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Inventory of Restoration Needs of National Forest Lands of the Contiguous United States: An Assessment Using Watershed and Terrestrial Ecosystem Classification Tools

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By

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Abstract

Ecological restoration assists the recovery of degraded ecosystems by returning their structure, processes, and functions to within their natural range of variation, improving long term sustainability and resilience. The United States Forest Service has sought to increase the pace and scale of restoration treatments on lands that it manages in order to continue to provide important ecosystem services including timber production, fish and wildlife habitat, grazing, watershed protection, and recreation. The Agency developed two classification systems to identify restoration need on Forest Service managed lands, the Watershed Condition Classification (WCC) and the Terrestrial Condition Assessment (TCA). These two classification systems could potentially be integrated or used concurrently in the future. This work is a first step in working with the two classifications together. Using GIS software, I completed an overlay analysis of the two classification systems to quantify Forest Service lands where both systems identified restoration need or where only one classification system identified restoration need. There was wide scale agreement between the WCC and TCA on areas that do not need restoration. Areas where the two classification systems both identify restoration need were relatively small, making up only 1% of all National Forest System lands. These results provide a first step in possible integration of these two classification systems to help prioritize restoration actions on Forest Service lands.

Acknowledgments

I would like to express my appreciation to my committee members Dr. Lin, Dr. Bixby and Dr. Jemison for their guidance and encouragement of this work. The input of Forest Service staff from the Southwestern Region and Washington Office was much appreciated. A thanks to John Fleck for guidance throughout the course of my time in the Water Resources Program. Finally, I wish to thank my wife, Katelyn for the boundless support and encouragement.

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Introduction

Ecological Restoration

The goal of ecological restoration is to assist the recovery of a degraded, damaged or destroyed ecosystem by bringing structure, processes, and function back within their natural range of variation. In returning these structures and functions to the ecosystem, ecological restoration aims to increase ecosystem sustainability and resilience (Allen et al., 2002; Landres, Morgan, & Swanson, 1999; McDonald, Gann, Jonson, & Dixon, 2016). Restoration interventions to ecosystem components can range from passive to active. Where damage is limited, natural regeneration is effective. This approach removes causes of degradation and allows natural processes to address degradation. Assisted regeneration addresses causes of degradation while including active intervention and manipulation to return desired ecosystem processes. In areas of greater damage, reconstruction of an ecosystem may be warranted, causes of degradation need to be addressed, and biota reintroduction is necessary (McDonald et al., 2016). A combination of approaches is often used where degradation is varied and occurs at large scales (McDonald et al., 2016). Where ecosystems have experienced high levels of degradation to the point of crossing biotic or abiotic thresholds, restoration to historical ecosystem structures may not be feasible. In these ecosystems, managing for novel ecosystem structure and function may be the best management choice (Hobbs, Higgs, & Harris, 2009).

Degradation of lands managed by the United States Forest Service and varies depending on ecosystem type. In terrestrial ecosystems, conifer encroachment, invasive species, changes in stand structure, and increased fuel density due to fire suppression may necessitate restoration treatments to return conditions to their desired state. In watersheds, conditions that may require restoration treatments include aquatic habitat fragmentation, degradation

due to past management activities, or invasive species (Schultz et al., 2012; USDA Forest Service, 2012). The Forest Service uses a variety of ecological restoration techniques to address both terrestrial and watershed degradation. Restoration treatments may include thinning of overly dense forest stands, prescribed and managed fire, improvement of stream connectivity, road and trail decommissioning or improvement, and stream side fencing (Ecosystem Restoration Policy, 2016; Schultz et al., 2012; USDA Forest Service, 2018b). These restoration strategies are used to address specific goals such as reducing risk of flooding in a burned landscape, improving water quality, reducing potential fire severity, or increasing habitat for threatened and endangered species.

USDA Forest Service Background

One of four major Federal land management agencies, the Forest Service was established in 1905 to unify administration of Forest Reserves which were previously overseen by the General Lands Office (Williams, 2000). The first forested lands set aside by the Federal Government were established by the Forest Reserve Act of 1891, which allowed the President to designate Forest Reserves from lands held in public domain. For six years following the Forest Reserve Act, there was no criteria for designation of Reserves or instruction for their management.

With the Organic Act of 1897, Congress created an organization to manage the nation's new Forest Reserves and identified criteria for establishment of new Reserves: they were to be set aside for timber production and for protection of forests and watersheds (USDA Forest Service, 2000; Williams, 2000). By 1915, the Forest Service was managing 162 million acres primarily located in the western United States. Under the authority of the Weeks Act, which

provided for the acquisition of lands to protect watersheds of navigable streams, the Forest Service added 24 million acres in the eastern United States (USDA Forest Service, 2000).

Today the Forest Service manages 193 million acres of lands across the United States (Figure 1) for multiple uses including timber production, fish and wildlife habitat, grazing, watershed protection, and recreation (USDA Forest Service, 2015; Williams, 2000). The Forest Service management structure consists of a headquarters in Washington D.C. and nine Regions, each containing a number of National Forests.

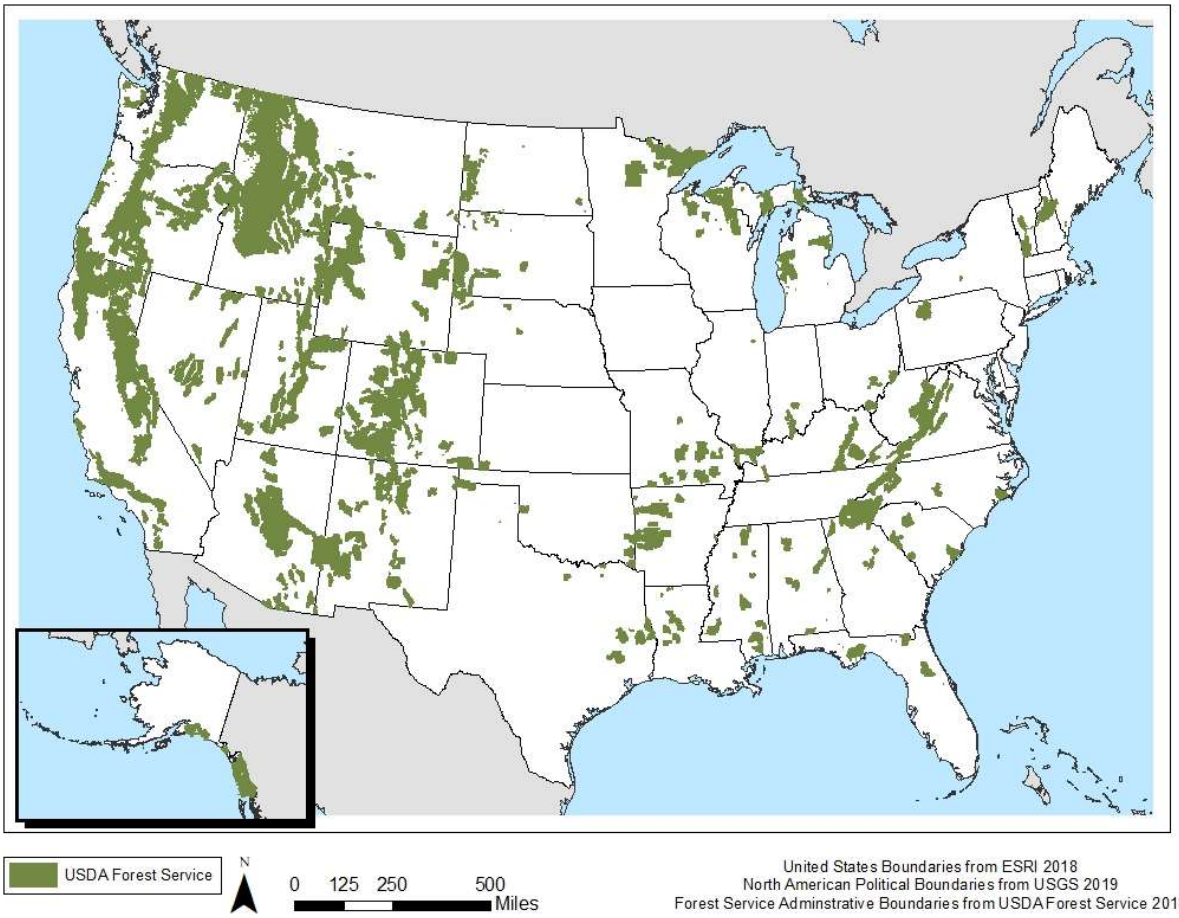

Figure 1: All lands managed by the USDA Forest Service, excluding lands in Puerto Rico.

The Forest Service and Restoration

In the 1990s, the management strategy of the Forest Service shifted away from resource production and toward long-term ecological sustainability. Under the natural resource agenda, the agency began to explicitly emphasize watershed health and restoration (Williams, 2000). Recently the Forest Service has sought to increase the pace and scale of restoration treatments. For example, the 2012 planning rule requires revised forest management plans to include maintenance and restoration of land and water ecosystems (National Forest System Land Management Planning, 2016; USDA Forest Service, 2012). Increasingly, restoration on Forest Service lands has been collaborative with an emphasis placed on forest and watershed health as well as benefits to local communities (USDA Forest Service, 2012).

National Forests provide wildlife habitat, recreation, drinking water for over 60 million people, natural resources, and economic opportunity (USDA Forest Service, 2000, 2012). The ability for Forest Service lands to continue to provide these ecosystem services is at risk due to stresses including past management activities, uncharacteristic wildfire and climate change (USDA Forest Service, 2012). In 2014, the agency had completed restoration treatments on 4.6 million acres nationally (USDA Forest Service, 2015). As of 2012, an estimated 65 to 82 million acres of Forest Service lands were potential candidates for restoration, with 12.5 million acres in need of mechanical treatment (USDA Forest Service, 2012). Given the potential scale of restoration needs, identifying areas in need of restoration treatment is critical for efficient and effective use of agency funds and personnel.

Watershed and Terrestrial Classification

Watershed Condition Framework and Watershed Condition Classification

Development

The Watershed Condition Framework (WCF) was developed to create a nationally consistent approach to evaluate watershed condition, prioritize and implement watershed scale restoration, track accomplishments, and monitor improvements in watersheds managed by the Forest Service (USDA Forest Service, 2011). The initial step of the WCF is a Watershed Condition Classification (WCC).

Classification Units

The WCC classifies watershed function of all sixth level hydrologic unit code (HUC) watersheds that include at least five percent Forest Service lands (USDA Forest Service, 2011, 2018b). Sixth level HUCs, or sub watersheds, are the smallest delineation of the Watershed Boundary Dataset, ranging in size from 10,000 to 40,000 acres (US Geological Survey and US Department of Agriculture, Natural Resources Conservation Service., 2013).

Indicators

The WCC is implemented using data and expert opinion from each National Forest by local interdisciplinary teams. Indicators used by the WCC can be grouped into four major processes that assess both the biological and physical functions that impact aquatic ecosystems (Figure 2). Each of these processes is given a different weight in the overall classification scheme: aquatic physical (30%), aquatic biological (30%), terrestrial physical (30%), and terrestrial biological (10%). A total of twelve indicators are used to develop process scores (Figure 3) (USDA Forest Service, 2018b).

Components for each of the twelve indicator attributes are scored and averaged to produce an indicator score. The indicators for each process are then averaged to determine a process category score. Finally, watershed condition is determined by a weighted average of the four major processes and the watershed placed into one of three classes (Figure 4), class 1 (score of 1.0 to 1.6): functioning properly; class 2 (score of 1.7 to 2.2): functioning at risk; and class 3 (score of 2.3 to 3.0): impaired function (USDA Forest Service, 2011). All watersheds on Forest Service lands were assessed in 2011 and are reassessed when conditions change or more information becomes available (USDA Forest Service, 2018b). For the purpose of this work, the 2011 WCC shapefile was used.

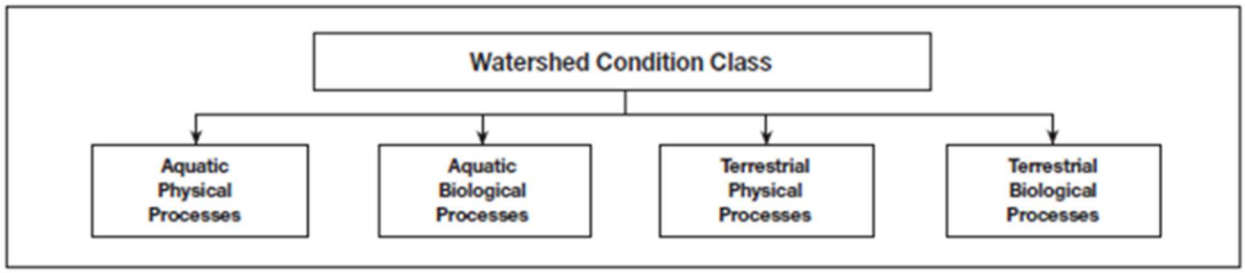

Figure 2: Four processes scored in the Watershed Condition Classification. (From USDA Forest Service 2011).

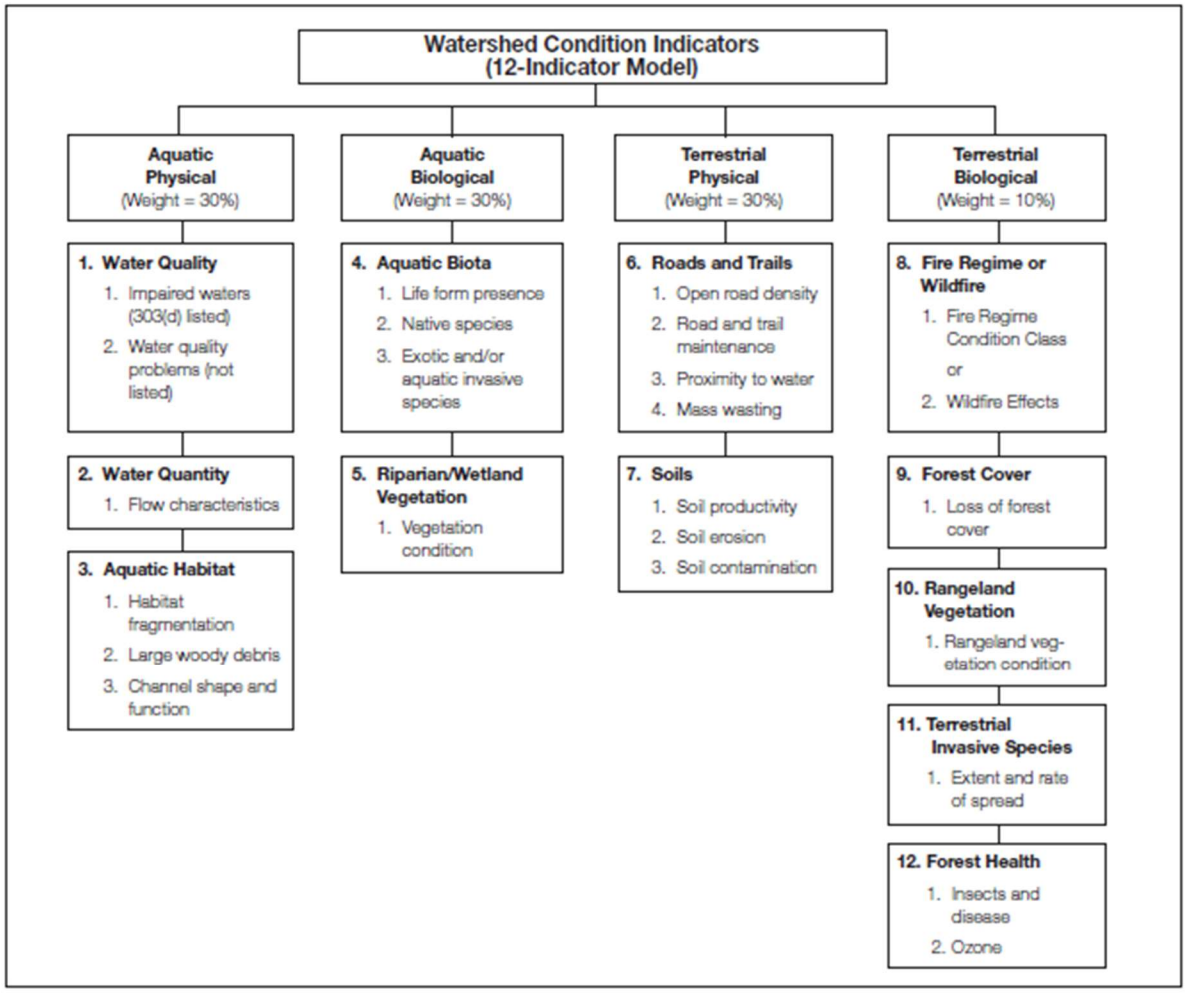

Figure 3: Twelve indicators used in the Watershed Condition Classification model (USDA Forest Service 2011).

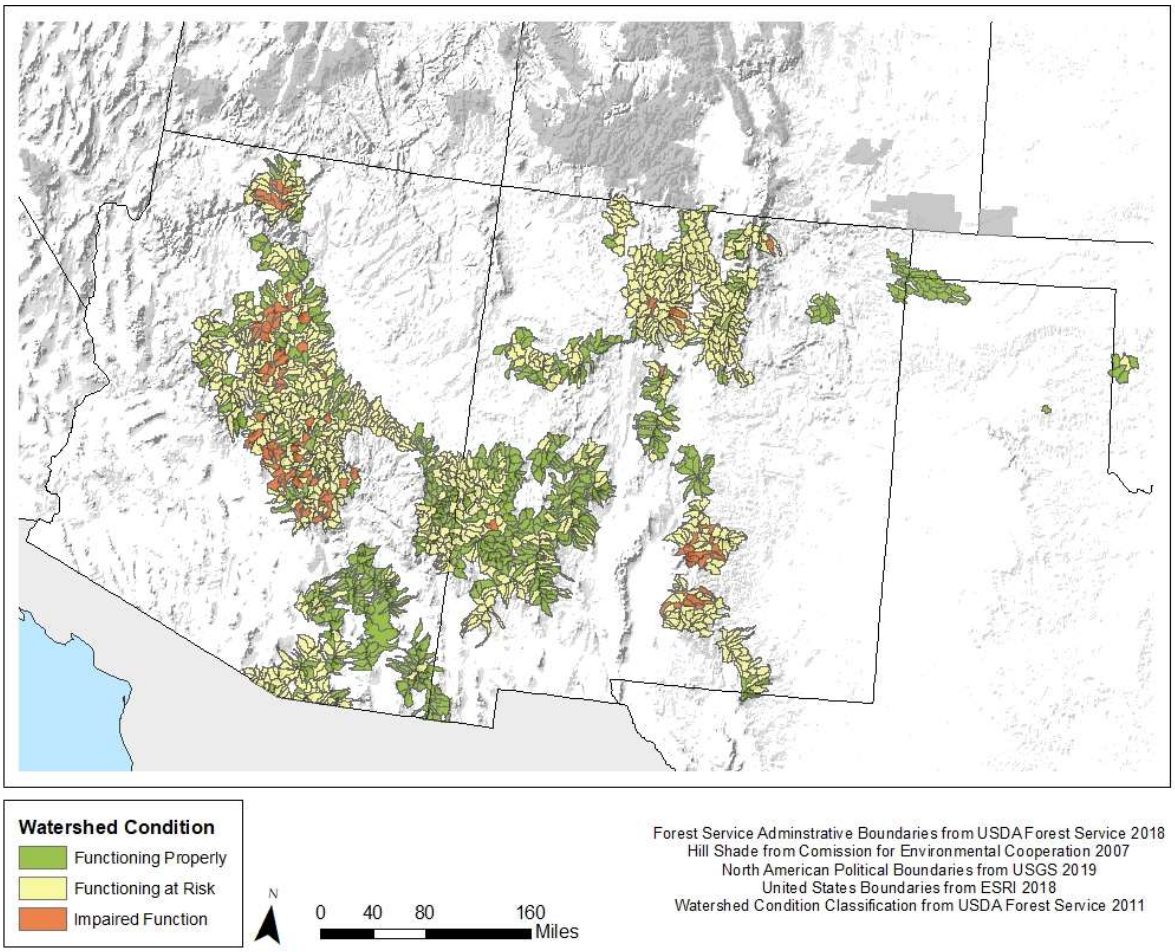

Figure 4: 2011 Watershed Condition Classification (WCC) for USDA Forest Service Southwestern Region. Note that watersheds extend beyond USFS lands.

Terrestrial Condition Assessment

Development

The Terrestrial Condition Assessment (TCA) seeks to assess terrestrial ecological integrity of Forest Service lands and was designed to complement the watershed condition classification of the WCC. The TCA can help identify areas for potential restoration treatment when incorporated into a larger planning process (Cleland et al., 2017).

Classification Unit

The TCA uses landtype associations (LTAs) as the unit of classification. The 2019 TCA uses LTAs that range in size from 3,000 to 34,000 of acres. Abiotic and biotic elements contribute to LTA delineation which includes similarities of geology, geomorphology, soils, and potential natural vegetation (Cleland et al., 1997; Winthers et al., 2005). Because geomorphology is most often the driving element for their delineation, LTAs are typically named in reference to landforms, such as North Fork Mountain LTA (Winthers et al., 2005).

Indicators

The TCA uses national datasets for metrics which inform indicators used to assess each LTA along a continuous scale from -1 to +1. This scale is broken into five condition classes, ranging from very low to very high terrestrial ecological integrity (Figure 5)(Cleland et al., 2017). The indicators of the TCA are organized into two categories: stressors, both biotic and abiotic, and vegetative condition. For each indicator a threshold is established for evidence of suitable condition and a threshold is set for no evidence of suitable condition, allowing condition to be assessed along a gradient (Cleland et al., 2017).

Information from the indicators utilized by the TCA is then used in the Ecosystem Management Decision Support System (EMDS), a framework for landscape evaluation which incorporates a spatial scale using geographic information systems, and logic and decision engines to assess landscape condition (Cleland et al., 2017; "Ecosystem Management Decision Support," 2018). For each LTA unit a score is assigned along the -1 to 1 scale, from which one of five terrestrial condition classes is assigned; very low, low, moderate, high, or very high (Cleland

et al., 2017). In a previous version of the TCA, insect and disease risk, tree mortality, and high wildfire potential had the greatest influence on overall condition rating (Cleland et al., 2017).

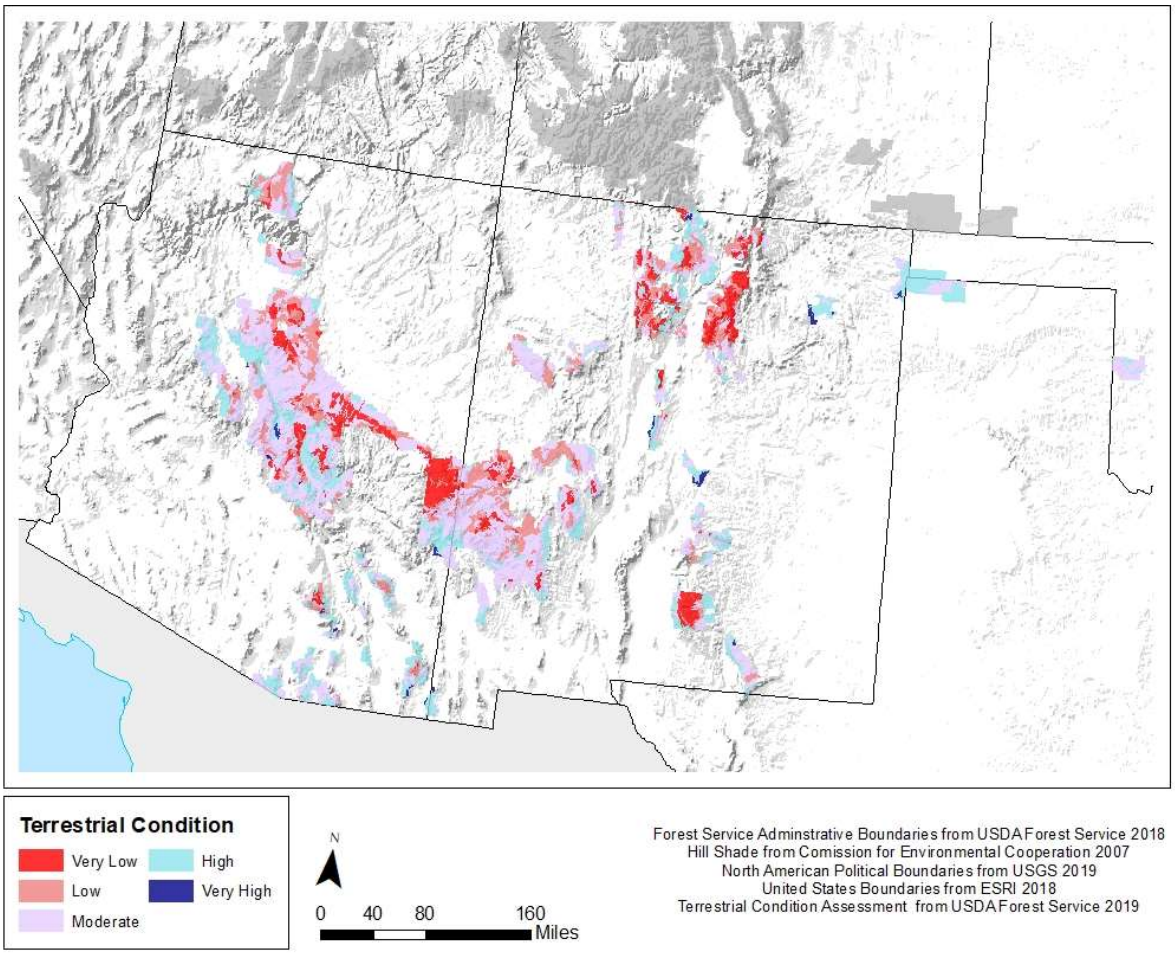

Figure 5: 2019 Terrestrial Condition Assessment (TCA) for USDA Forest Service Southwestern Region.

Problem Statement

The WCF and its associated classification system, the WCC, are currently implemented by the Forest Service as a tool to evaluate condition and prioritize restoration of watersheds. Following the development of the WCC, the TCA was developed to determine terrestrial ecosystem condition and identify areas of potential restoration need. The TCA was designed to

be complimentary to the WCC. There is interest in combining or integrating the two classification systems to provide a holistic assessment of ecosystem conditions on Forest Service lands. This research is a step in the integration of the WCC and the TCA by using GIS to inventory, map, and quantify the restoration needs identified by both tools.

Questions

On National Forest lands:

1. Where and at what extent do the WCC and TCA both identify areas with restoration needs?
2. Where and at what extent does the WCC identify restoration needs where the TCA does not?
3. Where and at what extent does the TCA identify restoration needs where the WCC does not?
4. What is the total extent of areas with no restoration need based on both assessments?

Methods

Three national datasets for this spatial analysis: the 2011 WCC shapefile, the 2019 TCA polygon feature class, and a Forest Service administrative boundaries shapefile. The nationwide 2011 WCC shapefile was obtained from the Forest Service Watershed Condition Framework website (https://www.fs.fed.us/naturalresources/watershed/condition_framework.shtml) and the 2019 TCA polygon feature class was received from the Forest Service Washington Office. The Forest Service administrative boundary shapefile was downloaded from the Forest Service geodata website (https://data.fs.usda.gov/geodata/edw/datasets.php).

All spatial analyses were completed in geographic information system (GIS) software ArcMap 10.3.1 developed by Environmental Systems Research Institute (ESRI) using the Albers Equal Area Conic projection. This projection preserves area proportion (Snyder, 1982), allowing for the accurate measurement of acreage.

Watersheds classified under the WCC extend beyond Forest Service administrative boundaries. For the purpose of this study, the WCC shapefile was clipped to only include lands managed by the Forest Service. Within the WCC, restoration needs were defined as watersheds classified as being in impaired function. Watersheds rated as having impaired function often require major changes to address degradation to return a to properly functioning condition (USDA Forest Service, 2011). Within the TCA, landtype associations classified as having low or very low ecological integrity were selected as areas with a restoration need. This is consistent with previous decisions of which categories of the TCA have potential restoration need (USDA Forest Service, 2018a). Areas identified by the TCA as having low or very low ecological integrity exhibit structure, function, or composition outside the natural range of variation and are less resistant or resilient to perturbation (USDA Forest Service, 2018a).

"Select by attribute" was used within ArcMap to create two national scale polygon features: restoration need as identified by the WCC and restoration need as identified by the TCA. These two polygon features were intersected and a new national polygon feature created of areas of restoration need identified by both the WCC and TCA (WCC-TCA restoration need). This national WCC-TCA restoration need polygon feature was then deleted from the national WCC restoration need polygon feature using the erase tool to determine areas where only the WCC identified restoration need (i.e., WCC restoration need). The same process was used to

identify areas where only the TCA identified a restoration need (i.e., TCA restoration need). These three national polygon features, WCC-TCA restoration need, WCC restoration need, and TCA restoration need, were then merged. The erase tool was used to delete all restoration need polygons from the Forest Service administrative boundaries shapefile to identify Forest Service lands with no restoration need.

The output of this analysis is four national scale polygon feature classes (Table 1): 1) areas where the WCC and TCA agree there is a restoration need. (WCC-TCA restoration need), 2) areas where only the WCC identified a restoration need. (WCC restoration need), 3) areas where only the TCA identified a restoration need (TCA restoration need), and 4) areas where the WCC and TCA agree there is no restoration need (no restoration need).

Table 1: The four national scale polygon feature classes created for this analysis and underlying WCC and TCA classifications.

New Polygon Feature Classes	WCC Condition Classification	TCA Condition Classification
WCC-TCA restoration need	Impaired Function	Low Very Low
WCC restoration need	Impaired Function	Moderate High Very High
TCA restoration need	Functioning Properly Functioning at Risk	Low Very Low
No restoration need	Functioning Properly Functioning at Risk	Moderate High Very High

Each of these polygon features was then clipped to each of the Forest Service administrative Regions. To calculate area, a new field was added to the attribute table for each restoration need or no restoration need polygon feature class. Using the calculate geometry tool, this new field was populated with the acreage of individual polygons within each polygon feature class. The statics tool within ArcMap was then used to sum the acreage each polygon feature by Forest Service Administrative Region.

USDA Forest Service Regions

Region 1

Forest Service Region 1 or the Northern Region is comprised of nine National Forests located in Montana and the panhandle of Idaho (Figure 6). The region also includes National Grasslands in North and South Dakota. Together, the National Forests and Grasslands of Region 1 manage 25 million acres. The western ecoregions in Region 1 are northwestern forested mountains, with semi-arid prairies of the great plains to the east (Commission for Environmental Cooperation, 2006).

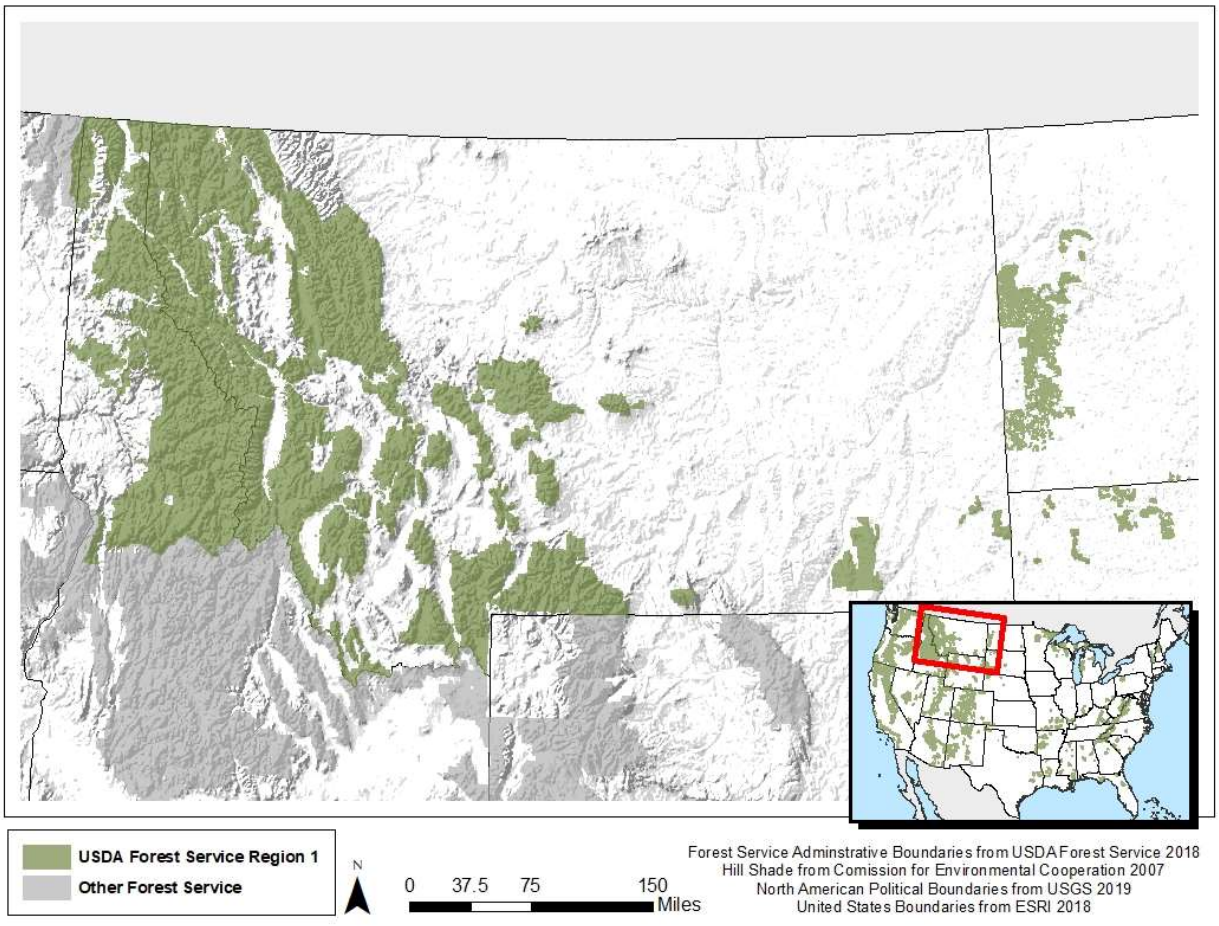

Figure 6: Lands managed by USDA Forest Service Region 1. Map excludes National Grasslands in far east North Dakota.

Region 2

The Rocky Mountain Region, Region 2, is home to 17 National Forests and seven National Grasslands which manage over 40 million acres in the states of Colorado, Kansas, Nebraska, South Dakota, and Wyoming (Figure 7). Region 2 is primarily located in the northwestern forested mountains ecoregion, with some eastern portions of the region in semi-arid prairie (Commission for Environmental Cooperation, 2006).

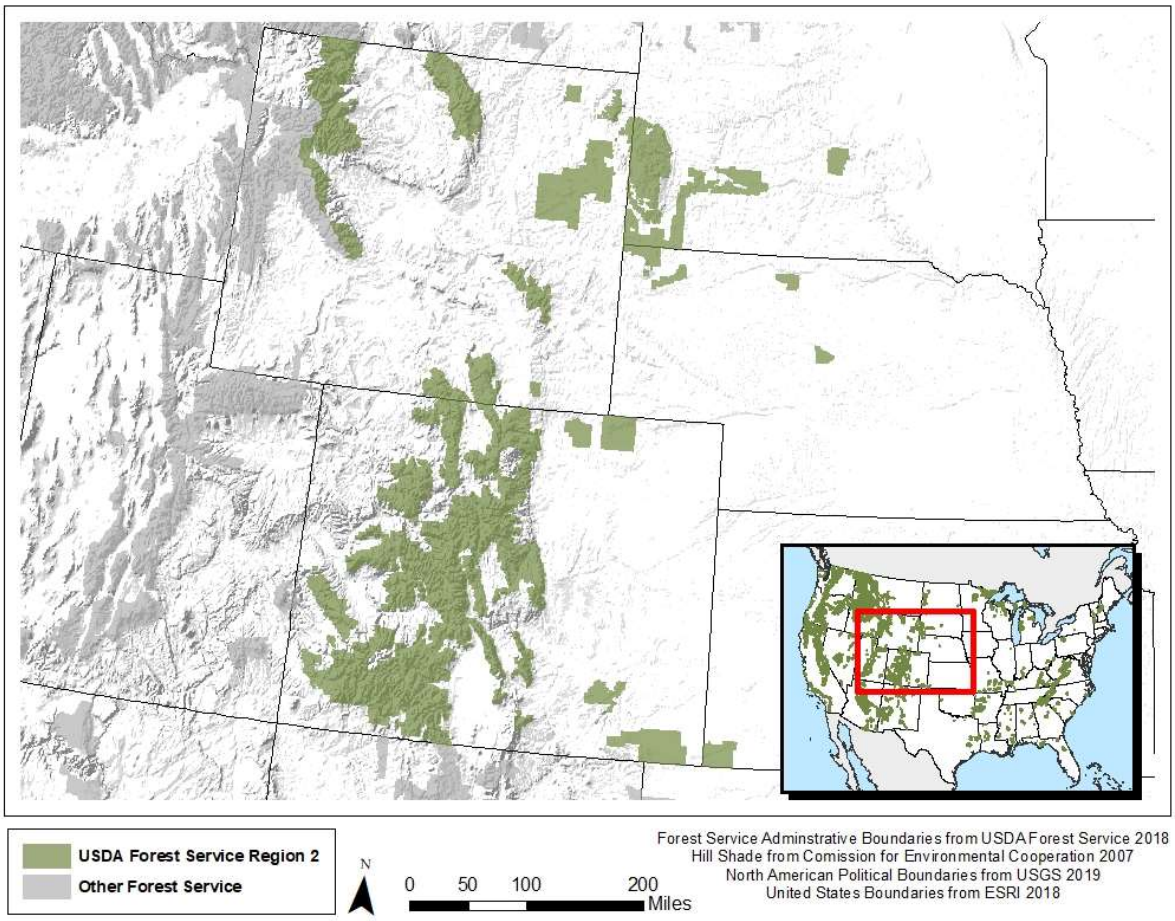

Figure 7: Lands managed by USDA Forest Service Region 2.

Region 3

Forest Service Region 3, the Southwestern Region, consists of 11 National Forests in Arizona and New Mexico and three National Grasslands located in New Mexico and the Texas and Oklahoma panhandles (Figure 8). Collectively, the National Forests and Grasslands of the Southwestern Region extend over 20 million acres. The Region is characterized by a temperate sierra forests along the Mogollon Rim in Arizona and the southern and central mountain ranges of New Mexico. In southern Arizona forests in the region occupy desert ecoregions. Forests in northern New Mexico manage lands in the northwestern forested mountain ecoregion, while National Grasslands in the east are located in semi-arid prairies of the Great Plains (Commission for Environmental Cooperation, 2006).

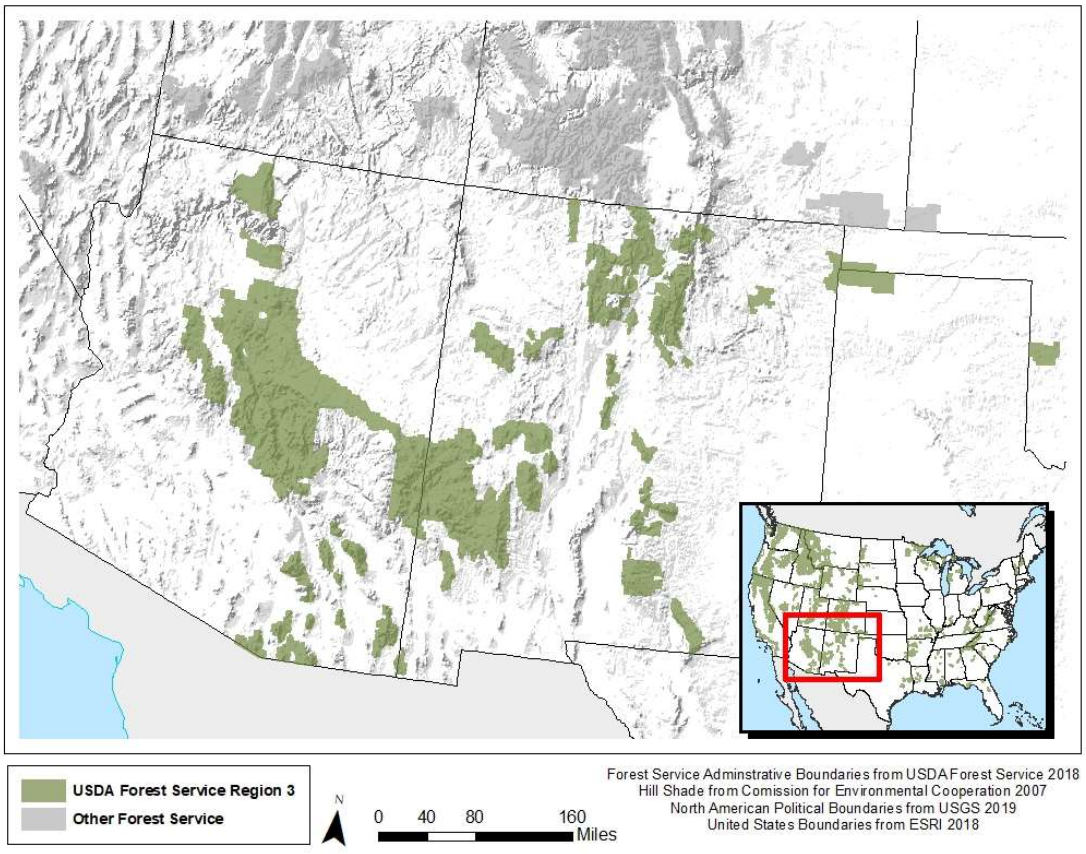

Figure 8: Lands managed by USDA Forest Service Region 3.

Region 4

Region 4, the Intermountain region, manages lands in Utah, Nevada, Idaho, Wyoming, California and Colorado (Figure 9). The Region consists of 12 National Forests covering 34 million acres. Northwestern forested mountains comprise much of the Forests in Idaho, Wyoming, and Utah. In the Great Basin area the primary ecoregion is cold desert which transitions to warm desert in southern Nevada (Commission for Environmental Cooperation, 2006).

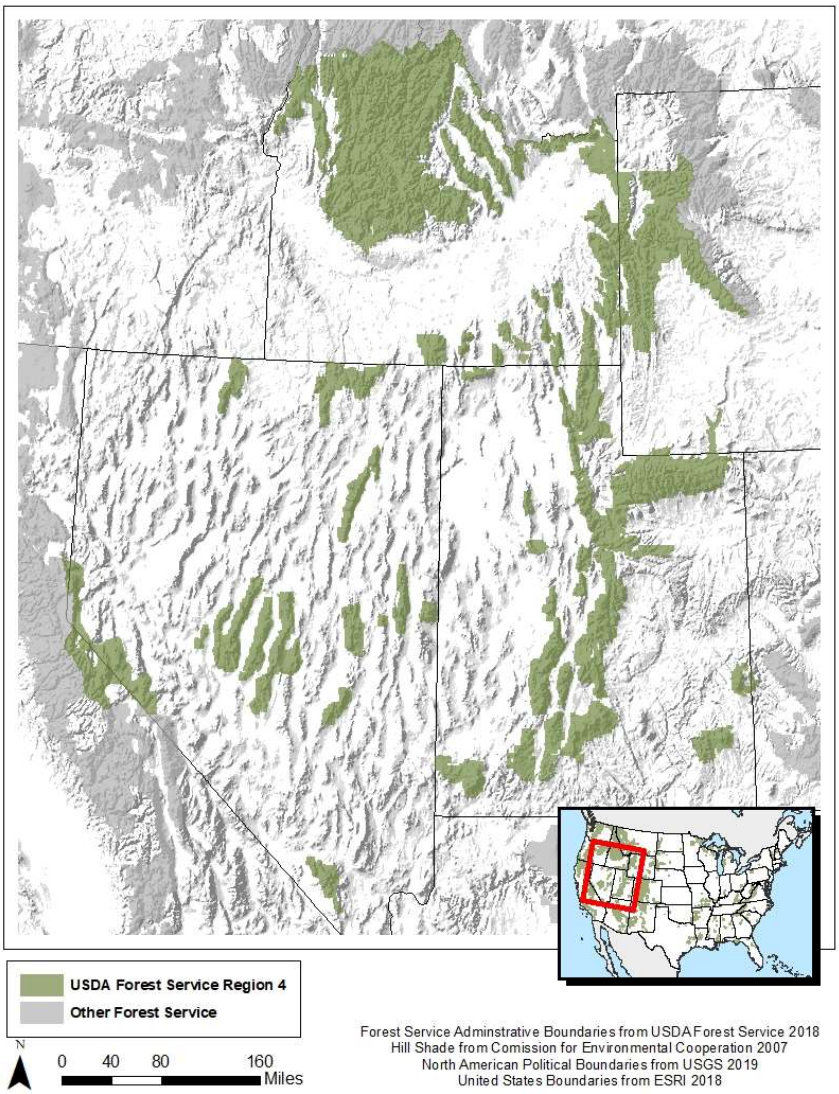

Figure 9: Lands managed by USDA Forest Service Region 4.

Region 5

The Pacific Southwest Region of the Forest Service is comprised of 18 National Forests covering 20 million acres entirely within the state of California (Figure 10). Northwestern forested mountains are the primary ecoregion in northern and eastern California while southern and coastal California National Forests are in the Mediterranean desert ecoregion (Commission for Environmental Cooperation, 2006).

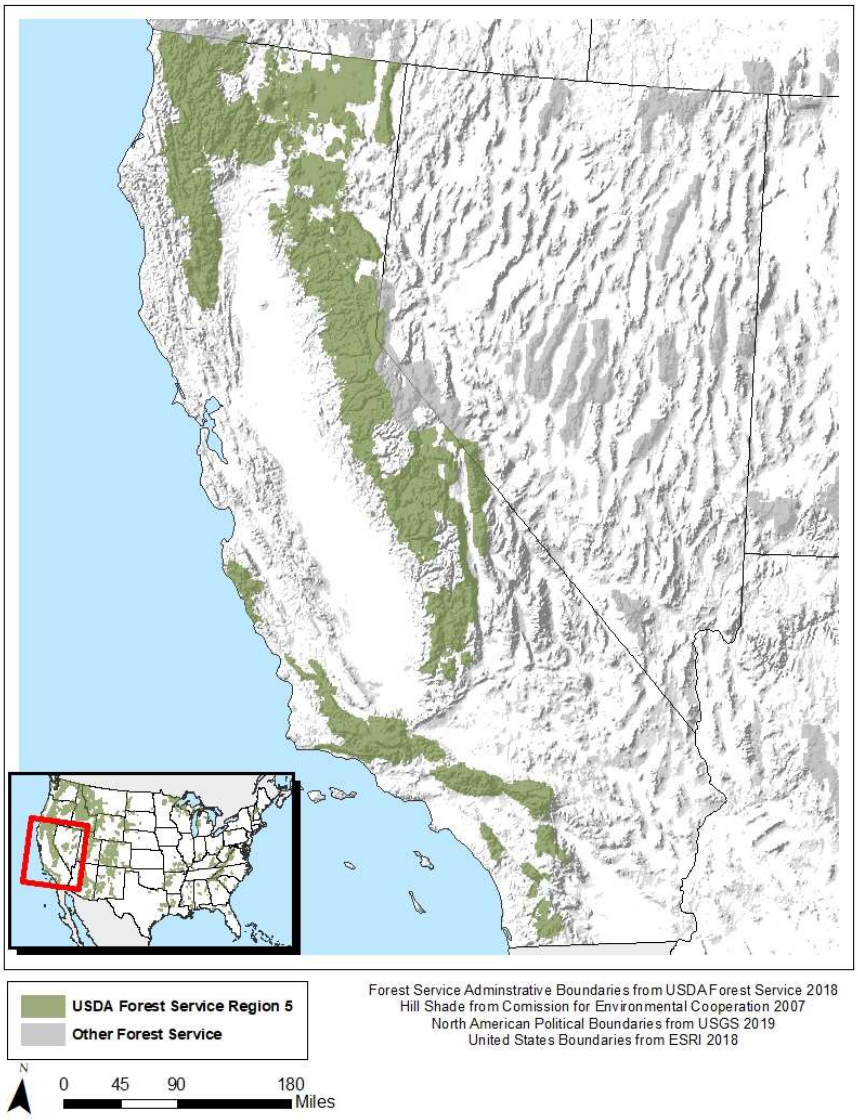

Figure 10: Lands managed by USDA Forest Service Region 5.

Region 6

Region 6, the Pacific Northwest Region, manages over 25 million acres in the states of Oregon and Washington and is home to 17 National Forests and one National Grassland (Figure 11). From the Cascade Range eastward, the ecoregion is northwestern forested mountains. Along the coast and the Olympic Peninsula are marine west coast forests (Commission for Environmental Cooperation, 2006).

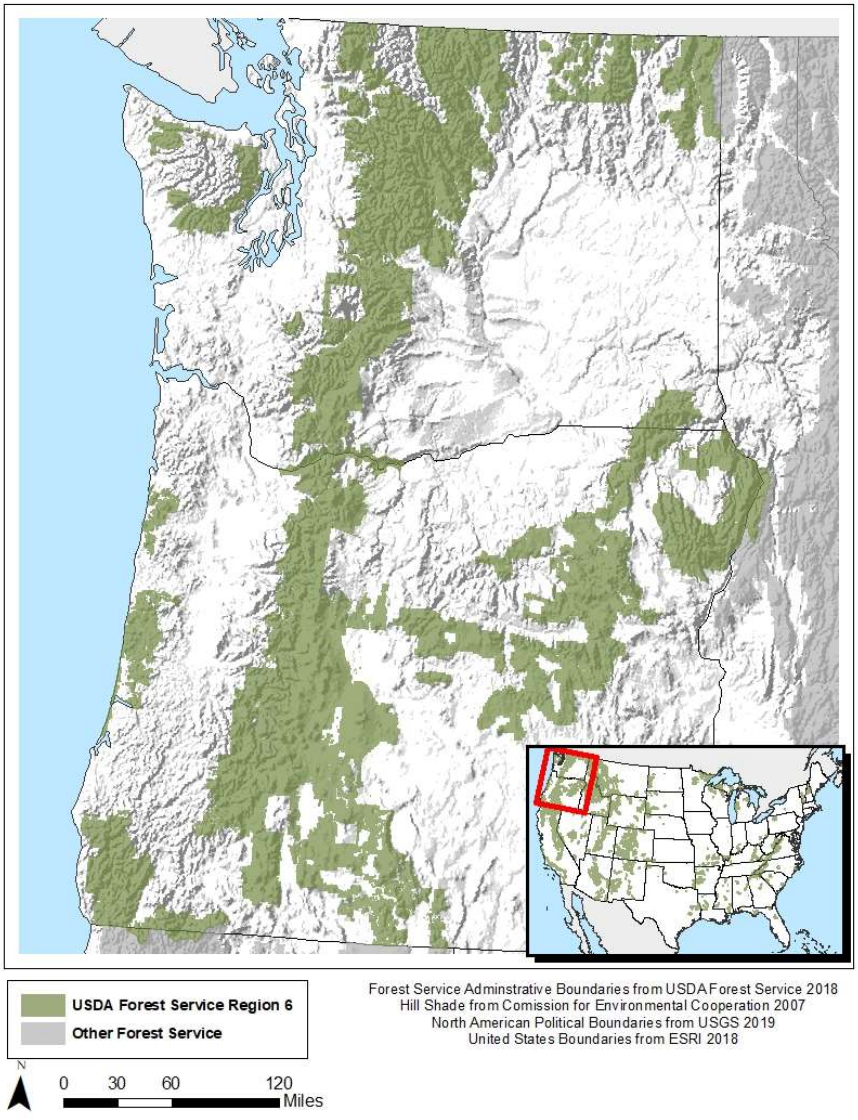

Figure 11: Lands managed by USDA Forest Service Region 6.

Region 7

Note that the Forest Service does not contain a Region 7 as it was absorbed into Region 9 in 1965.

Region 8

Extending from Virginia to Texas, the Southern Region of the Forest Service manages over 13 million acres of lands in the southeast United States and Puerto Rico (Figure 12). Ecoregions change with latitude, with eastern temperate forests in the northern mountain ranges moving south ecoregions transition from southeastern plains to coastal plains (Commission for Environmental Cooperation, 2006).

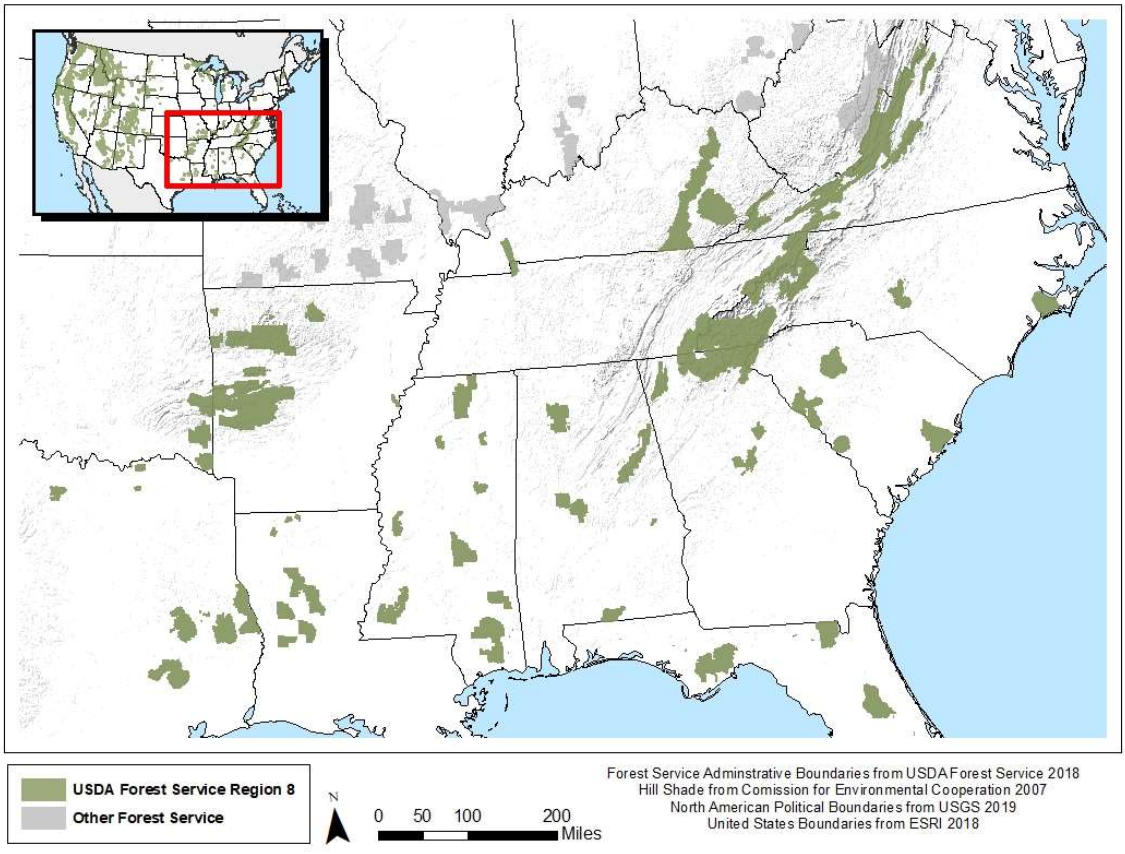

Figure 12: Lands managed by USDA Forest Service Region 8. Note-Puerto Rico excluded.

Region 9

Region 9 includes lands managed by the Forest Service from the mid-west to the northeast United States (Figure 13). There are 17 national forests in the Region which extend over 12 million acres. In the Ozark and Appalachian Mountains, the ecoregion is eastern temperate forests. Along the Great Lakes the region includes both northern coniferous and hardwood forests. In the northeast is the Atlantic highlands ecoregion which contains both hardwood and spruce-fir forests (Commission for Environmental Cooperation, 2006).

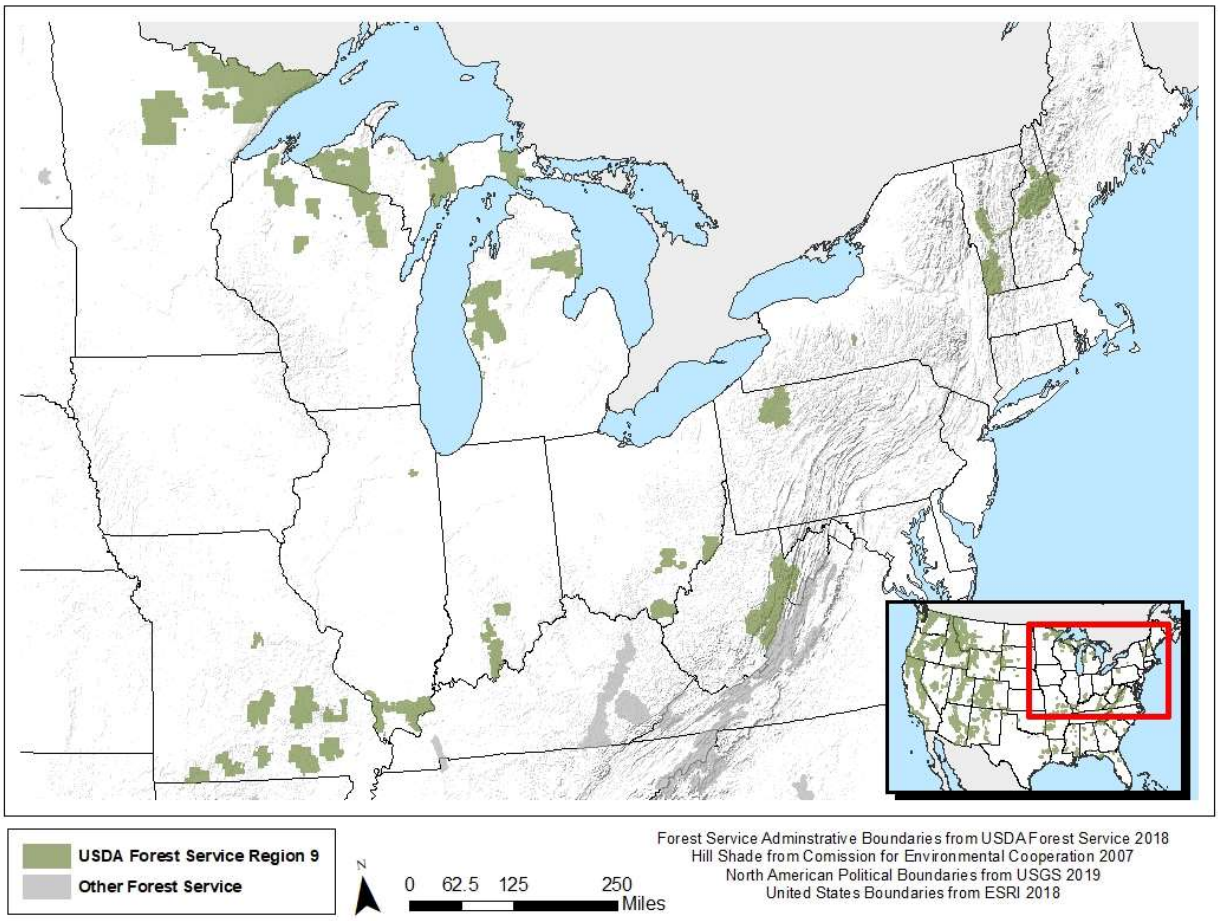

Figure 13: Lands managed by USDA Forest Service Region 9.

Region 10

This analysis did not include Region 10, Forest Service lands in Alaska, as the region was not included in the 2019 TCA output.

Results

This analysis shows that close to one third of Forest Service Lands have a restoration need (Table 2). There is wide variation on the proportion of lands with restoration need amongst Forest Service Regions. Generally, the Regions in the western United States; 1 (Figure 14), 2 (Figure 15), 3 (Figure 16), 4 (Figure 17), 5 (Figure 18) and 6 (Figure 19) have greater restoration needs than the two eastern Regions, 8 (Figure 20) and 9 (Figure 21). The proportion of area where only the WCC identifies restoration need is less variable that the areas where only the TCA identifies a restoration need (Figure 22) (Table 2). The variation in restoration needs of each Region appears to be due to differences in the area the TCA identified need.

The area where the WCC and TCA agree on restoration need (category WCC-TCA restoration need) is a small proportion of Forest Service lands. WCC-TCA restoration need is one percent, or 2.4 million acres of lands managed by the Forest Service in the contiguous United States (Table 2). The region with the highest percentage of WCC-TCA restoration need was Region 3 (Figure 16), with three percent A relatively moderate percentage of lands (2%) in Regions 4 (Figure 17) and 5 (Figure 18) was identified by both the WCC and TCA as having a restoration need. All other Forest Service regions had one percent or less of their lands identified by both the WCC and TCA as having restoration needs.

Area where only the WCC identified restoration need was also relatively small, though there is greater variation amongst Regions than WCC-TCA restoration need. The WCC identifies

restoration need on 4.9 million acres, two percent of Forest Service lands where the TCA does not (WCC Restoration Need; Table 2). WCC Restoration Need is highest in Regions 3 (Figure 16) and 4 (Figure 17), with six and five percent of their total area respectively identified as needing restoration by the WCC, but not the TCA. Two percent of the total area in Regions 1 (Figure 14) and 8 (Figure 20) is identified by only the WCC as having a restoration need. The remaining Forest Service Regions, 2 (Figure 15), 5 (Figure 18), 6 (Figure 19), and 9 (Figure 21) have one percent or less of their area classified as having a restoration need by only the WCC.

Areas that only the TCA identified as having a restoration need were much larger than WCC-TCA or WCC restoration need. TCA restoration need was also quite variable from Region to Region. The TCA identifies restoration need on 54.4 million acres, or 26%, of Forest Service lands where the WCC does not (TCA Restoration Need; Table 2). Region 5 (Figure 18) has the greatest percentage of area classified by only the TCA as having a restoration need with 61% (Table 2). Regions 1 (Figure 14) and 6 (Figure 19) have the next greatest percentage classified as having a restoration need by only the TCA with 37% and 38% (Table 2). Region 3 (Figure 16) has 27% of its lands classified as having a restoration need by only the TCA while Region 2 has 20%. Regions 4 (Figure 17), 8 (Figure 20) and 9 (Figure 21) has the lowest percentage classified by only the TCA as having restoration need with 12%, 10%, and three percent, respectively (Table 2).

The majority of Forest Service lands had no restoration need identified by either the WCC or TCA. No restoration need was identified by either classification system on 149.6 million acres, or 71% of Forest Service lands (Table 2). Region 5 (Figure 18) had the smallest percentage of area of no restoration need of all Regions with 36%. The WCC and TCA together identify no

restoration need for 61% of the lands managed by Regions 1 (Figure 14) and Region 6 (Figure 19). Combined, the WCC and TCA identify a similar percentage of land without restoration need, 64%, in Region 3 (Figure 16). The eastern Regions, 8 (Figure 20) and 9 (Figure 21), have the greatest extent of no restoration need identified by either the WCC or TCA, with 87% and 95% respectively (Table 2). Of the western Regions, Regions 2 (Figure 15) and 4 (Figure 17) have the largest extent by percentage of lands with no identified restoration with 78% and 81% (Table 2).

Results Maps

Region 1

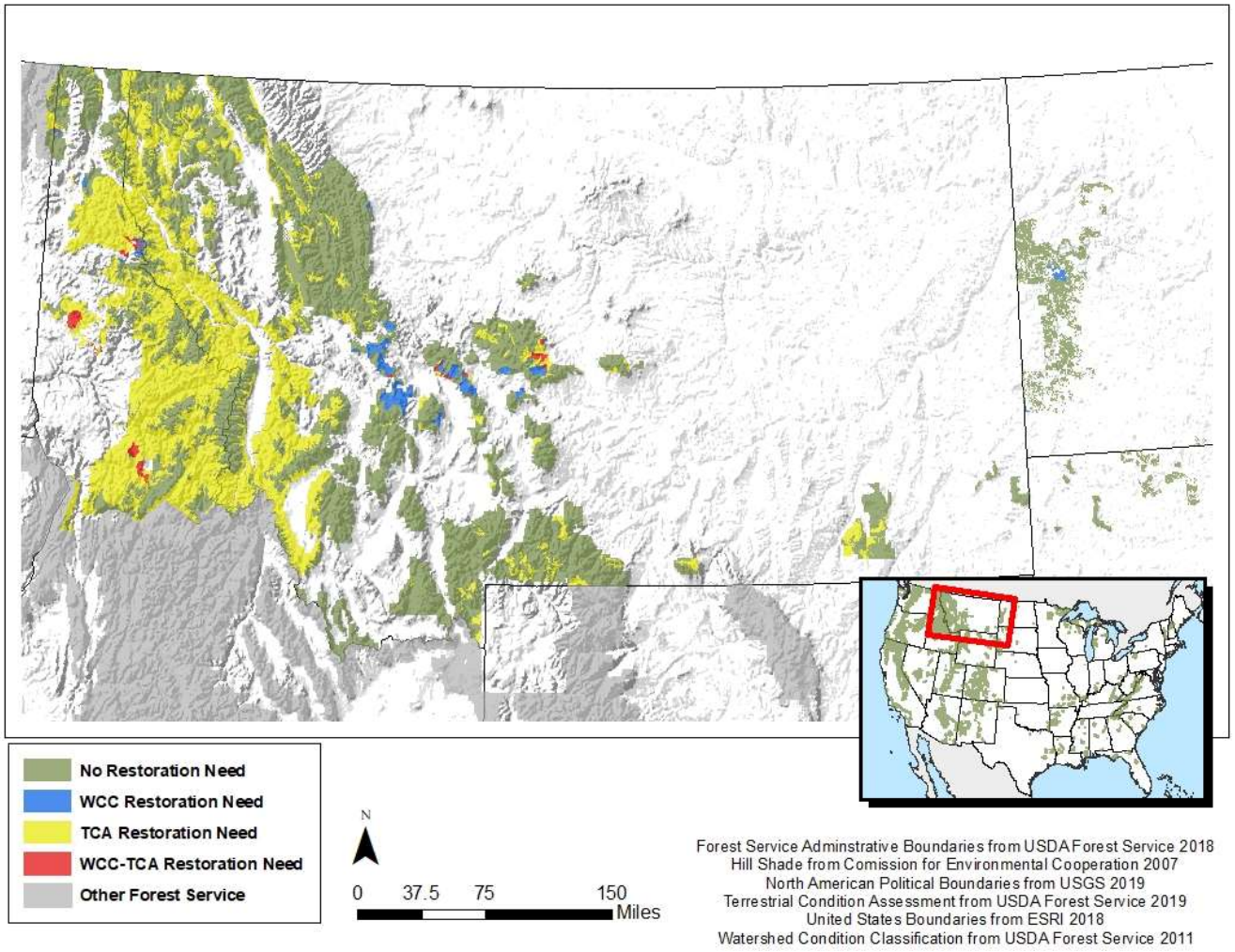

Figure 14: : Results for USDA Forest Service Region 1 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 2

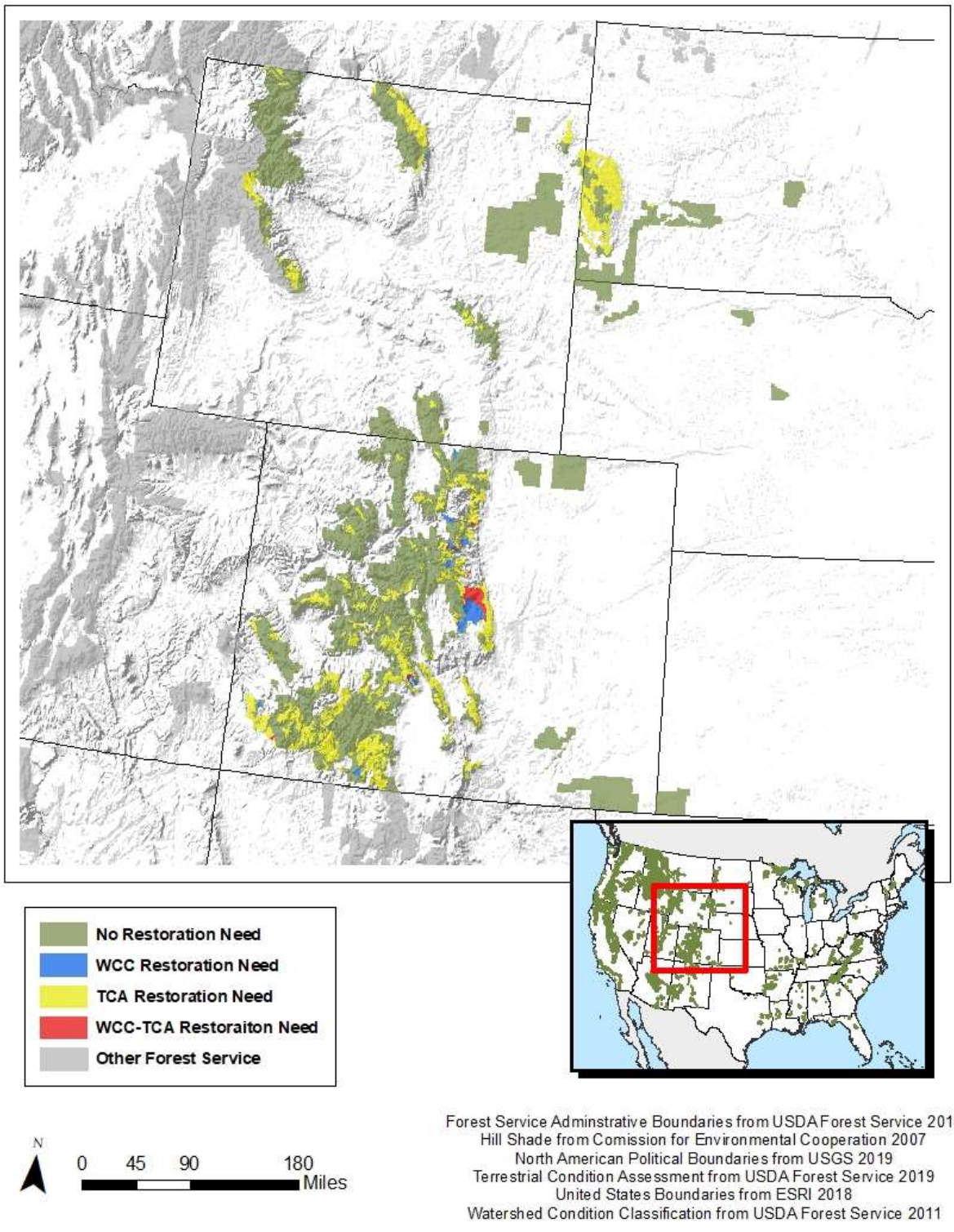

Figure 15: Results for USDA Forest Service Region 2 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 3

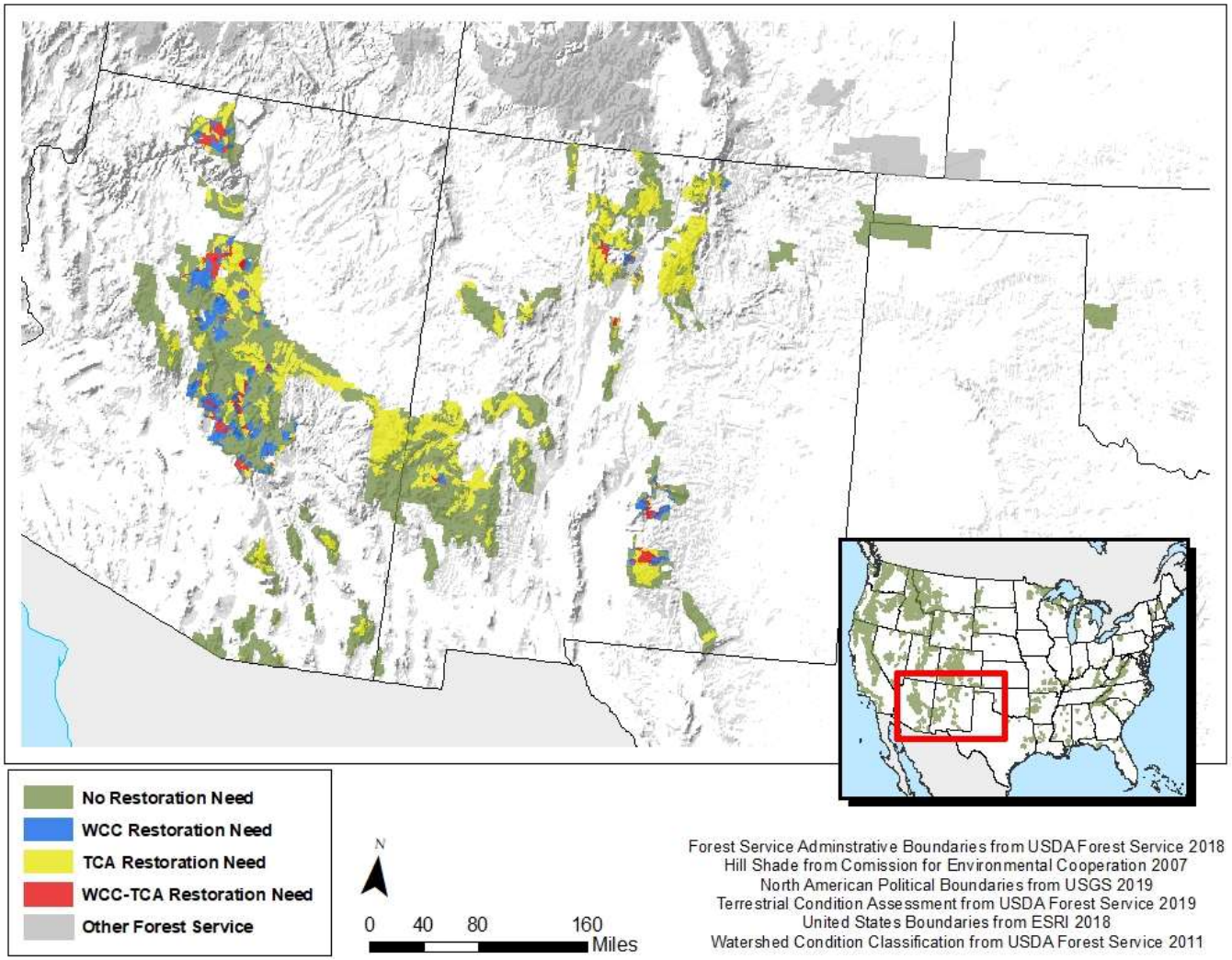

Figure 16: Results for USDA Forest Service Region 3 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 4

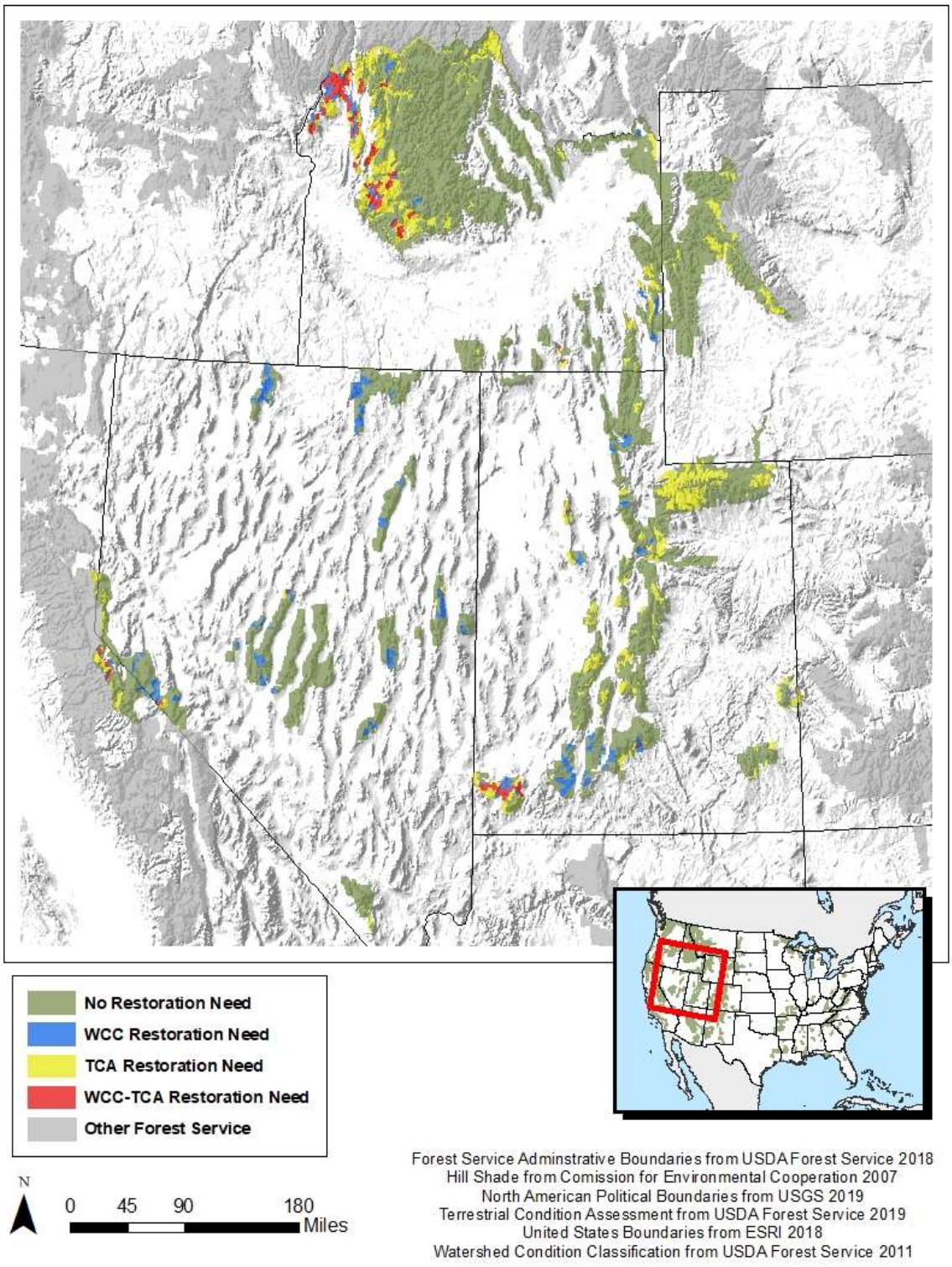

Figure 17: Results for USDA Forest Service Region 4 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 5

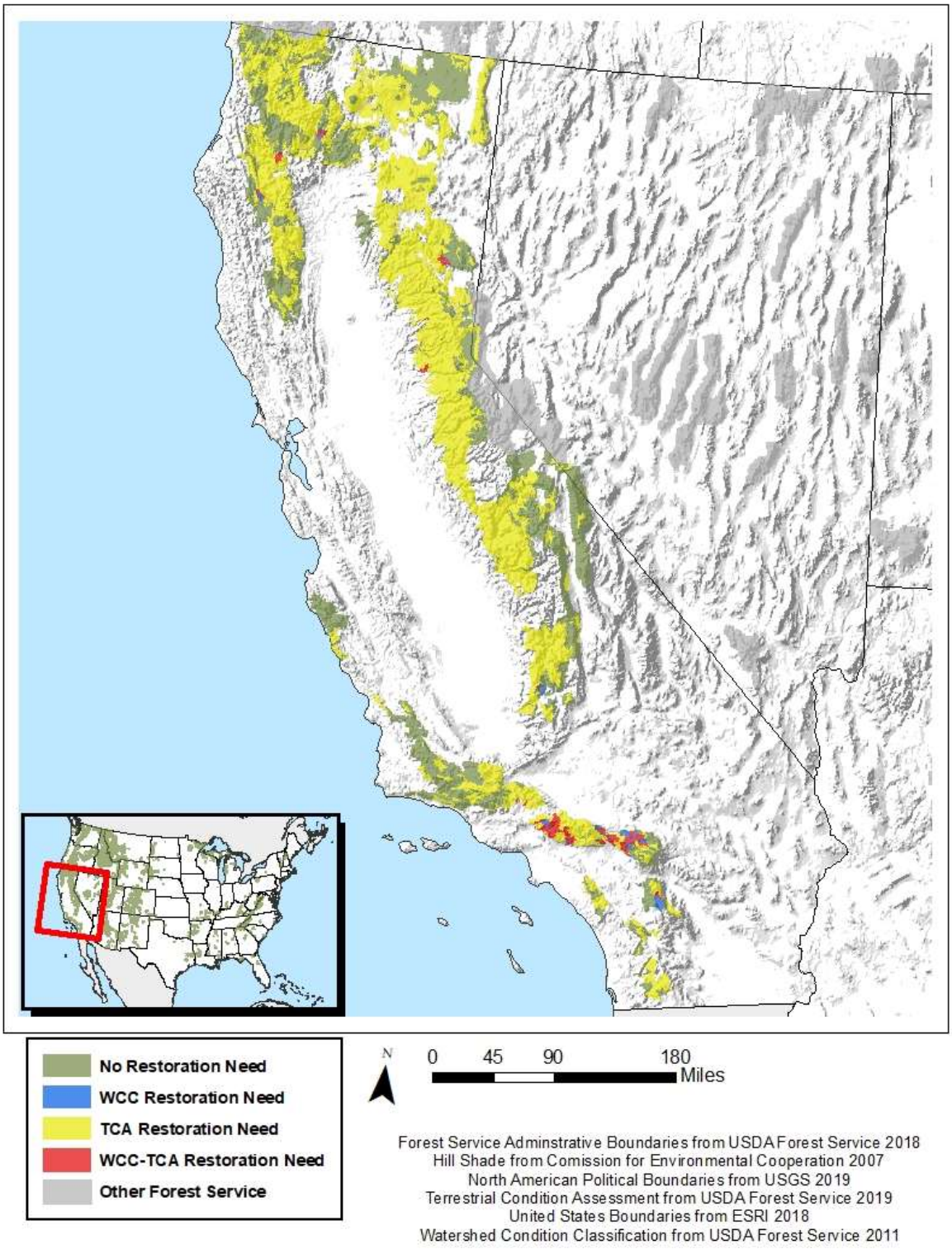

Figure 18: Results for USDA Forest Service Region 5 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 6

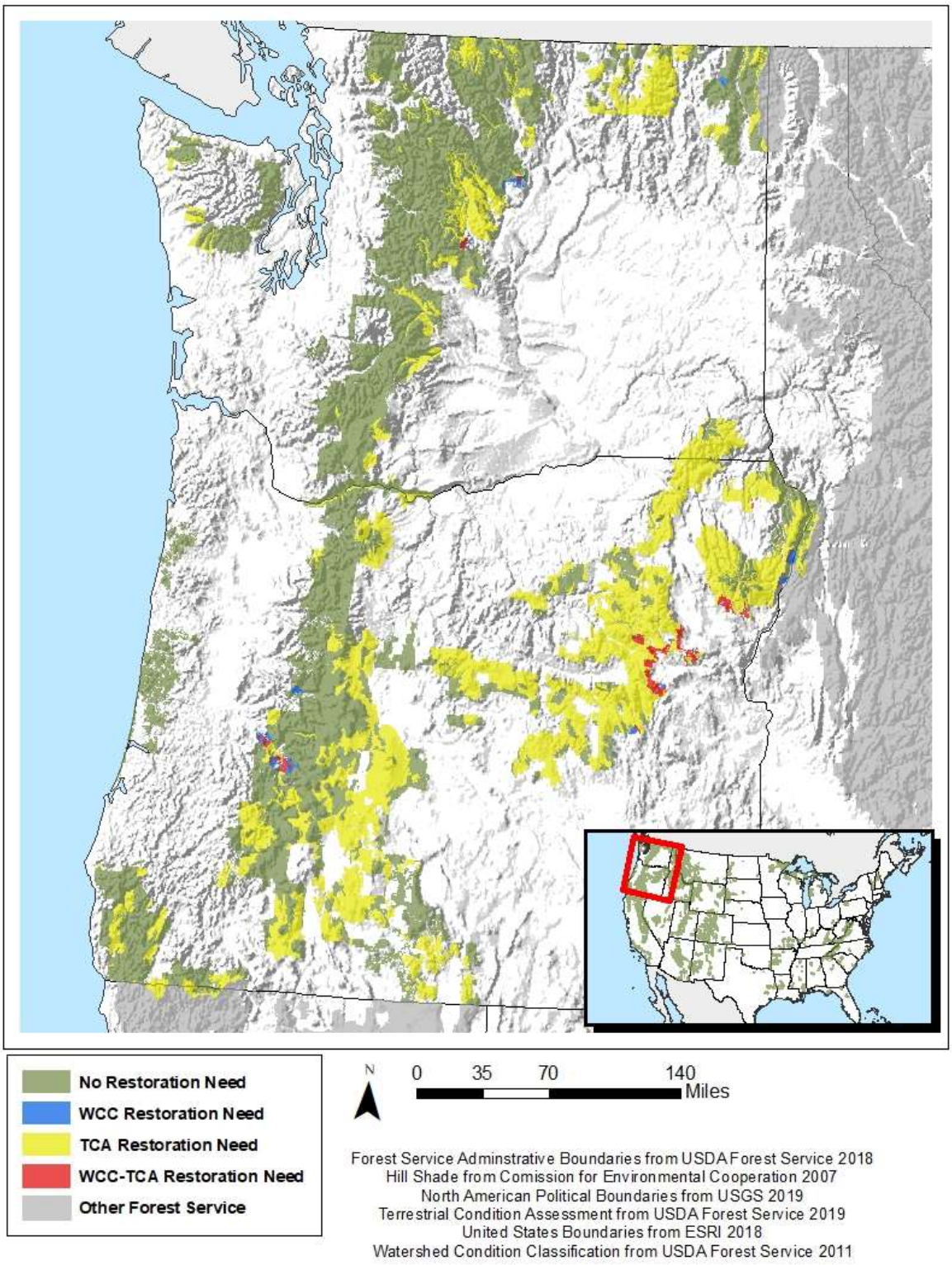

Figure 19: Results for USDA Forest Service Region 6 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 8

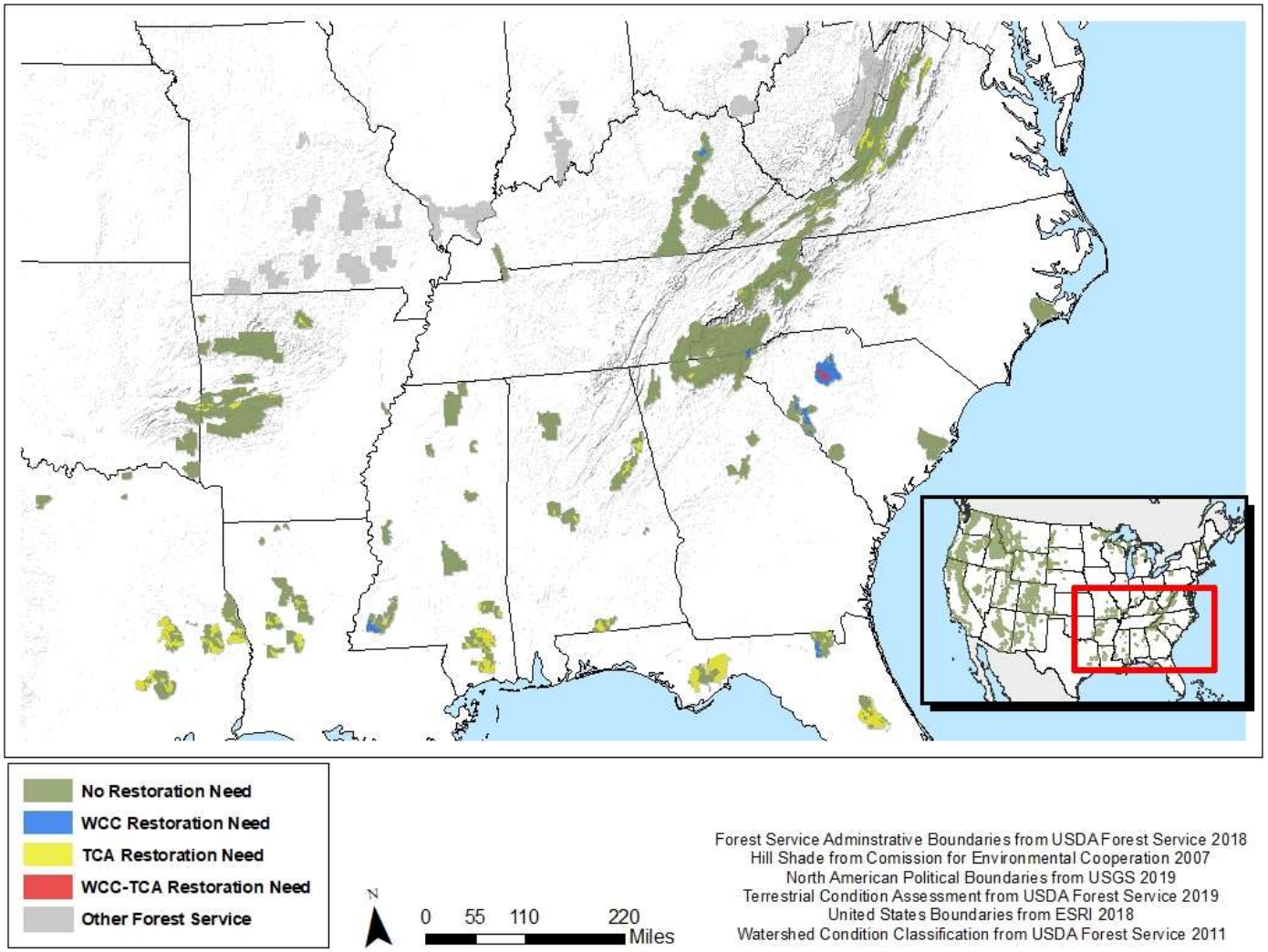

Figure 20: Results for USDA Forest Service Region 8 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Region 9

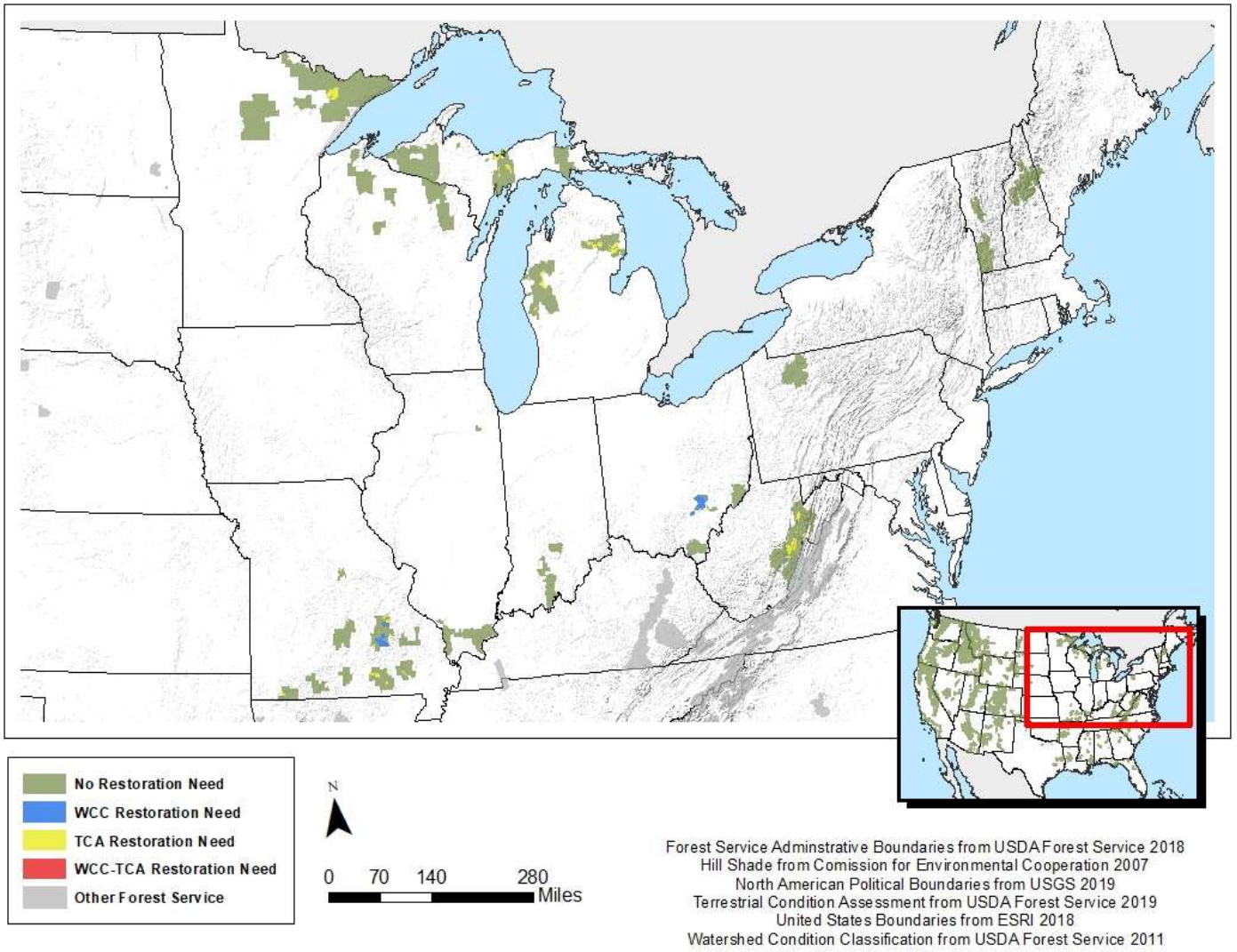

Figure 21: Results for USDA Forest Service Region 9 showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

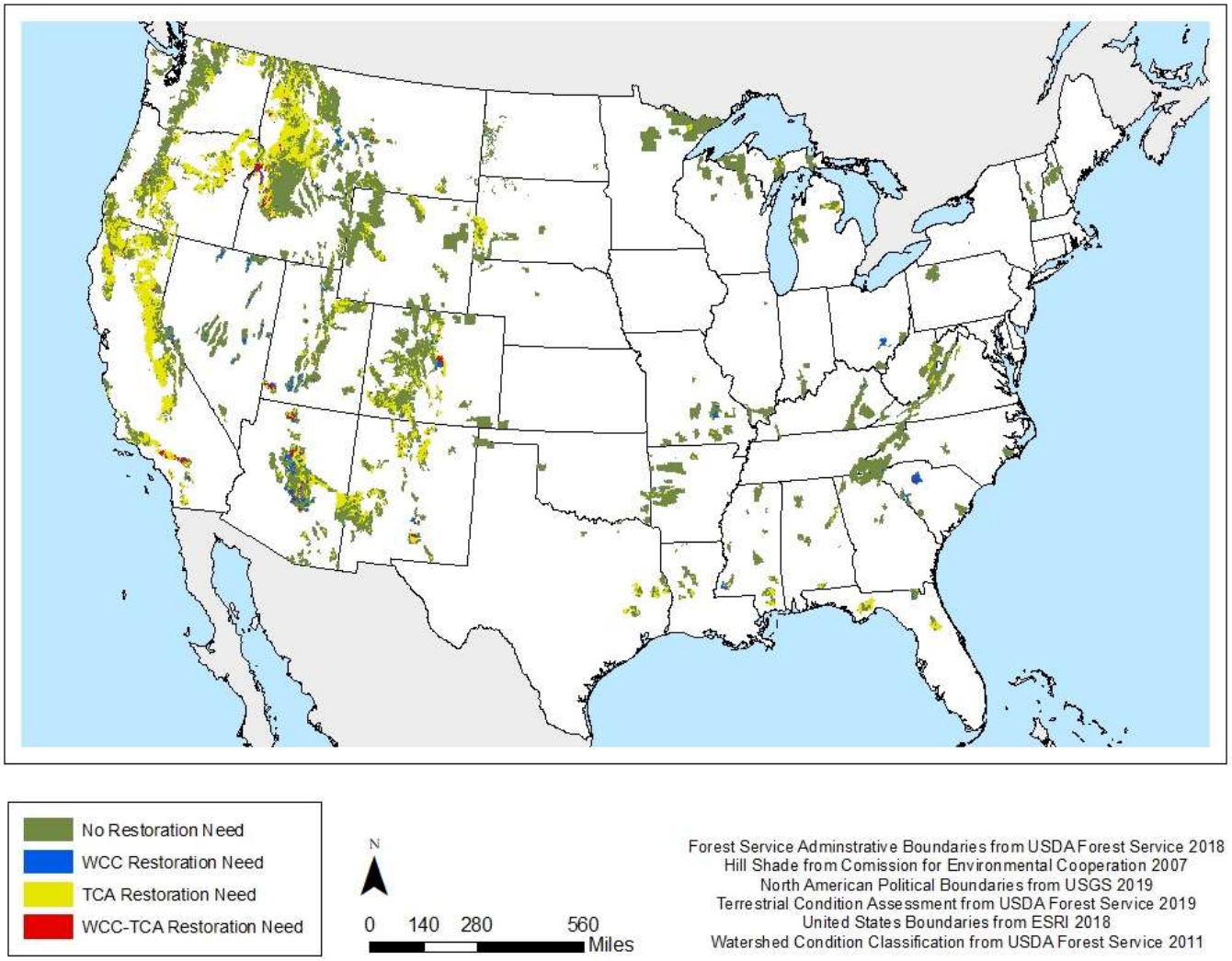

Figure 22: Results for all USDA Forest Service lands in the contiguous United States showing no restoration need, WCC only identified restoration need, TCA only identified restoration need and both WCC and TCA identified restoration need.

Table 2: Area in acres and by percent of total lands for no restoration need, WCC only identified restoration need, TCA only identified restoration need, areas where WCC and TCA both identify restoration need, and total restoration need.

Region	No Restoration Need	WCC Only Restoration Need	TCA Only Restoration Need	WCC and TCA Restoration Need	Total Restoration Need
1	17,229,945 61%	454,661 2%	10,300,888 37%	184,056 1%	10,939,605 39%
2	21,877,636 78%	365,048 1%	5,471,950 20%	191,564 1%	6,028,562 22%
3	14,726,115 64%	1,372,221 6%	6,266,691 27%	632,750 3%	8,271,662 36%
4	27,402,042 81%	1,583,082 5%	4,227,833 12%	786,389 2%	6,597,304 19%
5	8,696,948 36%	149,053 1%	14,599,890 61%	384,998 2%	15,133,941 64%
6	16,220,970 61%	132,108 < 1%	10,171,109 38%	225,528 1%	10,528,745 39%
8	22,399,556 87%	587,963 2%	2,661,015 10%	46,587 < 1%	3,295,565 13%
9	21,091,622 95%	331,636 1%	734,651 3%	1,680 < 1%	1,067,967 5%
National Total	149,644,834 71%	4,975,772 2%	54,434,027 26%	2,453,552 1%	61,863,351 29%

Discussion

Together the TCA and WCC identify restoration need on approximately one third of National Forest System lands in the contiguous United States; however, there is wide variation in the percentage of lands with restoration need among regions. For example, the eastern Regions (8 and 9) have the least amount of combined need, while western Regions (1,2,3, and 4) have an intermediate need. Region 5, the Forest Service lands in California, is the only region where total restoration need surpasses no restoration need.

Overall, Forest Service lands in the Eastern United States, Regions 8 and 9, displayed low restoration need when compared to the western Regions. The percentage of land in the eastern Regions identified by the WCC as having restoration need is comparable to other regions, although that percentage is on the lower end of the range. In contrast, the TCA identifies a very low proportion of lands in need of restoration in eastern Regions compared to western regions. It appears that National Forest lands in the west are experiencing greater impacts from stressors, such as insects and pathogens, and seasonal shifts in temperatures and precipitation. The vegetative condition in the eastern Regions also appears to be less impacted by risk to insects and pathogens and uncharacteristic buildup of fuels.

In contrast to the low restoration needs identified in the eastern Regions, Region 5 has a large percentage of its lands in need of restoration. In fact, it is the only Region where the acreage of restoration need exceeds no restoration need. WCC restoration need is comparable to other Forest Service Regions at one percent. However, the TCA identifies a large portion of the Region as in need of restoration. This large extent of restoration need identified by the TCA

is likely a result of extensive drought that occurred in the state of California from 2012 to 2017, with an exceptionally severe drought in 2014 and 2015 (USDA Forest Service, 2017).

The effects of recent drought in California are visible when examining the TCA indicators for Region 5, with changes in total precipitation, timing of precipitation, and changes in temperature evident. Precipitation exposure, or seasonal precipitation shifts, is uniquely rated low in California when compared to the rest of the western United States. More specifically, the western slopes of the Sierra Nevada Range are rated low or very low, reflecting a large decrease in annual precipitation. Examining seasonality of precipitation, the low and very low ratings for precipitation exposure tend to occur in winter and spring. This indicator reflects changes in the amount of precipitation received in Region 5 from December through June. Like precipitation, temperature exposure in much of California is also rated very low, reflecting increases in seasonal mean temperature. Increasing temperatures, however, are not unique to Region 5. Low ratings for temperature exposure are common throughout the western Regions. Decreases in precipitation and increasing temperatures can make forests more susceptible to mortality from insect and disease outbreaks (Anderegg et al., 2015). The drought in California was accompanied by a large scale bark beetle outbreak (USDA Forest Service, 2017). The impacts of drought have led to the death of nearly 130 million trees over 8.9 million acres in California's forests since the beginning of the drought (USDA Forest Service, 2017). This is reflected in TCA indicators for Region 5, which shows what appears to be the greatest extent of insect and pathogen incidence nationwide. The large extent of restoration need identified by the TCA in Region 5 provides an extreme example, but the results are similar to other regions in that the TCA identifies considerably more lands as having a restoration need than the WCC.

The greater identification of terrestrial restoration need occurs at both national and regional scales. While it is not surprising that the WCC and TCA do not identify the same lands in need of restoration as they were developed with different objectives, it is important to understand factors that contribute to the discrepancy in the amount of land identified as in need of restoration. Primarily, it is a result of the differences in indicators and scales; however, disagreement between the WCC and TCA is also likely, in part, influenced by the difference in timing of their development. The WCC shapefile used in this analysis was completed in 2011 and the TCA polygon feature class was completed in the spring of 2019.

The WCC watershed condition classifications were designed to be updated on both an annual and five-year timeframe. The annual update focuses on watersheds that have or are suspected to change condition class due to restoration activities or disturbance. On a five-year timestep a more detailed reclassification of all watersheds is to take place, sooner if conditions sufficiently change (USDA Forest Service, 2011). While some National Forests may be updating watershed condition classifications locally, the National dataset used in this analysis reflects only the first 2011 assessment. Including any updates of watershed condition post 2011 would likely result in changes to the acreages of restoration need calculated in this research. For example, if the WCC in Region 5 was updated to current conditions, the results would potentially change as a result of drought and tree mortality that is captured in the 2019 TCA. Drought and bark beetle mortality can change precipitation and snowpack, which in turn can influence quantity and timing of runoff (Edburg et al., 2012). These changes would be captured in the WCC's Flow Characteristic attribute of the Water Quality indicator. Large scale tree mortality also has the potential to decrease water quality by increasing turbidity and nutrient

leaching due to lack of forest uptake (Anderegg, Kane, & Anderegg, 2013). It is likely that updating the WCC to reflect 2019 conditions would result in a larger number of watersheds classified as impaired function due to impacts of drought and tree mortality. Ultimately, this would increase restoration need identified by the WCC and possibly identify larger acreages where the WCC and TCA agree that restoration is warranted.

As with any changes to the WCC, a reassessment of the TCA would lead to different results of this work. The national TCA assessment was designed as a template which can be customized to locality (Cleland et al., 2017). Possible customization of the TCA to better suit local context includes updating national data with local data where appropriate, changing thresholds of TCA metrics, inclusion of uncharacteristic disturbance, or customization of the national template to fit locality (Cleland et al., 2017).

The results of this work are also influenced by the choice of which condition classifications of the WCC and TCA to define as in need of restoration. Expanding the definition of categories within the WCC or TCA as having restoration need would naturally result in a change in outcome in area calculations of all four feature classes. In this analysis, only watersheds with the classification of impaired function were selected for restoration need. However, watersheds classified as functional-at-risk by the WCC also exhibit indicators of degradation and, in some cases, may be candidates for restoration treatments. For example, including both watersheds classified as at risk and watersheds classified as impaired as in need of restoration in Region 3 (Figure 4) would dramatically increase acreage of WCC restoration need. Presumably this change would also increase acreage of combined WCC-TCA restoration needs due to increased overlap with LTAs with a restoration need.

Changing the number of condition classes used by the TCA, to match the WCC categories, only appreciably impacts the proportion of TCA restoration need and no restoration need. Using the same methods described above, an analysis was completed at a national level using TCA data broken into three condition classes. The five condition classes of the TCA were converted by equally dividing the terrestrial ecologic integrity scale used by the TCA (-1 to 1) into three ranges and selecting the lowest integrity category (score -1 to -0.333333) as having a restoration need. TCA only restoration need decreased by 7% while areas with no restoration need increased by 9% (Table 3). WCC only restoration need increased due to less overlap with TCA restoration need. It is not surprising that decreasing the number of categories used by the TCA reduced the scale range of the lowest integrity rating and thus areas in need of restoration. The differences between the two classification systems is more complex than then number of categories that the classifications used to evaluate restoration needs.

Table 3: Analysis using the TCA rating divided into three categories instead of five. Area by percent of total lands for no restoration need, WCC only identified restoration need, TCA only identified restoration need, areas where WCC and TCA both identify restoration need, and total restoration need.

Region	No Restoration Need	WCC Only Restoration Need	TCA Only Restoration Need	WCC and TCA Restoration Need	Total Restoration Need
National Total	168,670,657 80%	5,927,053 3%	35,408,606 17%	1,502,274 1%	61,863,351 20%

As updates or changes occur to the WCC and TCA the four output feature classes of this project (i.e., WCC-TCA restoration need, WCC restoration need, TCA restoration need, and no

restoration need) will remain relevant. A majority of Forest Service lands show no restoration need identified by both the WCC and TCA. These areas could be low priority for restoration treatments and efforts may be best suited towards monitoring conditions to identify new degradation in watersheds or LTAs that may push them into impaired function or low ecological integrity.

Areas where the WCC and TCA both agree on restoration need are good candidates to focus restoration efforts and include treatments that address both watershed function and terrestrial ecosystem integrity. WCC-TCA restoration needs represent just one percent of Forest Service lands in the contiguous United States, with a maximum of three percent in Region 3. The timing difference in the initial WCC (2011) and the TCA (2019) could contribute to greater disagreement of restoration needs. Degradation that appears in the TCA may have impacts to watershed health that would also appear in an updated WCC.

As these classification systems are implemented and used by managers to help prioritize restoration, it is important to keep in mind that watersheds and watershed health are, in part, a reflection of their surrounding terrestrial environs. It is highly likely that terrestrial treatments addressing low ecological integrity as identified by the TCA will also benefit watersheds and the streams that drain them. The TCA uses indicators which could be expected to be reflected in some of the WCC indicators. For example, streamflow characteristics and aquatic biota may be altered by shifts in temperatures and precipitation regimes (Wrona et al., 2006). Fire severity and frequency could affect aquatic biota, water quantity, and water quality. Fires that burn at high severity can change timing or magnitude of runoff and increase sediment inputs into streams (Shakesby & Doerr, 2006).

Areas where only the WCC or only the TCA show a restoration need is not unexpected as the two systems assess were designed with different assessment goals using different scales and indicators. For management purposes, having an understanding of where one identifies restoration need and the other does not could be beneficial. It could be helpful for management to be able to justify treatments in one area over another and where to spend effort. In these areas developing an integrated classification system or providing guidance on order of implementation may be helpful.

Finally, this analysis has identified areas where only the WCC or only the TCA show a restoration need. It is especially important to understand what is driving one classification system to identify restoration need. This could better support decision making when selecting areas for restoration and to justify treatments, particularly when working with external partners.

Determining if areas where both the WCC and TCA identify or only one of the classification systems identifies restoration need is statistically significant is an important next step for this work. Identification of common conditions or factors where agreement or disagreement exists could prove beneficial for planning of restoration treatments. The separate development, focus, differences in scale, timing, and number of categories used by the WCC and TCA make the integration of the two classification systems a difficult prospect. However, a unified system to determine and aid in the prioritization of restoration needs, both watershed and terrestrial could prove to be very beneficial. An integrated assessment may help eliminate confusion and better focus restoration treatments.

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