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Assessing ecological and socio-political factors in site selection for ocelot reintroduction in Texas

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Abstract
Wildlife reintroduction site selection requires the consideration of not only a species' ecology but also socio-political factors that may impact conservation efforts. These socio-political dimensions may be especially important for endangered carnivore reintroductions on private lands in the United States, where landowner support for the reintroduction is a necessity given landowner concerns about ecological and legal impacts of carnivore restoration. We designed an assessment to identify potential sites for reintroduction of the federally endangered ocelot (*Leopardus pardalis pardalis*) in Texas, a state where over 97% of lands are privately owned. We incorporated International Union for Conservation of Nature recommendations into a geospatial analysis evaluating potential reintroduction sites based on site size, ecological and life history requirements of ocelots, potential natural and anthropogenic threats, and the socio-political context of each site. We identified the five highest-ranking sites that had species-specific suitable landscape structure of woody cover, fine-scale vegetative cover, minimal natural and anthropogenic threats, and that present land ownership patterns that are logistically feasible for conservation planners to navigate. Our assessment provided information for ocelot conservation planning and established a framework for incorporating private land data into large-scale assessments of wildlife reintroduction sites on private lands.

KEYWORDS
conservation planning, mammals, North America, private lands, remote sensing, threatened species

1 | INTRODUCTION

Felids are common subjects of conservation reintroduction programs due to felid population declines and severe range contractions, the importance of restoring the ecological roles of predator species, and the high intrinsic value and associated public interest in conserving felids (Seddon et al., 2005). Though felid reintroductions are common, they are not always successful, and the poor performance of many wildlife reintroduction efforts suggests a need for improved planning (Fischer & Lindenmayer, 2000; Jule et al., 2008; Thomas et al., 2023). While reintroduction site selection clearly must include an evaluation of ecological and life history requirements for species survival and population establishment, socio-political dimensions must also be considered to fully evaluate the feasibility of a reintroduction program (Behr et al., 2017; Carver et al., 2021; Ditmer et al., 2022; Gray et al., 2017; IUCN/SSC, 2013; Reading et al., 2002; Watkins, 2020). This may be especially important for carnivore reintroductions; globally, reintroduction planning efforts for felids or other carnivores must address potential human-wildlife conflict concerns, such as the possibility of depredation of wildlife populations on privately owned livestock (Drouilly & O'Riani, 2021). When assessing carnivore reintroduction sites, accounting for socio-political dimensions such as presence of protected areas, spatial patterns in land ownership, expected carnivore-human tolerance, and livestock stocking rates can provide a clearer picture of the potential socio-political issues at different reintroduction sites and the ecological-social tradeoffs present at each site (Connolly & Nelson, 2023; Ditmer et al., 2022; Pratzer et al., 2023).

Across North America, levels of private land ownership vary, and protected lands can sometimes fail to meet conservation requirements (Clancy et al., 2020; Jenkins et al., 2015). In the United States, endangered species conservation may also be complicated by some private landowners' concerns that the presence of species protected under the Endangered Species Act (ESA) on their lands will lead to federal regulations that restrict land use and habitat modifications (Hansen et al., 2018). This can make conservation and restoration of endangered species in the United States difficult. Historically, some private landowners in the United States have managed their lands to prevent occupancy by endangered species or have concealed information concerning presence of endangered species on their properties (Lueck & Michael, 2003). As such, endangered species reintroduction efforts in the United States that occur outside publicly owned or other dedicated private conservation lands (e.g., land trusts and preserves) require establishing regulatory assurance documentation (e.g., Safe Habor Agreements) with landowners to obtain their support for reestablishment of endangered species on their properties (Bork, 2011).

In the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) guidelines for species reintroductions (IUCN/SSC, 2013), IUCN recommends reintroduction sites: (1) are large enough to support a viable population of reintroduced species; (2) meet a species' ecological needs at all relevant scales; (3) have reduced threats to the species (including abatement of the historic threats that caused the decline of the species and reduced threats from present catastrophic events); and (4) are socio-politically feasible for reintroduction (IUCN/SSC, 2013). In short, IUCN suggests considering ecology/life history, size, abatement of human and natural threats, and socio-political factors in choosing a reintroduction area.

Published assessments to identify sites for felid reintroductions have focused on ecological factors such as land cover type or vegetation community, prey base, size and connectivity of habitat, and remoteness from human encroachment on habitat. Examples include assessments of Florida panther (*Puma concolor coryi*) reintroduction sites in Florida (Thatcher et al., 2006); tiger reintroduction sites in China (Hebblewhite et al., 2012; Qin et al., 2015); European wildcat (*Felis silvestris*) reintroduction sites in Europe (Klar et al., 2008); Eurasian lynx reintroduction sites in Europe (Hetherington et al., 2008; Schadt et al., 2002); Iberian lynx sites on the Iberian Peninsula (Garrote et al., 2020); and reintroduction sites throughout Asia for several leopard subspecies (Chiang et al., 2015; Gardener, 2020; Hebblewhite et al., 2011). However, these felid reintroduction site assessments lack consideration of socio-political factors in their determination of suitable reintroduction sites.

The ocelot (*Leopardus pardalis* spp.) is a medium-sized felid considered least concern range-wide but classified as federally endangered in several range countries, including the United States, where population expansion via reintroduction is needed for recovery (US Fish and Wildlife Service, 2016). In the United States, ocelots historically occupied Arizona, various regions of southern, central, and eastern Texas, and the western parts of Arkansas and Louisiana (US Fish and Wildlife Service, 2016). However, by the mid-20th century, habitat loss, pet trading, fur trapping, and predator control practices nearly extirpated ocelots from the United States (US Fish and Wildlife Service, 2016). Today, the United States has only two known breeding ocelot populations, which are theorized to number up to 100 individuals persisting in deep South Texas along the Gulf of Mexico (Figure 1, Lombardi et al., 2021). The larger of the remaining populations in Texas is the Ranch Ocelot Population, which exists on privately owned working ranches in Willacy and Kenedy Counties. The smaller Refuge Ocelot Population (16–20 ocelots) is found in and around Laguna Atascosa National Wildlife Refuge in Cameron County (Lombardi et al., 2022).

The two Texas ocelot populations occur in vegetation communities containing live oak (*Quercus virginiana*), palm (*Sabal* spp), and mesquite (*Propsis glandulosa*) woodlands and forests with open to dense patches of

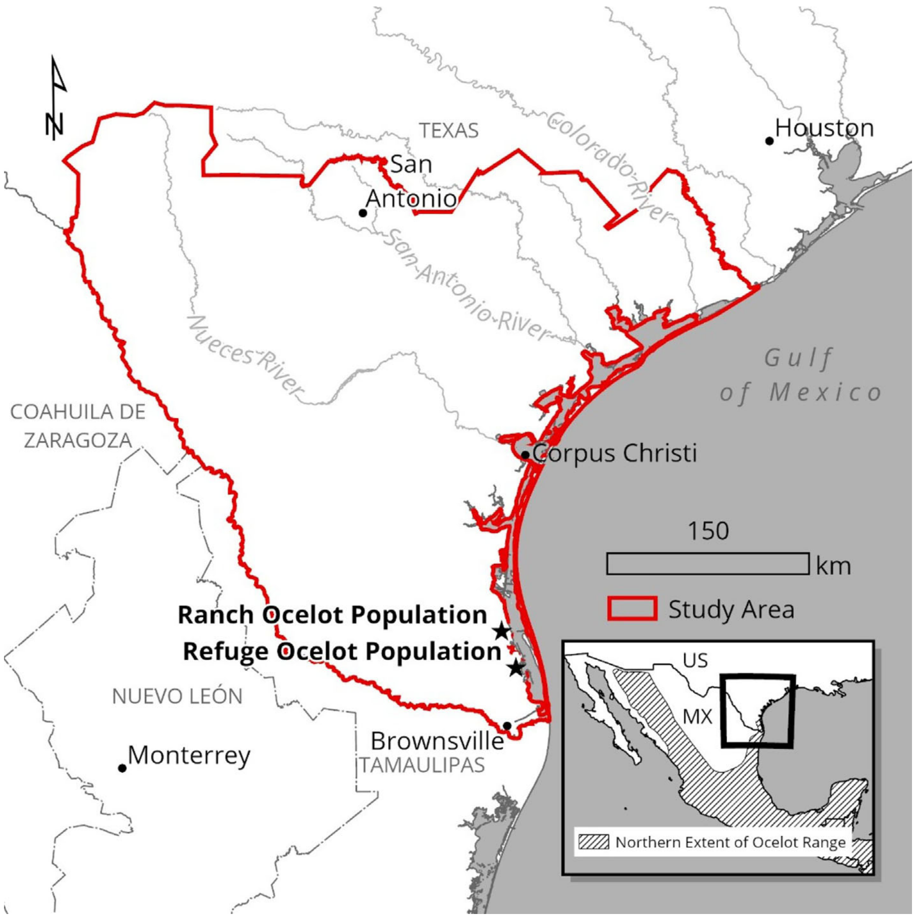

FIGURE 1 The study area assesses potential ocelot reintroduction sites in the lower 116,480 km^2 of Texas, United States, which is at the periphery of the northern half of the ocelot's (*Leopardus pardalis*) geographic range and currently has only two known populations.

thornshrub and herbaceous (i.e., cordgrass [*Spartina* sp.] and invasive guinea grass [*Megathyrsus maximus*]) understories (Lehnen et al., 2021; Lombardi et al., 2021; Sergeyev et al., 2022). Suitable landscape structure of woody cover for ocelots in Texas has been described as large, adjacent woody patches occurring in low densities on the landscape (Lombardi et al., 2021). Across their geographic range, ocelots inhabit a variety of mixed and dense vegetation communities and forested patches, including tropical deciduous forests (Lombardi, Haines, et al., 2022), pine-oak woodlands (Gómez-Ramírez et al., 2017), tropical broadleaf forests (Satter et al., 2019), savanna and galley forests (Paviolo et al., 2015) and semi-arid oak and shrub communities (Lehnen et al., 2021; Lombardi et al., 2021).

The small known range of ocelot populations in the United States—a few counties in coastal southern Texas—makes ocelots vulnerable to potential extirpation due to a local catastrophic event, such as a disease outbreak, mega-wildfire, or severe flooding from a major hurricanes. Major hurricanes are a particular concern for Texas's ocelots, which occur near low-elevation areas (<50 m) near the intercoastal Laguna Madre of the Gulf of Mexico. In the future, climate change may increase wildfire risk (Di Virgilio et al., 2019) and sea level rise (Sweet et al., 2022) and lead to increased frequency and severity of tropical cyclones and associated flooding (Knutson et al., 2020), which may threaten species occurring along coastlines.

The reintroduction of an additional, geographically distinct ocelot population in Texas is needed to ensure survival of ocelots in Texas and in the United States in the case of a catastrophic event such as wildfire. It also is necessary to increase the number of ocelots in the United States to achieve recovery from endangered species designation (US Fish and Wildlife Service, 2016). Selection of a site for reintroduction of an additional population of ocelots into historic but unoccupied habitat in southern Texas provides unique challenges for a felid reintroduction planning effort because over 97% of land in Texas is under private ownership (Leslie Jr, 2016; Lombardi et al., 2022). As such, private lands almost certainly must play a role in ocelot reintroduction in Texas, and private land dynamics such as ownership fragmentation and landowner concerns about legal implications of endangered species presence must be accounted for in site selection. This necessitates special consideration of socio-political factors when determining a reintroduction site, as both support and coordination from private landowners are needed to implement an ocelot reintroduction in Texas.

A multi-institutional collaborative study (https://RecoverTexasOcelots.org) was established in 2021 to partner state and federal wildlife agencies, academic institutions, conservation-minded non-governmental organizations, and private landowners to examine the feasibility of reintroducing an additional ocelot population to a portion of its historic but now unoccupied range in southern Texas within and proximate to the ecoregions currently occupied by ocelots in Texas. An initial objective in the effort was the use of IUCN guidelines for reintroduction (IUCN/SSC, 2013) in a large-scale geospatial assessment to identify possible reintroduction sites based on species ecology and socio-political dimensions. We designed an assessment to identify sites with high ecological suitability for ocelot occupancy as well as minimal natural and anthropogenic threats to ocelots. Furthermore, recognizing the need for sites to be socio-politically and logistically feasible for ocelot reintroduction, we considered patterns in land ownership to identify the most suitable potential reintroduction sites. Collectively, we used this information to identify potential reintroduction sites that were evaluated as candidates for future ocelot reintroductions. Our work was used to select a site for initial ocelot reintroduction efforts in southern Texas, and it has provided a model for the incorporation of private land information into assessments of potential wildlife reintroduction sites that occur in regions composed partly or even completely of private lands.

2 | METHODS

2.1 | Study area

We analyzed approximately the southern one-third (lower 46 counties) of Texas (approximately 116,480 km^2; Figure 1) as this area is presumed to be historic ocelot habitat (US Fish and Wildlife Service, 2016). The southern third of Texas encompasses a variety of ecoregions. The northernmost portion of the study area is the Edwards Plateau region, which contains ashe juniper (*Juniperus ashei*) and live oak woodlands and canyonlands. The center of the study area contains the southern Texas coastal plains region, which is primarily live oak and mesquite woodlands with extensive Texas-Tamaulipan thornshrub communities. Finally, the southernmost part of the region—which includes the range of existing ocelot populations—contains the Lower Rio Grande Valley and Rio Grande Delta of the western Gulf coastal plain, which is characterized by subtropical and tropical vegetation communities, extensive row-crop agriculture, and a highly urbanized bi-national metropolitan area (Griffith et al., 2007; Leslie Jr, 2016).

We took a two-step approach to assess ocelot reintroduction sites in the study area, beginning with an assessment of relevant factors at a macro-scale followed by an assessment of habitat at a fine scale. Metrics at both scales were calculated using R statistical software (R Core Team, 2020). The approaches in our stepwise process are described below.

2.2 | Macro-scale assessment

2.2.1 | Ecological/life history factors

We used published assessments to identify landscape-scale ecological factors that predict ocelot habitat in Texas. Ocelots use large patches of woody cover with characteristic measures of low landscape shape index, aggregation index, edge, and patch density in addition to high percentages of woody cover and largest patch index (see Table 2 in Lombardi et al., 2021). Using these measures, Lombardi et al. (2021) published a map of suitable landscape structure of woody cover for ocelots in the southernmost 19 counties of Texas. We replicated the methods from Lombardi et al. (2021) using the ocelot's optimal range of values for each landscape metric to expand the map of highly suitable landscape structure of woody cover for ocelots across our entire study area. We chose to limit our consideration of macro-scale ecological factors to landscape cover type (woody, herbaceous, bare ground, cropland, urban, or water) and structure (Lombardi et al., 2021). We did not include assessments of prey distributions because ocelots are dietary generalists (de Villa Meza et al., 2002; Moreno et al., 2006). In South Texas specifically, ocelots have been found to consume nine species of small rodents plus white-tailed deer (*Odocoileus virginianus*), black-tailed jackrabbit (*Lepus californicus*), eastern cottontail (*Sylvilagus floridanus*), and several species of birds and reptiles (Booth-Binczik et al., 2013). While a model of prey distribution may be necessary for identifying habitat for a dietary specialist, we believed the ocelot's generalist diet did not necessitate such an evaluation.

2.3 | Natural and human threats to ocelots

We next removed areas of suitable landscape structure of woody cover where a reintroduced ocelot population could be negatively impacted by natural and human threats. First, we considered major hurricane impacts (i.e., storm surge flooding) because one goal of the reintroduction is to establish an ocelot population that will not be impacted by stochastic, and potentially catastrophic, major hurricanes. We used the National Oceanic and Atmospheric Administration's Sea, Lake, and

Overland Surges from Hurricanes model (SLOSH; Zachary et al., 2015) to identify areas at risk of inundation during storm surges associated with hurricanes. We used SLOSH's Maximum of the Maximum Envelope of Water Category 5 output, which is an ensemble product of maximum "worse-case scenario" storm surge predictions from multiple hurricane simulations for the Saffir-Simpson category 5 (Stockdon & Thompson, 2007). We then removed suitable landscape structure of woody cover where maximum storm surge inundation was predicted to be at least 0.30 meters (one foot) above ground level to account for potential flooding of ocelot habitat.

Next, we considered human threats to ocelots. Given that roadways are the largest known source of mortality for the Refuge Ocelot Population in Texas (Blackburn et al., 2022) and that ocelot resource use is greatest at least 1 km from high-traffic roadways (Veals et al., 2022), we removed suitable landscape structure of woody cover within 1 km of any high traffic roadway, defined as a roadway with Annual Average Daily Traffic of at least 1000 vehicles/day (Texas Department of Transportation, 2021). Then, we accounted for potential habitat loss due to land development by removing any suitable landscape structure of woody cover predicted to be developed by 2050 according to the Integrated Climate and Land-Use Scenarios dataset (Version 2.1.1 with SSP2 and RCP4.5 Pathways, US Environmental Protection Agency, 2010).

Finally, we identified distinct patches of suitable landscape structure of woody cover based on the remaining suitable landscape structure available following the previous steps. To do this, we used a moving window analysis to determine the proportion of suitable landscape structure of woody cover within a neighborhood (window) of each suitable cell. We used a window size of 0.86 km^2, which represented a balance between computer system processing requirements and the daily movement range of an ocelot, which has been estimated at 1.5 km^2 in Texas (Blackburn et al., 2022). Cells of suitable landscape structure of woody cover with a neighborhood density of less than 75% suitable landscape structure of woody cover were removed from further consideration while remaining continuous cells were delineated into discrete patches.

2.4 | Ranking patches by including socio-political factors

After identifying continuous patches with suitable landscape structure of woody cover distinct from likely threats to ocelots, we uniquely identified and ranked patches based on patch size (km^2), threats to ocelots, and socio-political considerations by using Spatial Analyst tools in ArcGIS Pro (ESRI, 2020). To account for socio-political factors that may influence the feasibility of ocelot reintroduction on private lands, we incorporated land ownership data (Texas Natural Resource Information System, 2021). We identified individual land holdings (parcels) within discrete patches of suitable landscape structure of woody cover, considering adjacent parcels owned by the same landowner as one parcel, and extracted the size of each parcel. We also distinguished all areas of protected land under federal, state, or local ownership or private conservation organization (e.g., land trusts) ownership that were within 25 km of each patch (Texas Natural Resource Information System, 2021). We believed that, when implementing an ocelot reintroduction and seeking landscape-scale conservation, it is preferable to minimize ownership boundaries and to coordinate with a small number of landowners who own large parcels versus many landowners who each own a small parcel. Furthermore, we assumed that each reintroduction patch needs a large ownership parcel to serve as a central location for ocelot reintroduction activities. We defined large ownership parcels as land holdings of at least 25,000 acres (approximately 101 km^2), which would be large enough to support about 8–10 male ocelot home ranges with 2–3 female ocelots per male (US Fish and Wildlife Service, 2016.).

For each patch, we calculated several metrics: (1) area (km^2) of suitable landscape structure of woody cover, (2) degree of land ownership fragmentation in the patch (i.e., area of patch divided by the number of unique landowners in the patch), (3) area (km^2) of the patch found within large ownership parcels of at least 25,000 acres (approximately 101 km^2), (4) size (km^2) of the largest ownership parcel in the patch, and (5) minimum distance (m) between the boundary of the largest parcel in the patch and the nearest high traffic road. For each patch, we calculated the normalized value of each metric by subtracting the minimum value of all patches from that patch's value and then dividing by the difference between the maximum and minimum values of all patches. Each patch's final scoring was calculated as the mean of all five normalized metric values, which were all considered equally important. Patches were ranked based on their mean normalized score, and the five highest-scoring patches were further evaluated based on socio-political considerations and fine-scale assessment of ecology.

After identifying the highest-scoring patches, we also gathered high-level socio-political information about the patches to provide information about private landowner values within each patch and to inform future landowner outreach at patches. We obtained general information about private landowners within the patches from local project partners who participate in private land conservation and wildlife research in South Texas and are familiar with landowners there. These partners included the Texas Parks and Wildlife Department (TPWD), Caesar Kleberg Wildlife Research Institute (CKWRI) at Texas A&M University-Kingsville, and the East Foundation, a private landowner and member of the South Texas Property Rights Association. We queried these partners on their knowledge of landowners' likely attitudes toward collaborating with agencies and universities on the reintroduction of a federally endangered carnivore species on and around their lands. We did not conduct a formal survey of all landowners in the patches or contact any specific landowners in the high-ranking patches to avoid creating possible public concern about ocelot reintroduction during the early planning stages of the program. We believed that direct contact with specific landowners in the patches would be a necessary follow-up action on our assessment to provide more detailed data on the willingness of landowners to allow a reintroduction effort on their lands and to participate in the effort.

2.5 | Fine-scale ecological assessment

After identifying the top-ranking patches, we again assessed ecological factors, this time evaluating vegetation (including woody and herbaceous vegetation) at a fine scale within the highest-ranking patches. We used Light Detection and Ranging (LiDAR) metrics (US Geological Survey, 2018a, 2018b, 2018c, 2019) to identify appropriate fine-scale vegetation characteristics for ocelots. We evaluated two variables derived from Aerial LiDAR Scan (ALS) that may influence ocelot habitat use at a fine scale: canopy height (m) and understory vegetation density (Sergeyev et al., 2022). We used the R packages LidR (Version 1.0.4; Roussel et al., 2020) and raster (version 3.4-5; Hijmans & van Etten, 2012) to process ALS data for these metrics within 30-m grid cells. We calculated canopy height as the 95th percentile elevation value in meters above ground level for all points located within each 30-m grid cell. We represented vegetation density in the understory using the normalized relative point density (NRD) metric, which is a measure of LiDAR point density within a specific vertical stratum (US Department of Agriculture Forest Service, 2021). We calculated NRD within each 30-m cell by dividing the total number of LiDAR points between 0.5 and 1 m above ground level by the total number of points below 1 m above ground level. We selected this height filter because ocelots, which stand about 0.5 m in height, have been documented selecting for vegetative cover near 1 m in height while resting and hunting (Sergeyev et al., 2022, 2023). We applied a logarithmic transformation to the NRD values to reduce skewness in data.

We identified the average canopy height and vegetation density at known ocelot locations using data from 12 ocelots (4 adult males, 8 adult females) that were monitored on two private ranches within the Ranch Ocelot Population from 2017 to 2022 (Lombardi et al., 2021; Sergeyev et al., 2022). Monitored ocelots were equipped with GPS collars that recorded locations every 0.5–1 h over a duration of 4–9 months (Lombardi et al., 2021; Sergeyev et al., 2022). We characterized suitable fine-scale cover for ocelots in the reintroduction patches as within a threshold of two standard deviations from the means for each metric measured in the known ocelot locations (log-transformed normalized vegetation density mean was −2.23 and standard deviation 1.13; mean canopy height was 5.83 m with standard deviation 1.23 m). In the highest-ranking patches of suitable landscape cover, we classified pixels within the thresholds for both metrics as suitable fine-scale vegetative cover for ocelots. Then, we applied the same moving window analysis used earlier to identify dense and continuous patches of fine-scale vegetative cover within the highest-ranking patches of suitable landscape cover.

Finally, we estimated the carrying capacity for each patch based on its area of identified suitable landscape structure of woody cover (maximum estimated carrying capacity), and fine-scale vegetative cover (minimum estimated carrying capacity), and recent population estimates in comparable habitats in Northeastern Mexico (~11.6 ocelots/100 km^2; Lombardi et al., 2022) and southern Texas (17.6 ocelots/100 km^2; Lombardi et al., 2022). The northernmost of the high-ranking patches we identified occur in the Texas Hill Country, which is characterized by elevation >300 m and deciduous and evergreen forests; therefore, we calculated carrying capacity there based on estimates from the mountainous areas of the Sierra Tamaulipas in northeastern Mexico. The Central and Southern patches we identified have similar vegetation communities to those currently occupied by ocelots in southern Texas, so we used density estimates from existing ocelot populations in southern Texas (17.6 ocelots/100 km^2; Lombardi et al., 2022) to estimate carrying capacity in the Southern and Central patches.

3 | RESULTS

We found that the majority of our area of interest in southern Texas had suitable landscape structure of woody cover for ocelots (Figure 2A) that was also remote from anticipated anthropogenic or natural threats to

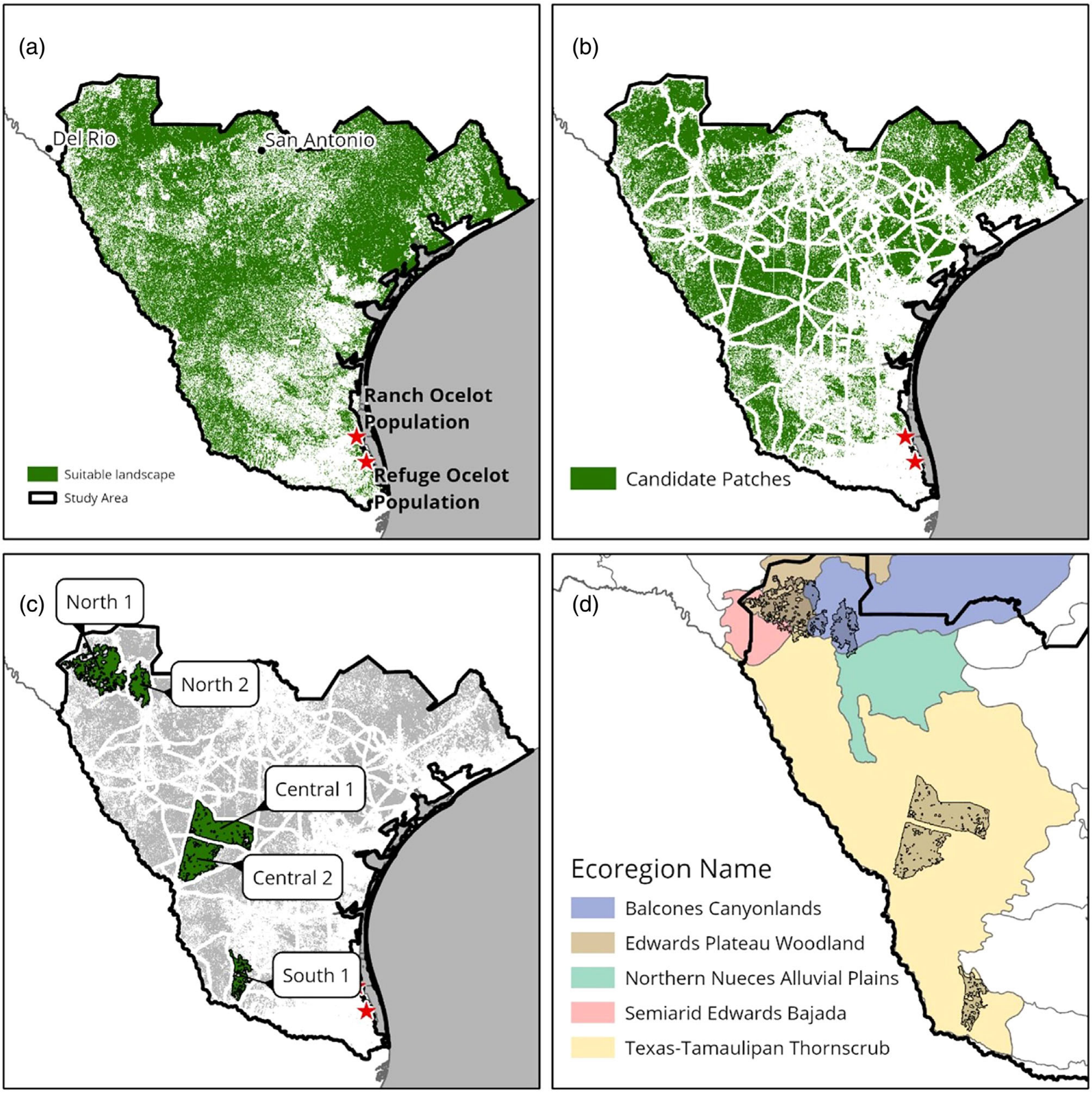

FIGURE 2 Progression of the methodology used in our assessment of potential ocelot (*Leopardus pardalis pardalis*) reintroduction sites in the southern 46 counties of Texas, starting with (A) all suitable landscape structure of woody cover for ocelots, (B) continuous patches of suitable landscape structure of woody cover that remained after areas likely to impacted by human or natural threats to ocelots (i.e., areas within 1 km from high-traffic roadways or areas of future urban development or storm surge from Category 5 major hurricanes) were removed, (C) the highest-ranking patches of remaining suitable landscape structure of woody cover (based on patch area [km^2], ownership fragmentation, area within large parcels exceeding 101 km^2, area of the largest single parcel, and distance between the largest parcel and a high-traffic roadway), (D) and the location of highest-ranking patches within ecoregions in Texas.

ocelots that must avoided in a reintroduction (Figure 2B). By ranking discrete patches of suitable contiguous landscape structure of woody cover based on size, degree of land ownership fragmentation, total area of large (≥101 km^2) parcels, size of the largest parcel, and remoteness of the largest parcel within each patch from a high-traffic road, we found that five patches emerged from our criteria as the highest-ranking possible reintroduction sites (Table 1). Assessment of canopy height and understory vegetation density at a fine scale within these five patches using LiDAR showed that suitable fine-scale vegetative cover was present in all patches (Figure 3). The

TABLE 1 Normalized metric and mean scores, on a scale from 0 to 100, for the top five habitat patches are reported. Higher scores indicate a greater suitability relative to all other patches.

Patch	Area of suitable landscape structure	Area within large parcels (>25,000 acres)	Size of largest parcel	Distance from the largest parcel to the nearest high-traffic road	Land ownership fragmentation	Mean score
North 1	29.99	13.01	20.56	98.57	2.34	32.90
North 2	30.95	15.92	21.08	100.00	1.56	33.90
Central 1	100.00	34.31	27.33	36.57	4.76	40.59
Central 2	76.30	100.00	73.55	31.72	8.26	57.97
South 1	30.28	22.80	56.87	49.25	2.01	32.24

TABLE 2 Areas of suitable landscape structure of woody cover and fine scale vegetative cover and estimated maximum and minimum carrying capacity values, respectively, for the five highest-ranking potential ocelot (*Leopardus pardalis pardalis*) reintroduction patches identified across the southern 46 counties of Texas. Carrying capacities were quantified based on the total available ocelot-specific suitable landscape structure (maximum) and fine scale vegetative cover (minimum) based on studies in similar habitat and elevational zones in Texas (17.6/100 km^2 Lombardi, Sergeyev, et al., 2022) and Northeastern Mexico (11.6 ocelots/100 km^2; Lombardi, Stasey, et al., 2022).

Patch	Area suitable fine-scale vegetative cover (km^2)	Area fine scale vegetative cover in largest single ownership parcel in patch (km^2)	Area suitable landscape structure of woody cover (km^2)	Estimated ocelot density from literature	Estimated minimum carrying capacity	Estimated maximum carrying capacity
North 1	1450	181	1548	11.6 /100 km^2	168.20	179.57
North 2	519	141	588	11.6 /100 km^2	60.20	68.20
Central 1	978	71	1577	17.6 /100 km^2	172.13	277.55
Central 2	943	226	1203	17.6 /100 km^2	165.97	211.73
South 1	363	124	478	17.6 /100 km^2	63.89	84.13

five patches have a wide geographic extent in Texas, and they represent diverse ecological communities; delineation based on Level IV Ecoregions (US Environmental Protection Agency, 2013) shows that the Central patches and South patch are located within the Texas-Tamaulipan thornshrub ecoregion while the two northern patches are at a nexus between Balcones Canyonlands, Edwards Plateau Woodland, and Semiarid Edwards Bajada ecoregions (Figure 2D).

The area of suitable landscape structure of woody cover and fine-scale vegetative cover varied between top patches, as did expected carrying capacities and land ownership patterns (Table 2). The North patches (Figure 3A) were adjacent patches separated by a high-traffic state highway with a large, combined area of suitable landscape structure of woody cover (2136 km^2) and fine-scale vegetative cover (1969 km^2). Estimated carrying capacities across both areas combined range from 228.40 to 247.77 ocelots (Table 2). The North patches had the most potential for connectivity to protected lands. Both patches were composed partially of protected lands, and there were networks of protected lands to both the east and west of the patches. Regarding private lands, TPWD biologists reported that many large landowners in the area were conservation-minded and may be agreeable to an ocelot reintroduction project on and around their lands. However, the largest known land holding in the area, the Briscoe Ranch, currently has a public controversy over property ownership.

The largest identified patches were the central patches, which were adjacent but separated by a high-traffic state highway (Figure 3B). Combined, these two adjacent patches had the largest tracts of suitable landscape structure of woody cover (2780 km^2) and fine-scale vegetative cover (1921 km^2) with estimated combined carrying capacities ranging from 338.10 to 489.28 ocelots (Table 2). The patches are bordered by an Interstate, state highways, and county Farm-to-Market roads. While there were several large (>101 km^2) private parcels in and around the patches, there was only one protected area in Central patch 1 and none in Central patch 2. Furthermore, there were limited protected lands in the vicinity of the Central patches. Biologists from project partners including CKWRI and TPWD expressed concern about

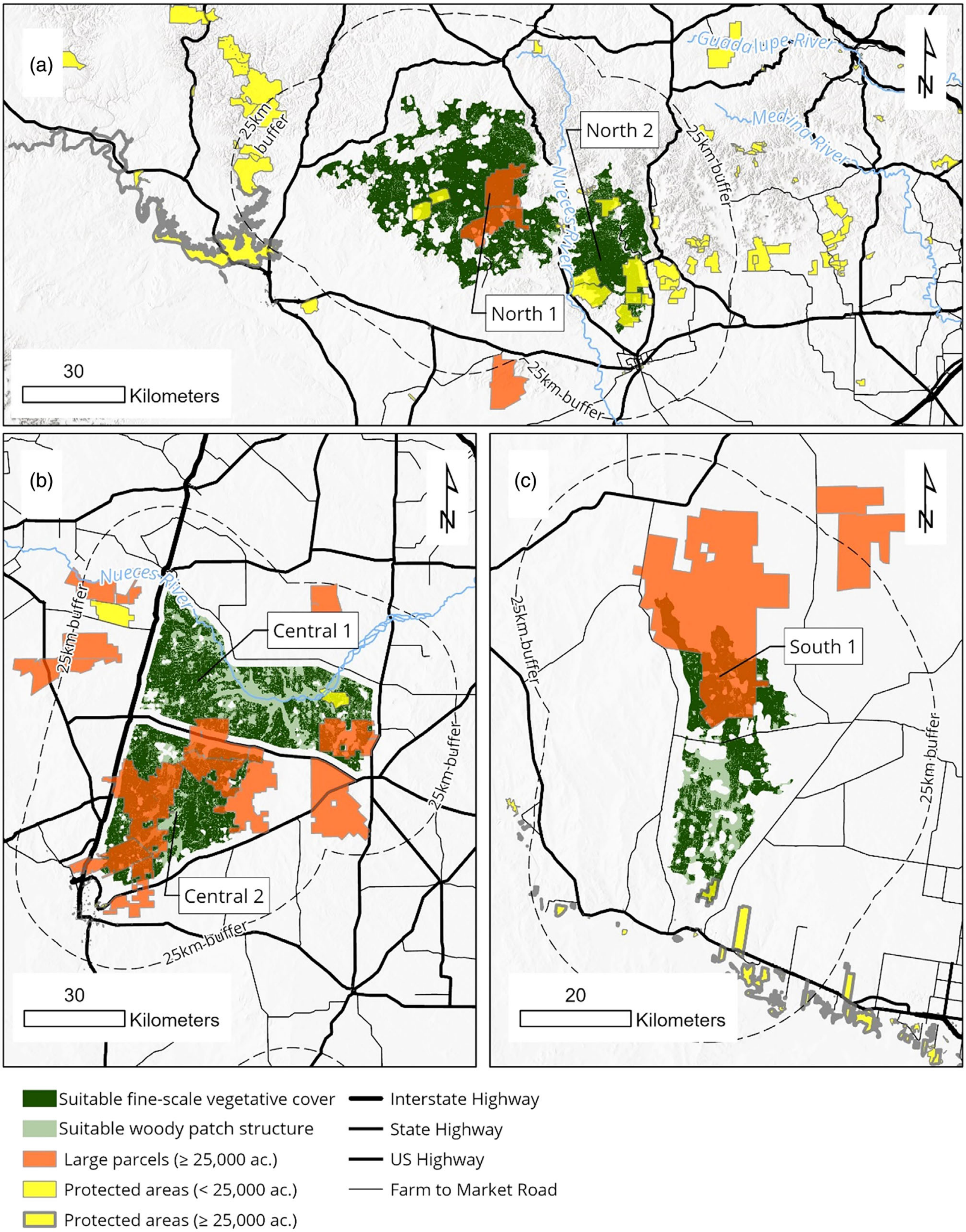

FIGURE 3 Within the five highest-ranking potential ocelot (*Leopardus pardalis pardalis*) reintroduction patches identified across the southern 46 counties of Texas, suitable fine-scale vegetative cover, identified using LiDAR analysis of canopy height and shrub and herbaceous-level vegetation density at 0.5–1 m in height, overlaid on suitable landscape structure of woody cover.

private landowner tolerance of ocelot reintroduction in these patches because several landowners in the patches have previously expressed disinterest in acknowledging the presence of endangered species on their properties. Partners believed it would be necessary to further study landowner attitudes in this area to assess whether it may be possible to obtain landowner support for ocelot reintroduction throughout the Central patches.

The South patch was the smallest (Figure 3C) in the extent of suitable landscape structure (478 km^2) and fine-scale vegetative cover (363 km^2) and had the lowest estimated carrying capacity (63.89–84.13 ocelots). It was also the most remote from high-traffic roadways, as it is near multiple county Farm-to-Market roads but no Interstates and only one state highway. The patch included only one protected area, which is found at the southern periphery of the patch, and there is a network of protected areas to the south of the patch. The largest private parcel in the patch is owned by project partner the East Foundation, an Agricultural Research Organization that has a mission to remain a working cattle ranch and promote land stewardship, in perpetuity. CKWRI and TPWD reported positive working relationships with other private landowners in the patch and agreed that this may aid in earning private landowner support for ocelot reintroduction, though the East Foundation needed to consult with its neighboring properties more closely to assess their tolerance for ocelot reintroduction in the South patch.

4 | DISCUSSION

We used a geospatial approach to analyze the southern 46 counties of Texas to identify the five highest-ranking patches that may be further assessed as suitable sites for the future reintroduction of an additional ocelot population. We identified the highest-ranking potential reintroduction patches based on IUCN recommendations for selecting reintroduction sites based on ecology, size, human and natural threats, and socio-political dimensions of land ownership (IUCN/SSC, 2013). The inclusion of socio-political information in our model, including spatial land ownership data relevant to the coordination of navigating land ownership patterns, and high-level knowledge of likely private landowner attitudes toward endangered species reintroduction at possible patches was unique for a felid reintroduction site assessment. The inclusion of socio-political information was mandatory considering that Texas is majority (>97%) privately owned and any ocelot reintroduction in Texas likely must occur on private lands. Indeed, we found that the majority of lands in and around the five highest-ranking potential ocelot reintroduction patches in Texas were privately owned, and there were limited protected lands within 25 km of the patches. This was particularly true for the Central patches and the South patch.

Our methodology can be a model for assessments of wildlife reintroduction sites for species that do not have sufficient habitat within protected lands and instead require a matrix of private and public lands for conservation. This is a common occurrence in the United States, where conservation efforts on private lands are critical to biodiversity conservation goals given that existing protected lands do not provide enough habitat (Jenkins et al., 2015). In Texas alone, there are several federally endangered wildlife species beyond ocelots whose recovery requires reintroductions that will likely occur on privately owned lands given the land ownership makeup of Texas. Reintroduction planning for these species should include an assessment similar to ours. For example, the jaguarundi (*Puma yagouaroundi*) is a small neotropical felid recently extirpated from the United States (Lombardi et al., 2022) that requires reintroduction efforts in southern Texas (US Fish and Wildlife Service, 2013). Also in Texas, a captive breeding and reintroduction program exists for the Attwater's prairie chicken (*Tympanuchus capido attwateri*), a federally endangered grouse, and managers are seeking additional release sites on private lands (US Fish and Wildlife Service, 2010).

For carnivore reintroduction site assessments in areas with a significant makeup of private lands, we recommend mapping land parcel fragmentation within patches of ecologically suitable habitat and obtaining information about likely private landowner tolerances for conservation efforts. Land ownership fragmentation patterns must be considered because coordinating with a small group of large landowners rather than many small entities is likely to ease the burden of organizing field coordination and securing site-wide landowner support for reintroduction. Obtaining information from local organizations familiar with private landowners about likely landowner tolerances and values, meanwhile, will help guide further prioritization of sites and outreach to landowners to obtain more socio-political information. Background knowledge of private landowner attitudes will also help prevent contact with individuals who are unlikely to be supportive of a conservation project and may become opponents of the effort. At the highest-ranking sites where landowners are likely to be tolerant of reintroduction, managers should approach private landowners to individually assess their willingness to offer their lands for reintroduction and to provide additional logistical field support, as necessary.

Only two published assessments of felid reintroduction sites have explicitly considered land ownership data, though neither used land ownership as a variable in their models of habitat. Thatcher et al. (2006) identified whether large tracts of protected public lands, such as National Parks, were present in potential Florida panther reintroduction sites that were otherwise identified by models of landscape cover and human disturbance. More recently, panther conservationists have recognized that the conservation value of privately owned ranchlands should not be discounted and in fact, private lands are likely critical for recovery of the Florida panther (Kreye & Pienaar, 2015). Garrote et al. (2020) created a model of reintroduction habitat for Iberian lynx based on landscape cover and found that over half of the identified lynx habitat was on private lands. Rather than considering routes for conserving lynx on private lands, the authors suggested that the model's results "should be used as a guide for the creation of new protected areas."

IUCN guidelines for reintroduction (IUCN/SSC, 2013) suggest that reintroduction sites should be legally protected and thus "secure from incompatible land-use change…ideally, in perpetuity." This guideline promotes discounting private lands as potential wildlife reintroduction sites rather than using private land ownership data in reintroduction site assessments and evaluating the feasibility of conducting a reintroduction on private lands. As in the panther and Iberian lynx studies, land ownership data is sometimes used only to differentiate sites based on the presence of public lands, with the assumption that public lands provide better long-term protection for wildlife and habitat than private lands do (e.g., Sneed, 2001). Wildlife reintroduction planners may focus on public lands and disregard potential habitat on private lands because of assumptions that human-wildlife conflict will be high on private lands and that possible turnover in private land ownership and landowners' changing interests in conservation projects will hinder long-term cooperation. Ditmer et al. (2022) have complicated this by pointing out that private lands are not homogenous regarding the potential for human-wildlife conflict, landowner attitudes, and land uses, while Carver et al. (2021) have suggested that private lands can even serve as core areas for rewilding efforts.

An ocelot reintroduction at any of the highest-ranking patches identified in our analysis has the potential to increase ocelot numbers in Texas and promote ocelots' delisting from the endangered species list. Furthermore, the estimated minimum carrying capacities at each of the highest-ranking patches exceed 50 individuals, the estimated minimum effective population size for avoiding inbreeding depression in small populations (Franklin & Frankham, 1998). Any of the identified sites can also expand the ocelot's currently occupied range in southern Texas. A reintroduction at one of these sites will create resistance to the complete loss of ocelots in Texas in the case of a catastrophe—whether it be a wildfire, disease outbreak, or a major hurricane—that impacts the two small existing ocelot populations in the state. The trade-off with choosing a reintroduction site geographically distinct from existing populations is that natural connectivity between the existing populations and the potential reintroduction sites is unlikely to occur without significant habitat restoration to create connectivity. The highest-ranking reintroduction patches we identified are all over 100 km from the existing ocelot populations. Given that the longest recorded ocelot dispersal is 50 km (Booth-Binczik, 2007), significant habitat connectivity efforts would be necessary to promote natural connectivity between reintroduced and existing ocelot populations in Texas.

A reintroduction at any of the sites identified in this analysis is only feasible if landowner support can be secured there. Though protected lands may be ideal sites for wildlife conservation projects, they were mostly unavailable in the large reintroduction sites we identified. Private landowners are needed to make reintroduction possible and must provide access to their properties, directly release ocelots on their lands, and manage lands in a way that can sustain ocelots, for example. Some landowners may be willing to voluntarily contribute to ocelot reintroduction efforts, and their support will require development of legal assurances that landowners' voluntary participation in ocelot reintroduction will not result in land use restrictions related to Endangered Species Act regulations.

Although it was the smallest of the highest-ranking potential reintroduction sites identified in our assessment, ocelot reintroduction planners believed that the South patch may provide the most viable option for an initial ocelot reintroduction effort in Texas. Project partner the East Foundation, an Agricultural Research Organization, owns a ranch covering over 30% (124 km^2 of fine-scale vegetative cover) of the patch, which occurs within a sparsely populated region of remote ranchlands. Following the presentation of this study, East Foundation offered to meet the critical operational needs of a reintroduction effort, such as constructing facilities and employing program personnel (Reading et al., 2002). In contrast to the South patch, the North patches had more protected lands in and around the patches, but the only private land holding over 25,000 acres (101 km^2) in the area is complicated by a public legal battle over control and ownership of the property. Meanwhile, the Central patches had almost no protected lands, and local stakeholders TPWD and CKWRI were concerned that private landowners in the area would have low tolerances for endangered species given past interactions between the landowners and wildlife research and conservation organizations and agencies.

The remoteness of the South patch from both urban development and high densities of high-traffic roadways (though it is still framed by low-traffic county roadways), coupled with its relatively strong social tolerance for ocelot reintroduction creates a strong case for selecting this patch for initial ocelot reintroduction efforts in Texas. Following the analysis conducted here, the East Foundation held meetings with private landowners also within the South patch and found that they were supportive of ocelot reintroduction on and around their lands if their regulatory concerns about endangered species could be addressed. East Foundation and the US Fish and Wildlife Service then developed a proposed Safe Harbor Agreement for ocelot reintroduction on the East Foundation property within the South patch (88 US Federal Register 63598). The Safe Harbor Agreement will authorize the East Foundation to release ocelots onto its land in exchange for federal government assurances that the East Foundation, and any of its private landowner neighbors whose lands ocelots may disperse to, will not be subject to any new land use restrictions normally associated with Endangered Species Act regulations for federally protected species.

While the favorable socio-political situation at the South patch may make it at present the most realistic ocelot reintroduction site, any patches not initially selected for ocelot reintroduction should still be considered for future reintroductions. Continued research by the ocelot reintroduction study partners is now underway to further assess the socio-political dimensions of the Central and North patches to inform selection and prioritization of future possible ocelot reintroduction sites. Socio-political factors such as management on protected lands, private conservation easement designations, private landowner participation in state or university wildlife research or recreation programs, and planned development projects are being considered to determine whether private landowner support for ocelot reintroduction may be developed in the future at these patches to expand the scale of ocelot reintroduction efforts in Texas. If landowner support for ocelot reintroduction can be secured at these other patches, additional ocelot reintroductions may be planned there to provide further conservation support to the ocelot. Further, historic habitat outside of our initial area of interest (e.g., eastern Texas) should also be assessed for presence of potential ocelot habitat, which was historically destroyed due to clear-cutting or other land modifications.

Our work, along with that of Ditmer et al. (2022) and Carver et al. (2021), encourages the assessment of private lands, not just public protected lands, as potential wildlife reintroduction sites. We provide a method to integrate private land ownership data into reintroduction site assessments from a feasibility/coordination perspective by accounting for land ownership fragmentation and the size of land ownership parcels. Further, rather than seeing all private landowners as equal in terms of their likely willingness to engage in the reintroduction of an endangered species, we suggest gathering information from locally relevant stakeholders to assess and compare private landowner attitudes at potential reintroduction sites. We provide this assessment as a model for other conservation reintroduction planners who wish to account for the socio-political dimensions of private lands in their assessments of wildlife reintroduction sites.

AUTHOR CONTRIBUTIONS

Martinez, Lombardi, Powers, Anderson, Campbell, and Lopez contributed to the conceptual design of the habitat suitability model. Powers and Anderson conducted mapping and computational work. Martinez and Lombardi led the writing of the manuscript. All authors contributed to the development and revision of the manuscript drafts, and all gave their approval for publication.

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DATA AVAILABILITY STATEMENT

Due to the endangered species status of ocelots, we cannot share location-specific data of ocelots. Interested parties may contact Roel Lopez (roel@tamu.edu) of the Texas A&M Natural Resources Institute. All other data sets included in our analyses have been cited and are accessible online.

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