Materials and Methods

Keith et al. (2013) and Bland et al. (2017) recommend a series of steps to apply the IUCN criteria beginning with classification and description of the ecosystem type to be assessed and development of a conceptual model to organize information about factors that cause environmental degradation or disruption of biotic processes. Depending on the characteristics of the ecosystem type and available data, appropriate indicators are then selected for measurement under each assessment criterion. The classification of ecosystem types used in these assessments must therefore be suitable for describing recurrent species composition, it must be practical for mapping, and it must support measurement under IUCN assessment criteria. Below we describe the specific classifications we used and then illustrate analysis steps taken in this assessment under criteria A-D.

Ecological Classifications

Keith et al. (2013) state that to be useful for red listing, ecosystem classifications "should be finer units than ecoregion or biomes and should encompass variation that may be recognizable at regional and local scales." And that, ecosystem assessments "…will be most useful when based on established national or regional classifications that are cross-referenced to global assessment units…"

We addressed terrestrial ecosystem types, and both upland and wetland types that are readily identified with rooted plants that form recognizable patterns of vegetation. Forest, shrubland, savanna, grassland, river floodplain, wetland, and sparsely vegetated ecosystem types are treated here. We did not treat freshwater ecosystems, such as lakes and streams, marine ecosystems, such as oyster beds and coral reefs, or subterranean ecosystems, including all types of caves.

We used NatureServe's Terrestrial Ecological Systems classification (Comer et al. 2003, Josse et al. 2003) as our assessment units. The NatureServe classification was built upon numerous national and local classifications across the Americas (e.g., Borhidi 1991, NEGI 2013, Cohen et al. 2020). This classification integrates information on plant communities, geophysical settings, and characteristic dynamic processes to describe natural, local- to medium-scaled ecosystem types. It has been in wide usage for mapping and assessment at regional, national, and multi-national scales (Calderon et al. 2004, Comer and Schulz 2007, Rollins et al. 2009, Sayre et al. 2009, Aycrigg et al. 2013, Comer et al. 2013, Comer et al. 2018, Comer et al. 2019) and 640 natural units were mapped within this study area (Comer et al. 2020). See and NatureServe Explorer (http://explorer.natureserve.org/) and S2 (Supporting Information) for descriptions and conceptual models of all terrestrial ecological systems treated in this study. Nearly 51% of types addressed in this analysis are considered endemic to the USA, while the rest are shared with either Canada, Mexico, the Caribbean, or occur throughout Central America.

In order to place this classification in global context, we have maintained relationships between the ecological systems classification and the taxonomic hierarchy of the International Vegetation Classification (IVC) (Faber-Langendoen et al. 2014), the U.S. National Vegetation Classification (USNVC) (FGDC 2008, Jennings et al. 2009) and the Canadian National Vegetation Classification (CNVC) (Baldwin and Meades 2008). The eight hierarchical levels of the IVC include three global formation-type units at upper levels based primarily on vegetation physiognomy, followed by three continental mid-level types defined by a combination of physiognomy and floristics, and two lower-level units, defined primarily by floristic composition. See the US National Vegetation Classification website for descriptions of these classification units (http://usnvc.org/).

Table S1-1 provides a summary of the IVC hierarchy with a brief statement of defining characteristics and number of units at each level. The example from Table S1-1 includes the IVC Group called

Intermountain Dry Tall Sagebrush Steppe & Shrubland. This is a cold desert shrubland that encompasses a diverse range of shrubland and steppe occurring throughout the intermountain west of North America from British Columbia south to northern Arizona and New Mexico. Because the NatureServe terrestrial ecological systems classification describes units with floristic, biophysical, and natural disturbance attributes, types are closely related to, but distinct from, existing vegetation concepts in the IVC. In general, ecological systems concepts align most closely with the Group or Alliance level concepts of the IVC (Table S1-1). For example, the *Intermountain Basins Big Sagebrush Shrubland* is one of three terrestrial ecological system types related to the *Intermountain Dry Tall Sagebrush Steppe & Shrubland* Group.

Table S1-1. International Vegetation Classification Hierarchy, including numbers of natural types *(as of October 2020)* **in temperate North America** *(Faber-Langendoen et al. 2014).*

Level No.	Level Name	Defining Characteristics	No. Types*	Example
1	Class	Life Form Physiognomy	6	Desert & Semi-Desert
2	Subclass	Global Physiognomy	11	Cool Semi-Desert Scrub and Grassland
3	Formation	Global Physiognomy	25	Cool Semi-Desert Scrub and Grassland
4	Division	Continental Floristics	53	Western North American Cool Semi-Desert Scrub & Grassland
5	Macrogroup	Subcontinental Floristics	124	Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland
6	Group	Regional Floristics	313	Intermountain Dry Tall Sagebrush Steppe & Shrubland
7	Alliance	Subregional Floristics	1,110	*Artemisia tridentata ssp. tridentata - Artemisia tridentata ssp. xericensis Dry Steppe & Shrubland Alliance*
8	Association	Local Floristics	5,878	*Artemisia tridentata ssp. tridentata / Poa secunda Shrubland*

***estimated number for the conterminous USA portion of the study area*

The IUCN has established a 6-level standard global typology for ecosystems being red listed (Keith et al. 2020) and terrestrial ecosystems identified in that typology (L1) link to the IVC classification at approximately Level 3, the IVC Formation or IUCN Ecosystem Functional Group (EFG). We address 28 EFGs in our analysis. These relationships are documented in the summary table of S3 (Supporting

Information). The terrestrial ecological systems treated in our analysis approximate Level 5 or "Global Ecotype" in the IUCN global typology. Our analysis provides a complement to the prior hemisphere-wide analysis of forests (Ferrer-Paris 2019) assessed at the IVC Macrogroup level (or IUCN Level 4).

Mapping Ecosystem Type Distributions for Red List Assessment

As noted previously, the terrestrial ecological systems classification been extensively applied to land cover mapping by federal and state resource agencies in the USA and Latin America. Within the U.S. the primary source of ecological system type distributions is the interagency LANDFIRE Program (Rollins 2009; https://landfire.gov/). That effort produces nationally consistent map layers to support strategic decisions for managing wildfires. Multiple map layers depict existing distributions of each ecological system type with other land cover classes, canopy closure and height (each at 30 m pixel spatial resolution; starting with condition *circa* 2003), as well as "biophysical setting" or the expected "potential" distribution of each ecological system type, mapped at 90 m pixel resolution. Each layer is produced within regional mapping zones using inductive modeling tool Random Forests (Liaw and Wiener 2002, Gislason et al. 2006). In the 2020 map update >1M georeferenced samples, each labeled to one of the terrestrial classification units, were used to "train" the model that utilized national map surfaces for climate, landform, and soil variables.

Maps of existing vegetation type and land use classes utilize satellite imagery to take advantage of image indices and distinguish natural vegetation units from human land use classes. The biophysical settings map did not utilize current satellite imagery, but instead integrated spatial simulations of fire behavior to depict where types likely occurred with expected natural fire regimes (Rollins 2009).

For this effort, we completed extensive review and editing of maps within the USA and then extended maps beyond the US into adjacent Canada, Mexico, Central America, and the Caribbean (Comer et al. 2020). If desired, one can then aggregate ecological system-based map classes to display the location and extent of units at Levels 1-5 of the IVC hierarchy (Table S1-1) or the IUCN global typology (EFGs). This eases the establishment of linkages among global vegetation-based classifications and facilitates summarizing assessment results from local to global scales.

Since an update to LANDFIRE existing distributions (Picotte et al. 2019) was ongoing during this analysis (depicting conditions *circa* 2016 in the USA), we referenced these updated data as a quality-control step as red list scores were being finalized.

The maps provide multiple kinds of data relevant to the listing process. For example, the IUCN assessment framework requires estimates of range-wide extent sensitive to categorization within 20% intervals (Bland et al. 2017). Other criteria utilize populating distributions within 10 X 10 km^2 cells for standardized analysis of types with restricted distributions. Measures under Criteria C and D may involve overlay of other mapped expressions of human land uses depicting different time periods, as indicators of ecosystem degradation. Therefore, spatial resolution of the map needs to be sufficient for reliable use of these other data sets. These requirements suggested an effective minimum map unit size, or mapped pixel resolution ranging from 90m x 90m to $1km^2$.

While 655 upland and wetland units from this classification have been mapped for this project area, not all types have been mapped sufficiently to support red listing. Of the total, 164 types (25%) were treated as Data Deficient (DD), or Not Evaluated (NE), based primarily on lack of sufficient distribution information. In some cases, types that naturally occur in small patches and linear patterns were not adequately mapped range wide in either or both "potential" or current distribution maps. As a result, a total of 491 types were carried forward for assessment, each with raster maps of "potential" extent, current extent, and range maps depicting areal extent by 96km^2 hexagon.

Conceptual Models of Ecosystem Composition, Key Processes, and Interactions

For each ecosystem type to be assessed, we completed a literature review and a brief descriptive conceptual model. Each model concisely characterizes what is known about the biotic composition, physical setting, and natural dynamic processes, along with prevalent threats and stressors for the type. The intent of these models is to clarify factors likely to result in ecosystem collapse (Bland et al. 2018) at a given location, and then to provide insights for subsequent measurement to indicate status and trend in these factors.

As referenced above, an example of an ecological system unit would be the *Intermountain Basins Big Sagebrush Shrubland*. This system is one of the most extensive types in temperate North America, occurring throughout much of the western U.S., typically in broad basins between mountain ranges, plains and foothills between 800 and 2500 m elevation. Soils are typically deep, well-drained and non-saline. These shrublands are dominated by *Artemisia tridentata* ssp. *tridentata* and/or *Artemisia tridentata* ssp. *wyomingensis*. Perennial herbaceous components typically contribute less than 25% vegetative cover. Common graminoid species can include *Achnatherum hymenoides, Bouteloua gracilis, Elymus lanceolatus, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Pleuraphis jamesii, Pascopyrum smithii, Poa secunda,* or *Pseudoroegneria spicata*.

A graphical conceptual model for this type is depicted in Figure S1-1. The primary land uses that alter this ecosystem type are associated with livestock grazing, fire regime alteration, direct soil surface disturbance, invasive plant species, and other effects of landscape fragmentation. Excessive grazing stresses the system through fragmenting biological soil crust, soil compaction, altering the composition of perennial plant species, and increasing the establishment of non-native annual grasses, particularly cheatgrass (*Bromus tectorum*).

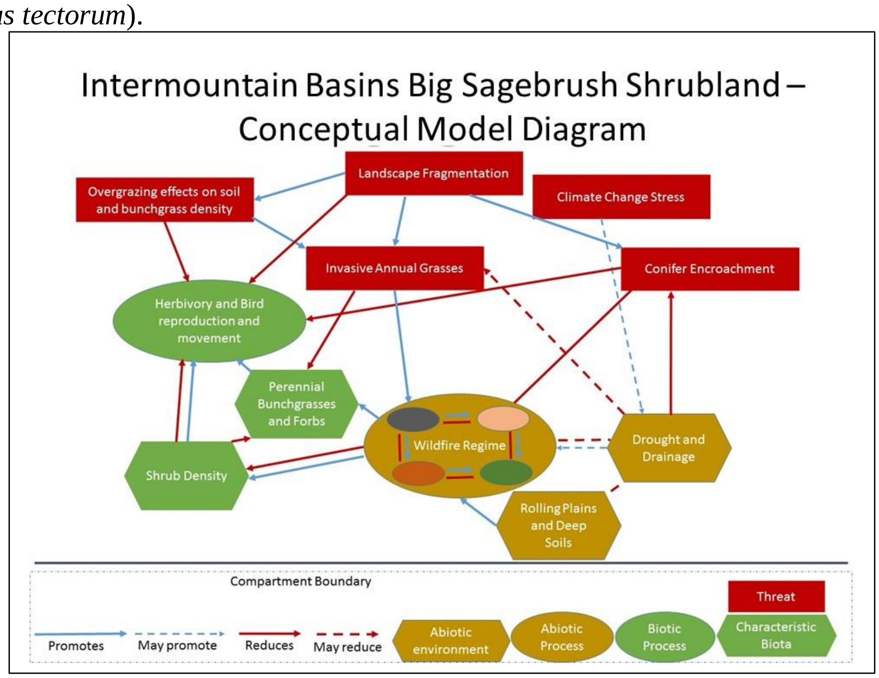

Figure S1-1: Graphical conceptual model for Intermountain Basins Big Sagebrush Shrubland; one ecosystem type used in red-list assessment.

Fire further stresses livestock-altered vegetation by increasing exposure of bare ground and invasive annual grasses and decreasing perennial bunchgrass and sagebrush abundance. Prior to the 1800s, stand-replacing fire frequency was likely 40-60 years, with smaller fires every 20-25 years. Repeated burning or burning in summer deplete perennial grasses and allow invasive forbs and cheatgrass to increase. Fine fuel from invasive annual grasses can represents the most important fuel component in the system and can substantially increase the fire frequency. In areas with a high fire frequency (every 2-5 years) or high-severity fire, perennial grasses and shrubs may be eliminated. Conversely, fire suppression can lead to conifer tree encroachment with subsequent loss of shrub and herbaceous understory.

Fragmentation of shrub-steppe by agriculture increases cover of annual grasses, total annual/biennial forbs, and bare ground, and decreases cover of perennial forbs and biological soil crusts and reduces obligate insects and obligate birds and small mammals. A fully "collapsed" example of this shrubland type could be said to occur when invasive plant taxa have overwhelmed the site and little or no native vascular plant regeneration.

From this conceptual model, one can discern key ecological attributes of fire regime and native plant composition and structure, that point to indicators one might use in red-list assessment under criteria for environmental degradation or disruption of biotic processes. These could include measures of landscape fragmentation, grazing intensity, invasive annual grass presence or abundance, and measures of wildfire regime and its departure from natural conditions.

Descriptive conceptual models for types treated in this assessment accompany general types descriptions in S2 Supplemental Material.

Criteria and Indicators of At-Risk Conservation Status

Keith et al. (2013) and Bland et al. (2017) provide additional background on the IUCN framework for risk assessment. Under Criterion A, C and D, component indicators address trends over different time periods (Table S1-2). These include long-term trends, such as those taking place since industrial-scale land uses that were initiated in the 16-18th centuries, trends of the past 50 years up to the present, and trends from the present over the next 50 years. Criterion B addresses only the present time, but measures distribution of the ecosystem types in several distinct ways.

Table S1-2. Criteria summary for ecosystem red listing using the IUCN framework (Bland et al. 2017) *(grey shaded analyses completed for terrestrial ecosystems in Temperate & Tropical North America).*

Criterion	A Reduction in distribution	B Restricted distribution	C Environmental degradation	D Disruption of biotic processes	E Quantitative analysis
Data gathering and analysis	Gather and process spatial data		Select abiotic variables and collapse thresholds	Select biotic variables and collapse thresholds	Select abiotic and biotic variables and collapse thresholds
	Classify, validate, and create time-series of maps		Estimate relative severity and extent of degradation	Estimate relative severity and extent of disruption	Implement appropriate ecosystem model
Application	Extent over time:	Current extent:	Relative severity and extent:	Relative severity and extent:	Probability of collapse:

Criterion	A **Reduction in distribution**	B **Restricted distribution**	C **Environmental degradation**	D **Disruption of biotic processes**	E **Quantitative analysis**
	A1. Past 50 years	**B1. EOO**	C1. Past 50 years	D1. Past 50 years	CR. >50% within 50 years
	A2a. Next 50 years	**B2. AOO**	C2a. Next 50 years	D2a. Next 50 years	EN. >20% within 50 years
	A2b. Any 50 years including present	B3. Number of locations	C2b. Any 50 years including present	D2b. Any 50 years including present	VU. >30% within 100 years
	A3. Since 1750 (or pre-industrial land use)		**C3. Since 1750 (or pre-industrial land use)**	**D3. Since 1750 (or pre-industrial land use)**	

Under each indicator, the level of severity in each trend categorizes the relative risk of range wide ecosystem collapse (Critically Endangered (CR), Endangered (EN), Vulnerable (VU), etc.), and so measures aim to describe the relative proportion of the range wide distribution of the ecosystem type impacted at different levels of relative severity, each corresponding to a level of risk of collapse. For example, under Criterion C3 for long-term environmental degradation, a type could surpass the threshold for listing as VU if >70% of its extent occurs with >70% severity, OR >90% of its extent occurs with >50% severity, OR >50% of its extent occurs with >90% relative severity (Table S1-3).

Table S1-3. Summary of indicator thresholds for scoring Environmental Degradation (C3) under the IUCN Framework for Red list of Ecosystems.

Criterion C3	Critically Endangered	Endangered	Vulnerable
Environmental degradation since 1750 based on change in abiotic variables affecting the native biota of the ecosystem type.	≥ 90% extent with ≥ 90% relative severity	≥ 70% extent with ≥ 90% relative severity ≥ 90% extent with ≥ 70% relative severity	≥ 70% extent with ≥ 70% relative severity ≥ 90% extent with ≥ 50% relative severity ≥ 50% extent with ≥ 90% relative severity

Where data were evaluated but deemed inadequate for measurement, a score of Data Deficient (DD) was applied, and if no attempt was made to address a specific measurement a score of Not Evaluated (NE) was applied.

Overall status is then based on the most severe rating of any of the component indicator scores; i.e., if a type scores as CR under by any indicator, it will receive and overall score of CR. Below we describe component indicators measures we used under each criterion.

Criterion A – Reduction in Geographic Distribution

Criterion A measures trends in overall extent of a given ecosystem type, estimating the proportional change over time. With loss of areal extent, one can infer a decrease in niche diversity, the pool of characteristic species, and variability in key ecological processes; leading to altered species composition in remaining examples (Rosensweig 1995, Lockwood et al. 1997, Kuussaari et al. 2009). Criterion A1 addresses trends of the past 50 years up to the present, A2 addresses trends from the present over the next 50 years, and A3 addresses long-term trends since pre-industrial times.

We limited our measurement to A3 for several reasons. First, long-term trends in land conversion for agriculture have been the strongest global driver of ecosystem transformation since the industrial revolution (Ramankutty & Foley 1999, Ellis et al. 2010), and these trends are dominant in temperate tropical North America. Research into pre-Columbian land use and effects of European contact and the "Great Dying" suggest that, as of 1492, perhaps 1.4% of the land area in the Americas was under cultivation (Koch et al. 2019). In temperate and tropical North America, human populations (an intensive vegetation conversion) were most densely concentrated in the Valley of Mexico, Central America, and the Caribbean. Across temperate North America, human population densities were lower – with estimates ranging between 2.8-5.7 million (Milner and Chaplin 2010), and hunting/gathering strategies utilized fire over extensive lands. We anticipated that this one indicator would explain much of overall red-list status for terrestrial ecosystems, especially for those associated with agricultural regions. Second, threshold measures to trigger Vulnerable status under A1 (recent 50 years) and A2 (next 50 years) are losses of >30% of the range wide extent. While there may be exceptions, land use trends in North America have stabilized since the mid-20th century (Tilmen et al. 1994, Whitney 1996, Grau and Aide 2008, Riley 2013) and based on forecasts (Theobald 2010), we anticipated that this threshold would be crossed in very few cases. Under Criterion A3, we aimed to determine long-term trends in extent by comparing current extent estimates with those from our "potential" distribution map (Figure S1-2). The potential distribution includes biophysical conditions where each type might occur today had there not been any prior intensive human intervention.

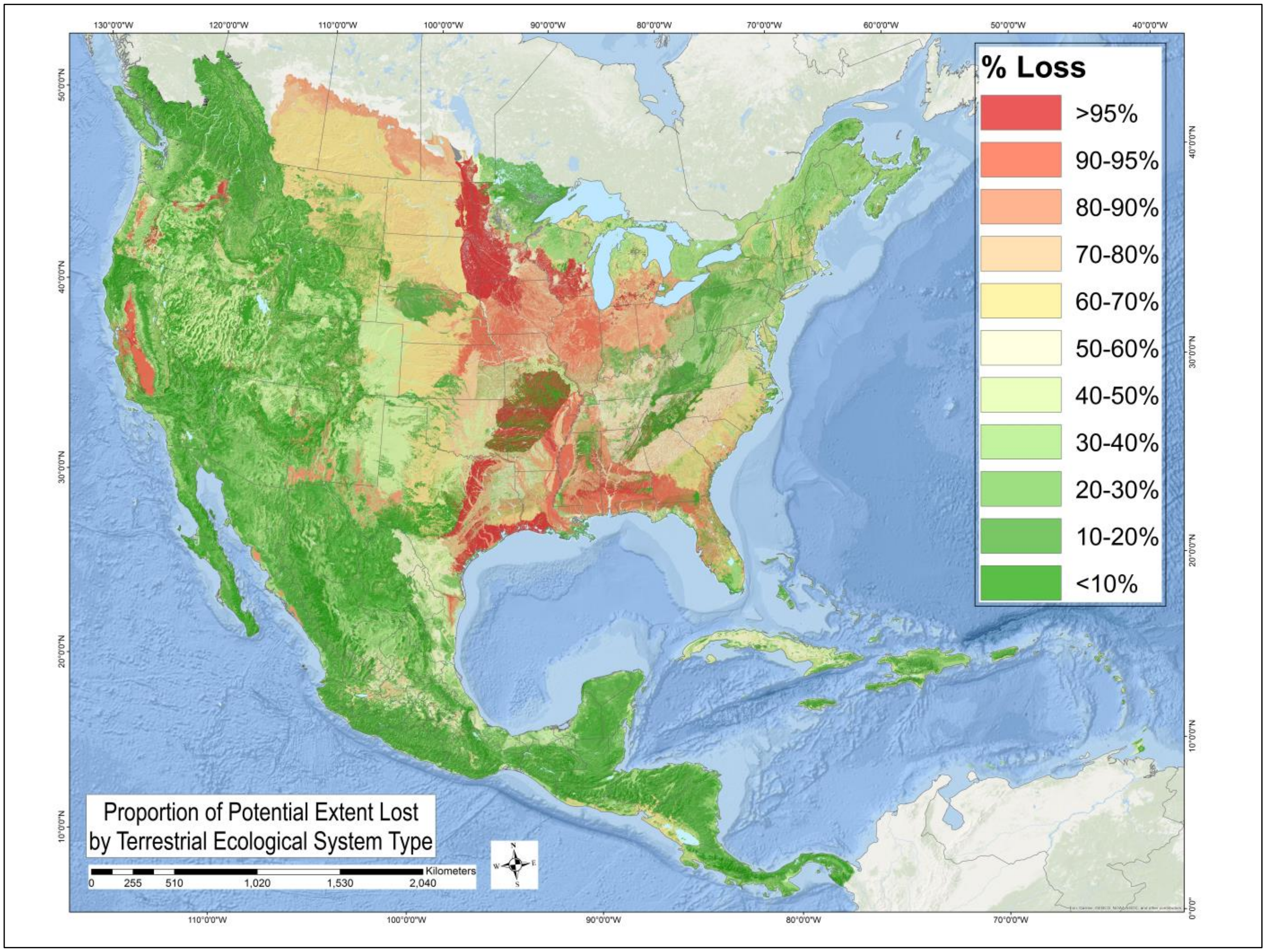

Figure S1-2. Long-term trends in ecosystem extent (A3) mapped onto potential extent map for terrestrial ecosystems in temperate and tropical North America.

Criterion B - Restricted Distribution

Criterion B aims to assess risk to types with restricted current distributions. Types with highly restricted distributions face increased risk from spatially explicit threat or catastrophe, as compared with types with less restrictive distributions (Fischer & Lindenmayer 2007). Several indicators are used to address this criterion and are described in detail in Bland et al. (2017), each of which combine measures of areal extent and support inferences of continued decline toward ecosystem collapse. We scored types under B1 and B2 criteria. B1 measures extent of occurrence (EOO) using a minimum convex polygon surrounding the current distribution of the ecosystem type; with areas ≤50,000km^2 ≤20,000km^2 or ≤2000km^2 scored as VU/EN/CR, respectively. B2 measures area of occupancy (AOO) and we used a systematic grid 96 km^2 cells populated with ≥100 hectares of each ecosystem type; with numbers of hexagons being ≤50, ≤20 or ≤2 scored as VU/EN/CR, respectively. Again, using big sagebrush shrubland, Figure S1-3 includes one example of the range of an assessed ecosystem type in terms of the standardized hexagonal grid. Due to the widespread range of this particular ecosystem type, a LC score results under both criteria B1 and B2.

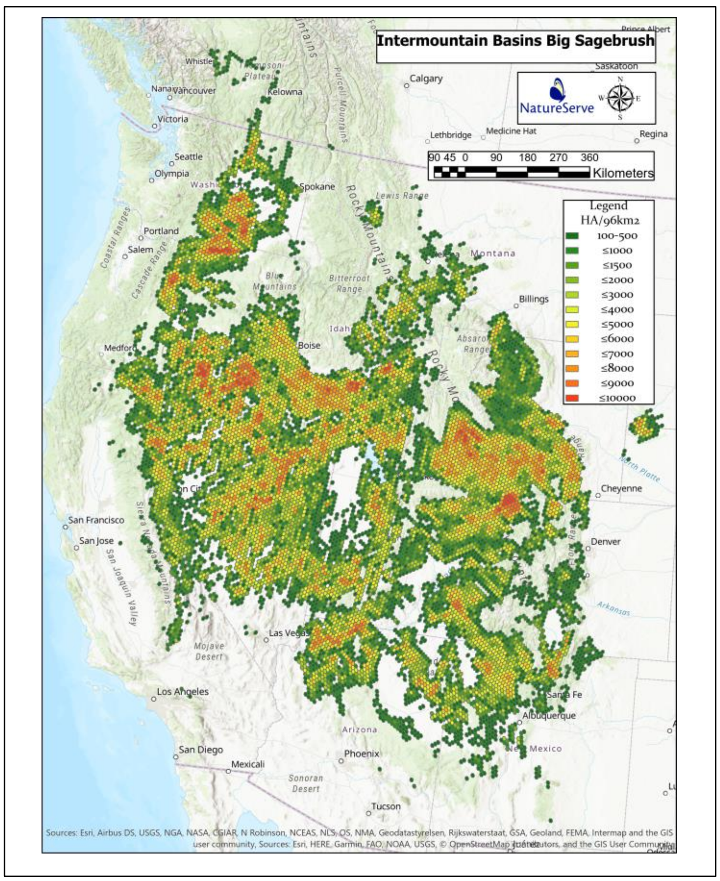

Figure S1-3. Current distribution of Intermountain Basins Big Sagebrush Shrubland by 96km^2 hexagon used for calculations under criterion B2.

Criterion C - Environmental Degradation

Criteria C gauges trends in environmental degradation emphasized abiotic aspects of ecosystems. Wildfire regime (frequency, intensity, patch size, etc.) is central to the function of these ecosystems, shaping vegetation structure and composition of forests, shrublands, and grasslands throughout temperate and boreal latitudes (Kilgore 1981, Collins & Wallace 1990, Ewel 1995, Nowacki & Abrams 2008). We selected *fire regime departure* as a primary indicator suitable for measuring relative degradation of key ecological process common to nearly all upland and many wetland ecosystems in temperate North America.

Fire Regime Departure - Using estimates of fire frequency and rates of vegetation succession, quantitative fire regime models predict the relative proportion of natural successional stages one might expect to encounter for an ecosystem type across a given landscape. They are therefore useful for indicating ecosystem degradation due to wildfire suppression, artificially elevated fire frequency, or other human-caused alteration (Swaty et al. 2011). The US Interagency LANDFIRE effort provides both quantitative reference models of vegetation states and transitions, as well as maps of wildfire regime departure that compare observed vs. predicted aerial extent of successional stages for all major upland ecological system types in the USA (Rollins 2009). Fire Regime Condition Class (FRCC) describes conditions where fire regimes are within expected range (FRCC1), where moderate departure has occurred (FRCC2) and severe departure has occurred (FRCC3).

Because wildfire suppression and alteration has been pervasive across temperate North America since the early 20th century (Pyne 1984), modern conditions reflect the cumulative effect of policy and practice over 100 years. Therefore, we applied existing FRCC departure measures to C3, expressing environmental degradation since pre-industrial times. Table S1-3 above described the threshold combinations of extent and severity for scoring types as VU, EN, or CR. As with all indicator measures under criteria C and D, we needed to translate the indicator values to the 50%, 70%, and 90% severity thresholds for red listing. Here, we equated FRCC2 with 50% severity and FRCC3 with 70-90% severity. LANDFIRE spatial models of FRCC are expressed as 30 m pixel rasters but are appropriately applied to landscape measures at much broader scales. Therefore, we completed a spatial overlay of the FRCC models with each ecosystem type and summarized overlapping FRCC scores by 96km^2 hexagon. A weighted average of FRCC scores for each type was then standardized to a 0.0 – 1.0 range, with FRCC1 = 1.0, FRCC2 = 0.5, and FRCC3 = 0.3. The indicator was limited to the extent of the lower 48 states of the United States, with 405 types scored. Again, using big sagebrush shrubland, Figure S1-4 includes example of results in terms of the standardized hexagonal grid.

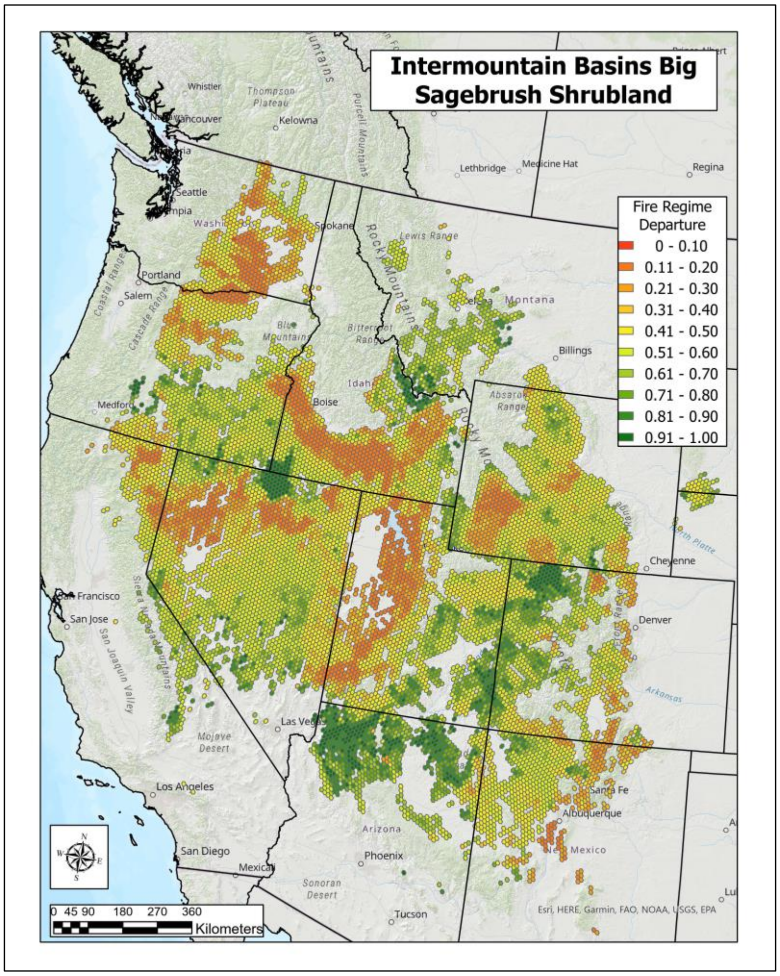

Figure S1-4. Current distribution of Intermountain Basins Big Sagebrush Shrubland by 96km^2 hexagon used for calculations of Fire Regime Departure under criterion C3.

Criterion D - Trends in Disruption of Biotic Processes or Interactions

Criteria D aims to gauge trends in the disruption of biotic processes. For red listing, measures focus on elements of biotic composition, structure, or processes that directly alter biotic composition for the ecosystem type. We assembled two primary indicators of biotic disruptions and combined them as appropriate for different groups of related ecosystem types.

Throughout upland and wetland ecosystems of temperate North America, pervasive effects of landscape fragmentation result in disruptions to species dispersal, introduction and spread of invasive species, and other disruptions of biotic processes (Farig 2003, Larson et al. 2005, Brennan & Kuvlesky 2007, Fischer & Lindenmayer 2007). We therefore aimed to identify an appropriate indicator to address these effects for all types. Since many assessed types occurring through western interior cold deserts are known to be affected by invasive annual grass invasion, we aimed to establish an indicator of relative invasion severity. Below we briefly describe each of these indicators.

In parallel to Environmental Degradation measures, the relevant forms of biotic process disruptions that we can measure have been pervasive across temperate North America since the 18th and 19th centuries, so modern conditions reflect the cumulative effect of policy and practice of that 200-year timeframe. Therefore, we applied existing the following measures to D3, expressing disruption of biotic processes since pre-industrial times.

Landscape Fragmentation Effects - Since human land uses, such as built infrastructure for transportation, urban development, industry, agriculture and other vegetation alterations, are depicted in maps that are periodically updated, they can be used in spatial models to make inferences about the status and trends in human-induced stress and ecological condition of landscapes at regional to global scales (Sanderson et al. 2002, Theobald 2013, Haddad et al. 2015). The spatial model of landscape condition used here (Hak and Comer 2017) built on a growing body of published methods and software tools for ecological effects assessment and spatial modeling; all aiming to characterize relative ecological condition of landscapes (Riitters and Wickham 2003, Leu et al. 2008). The intent of the model is to use regionally available spatial data to transparently express user knowledge regarding the relative effects of land uses on natural ecosystems and communities. Values close to 1.0 indicate almost no measurable ecological impact from the land use. As described in Hak and Comer (2017), model parameters were calibrated, and subsequently validated using tens of thousands of field observations indicating relative ecological condition. The result is a map surface provided relative index scores per pixel between 0.0 and 1.0. Calibration of this model against over 50,000 field locations each ranked as A=excellent, B=good, C=fair, and D=poor condition was used to identify thresholds in the 0.0-1.0 scale for applications. In this instance, we used one standard deviation above the mean of the index value for the D occurrences to determine the C. vs. D threshold. The overall threshold value breaks are as follows; A-Rank ≥ 0.36, B-Rank ≥ 0.30, C-Rank ≥ 0.25, D-Rank< 0.25. We equated landscape condition scores of 0.25-0.30 with 50% severity and scores 0.20-0.25 as 70% severity, and scores <0.2 as 90% severity. Per pixel scores, displayed along a color ramp, are depicted in Figure S1-5. All types were scored for this indicator. These per pixel scores were then summarized to average values per vegetation type per 96 km^2 hexagon.

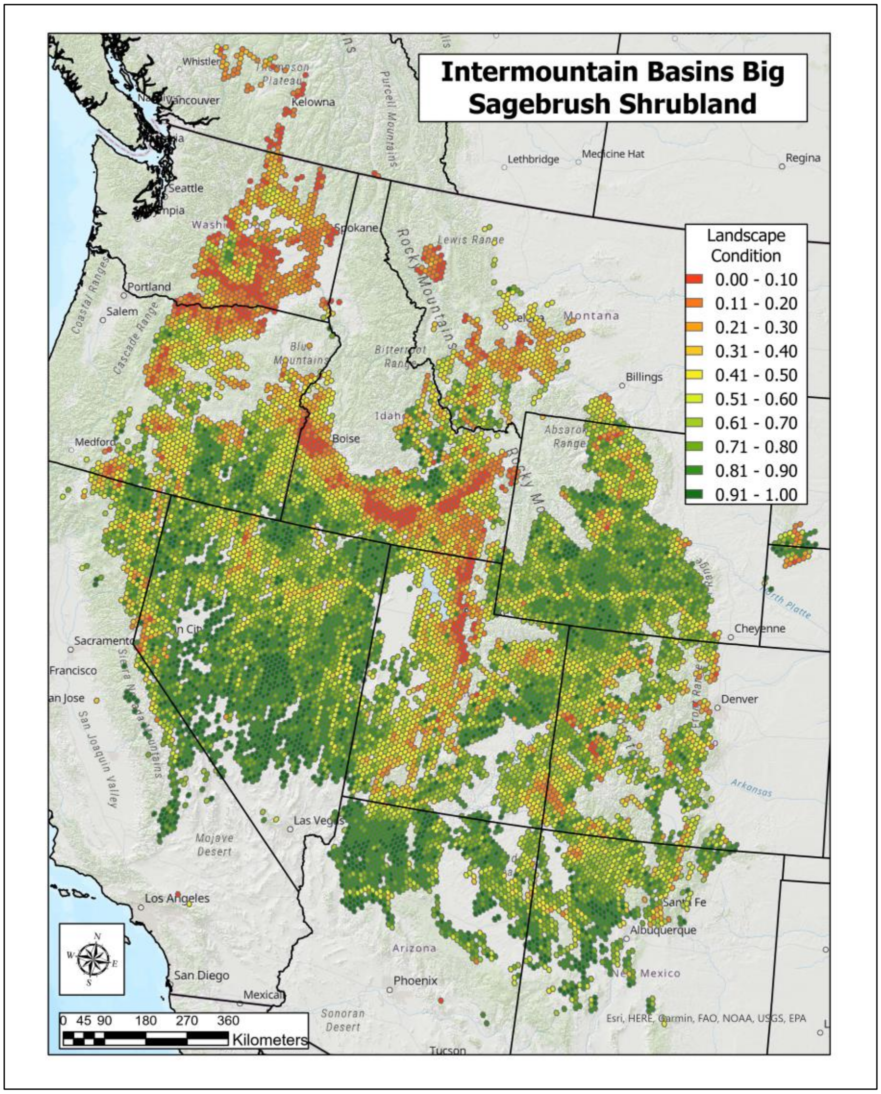

Figure S1-5. Current distribution of Intermountain Basins Big Sagebrush Shrubland by 96km² hexagon used for calculation of Landscape Condition (Hak and Comer 2017) under criterion D3.

Invasive Plant Species in Cold Desert Shrublands - Among desert shrubland and steppe especially, the effects of invasive species on ecosystem integrity are well known and there is considerable concern for their interactions with climate change (Abatzoglou and Kolden 2011). Spatial models depicting likely presence and abundance of invasive annual grasses provide an important indication of vegetation condition, and therefore, relative severity of biotic disruption. See Hak and Comer (2020) for further explanation of spatial models used here. Using the master database of over 20,000 invasive plant locality records with satellite imagery and a suite of environmental variables, inductive modeling was completed using Random Forest (Liaw & Wiener 2002). The resultant independently evaluated map surfaces represent invasive annual grass presence in five categories of expected absolute cover (<5%, 5-15%, 16-25%, 26-45%, and >45%). The five models were then combined onto one surface with higher predicted invasive cover classes taking precedence over lower cover classes on a per pixel basis. These absolute cover values were translated to index scores to reflect "1.0 = most favorable" to "0.0 = least favorable" index values as follows: <5% = 1.0, 5-15% = 0.80, 16-25% = 0.6, 26-45% = 0.4, >45% = 0.2. Figure S1-6 depicts the invasive plant model combined with the distribution of Intermountain Basins Big Sagebrush Shrubland. In this instance, 0.6-0.8 equates with 50% severity, 0.4-0.6 equates with 70% severity, and <0.4 equates with 90% severity. These per pixel scores were then summarized to average values per vegetation type per 100 km^2 hexagon. This measure applied to desert shrubland and grassland vegetation types only where invasive annual grasses have substantial impact with 231 Western North America types scored for this indicator.

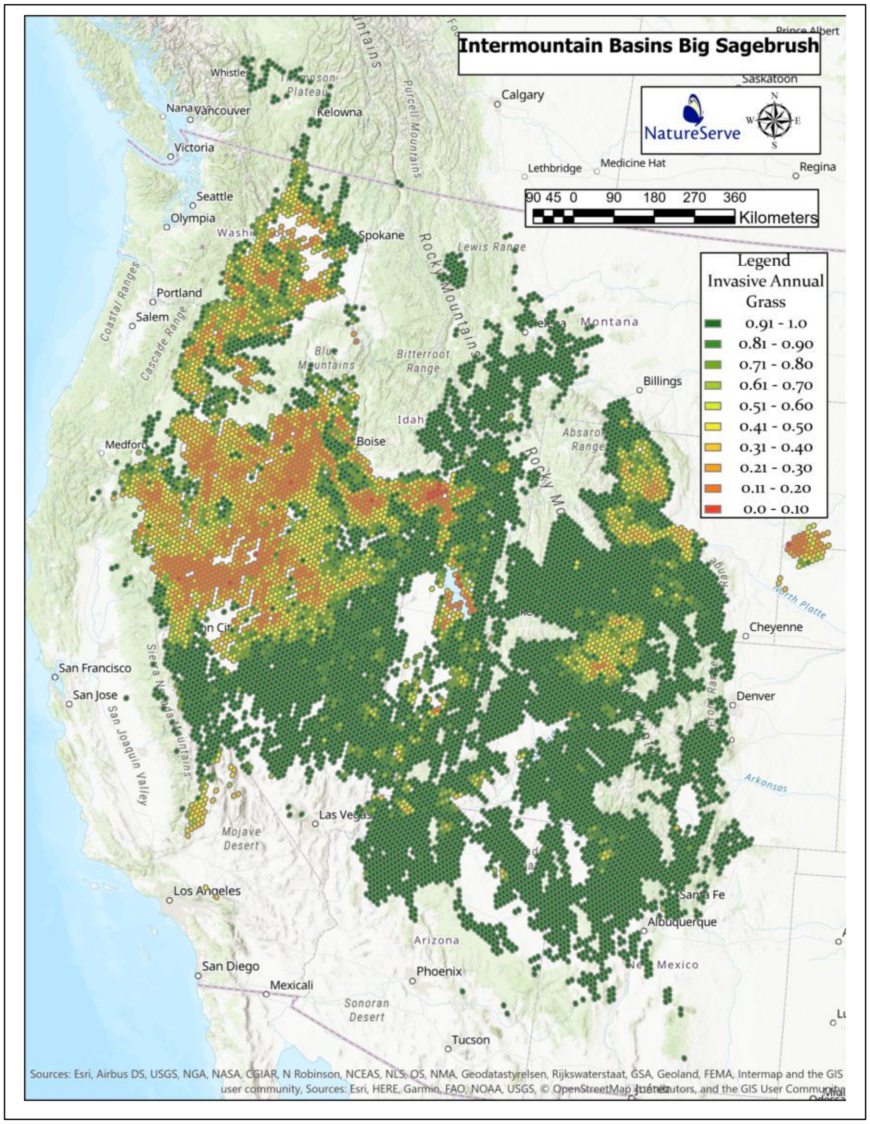

Figure S1-6. Current distribution of Intermountain Basins Big Sagebrush Shrubland by 96km^2 hexagon used for calculation of Invasive Annual Grass effects (Hak and Comer 2020) under criterion D3.

Combined Results for Disruption of Biotic Processes

Component measures under D3 were combined by spatially weighted averaging per 96km^2 hexagon unit to arrive at an overall measure of extent by relative severity category.

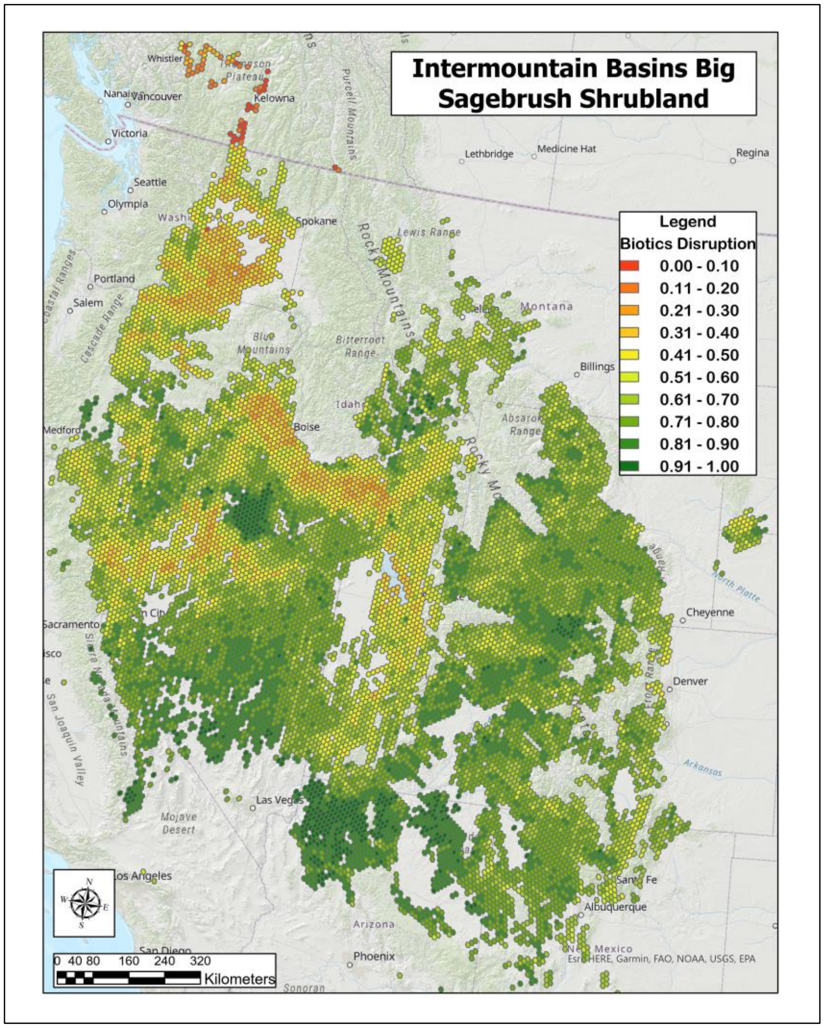

Figure S1-7. Current distribution of Intermountain Basins Big Sagebrush Shrubland by 96km^2 hexagon used for combined calculations for biotics disruption under criterion D3.

Overall Red List Scores

As noted previously, overall red-list status is based on the most severe rating of any of the component indicator scores; i.e., if a type scores as CR under by any one (A-D) indicator, it will receive and overall score of CR. However, to address inherent uncertainty in component indicator measures, expert judgement may be applied to list a given ecosystem type across a range of red list status categories. For example, where only one indicator suggests a score of EN, but others suggest a score of VU, one might list the type as EN-VU. We applied a similar logic in application of final scores for all types in this assessment.

Factors Contributing to At-Risk Conservation Status

Each of the Red List criteria represent a different contribution to risk of collapse for a given ecosystem type. While not all criteria in the IUCN framework were addressed with available data, those that were indicate some primary contributors to ecosystem risk. Table S1-4 summarizes the count of ecosystem types scoring within each of the red list categories under each criterion. Reduction in geographic distribution since 1750 (A3), Restricted distribution (B1 and B2), Environmental degradation since 1750 (C3), and Disruption of biotic processes since 1750 (D3) are the five criteria contributing to overall Red List scores.

Table S1-4. Count of types and by overall RLE status and RLE subscores for Temperate and Tropical North America.

	Count of Types					
Red List Status	**A3**	**B1**	**B2**	**C3**	**D3**	**Overall Status**
CR	44	1		2	24	41
CR (EN-CR)						5
CR (LC-CR)						1
EN (EN-CR)						7
EN	54	14	2	23	74	61
EN (VU-EN)				11	1	23
EN (LC-EN)						1
VU (VU-EN)	1					10
VU	60	16	7	43	58	72
VU (LC-EN)						10
VU (LC-VU)						20
NT (LC-VU)						3
NT	19		3	46	37	43
NT (LC-NT)						3
LC (LC-EN)	1				1	1
LC (LC-VU)				1		6
LC (LC-NT)						6
LC	221	475	493	22	273	178
DD	249	137	136	397	162	153
NE	6	12	14	110	25	11
Total	**655**	**655**	**655**	**655**	**655**	**655**

The count of types for Overall Status does not equate with maximum values under any given criteria because more than one subscore could contribute to overall status, and because uncertainty in component subscores led to scoring within a range of values. Results from subscores C3 and D3 are briefly summarized below with Figures S1-7 and S1-8. Summary maps for results under C3 indicate where many forest types crossed thresholds for scoring as VU, and in some instances EN with the indicator for fire regime departure. This was concentrated in several regions, including forests in the Central Appalachians, Ozark Mountains, woodlands and shrublands in the southwestern US and adjacent Mexico, California shrublands, and northwest Pacific forests.

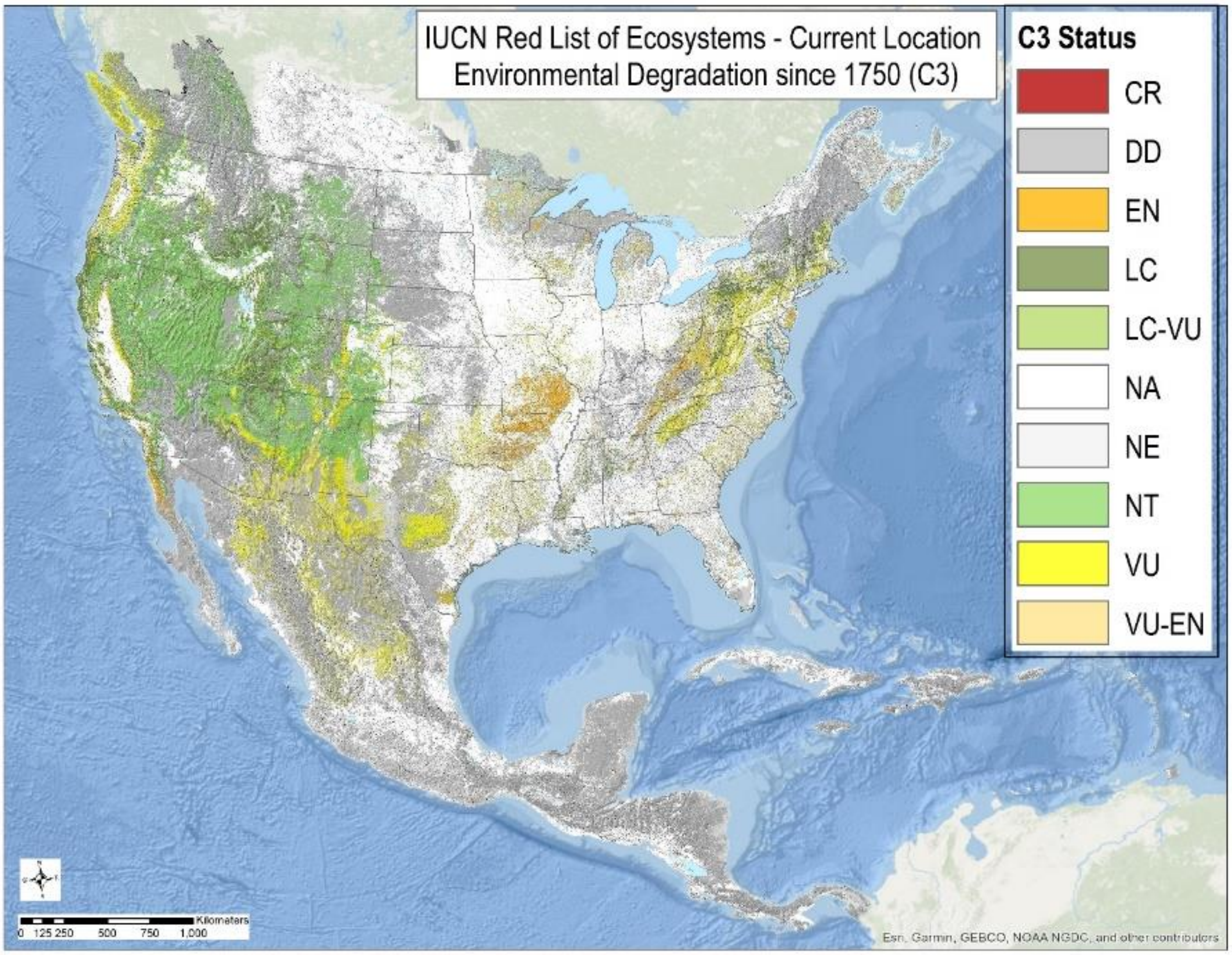

Figure S1-7. Current distribution of terrestrial ecosystems with scores under criterion C3.

Summary maps for results under D3 indicate where many types crossed thresholds for scoring as VU, and in some instances EN or CR with the indicator for landscape condition and for invasive plant impacts. This was pronounced in several regions, including forests in the Central Appalachians and adjacent coastal Plain, Western Great Plains prairies, intermounatin shrub steppe, and coastal California shrublands and woodlands, both extending into Mexico.

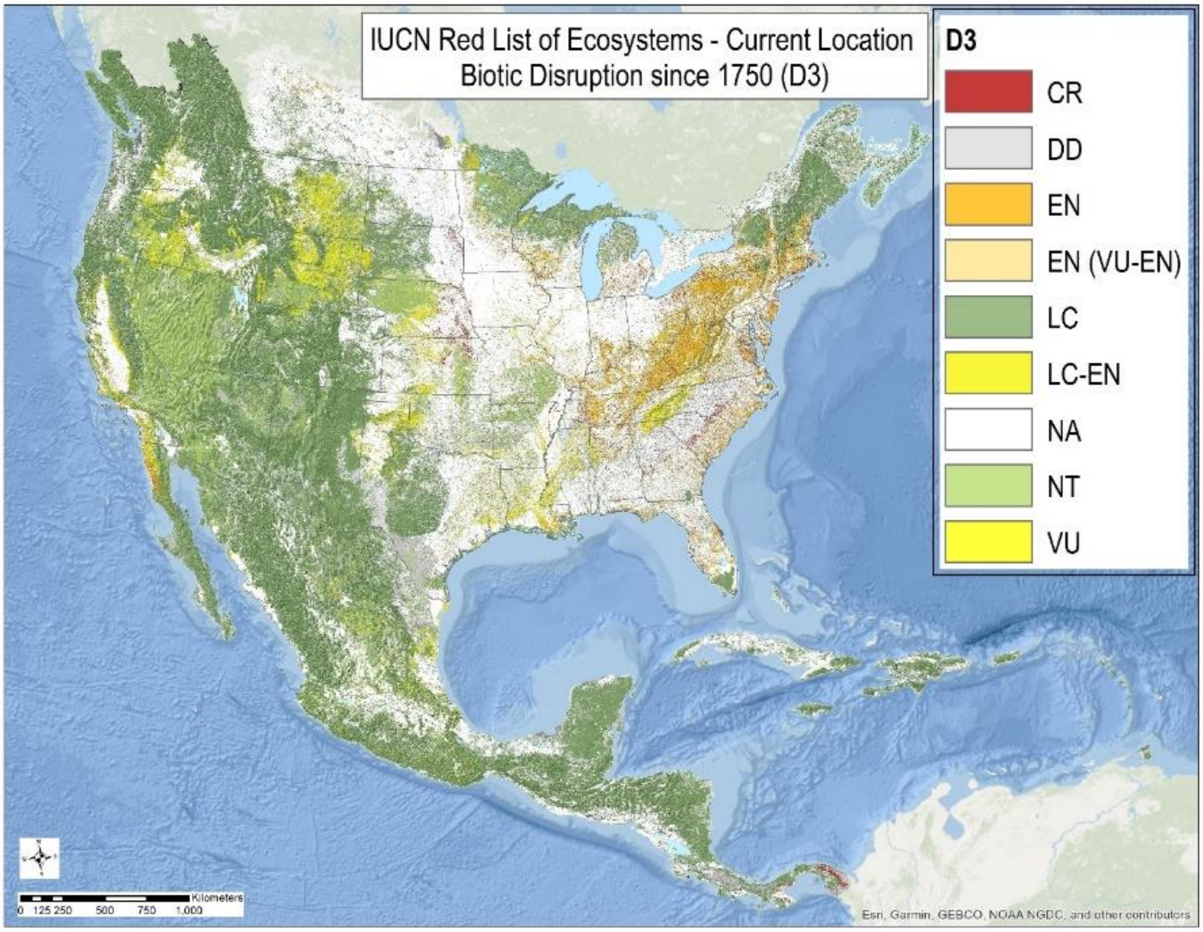

Figure S1-8. Current distribution of terrestrial ecosystems with scores under criterion D3.

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