





The case for reintroduction: The jaguar (*Panthera onca*) in the United States as a model

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Abstract

Reintroduction—defined here as the return of a species to a part of its range where it has been extirpated—is a critical pathway to conservation in the 21st century. As late as the 1960s, jaguars (*Panthera onca*) inhabited an expansive region in the central mountain ranges of Arizona and New Mexico in the United States, a habitat unique in all of jaguar range. Here, we make the case for reintroduction, building a rhetorical bridge between conservation science and practice. First, we present a rationale rooted in the philosophy of wildlife conservation. Second, we show that the species once occupied this territory and was extirpated by human actions that should no longer pose a threat. Third, we demonstrate that the proposed recovery area provides suitable ecological conditions. Fourth, we discuss how return of the species could be a net benefit to people, explicitly recognizing a diversity of values and concerns. Fifth, we show that reintroduction is practical and feasible over a realistic time horizon. Returning the jaguar to this area will enhance the recovery of an endangered species in the United States, further its range-wide conservation, and restore an essential part of North America's cultural and natural heritage.

KEYWORDS

Endangered Species Act, human dimensions, human–wildlife coexistence, natural recolonization, predator, prey base, restoration, rewilding, species recovery

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“We saw neither hide nor hair of him, but his personality pervaded the wilderness...”

Aldo Leopold (1949)

1 | INTRODUCTION

Conservation depends on convincing people that keeping species and natural systems from destruction, or restoring them after they have been lost, is worth the effort and expense (Leopold, 1921; Roosevelt, 1908; Thoreau, 1861). Conservation science develops reliable information on which to make decisions (Sutherland, Pullin, Dolman, & Knight, 2004), whereas conservation practice focuses on implementing strategies and evaluating progress once a decision has been made (Folke, Hahn, Olsson, & Norberg, 2005; Schwartz et al., 2018). What connects science and practice is an argument: the case for conservation of a species or ecosystem. An argument depends on facts and values assembled with the aim of persuasion. Here, we make the case for reintroducing jaguars in the United States, as an example of the form.

Reintroduction, restoration, and rewilding are all becoming more important conservation approaches in the 21st century, despite much debate about what exactly these concepts mean and how they should be applied (Corlett, 2016; Jørgensen, 2015; Hayward et al., 2019; Pettorelli et al., 2018). Here, we see reintroducing the jaguar to the mountains of central Arizona and New Mexico as essential to species conservation, ecosystem restoration, and rewilding (*sensu* Pettorelli et al., 2018; see also, Soule & Noss, 1998). The IUCN Red List assessment process (IUCN, 2013) considers range loss and population declines as moves toward extinction, so reversing these factors decreases the probability of global loss of the species. The proposed IUCN Green Status assessment (Akçakaya et al., 2018) interprets range expansion to “spatial subunits”—defined either taxonomically, in terms of subspecies, or ecologically, in terms of ecosystem proxies across the “indigenous range” (*sensu* Grace et al., 2019; Sanderson, 2019)—as critical steps toward the full recovery of a species, and by extension, the ecosystems that the species inhabits. Full recovery of species is particularly important when species have cascading ecological impacts as apex predators (Estes et al., 2011), ecosystem engineers (Crumley, 2015), or landscape species (Didier et al., 2009).

How does a conservationist justify species reintroduction efforts given the many different priorities society has for land and resources? Following others (e.g., IUCN, 2013), we suggest that there are at least five dimensions of the argument that must be persuasive to relevant decision makers (Table 1). First, we need to

TABLE 1 Dimensions of the case for species reintroduction

Dimension	Key question
Conservation rationale	Would recovery in this area enhance species conservation range-wide?
History	Was the species historically part of the fauna and have the threats that caused its extirpation been extirpated?
Ecological context	Does the area currently have suitable habitat and other conditions (e.g., prey items) for the species?
Human context	Will people gain a net benefit, or at least, not suffer a net harm?
Practical considerations	Can the species be reintroduced?

present a rationale rooted in the philosophy of wildlife conservation (e.g., Redford et al., 2011), which in turn is rooted in a system of values (Cook, de Bie, Keith, & Addison, 2016). Second, we need to make the historical case that the species once occupied the territory and was extirpated through human actions that could be reversed. Third, we need to demonstrate that the area currently provides the conditions for species survival. Fourth, we need to address any impacts the species might have on other social priorities for the same land base. That is, for people, not compelled by the conservation rationale alone—which, admittedly, is many people—we need to demonstrate convincingly that reintroduction will improve, or at least, not harm, human welfare. Fifth, we need to show that this effort is practical and feasible over a realistic time horizon. Fortunately successful models have been developed elsewhere in jaguar range (Zamboni, Di Martino, & Jiménez-Pérez, 2017; Gasparini-Morato et al., 2021).

Persuasion works most effectively with the relevant audience in mind. In this example, our argument is directed toward two audiences: the legal authorities, including the Tribal, Federal, state, and local agencies in the States of Arizona and New Mexico, that will decide whether jaguars can return; and members of the public, who decide who manages the land and administers the law on our collective behalf. The public is diverse and changing in important ways in the Southwest US, as explored below, with important implications for jaguar reintroduction. Our review is also presented as a case study to the conservation community, which, given the sweeping socioeconomic and environmental changes affecting not only the United States but also our planet (Sanderson, Walston, & Robinson, 2018; Steffen et al., 2015), needs to constantly hone its skills in this kind of rhetorical work (Baynham-Herd, Redpath, Bunnefeld, Molony, & Keane, 2018).

Jaguars in the United States provide a fascinating case study. Throughout the Americas, the jaguar has lost more than 50% of its historic range (Quigley et al., 2016), largely due to hunting and/or habitat loss (Olsoy et al., 2016; Sanderson et al., 2002). In the United States, at present, the species has been reduced to a few male cats that seem to be dispersing north from an established but threatened population in Sonora, Mexico, despite the burgeoning border infrastructure and associated activity (Peters, 2017; USFWS, 2018). Historical scholarship has shown that jaguars once inhabited a much larger area (e.g., Brown & López González, 2001), including the rugged, mountain forests of Central Arizona and New Mexico. Much of this area remains potential habitat (Sanderson et al., 2021). Population viability analysis suggests that this habitat block is large enough to sustain a

demographically viable population, but that connectivity to southern populations may have been lost (Miller, 2019). In 2019, the U.S. Fish and Wildlife Service (USFWS) released its Jaguar Recovery Plan (USFWS, 2018), which did not consider this habitat block. We call this area the Central Arizona—New Mexico Recovery Area (CANRA) (Figure 1).

2 | THE CASE FOR REINTRODUCTION

2.1 | Conservation rationale

The most important reason to reintroduce jaguars to the CANRA is that jaguars living once again in central

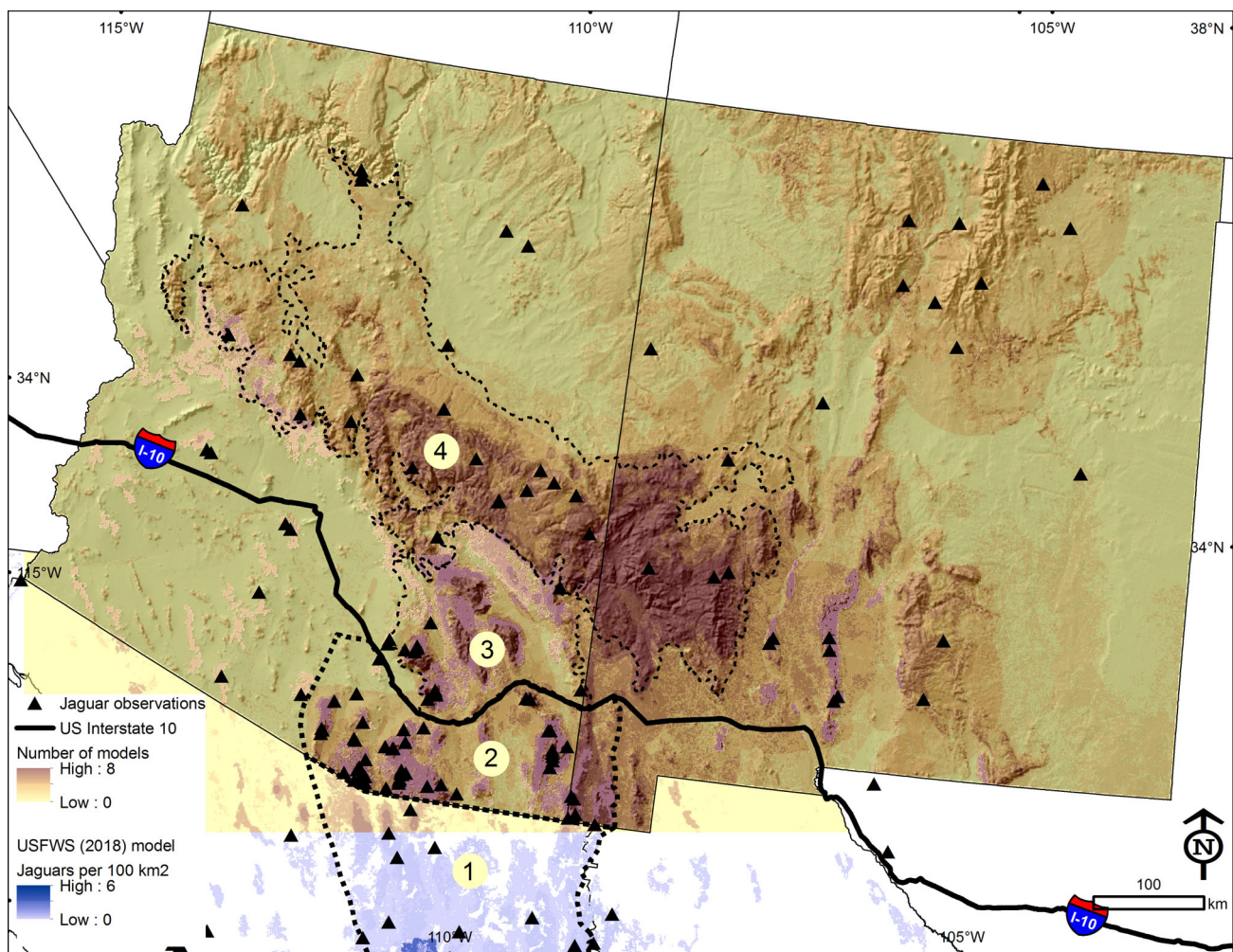


FIGURE 1 Agreement between 12 potential habitat models for the jaguar (*Panthera onca*), shown in brown, with existing and proposed management units, delimited by dotted lines on the map. From south to north, they are: (1) Borderlands Secondary Area – Mexico portion; (2) Borderlands Secondary Area—U.S. portion; (3) proposed Arizona Secondary Area; and (4) proposed Central Arizona – New Mexico Recovery Area (CANRA). U.S. Fish and Wildlife Service (USFWS) defined the Borderlands Secondary Area units as part of the Northern Recovery Unit (NRU) in its jaguar recovery plan (USFWS, 2018). For model details, see text and Sanderson et al., 2021. The USFWS (2018) habitat model for the NRU is shown in blue. Only areas south of US Interstate 10 (I-10) were considered, neglecting potential habitat north of the highway

Arizona and New Mexico will add a distinct and unique habitat type to the kaleidoscope of ecosystems where jaguars occur, thus enhancing ecological representation for the species (IUCN, 2008; Shaffer & Stein, 2000). Representation, redundancy, and resiliency are used by the USFWS as a cornerstone of its Species Status Assessment Framework to “measure the health of the species as a whole” (Malcolm & Carter, 2020; USFWS, 2016). They are also central to definitions of what it means to successfully conserve a species (Redford et al., 2011).

Nowhere else in jaguar range does the species inhabit what Brown (1994) characterizes as Madrean Evergreen Woodland (Povilitis, 2002; Sanderson et al., 2002). This zone represents a meeting point of subtropical and temperate species (Coronel-Arellano, Lara-Díaz, Moreno, Gutiérrez-González, & López-González, 2018), with cool, moist pine forests above dry, pinyon-pine-juniper-oak woodlands (DellaSalla, 2019; Kricher & Morrison, 1993). These forests are open and park-like where the natural fire regime is maintained (Schussman, Enquist, & List, 2006), an ideal habitat for ungulate species. The closest analogous habitats are tropical pine forests in Central America (Sanderson et al., 2002).

Reintroducing the jaguar could improve ecosystem quality by adding an additional apex predator to these ecosystems (Estes et al., 2011; Ripple et al., 2014). Mexican wolves (*Canis lupus baileyi*) were reintroduced in 1998 after a long, controversial process that informs this work. Eleven captive-reared individuals were introduced as a “Nonessential Experimental Population” under the U.S. Endangered Species Act (ESA; USFWS, 2005). Today, the population has grown to 163 individuals in 37 packs (USFWS, 2020), though studies suggest that the population has yet to reach an ecologically effective density (Beschta & Ripple, 2010; Hoskinson, 2018).

In the United States, jaguars are listed as an endangered species (USFWS, 1997), and as a “Species of Greatest Conservation Need” in Arizona (AZGFD, 2004) and New Mexico (NMDGF, 2019). Globally, jaguars are considered “Near-Threatened” (Quigley et al., 2016). Establishing a population entirely within the bounds of the United States would add to the resilience of the species, enabling U.S. people and agencies to contribute directly to its recovery. Since Americans caused the loss of this ecologically unique population, restoring jaguars to the CANRA would help remedy the injustice caused by its extirpation (Antonelli & Perrigo, 2018).

Jaguar reintroduction could also provide an opportunity for indigenous Tribes. The White Mountain and San Carlos Apache Tribes have sovereign rights over 13% of land in the CANRA, with their own laws, regulations, wildlife departments, and conservation programs (Tribal Working-group of the Mexican Wolf Recovery

Team, 2017). The White Mountain Apache Tribe has been active in restoration of other extirpated species, including the Mexican wolf and the Apache Trout (*Oncorhynchus apache*).

2.2 | Evidence for historical presence and extirpation by human hands

Male and female jaguars inhabited the central mountains of Arizona and New Mexico up until the 1960s, suggesting there was a long-term resident population (Povilitis, 2015). As part of the recovery planning process, Sanderson and Fisher (2011) systematically reviewed the historical literature on jaguars in the US and northern Mexico, drawing heavily on earlier reviews (especially Brown & López González, 2001; also see references in Supporting Information). Extracting from their online database (USFWS & WCS, 2020), we found 16 independent jaguar observations between 1890 and 1964 in the CANRA, including males, females, and females with cubs (Table S1). Four observations have well-attested physical evidence, including the type specimen for the putative subspecies, *Panthera onca arizonensis*, whose skull and skin are in the U.S. National Museum (Nelson & Goldman, 1933). Other observations have photodocumentation (Brown & López González, 2001). Jaguars were observed on 16 other occasions in areas north, south and east of the CANRA in Arizona and New Mexico, not including observations in the NRU (Table S2).

Jaguars no longer inhabit the CANRA, almost assuredly because they were hunted to extirpation (Brown & López González, 2001). Russell Culbreath, a U.S. government hunter, killed the last known jaguar in the CANRA on the White Mountain Apache Reservation in January 1964 (Arizona Republic, 1964). Today killing a jaguar, an endangered species (USFWS, 1997), is illegal under state and Federal law, with violators facing civil and criminal penalties. Law enforcement coupled with advance communications, incentive programs, and other social and economic benefits, as described below, should help mitigate this threat in the future.

2.3 | Current ecological suitability

The proposed reintroduction area is vast, covered with suitable vegetation, and well populated with prey. As delimited by Sanderson et al. (2021), the CANRA comprises 82,406 km² (Figures 1 and 2), following the outlines of the “Arizona/New Mexico Mountains” ecoregion (Omernik & Griffith, 2014). This area is larger than Jaguar Conservation Units (Sanderson et al., 2002) mapped in adjacent

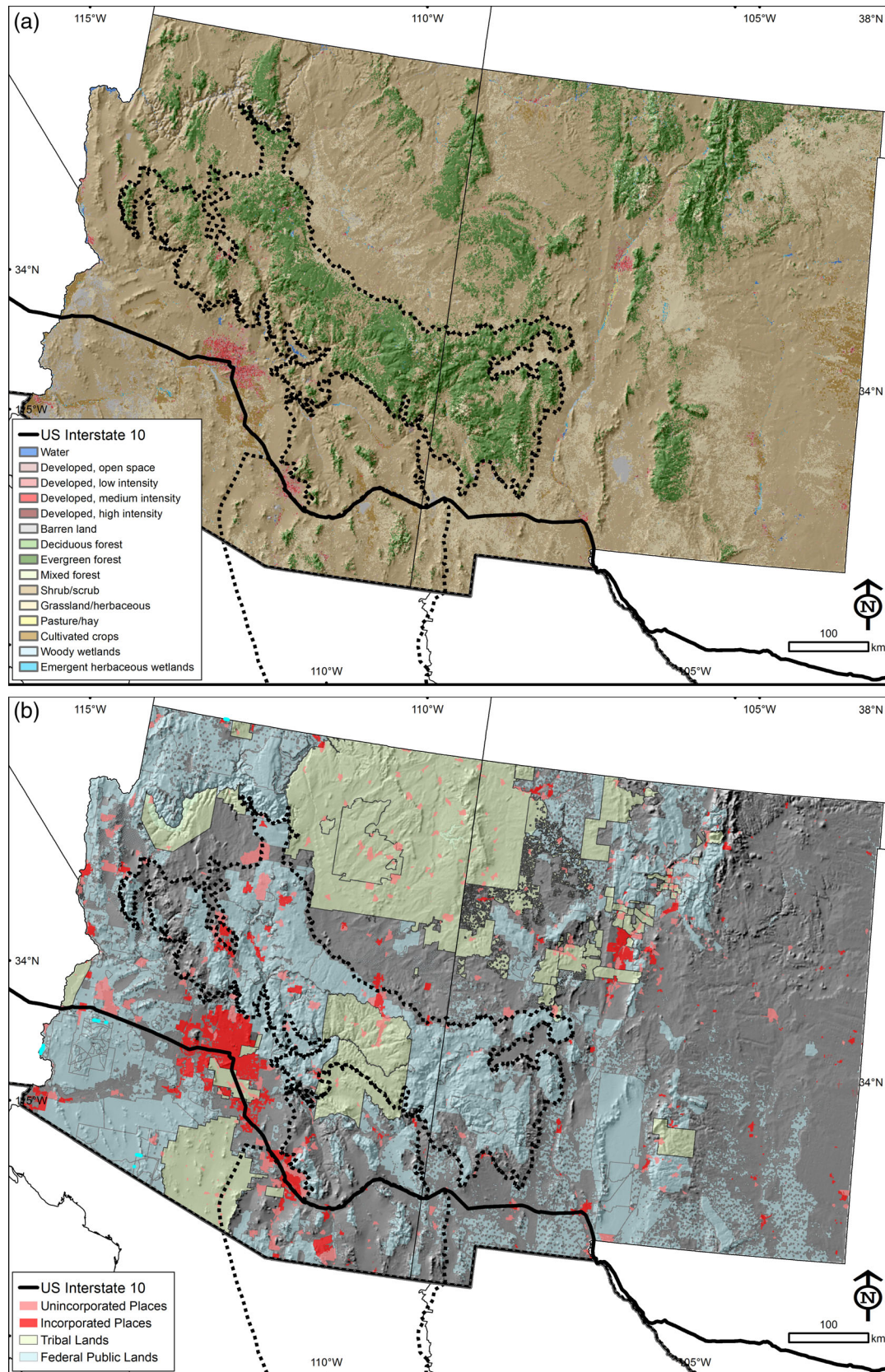


FIGURE 2 Land use and land cover (a) and land tenure (b) in the Central Arizona—New Mexico Recovery Area (CANRA). The dotted lines delineate existing and proposed management units, as listed in the caption of Figure 1

Mexico, including units mapped in Jalisco (29,409 km²) and Sonora (13,859 km²), that support viable jaguar populations on much smaller land bases. Using the same carrying capacity methods as the recovery plan (USFWS, 2019), Sanderson et al., 2021, estimated that the CANRA could potentially support 69–106 adult jaguars. Miller (2019) adapted the USFWS' population viability analysis to study a hypothetical CANRA population. Their results suggest that once established, a population would be viable for at least 100 years, though periodic introductions of new individuals would be necessary to maintain genetic diversity, since the loss of habitat to development and border wall infrastructure have severely hampered the possibility of natural reestablishment.

Jaguars in the southwestern U.S. and northern Mexico inhabit predominantly forest and scrub ecosystems, with preference for wetter places. In their study, Brown & López González, 2001, found that 80% of jaguars killed by people in Arizona and New Mexico historically were in conifer or piñon-juniper-oak woodlands; a smaller percentage was in scrub habitat. A male jaguar monitored by the University of Arizona's Jaguar Detection and Monitoring Project in the NRU spent 72% of his time in Madrean evergreen woodland and 26% in semi-desert grassland (Culver, 2016). In comparison, the CANRA consists of 46% forest (primarily evergreen) and 45% shrub/scrub (Figure 2a, Table 2).

Twelve habitat assessments reviewed by Sanderson et al., 2021, agree that the CANRA is potential jaguar habitat: it is rugged, has adequate water, provides prey and suitable cover, and is relatively free from human disturbance. Analysis of the CANRA against the National Land Cover Dataset 2016 (Yang et al., 2018) indicates that only 1.1% has been developed for urban uses, cultivated crops, or pasture or hay (Table 2).

Coues white-tailed deer (*O. v. couesi*) are potential jaguar prey and occur abundantly in the CANRA. In Jalisco, Mexico, white-tailed deer represented 54% of the biomass consumed by jaguars (Nuñez, Miller, & Lindzey, 2000). Hayward et al. (2016) reported that, although jaguars take a wide range of prey, they prefer prey ranging from 45 to 85 kg. Coues deer average approximately 50 kg for mature males and 25 kg for adult females (Heffelfinger, 2005). Mule deer may also be an important prey item in the CANRA. Although adult mule deer males can weigh in excess of 90 kg, females weigh only about 60 kg and fawns less than 4 kg at birth (Robinette, Baer, Pillmore, & Knittle, 1973). Given the existing prey base, it seems reasonable that jaguars in the CANRA would rely predominately on deer, supplemented by smaller prey such as javelina (*Pecari tajacu*), and perhaps, immature Rocky Mountain elk (*Cervus elaphus nelsoni*). The female jaguar slain in 1963 had elk remains

in her digestive system, though these may have been scavenged carrion (Brown & López González, 2001). Historically jaguar distribution overlapped with bison on the Colorado Plateau (Martin, Martin, & Mead, 2017).

Cervid numbers in Arizona have increased over the past 15 years. Arizona is estimated to have 85,000 white-tailed deer, 105,000 mule deer, and 30,000 elk (AZGFD, 2018; Gibbons, 2018). New Mexico has an estimated 10,000–15,000 white-tailed deer (Webb, 2017), 80,000–100,000 mule deer (Mule Deer Working Group, 2018), and 81,000–106,000 elk (NMDGF, 2019).

Smaller prey consumed by jaguars in northern Mexico include coatis (*Nasua* spp.), javelinas (*Pecari tajacu*), and desert tortoises (*Gopherus* spp.; Hernández-Saint Martín et al., 2015; López-González & Miller, 2002). Adding an apex predator like the jaguar in the CANRA could in theory change the mix of small to mid-size prey by suppressing small to mid-size predators such as bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), and coyotes (*Canis latrans*), in turn increasing numbers of their prey such as turkeys (*Meleagris gallopavo*) or rabbits (*Sylvilagus* spp.; Moreno, Kays, & Samudio, 2006; Ritchie & Johnson, 2009).

Adding (or removing predators) from an ecosystem shifts predator guild dynamics (Ripple et al., 2014). Jaguars directly compete with cougars in northern Mexico (Rosas-Rosas, Bender, & Valdez, 2008), though not to the extent of competitive exclusion (Gutiérrez-González & López-González, 2017). If jaguars kleptoparasitize cougars, then cougars may kill more prey to replace lost food and switch to other prey items (e.g., Krofel, Kos, & Jerina, 2012; Rominger, 2018). Jaguars might also compete with non-felid predators, such as black bears (*Ursus americanus*; Fourvel et al., 2014; Tallian et al., 2017). To our knowledge, wolf–jaguar interactions have not been studied in the scientific literature, though Audubon and Bachman (1854) left an account of wolves circling a jaguar on a kill.

Jaguars may have indirect interactions with human hunters seeking similar prey. We discuss ways to minimize the potential for modern human–wildlife conflict in the next section.

2.4 | Impact on other social priorities

So far, we have provided the conservation rationale for taking a reintroduction decision, shown that jaguars inhabited the CANRA until extirpated by human action, and established that given the existing space, vegetation, and prey base, jaguars could thrive in the CANRA again. In this section, we turn to how a restored jaguar population might impact other priorities in society.

TABLE 2 Analysis of land cover within the Central Arizona / New Mexico Recovery Area

National land cover dataset 2016 class ^a	Area (km ²)	Percentage of total (%)
Open water	40	<0.05
Developed, open space	79	0.7
Developed, low intensity	194	0.2
Developed, medium intensity	82	0.1
Developed, high intensity	17	<0.05
Barren	152	0.2
Deciduous forest	103	0.1
Evergreen forest	38,043	46.2
Mixed forest	19	<0.05
Shrub/scrub	37,203	45.1
Grassland/herbaceous	5,806	7.0
Pasture/hay	5	<0.05
Cultivated crops	12	<0.05
Woody wetlands	75	0.1
Emergent herbaceous wetlands	76	0.1
Total	82,406	100.0

^aYang et al., 2018.

Species, ecosystems, and conservation do not exist in a vacuum; they constantly contend with other social forces and desires. While there are strong moral and ethical claims for conservation, those values have to co-exist with other values.

The question of values, of course, depends on whom you ask, and when you ask them. Values vary by age, education, economic status, and political affiliation (Dietz, Fitzgerald, & Shwom, 2005; Kempton, Boster, & Hartley, 1996). For example, in a 2019, Pew Research Center poll, 65% of Americans agreed with the statement “environmental regulations are worth the cost,” while 33% said such regulations “cost too many jobs and hurt the economy” (Funk & Hefferon, 2019). Although support for the environment has dipped as low as 50%, over the last five years it has been increasing nationwide. In a 2020 poll by Colorado College, 72% of surveyed Arizonans and New Mexicans considered themselves conservationists; 78% (AZ)/68% (NM) thought loss of habitat for fish and wildlife a serious problem; and 80% (AZ)/78% (NM) considered environmental issues important when deciding which elected official to support (Colorado College, 2020).

The last point is important because variation in the body politic is filtered through the mechanics of representative democracies, such as the United States, where people elected to office or employed to work on behalf of government, make crucial day-to-day decisions,

including choices effecting wildlife. As a practical matter, it will be authorities at the Tribal, Federal, state, and local levels who will need to approve, manage, and support jaguar reintroduction at specific times and places, balancing the needs of the jaguar with other species of conservation concern. Over the longer-term, politics and societal attitudes about wildlife and animal welfare will influence who makes what decisions (George, Slagle, Wilson, Moeller, & Bruskotter, 2016; though see Sheffer, Loewen, Soroka, Walgrave, & Sheafer, 2018).

Below, we summarize some essential data about people living in the CANRA today: who they are, how they make a living, and who manages the habitat. Such information is key to understand who and how people might be impacted by the return of the jaguar. We then consider how likely it is that 60–100 jaguars in ~82,000 km² would affect these people, in terms of life, livelihood, and recreation. Where opportunities exist to mitigate adverse effects, we call these out.

2.4.1 | Demographics of the CANRA

Approximately 371,000 Arizonans and 10,000 New Mexicans lived within the boundaries of the CANRA as of July 1, 2018, at overall population densities between 0.1 and 10.7 people per km², depending on county (Table 4). CANRA residents represented approximately 6.5% of the counties where they live, or about 4% of the populations of both states.

Low population density in the CANRA reflects Arizona's and New Mexico's rapid urbanization over the last five decades. Nearly 9 in 10 people live in cities in Arizona and over 3 in 4 live in cities in New Mexico (U.S. Census, 2010). The largest city within the CANRA's boundaries is the Flagstaff (Arizona) metropolitan area, with 142,523 residents in 2018. The Prescott Valley—Prescott metropolitan area falls partially within the CANRA; it had 231,772 residents in 2018. Increases in income, education, and urbanization seem to be leading to a generational switch from valuing “domination” of nature to “mutualism” in the western US states (Manfredo, Teel, & Henry, 2009), which may influence opinions and decisions about the environment now and into the future.

2.4.2 | Economic livelihoods in the CANRA

We estimated CANRA's GDP was about \$12 billion in inflation-adjusted 2012 dollars in 2015 (BEA, 2016; Table 4). This productivity represents approximately 4.1% of Arizona's economic production; and 0.4% in New

Mexico. In 2017, the latest year for which detailed data is available, the CANRA provided approximate 178,000 jobs, of which 3.5% were in farming or ranching occupations (Table 4). Local government, accommodation and food services, health care and social assistance, and retail trade each provided about 12% of nonfarm jobs (Table S3). Forestry, fishing, and related occupations represented less than 1% of nonfarm jobs. (U.S. BEA did not disclose data for several counties for this category, so this is a minimum estimate.) These changes in economic activity represent a historic shift from the “three C’s”—copper, cotton, and cattle—that traditionally characterized Arizona’s economy (Sheridan, 2012).

2.4.3 | Land tenure in the CANRA

The CANRA is mostly public or tribal land (Table 3). Analysis of the CANRA geography with respect to the U.S. Geological Survey National Boundaries Dataset (USGS, 2018) and state and private land data (CBI, 2016) shows that the U.S. Federal government manages 68% of the area, tribal sovereign nations 13%, and state agencies 8% (Figure 2b). The remaining 11% is private. Of the Federal agencies, the U.S. Forest Service (USFS) manages the greatest area, with eight different national forests covering more than 3,000 km² each (Table 3). The Bureau of Land Management (BLM) and National Park Service are also important land managers. The two largest American Indian sovereign nations are the White Mountain Apache (6,790 km²) and the San Carlos Apache (3,294 km²).

Federal and state public land covers over three-quarters of the CANRA (Table 3). Within Federal lands, 6,690 km² (8.1% of the CANRA) has been designated wilderness, 97% of which is under USFS management (the remainder, BLM; see Table S4). The Gila Wilderness, the world’s first declared wilderness area, lies immediately adjacent to the Aldo Leopold Wilderness in the eastern CANRA. This wilderness complex provides a roadless, well-protected, habitat block of 3,068 km², an area of high quality potential habitat larger than the state of Rhode Island, and is potentially a site for reintroduction (Sanderson et al., 2021). The CANRA as a whole is about the same size as the state of South Carolina.

2.4.4 | Direct jaguar caused mortality

Jaguars are unlikely to directly attack people, unless people attack first. In their historical review of jaguars in the Borderlands Region, Brown and López González (2001) write:

TABLE 3 Analysis of land tenure by management authority in the Central Arizona/New Mexico Recovery Area. Bolded numbers indicate totals for indicated categories

Land management authority	Area (km ²)	Percentage of total (%)
American Indian Tribal Lands	10,261	12.5
White Mountain Apache Reservation	6,790	8.2
San Carlos Apache Reservation	3,294	4.0
Navajo Nation Reservation	125	0.2
Other Tribal Lands	52	0.1
US Federal Managed Lands	56,087	68.1
US Forest Service	51,605	62.6
Gila National Forest	11,047	13.4
Tonto National Forest	8,870	10.8
Coconino National Forest	7,993	9.7
Apache National Forest	7,606	9.2
Prescott National Forest	5,624	6.8
Kaibab National Forest	3,667	4.4
Sitgreaves National Forest	3,431	4.2
Cibola National Forest	3,367	4.1
Bureau of Land Management	4,040	4.9
Kingman Field Office	1,413	1.7
Socorro Field Office	897	1.1
Hassayampa Field Office	834	1.0
Las Cruces District Office	683	0.8
Tucson Field Office	151	0.2
Other Field Offices	62	0.1
National Park Service	326	0.4
Grand Canyon National Park	291	0.4
Other NPS managed lands	35	<0.05
Department of Defense (DoD)/ National Guard	116	0.1
Camp Navajo	115	0.1
Other DoD managed lands	1	0.0
State/Local Managed Lands	6,632	8.0
Arizona	5,056	6.1
Arizona State Land Board	4,993	6.1
Other AZ State Lands	51	0.1
Arizona County Lands	12	<0.05
New Mexico	1,576	1.9
New Mexico State Land Board	1,571	1.9
Other NM State Lands	5	0.0

“Although we have heard of several dogs having been killed while fighting jaguars, we know of no person who has actually been

killed by a jaguar. Reports of unprovoked attacks by jaguars are extremely rare, and most of these take place prior to 1850 so they are now nearly impossible to verify. We are unaware of even a single American newspaper account describing the occurrence of such an incident, although a few such attacks have been documented in South America.”

No jaguar attacks on people have been recorded in the United States in the 21st century, despite near continuous occupation by the species, albeit at very low densities, including near populated areas such as Tucson, Arizona.

Jaguars are likely to kill livestock, at least occasionally. All of the National Forests and BLM areas currently provide livestock allotments as part of their multiple use management within the CANRA. Apache people also keep livestock on Tribal lands. In Sonora, Mexico, the percent of calves confirmed killed by jaguars varied from 0 to 1.8% of total production each year over a six-year period; overall calf survival was 89 to 98% after accounting for all sources of mortality (Rosas-Rosas, Bender, & Valdez, 2010). Fewer animals were killed by jaguars than died from abandonment, disease, and other natural causes. In the Chamela-Cuixmala Biosphere Reserve in western Jalisco, Mexico, where livestock coexisted with abundant wild prey and jaguars, no depredation occurred during a four-year study (Nuñez et al., 2000). Losses due to both jaguars and cougars on a ranch in central-western Brazil were 0.4% of annual holdings (Palmeira, Crawshaw, Haddad, Ferraz, & Verdade, 2008), while losses in the Brazilian Pantanal, a large, flat wetland region, were 2.3% of cattle holdings (Zimmermann, Walpole, & Leader-Williams, 2005). Such losses may be minimized by proactively deploying mitigation strategies as described in the next section.

2.4.5 | Economic impacts of a restored jaguar population in the CANRA

How would 60+ jaguars in 82,000 km² impact the economy of Arizona and New Mexico? Next, we discuss potential economic consequences on ranching, hunting, and recreation.

Ranching

Although at a macroeconomic level, livestock ranching is a minor industry in the CANRA (Table 4), for some ranchers, jaguar predation may still be a significant financial issue. Fortunately, livestock management practices

can significantly decrease vulnerability to predators (Sillero-Zubiri, Sukumar, & Treves, 2007; Treves, Krofel, & McManus, 2016). Successful strategies include managing for abundant wild prey populations, establishing water sources for cattle away from hunting cover, using fences to exclude cattle from riparian and other sensitive areas, and employing range riders to manage cattle and scare off predators (Hayward & Somers, 2009; Khorozyan, Ghoddousi, Soofi, & Waltert, 2015; Parks & Messmer, 2016; Polisar et al., 2003; Rosas-Rosas et al., 2010). Such efforts are most effective when focused on potential conflict “hotspots” identified through regular monitoring (Goljani Amirkhiz, Frey, Cain, Breck, & Bergman, 2018; Miller, 2015).

Financial losses can be mitigated with direct compensation programs that pay ranchers when predators kill livestock (Ravenelle & Nyhus, 2017) and pay-for-presence programs (Dickman, 2010), which provides cash when predators are confirmed to be present on a rancher's land (Miller et al., 2016; Persson, Rauset, & Chapron, 2015). One such program in Sonora pays landowners when jaguars or other cats are photographed on their property, providing supplementary income (Northern Jaguar Project, 2019). A similar program has been suggested for wolves in the CANRA (Hernandez, Crigler, & Hutchinson, 2014).

Hunting

Jaguars may influence hunting and trapping in this region. Interestingly, research suggests that adding a new predator might actually make deer easier to find. Adding jaguars could alter the “landscape of fear” (Gaynor, Brown, Middleton, Power, & Brashares, 2019; though see Hoskinson, 2018). The best strategy for deer to avoid a nocturnal ambush predator such as the jaguar is to avoid thick and dark cover at night (Ditmer et al., 2020; Gehr et al., 2017), forcing deer into more open areas, where human hunters are more successful (Lone et al., 2014). In Europe, restoring the Eurasian lynx (*Lynx lynx*) facilitated greater human hunting success for roe deer (*Capreolus capreolus*; Gehr et al., 2018). Given the abundant prey base, significant competition between hunters and jaguars for kills seems unlikely.

Effects on other game species will be difficult to predict *a priori*. Cougars are regularly hunted in Arizona and New Mexico, including in the CANRA, usually with dogs. The first live jaguar ever photographed in the US was discovered this way (Glenn, 1996) and in 2011, another jaguar was treed inadvertently during a cougar hunt (Decker, 2011). Both those jaguars escaped alive, with no harm to the hunters, though some chase hounds were injured. As with deer, jaguars may influence the behavior of cougars, wolves, and smaller predators, with

TABLE 4 Population and economic characteristics of the CANRA. We made these estimates by measuring the proportion of people living within each of the 16 counties that intersect the CANRA using spatial population data at 1 km² resolution (SEDAC, 2019), and adjusting to match 2010 US Census results. Assuming these proportions were the same eight years later, we prorated county-level US Census estimates from 2018 (Census Bureau, 2019)

Within the Central Arizona / New Mexico Recovery Area								
State	County ^a	Area (km ²)	Proportion of county population, 2010	Estimated population 2018 (number of people)	Estimated population density, 2018 (people/km ²)	Estimated GDP, 2015 (thousands of 2012 dollars)	Estimated number of jobs, 2017	Estimated number of farm jobs, 2017
Arizona	Apache	4,700	14%	10,181	2.2	290,634	3,999	777
Arizona	Coconino	13,360	75%	107,042	8.0	4,638,685	64,668	1,689
Arizona	Gila	10,277	84%	45,469	4.4	1,405,911	17,840	156
Arizona	Greenlee	3,058	2%	180	0.1	25,070	100	3
Arizona	Mohave	2,829	1%	1,697	0.6	33,906	564	4
Arizona	Navajo	4,993	42%	46,916	9.4	1,337,578	17,755	1,658
Arizona	Yavapai	14,867	68%	158,491	10.7	3,685,529	67,869	808
New Mexico	Catron	12,179	74%	2,652	0.2	49,033	1,221	270
New Mexico	Grant	6,748	25%	6,828	1.0	300,133	3,229	100
New Mexico	Sierra	2,811	2%	266	0.1	5,525	121	8
New Mexico	Socorro	2,933	2%	264	0.1	6,578	124	13
	Total	82,422		381,014		11,808,499	177,893	5,490

^aCounties that make up less than 0.5% of the CANRA are not shown, but are included in the totals. They are Graham, Maricopa, and Pinal counties in Arizona, and Hidalgo and Luna counties in New Mexico.

cascading consequences for other hunted species, such as turkeys, javelinas, and bighorn sheep (*Ovis canadensis*; e.g., Rominger, 2018). Jaguars might take young Rocky Mountain elk, another reintroduced species (Witmer, 1990). Sale of permits to shoot trophy quality elk is critical to the economy of the White Mountain Apache Reservation (C. Dale, pers. comm.), so compensation may be needed.

Ecotourism

“Apex predator ecotourism” marketed around the jaguar, “America’s Great Cat,” could possibly generate new jobs and income as it has for other species (Macdonald et al., 2017). Ecotourism already contributes to local economies in Arizona and New Mexico. For example, the town of Patagonia, Arizona, saw a large increase in sales tax revenue as the economy switched from mining to ecotourism centered on birding (Shafer, 2014). Out-of-area non-consumptive visitors to Bosque del Apache National Wildlife Refuge in New Mexico generate \$15.5 million per year for Socorro County (USFWS, 2019). Presence of jaguars could also be the basis of education and engagement, even a source of local pride (Caruso & Jiménez Pérez, 2013). For example, the White Mountain Apache Tribe has a youth conservation program that tracks the

status of wolves (Eno & DiGiorgio, 2019), with five packs on Tribal lands in May 2019.

The potential draw of large predators in the United States is exemplified by the Yellowstone wolves, which were generating \$5 million per year in ecotourism ten years after they were reintroduced (Weiss, Kroeger, Haney, & Fascione, 2006). Wildlife tours to see wolves are offered in the White Mountains of Arizona already (Ravens-Way Wild Journeys, 2020). In the Pantanal, guided jaguar ecotourism yielded a gross annual income of \$6.8 million in 2015 across an 81,000 ha area, yielding three times more revenue than cattle ranching per hectare (Tortato, Izzo, Hoogesteijn, & Peres, 2017).

In this instance, a resident jaguar population would be a first in the United States in a half-century, with significant and sustainable new publicity value. We acknowledge that compared to wolves in Yellowstone or jaguars in the Pantanal, jaguars in the CANRA would be difficult to see. That might not lessen their appeal. Leopold (1949) described his visit to the Colorado River Delta in 1922 this way:

All of this wealth of fowl and fish was not for our delectation alone... We always examined these deer trails, hoping to find signs of the

despot of the Delta, the great jaguar, el tigre. We saw neither hide nor hair of him, but his personality pervaded the wilderness; no living beast forgot his potential presence, for the price of unwariness was death. No deer rounded a bush, or stopped to nibble pods under a mesquite tree, without a premonitory sniff for el tigre. No campfire died without talk of him. No dog curled up for the night, save at his master's feet; he needed no telling that the king of cats still ruled the night...

2.5 | Practical considerations for reintroduction

In the last section, we discuss practicalities. If the public supported reintroduction and decision makers agreed, how could jaguars return?

Reintroduction of jaguars to the central mountains of Arizona and New Mexico will require concerted cooperation between Federal, state, Tribal agencies, and civil society. Mexican wolf recovery provides an example: years of negotiation and compromise took place before the first wolves were released into Arizona and New Mexico. Some 20 years later, through collaboration with USFWS, state game agencies, Tribes, nonprofits, and ranchers, now there are at least 163 Mexican wolves in the U.S. Southwest (USFWS, 2020). A coexistence program helped ranchers minimize predation through herd management (Hernandez et al., 2014). Nonetheless, hostility to Mexican wolves in the recovery area remains. At least 13 Mexican wolves died from poaching in 2018 (Gardner, 2018), a not uncommon problem when predators have been brought back (Liberg et al., 2012; Treves, Langenberg, López-Bao, & Rabenhorst, 2017).

Reintroducing jaguars to the CANRA might face less social resistance if the population were designated as a nonessential, experimental population by the USFWS under Section 10(j) of the ESA as was done for Mexican wolves (Parker and Phillips, 1991; Pavlik, 1999). 10(j) designation as a nonessential population relaxes ESA protections by barring designation of critical habitat in the 10(j) area and giving wildlife managers more flexibility, including the option of removing individuals that prey on domestic livestock (USFWS, 2015).

It will also be important to amend the USFWS' jaguar recovery plan to include consideration of the CANRA (Sanderson et al., 2021). The recovery plan anticipated this necessity, including this note: "... as more information is gathered on the distribution and status of jaguars within the NRU [Northwestern Jaguar Recovery Unit] and adjacent areas, the boundaries of the NRU may need

to be expanded or reconfigured" (USFWS, 2018; our underline). We note that agencies are required to use "best available" science in making policy about endangered species (Murphy & Weiland, 2016). Future analyses as part of the plan could identify possible reintroduction sites. Fortunately, there exist large, roadless areas, such as the contiguous Gila—Aldo Leopold—Blue Range Wilderness block, that provide remote potential habitat.

Social science research, polling, economic and political analysis are needed to more fully understand the potential costs and benefits of jaguar reintroduction (e.g., Caruso & Jiménez Pérez, 2013; Heydlauff, Krausman, Shaw, & Marsh, 2006). We have no specific information about perceptions either for or against the reintroduction of jaguars in the CANRA, though polls for other predators in the western US have found increasing support for reintroduction programs (George et al., 2016; Center for Human-Wildlife Coexistence, 2020; also see Warshall & Bless, 2003). A survey of local attitudes is a first order of business; we offer a preliminary set of considerations for social science research in the Supplemental Information. Such information will be key to focusing engagement and identifying common ground with effected communities regarding reintroduction efforts.

Ecological research to document the prey base and assess potential interactions with other predators, wild prey, livestock, and human hunters, before and after reintroduction, will also be necessary (Hayward & Somers, 2009). Climate change effects also need investigation, as changing temperature and precipitation patterns may influence shift the availability of water and prey (Garfin et al., 2014), potentially increasing the importance of the peripheral, northern part of the range relative to areas farther south (Lesica & Allendorf, 1995; Povilitis, 2015).

Unfortunately it seems likely that habitat connectivity has been severely constricted, if not entirely lost, to existing populations south of the US-Mexico border (Miller, 2019; Peters, 2017), making natural reestablishment unlikely in coming decades. Active translocations will be required (Miller, 2019). Translocation efforts using proper veterinary support and following established guidelines (e.g., IUCN, 2013) have been successful for other large cat species (Bennett, 2015). An Iberian lynx (*Lynx pardinus*) population grew from 59 to 179 individuals in eight years, and a lion (*Panthera leo*) population founded with 35 reintroduced individuals grew to 56 in seven years (Miquelle et al., 2016).

The question of sourcing individuals for reintroduction needs careful consideration. There are two options: captive-bred individuals or translocation from existing wild populations. Because modern analyses of nuclear DNA have concluded that jaguars are too similar range-wide to be divided into subspecies (Eizirik

et al., 2001), Kelly and Silver (2009) suggested that genetic provenance of founders is not critical. They suggest animals for translocation might be found in zoological parks and rehabilitation centers, where animals have been rescued after accidents and anti-depredation efforts or raised for the purpose. In the Iberá Rewilding program in Argentina, for example, a captive-breeding center was constructed to produce offspring capable of hunting wild prey with no dependence on humans (Zamboni, Di Martino, & Jiménez-Pérez, 2017).

Culver and Hein (2016) found that jaguars from Arizona and Sonora possessed mitochondrial DNA haplotypes found nowhere else. They hypothesized that because northern jaguars are an edge population (Lesica & Allendorf, 1995; van der Valk et al., 2018), they may harbor genetic adaptations to hot, arid conditions, which might become more prevalent in the future (Garfin et al., 2014). However northern jaguar populations in Sonora and Sinaloa are sparse and semi-isolated (Davis, 2018), so removing animals may be ill advised. Possibly animals could be obtained from more robust populations in the southern hemisphere. Any effort to translocate wild jaguars into the CANRA obviously must not endanger the security of any existing populations and must respect the sovereignty of the nations involved.

Once jaguars are reintroduced, concerted work will be required to monitor the health and welfare of jaguar and prey populations, minimize livestock losses, and share information with local communities, tourists, and the public.

3 | SUMMATION

Jaguars have been part of the American faunal assemblage for nearly 1.5 million years (Kurten & Anderson, 1980), but are now reduced as a matter of government policy and a long history of interactions with American society to a small area south of the U.S. Interstate 10 highway, in southeastern Arizona and southwestern New Mexico. The jaguar's loss is also a loss for the nation (Peters, 2017), the ecology of the Southwest (Brown & López González, 2001), and the jaguar as a species (Sanderson et al., 2002). Our world's natural heritage is diminished nearly everywhere; here is a model for who, where, how and why people should invest in restoring it. For the jaguar, America's Great Cat, the question is when.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Rob Peters and Eric Sanderson conceived the study. Jon Beckmann, Bryan Bird, Kim Fisher, Jennifer Miller, Cristina Mormorunni, Rob Peters, Eric Sanderson, and Sharon Wilcox contributed to the conceptualization of the study, design of the methodology, and collection of the data. Jon Beckmann, Kim Fisher, Jennifer Miller, Rob Peters, Eric Sanderson, and Sharon Wilcox performed the analyses. Eric Sanderson and Rob Peters led the writing of the manuscript. All authors contributed to the preparation and revision of the manuscript.

DATA AVAILABILITY STATEMENT

Jaguar observations can be accessed at jaguardata.info (USFWS & WCS, 2020).

ETHICS STATEMENT

The authors are not aware of any ethical issues regarding this work.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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