common on the Forest. A list of each National Forest with dominant or codominant canopy and the corresponding vegetation-type map unit used (from VCMQ) is included in appendix 1.

Quaking aspen. The N deposition levels that protect quaking aspen against a >1 percent decline in growth rate (>13.6 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (6.6 kg N ha^{-1} yr^{-1}) were exceeded within 0.2 percent (4 km^2) and 63 percent (1,185 km^2), respectively, of the area

where this species is modeled as dominant or codominant on the Uinta-Wasatch-Cache National Forest (**Table**s **5-10** and **5-11**). Exceedances of the CL associated with 1 to 5 percent declines in growth rate occurred in the northern portion of the Forest (**Figure 5-175**). Exceedances associated with a 1 to 5 percent decline in probability of survival were common throughout the Forest (1,167 km^2), including parts of all Wilderness Areas. Only 1 percent (18 km^2) of the Forest, mostly in Mount Naomi Wilderness Area, exceeded the N deposition level that protects against a 5 to 10 percent decline in probability of survival (**Figure 5-176**).

Balsam poplar. The N deposition levels that protect balsam poplar against a >1 percent decline in growth rate (>3.4 kg N ha^{-1} yr^{-1}) and probability of survival over 10 years (>5.0 kg N ha^{-1} yr^{-1}) were exceeded within nearly 100 percent (118 km^2) and 95 percent (112 km^2), respectively, of the area where this species is modeled as dominant or codominant (**Table**s **5-12** and **5-13**). Exceedances were predominantly associated with >10 percent declines in growth rate, including some Wilderness Areas (**Figure 5-177**). Exceedances associated with 5 to 10 percent declines in probability of survival were common throughout the Forest with only 2.2 km^2 (1.8 percent) of balsam poplar modelled range associated with >10 percent declines in probability of survival (**Figure 5-178**).

Douglas-fir. The N deposition level (3.5 kg N ha^{-1} yr^{-1}) that protects Douglas-fir against a >1 percent decline in probability of survival over 10 years was exceeded within 100 percent (862 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-7**). Seventy percent (607 km^2) of exceedances were associated with 5 to 10 percent declines in probability of survival. The highest magnitudes of exceedance occurred in the northern and western portions of the Forest, including most Wilderness Areas (**Figure 5-179**).

Utah juniper. The N deposition level (3.9 kg N ha^{-1} yr^{-1}) that protects Utah juniper against a >1 percent decline in probability of survival was exceeded within 93 percent (287 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-8**). Exceedance associated with 1 to 5 percent declines in probability of survival were common throughout the Forest with only 5 km^2 (1.5 percent) of Utah juniper modelled range associated with 5 to 10 percent declines in probability of survival (**Figure 5-180**).

Singleleaf pinyon. The N deposition level (4.5 kg N ha^{-1} yr^{-1}) that protects singleleaf pinyon against a >1 percent decline in probability of survival probability of survival over 10 years was exceeded within 85 percent (263 km^2) of the area where this species is modeled as dominant or codominant (**Table 5-9**). Areas of exceedance were common throughout the forest, including Wilderness Areas where this species is modelled to occur (**Figure 5-181**). Exceedances (56 percent, 172 km^2) associated with 1 to 5 percent declines in probability of survival occurred in the southern part of the Forest (**Table 5-9)**. Higher magnitudes of exceedance occurred in the central and northern portions of the Forest with estimated 5 to 10 percent declines in probability of survival for 87 km^2 (28 percent) and >10 percent declines for 4 km^2 (1.3 percent), including some Wilderness Areas (**Table 5-9** and **Figure 5-181**).

Other tree species on the Uinta-Wasatch-Cache National Forest where N response curves for growth rate and probability of survival were generated had either increasing or flat responses to N deposition (**Table 5-25**). An increased growth rate as a result of N deposition may change the composition and structure of the Forest.

Table 5-25.—Nitrogen deposition levels (kg N ha^{-1} yr^{-1}) that protect against declines of 1 percent, 5 percent, and 10 percent in tree growth rate and probability of survival (over 10 years) for species (in bold font) found within the Uinta-Wasatch-Cache National Forest. Critical loads (CLs)were not calculated for species with an increasing or flat response to N deposition.

Common name	Species name	Form of response to N deposition		CL	N levels that protects against various percent declines in tree growth and survival		
					1%	5%	10%
White fir	*Abies concolor*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Subalpine fir	*Abies lasiocarpa*	Growth	Increasing	---	---	---	---
		Survival	Flat	---	---	---	---
Boxelder	*Acer negundo*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Utah juniper	***Juniperus osteosperma***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**1.7**	**3.9**	**10.7**	**23.6**
Engelmann spruce	*Picea engelmannii*	Growth	Decreasing[a]	---	---	---	---
		Survival	Threshold[a]	---	---	---	---
Lodgepole pine	*Pinus contorta*	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Common or two-needle pinyon	Pinus edulis	Growth	Flat	---	---	---	---
		Survival	Flat	---	---	---	---
Singleleaf pinyon	***Pinus monophylla***	Growth	Increasing	**---**	**---**	**---**	**---**
		Survival	**Threshold**	**3.0**	**4.5**	**7.4**	**10.9**
Balsam poplar	***Populus balsamifera***	**Growth**	**Decreasing**	**3.3**	**3.4**	**4.2**	**5.4**
		Survival	**Threshold**	**3.7**	**5.0**	**7.5**	**10.2**
Quaking aspen	***Populus tremuloides***	**Growth**	**Threshold**	**11.1**	**13.6**	**17.5**	**21.3**
		Survival	**Threshold**	**4.2**	**6.6**	**11.8**	**18.4**
Douglas-fir	***Pseudotsuga menziesii***	Growth	Increasing	---	---	---	---
		Survival	**Threshold**	**2.0**	**3.5**	**7.4**	**13.2**

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

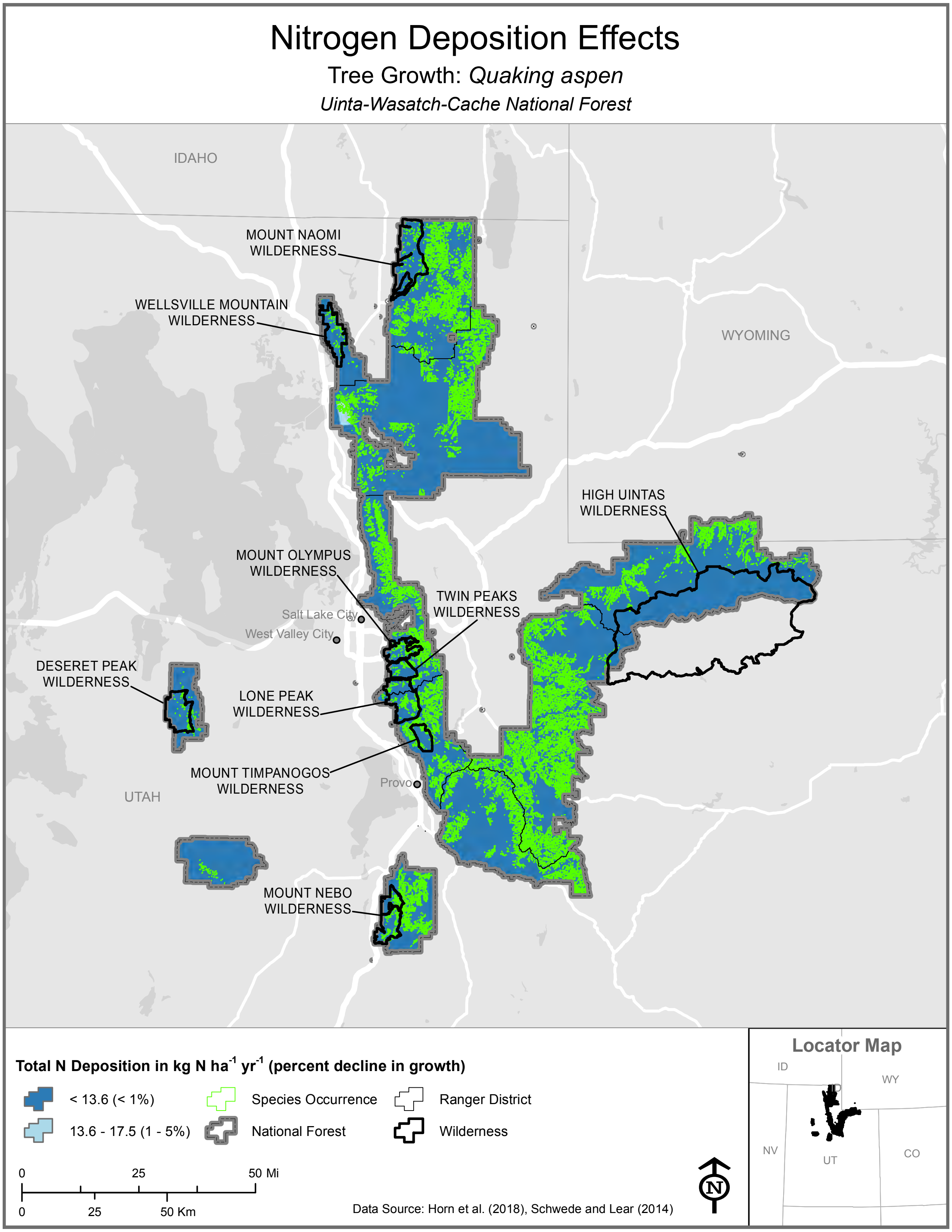


Figure 5-175.—Total (wet + dry) N deposition and percent of decline in growth rate for quaking aspen within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

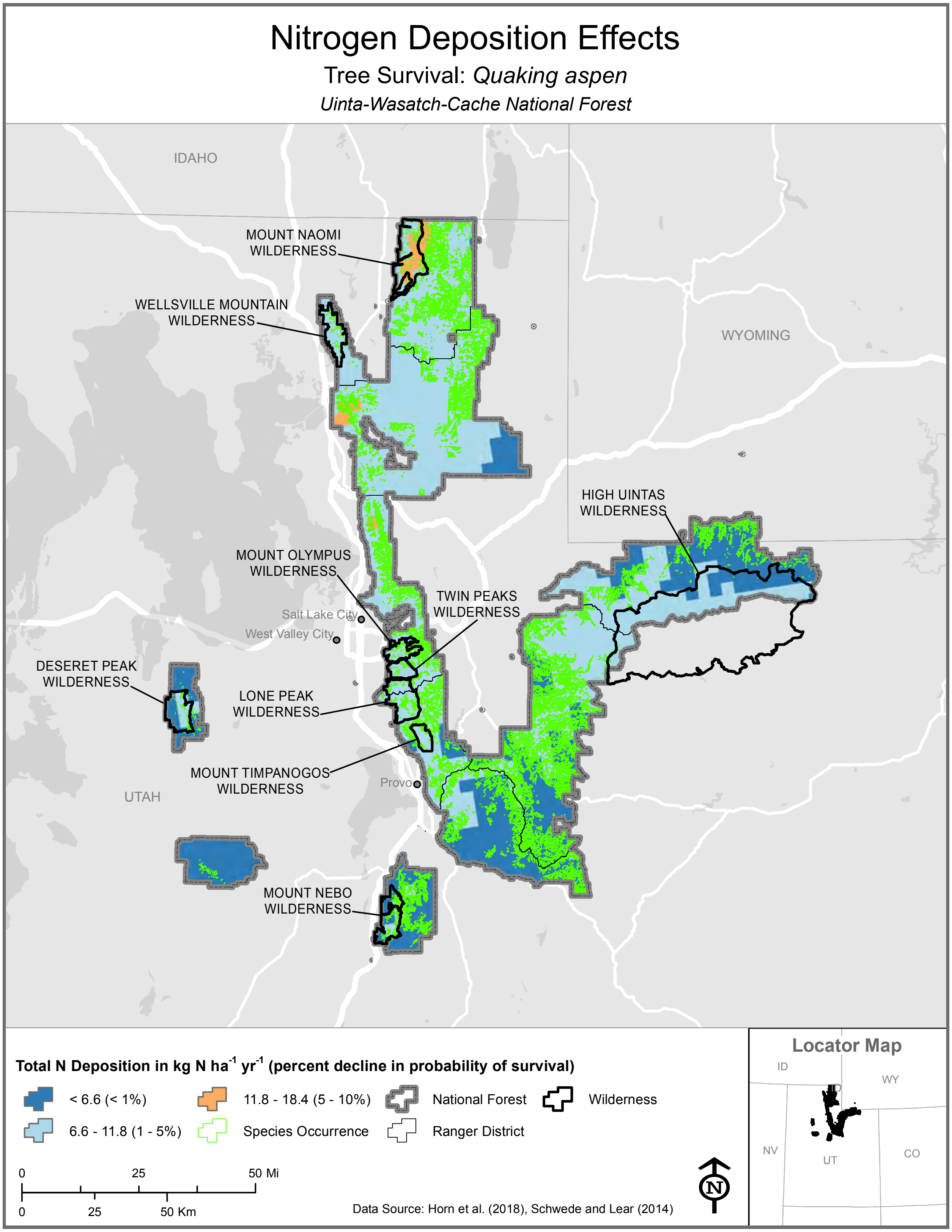


Figure 5-176.—Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for quaking aspen within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

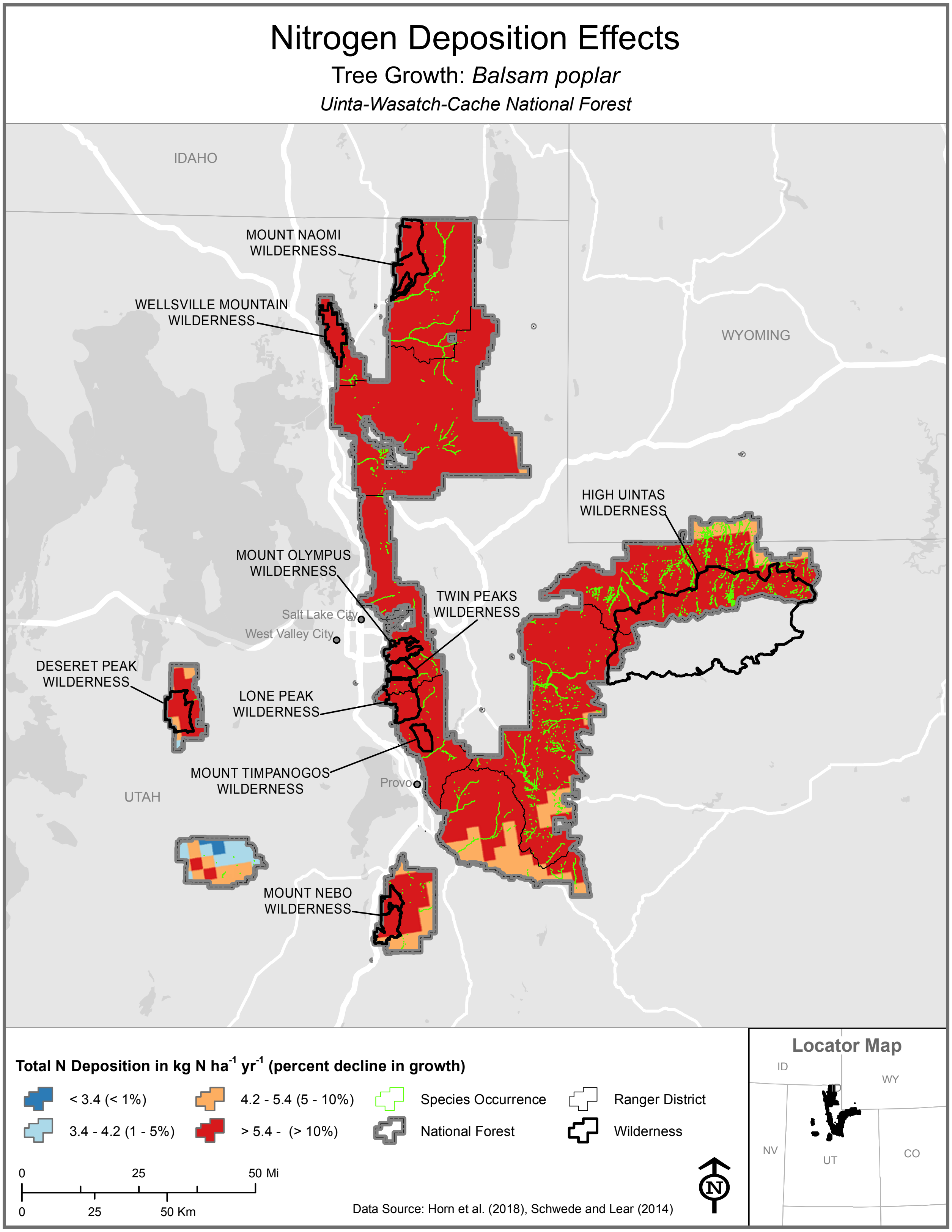


Figure 5-177.— Total (wet + dry) N deposition and percent of decline in growth rate for balsam poplar within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

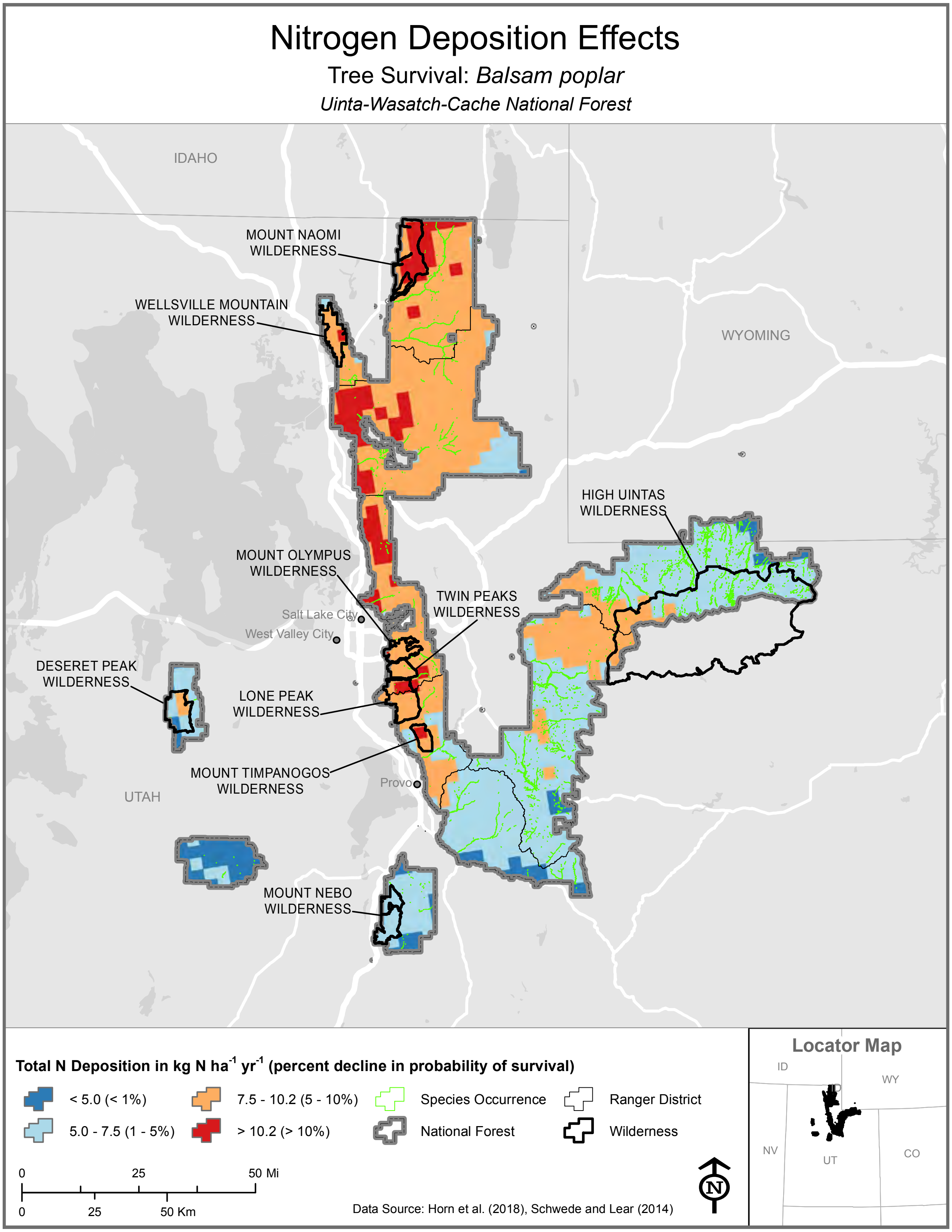


Figure 5-178.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for balsam poplar within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

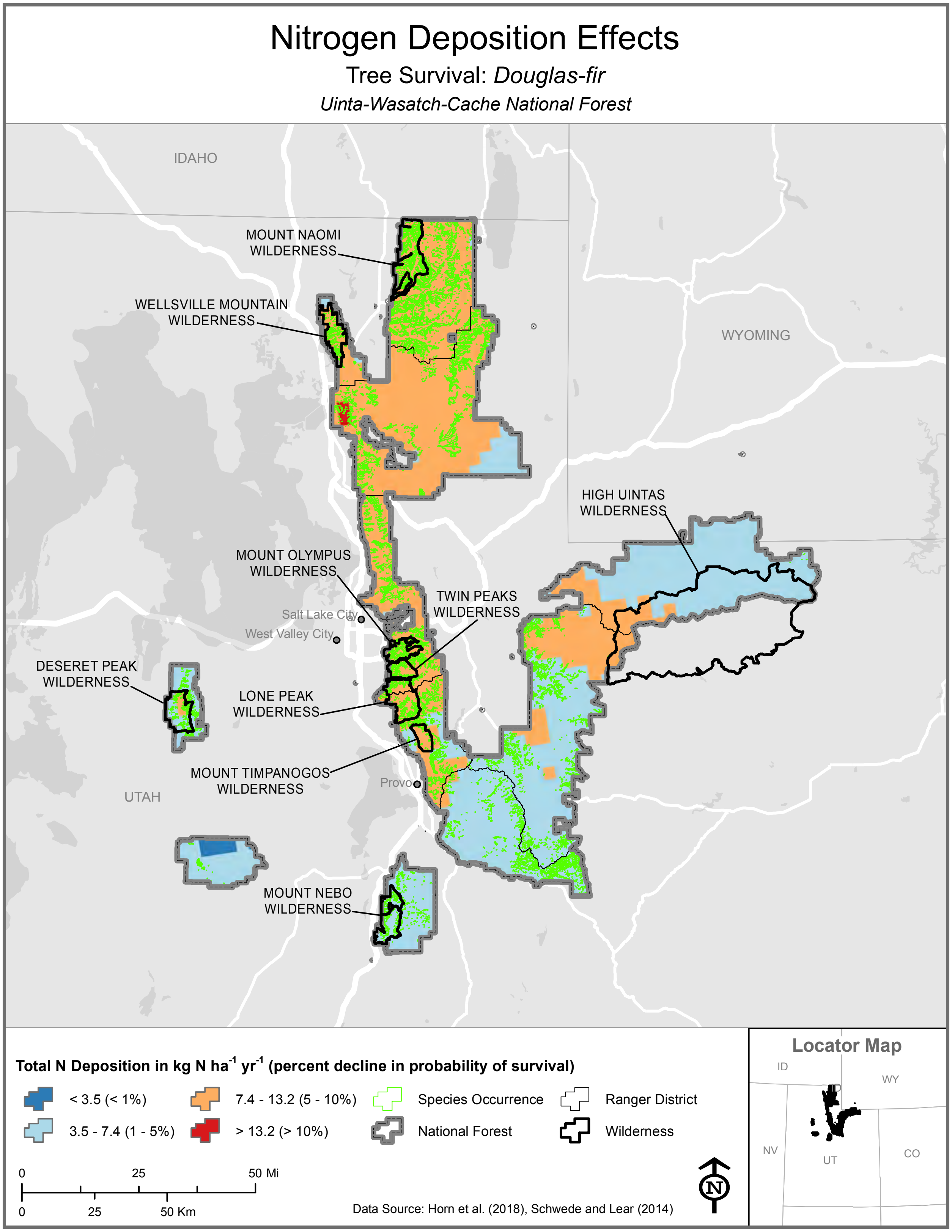


Figure 5-179.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Douglas-fir within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

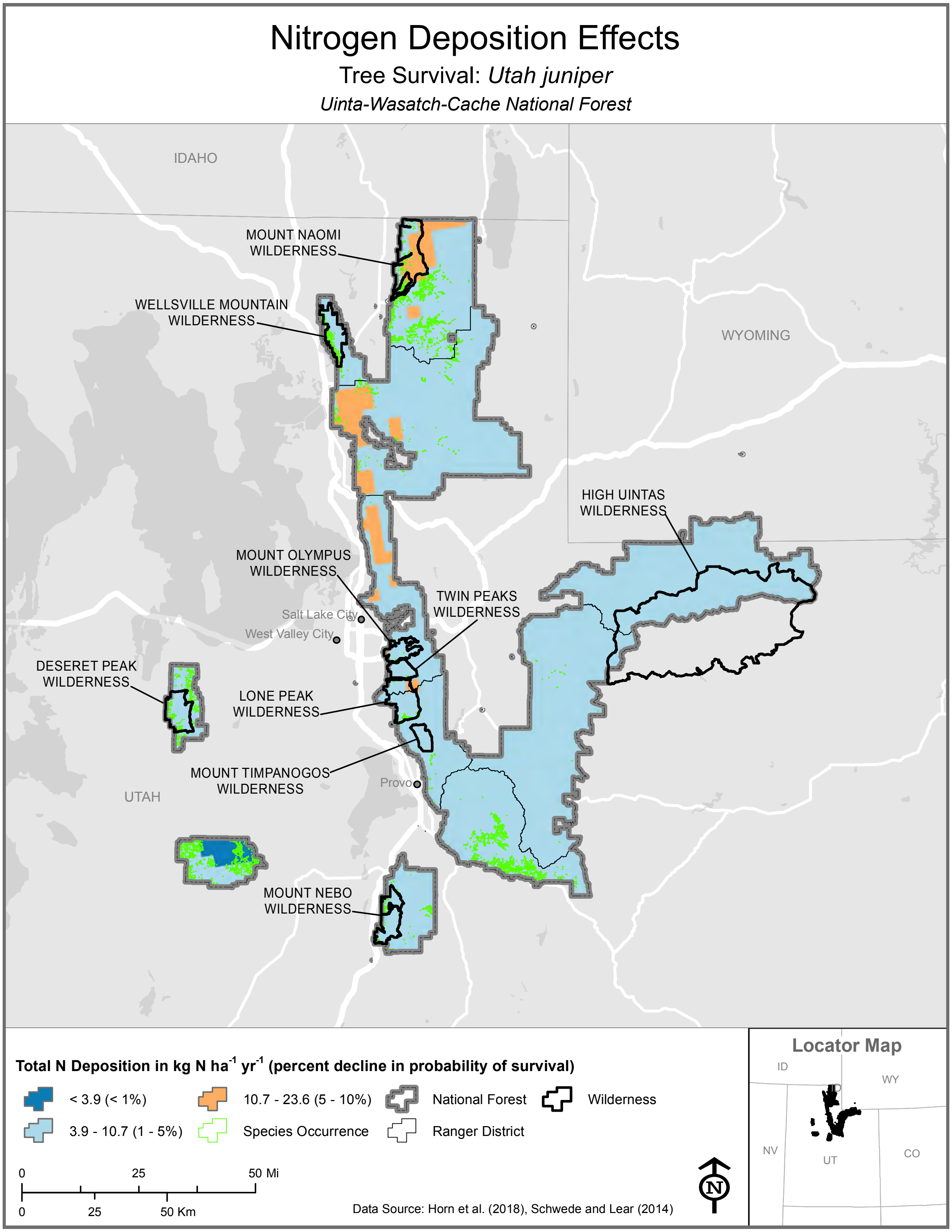


Figure 5-180.— Total (wet + dry) N deposition and percent of decline in probability of survival over 10 years for Utah juniper within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

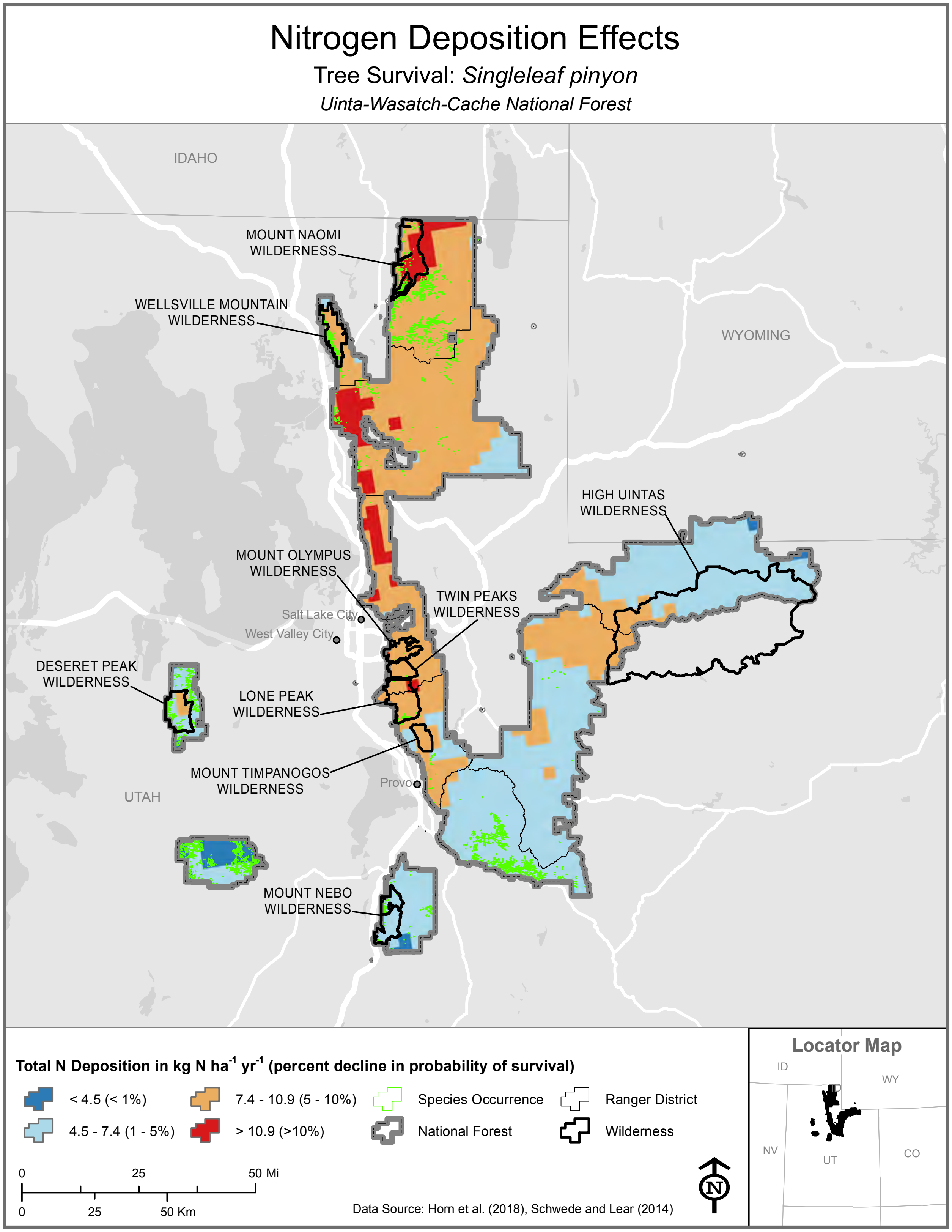


Figure 5-181.— Total (wet + dry) N deposition and percent of decline probability of survival over 10 years for singleleaf pinyon within the Uinta-Wasatch-Cache National Forest. Species occurrence (in green) represents the area where the species canopy cover is modeled as dominant or codominant on the Forest.

Pearl Creek, south of the Ruby Mountains, Humboldt-Toiyabe National Forest. USDA Forest Service photo.

6 CONCLUSIONS

6.1 Surface Water Acidification

Surface waters within the Forest Service Intermountain Region with low CLs that protect surface water ANC from decreasing below 50 μeq L^{-1}, have a higher likelihood of CL exceedance. Wilderness Areas often contained surface waters with low CLs and N and S deposition loading high enough to exceed acidification CLs associated with ANC decreasing below 50 μeq L^{-1}. Surface waters within National Forests in the Intermountain Region that are exceeding N CLs have an increased risk of episodic or chronic acidification. The larger the magnitude of exceedance, particularly when CLs are low, the higher the risk for acidification. Acidification can affect change in aquatic ecosystems, including declines in abundance and diversity of primary producers, zooplankton, and macroinvertebrates.

6.2 Surface Water Eutrophication

Surface waters, primarily streams and lakes throughout large portions of the Forest Service Intermountain Region, including many Wilderness Areas, were in exceedance of the N CLs that protect against biological effects associated with surface water eutrophication. Areas with high magnitudes of exceedance are at higher risk to experience effects such as an increase in algal abundance and shifts in diatom communities. Changes in algal abundance can alter competitive interactions among primary producers and may negatively affect processes at higher trophic levels.

6.3 Lichen Species Richness and Abundance

Large portions of the Forest Service Intermountain Region exceeded the CL that protects against declines in forage lichen abundance. Lichen CLs were based on N deposition estimates that are known to underestimate certain types of N deposition. Consequently, CLs for the lichen functional groups may also be underestimated and the CL exceedances may be overestimated. Therefore, interpretation of these results should focus on locations and relative magnitude of exceedance, rather than absolute levels of exceedance. Forage lichens are an important group of lichens that many wildlife species, such as ungulates, birds, rodents, lagomorphs, and invertebrates, rely on for food or habitat needs. 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 [b]). Lichen-dependent wildlife can be prey for other species. Many bird species depend on forage lichens for nesting material and many invertebrates use lichens for habitat and camouflage. High magnitudes of N CL exceedance increase the risk of drastic declines in forage lichen abundance and thus increases the risk of negative impacts to these species that use forage lichens. 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 exceedances for tree species, declines in growth rate of balsam poplar and probability of survival over 10 years for balsam poplar, Douglas-fir, and Utah juniper were expected to be widespread throughout the modeled range of these species in the Forest Service Intermountain Region. Potential effects related to decreased growth rate and probability of survival for these species include, but are not limited to, changes in: tree

species composition and structure, riparian conditions, habitat for other plant and animal species, wilderness character, and fire regimes. Tree species affected by atmospheric N and S deposition may be more susceptible to insect infestations, diseases, and changes in climatic conditions (e.g., drought). In addition to the ecological effects associated with reduced growth rate and probability of survival of these species, decreased survival of Douglas-fir may also have economic implications given its importance as a commercial timber species. The tree response models that were the basis for the CLs in this assessment used information throughout the entire range of distribution for each tree species. Thus, a broad range of ecological conditions and deposition rates were used to inform the models. Regional and local response rates for tree species growth rate and probability of survival may differ from the nationally modeled responses used, due in part, to local effects to tree growth and survival from disturbances such as insect infestations, fire, and seasonal drought.

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APPENDIX 1

List of Vegetation Classification, Mapping, and Quantitative Inventory (VCMQ) map unit names by National Forest used for mapping tree species critical loads (CLs), from Horn et al. (2018).

Ashley National Forest	
VCMQ Map Unit	**Species Mapped**
Aspen	Aspen
Aspen/Conifer	Aspen
Douglas-fir	Douglas-fir
Douglas-fir Mix	Douglas-fir
Pinyon-Juniper	Singleleaf pinyon, Utah juniper

Boise National Forest	
VCMQ Map Unit	**Species Mapped**
Douglas-fir	Douglas-fir
Douglas-fir/Ponderosa	Douglas-fir
Riparian Shrubland/Deciduous Tree	Balsam poplar
Aspen	Aspen
Douglas-fir/Lodgepole	Douglas-fir

Bridger-Teton National Forest	
VCMQ Map Unit	**Species Mapped**
Douglas-fir Mix	Douglas-fir
Aspen	Aspen
Aspen/Conifer Mix	Aspen
Cottonwood	Balsam poplar

Caribou-Targhee National Forest	
VCMQ Map Unit	**Species Mapped**
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 National Forest	
VCMQ Map Unit	**Species Mapped**
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 National Forest	
VCMQ Map Unit	**Species Mapped**
Pinyon-Juniper	Utah juniper, singleleaf pinyon
Aspen/Conifer	Aspen
Aspen	Aspen
Douglas-fir Mix	Douglas-fir

Humboldt-Toiyabe National Forest	
VCMQ Map Unit	**Species Mapped**
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

Manti La Sal National Forest	
VCMQ Map Unit	**Species Mapped**
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 National Forest

VCMQ Map Unit	Species Mapped
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 National Forest

VCMQ Map Unit	Species Mapped
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 National Forest

VCMQ Map Unit	Species Mapped
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 National Forest

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

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