Modeling restoration areas for grizzly bears in the Southwest

David J. Mattson[1], Troy Merrill[2]

[1]*Grizzly Bear Recovery Project, Livingston, MT 59047, USA*
[2]*LTB Institute of Landscape Ecology, Moscow, ID 83843, USA*

Abstract

We appraised the suitability of Arizona, New Mexico, southern Utah, and southern Colorado for restoration of grizzly bears *Ursus arctos horribilis* by extending and integrating existing models of habitat capability and remoteness from humans, calibrated to historical grizzly bear locations in our Southwest study area. We applied previously published standards or new standards based on established concepts to identify areas productive enough and remote enough from humans to sustain grizzly bears locally, as well as habitat complexes that were capable of supporting robust grizzly bear populations because of large size and high quality. We identified three promising complexes of suitable habitat ranging in size from 8,000 to >15,000 km^2: the Mogollon, San Juan, and Sangre de Cristo Complexes, of which the last two potentially functioned as one conservation area. These complexes of suitable habitat were, in turn, the basis for delineating three candidate Recovery Areas with estimated average carrying capacities of 620, 425, and 281 grizzly bears, respectively. We also assessed these candidate Recovery Areas for overlap with areas offering additional protections (e.g., Wilderness Areas and National Parks) as well as additional prospects of human-grizzly bear conflict (e.g., private property and public land sheep grazing allotments).

1. Introduction

Restoration is increasingly a focus for those promoting ecological conservation. For at-risk animal species that experienced widespread extirpation owing to historical human activities, restoration often includes reintroduction to former range. At a practical and operational level, this kind of restoration is similar to the introduction of game species to former range or to potentially suitable areas outside historical distributions. However, restoration of at-risk species differs from establishment of game populations by demanding greater odds of success (Breitenmoser et al., 2001). By definition, at-risk species offer fewer robust populations as potential sources of translocated animals. In contrast to game species, human acceptance of translocated at-risk species is also often less assured in restoration areas. Overall, restoration of at-risk species requires more attention to human dimensions as well as more reliable appraisals of biophysical conditions in potential restoration areas (Miller et al., 1999; Breitenmoser et al., 2001).

One obvious difficulty in assessing restoration prospects for extirpated animal species arises because there are no i*n situ* populations that can, through scientific study, provide site-specific answers to site-specific questions. Appraisal of potential restoration prospects necessarily involves the application of ecological theory to analysis of historical data together with extrapolation of ecological relations observed for extant populations elsewhere. In general, a few key questions need to be addressed in any appraisal of restoration prospects: What factors caused initial extirpations?; What is the current status of these stressors in potential restoration areas, especially in contrast to times when extirpations occurred?; What are the current ecological effects of these stressors?; and, as a bottom line, Does enough suitable habitat exist to support a robust restored population? (Yalden, 1993; Miller et al., 1999; Simberloff et al., 1999; Breitenmoser et al., 2001). Given that the spatial configuration of habitat conditions affects the population dynamics of virtually all species, these questions need to be answered in a spatially-explicit manner. Thus, data need to be geospatially referenced, spatially comprehensive, and with adequate surrogates for important ecological factors. Where funding is limited and potential restoration areas are extensive, data also need to be available at a modest price and with modest expenditure of effort (Yalden, 1993; Miller et al., 1999; Haight et al., 2000). These constraints make appraisal of restoration prospects for extirpated species one of the greatest challenges of applied ecology (Simberloff et al., 1999).

Grizzly bears *Ursus arctos horribilis* once occupied most of the western U.S.A. (US), including non-desert areas of Arizona, New Mexico, Colorado and Utah (Mattson and Merrill, 2002). Between 1850 and 1950 they were extirpated from about 98% of their former range, including all of the southwestern US and adjacent Mexico. Compared to Eurasia during the same period, these extirpations were rapid and extensive (Mattson, 1990). There is no mystery why grizzly bears almost disappeared from the contiguous US. They died because humans – primarily rapidly spreading European settlers – killed them (Storer and Tevis, 1955; Brown, 1996). Grizzly bears continue to die in the US almost solely of human causes (Mattson et al., 1996a; McLellan et al., 1999), at rates that are determined by how often they encounter humans and the probability that the encounter will turn lethal (Mattson et al., 1996b). Between 1850 and 1920 humans were highly lethal to grizzly bears, with rates of extirpation modified by landscape features that affected how often humans encountered bears (e.g., the distribution of attractive habitats and the presence of mountainous terrain; Merrill et al., 1999; Mattson and Merrill, 2002). Within the last 70 years humans have become much more accepting of grizzly bears in the contiguous US (Kellert et al., 1996), with greatest reductions in human lethality occurring since the institution of protections under the US Endangered Species Act (ESA) in 1974 (Mattson and Merrill, 2002).

Grizzly bears are ideal candidates for restoration to parts of their former ranges in the contiguous US. We suspect that grizzly bears are currently absent from many otherwise suitable areas solely as an historical artifact of the rapid pace of extirpations and the extreme lethality of humans between 1850 and 1950 (Mattson, 1990). Moreover, humans are not only much more benign, on average, but motivated to restore species like grizzly bears by national conservation policies such as the US ESA as well as non-governmental programs such as the Rewildling Institute and Yellowstone-to-Yukon Conservation Initiative (Soulé and Terborgh, 1999).

We also know a great deal about the ecology and broad-scale habitat relations of grizzly bears in the contiguous US. Mace et al. (1999), Merrill et al. (1999), Carroll et al. (2001), Mattson and Merrill (2002, 2004), and Merrill and Mattson (2003) developed broad-scale models that explain landscape-level relations and predict the location and extent of potential habitat. Merrill et al. (1999) developed a method for representing habitat relations at an appropriate scale and for predicting areas of potential conflict between humans and grizzly bears. Mattson and Merrill (2002) developed size and shape criteria for judging the robustness of grizzly bear ranges. Mowat et al. (2013), Mattson and Merrill (2021), and Mattson (2021a) each developed methods for estimating potential carrying capacity of regions currently unoccupied by grizzly bears. This previous research provides many of the tools needed for a reliable appraisal of restoration prospects for grizzly bears in areas where they have been extirpated.

The US states of Arizona, New Mexico, Utah, and Colorado have self-evident potential for supporting grizzly bears. Extirpations in this region were comparatively recent—during the 1920s in Utah, 1930s in Arizona and New Mexico, and 1970s in Colorado. The last known grizzly bear in the Southwest was killed by a big game hunter in the San Juan Mountains of southwestern Colorado in 1979, although rumors of surviving grizzlies persist (Bass, 1997; Petersen, 2009). There are, moreover, extensive areas of roadless productive habitat throughout mountainous regions of the Southwest. The US Fish & Wildlife Service 1993 Grizzly Bear Recovery Plan (US Fish & Wildlife Service, 1993) recognized the persisting potential of the San Juan Mountains to support grizzly bears by including this, at the time, undefined region in its prospectus for recovery of grizzlies. Even so, with the exception of Povilitis (1989), an explicit appraisal of this potential remained in limbo for 28 years.

1.1. The US Fish & Wildlife Service analysis

The US Fish and Wildlife Service (USFWS) published an analysis in 2021 of prospects for restoring grizzly bears to the San Juan Mountains as part of its updated status assessment for this species (US Fish and Wildlife Service, 2021a). This analysis was undertaken in response to the settlement of a lawsuit filed in 2019 by the Center for Biological Diversity claiming that the Service had failed to "evaluate and pursue grizzly bear recovery in violation of section 7(a)(1) of the ESA…"

The USFWS limited its analysis for unclear reasons to a study area defined by the geographic extent of the San Juan Mountains (US Fish and Wildlife Service, 2021:287; Figure 1). This somewhat arbitrary delineation encompassed 26,512 km^2. Their analysis focused almost exclusively on delineating "secure" habitat, defined conventionally as being any area beyond 500 m of a road, with the added provision that "core" secure areas be >1,000 ha. The analysts also calculated overlap of secure areas with Bureau of Land Management (BLM) and US Forest Service (USFS) sheep grazing allotments as well as census blocks with >19 people/km^2.

For unexplained reasons, the USFWS did not explicitly consider habitat productivity, carrying capacity, regional human population densities, likely acceptance of grizzly bears by local residents, likely levels of human traffic on roads, overlap with private property, or the "human footprint" (i.e., the totality of lands permanently appropriated for residences, highways, and croplands), all of which are relevant to judging carrying capacity and the potential for conflict with or displacement by humans. Nor did the USFWS consider the scale-dependent effects of these factors on grizzly bears (e.g., foraging area versus home range versus life range). A partial list of studies documenting the effects of these factors includes Merrill et al. (1999), Carroll et al. (2001), Mattson and Merrill (2002, 2004), Merrill and Mattson (2003), Johnson et al. (2004), Wilson et al. (2006), Schwartz et al. (2010), Northrup et al. (2012a, 2012b), Mowat et al. (2013), Proctor et al. (2020), and many more.

Not surprisingly, the USFWS concluded: "A population could be established through reintroduction. However, neither of these areas [the Sierra Nevada and San Juan Mountains] are large enough to contain sufficient numbers of bears to maintain long-term fitness, and ongoing translocations would likely be needed to ensure long-term genetic health. A total population size of approximately 400 animals is needed for short-term fitness (Miller and Waits 2003, p. 4338) …". The highly-circumscribed nature of the analysis area preordained this conclusion. Even so, the USFWS offered no estimate of carrying capacity by which to judge potential population size against the benchmark of 400 animals.

This analysis by the USFWS was clearly deficient in many ways. It was constrained to a more-or-less arbitrarily defined and spatially limited area that did not account for the potential to restore grizzly bears to a much larger and potentially contiguous area within the Southwest, most of which falls within the bounds of historical distribution and is typified by relatively recent extirpations (Mattson and Merrill, 2002). It neglected a number of factors with well-documented effects on grizzly bears. It failed to provide systematic estimates of potential densities or population sizes for its study area, both of which are relevant to judging potential population viability.

Deficiencies of the USFWS analysis are all the more striking when compared to an appraisal of restoration potential for the San Juan Mountains reported roughly 32 years earlier by Povilitis (1989), along with an accompanying proposal for management of this area as a biosphere conservation area (Povilitis, 1993). These analyses were much more comprehensive, especially in the attention given to distributions of habitats and bear foods. Comparison with this earlier work highlights the extent to which the USFWS approach seemed to conflate precision with conceptual adequacy.

1.2. Goals of this analysis

Here we provide a spatially comprehensive analysis of prospects for restoring grizzly bears to the Southwest, inclusive of Arizona, New Mexico, southern Utah, and southern Colorado. To do this, we extend and integrate previous models and metrics for appraising biophysical conditions, calibrate these models to historical and contemporaneous data, and assess overlap with landscape features that potentially engender human-grizzly bear conflict. Our appraisal addresses the following hierarchical questions: (1) What areas are the most remote from humans?; (2) What areas exhibit the greatest intrinsic biophysical capability of supporting grizzly bears?; (3) What are thresholds for identifying areas sufficiently remote and sufficiently productive to allow bears to survive and replace themselves?; (4) Which areas or complex of areas are biophysical capable of supporting a robust grizzly bear population?; (5) What is the carrying capacity of these potential restoration areas; (6) How are these potential restoration areas configured relative to jurisdictions managed for conservation priorities or, conversely, with priority given to human activities that engender human-bear conflict?; and (7) How are candidate recovery areas configured relative to attitudes of local human residents that likely affect how accepting they will be of grizzly bears?

1.3 Human lethality and acceptance

The last of our questions (question 7, Section 1.2) is perhaps one of the most difficult to adequately address, especially in the absence of a large-sample survey designed to directly elucidate potential acceptance of grizzly bears among populations of people stratified by well-though-out demographic, occupational, and geospatial categories. Because we lacked such information, we employed geospatial proxies for likely acceptance of grizzly bears by human occupants or users of various jurisdictions. We also viewed these proxies as plausible indicators of how lethal people might be to resident grizzly bears (e.g., Mattson et al., 1996a, 1996b).

Human attitudes or "values" are unambiguously associated with acceptance of large carnivores and, as a corollary, more directly with the likelihood that people will kill animals such as bears and mountain lions (*Puma concolor*) for sport or in response to a provocation. The research supporting this premise is unassailable (for example, Kellert et al. [1996], Zinn et al. [2002], Mattson and Ruther [2012], Manfredo et al. [2018], and the review in Mattson [2020: Section E]). Apropos, Manfredo et al. (2021) developed an ordinal index of so-called "wildlife values" by which they were able to specify these values at a county level, which we employed as one of our geospatial proxies for potential acceptance of grizzlies.

Different management jurisdictions or designated land uses also demonstrably influence lethality of humans to grizzly bears. Most obviously, these include jurisdictions such as Wilderness Areas, National Parks, and National Monuments, typified by management that has been shown to mitigate human lethality and increase odds of grizzly bear survival (e.g., Mattson et al., 1996a; Johnson et al., 2004; Schwartz et al., 2010). Conversely, private property engenders a certain set of expectations that tend to reduce acceptance of large carnivores and increase human lethality (Northrup et al., 2012b; Wilson et al., 2006). Public land grazing allotments stocked with domestic sheep also predictably lead to heightened levels of human-grizzly bear conflict and resulting grizzly bear deaths (Johnson and Griffel, 1982; Knight and Judd, 1983; Jorgensen, 1983; US Fish and Wildlife Service, 2021). Because of these demonstrable effects, we incorporated maps of each management delineation into our development and appraisal of candidate Recovery Areas.

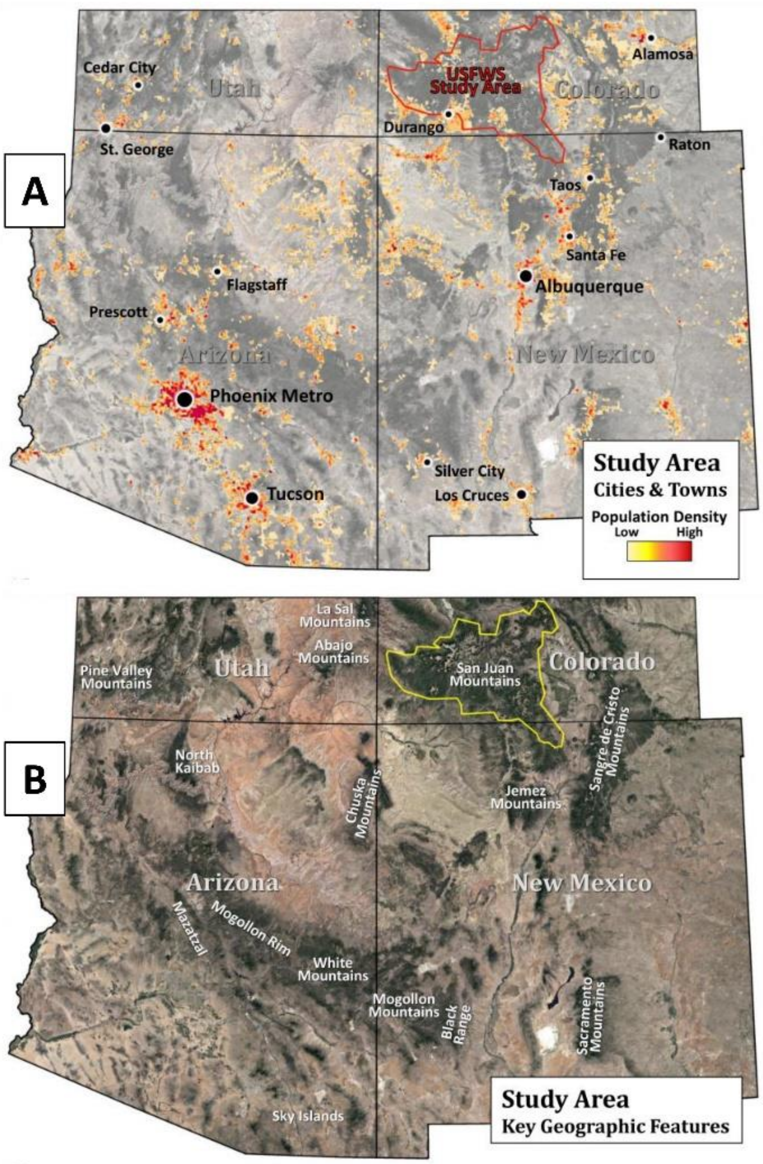

Figure 1. These maps show key human-associated and geographic features of the Southwest study area, including (A) human population densities and larger cities; and (B) major mountain ranges or other highlands of relevance to the analysis of grizzly bear habitat suitability. The study area used by the US Fish & Wildlife Service to evaluate recovery potential in the Southwest (US Fish & Wildlife Service 2021) is delineated in red in (A) and yellow in (B).

2. Study Area

Our 777,865-km^2 study area consists of Arizona, New Mexico, southern Utah, and southern Colorado, extending south to north from 31° 20’ to 38° 07’ N latitude and east to west from 103° 00’ to 115° 00’ W longitude. As such, our study area is approximately 29-times larger than the USFWS San Juan Mountains study area, delimited to the east by arid grasslands, to the south and west by the Mohave, Sonoran and Chihuahuan deserts, and to the west by the Great Basin (Figure 1b).

In Arizona, elevations range from 30 m to 3860 m, in New Mexico, from 915 m to 4011 m, and in Colorado, from 1490 m to 4360 m. Most of the north-central part of our study area consists of the deeply incised Colorado Plateau, surrounded by higher elevations of the San Juan, Sangre de Cristo, and Mogollon Mountains in New Mexico and Colorado, and the Kaibab and Mogollon Plateaus and their escarpments in Arizona. The southern and eastern parts of the study area consist of broad plains or valleys broken by isolated peaks and mountain ranges such as the San Mateo, San Andreas, Sacramento, and Guadalupe Mountains in New Mexico. The large size and elevational amplitude of the study area results in a broad spectrum of climates ranging from alpine on the highest peaks to hot arid desert in the lowest plains and valleys. During the last 20 years annual precipitation and temperatures averaged about 90–200 mm and 22–24 °C in the hottest driest deserts and about 400–800 mm and 5–10 °C at the coldest wettest weather stations, excluding the highest mountains. Annual snowfall at elevations >2100 m often exceeded 250 cm.

As of 2020, Arizona and New Mexico have 7,152,00 and 2,118,000 residents, respectively, but with most people concentrated in large population centers such as the Phoenix (4,846,000), Tucson (1,043,000) and Albuquerque (923,600) metropolitan areas. Most areas remain relatively unpopulated (Figure 1a), largely due to the fact that 39% of Arizona, 35% of New Mexico, 65% of Utah, and 36% are in federal ownership.

3. Methods

3.1. Data

We obtained historical locations of grizzly bears in the Southwest from Cary (1911), Brown (1996), Armstrong (1972), Hoffmeister (1986), and the National Museum of Natural History, Division of Mammals Collection. Known locations of grizzly bears in northern Idaho came from Layser (1978), Zager (1983), and Kasworm and

Their (1994; Merrill et al., [1999]). We also obtained delineations of grizzly bear ranges in the Southwest circa 1800 and circa 1918 from Mattson (2021a) and Brown (1996), respectively. Information in Brown (1996) was derived from historical records from 1825 through 1979, the last year any grizzly bear was known to be alive in the Southwest. Locations in northern Idaho were derived from historical and contemporary records for 1950 through 1993. We scanned maps of locations or ranges from each of these sources, edited out extraneous digital information, and registered the remaining points or areas to a 1-km^2-resolution grid.

We used existing sources of digital data to develop a geographic information system for our analysis. We used US Census Bureau TIGER files (scale 1:100,00) to calculate road densities. We converted TIGER line files to raster format with a cell size of 50 m. Cells representing roads and non-roads were coded 1 and 0, respectively. We calculated density using a circular moving window to sum cell values within a 1 km^2 area. We obtained spatially referenced information on human populations in the Southwest from updated 2010 US Census Bureau data summed at the block group level. Finally, for refinement of our representation of human impacts, we used a map of the human footprint in the West available at: https://databasin.org/maps/new/#datasets=347b5f3cc0ed4b4bb72e0f4797e5b85c. This index incorporated the physical footprint of anthropogenic features (e.g., roads, residences, power lines) with results of several different models that accounted for human-associated ecological effects (e.g., invasives, human-caused fires, energy extraction, and synanthropic predators; Leu et al. [2008]). We used the county-level map of "human values" or attitudes towards nature from Manfredo et al. (2021) as our primary direct indicator of human attitudes, generalized to a scale of 900-km^2 through use of moving window of corresponding size.

We used three different spatially comprehensive metrics derived from remotely sensed imagery for assessing intrinsic productivity of grizzly bear habitat. Our first method employed Wetness, Greenness, and Brightness indices derived from July 19–26, 2000, 8-day composite MODIS Level 3 images, averaged for each pixel on the basis of a 30-km^2 moving window, subsequently transformed into an estimate of grizzly bear density using models developed by Mattson & Merrill (2021; see Section 3.3). Our third metric was the Normalized Difference Vegetation Index (NDVI) derived from near-infrared and red channels on Landsat-mounted AVHRR sensors. We generalized the 1-km^2 resolution of this imagery to 30-km^2 through use of a moving window.

We based maps of ownership on several different sources. We obtained delineations of protected areas, private lands, and the Turner Ranches from the Protected Areas Database of the US (PAD-US 2.1; https://maps.usgs.gov/padus/). We obtained spatial information on private lands conservation easements from the National Conservation Easement Database (https://www.conservationeasement.us/interactivemap/). Finally, we obtained spatial delineations of sheep grazing allotments on US Forest Service lands from: https://catalog.data.gov/dataset/range-allotment-feature-layer, and for Bureau of Land Management lands from: https://gis.blm.gov/EGISDownload/LayerPackages_/BLM_National_Grazing_Allotments.zip.

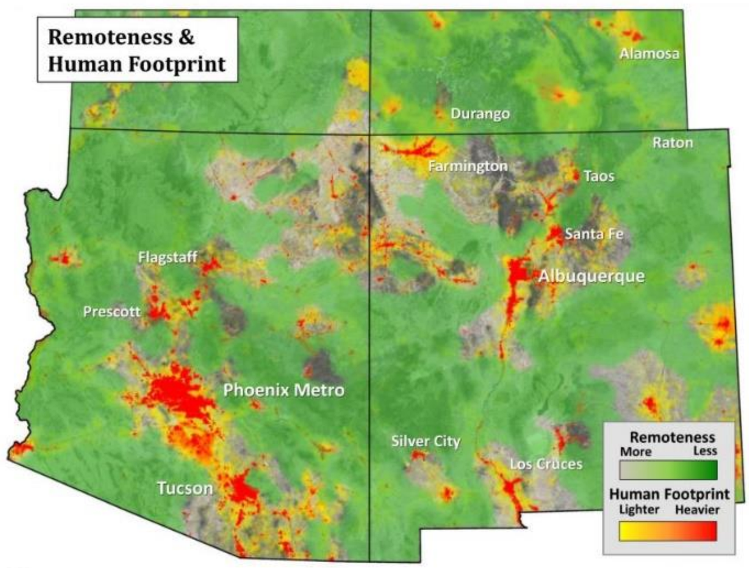

Figure 2. This map combines two different representations of human impacts in the Southwest study area. The "human footprint" is shown in shades of red to yellow, representing all physical impacts attributable to human infrastructure, including croplands, residences, and highways. "Remoteness" (i.e., remoteness from humans) is shown in shades of green, integrating regional population sizes, local road densities, and likely levels of local human activity as a function of these two metrics.

3.2. Modeling remoteness from humans

We used methods described in more detail by Merrill et al. (1999) to model the remoteness of a given map pixel from human activity (Figure 2). The metric that we term "remoteness" here was termed "habitat effectiveness" (HE) by Merrill et al. (1999). Remoteness is a function of road density (ACCESS) within a 2.8-km radius and the potential amount of human activity on these roads (H'). Potential human activity is a function of regional (i.e., 80 km-radius) human population size, the presence (or absence) of a National Park, and distances to and population sizes of all surrounding censused units (e.g., census blocks or town sites). The effects of regional population size and nearness of a National Park on levels of backcountry activity were estimated empirically by Merrill et al. (1999) from records of activity in US National Forests. The effects of site-specific populations and distances from them were modeled by inverse distance weighting interpolation, with the scaling (i.e., power) parameter derived from observed frequency distributions of trip distances by recreationists in the western US.

3.3. Modeling biophysical habitat capability

We modeled the intrinsic biophysical capability of map pixels to support grizzly bears in two different ways. Our first method employed a model developed by Mattson and Merrill (2021) based on Wetness and Greenness indices derived from Landsat MODIS imagery (Figure 3b). This well-conditioned model (F = 14.7, P < 0.0001, R^2 = 0.90) related coarse-grained estimates of grizzly bear density (Density) to Wetness and Greenness:

$$\text{Density}^2 = 7.42 + 2.82\ \ln(\text{Wetness}) + 0.014\text{Greenness}^2 \quad (1)$$

Our other method used untransformed smoothed values of NDVI, as described in Section 3.1, but constrained to exclude all areas with NDVI values <0 (Figure 3a).

3.4. Scaling modeling results

Representations of habitat capability or suitability should match the spatial scale at which focal animals move, live, and die, as well as the scale appropriate to management time frames (Schonewald-Cox et al., 1991; Ruggerio et al., 1994). In this analysis we addressed outcomes relevant to populations spanning the lifetimes of many animals (i.e., population viability or robustness). The appropriate proximal scale for generalizing map information was thus the life-range, and given the demographic importance of females, the life-range of a female bear (Merrill et al., 1999). This parameter is known for grizzly bears in the Yellowstone region of Wyoming, Montana, and Idaho (Blanchard and Knight, 1991), where females, on average, use about 900 km^2 during a lifetime. We adopted this value for our analysis in the southwestern US because we judged conditions here to be similar to those in the Yellowstone region; i.e., both areas are mountainous, relatively arid, and produce few fleshy fruits (Mattson and Merrill, 2002).

We rescaled our results by recalculating the modeled values of remoteness and biophysical habitat capability for each map pixel as the average of values within a surrounding 300-km^2 area. The resulting surface of values was smoothed in comparison to values calculated at the resolution of our digital data (i.e., the grain of the results was considerably increased), resulting in the spatial aggregation of areas with high or low average values.

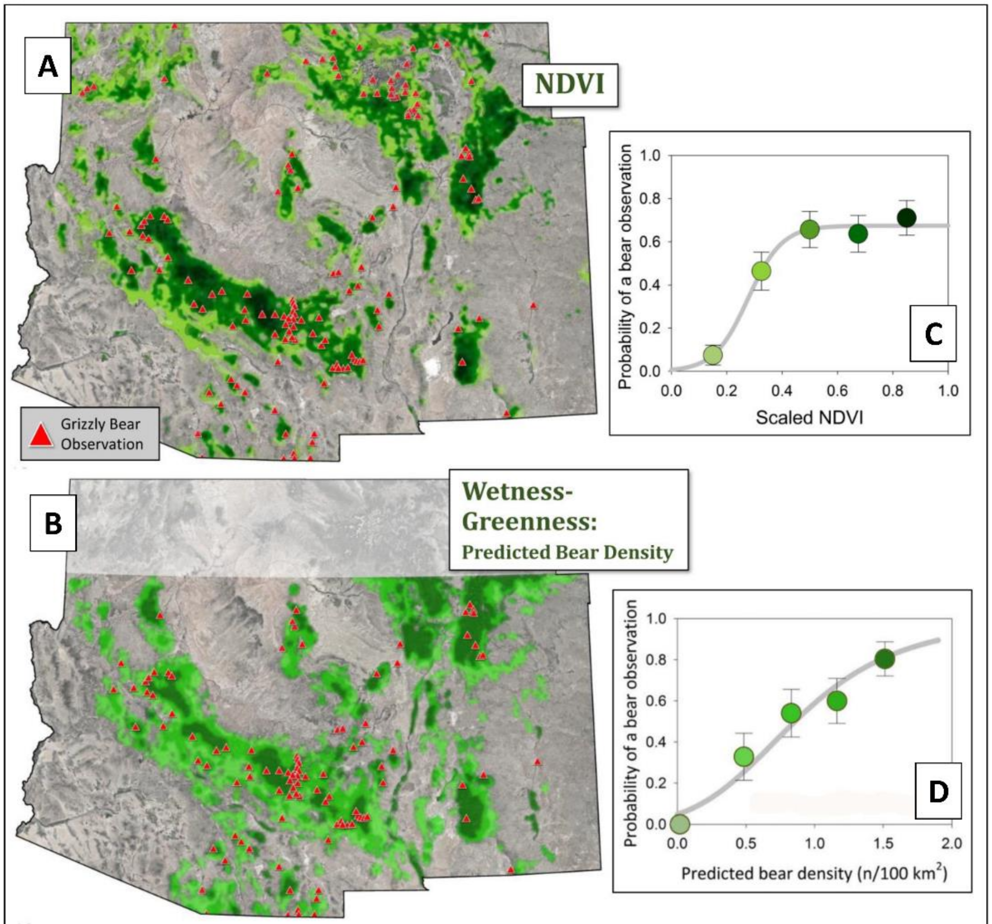

Figure 3. The maps in (A) and (B) show two different representations of intrinsic habitat productivity, in (A) based on imagery-derived NDVI (Normalized Difference Vegetation Index) for the entire study area and in (B) as predicted grizzly bear densities based on imagery-derived Wetness and Greenness, but only for Arizona and New Mexico (Mattson & Merrill 2021). The graphs in (C) and (D) show logistic relations between the probability that a given 180-km^2 grid cell contained an historical grizzly bear observation versus a random point—in (C) as a function of NDVI and in (D) as a function of predicted grizzly bear density (Mattson & Merrill 2021). Historical grizzly bear observations are shown as red triangles.

3.5. Calibration and establishment of thresholds

We adopted a threshold previously used to identify suitable grizzly bear habitat in Idaho (Merrill et al., 1999) for application to our index of remoteness. This threshold was expressed in terms of a probability (p = 0.012), specifically the probability that a 1-km^2 grid cell in northern Idaho would contain a bear location (n = 124; see 3.1.) versus not as a function of habitat suitability. To apply this threshold to our index of remoteness, we calculated remoteness for 1-km^2 grid cells in northern Idaho, specified a relation between remoteness and the logit-transformed probability that a cell would or would not contain a bear location (by logistic regression; Hosmer and Lemeshow, 1989; Demaris, 1992), and then, based on this relation, identified the remoteness value corresponding to the threshold probability (Merrill et al., 1999). We thus deemed areas where remoteness was greater than this threshold to be sufficiently remote from humans to support grizzly bears. The extrapolation of this threshold from northern Idaho to the southwestern US was possible because the data sources and model used to calculate remoteness were identical for the two areas.

We developed a threshold for biophysical habitat capability that was specific to our southwestern US study area. This was necessary because of differences between intrinsic habitat conditions in the Southwest and in areas farther north still inhabited by grizzly bears. We adopted an a priori threshold of p = 0.5; that is, that a given 1-km^2 grid cell in the Southwest would be equally likely to contain a historical grizzly bear location (see 3.1.) versus a randomly located point. This was analogous in concept to a drug dose that is lethal 50% of administrations (Woodroffe and Ginsberg, 1998). The challenge was to develop a modeling approach that captured this concept.

We used weighted logistic regression (Hosmer and Lemeshow, 1989) and an arbitrarily large number of random points (1,315), each weighted (= 0.1027) so that the total frequency of random points used to specify the model equaled the total number of bear locations (n = 135) in effects on model specification. The resulting model allowed for direct translation of the p-value threshold to a corresponding habitat capability value. Thus, we deemed areas where habitat capability was greater than the threshold to be intrinsically capable of supporting grizzly bears, all human-related factors set equal.

We developed two different models, one with NDVI as the predictor variable and the other with the Mattson and Merrill (2021) model of grizzly bear density as the predictor variable (Figure 3c and 3d). As with remoteness, with used logistic regression to specify relations between our two predictor variables and the probability that the corresponding cell would contain an historical bear location versus a random point. We developed two different cut-points for each of our two different predictors because NDVI was comprehensive for our study area, whereas we had developed a grizzly bear density surface only for Arizona and New Mexico. Predicted grizzly bear density, as per Mattson and Merrill (2021), was highly correlated with NDVI (Moran's I = 0.92).

3.6. Identifying biophysically suitable habitat

We identified areas biophysically suitable for restoration of grizzly bears by applying remoteness and habitat capability thresholds refined by the application of broader-scale design criteria. In addition to productivity thresholds corresponding with the probability of grizzly bears being historically present in the Southwest or currently present in the northern Rockies, we also established cutpoints that were half-the value above and below the predictor thresholds themselves. This allowed us to identify areas that were highly productive at one extreme and areas merely exceeding the likely minimum productivity needed to sustain grizzlies at the other; as well as areas that were most remote from people at one extreme, and merely able to likely provide minimum security at the other. Permutating thresholds as well as cutpoints provided us with 9 different categories productivity and remoteness that we could use for identifying suitable habitat and designing recovery areas (see Section 3.7).

Our identification of suitable habitat involved two steps. We first delineated areas (i.e., patches) that exceeded both the remoteness and the habitat capability thresholds—that were above the calibrated mid-points of both intrinsically productive grizzly bear habitat and remoteness from humans. We considered these areas to be biophysically highly suited to supporting grizzly bears. We next delineated areas contiguous with highly suitable habitat that were either above both the minimum cutpoint for productivity and the high cutpoint for remoteness, or, conversely, above both the minimum cutpoint for remoteness and the high cutpoint for productivity. We considered these areas to be of intermediate suitability.

Our next step involved excluding all patches that were less than the approximate size of an adult female grizzly bear's annual range (300 km^2; Blanchard and Knight, 1991). We assumed that bears ending up in these patches would have low odds of surviving a single year. We then identified patches that were larger than a female life range (900 km^2). We considered these areas to be potential demographic sources of dispersing animals; that is, "source" patches (Merrill et al., 1999). We then identified groups of patches all >300 km^2 in size that, if >900 km^2 in size, potentially functioned as a complex by virtue of being within reciprocal dispersal distances of each other or, if all but one were ≤900 km^2, functioned as a complex by virtue of being within potential dispersal distance of the common source patch. We adopted 20 km as our threshold for potential dispersal, which is well within the range observed for young males, but at the upper limits observed for young females (Blanchard and Knight, 1991; McLellan and Hovey, 2001).

3.7. Designing Candidate Recovery Areas

We defined candidate grizzly bear recovery areas and zones by adapting concepts formalized in the Interagency Grizzly Bear Management Guidelines (US Forest Service, 1986), the Grizzly Bear Recovery Plan (US Fish and Wildlife Service, 1993), and the Conservation Strategy for the Grizzly Bear in the Greater Yellowstone Area (Interagency Conservation Strategy Team, 2007). The frameworks defined in these various documents evolved over time, using somewhat different terminology, but all built on four basic considerations or management directions. The first is whether a locally robust population of grizzly bears is present with the potential of serving as a demographic source area; the second is the extent to which habitat maintenance and improvement is prioritized; the third is the extent to which prevention of human-grizzly bear conflicts is prioritized; and the fourth is how and whether emerging conflicts are resolved.

Although perhaps suited to on-the-ground conditions for extant grizzly bear populations, previously-defined frameworks based on the notions of "Management Situation" and "Primary Conservation Area" are not well suited to the restoration of an extirpated grizzly bear population if for no other reason than the obvious fact that reproducing grizzly bears are not present. For this reason, we tailored a framework that was functionally and semantically appropriate to the task of not only restoring grizzly bears, but also anticipating management situations that might arise during the process of species recovery. Even so, we built our framework around shared considerations regarding the extent to which habitat maintenance and improvement, conflict minimization, and conflict resolution were prioritized.

We defined three different zones for stratifying *Recovery Areas*. *Restoration Areas* encompass highly suitable habitat, modified by delineations that encompassed pronounced linear intrusions of less suitable habitat that did not comport with likely annual movements of newly reintroduced grizzly bears. Restoration Areas constitute primary reintroduction areas, where reintroduced bears would have the opportunity to establish ranges in the most secure and productive habitats. Habitat protection as well as conflict minimization would prospectively be top management priorities.

Conservation Areas are contiguous to or nearby Restoration Areas, and comprise comparatively secure and productive habitats which bears dispersing from Restoration Areas would likely colonize in the foreseeable future. Habitat protection and conflict minimization would likewise prospectively be prioritized in these areas.

Finally, *Protection Areas* have either, but not both, relatively unsecure or unproductive habitat adjacent to Conservation Areas and Restoration Areas into which grizzly bears will likely disperse either because they are attracted by productive habitats or because security is sufficient for occupancy despite low intrinsic productivity. Habitat protection would prospectively be given a low priority, although protection of individual grizzly bears would be an important management consideration, especially in response to emerging conflicts with humans.

We prioritized the inclusion of contiguous Restoration, Conservation, and Protection Areas in our delineation of candidate Recovery Areas, which were further modified to minimize overlap with large blocks of private property not managed for conservation purposes. We also excluded habitat blocks of high and intermediate suitability that were *prima facie* too small to support a robust population of grizzly bears and isolated from primary Recovery Areas (i.e., with the potential of supporting >200 bears; see Section 3.8) either by distance or by highways with high volumes of traffic (e.g., Interstate Highways 17, 25, and 40; see Figure 1a).

3.8 Estimating Potential Carrying Capacity

Producing a useful estimate of potential carrying capacity is one of the more challenging tasks entailed by designing potential recovery areas for an extirpated species. Nonetheless, these sorts of estimates are crucial to judging whether recovery of a robust population is or is not feasible. Failure to undertake this task is, in fact, one of the more serious short-comings of the US Fish and Wildlife Service's assessment of prospects for recovering grizzly bears in the San Juan Mountains (US Fish and Wildlife Service [2021]; see Section 1.1).

We drew on the compilation of density estimates for grizzly bear populations in North America provided by Mattson (2021a) to estimate potential carrying capacity of suitable habitat and Recovery Areas. This compilation is stratified by broad-scale ecological and management conditions, with summary statistics provided for each stratum. For example, averages and standard errors are presented for Low Density Dry Interior, High Density Dry Interior, and Low Density Wet Interior ecosystems, each of which reflects different management regimes as well as intrinsic ecological productivity.

We employed summary statistics from ecological and management strata in Mattson (2021a) that most closely matched on-the-ground conditions in the Southwest to estimate potential carrying. We limited our estimates to blocks of suitable habitat that were of a size plausibly large enough to support more than a trivial number of bears. We applied estimates for High Density Dry Interior populations ($\bar{x}$ = 15.1 bears/1000 km^2 [Lower 95% Confidence Limit = 10.1; Upper 95% Confidence Limit = 20.2]) to Highly Suitable habitat and Restoration Areas; estimates for Low Density Dry Interior populations ($\bar{x}$ = 5.3 bears/1000 km^2 [Lower 95% Confidence Limit = 3.9; Upper 95% Confidence Limit = 6.7]) to Protection Areas; and estimates for Low Density Wet Interior populations ($\bar{x}$ = 11.4 bears/1000 km^2 [Lower 95% Confidence Limit = 6.4; Upper 95% Confidence Limit = 16.3]) to areas that were of Intermediate Suitability to Conservation Areas.

4. Results

4.1. Remoteness and habitat productivity thresholds

The index of remoteness (Remote) was strongly related to logit-transformed probabilities that a given 1-km^2 cell contained a grizzly bear location, versus not, in northern Idaho (Logit[p]NI). The best fit was obtained with a polynomial because incidental sightings of bears by humans declined in the most remote areas (Merrill et al., 1999). The relation most useful for our purposes was described by a single-term model that was nearly as informative as the polynomial (sample-size-corrected Akaike Information Criterion [AIC$_c$] = 1194 and 1188, respectively):

$$\text{Logit(p)NI} = -5.71 + 3.57\text{Remote} \qquad (3)$$

Somer's D = 0.37, R^2_L = 0.87, and G^2 = 399 (P = 1.00) for the model. The test statistics are for goodness-of-fit. Based on this relation, p = 0.012 (our a priori threshold probability; Merrill et al., 1999) corresponded to Remote = 0.35 with upper and lower cutpoints of 0.18 and 0.52.

NDVI and predicted grizzly bear density (Density)

Table 1. This table provides, at top, statistics for the aerial extent and potential carrying capacity of habitat suitable for grizzly bears in various complexes and discrete patches in the Southwest, differentiating highly suitable areas from areas of intermediate suitability. The bottom portion of this table provides the same summary statistics for Recovery Areas inclusive of the largest complexes of suitable habitat as well as adjacent protected areas and intrinsically productive habitat. Recovery Areas are stratified by Restoration, Conservation, and Protection Areas (see the main text of definitions of each). LCL stands for lower bound and UCL for upper bound of 95% confidence intervals.

				Habitat Complex						
Parameter	Units	Stratum	Bound	Mogollon Complex	San Juan Complex	Sangre de Cristo Complex	Southern Utah Complex	Sacremento	North Kaibab	Abajo
Suitable Habitat Area	km^2	Core		5,763	6,536	4,410	2,598	0	596	236
		Periphery		9,339	6,063	3,622	2,284	3,278	596	315
		Total		**15,102**	**12,599**	**8,032**	**4,882**	**3,278**	**1,192**	**551**
Suitable Habitat Population Potential	*N*	Core	LCL	151	171	115	68	0	16	6
			UCL	302	342	231	136	0	31	12
			Mean	225	256	172	102	0	23	9
		Periphery	LCL	155	108	60	43	54	10	5
			UCL	394	276	153	110	138	25	13
			Mean	276	193	107	77	97	18	9
		Total	LCL	306	279	175	111	54	26	11
			UCL	696	618	384	246	138	56	26
			Mean	**501**	**449**	**279**	**178**	**97**	**41**	**18**
Recovery Area	km^2	Restoration Area		7,849	6,221	4,567				
		Conservation Area		5,166	3,622	1,732				
		Protection Area		11,724	5,433	3,701				
		Total		**24,740**	**15,276**	**10,000**				
Recovery Area Population Potential	*N*	Restoratiion Area	LCL	205	163	120				
			UCL	411	326	239				
			Mean	307	243	179				
		Conservation Area	LCL	86	60	29				
			UCL	218	153	73				
			Mean	152	107	51				
		Protection Area	LCL	118	55	37				
			UCL	203	94	64				
			Mean	161	75	51				
		Total	LCL	409	278	186				
			UCL	832	573	376				
			Mean	**620**	**425**	**281**				

were both strongly positively related to logit-transformed probabilities that a location was that of an historical grizzly bear sighting versus a random point in our southwestern study area. The model describing the relation to Density in Arizona and New Mexico (AZ/NM) was (Figure 3d):

$$\text{Logit}(p)\text{AZ/NM} = -2.97 + 4.80\ln(\text{Density} + 1) \qquad (4)$$

where n = 92, Score statistic = 26.2 (P < 0.0001), area under the ROC curve = 0.80, and R_L^2 = 0.24. The model describing the relation to NDVI for our entire Southwest study area (SW) was (Figure 3c):

$$\text{Logit}(p)\text{SW} = -2.10 + 2.23\ln(\text{NDVI}) \qquad (5)$$

where n = 135, Somer's D = 0.46, Score statistic = 58.5 (P < 0.0001), G^2 = 5.0 (P = 0.173), and area under the ROC curve = 0.73 for this model. Based on these modeled relations and our *a priori* benchmark of p = 0.5 for likelihood of an historical grizzly bear location, the thresholds for NDVI and Density were 0.37 and 8.5 bears/1000 km^2, respectively. The corresponding upper and lower cut-points for each were 0.18 and 0.74 and 4.2 and 12.8 respectively.

4.2. Suitable habitat

We estimated that there was >45,000 km2 of habitat suitable for grizzly bears in our Southwest study area, capable of supporting a minimum of 960 bears, but more likely >1,500 (Table 1). Within this larger area of suitable habitat we identified four larger complexes and five smaller more isolated blocks of habitat suitable for grizzly bears (Figure 4a): the San Juan, Sangre de Cristo, Southwest Utah, and Mogollon complexes; and the Abajo, North Kaibab, and Sacramento blocks. The Mogollon complex was largest, at 15,102 km^2, followed by the San Juan and Sangre de Cristo complexes at 12,599 km^2 and 8,032 km^2, respectively (Table 1). Estimated carrying capacity for these habitat complexes was 501 (95% Confidence Limits = 306-696), 449 (279-618), and 279 (175-384), respectively (Table 1). We estimated that none of the other blocks or complexes could support roughly 200 bears (Table 1), and were eliminated from further consideration.

The San Juan and Sangre de Cristo complexes are connected to the north and south by narrow corridors of suitable habitat (Figure 4a), which allows for a potential total carrying capacity of 728 (454-1,002) if these two complexes were to be combined. We included the La Sal block with San Juan complex for design of a recovery area because this somewhat isolated block was within potential dispersal distance of the San Juan complex, especially if dispersing bears were included in a Protection Area.

4.3. Recovery Areas

After eliminating smaller blocks of suitable habitat isolated either by distance or by heavily-trafficked transportation corridors, we ended up with two to three large complexes that were the centerpieces of three Recovery Areas: the Mogollon, San Juan, and Sangre de Cristo Complexes (Table 4b). These Recovery Areas were 24,740 km^2, 15,276 km^2, and 10,000 km^2 in size, respectively, of which 7,849 km^2, 6,221 km^2, and 4,567 km^2 consisted of Restoration Areas (Table 1). If the San Juan and Sangre de Cristo Complexes were combined, the total encompassed area would be 25,276 km^2.

Including Protection Areas, we estimated carrying capacity of the Mogollon, San Juan, and Sangre de Cristo Complexes to be 620 (409-832), 435 (278-573), and 281 (186-376) bears, respectively. The latter two combined could correspondingly support 716 (464-949) bears (Table 1).

We estimated that Restoration Areas in each of the three Recovery Areas (Mogollon, San Juan, and Sangre de Cristo) could support an average of 307, 243, and 179 grizzly bears. For ease of reference, we identified the largest Restoration Areas in each Recovery Area: the Gila and Mazatzal in the Mogollon Complex; the Delores-San Juan in the San Juan Complex; and the Pecos-Vermejo in the Sangre de Cristo Complex (Figure 4b).

4.4. Variation in probable human lethality

Figure 5 shows the overlap of candidate grizzly bear Recovery Areas with officially-designated public land conservation and protected areas. There is substantial overlap with Wilderness Areas, notably the Gila, Aldo Leopold, and Mazatzal Wilderness Areas with the Mogollon Complex; the La Garita and Wenimuche Wilderness Areas with the San Jaun Complex; and the Sangre de Cristo and Pecos Wilderness Areas with the Sangre de Cristo Complex. Proportionately greatest overlap with Wilderness Areas occurs in New Mexico portions of the Mogollon Complex. The Rio Grande del Norte National Monument provides a notable bridge of protected habitat between the San Juan and Sangre de Cristo Complexes to the south.

Overall, there is minimal overlap of candidate Recovery Areas with private property, with the notable exception of especially central portions of the Sangre de Cristo Complex (Figure 6a). However, this substantial overlap is offset to some extent by a remarkably large block of contiguous properties managed for conservation purposes; from north to south, the Blanca, Trinchera, Cielo Vista, Vermejo, and Philmont Scout Ranches. Any realistic prospects for restoring grizzly bears to this Recovery Area would thus require considerable

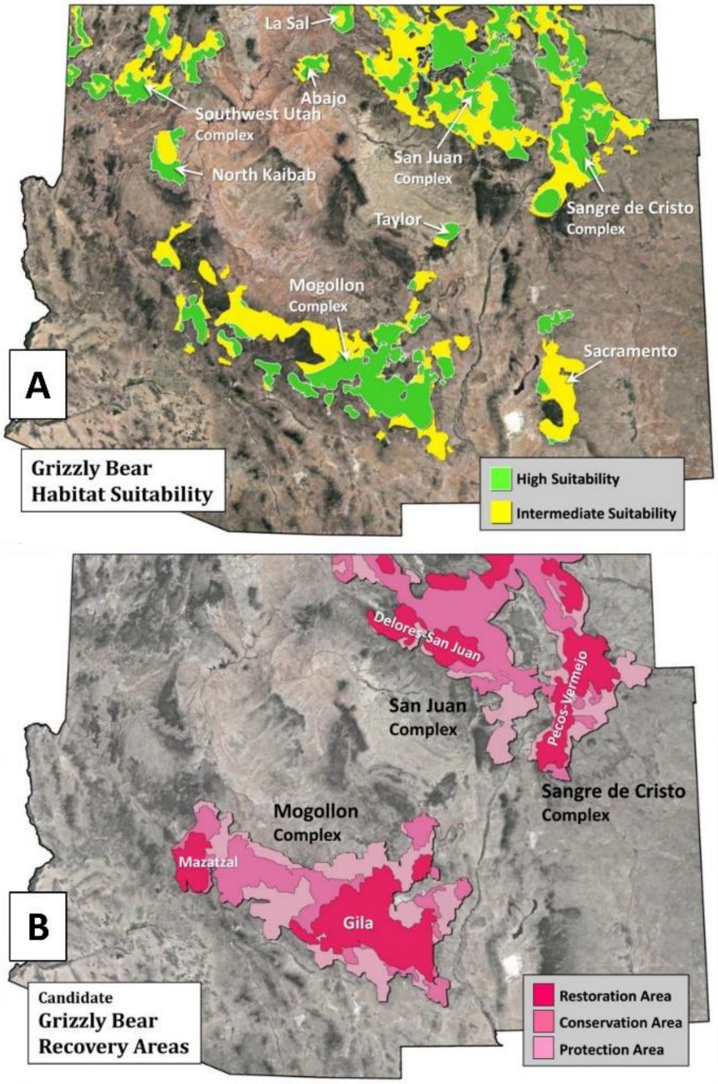

Figure 4. The map in (A) shows the extent of areas deemed suitable for occupancy by grizzly bears based on intrinsic habitat productivity and remoteness from humans and human infrastructure. Highly suitable areas are shown in green; areas of intermediate suitability in yellow. Larger areas or complexes of suitable habitat are labeled. The map in (B) shows candidate grizzly bear recovery areas in shades of magenta, differentiating restoration, conservation, and protection areas (see the main text for definitions of each). Each recovery area is labeled in black; primary restoration areas within each are labeled in white.

coordination with and buy-in from the owners of these properties. Insofar as federally-administered sheep and goat grazing allotments are concerned, again, there is minimal spatial overlap (Figure 6b). Most overlap occurs in northern portions of the San Juan Complex, adjacent to the La Garita and Wenimuche Wilderness Areas. Prospects for restoration of grizzly bears in these environs would plausibly require mitigating the potentially lethal effects of grazing-allotment permittees.

There is considerable variation in human attitudes towards wildlife and nature within areas encompassed by candidate Recovery Areas (Figure 7). Not surprisingly, the potentially most lethal and unaccepting human environs are centered on Catron County in New Mexico, whereas the potentially most benevolent human environs occur in southern portions of the San Juan and Sangre de Cristo Complexes, augmented by an arc of favorable attitudes encompassing the western and southern portions of the former. The potential hostility of people localized in Catron County is potentially offset by overlap with extensive Wilderness Areas and by a predominance of more accepting attitudes in far western and far southeastern portions of the Mogollon Complex. Regardless of this offset, prospects for restoration of grizzly bear could be considerably compromised by lack of investment in law enforcement and recruitment of support focused on Catron County's small and slowly declining population (roughly 3,600 as of 2020, down from roughly 3,700 in 2010; US Census Bureau QuickFacts: https://www.census.gov/quickfacts/fact/table/catroncountynewmexico/PST045219).

5. Discussion

5.1 Design Criteria Met

Restoration of extirpated species has been most successful where undertaken in areas large enough to sustain large populations—where causes of historic extirpations were rectified and habitat was highly productive (Smith and Clark, 1996; Wolf et al., 1998; Miller et al., 1999; Breitenmoser et al., 2001). There is also evidence that success rates have been higher with omnivores and when undertaken in the core of historic range (Wolf et al., 1998). Grizzly bears are omnivores and thus benefit from dietary flexibility that, in theory, buffers them from environmental vicissitudes of potential restoration sites. On the other hand, our study area is not near the core of historic North American grizzly bear range, although it is not clear what being "near the core" means functionally (Lomolino and Channell, 1998). Grizzly bears were extirpated deterministically at scales considerably finer than the scale of their North American range (Mattson and Merrill, 2002). Consistent with Lomolino and Channell (1995), such a pattern tends to discount the importance of being near the core of historic range rather than elsewhere. Regardless, the most robust features of past successes pertained to the extent, productivity, and current hostility of restoration areas. Our challenge was to bridge from these generalities to a meaningful site-specific assessment.

Our standards and model metrics explicitly addressed productivity, security, and extent of prospective restoration areas in the Southwest. Given that humans

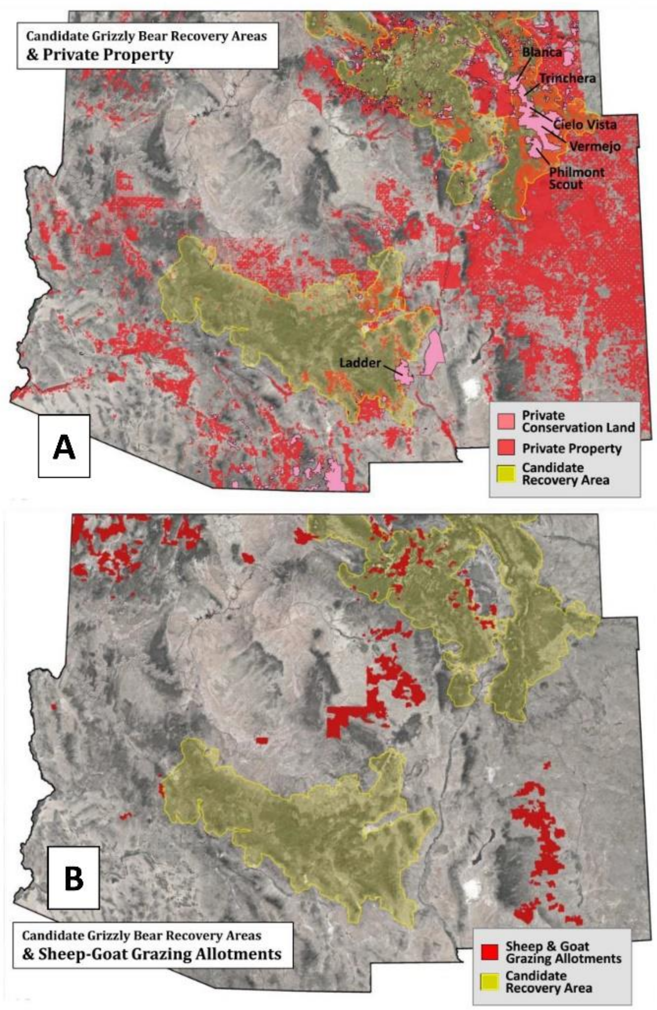

Figure 6. The map in (A) shows the overlap of deeded private lands and candidate grizzly bear Recovery Areas, with private lands managed as conservation properties shown in pink. This latter category includes lands in conservation easements as well as Turner Ranches. Noteworthy private conservation lands are labeled in black. The map in (B) shows federal public lands allotted to sheep and goat grazing in red. Data are incomplete for US Forest Service lands in Arizona and New Mexico.

are the primary cause of historical extirpations and the current cause of almost all grizzly bear deaths (Mattson et al. 1996a; McLellan et al., 1999; Mattson and Merrill, 2002), we addressed security by site-specific remoteness from humans (i.e., potential frequency of contact) and potential for conflict (i.e., human lethality). Habitat productivity addressed the intrinsic ability of a site to support bears. Standards for size and shape addressed the broader-scale sufficiency of potential restoration areas. Thus, in concept, we addressed three key dimensions of potential restoration areas. However, the dimensionless indices that were model outputs needed to be translated into some meaningful measure of potential grizzly bear presence and persistence.

We calibrated our landscape metrics to the historical presence of grizzly bears in our study area or, where calibration was to the presence of grizzly bears elsewhere, we used metrics with consistent meaning across regions (i.e., remoteness). Partly we took this approach because we had no resident animals from which to estimate *in situ* vital rates. However, we had other compelling reasons. Vital rates are normally calculated on an annual basis for specific animals and thereby vary in time and space as a function of annual variation in environmental conditions at the scale of annual ranges. This makes extrapolation of vital rates from other times and places particularly uncertain and risky, and ostensibly necessitates landscape metrics for calibration that have a temporal resolution of years and a spatial resolution of annual ranges, if not finer. Vital rates also need to be translated by demographic models into probabilistic estimates of long-term population growth. Such an exercise requires, at a minimum, that environmental variation and density dependence be specified either on the basis of empirical estimates or assumptions about population processes (Boyce et al., 2001). We know little about such phenomena among bears, but enough to know that they have potentially major effects on the performance of demographic models and related uncertainties of population projections (Mills et al., 1996; Boyce et al., 2001). Thus, vital rates estimated elsewhere combined with demographic models that contain momentous assumptions create large uncertainties (Boyce et al., 2001; Breitenmoser et al., 2001).

The approach we took to calibration and setting standards was, by comparison, more likely to be robust. By generalizing and calibrating our landscape metrics to and at the scale of decades and life-ranges, we subsumed irrelevant details of finer-scale variation. Moreover, we calibrated to the presence of grizzly bears documented at comparably broad temporal and spatial scales as well as during times of duress. The scale of model and data matched and the resulting calibration and thresholds reflected broad-scale long-term persistence of grizzly bears under onerous conditions – during times when human persecution was often intense. Thus, our appraisal is relevant to long time frames and more likely to be conservative rather than liberal with respect to the risk of over-estimating suitability of biophysical conditions for grizzly bears in the southwestern US.

5.2. Adequate Recovery Areas identified

We identified and delineated three candidate grizzly bear Recovery Areas that are large in size and capable of supporting hundreds of bears: the Mogollon, San Juan, and Sangre de Cristo Complexes. Sizable blocks of suitable habitat in southwestern Utah, the Sacramento Mountains, and on the North Kaibab Plateau were debarred from consideration as candidate Recovery Areas by isolation and comparatively small size, and also, in the case of southwestern Utah, by a high edge to area ratio. Smaller blocks of suitable habitat centered on Mount Taylor and plateaus and canyons west of Flagstaff, although within theoretical dispersal distance of large complexes, were excluded from inclusion because of isolation by interstate highways with high volumes of traffic (I-40 and I-17, respectively).

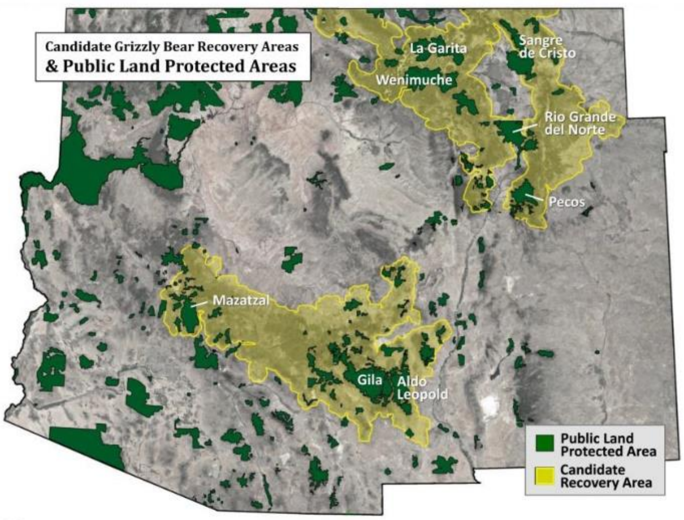

Figure 5. This map shows overlap of candidate grizzly bear Recovery Areas with legislatively protected areas on public lands, including Wilderness Areas, Wilderness Study Areas, National Parks, National Monuments, National Conservation Areas, Wildlife Refuges, and State Parks. The names of noteworthy protected area are shown in white.

The question remains, though, whether the three candidate Recovery Areas that we identified are large enough and productive enough to surpass biologically meaningful or normative thresholds for recovering grizzly bear populations. The US Fish and Wildlife Service invoked Miller and Waits (2003) as a basis for using 400 bears as a standard of sufficiency, reckoned as "short-term fitness" (US Fish & Wildlife Service, 2021). The US Fish and Wildlife Service has also delineated officially-designated Recovery Areas which it deems sufficient for achieving recovery goals in six different ecosystems (US Fish & Wildlife Service, 2021). As a corollary, the Service has established explicit or tacit population standards for each, either minimum population size (500 for the Yellowstone Ecosystem), sanctioned minimum population management target (800 for the Northern Continental Divide Ecosystem), or tacitly sanctioned potential carrying capacity (ranging from around 100 to 380 for the Cabinet-Yaak, Selkirk, and Bitterroot Ecosystems).

Figure 8 shows sizes and estimated carrying capacities of candidate Grizzly Bear Recovery Areas in the Southwest (as dots) relative to sizes and population standards of existing Recovery Areas in the northern Rockies (summarized as box plots). Relative to the 400-bear standard, two of the candidate Recovery Areas identified for the Southwest (the Mogollon and San Juan Complexes) clearly meet this criterion. If the San Juan and Sangre de Cristo Complexes are managed as a merged Recovery Area, then this mega-complex far exceeds the 400-bear standard. Relative to standards for recovery adopted *de facto* for northern Rockies Recovery Areas, estimated carrying capacity of the Mogollon Complex well-exceeds standards for four existing Recovery Areas, whereas as that of the San Juan Complex is comparable to or exceeds three. Again, combining the San Juan and Sangre de Cristo Complexes yields a potential comparable to the high standard applied to the Northern Continental Divide Ecosystem.

A comparison of Recovery Area sizes reveals much the same pattern (Figure 8). The two largest candidate Southwest Recovery Areas are comparable in size to the four largest northern Rockies Recovery Areas, and if the San Juan and Sangre de Cristo Complexes are combined, this mega-complex is larger, at 25,276 km^2, than the largest Recovery Area in the northern Rockies—the Greater Yellowstone at 23,853 km^2.

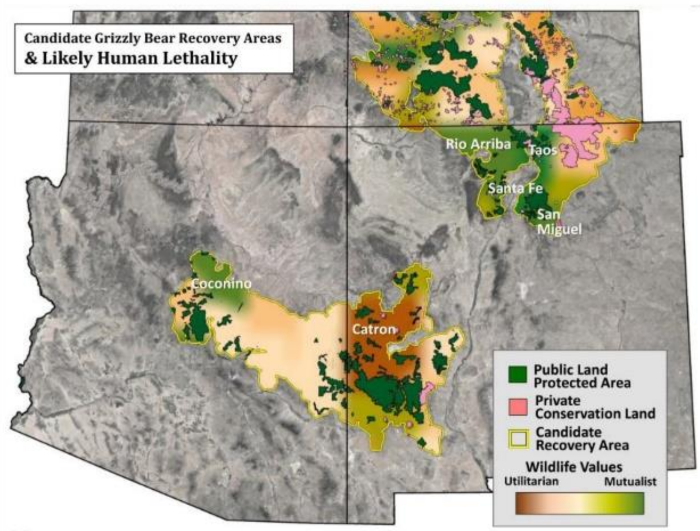

Figure 7. This map depicts the predominance of Utilitarian versus Mutualist wildlife values (Manfredo et al., 2021) in counties encompassed by candidate grizzly bear Recovery Areas, together with private conservation properties and public protected areas that mitigate against the potential lethality of predominantly Utilitarian Values. Counties with either pronounced Utilitarian or Mutualist Values are labeled in white.

Returning to the question of whether candidate Recovery Areas in the Southwest would be sufficient to support recovered grizzly bear populations, the answer is unequivocally "yes" for the Mogollon and San Juan Complexes, and very likely "yes" for the Sangre de Cristo Complex, but with the proviso that the latter two Complexes combined would almost certainly be sufficient. This unequivocal affirmative is clearly at odds with conclusions reached by the US Fish and Wildlife Service (2021) for its San Juan Mountains study area (as per

Figure 1), explicably because of deficiencies in the Service's analysis (described in Section 1.2.), as well as an argumentative tone that the Service adopted in service of what seemed to be a preconceived outcome.

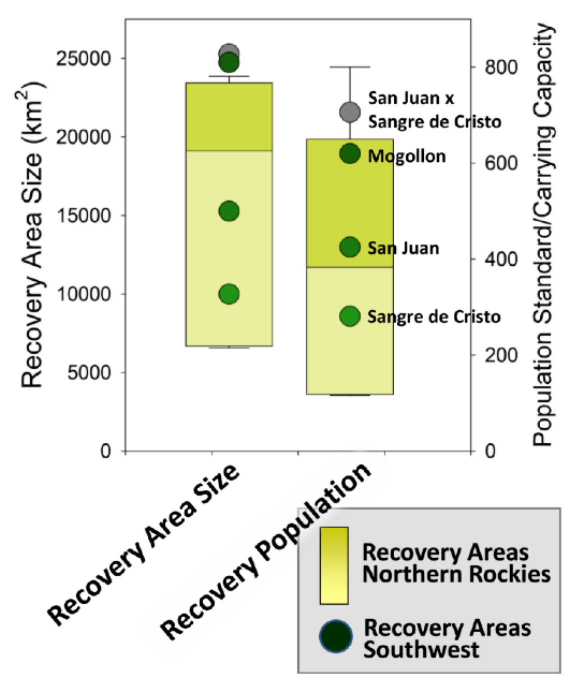

Figure 8. This figure compares sizes of designated Recovery Areas in the northern Rockies, together with associated population recovery standards, estimated carrying capacities, or minimum desired population sizes with sizes and estimates of carrying capacities of candidate Recovery Areas identified in the Southwest. Recovery parameters in the northern Rockies are summarized by box plots. Parameters for candidate Recovery Areas in the Southwest are shown as dots.

5.3. Contingencies of human lethality

The effects of human lethality have very real effects on persistence of grizzly bear populations. In the absence of protections and with the prevalence of cultural norms that encourage eradication of carnivores such as grizzly bears, history has shown that relatively few people can eliminate thousands of bears in a remarkably short period of time (Brown, 1996; Mattson and Merrill, 2002). Regardless of how remote or productive an area might be, highly-motivated bear killers can have devastating effects. Yet this all-important lethality factor is hard to objectively measure. As a consequence, rather than ignore this factor, we resorted to various evidence-based proxies such as human attitudes towards wildlife and levels of protection associated with different land uses and management jurisdictions.

Demarcations of jurisdiction, land use, and ownership are geospatial shorthand for different policies, practices, and tacit norms that influence whether people are readily armed or not (National Parks versus the rest), have comparatively unrestrained prerogative to act as they wish (private versus public property), or are subject to constraints designed to preserve wildlife and wildlands (e.g., Wilderness Areas and Wildlife Refuges). But an overarching framework of Endangered Species Act (ESA) protections is perhaps most important of all (Mattson and Merrill, 2002). Given, the premise of meaningful ESA protections, grizzly bears would be most likely to survive in National Parks and Wilderness Areas, and least likely to survive on private property and on public lands grazing allotments, with the effects of private ownership mitigated by the attitudes of property owners (e.g., conservation easements and The Turner Ranches).

Different configurations of concerns related to human lethality typify each candidate Recovery Area in the Southwest. The Mogollon Complex has the largest absolute overlap with Wilderness Areas, and the least proportional overlap with private property, yet Catron County, New Mexico, stands out as a potentially lethal environment for bears because of the prevalence of utilitarian values—and despite having relatively few residents. The San Juan Complex has considerably overlap with Wilderness Areas, and benefits from a prevalence among nearby residents of "Mutualist" values (Manfredo [2021]; i.e., values aligned with tolerance of wildlife)—but is challenged by comparatively extensive sheep grazing allotments. Large portions of the Sangre de Cristo Complex are either remote or highly productive, but, overall, this Complex is compromised by extensive overlap with private property.

The 2021 US Fish and Wildlife Service analysis of the San Juan Mountains did not expressly address factors related to human lethality, other than as certain landscape features that tacitly expressed policies, practices, and norms—specifically the presence of sheep grazing allotments and private property. The Service's analysis treated both as essentially fixed and unmitigable constraints on opportunities to recover grizzly bears despite the fact that potentially lethal human attitudes or practices embedded in both sheep allotments and private property have elsewhere been demonstrably addressed in areas occupied by grizzly bears.

Conflicts arising from the presence of sheep on grazing allotments have been addressed in several ways. Perhaps the most efficacious has been through retirement of allotments used for sheep grazing or conversion to use by cattle. Although beset by legal and institutional barriers (Leonard and Regan, 2019), this strategy has been used to good effect in the Greater Yellowstone Recovery Area where roughly 20 sheep allotments amounting to >3,440 km^2 have been closed after permits were voluntarily sold to non-governmental conservation buyers (National Wildlife Federation, 2016). There have been no subsequent sheep-related conflicts with grizzly bears in these areas (Wells, 2017). Perhaps less ambitiously, there are several husbandry practices such as strategic deployment of electric fencing, use of specialized breeds of guard dogs, and close attendance by herders that have been shown to be effective at deterring grizzly bears (Linnell et al., 2012; Kinka and Young, 2019). Although these practices are labor-intensive, experiences elsewhere have shown that this logistical and financial obstacle is not insurmountable with outside financial support and willing allotment permittees.

Owners of private property are also obviously not homogeneous in their attitudes towards wildlife such as grizzly bears. Numerous owners of large properties have chosen to manage for conservation purposes (National Conservation Easement Database (https://www.conservationeasement.us/interactivemap/), most prominently, The Turner Ranches. The efficacy of positively managing for human-grizzly bear coexistence on large contiguous blocks of private land has been amply demonstrated by the Blackfoot Challenge (Wilson et al., 2014), Tom Miner Basin Association (http://tomminerbasinassociation.org/what-we-do), and High Divide Collaborative (Sage, 2019), among others. These efforts have also highlighted the importance of collaboration among landowners and wildlife managers to the prevention of grizzly bear-human conflicts on landscapes with multiple ownership, as typifies middle portions of the Sangre de Cristo Complex. These collaborations of the willing potentially serve as models for constituting similar efforts in the Southwest designed to promote coexistence between people and grizzly bears in otherwise problematic landscapes.

However, the problem of acculturated and community-sustained intolerance of large carnivores is probably the most difficult of all to address. Animals such as grizzly bears readily become symbols upon which resentments are projected by residents caught up in culture wars involving what they perceive to be an increasingly hostile and alien world (e.g.; Gangass et al., 2013; Kaltenborn Brainerd, 2016; Højberg et al., 2017). This dynamic is perhaps nowhere better illustrated than with Mexican gray wolves (*Canis lupus baileyi*) (e.g.; Vynne, 2008; Marchand 2013; Bickel et al., 2020; Waters and Mars, 2021), manifest at times in displacement activities such as poaching. The symbolic and cultural aspects of this problematic can reasonably be viewed as intractable. Even so, there has been limited success ameliorating conflict through collaborative community-based approaches (Wilson et al., 2017), as well as largely theory-based suggestions that reformation of communication strategies might yield benefits (Walsh, 2019; Waters and Mars, 2021). Perhaps more hopefully, the symbolic construction of grizzly bears differs in positive ways from that of wolves, with the potential to engender better prospects of successful restoration (Lopez, 1978; Shepard and Sanders, 1992; Kellert et al. 1996). And, of course, given the extent to which malicious human behaviors can subvert the larger public interest, meaningful law enforcement will always be needed in areas where a small minority of people resort to illegal behavior as acts of resentment.

5.4. Areas of greatest promise

The Mogollon Complex holds the greatest promise of any for restoring grizzly bears to the Southwest. It is the largest Complex, and, when Protection Areas are included, has a low edge to area ratio. It also encompasses some of the most remote and productive areas in the Southwest. Even so, if reintroduction of grizzly bears were to be seriously considered, a well-thought-out effort would need to be undertaken well in advance not only to educate area residents about grizzlies, but more importantly engage them in a productive dialogue that ideally included sharing of experiences and coexistence techniques by people who currently occupy areas occupied by grizzly bears.

Although the San Juan and Sangre de Cristo Complexes are beset by significant challenges that potentially compromise prospects for restoring grizzly bears, they at the same time offer unique opportunities and assets. Perhaps most important, if managed for connectivity as a single Recovery Area, these combined Complexes would be the largest (Figure 8) as well as most productive, resulting in the potential to support a grizzly bear population comparable in size to the largest in the northern US Rocky Mountains.

One major challenge arises from the fact that much of the productive habitat in the San Juan Complex falls outside of Wilderness Areas comprised of comparatively unproductive high-elevation habitats, and is offset instead towards areas with greater numbers of people, as along the southwestern flank of the San Juan Mountains facing Durango. Even so, the more favorable predispositions of residents in this region (Figure 7) provide opportunities for productive advance engagement that could reduce preventable conflicts and increase understanding and acceptance of grizzlies.

The Sangre de Cristo Complex is compromised by both the extent of private property and by a high edge to area ratio engendered by the lineated nature of the northern Sangre de Cristo Mountain Range. This latter feature is immutable, with prospects of compromising security for any grizzly bears living in this part of the Complex. But, at the same time, the large privately-held conservation properties in the heart of this Complex could be more secure for grizzlies than any federally-owned jurisdiction given that landowners have the prerogative to limit or altogether prevent public access. But this potential could only be realized if owners of these properties were supportive of grizzly bear restoration and, ideally, willing to collaborate on coordinated conservation efforts. Aside from The Turner Ranches, prospects for this kind of accommodation are largely unknown at this point in time.

As a bottom line, there are ample opportunities for restoring grizzly bears to the Southwest and, at the same time—as elsewhere in areas occupied by grizzly bears—considerable foreseeable challenges. Nonetheless, very few of these challenges are insurmountable, especially with insightful advance planning that gives due regard to factors potentially driving human lethality as well as acceptance of grizzly bears.

5.6. Remaining analytic tasks

The analysis presented here is not intended to be comprehensive, especially in attending to the larger spatial-temporal context of past history and foreseeable futures for grizzly bears in the Southwest. Brown (1996) and Petersen (2009) offer a picture of the comparatively recent past, but without delving into deep history. The USFWS (2021) makes passing reference absent any data or analysis to the prospect of increasing regional human populations, but fails altogether in addressing the pending and potentially cataclysmic effects of climate change. Povilitis (1989) offers insights into what grizzly bears might eat, but with a limited spatial focus on the San Juan Mountains.

To address the limited temporal and spatial scope of previous analyses, Mattson (2021b) examines the deep history of grizzly bears, grizzly bear diets, and grizzly bear-human relations in the Southwest going back to the Pleistocene; assesses what grizzly bears might eat for the full of extent of the study are used in this analysis; and provides evidence-based projections of what a world with more people and a warmer drier climate might hold for grizzlies. We refer readers to this report for a fuller examination of the broader context informing potential restoration of grizzly bears to the Southwest. In the end, though, as with all scientific analyses, this analysis and Mattson (2021b) cannot claim to be definitive, merely the best currently available science.

5.7 Conclusions

The Southwest contains extensive biophysical and human environments capable of supporting sizable populations of grizzly bears, but with this conclusion contingent on broadening the scope of analysis from the more-or-less arbitrarily defined area employed by the US Fish and Wildlife Service (2021) to include all historical grizzly bear range in the region. The language of the Endangered Species Act seemingly requires that this larger geographic extent define the bounds of candidate restoration areas, especially given the likelihood that factors driving historical extirpations have largely been ameliorated in the Southwest. There would be indisputable challenges facing any restoration effort—none insurmountable. This analysis hopefully provides a roadmap for those pursuing restoration of grizzly bears to the Southwest along with fulfillment of societal commitments codified in the US Endangered Species Act.

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