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Rangelands on the Edge: Quantifying the Modification, Fragmentation, and Future Residential Development of U.S. Rangelands

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Abstract

Rangelands are increasingly urban, subdivided, and fragmented. About 62 percent of coterminous U.S. rangelands occur on private land and are at further risk for conversion. This Rangelands on the Edge (ROTE) project improves our understanding of the fate of rangelands from historical, present day, and future perspectives by describing human modification, fragmentation, and future residential growth projections for rangeland-dominated vegetation. Since pre-European settlement, some 340 million acres (over 34 percent) of rangelands, particularly in the Great Plains, have been converted to alternative land uses, especially intensive agriculture (croplands, pastureland). Approximately 11 percent of private rangelands are likely to experience significant increases in housing development over the next 15 years.

Keywords: fragmentation, rangelands, ecosystem goods and services, sustainability, residential development, human modification, fragmentation

Front cover: Rangelands are diverse ecosystems that provide numerous goods and services. Future development of rangeland landscapes will benefit from synoptic perspectives.

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Contents

Introduction

In 2005, the Forests on the Edge project (Stein et al. 2005) (http://www.fs.fed.us/openspace/fote/housing.html) began producing a series of publications aimed at evaluating the trends and implications of increased residential development on America's private forestland. This effort increased public awareness and understanding of the pressures on and contributions of private forests and the processes associated with increases in housing density. Many of the same issues facing America's private forests are also significant factors and driving forces in rangeland landscapes. Rangeland areas across the West are undergoing transitions in demography, economics, and ecosystems as residential development is increasingly built outside of cities, suburbs, and towns. This type of exurban development produces a footprint that is 5 to 10 times larger than the urban footprint. Other factors such as agricultural expansion and energy development also contribute to an increasing anthropogenic footprint. This is an important matter because rangelands are a major resource worldwide, occupying 65 million km^2, or roughly 50 percent of the land area of the world (Hobbs et al. 2008). Rangelands occupy about 662 million acres in the coterminous United States and provide food, fiber, clean water, biofuels, opportunities for energy development, and critical habitat for numerous imperiled species. Species such as the lesser prairie chicken (*Tympanuchus pallidicinctus*), black-footed ferret (*Mustela nigripes*), and Sonoran pronghorn (*Antilocapra americana sonoriensis*) depend on rangeland habitats for survival.

Though it is hard to quantify the value of the goods and services that rangelands provide, the amount is substantial. Farm cash receipts for cattle and calves in the United States exceeded $67 billion in 2016 (NCBA 2016). Direct expenditures for hunting in 2001 approached $25 billion (IAFWA 2002). Since Euro-American settlement, more intensive forms of land use such as cropland, urban areas, and transportation have replaced native rangeland systems. The rate of decline of rangeland area has been slow but steady due to population increase and urban expansion in the United States (Mitchell 2000). For example, the Natural Resources Conservation Service estimated that 406 million acres of rangeland occurred on *private* rangelands in 2012, a 3 percent decrease from 1982 (USDA 2009); this amounted to a decline of about 470,000 acres per year.

Much of the decline in rangeland area is due to land use changes associated with exurban development and subdivisions, which arguably constitute one of the foremost threats to intact, high-quality wildlife habitat (Theobald et al. 1997). The effects of residential development on rangeland ecosystem goods and services are numerous. The size of the total effect of residential development depends on the total area converted as well as the timing of the exposure to development activity (Hamer et al. 2006; Polfus 2011). The effects of ecosystem fragmentation from residential development are seen through nest predation, disruption of wildlife dispersal and movement patterns, structural habitat changes, and effects associated with domestic pets and increased human-wildlife conflicts (Glennon and Kretser 2005). Ungulates such as mule deer, elk, pronghorn, and bighorn sheep migrate long distances (50–100 km) in the fall and spring (Hoekman et al. 2006; Sawyer et al. 2009) but these migration routes are increasingly interrupted by energy development, tourism, exurban development, and highway mortality (Berger 2004; Gude et al. 2007).

Species that are well-adapted to intensively modified urban environments and dependent on human-subsidized resources gradually replace those that are intolerant of human modifications. This process is referred to as "biotic homogenization" (McKinney and Lockwood 1999), characterized by species tolerant of anthropogenic disturbance and influence. These issues have led the researchers to suggest that when development, even at low densities, "borders wild or undisturbed lands, a buffer of up to 600 feet around the development should be considered as affected habitat" (Odell and Knight 2001). Other effects of residential development can be more subtle (Odell et al. 2003). For example, the effect of anthropogenic noise on wildlife patterns is often overlooked despite being important determinants of the types and amount of wildlife that occur in an area. Chronic exposure to noise can lead to deleterious physiological and behavioral effects such as increased stress levels and decreased reproductive success (McKinney and Lockwood 1999). Another subtlety is that ranches comprised mainly of rangelands (as opposed to pasturelands) demand little water as compared with the other types of development. Thus, an understanding of how residential development may manifest itself in the future is essential to assessing the status of rangelands over the next generation.

Land use changes and resulting human modifications tend to (Stein et al. 2005):

- decrease native fish and wildlife populations and their habitats;
- decrease rangeland health;
- reduce opportunities for outdoor recreation;
- reduce water quality;
- alter hydrology;
- change traditional uses of rangelands;
- decrease production of natural goods and services; and
- increase water consumption.

Implications

Changes in housing density and patterns of human modification and fragmentation documented by Rangelands on the Edge have implications for the present and future condition and sustainability of goods and services derived from rangelands. Increased residential development, human modification, and fragmentation lead to a variety of challenging situations, as indicated by the following eight examples.

1. There could be a decrease in native wildlife populations of rangeland obligates, such as sage grouse and pronghorn, owing to decreased wildlife habitat quantity, quality, and connectivity; increased mortality and conflicts with humans; and increased predation from domestic pets (Balogh 2011).
2. Another impact can be decreased biodiversity, increased prevalence of non-native species (Ferreira and Laurance 1997; Meekins and McCarthy 2002), and at some level, a complete avoidance of areas by some faunal populations (Hansen et al. 2005).
3. Reduced resiliency and adaptability of species to climate change and limited flow of genetics across barriers is another impact. Reduced gene flow, through fragmentation,

can isolate populations and decrease genetic diversity through drift and inbreeding (Allendorf and Luikart 2007).

4. There could be a decrease in ecosystem goods and services such as food and fiber; changes in scenic quality and recreational opportunities can degrade recreational experiences.
5. Decreased production of protein from livestock from lands that are often unarable is another impact from increased residential development, human modification, and fragmentation.
6. An increased likelihood for user conflicts as more people seek use of a decreasing land base is very possible. Oftentimes, in the western United States as land ownership changes, so do landowner views on allowing easement across private land to provide access to public land. In this manner, reduction in access to rangeland landscapes is therefore not limited to just the mere footprint of the residential development or private land itself.
7. Conservation and management of faunal populations through hunting opportunities can be paired by fragmentation of open range. In extreme cases, a single new dwelling or change in land ownership can reduce recreational access to tens of thousands of acres of public land. Figure 1 demonstrates how development can directly impact recreational opportunities and disrupt ungulate movements between seasonal ranges (Harden et al. 2005). This suggests that procuring easements to maintain access to public land may enhance or maintain recreational opportunities for the American public at large.
8. There can be a potential for greater wildfire ignition due to residential development and concomitant restrictions in management options for mitigating threats to rangelands (Russell and McBride 2003).

Rangelands provide critical habitat for numerous species, including some iconic western species such as sage grouse, black-footed ferret, and Rocky Mountain bighorn sheep (photos courtesy of Matt Reeves and Lane Eskew).

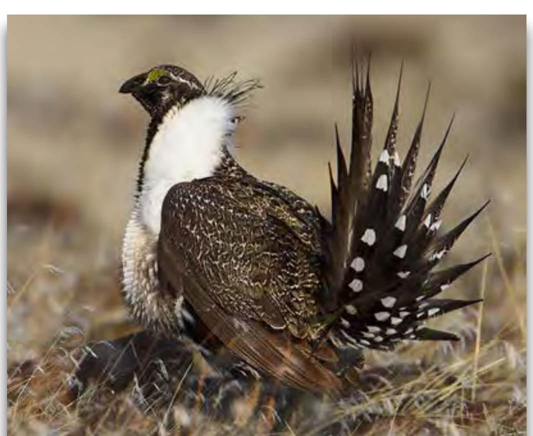

Figure 1—The trail shown in the aerial photographs is no longer accessible, which substantially reduces the variety of goods and services that could be enjoyed in the future on this landscape. Access was apparently prohibited around 2008. By identifying key parcels, such as this one, stakeholders, planners, and managers can collaboratively and proactively procure more rigorous modes of easement for maintaining access to public lands.

While Forests on the Edge (FOTE) developed a series of informative publications, the effort was generally focused on residential development on forestlands. Concern about the effects of modification on America's rangelands has also risen in recent years in recognition that fragmentation of natural ecosystems alters ecological processes, leads to declines in biodiversity, and reduces the ability of landscapes to adapt to climate change (Theobald et al. 2012). The present effort called Rangelands on the Edge (ROTE) was inspired by FOTE and, when combined with FOTE, enables a more complete understanding of the landscape scale perturbations to America's rangelands and forestlands.

Although not officially affiliated with FOTE, the ROTE project is nevertheless complementary to it. In light of this, we attempted to maintain similarities in report format and analytical structure to FOTE, so that these two projects can be viewed in tandem to provide a more complete, consistent, and seamless picture of landscape-level threats to wildlands of the United States. While FOTE originally focused on residential development, the current report provides an expanded analysis of the degree to which human modification has changed rangeland landscapes. To accomplish this goal, we pursued the following objectives: (1) estimate the historical (pre-European settlement) extent of rangelands to provide a baseline of change; (2) quantify the degree of human modification from a database on detailed land use patterns collected from interpretation of aerial photography; (3) analyze the loss and fragmentation of rangeland vegetation and; (4) estimate the amount of additional residential development on U.S. rangelands by 2030.

It is important for the reader to recognize that here we focused on watersheds that are dominated (≥50 percent of vegetated area) by rangelands while the FOTE project focused on forest-dominated watersheds. In some cases, a watershed might have a significant area of rangeland but is addressed in the FOTE project (e.g., see page 12 of Stein et al. 2007). As a result, in an effort to complement FOTE, we left out watersheds that have already been evaluated and focused on those watersheds dominated by rangelands that were not presented in the FOTE project.

This work aids identification of watersheds whose sustainable production of natural goods and services is potentially compromised; it also supports future analyses to identify imperiled habitats, as well as intact lands acting as corridors for species dispersal. This is important because nationally consistent data describing these conditions are lacking and information is needed to improve our understanding of the present character of rangeland landscapes. These data enable a large number of questions to be explored and answered, but this report only provides a cursory and not a definitive analysis. As a result, readers are encouraged to request these data and use them for regional studies. These data are available from the authors and interested parties should contact the lead author.

Rangelands encompass many vegetation types and "rangeland" is viewed as a land cover and not a land use. Using the National Resources Inventory (NRI) definition discussed in this report, we estimate from Reeves and Mitchell (2011) that there are about 662 million acres of rangelands in the coterminous United States.

Rangelands Defined

Many definitions of rangelands exist, but generally speaking, rangelands are a land type primarily supporting herbs, shrubs, and grasses that provide food, fiber, clean water, biofuels, and cultural heritage and recreation opportunities (table 1). Table 1 shows the contrasting definitions from the Bureau of Land Management (BLM), the U.S. Forest Service through the Forest Inventory and Analysis (FIA) Program, and the Natural Resources Conservation Service (NRCS) through the National Resources Inventory (NRI). Although several definitions of rangelands are used by U.S. land management agencies (provided in table 2), here we adopt the rangeland definition developed by the NRCS. Oftentimes, grazing land is incorrectly used synonymously with rangeland. Grazing lands include rangelands but also many other kinds of land types including pastures and agricultural landscapes, which provide a variety of feedstuffs for

Table 1—Examples of ecosystem goods and services and the benefits they provide.

Rangeland ecosystem good or service	Benefit		
	Economic	**Environmental**	**Social/cultural**
Forage production (for livestock consumption)	- Sale or lease of feed for grazing - Hay production	- Landscapes for biodiversity, native species - Soil stability - Clean air and water - Some crops, e.g., nitrogen fixers, enrich soil	- Open space - Rangeland-dependent rural communities
Beef and lamb production (food for human consumption)	- Sale of meat and fiber products - Ranching operations - Economic base for ranching communities	- See forage production above	- Satisfaction people enjoy in ranching as a way of life - Open space
Fishing and hunting	- Sales of licenses, gear, guide services - Access rights (to fish or hunt) on private or public lands	- Promotion of healthy wildlife populations - Biodiversity maintenance - Control of hunted wildlife	- Pleasure involved in fishing and hunting - Watchable wildlife
Clean water	- Satisfaction of household, agricultural, and industrial needs - Sale of bottled water - Income from water-based recreation (swimming, boating, fishing)	- Habitat for fish and other aquatic organisms - Drinking water for wildlife - Rejuvenation of channels and riparian areas via sediment transport and deposition, creating bare soil for germination, etc.	- Aesthetic qualities of unpolluted water bodies - Pleasure people derive from water-based recreation
Wind	- Capture and sale of wind energy	- Dispersal/dilution of pollutants - Pollination of wind-pollinated plants - Seed dispersal	- Sense and smell of gentle breezes
Wood	- Sale of fuelwood and fenceposts	- Wildlife habitat - Spatial diversity in litter, soil nutrients, etc.	- Warmth, sight and smell of campfires
Seeds and plant materials	- Seeds and cultivars for forage and land restoration	- Genetic diversity	- Human values relating to restored rangelands

domestic and wild ungulates. Further, grazing is not a requisite for a rangeland designation because, here, rangelands are viewed as a vegetation *cover type* rather than a *land use*. Rangelands also occupy many vegetation types. The rangeland statistics mentioned in this document consistently conform to the NRI definition unless otherwise noted. In addition to defining rangelands, it was necessary to identify where these rangelands exist in the coterminous United States. It follows that estimating where rangelands are depends on the definition used to identify them.

Here we used the geospatial data describing the extent of rangelands from Reeves and Mitchell (2011). Reeves and Mitchell (2011) estimated the extent of U.S. rangeland by applying the two contrasting FIA and NRI definitions of rangelands to geospatial data describing existing and historic vegetation. The difference between these two definitions resulted in a discrepancy of about 62 million acres of more rangeland using the NRI definition. In ROTE, we adopted the NRI rangeland definition and associated rangeland map from Reeves and Mitchell (2011), which is shown in figure 2. Figure 2 demonstrates that rangelands of the coterminous United States are primarily found west

Table 2—Rangeland definitions used by the USFS FIA and NRCS NRI programs. Also included is the definition adopted by the BLM.

Agency	Definition
USDA Forest Service (through the FIA Program)	**Rangeland:** "Land primarily composed of grasses, forbs, or shrubs. This includes lands vegetated naturally or artificially to provide a plant cover managed like native vegetation and does not meet the definition of pasture. The area must be at least 1.0 acre in size and 120.0 feet wide," (USFS 2011, p. 93).
Natural Resources Conservation Service (through the NRI Program)	**Rangeland:** "A land cover/use category that includes land on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and practices such as deferred grazing, burning, chaining, and rotational grazing, are used with little or no chemicals/fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain low forb and shrub communities, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland," (NRCS 2015).
Bureau of Land Management	**Rangeland:** "Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows," (SRM 1998, p. 23).

of the 95th meridian. This line corresponds to a level of aridity that generally favors production of grasses and shrubs over trees. In the coterminous United States, there are about 662 million acres (Reeves and Mitchell 2011), which compares with the NRCS estimate of 406 million acres of rangeland that occurred on non-Federal lands in 2012, a 3 percent decrease from 1982 (USDA 2009).

Further, figure 2 shows that privately owned rangelands represent about 62 percent (USDA 2009) of America's rangelands while the remaining 256 million acres are owned by a consortium of Federal, State, and local governments (Reeves and Mitchell 2012). Tribal lands are not included in the public land data statistics derived in this project since they are sampled during the NRI private land rangeland survey (Ken Spaeth, Rangeland Management Specialist, Natural Resources Conservation Service (NRCS) personal communication 27 February 2014). The classes used for determining ownership to develop figure 2 are found in table 3.

Historical Extent of Rangelands

To generate a map of historical rangelands (roughly pre-European settlement; the NRI definition was applied here), Ecological Systems (Comer et al. 2003) were used. Rangeland ecosystems were identified from the Biophysical Setting (BpS) layer from the LANDFIRE database (Rollins 2009) using the definition adopted by the National Resources Inventory (USDA). According to this definition, found in table 2, rangeland systems are those that, given pre-Euro-American settlement disturbance regimes, would have generally maintained less than 25 percent canopy cover by trees, either due to natural disturbances or limits to tree growth.

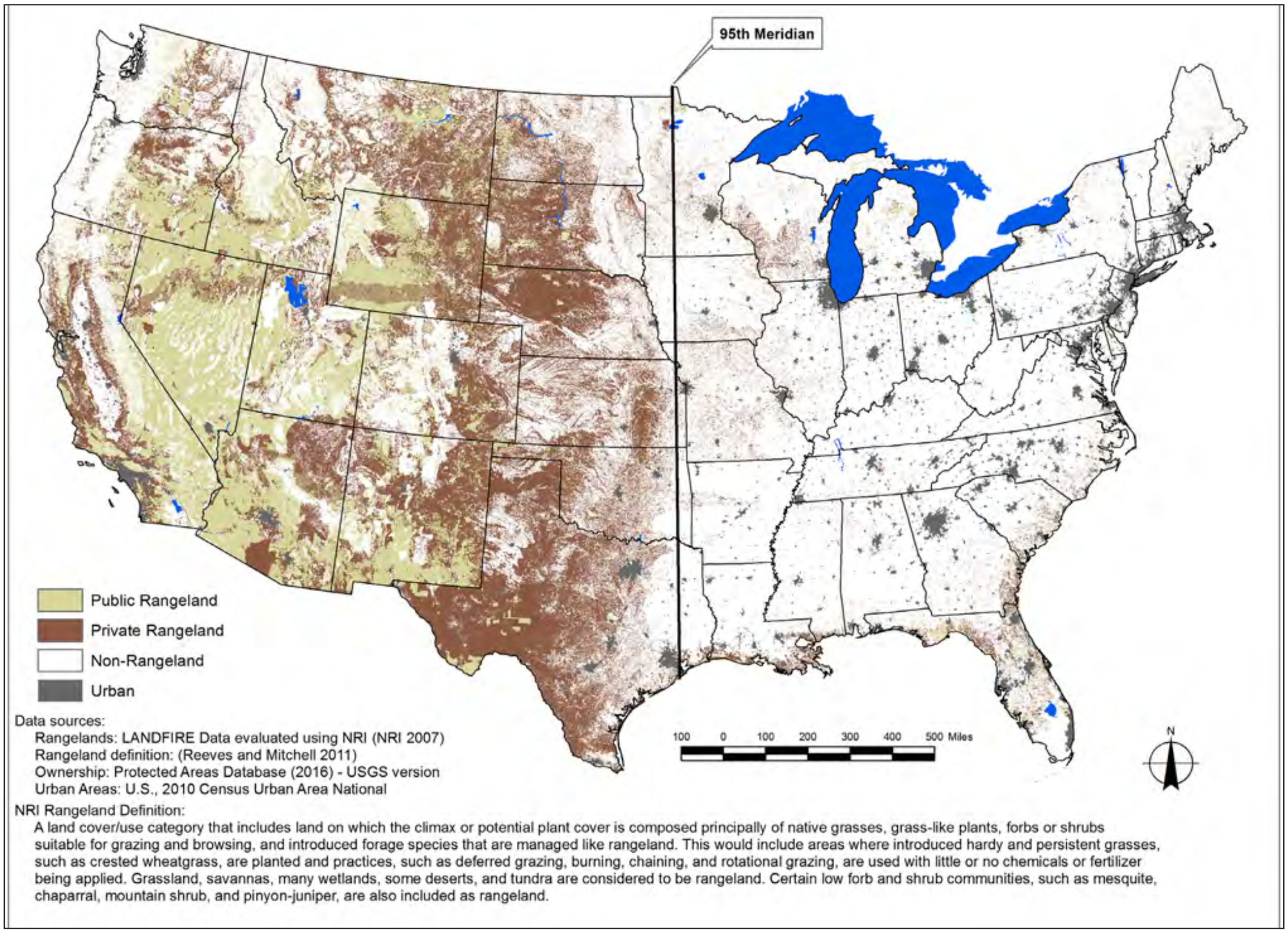

Figure 2—Location of private and public rangelands, non-rangelands, and urban areas. The "public" versus "private" ownership designations are not completely straightforward.

Examples of these systems include: semi-desert grasslands, tall-grass prairie, some Florida flatwood sites (i.e., sites with summer fire regime and high lightning strikes producing savannah-like conditions with tree cover generally <25 percent), Great Basin piñon-juniper, and sagebrush steppe. Mapping the hypothesized historical extent of rangelands was a necessary first step because it enables estimates of total human modification of rangelands nationwide by comparing present versus historical distribution. The estimated historical extent of rangelands in the coterminous United States is found in figure 3. As depicted in figure 3 rangelands once extended through the Midwest and upper Midwest and also occurred extensively in the southeastern United States, especially in Florida. The widespread occurrence of historic rangelands in Florida is a consequence of the summer fire regime and extremely high fire return intervals, which often created savannah-like conditions where tree cover was often less than 10 percent. Presently, forest management encourages forest cover in excess of 10 or even 25 percent, which causes many of these lands to be considered forests or "afforested rangeland" as indicated in Reeves and Mitchell (2011).

Table 3—This table documents how the PADUS data were characterized for the purposes of developing figure 2. Most assignments were based primarily on the Owner Type attribute and secondarily on the Manager Name for a couple of categories according to the following: PADUS_USGS version 1.4 metadata is located here: https://gapanalysis.usgs.gov/padus/data/metadata/.

Owner type (primary)	Manager name (secondary)	Assignment
Territorial	N/A	-99 Territorial
Federal	N/A	0-Public
American Indian lands	N/A	1-Private
Designation	N/A	0-Public
Local government	N/A	0-Public
State	N/A	0-Public
Joint	(except for NGO, Private, Unknown where Private was assigned) (see below)	0-Public
District	N/A	0-Public
Unknown	(except for NGO, Private, Unknown where Private was assigned) (see below)	0-Public
NGO	N/A	1-Private
Private	N/A	1-Private
Joint	(included only NGO, Private, and Unknown)	1-Private
Unknown	(included NGO, Private, and Unknown)	1-Private

Human Modification and Fragmentation

In this study, human modification is defined as the degree to which an activity at a location modifies an ecological system including the spatial extent (Theobald 2013). To estimate human modification for the coterminous United States, interpretation of land cover from high resolution (~1-m) color aerial photography from the National Aerial Imaging Program (NAIP) was used as the primary source. Leinwand et al. (2010) conducted this work using approximately 6,000 samples drawn from a spatially balanced network of random locations. At each sample, a 600 m^2 quadrangle was placed over the NAIP imagery and trained interpreters collected land use data using a 10-m^2 minimum mapping unit. At each sample location, three types of features were discerned and digitized by trained interpreters using an established protocol (Leinwand et al. 2010). The features were: (1) the "footprint" of buildings and structures; (2) human-modified land cover (e.g., agricultural fields and parking lots), and; (3) linear features (e.g., roads, irrigation ditches, utility lines).

Polygons of land cover that had either been converted to an anthropogenic land cover (e.g., house, road) or sustained substantial human modification (e.g., mowed lawn) were merged to create a geospatial depiction of "human-modified land cover" (HMc) (Leinwand et al. 2010). The HMc polygon layer was then converted to a raster layer (90-m resolution) representing the proportion of each cell that was

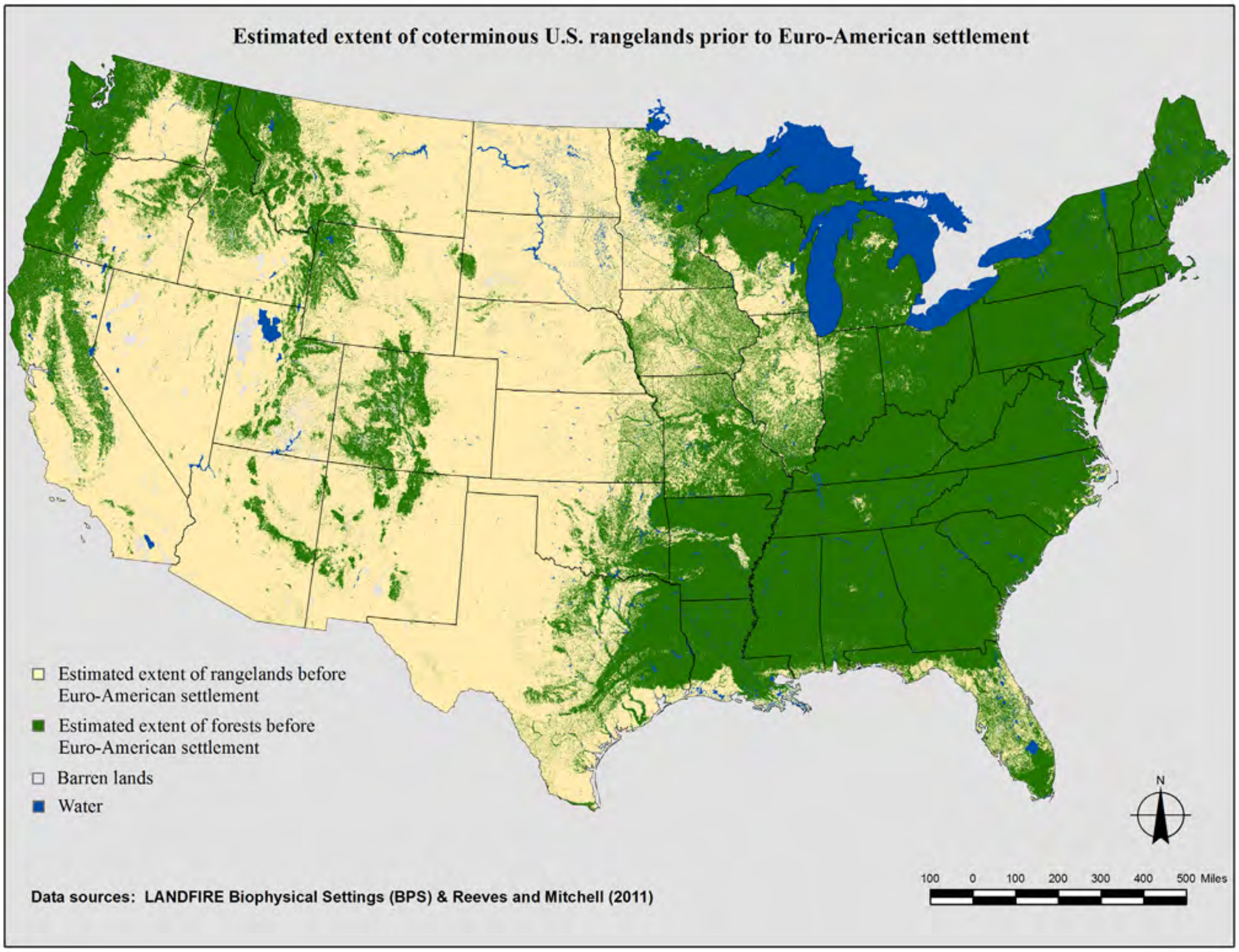

Figure 3—Estimated distribution of rangelands prior to Euro-American settlement, adapted from Reeves and Mitchell (2012).

Fragmentation differs depending on the resource being evaluated. Energy development and agricultural development are two sources of fragmentation beyond residential development. Wildlife species will respond differently to these types of disturbances. What affects one species may be less impactful to another.

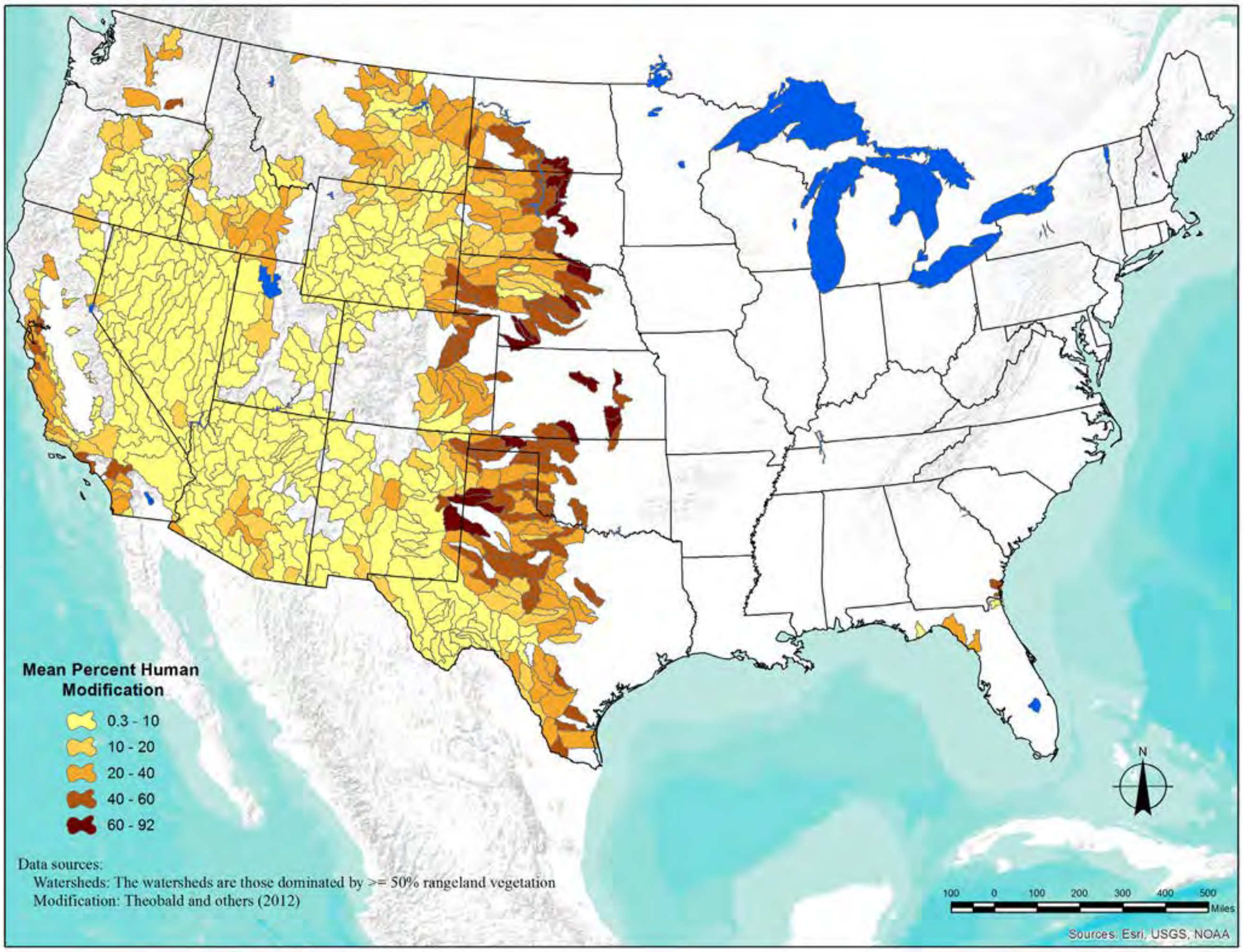

Figure 4—Extent and magnitude of human-modified land cover (HMc), aggregated to rangeland-dominated watersheds in the coterminous United States.

human-modified. Raster cells that were within the chip boundary were used as sample points, resulting in roughly 140,000 sample points representing values of HMc. We randomly selected 90 percent of these points to construct a regression model and reserved 10 percent for model validation.

After characterizing HMc at 6,000 locations, a classification and regression tree (CaRT) modeling approach (Friedl and Brodley 1997) was used to extrapolate HMc for all 662 million acres of rangelands. This approach was chosen because the distribution of our response and many of the input variables were non-parametric. CaRT approaches also are able to handle the nonlinear relationships and complex high-order interactions we anticipated in modeling complex land use patterns (De'ath and Fabricius 2000). CaRT analysis was conducted using the *cv.tree* function in S-Plus statistical package (Insightful Corporation, Seattle, Washington). The resulting estimated extent of HMc is found in figure 4. As depicted in figure 4, a broad swath of rangelands, stretching from the entire eastern halves of north and South Dakota, all the way through northern Texas, have experienced total conversion to other land uses. Other areas experiencing such conversions include the western half of Minnesota, the majority of rangelands once found in Iowa and Illinois, and much of the Gulf Coast.

Table 4 exhibits the explanatory variables used in the regression model, including land cover, topography, soils, roads, land use, public ownership, housing density, and geographic location. To create a spatially explicit representation of our models, we converted the *cv.tree* output into a series of if-then-else map algebra statements in ArcGIS 9.3.1 (ESRI, Redlands, California).

While this modeling approach enables direct quantification of human modification, it does not, by itself, reveal extent and magnitude of loss since pre-Euro-American settlement. Instead, quantifying the extent of historical rangeland that has been lost due to human activities associated with intensive land uses was accomplished by combining HMc with the historic extent of rangeland vegetation and the National Land Use Dataset created by Theobald (2014). Understanding the extent to which human modification has altered landscapes is only part of the story and perhaps even less meaningful when using it to estimate fragmentation.

To understand and quantify how human modification has fragmented rangelands, we measured the distance from human-modified areas into the interior of rangeland "patches" with GISFrag (Ripple et al. 1991; Theobald 2003). This approach provides a spatial depiction of fragmentation where longer distances indicate a more contiguous, less fragmented pattern of rangelands. Note that our approach avoids the challenge of arbitrarily defining a threshold for patch size, which has been widely discussed for forested ecosystems (e.g., Kupfer et al. 2006) but is even more problematic for rangeland ecosystems (Hobbs et al. 2008). We removed small groupings of rangeland cells (<15 acres) to reduce the effect of very small patches of rangeland that often result from artifacts of remote sensing classification. Fragmentation was computed using HMc thresholds of 50 percent. For example, in the case of quantifying fragmentation using the 10 percent threshold, at each pixel, the fragmentation algorithm searches outward to find the next pixel that is at least 10 percent modified and calculates the Euclidean distance between the cells. This is just one approach to estimating landscape fragmentation among numerous others. The estimated extent of fragmentation, using this approach, is found in figure 5. As shown in figure 5, patterns of fragmentation are similar to those of modification suggesting that large swaths of rangeland have experienced near total conversion to other land uses.

A notable caveat to these data describing modification and fragmentation exists. These data represent the landscape circa 2010 and it is possible that other significant modifications and resulting fragmentation may have occurred since that time. As a result, developing a more updated depiction of landscape conditions requires new data describing such activities as new breakings (where native prairie is plowed for agricultural purposes) and energy development with associated infrastructure such as roads as well as well pads.

Table 4—A list of explanatory variables used to estimate human modification of cover in rangelands (HMc).

Input type	**Description**	**Processing**
Geographic	Travel time (minutes) to population centers ≥100 km, 10 km, 1 km	Calculate cost distance from US Census places with population ≥100 km, 10 km, 1 km, using cost weights on transportation infrastructure (Esri Streetmap 2006) based on speed limit and slope (270 m)
	U.S. subregion from ESRI State layer	Dissolve State polygons into subregions and rasterize at 90 m
Housing density	Block housing density estimate for 2000	Resampled SERGoM (Theobald 2005) from 90 m to 100 m resolution
Land cover	Major land cover types from Nature Serve Ecological Systems	Nature Serve Land Cover at 90 m resolution
	Percent impervious surface	Impervious surface model developed from CaRT analysis based on data collect from sample chips. (Theobald et al. 2009; Theobald et al. in prep.)
Land use	Oil and gas wells	Converted active wells using 1 km radius kernel density function, updated using presence of active wells (Copeland et al. 2009; Leinwand 2010)
	National Land Use Dataset (90 m)	Theobald 2014
Ownership	General land ownership from protected area database by class	Rasterized PAD-US v1.1 (CBI Version) polygons to general ownership classes (i.e., Private, USFS, BLM, Other Federal, State, Regional/ Local Gov., NGO, BIA) at 90 m resolution
	Public or private land ownership	Dissolved ownership into public and private classes rasterize to 90 m resolution
Road	Road class (highway, secondary, local, other)	Rasterize Esri Streetmap 2006 by road class
	Roaded area within 270 m	ESRI Streetmap converted to 30 m, then Euclidean Distance tool out to 270 m
	Road density (km/km^2) within 1 km kernel	Density tool, used 1,000 meter moving window, kernel density
	Human use by traffic volume (number of people/cars assuming time-decay function)	Theobald 2008
Soil	Soil index variables (1 = well drained to 4 = poorly drained)	Rasterized State Soil Geographic (STATSGO) Database polygons to 90 m resolution based on soil attributes, https://sdmdataaccess.nrcs.usda.gov/ accessed 20 February 2018.
	Annual flood frequency (1 = frequent (> 50% chance); 2 = occasional (5–50% chance); 3 = rare (<5% chance)	
	Available water capacity (AWC)	
	Clay content of soil (% soil <2 mm)	
	Soil index variable (1 = well drained to 7 = poorly drained)	
	Hydric soil indicator (1 if hydric)	
	Soil erodibility k-factor	
	Liquid limit (% moisture by weight)	
	Organic matter content (% by weight)	
	Permeability rates (inches/hr)	
	Total thickness of all sampled soil layers (in)	
Topographic	Digital elevation model from USGS NED (30 m)	Upscaled (mean) to 90 m from 30 m
	Slope (degrees)	Slope computed at 30 m, upscaled (mean) to 90 m
	Topographic Position Index (Weiss 2000)	Computed at 90 m

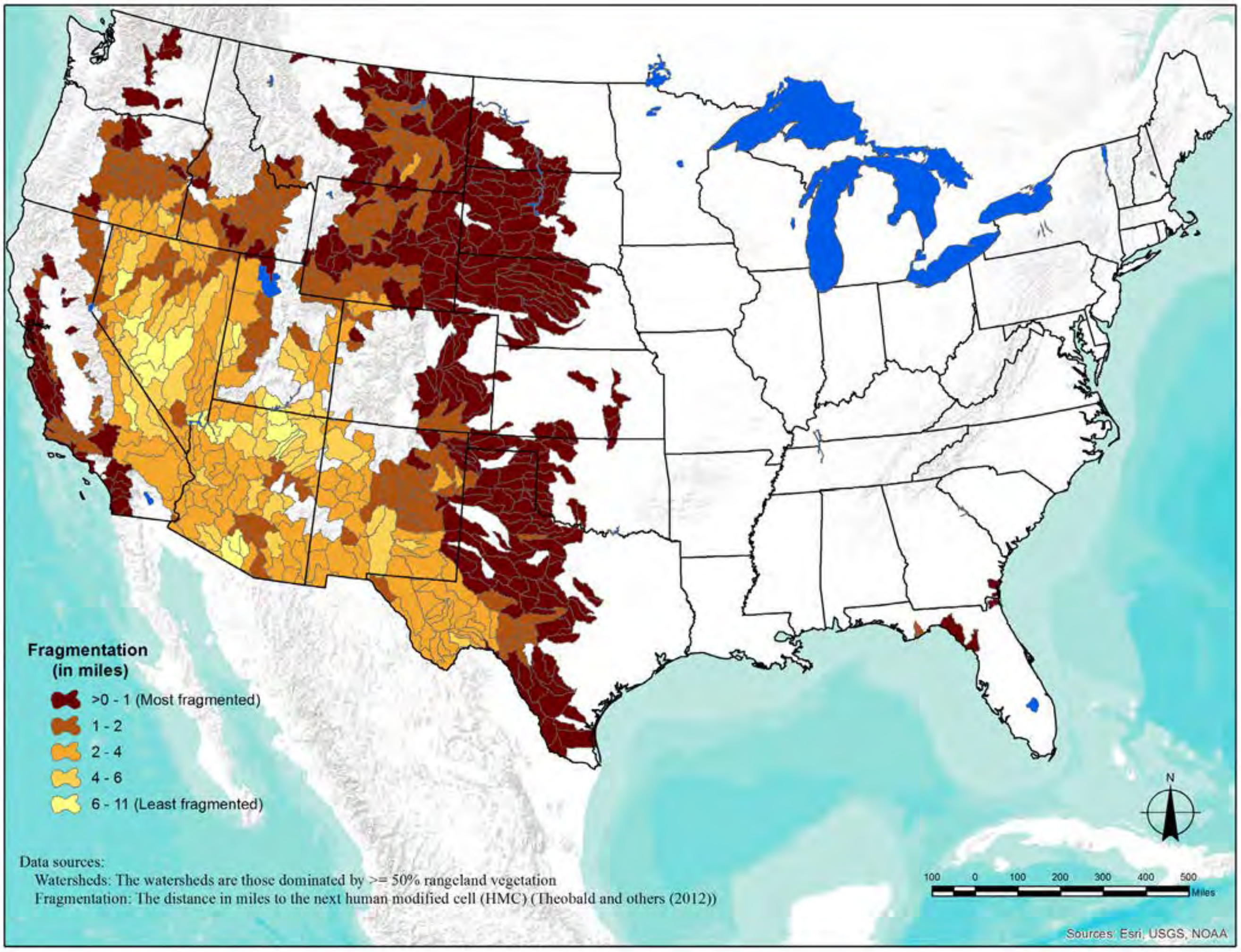

Figure 5—Extent and magnitude of fragmentation, aggregated to rangeland-dominated watersheds in the coterminous United States.

Projecting Residential Development to 2030

In general, the overall extent of the privately owned U.S. rangeland base has slowly decreased by 4 percent from 1982 to 2012. However, the loss has not been distributed evenly and there are hotspots of residential development that must be addressed to present a complete picture of the situation. In addition, the total extent of residential development is perhaps less important to sustaining rangeland goods and services than where and how the development is occurring. To aid our understanding of this situation, the final spatially explicit dataset produced here represents a projection of residential housing development to 2030. The process for developing these data is described in Theobald (2005). Here, we provide an abbreviated review of methods to enable a cursory understanding of how the projections of residential development were made. Residential development was projected across the landscape, to the year 2030, using the Spatially Explicit Regional Growth Model (SERGoM; Theobald 2005). SERGoM is a hierarchical (national to State to county) deterministic

Residential development creates new kinds of landscapes for both humans and animals. Sometimes residential development can aid the dispersal and establishment of invasive species such as cheatgrass. When new residential development occurs in areas of migration corridors, sometimes conflict can occur providing opportunities for managers and communities to collaborate to maintain and facilitate regional patterns of wildlife movement (photos courtesy of Joe Riis, Matt Reeves, and Perry Backus).

model that calculates the number of additional housing units needed in each county to meet the demand specified by population projections, based on the ratio of housing units to population (downscaled from census tract to block). Housing units are spatially allocated within a county in response to the spatial pattern of land ownership, previous growth patterns, and travel time accessibility. The model is dynamic in that as new urban core areas emerge, the model recalculates travel time from these areas.

In the first step, the number of new housing units in the next decade is forced to meet the demands of the projected county-level population. There is significant variability in the population per housing unit ratio (area-weighted mean = 2.509, SD = 2.383), so that in the 2000 Census, 440 counties had <2.0 people/unit and 70 counties <1.5 people/unit. Rather than using a single nationwide conversion factor, population growth was converted to new housing units by the county-specific housing unit per population ratio for 2000.

The second step was to compute a location-specific average growth rate from the previous to current time step (e.g., 1990 to 2000). These growth rates were computed for each 100-m cell using a moving neighborhood (radius = 1.6 km). For each State, the average growth rate for each of 16 development classes was quantified. These 16 classes were found by overlaying four density classes (urban, suburban, exurban, and rural) with four accessibility classes measured as travel time (number of minutes one way) from the nearest urban core (see below): 0–10, 10–30, 30–60, and >60 minutes.

Growth rates averaged over the classes generated from the housing density and accessibility patterns that reflect the previous time step were then joined to a map that depicts the current time step housing density and accessibility pattern. Because these classes and rates are computed locally, both within-county heterogeneity and cross-boundary patterns can be captured. This allows rates of growth to vary across the nation, across a region, and even within a county, and does not assume stationarity. The distribution of new housing units was adjusted according to accessibility to the nearest urban core. That is, growth typically occurs at locations on the urban fringe. Accessibility from all developable land to the nearest urban core was computed—based not simply on straight-line distance, but in terms of minutes of travel time from a location along the main transportation network (major roads and highways) to the nearest urban core. An urban core area is defined here as a contiguous cluster (>100 ha) at urban housing density, but alternative definitions could be developed. Because it is difficult to forecast when roads will be enlarged or where new roads will be constructed, travel time to move across locations that are not on the network of major roads was modeled as an average travel time of 15 miles per hour (24.2 km/hour). Travel speed was assumed to be 70 mph (113 km/hour) on interstates, 55 mph (89 km/hour) on highways, and 45 mph (72.4 km/ hour) on major county roads. An accessibility surface was then created from a cost weight based on travel time from urban areas along major roads. New housing units are allocated as a function of the accessibility surface. Here, the allocation is based on the distribution of new units realized in the previous decade, but other weightings could be applied to develop denser or more dispersed growth scenarios. Accessibility is computed at each decadal time step because new "islands" of urban core may emerge over time. This allows complex growth patterns to be modeled, and it incorporates the emergent nature of development patterns. The third step was to add the map layer of new housing density to the current housing density (i.e., adding new housing units to 2000 housing density). SERGoM assumes that housing density cannot decline over time. This is a reasonable assumption when examining patterns of expansion in suburban and exurban areas. However, this current implementation is limited when investigating urban-centric processes, such as urban decay or expansion of commercial land use into urban and suburban residential areas. The result of implementing SERGoM in these three steps provides estimated growth in percent change from the baseline of 2000 to 2010. This baseline was used since the original projections were completed in 2011 and are being published here, in this context, for the first time. The estimated intensity and extent of projected residential development is found in figure 6.

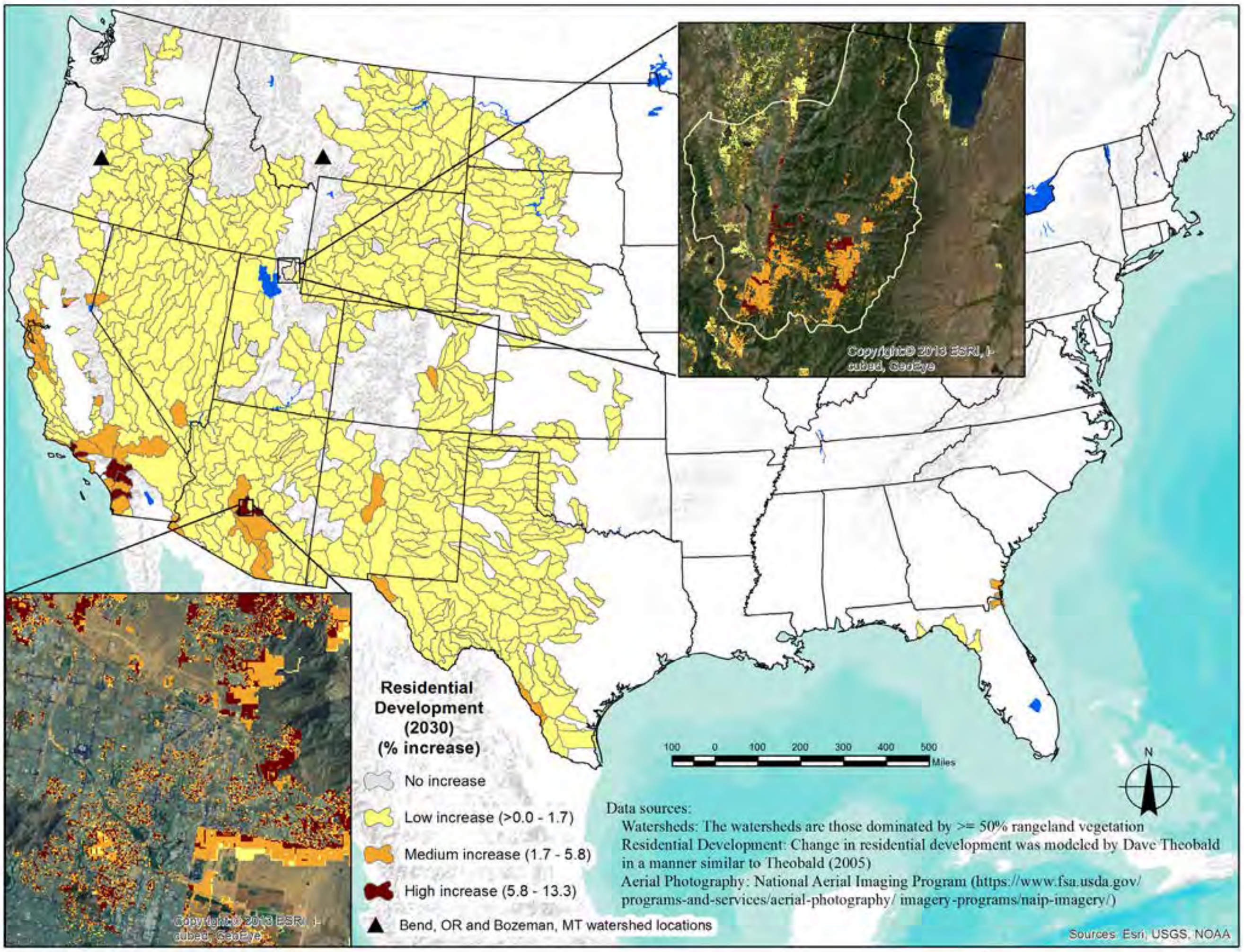

Figure 6—Projected percent increase in residential development in rangeland watersheds across the United States by 2030. Lower left inset indicates projected residential development for the area near Phoenix, Arizona, at the pixel-level (90 m). Watershed-level percent class breaks are as follows: Low: >0–1.7; Medium: 1.7–5.8; and High: 5.8–13.3. Inset pixel-level percent class breaks are as follows: Low: 1–10; Medium: 10–30; and High: 30–91. Likewise, the upper right inset provides an example of a watershed, encompassing much of the Wasatch Front, where significant residential development is expected to occur but the watershed does not meet the threshold criteria of 50 percent of the area being dominated by rangeland vegetation.

Rangelands exhibit land use strategies becoming increasingly influenced by housing development that competes with more traditional uses (photo: Carrie MacLaren, courtesy of 1000 Friends of Oregon).

Data Analysis and Aggregation

Data describing human modification, fragmentation, and increased residential development by 2030 were produced for all coterminous U.S. rangelands at 90-m spatial resolution. All these data were subsequently aggregated to watersheds in an effort to be consistent with the analysis framework found in FOTE. An example of these data, at the pixel level, can be seen in figure 7, which depicts the estimated HMc at every pixel considered to be rangeland. These estimates of HMc clearly show the extent of conversion of rangelands to other land uses, especially agriculture.

Here, in the inaugural ROTE report, we present a snapshot of these data to facilitate communication of the ideas they foster. Where appropriate, linkages between FOTE and ROTE analysis methods were maintained. Analysis of the ROTE data was conducted in a similar manner to FOTE in terms of display and aggregation. Both FOTE and ROTE sought to characterize results in relation to watersheds of the United States, recognizing the contributions of wildlands to providing clean and abundant water resources. In accordance with this understanding, results were aggregated to watershed—and State—levels using the following data sources:

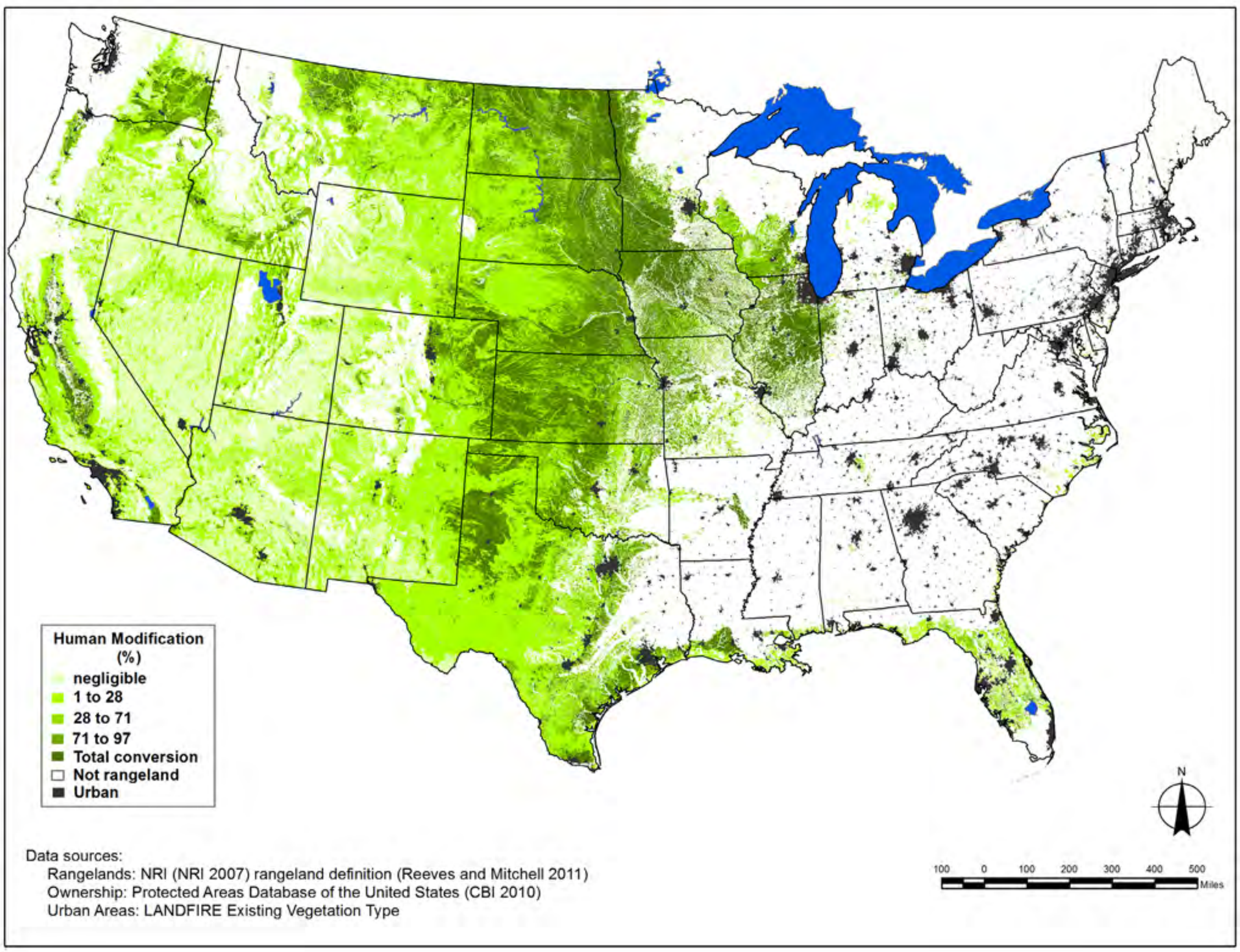

Figure 7—Extent and magnitude of human-modified land cover (HMc), displayed at a spatial resolution of 90 m. Pixel-level data such as these were also developed for fragmentation and projections of residential development.

1. Fourth-level watershed boundaries defined by Steeves and Nebert 1994 (sixth code hydrologic unit codes, i.e., HUCs)
2. Rangeland extent (Reeves and Mitchell 2011)
3. Human modification (Theobald 2013)
4. Rangeland fragmentation (Theobald 2013)
5. Projected residential development to 2030 (Theobald 2005)

Several key concepts are important for the reader to understand. All analyses were done for rangeland landscapes only. Additionally, in the case of evaluating projected rangeland development, only the "buildable" areas located within rangeland landscapes were identified. To illustrate, consider the case of a very large watershed with a high proportion of rangelands under Federal ownership with a few urban areas (like many areas in the western United States). The projected residential growth in the Federal ownerships will be zero and when the mean of projected residential development is computed, the watershed will appear to exhibit almost no growth at all. This is misleading. Likewise, the same will be true in watersheds with a high proportion of private land dominated by complex terrain that may be unsuitable for building. To account for these issues, it is important to understand the method and implications of how values of "0" were dealt with in the ROTE analysis framework. For analyzing human modification and aggregating to watersheds, the values of zero were left intact. This has implications for interpretation of the results. By allowing values of zero (no modification) to influence watershed-wide results, the question most appropriately answered with this process is, "Across the entire extent of a watershed, regardless of jurisdiction, what is the average amount of modification?" The result of this analysis is shown in figure 4. This is different from asking the question, "On lands that are modified, what is the average amount of modification?" This would yield a different result, especially in watersheds exhibiting a large proportion of public lands where modification is likely to be considerably less than watersheds dominated by privately owned rangelands.

The analysis procedure and assumptions are the same for analysis of fragmentation where zeroes were used for analysis purposes since areas of "zero" modification theoretically represents robust corridors for species dispersal. The result of this fragmentation analysis is found in figure 5. In contrast, the watershed level analysis of residential development did not include areas of "zero or no development." So the correct question to be answered using this framework is, "On lands where residential development is expected to increase, what is the expected amount of increase across each watershed?" The assessment of projected residential development, at the national level, is found in figure 6 while the results are summarized to States and displayed in table 5.

Two other points are critical to understand about the analysis portrayed in figure 6. First, many of the areas of the country that are experiencing high residential growth in areas where rangelands are common (such as the Wasatch Front near Salt Lake City, Utah, and Rocky Mountain Front near Denver, Colorado) are not evaluated in figure 6. This occurs because the watersheds they belong to are dominated by forest (i.e., <50 percent rangeland), or the amount of urban land cover prevents rangelands from being the dominant land cover. Hence, readers are encouraged to obtain the data describing the

Table 5—Historic area, modified area, projected residential development by 2030, and fragmentation for States where rangelands occupy 1 million acres in a State. Note that not all States are included in the analysis because they do not meet the criterion of possessing a watershed dominated by ≥50 percent rangeland. Here the fragmentation metric represents the distance between modified pixels where modification is ≥50 percent.

State	Historic area	Modified area	Projected additional residential development by 2030	Fragmentation (average distance between modified pixels)
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Arizona	66,974	3,587	364	8.45
California	70,874	13,319	1,354	3.8
Colorado	45,916	13,494	256	1.37
Florida	12,096	4,801	438	0.79
Iowa	23,108	20,219	93	0.01
Idaho	29,763	5,885	77	3.16
Illinois	20,247	17,684	188	0.01
Kansas	46,799	35,102	115	0.03
Minnesota	21,708	18,233	116	0.05
Missouri	15,027	10,397	132	0.01
Montana	67,604	16,540	28	1.43
Nebraska	47,538	26,579	74	0.43
New Mexico	68,636	5,969	137	5.31
Nevada	67,266	1,858	161	8.64
North Dakota	43,214	30,478	29	0.11
Oklahoma	28,851	17,124	125	0.16
Oregon	34,488	5,014	80	3.09
South Dakota	45,924	23,716	46	0.4
Texas	128,547	46,551	1,129	1.72
Utah	38,748	2,845	166	6.29
Washington	17,249	7,530	102	0.78
Wisconsin	11,423	7,002	146	0.04
Wyoming	49,306	4,092	13	2.13
Total	**1,001,306**	**338,019**	**5,369**	**NA**

increased residential growth by 2030 from the lead author to perform their own analyses to meet the needs of other projects.

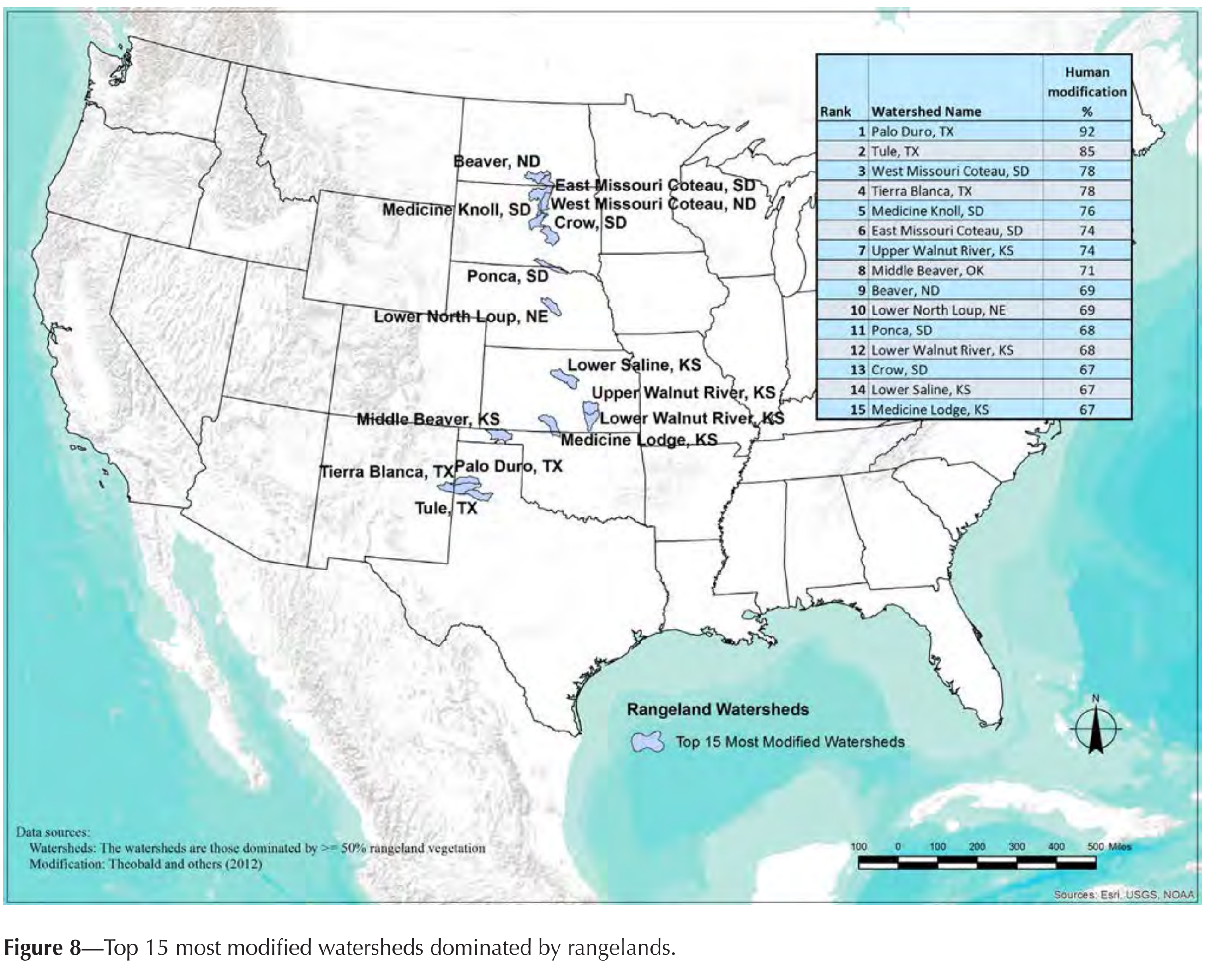
Watershed Selection Criteria

Several strategies were used to determine which watersheds should be used to aggregate HMc, fragmentation, and projected housing development. Unlike FOTE we did not differentiate between public or private lands for the purposes of characterizing the extent of modification. It is logical to expect, however, that most (but not all) of the modification and resulting fragmentation estimated across rangelands is found on privately owned lands.

For communicating the primary elements of the study, we chose to use watersheds that were dominated by rangelands, where rangelands occupy ≥ 50 percent of the area. To determine this quantity, the fractional amount of existing vegetation occupied by rangelands in each watershed was estimated from Reeves and Mitchell (2011, 2012). Since fragmentation, human modification, and projected residential development are produced at a 90-m spatial resolution, they can be aggregated to any summary unit that makes sense for a given study. In addition, for figures 3, 4, and 5 summarizing watershed attributes for each State, top-ranked watersheds were selected that had the majority (>50 percent) of their area within the represented State. This was done to avoid depicting watersheds in one State that had larger overlapping areas in another. It more fairly characterizes watersheds with the most modified, most fragmented, and highest projected increase in residential development within each State. This is necessary because some watersheds cover multiple States.

Top 15 Modified Watersheds

At a watershed scale, patterns of human modification, displayed in figure 8, follow an increasing gradient of modification from west to east reflecting increasing agricultural land use. Within these patterns, identification of the top 15 most modified watersheds



Rank	Watershed Name	Human modification %
1	Palo Duro, TX	92
2	Tule, TX	85
3	West Missouri Coteau, SD	78
4	Tierra Blanca, TX	78
5	Medicine Knoll, SD	76
6	East Missouri Coteau, SD	74
7	Upper Walnut River, KS	74
8	Middle Beaver, OK	71
9	Beaver, ND	69
10	Lower North Loup, NE	69
11	Ponca, SD	68
12	Lower Walnut River, KS	68
13	Crow, SD	67
14	Lower Saline, KS	67
15	Medicine Lodge, KS	67

Figure 8—Top 15 most modified watersheds dominated by rangelands.

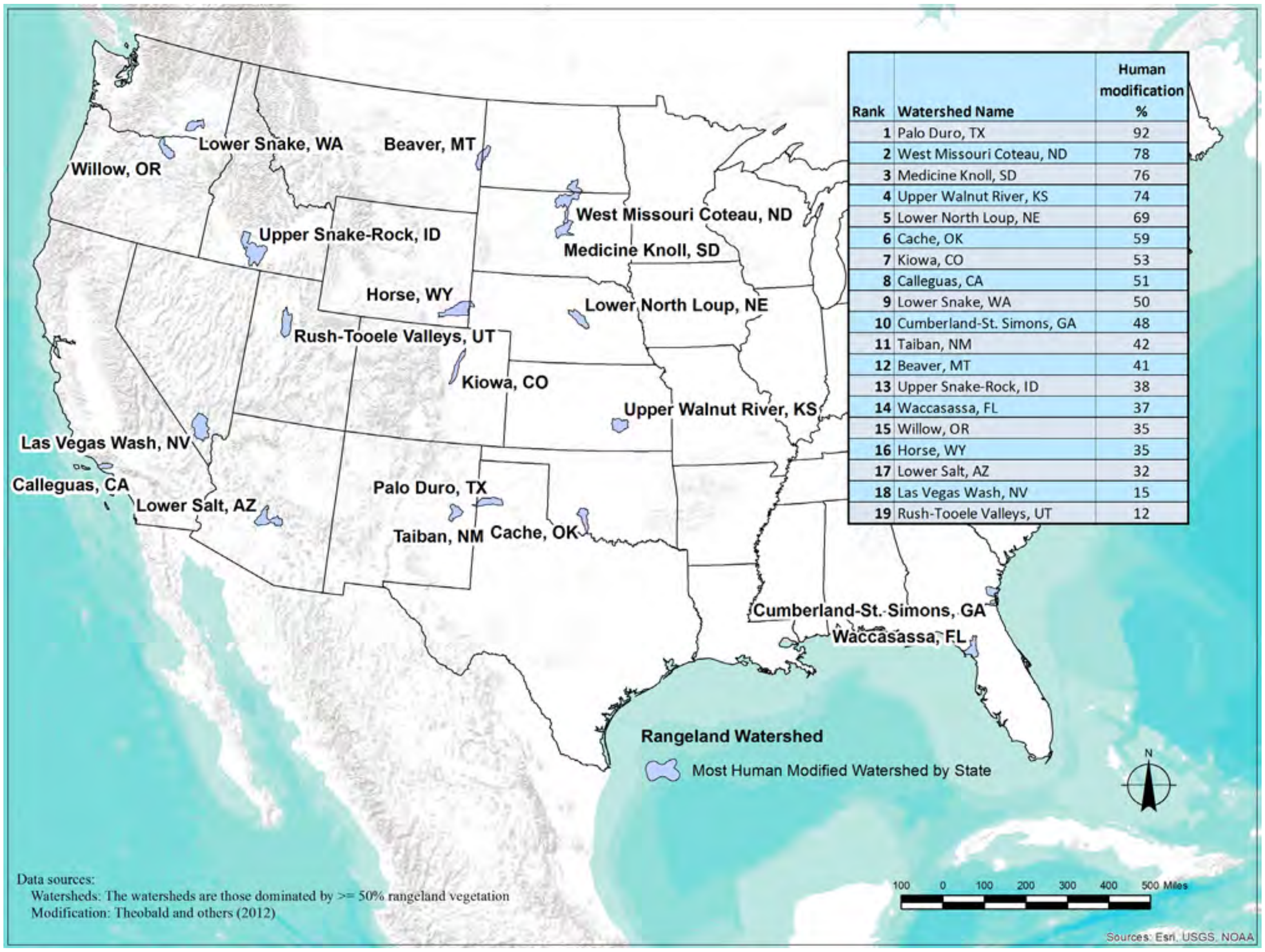


Figure 9—Most modified (highest amount of average human-modified cover) rangeland-dominated watershed in each State.

required selection criteria yielding only those watersheds currently occupied by ≥50 percent rangeland vegetation. The resulting analysis revealed that the most highly modified rangeland-dominated watersheds are those with a high agricultural component in the Central Plains region.

In addition to this analysis, the most modified rangeland-dominated watershed in each State is identified in figure 9. Although private ownership was not used as a selection criterion for identifying the watersheds with the greatest modification, as indicated in figure 2, the most modified rangelands occur in regions where private ownership dominates the landscape. In addition, the most highly modified watershed in each State invariably occurs in areas dominated by agricultural land uses.

This assessment could be improved by accounting for the impacts of invasive species as agents of permanent change. Invasive species such as cheatgrass (*Bromus tectorum*), knapweed (*Centaurea* spp.), and feral faunal species such as wild horses and burros (*Equus* spp.) and pigs (*Sus* spp.) are causing ecological harm (e.g., Cushman et al. 2004; Downing and Snell 2016) and slowly and steadily reducing the likelihood of rangelands to maintain production of goods and services in the future. This type of modification, however, is beyond the scope of this report but methods such as those employed by Reeves and Baggett (2014) could be used with relatively high-resolution, remotely sensed data to estimate degradation due to faunal invasive species.

Top 15 Fragmented Watersheds

One might expect patterns of fragmentation to mirror those of human modification, since a result of the analyses and assumptions employed here required lands to be modified (≥50 percent) before they can be fragmented. However, figure 10 reveals that regions may be only slightly modified but still exhibit a high degree of fragmentation.

The relationship between modification and fragmentation depends on how the modifications are juxtaposed with one another. The present analysis reveals that, as landscapes approach 40 percent modification, they become almost fully fragmented. Fragmentation based on the modification threshold of ≥50 percent was used for analysis and display purposes. Fragmentation here is represented as the Euclidean distance between modified cells (50 percent modified is the threshold). Using this threshold, the most fragmented watershed in each State is shown in figure 11, while the top 15 fragmented watersheds are identified in figure 12. The most fragmented watersheds occupy the eastern boundary of rangelands in the United States, while those in the interior and southwestern United States are relatively intact, with little fragmentation. Five of the top 15 most fragmented watersheds occur in Kansas alone.

Top 15 Watersheds With Increased Residential Development

Future residential development in areas dominated by rangelands is projected to be greatest near existing urban centers (e.g., where parcels are closer to utilities and roads and land is suitable for development) and is shown in figure 6. As demonstrated in figure 13, the top 15 watersheds experiencing the highest growth rates are clustered mainly in California and the southwestern United States. In fact, 13 of the top 15 of the watersheds expected to experience the highest projected growth rates are found in California.

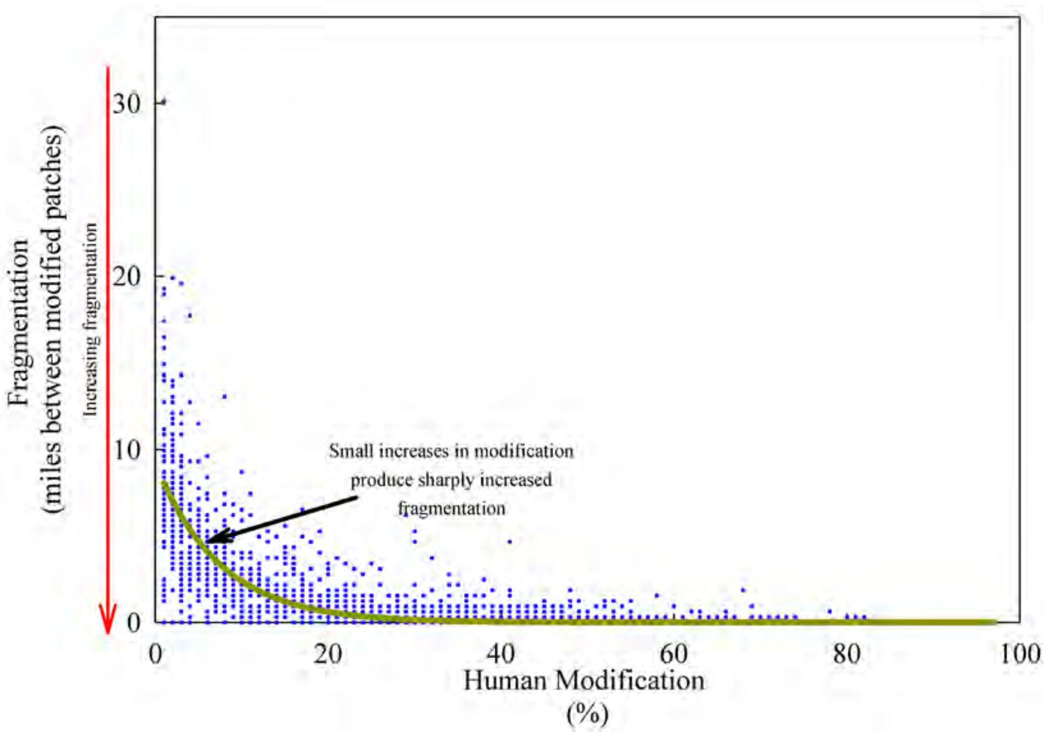
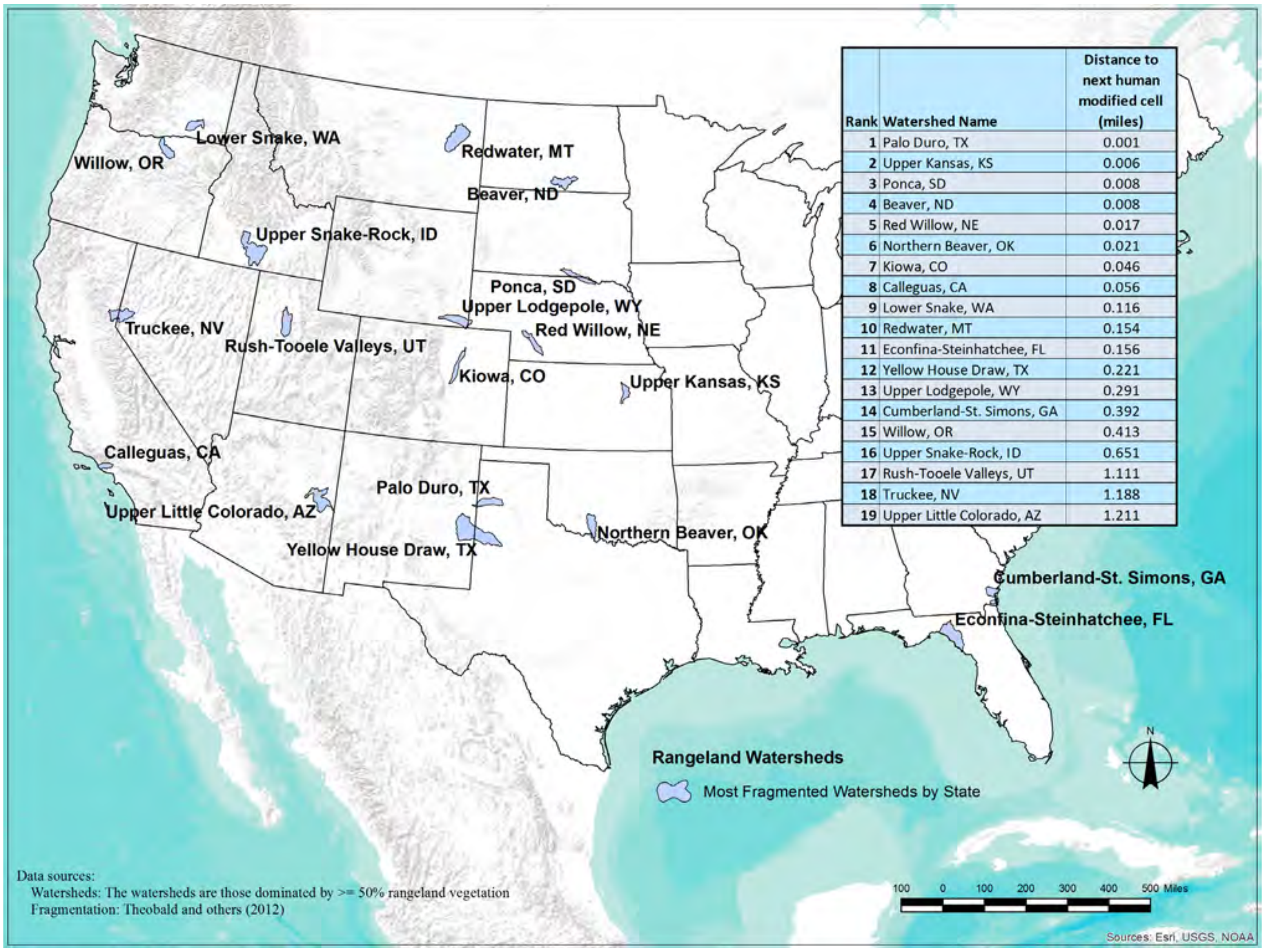


Figure 10—Relationship between human-modified cover and fragmentation calculated for each watershed in the coterminous United States.



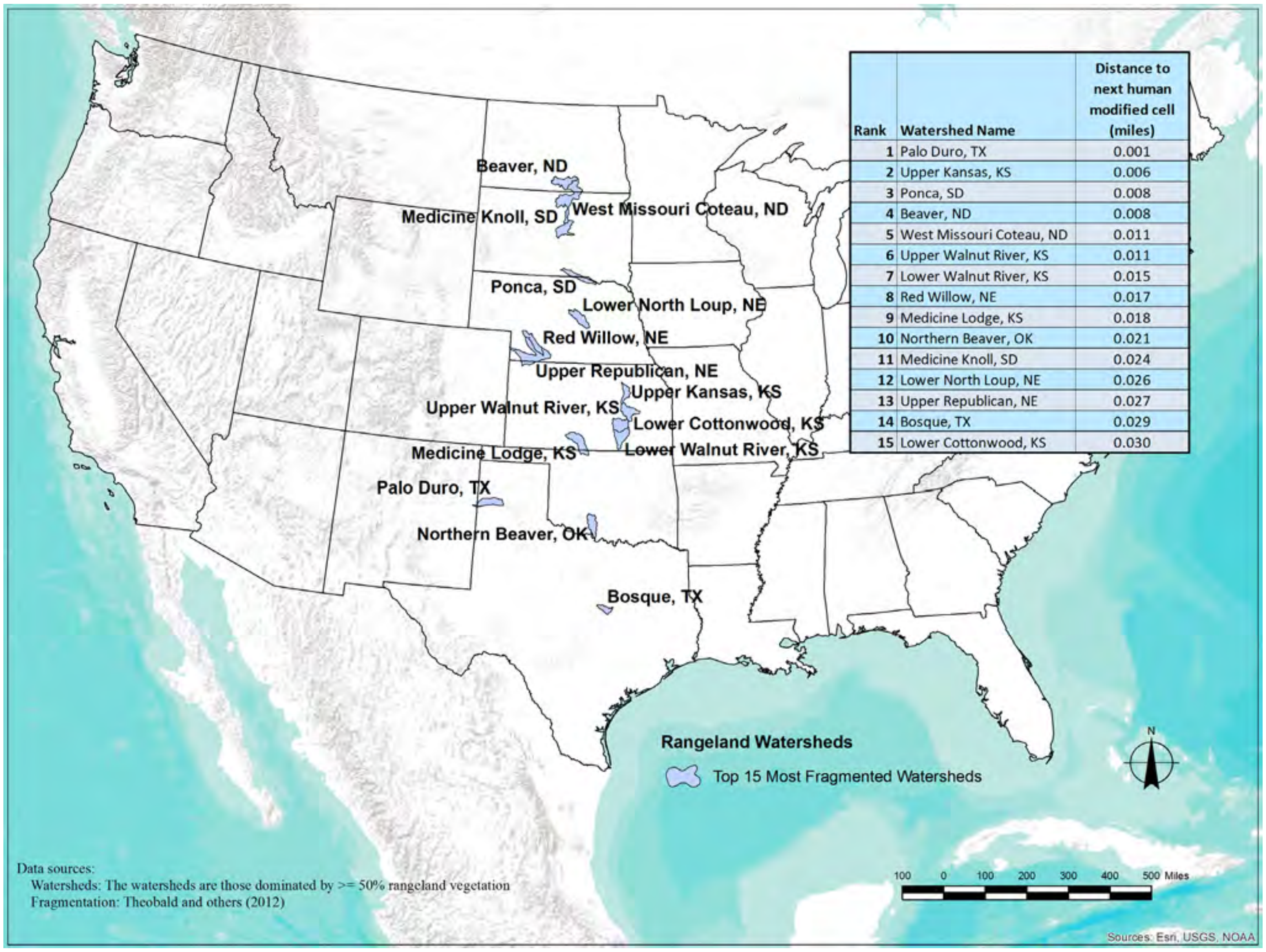
Rank	Watershed Name	Distance to next human modified cell (miles)
1	Palo Duro, TX	0.001
2	Upper Kansas, KS	0.006
3	Ponca, SD	0.008
4	Beaver, ND	0.008
5	Red Willow, NE	0.017
6	Northern Beaver, OK	0.021
7	Kiowa, CO	0.046
8	Calleguas, CA	0.056
9	Lower Snake, WA	0.116
10	Redwater, MT	0.154
11	Econfina-Steinhatchee, FL	0.156
12	Yellow House Draw, TX	0.221
13	Upper Lodgepole, WY	0.291
14	Cumberland-St. Simons, GA	0.392
15	Willow, OR	0.413
16	Upper Snake-Rock, ID	0.651
17	Rush-Tooele Valleys, UT	1.111
18	Truckee, NV	1.188
19	Upper Little Colorado, AZ	1.211

Figure 11—Most fragmented (smallest average distance between areas exhibiting ≥50 percent human-modified cover) rangeland-dominated watershed in each State.

In addition to presenting the top 15, the watershed experiencing the greatest growth rate in each State is shown in figure 14.

Key Findings

The historic (pre-European settlement) extent of rangelands in the coterminous United States was roughly 1 billion acres. Based on figure 7, we estimate that 34 percent or 343 million acres of historical rangelands have been modified and converted to other land uses (table 5). The proportion of historic rangeland lost in each State ranged from a high of 88 percent for Iowa to a low of 3 percent for Nevada. In terms of total area, Texas had the greatest historic, modified, and existing rangeland areal extent. Figure 7 clearly demonstrates the extent and magnitude of change, especially in the Great Plains regions where fertile soils and favorable growing conditions enable widespread and intensive modification. Conversion of former rangeland to agriculture is a well-known phenomenon and does not, by itself, yield useful information. Recognition of this situation gave rise to analyzing the extent of modification in a variety of ways. The analysis of spatial patterns of modification enables estimates of fragmentation at a national scale across the extent of rangelands. This novel approach enables a new perspective on



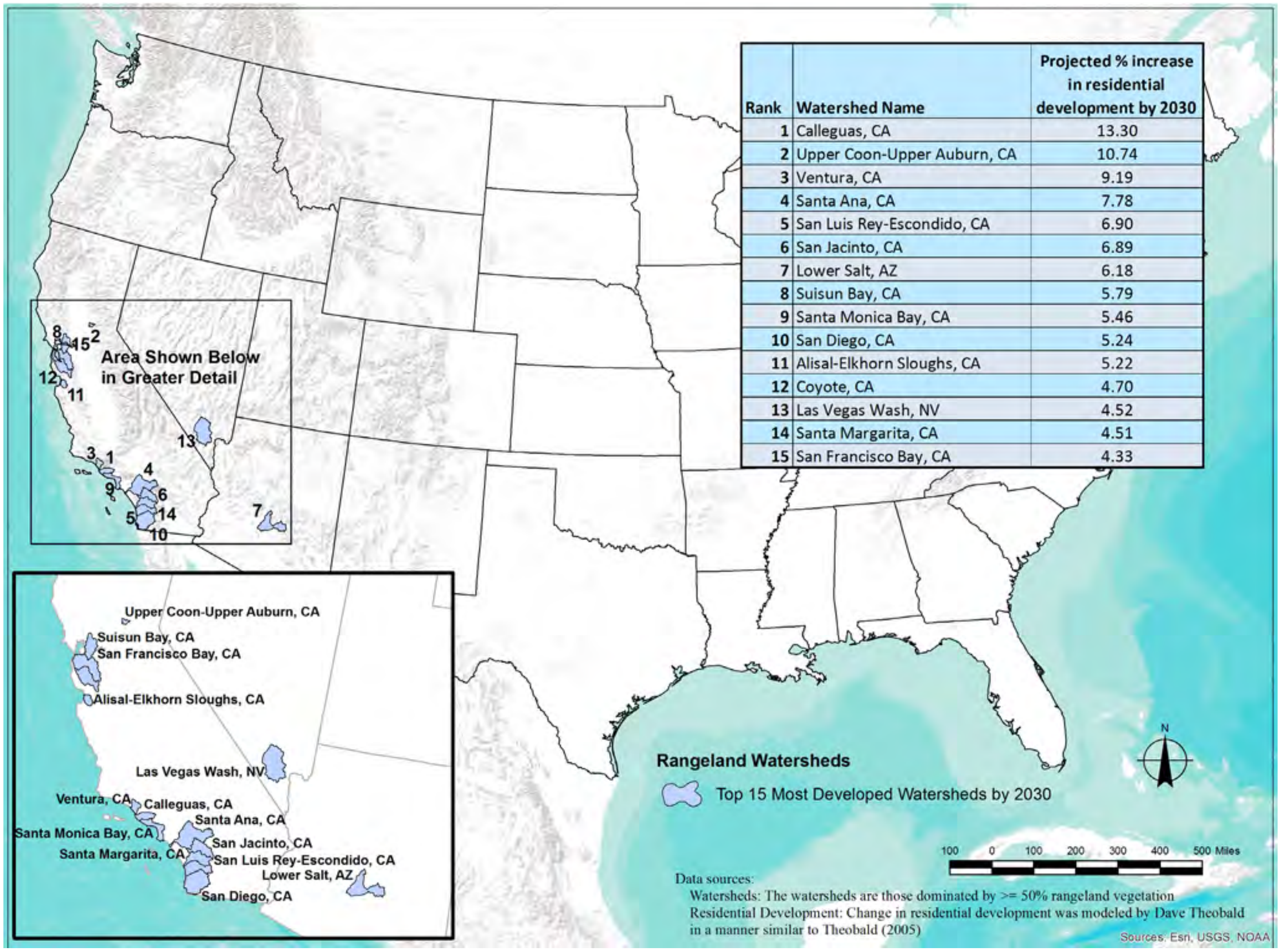
Rank	Watershed Name	Distance to next human modified cell (miles)
1	Palo Duro, TX	0.001
2	Upper Kansas, KS	0.006
3	Ponca, SD	0.008
4	Beaver, ND	0.008
5	West Missouri Coteau, ND	0.011
6	Upper Walnut River, KS	0.011
7	Lower Walnut River, KS	0.015
8	Red Willow, NE	0.017
9	Medicine Lodge, KS	0.018
10	Northern Beaver, OK	0.021
11	Medicine Knoll, SD	0.024
12	Lower North Loup, NE	0.026
13	Upper Republican, NE	0.027
14	Bosque, TX	0.029
15	Lower Cottonwood, KS	0.030

Figure 12—Top 15 most fragmented (smallest average distance between areas exhibiting ≥50 percent human-modified cover) watersheds dominated by rangelands.

where and how rangelands are being changed. Present patterns of fragmentation follow similar patterns of modification, but residential development projections are unique.

Areas with the highest degree of projected residential development are plainly not occurring in areas that have historically exhibited the highest levels of modification. Indeed, agricultural development has had the greatest impact, especially on the Great Plains. These lands are generally more productive, while in contrast the greatest expected changes in residential growth rates are occurring primarily in the arid southwestern United States and California. This has significant implications for regional planners since the demand for water is going to increase commensurately with residential growth occurring in these relatively arid regions.

As shown in figure 13, 13 of the top 15 watersheds with the greatest anticipated growth rates are found in California. Over the next 18 years or so, we estimate an additional loss of 5.6 million acres of rangelands (about 280,000 acres lost annually) to residential development, with over 1 million acres of rangeland loss estimated for California and Texas alone. This amount of increased residential development is about 1.4 percent of the current privately owned rangeland base of 409 million acres (USDA 2009). Our analysis does not account, however, for potential conservation efforts that



Rank	Watershed Name	Projected % increase in residential development by 2030
1	Calleguas, CA	13.30
2	Upper Coon-Upper Auburn, CA	10.74
3	Ventura, CA	9.19
4	Santa Ana, CA	7.78
5	San Luis Rey-Escondido, CA	6.90
6	San Jacinto, CA	6.89
7	Lower Salt, AZ	6.18
8	Suisun Bay, CA	5.79
9	Santa Monica Bay, CA	5.46
10	San Diego, CA	5.24
11	Alisal-Elkhorn Sloughs, CA	5.22
12	Coyote, CA	4.70
13	Las Vegas Wash, NV	4.52
14	Santa Margarita, CA	4.51
15	San Francisco Bay, CA	4.33

Figure 13—The top 15 rangeland-dominated watersheds with the greatest projected increase in residential development.

may slow the rate of development in some rangeland types. Further, it is important to understand that although the biggest changes in residential development occur in areas with large populations, greater relative effects on rangeland systems may occur elsewhere. For example, as pointed out in FOTE (Stein et al. 2007), Ravalli County, Montana, may continue to experience rapid changes in ecosystem goods and services based on the issues outlined in this document, such as increased prevalence of invasive species, greater conflicts between users, decreased land base for recreation, greater fragmentation of rangelands, etc. Likewise, areas such as Bend, Oregon, the Rocky Mountain Front in Colorado, and Bozeman, Montana, are also experiencing rapid change; thus, we encourage future analyses that may yield insights useful for planners using the data we developed here in ROTE.

Special Consideration: Rangelands in the East and Piñon-Juniper

Because this study focuses on rangelands, which by definition typically exhibit tree cover ≤25 percent (table 2), most of the analyses portrayed in this report focus on western watersheds dominated by non-forest vegetation. There are, however, some

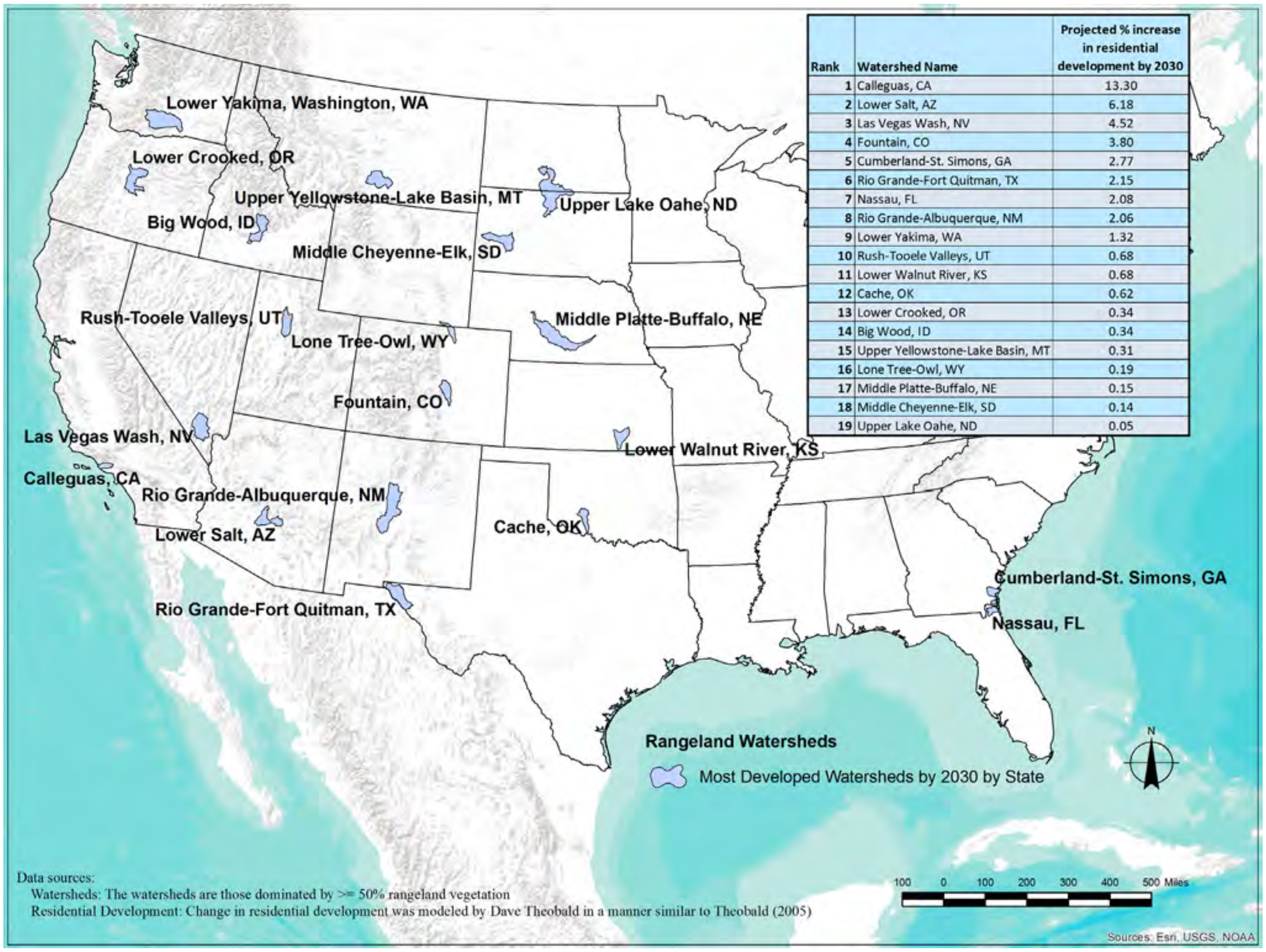


Figure 14—The rangeland-dominated watershed with the greatest projected increase in residential development in each State.

unique areas east of the 95th meridian where rangelands are common, especially in Louisiana, Florida, and Georgia. Therefore, despite the general lack of eastern watersheds evaluated in this report (due to relatively low area of rangeland compared with other cover types), we encourage readers to obtain data produced here because, as shown in figure 2, data were produced for eastern landscapes.

Likewise, in the western United States, many stands of piñon-juniper and oak woodlands that might be considered forest using the Forest Inventory and Analysis (FIA) definition are often considered rangelands using the National Resources Inventory (NRI) definition. This is an important concept because FOTE (Stein et al. 2005) identified the piñon-juniper areas as mapping challenges. This mapping difficulty was partially overcome in ROTE through increased thematic resolution of the LANDFIRE geospatial products by specifically identifying and accounting for some piñon-juniper areas being classified as rangelands, which were not fully evaluated in FOTE (see page 11 of Stein et al. 2005). Many of the landscapes dominated by piñon-juniper vegetation were included in ROTE.

Rangelands provide many goods and services. Some, such as forage production, are widely recognized but others, such as wildlife viewing, hiking, and clean drinking water, are also important services provided by healthy rangelands (photos: courtesy of Matt Reeves).

Conclusions

Conversion of rangelands for exurban development will continue, more rapidly in some areas and more slowly, if at all, in others. California and Texas are expected to be impacted the most, followed by Florida, Arizona, and Colorado. States with less dense human populations, like Wyoming, Montana, and North Dakota, will be impacted the least. This process is expected to take place primarily around urban centers, that is, on the edge of rangelands, as our title infers. The higher relative value of land for housing in areas of expanding U.S. population makes such a trend inexorable. Mitigation of housing development impacts is most commonly enacted by local governments and developers themselves. Examples include setting aside and managing open space (e.g., https://vimeo.com/224369869, accessed 29 October 2017) through conservation easements (http://www.hcn.org/issues/271/14648) or outright purchase, and layouts of exurban developments that concentrate structures, allowing larger open areas for natural resource management and aesthetics.

In this inaugural Rangelands on the Edge report, modification, fragmentation, and projected residential development were quantified for coterminous U.S. rangelands. Because the assessment was produced with primarily regional to national applications in mind, the data are probably less reliable at finer spatial scales (<1 km^2). Nevertheless, spatial information about future patterns of land use change provides an important mechanism for identifying future challenges and fostering dialogue among scientists, managers, and counties as they strive to implement policies aimed at maintaining sustainable production of goods and services from our nation's rangelands.

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