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# Better late than never: a synthesis of strategic land retirement and restoration in California

Christopher J. Lortie [1,2,†] A. Filazzola [2] R. Kelsey,[3] Abigail K. Hart,[3] and H. S. Butterfield[3]

[1]The National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, California 93101 USA
[2]Department of Biology, York University, Toronto, Ontario M3J 1P3 Canada
[3]The Nature Conservancy, San Francisco, California 94105 USA

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**Abstract.** Strategic retirement and restoration of agricultural lands is a critical conservation opportunity globally. The objective of this synthesis was to examine whether ecological habitat assessments, endangered species historical occurrence data, and restoration research can be used to develop evidence-based strategy for retiring and restoring agricultural lands. The San Joaquin Desert (SJD) of California is a prominent example because it experienced an extensive conversion to agriculture. Now, new groundwater regulations will lead to retirement on large areas of agricultural lands over the next 20 yr. This presents an opportunity to not only restore some of these lands but also explore the challenges associated with balancing direct human needs with other ecosystem-level functions. California is thus an ideal case study for globally rethinking context-specific, single-case study solutions. We used a systematic review and synthesis to address the following three main questions for habitat recovery of endangered species in the SJD. (1) What are the habitat requirements for key endangered animal species in the region? (2) Is there historical evidence to support an assessment of suitable habitats for these species? (3) What restoration techniques apply to these species? Using the Web of Science and other resources, we reviewed over 1000 independent studies on this topic, refined the evidence, and selected a total of 266 relevant publications. Habitat requirements for each species were described, but there was a critical need to examine quantitative thresholds for these factors to better evaluate habitat suitability of retired lands. There was sufficient evidence of historical vegetation to model suitable habitats and design the physical restoration of retired lands. Direct interventions associated with restoration strategies have been infrequently tested. Sparse and diverse evidence associated with direct experimental manipulations is not uncommon in applied ecology, and synthesis is an excellent tool for highlighting these gaps for future research to examine. This review suggests that retired agricultural land is a viable asset for threatened and endangered species, but to effectively advance restoration research and management, direct tests of restoration techniques and an assessment of relative costs for interventions are needed for a given region.

**Key words:** agriculture; arid; desert; endangered species; fallowing; PRISMA; restoration; retired lands; San Joaquin Desert; semi-arid; synthesis; systematic review.

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† **E-mail:** lortie@yorku.ca

## Introduction

Land transformation is a pressing global issue, and California is no exception. Managing large landscapes to balance the needs of humans and the function of natural systems is now a universal imperative and the focus of most sustainable development goals. Given that agricultural systems comprise up to 40% of the land surface globally (Ramankutty et al. 2008), strategic retirement and restoration of marginal or degraded agricultural lands is a critical and novel conservation opportunity. It is also likely that retirement of many agricultural lands will increase in the future due to limited water, poor soils, and a changing climate in many, if not all, major food-production regions (Webb et al. 2017). Reconciling food production with biodiversity conservation is arguably one of our greatest challenges. Strategic retirement and restoration can increase sustainable production on the best agricultural lands while facilitating recovery of natural systems and imperiled species in adjacent lands (Hopkins 2003). This is true even within highly developed agricultural regions like California. Landscape-level changes within the Central Valley of California, including the San Joaquin Desert (SJD), have been significant, ongoing for over 100 yr, and more recently accelerating (Germano et al. 2011). Anthropogenic drivers of change can be direct through agriculture, urban development, or energy developments and indirect through invasive species, native species displacement, and water use coupled with changes in local and regional climate (Charbonneau and Kondolf 1993, Berger-Tal and Bar-David 2015, Soulard and Wilson 2015, Tamara et al. 2016). To combat large-scale reductions in groundwater levels and land subsidence on over 2 million acres of irrigated agricultural lands, groundwater regulations in California have been enacted that will require retirement of more than 500,000 acres of agricultural land in the San Joaquin Valley in the next 10–20 yr (Hanak et al. 2017). This region is thus an ideal case study for scientific synthesis to explore whether there is sufficient evidence for strategic planning to optimize conservation, to maximize ecological recovery, and to further global insights and knowledge associated with general principles for effective restoration in all drylands. The extent of relevant primary research and delineation of critical evidence gaps are needed not only for strategy, planning, and targeted ecological research but also to elucidate specific solutions and general lessons that can be applied in other contexts regionally and globally.

The Central Valley of California has been converted to one of the most productive agricultural landscapes in the world. Formerly, this specific desert region was characterized by arid and semiarid grasslands, shrublands, and scrublands with a host of endemic desert-adapted species that ecologically differentiated it from other ecosystems (Germano et al. 2011). The SJD is now 90% dominated by agricultural and industrial land use, and it has one of the highest concentrations of threatened and endangered species in the continental United States (Williams et al. 1998). Three such species are the San Joaquin kit fox, the blunt-nosed leopard lizard, and the giant kangaroo rat (Prugh and Brashares 2012, Stewart et al. 2018). Habitat for these species is threatened by agricultural, energy (i.e., solar and oil), and residential developments (Williams et al. 1998, Germano et al. 2012). Drought, climate change, and invasion by exotic grasses and animals are exacerbating the impacts of habitat loss (Kozlowski et al. 2008, Westphal et al. 2016). This situation is not unique to California but indicative of pressures that drylands face globally (Winslow et al. 2011, Stringer Lindsay et al. 2017). Ecologically strategic planning for the retirement of agriculture will be essential to identify the most suitable current habitats for imperiled species and to restore vegetation that can effectively support the natural community as a whole.

The objective here was to use formal synthesis tools to examine the capacity for strategic agricultural retirement and restoration planning to support habitat for endangered animal species. This is a novel form of conservation because the focus is not on setting aside the best lands (that ship has sailed) but on recovering "used" lands (Toombs and Roberts 2009). This review summarized existing research on the three endangered SJD species listed above and used the following driving questions to structure a systematic review and general synthesis of research using this region as a case study. (1) What are the current habitat requirements for endangered species in a desert region with significant retiring land and anthropogenic pressures (i.e., species-level evidence)? (2) Is there historical evidence to support relatively larger-scale habitat planning for endangered species (i.e., landscape-level records)? (3) What are the applicable techniques for restoring retired agricultural lands (i.e., implementation-level tools)? To address these questions, we aggregated relevant studies and examined broad trends. However, we also introduced the concept of "flagship studies" to identify highly pertinent studies based on the provision of directly relevant solutions. The concept of flagship species is from conservation biology, and it characterizes species that are representative or strongly indicative of conservation priorities for a region (Bowen-Jones and Entwistle 2002). Typical of many scientific reviews, extensive sets of studies indirectly support evidence-based decision making for an applied conservation or restoration issue while a reduced subset of studies provide direct findings needed to address a problem including specific-needs data, maps, or identification of critical ecological requirements for a target species (Stewart and Schmid 2015). Consequently, we used this new synthesis-summary concept to provide a rapid mechanism for the end user to explore representative specific solutions.

## Methods

### *Systematic review*

We used the following three steps to complete a synthesis for these issues: (1) key terms searches on the Web of Science and other bibliometric resources including Google Scholar to assemble a robust and representative set of literature, (2) reproducible sorting to review each peer-reviewed publication for relevance to the driving questions, and (3) extraction of evidence from relevant peer-reviewed publications and other associated assets such as maps and occurrence data repositories. The Global Biodiversity Information Facility (GBIF), the Data Basin Repository, and other resources such as the Endangered Species Recovery Program were used to support and validate this synthesis. A total of 59 independent searches were done on the Web of Science generating over 1600 peer-reviewed publications (Appendix S1: Table S1). Every Web of Science return was checked for duplication and relevance. All exclusion criteria were documented, and a total of 941 peer-reviewed publications remained for further detailed screening (Lortie et al. 2018*b*). From this set of literature, a total of 266 publications were reviewed in depth (Appendix S1: Table S2). A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) report (Moher et al. 2009) was generated to show this workflow in detail (Appendix S1: Fig. S1).

We used 96 peer-reviewed publications to address the habitat preferences of the species, 14 peer-reviewed publications to address the suitability of historical assessments, and 156 peer-reviewed publications to address the restoration of retired agricultural lands. The most relevant contemporary gray literature was also queried from agencies and universities within California. The species measured, tools used, key factors examined, primary outcomes, sample sizes, and other detailed information were captured from every study. The flagship study designation was also applied to highlight and summarize representative solution studies for each driving question (Table 1).

### *Indicator species selection*

The San Joaquin kit fox (*Vulpes macrotis* ssp. *mutica*) is a subspecies of the desert kit fox (*V. macrotis*) and was both federally and state listed as endangered in 1967 (Williams et al. 1998). The subspecies is endemic to the San Joaquin Valley of California, but the kit fox species is distributed in all the North American deserts. The giant kangaroo rat (*Dipodomys ingens*) is a semi-arid-to-arid species that is restricted to relatively productive desert areas with high biomass because of their dietary requirements (Bean et al. 2014). It is the largest of the 21 kangaroo rat species and endemic to the San Joaquin Valley (Williams 1992). It was federally and state listed as endangered in 1987 (Williams et al. 1998). The giant kangaroo rat is considered an ecosystem engineer because it provides burrows for lizard species and reduces vegetation cover that benefits other foraging animals (Prugh and Brashares 2012). This species is a prey resource for the San Joaquin kit fox and blunt-nosed leopard lizards. The blunt-nosed leopard lizard (*Gambelia sila*) is also endemic to the SJD (Germano et al. 2001). It was federally and state listed as endangered in 1971 (Williams et al. 1998). These three animal species are thus representative indicators of connections between retired agricultural lands and restoration research because of their conservation status, sensitivity to change, and former distribution throughout region, endemism, and respective ecologies.

Table 1. A list of flagship studies that specifically explore habitat assessment and quantification for the SJD.

| Q | Title | Year | Species | Tool |
|---|---|---|---|---|
| 1 | Optimizing habitat protection using demographic models of population viability | 2002 | San Joaquin kit fox | Model |
| 1 | Optimizing reserve expansion for disjunct populations of San Joaquin kit fox | 2004 | San Joaquin kit fox | Model |
| 1 | Partitioning the effects of an ecosystem engineer: Kangaroo rats control community structure via multiple pathways | 2012 | Giant kangaroo rat | Trapping |
| 1 | Persistence of historical population structure in an endangered species despite near-complete biome conversion in California's SJD | 2017 | Blunt-nosed leopard lizard | Transects |
| 1 | Species distribution models of an endangered rodent offer conflicting measures of habitat quality at multiple scales | 2014 | Giant kangaroo rat | Trapping |
| 1 | Translocating endangered kangaroo rats in the San Joaquin Valley of California: recommendations for future efforts | 2013 | Tipton kangaroo rats | Review |
| 1 | Use of agricultural lands by San Joaquin kit foxes12 | 2007 | San Joaquin kit fox | Telemetry |
| 2 | Can Orchards Help Connect Mediterranean Ecosystems? Animal Movement Data Alter Conservation Priorities | 2015 | Bobcats | Survey |
| 2 | Ghost of habitat past: Historic habitat affects the contemporary distribution of giant garter snakes in a modified landscape | 2014 | Giant garter snake | Survey |
| 2 | Habitat restoration and agricultural production under land retirement | 2001 | None | Simulation model |
| 2 | Is there room for all of us? Renewable energy and Xerospermophilus mohavensis | 2013 | Mohave ground squirrel | Survey |
| 3 | A genetic assessment of the recovery units for the Mojave population of the desert tortoise, Gopherus agassizii | 2007 | Desert tortoise | Survey |
| 3 | Agricultural legacies in the great basin alter vegetation cover, composition, and response to precipitation | 2006 | Plants | Survey |
| 3 | Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration | 1999 | Plants | Review |
| 3 | Benefit-cost model for an artificial recharge scenario in the San Joaquin Valley, California | 1999 | Hydrology | Model |
| 3 | Conserving species in fragmented habitats: population dynamics of the flat-tailed horned lizard, Phrynosoma mcallii | 2009 | Flat-tailed horned lizard | Survey |
| 3 | Energy analysis of reclaimed water application for irrigation in arid and semi-arid regions | 2016 | None | Model |
| 3 | Enhancing Quality of Desert Tortoise Habitat: augmenting Native Forage and Cover Plants | 2015 | Desert tortoise | Restoration |
| 3 | Guidelines for the field evaluation of desert tortoise health and disease | 2001 | Desert tortoise | Monitoring |
| 3 | Lack of native species recovery following severe exotic disturbance in southern Californian shrublands | 1999 | Shrubs | Monitoring |
| 3 | Mitigation-driven translocation effects on temperature, condition, growth, and mortality of Mojave desert tortoise (Gopherus agassizii) in the face of solar energy development | 2016 | Desert tortoise | Monitoring |
| 3 | Multiple factors affect a population of Agassiz's desert tortoise (Gopherus agassizii) in the northwestern Mojave Desert | 2013 | Desert tortoise | Monitoring |
| 3 | Perspectives in dryland restoration: approaches for climate change adaptation | 2012 | Plants | Review |
| 3 | Phytolith evidence for the extent and nature of prehistoric Californian grasslands | 2013 | Plant community | Survey |
| 3 | Restoration of Mediterranean ecosystems | 1999 | Plants | Review |
| 3 | Spatially explicit decision support for selecting translocation areas for Mojave desert tortoises | 2008 | Desert tortoise | Model |
| 3 | The SJD of California: ecologically Misunderstood and Overlooked | 2011 | All | Review |
| 3 | Using livestock to manage plant composition: a meta-analysis of grazing in California Mediterranean grasslands | 2013 | Plant community | Review |

*Notes:* SJD, San Joaquin Desert.
In this synthesis, a flagship study was defined as high-quality instances that directly provided evidence associated with the driving questions that structured this review. Each of these studies highlighted either a specific tool, approach, or proof of concept for restoration, or critical species information. Full citation detail for each provided in the appendices.

### *Climate profiles*

Species-level evidence relevant to restoration can be compiled from individual studies and from data repositories. We calculated an estimate of the range of climatic conditions for each species using occurrence data from GBIF to augment the primary research papers reviewed (Appendix S1: Eq. S1). The occurrences were cropped to the spatial boundary of California, and duplicates were removed. Mean annual temperature, mean annual precipitation, and altitude were retrieved from WorldClim (Hijmans et al. 2005). An aridity raster was also downloaded from the Global Aridity Index database. The aridity index is calculated based on the total precipitation for a given site divided by the potential evapotranspiration at the same site (Zomer et al. 2008). The Global Aridity Index is a useful indicator of productivity in deserts where lower values are more arid and less productive and higher values are less arid and more productive. These datasets represent long-term averages at a resolution of 30 arc-seconds (~1 km). The extents of these rasters were refined to California, and climatic variables with altitude were extracted for each occurrence for each species. The mean, maximum, minimum, and standard error were then calculated for the total occurrences for each species. The climatic ranges were defined as the maximum and minimum values.

### *Analyses*

All search, sort, synthesis, visualization, climate and occurrence retrieval, and literature processing were done in R version 3.5.0, version controlled using GitHub, and published to the code repository Zenodo (Lortie et al. 2018*a*).

## Results

### *Habitat requirements*

There were a total of 96 relevant studies describing habitat requirements, and seven studies were labeled as flagship studies. This set of evidence reported detailed species-level data with respect to specific habitat requirements for the three endangered species used in this case study.

The Carrizo Plain National Monument, Ciervo-Panoche, Western Kern County, and Contra Costa and Alameda counties have been used to study the San Joaquin kit fox and are all within the SJD (Table 1). Species distribution models (SDMs) estimate that the San Joaquin kit fox requires between 5600 and 12,000 ha of suitable habitat for persistence, but previously retired agricultural lands have been excluded from projects because of proposed limitations in acreage and availability of prey (Cypher et al. 2011, 2013). The assessment of habitat for the San Joaquin kit has been tested, and interactions with vegetation and other animals including coyotes and prey items have been confirmed as important criteria (Gerrard et al. 2001, Church et al. 2003). It has also been proposed that significant habitat connectivity is critical for this species (Haight and Travis 2008). San Joaquin kit fox tend to associate with saltbush (*Atriplex polycarpa*), and they avoid areas of high exotic grass densities (Smith et al. 2005). However, competition and predation from coyotes often exclude San Joaquin kit foxes from shrubland habitats (Nelson et al. 2007). Generally, predation and topography are reportedly more important predictors of occurrence for San Joaquin kit fox than prey availability or other habitat variables (Warrick and Cypher 1998), and the San Joaquin kit fox is found at a wide range of altitudes (Table 2).

San Joaquin kit foxes are also present in the urban areas within the region such as in Bakersfield, California. In developed areas, San Joaquin kit foxes are generally outcompeted by coyotes for anthropogenic food sources (Cypher and Spencer 1998). Decreases in natural prey items can consequently result in negative effects for the San Joaquin kit fox because there is a simultaneous decrease in food availability and inability to compete for remaining food sources. In the absence of coyotes, urban environments can provide additional resources at no cost to health of the animals (Cypher and Spencer 1998, Nelson et al. 2015). Sarcoptic mange from coyotes is a disease however only detected in urban populations of San Joaquin kit fox (Cypher et al. 2017).

The two largest remaining populations of giant kangaroo rats have been reported in the Ciervo-Panoche Area and the Carrizo Plain National Monument and represent a significant decline in regional extent (Williams et al. 1998). The giant kangaroo rat is found at elevations between 760 m and 1200 m (Braun 1985). This species prefers sandy-loam soil with topography that is gently sloping and that is <25°, and the home range of the giant kangaroo rat is 60–350 $m^2$

Table 2. The climate profile for the San Joaquin Desert animal species used to explore retired lands in this regional synthesis.

| Measure | Temperature (°C) | Precipitation (mm) | Altitude (m) | Aridity |
|---|---|---|---|---|
| San Joaquin kit fox | | | | |
| Mean | 16.7 ± 0.07 | 230 ± 3.4 | 274 ± 8.6 | 1554 ± 25.7 |
| Range | 6.6–22.8 | 66–715 | 4–2320 | 361–6147 |
| Giant kangaroo rat | | | | |
| Mean | 15.4 ± 0.06 | 316 ± 8.72 | 463 ± 17.9 | 2197 ± 68.3 |
| Range | 12.7–17.7 | 151–620 | 84–1217 | 977–5032 |
| Blunt-nosed leopard lizard | | | | |
| Mean | 16.6 ± 0.08 | 243 ± 7.73 | 242 ± 18.4 | 1680 ± 66.5 |
| Range | 12.1–18.8 | 158–662 | 45–1169 | 1032–5713 |

*Note:* Data were derived from WorldClim values extract on Global Biodiversity Information Facility occurrences in the last 100 yr. See *Methods* for details of data extraction and summary.

depending on annual precipitation (Baltosser and Best 2018). The minimum area required for populations and to support species recovery is proposed to be at least 20,000 ha (Butterfield et al. 2017).

The association of giant kangaroo rats with human development varies, and populations reportedly occur in areas that are rich in natural resources particularly for crude oil and natural gas (Cypher et al. 2017). Previous research has concluded that seismic surveys of hydrocarbons do not impact the survival or health of this species at these sites (Cypher et al. 2017). The giant kangaroo rat is a nocturnal animal, but it displays no change in behavior with moonlight (Prugh and Brashares 2010). The species is thus at risk in areas with human developments that are more brightly lit and therefore experience increased predation risks. Giant kangaroo rats typically utilize shallow burrows that are <30 cm in depth, suggesting that surface-level tilling can negatively impact this species (Williams et al. 1998). In some instances, reductions in exotic grass cover increased the abundance of giant kangaroo rat populations (Germano et al. 2012).

The largest remaining blunt-nosed leopard lizard populations have been reported in the Carrizo Plain National Monument, but there are likely scattered smaller populations present throughout the western portions of the San Joaquin Valley agricultural regions in the Ciervo-Panoche Area and the Cuyama Valley (Germano et al. 2001, 2011). Blunt-nosed leopard lizard prefer annual temperatures of approximately 16.6°C (Table 2), but the optimum daily temperatures where the species is active are between 25° and 35°C (Williams et al. 1998). On days where the temperature is not optimal, the species resides underground in burrows. The blunt-nosed leopard lizard mostly occupies lower elevations although populations have also been reported in foothills (Filazzola et al. 2017). The minimum area needed to sustain populations of blunt-nosed leopard lizards is between 400 and 500 ha (Bailey and Germano 2015). Blunt-nosed leopard lizards prefer open landscapes with low vegetation cover and some shrub cover, and exotic grass density was negatively associated with lower population densities (Filazzola et al. 2017). In the SJD, blunt-nosed leopard lizards were associated with shrubs at relatively intermediate densities and with exotic grasses at low densities (Germano et al. 2001). The occurrence of blunt-nosed leopard lizard also strongly correlated with Mormon tea (*Ephedra* spp.) and saltbush (*Atriplex* spp.) (Germano et al. 2001, 2011). Grazing has been documented as an effective method to reduce exotic grass cover to provide improve habitat for the blunt-nosed leopard lizard, particularly when giant kangaroo rats are absent (Germano et al. 2012). Blunt-nosed leopard lizards have been shown to move long distances relative to small patch sizes, and at least a 2-km buffer from human developments and roadways has been recommended (Germano and Rathbun 2016).

### Historic habitat assessments

There were a total of 14 studies that used historical landscape-level data to describe habitat occupancy for the three endangered animal species reviewed herein. We identified four flagship studies that best captured the evidence and approaches to use data at these scales. In this set of literature, there were four classes of historic landscape-level habitat assessments applied to each of the three SJD animal species (Table 3). The approaches included aggregated historic vegetation maps, proxy vegetation studies, historic range maps, and survey records to explore species-centric habitat assessments. Historic vegetation maps for the Central Valley provided an indication of the extent of the major classes of vegetation within the San Joaquin region pre-1900 (Nelson et al. 2003). Common vegetation classes important to these three regional indicator species included alkali desert scrub, chaparral, and grassland. Agricultural and retired lands with former land use histories were also included in the vegetation maps. Field surveys of animal occurrence frequencies and percentage cover of vegetation types have been used in factor analysis to assess whether distance to historic preferred vegetation type significantly predicted probability of occurrence (Halstead et al. 2014). In this instance, increasing distances from historic habitat that included preferred vegetation decreased the likelihood of occupancy.

A contemporary tool that provides a powerful analog to the historic maps is the National Land Cover Database (NLCD). This asset was used with global positioning system (GPS) tracking of large mammals in the region to test whether contemporary woody vegetation such as orchards can provide suitable habitat or corridors for animals (Nogeire et al. 2015). Species distribution models are another mechanism that can use historical assessments of occupancy for target species within the region to infer relatively large-scale habitat suitability (Pollock et al. 2014, Fieberg et al. 2018). The flagship study by Inman et al. (2013) illustrated an ideal workflow for historic animal presence data within the region to augment other planning and restoration tools. Animal trapping and survey work dating back to 1975 was compiled to anchor models within a long-term temporal context (Inman et al. 2013). This flagship study then used similar approaches described above including the development of climate maps, physical attribute maps, and vegetation classifications from the NLCD. Historic sighting can thus be used as a baseline predictor in subsequent models relative to other predictors such as soil or climate. MaxEnt models can provide an estimate of likelihood under different scenarios to predict a contemporary range map for a plant or animal species (Phillips et al. 2006, Pearson et al. 2007, Elith et al. 2011).

Historic range maps have been developed for each species using former reported occurrence data from the Data Basin Repository, the Vegetation Type Mapping project (http://vtm.berkeley.edu/#/data/vegetation), and the Endangered Species

Table 3. A summary of the four major classes of historical habitat assessment tools for desert animal species in agricultural landscapes with three endangered species as focal search terms in this synthesis (i.e., primarily species-centric estimates and methods).

| Tool classification | Description | Application |
|---|---|---|
| Historic vegetation maps | Regional maps that provided longitudinal data for vegetation relevant to indicator animal species | The habitat requirements typically included vegetation preferences and association patterns. Matching historic vegetation occurrences with animal preferences provided an estimate of likely habitat suitability within a region |
| Proxy vegetation studies | The ecological function of contemporary vegetation such as orchards or other woody plant species was assessed | Focus on the function of vegetation for indicator animal species including cover, shelter, refuge, or habitat connectivity is examined through occurrence or tracking surveys |
| Historic range maps | Maps within a region specific to an animal species that delineates reported sightings and/or estimated extents of movement within an area | Maps are used to infer former occupancy and typically assumed that occupancy was an indicator of suitable habitat. Most commonly applied to a region to show the extent that an animal species occupied a region over a specified period of time in the past |
| Historic survey records | Occurrence data from VertNet or GBIF that provide occurrence data for a given species. Can be refined by time or region | Used for species distribution models such as MaxEnt or other tools to estimate habitat suitability and relative occupancy patterns |

*Notes:* GBIF, Global Biodiversity Information Facility.
Each class was reported at least once in a study listed in the flagship studies (listed in Table 1). Full details described in Results for relevant applications to the San Joaquin kit fox, giant kangaroo rat, and blunt-nosed leopard lizard.

Recovery Program Resources (http://esrp.csustan.edu/gis/). Historic occurrences are also reported in GBIF and provide another valuable mechanism to examine reported occurrences for a region and by time. This workflow has not been extensively used in the literature except in a recent instance applied to the blunt-nosed leopard lizard using GBIF and a similar occurrence resource VertNet (Stewart et al. 2018). This is an important set of evidence that can support systematic reviews and future primary research endeavors. In this study, habitat suitability models predicted that there is suitable historical habitat in retired agricultural lands for the blunt-nosed leopard lizard within the SJD (and that this species is an excellent umbrella species for the region). Species distribution models using occurrence data are an increasingly common approach for predicting habitat occupancy, particularly for animal species (Cypher et al. 2013), but have not been linked to current or former land use patterns. Using the rgbif package for R (Chamberlain et al. 2016) to explore this limitation, all occurrences were downloaded for each indicator species in the SJD, and contemporary and historical occurrences were scraped and plotted. Historical occurrences were defined here as pre-1975 for the giant kangaroo rat and blunt-nosed leopard lizard and pre-1990 for the San Joaquin kit fox (due to limited reported records). A map of these data shows the landscape-level former extents that all three species occupied within the SJD (Fig. 1).

### *Restoration tools relevant to retiring agricultural lands*

The evidence set for restoration techniques was the most extensive of all reviewed with a total of 156 relevant studies and 17 identified as flagship studies that directly addressed this focal question (Table 1). The reporting of efficacy for techniques was extremely diverse in this literature comprised of very different forms of data both within and between restoration approaches. Consequently, we summarized spatial extents, sampling efforts, and relative frequencies to synthesize these studies but recognize that this does not constitute a measure of the relative strength of treatments/interventions (i.e., effect sizes) for each respective technique (Koricheva and Gurevitch 2014, Lortie and Bonte 2016).

The studies specific to restoring retired lands were well distributed across the southwestern United States for arid animal species but not within the SJD (Fig. 2). The flagship studies that provided direct evidence were more tightly distributed around and within the SJD but were still relatively limited with this region (i.e., <5 studies total examined restoration for the three indicator species). The extent of sampling sites for identification of habitat, measurement, and monitoring within arid and semi-arid regions is extensive with a mean of five sites per study/model/monitoring protocol and a minimum of one site if the area was very large. If the sampling was distributed regionally, a maximum of 60 sites were used in a single study. Similarly, the number of samples within a study in terms of individual animals, shrubs, plots, or soil survey locations was extensive within the studies examining restoration of landscapes and habitats (Fig. 3). The mean number of samples per study was 473 with a minimum of 1 and a maximum of 12,411 replicates. The relatively lower number of replicates for sites was associated with larger-scale sampling of extensive areas or for woody vegetation, and the relatively higher number of samples (sometimes including values in the thousands) described individual animal occurrences often from long-term studies monitoring a species within a region. Finally, the most common tools were landscape-level GIS estimates and rapid survey-based assessments often done using transects within arid and semi-arid regions to assess habitat or document species occurrence data for a region (Fig. 4). Monitoring surveys were more common within this domain than active restoration not only because of assumed relative costs but also because of the need to match data at the landscape level to the threats and land conversion processes happening at these scales.

Survey techniques associated with land use classification varied in frequency depending on the indicator species for the region. Scat detection by dogs for the San Joaquin kit fox was a frequent method in assessing kit fox presence and habitat preferences (Smith et al. 2005, 2006). Visual surveys were infrequently used for monitoring San Joaquin kit fox (Fig. 4). The most common technique for estimating population sizes of giant kangaroo rats was trapping and mark–recapture (Fig. 4). Aerial surveys of burrow density have also been used as a rapid and accurate method for estimating the relative abundance of giant kangaroo rats when averaged over

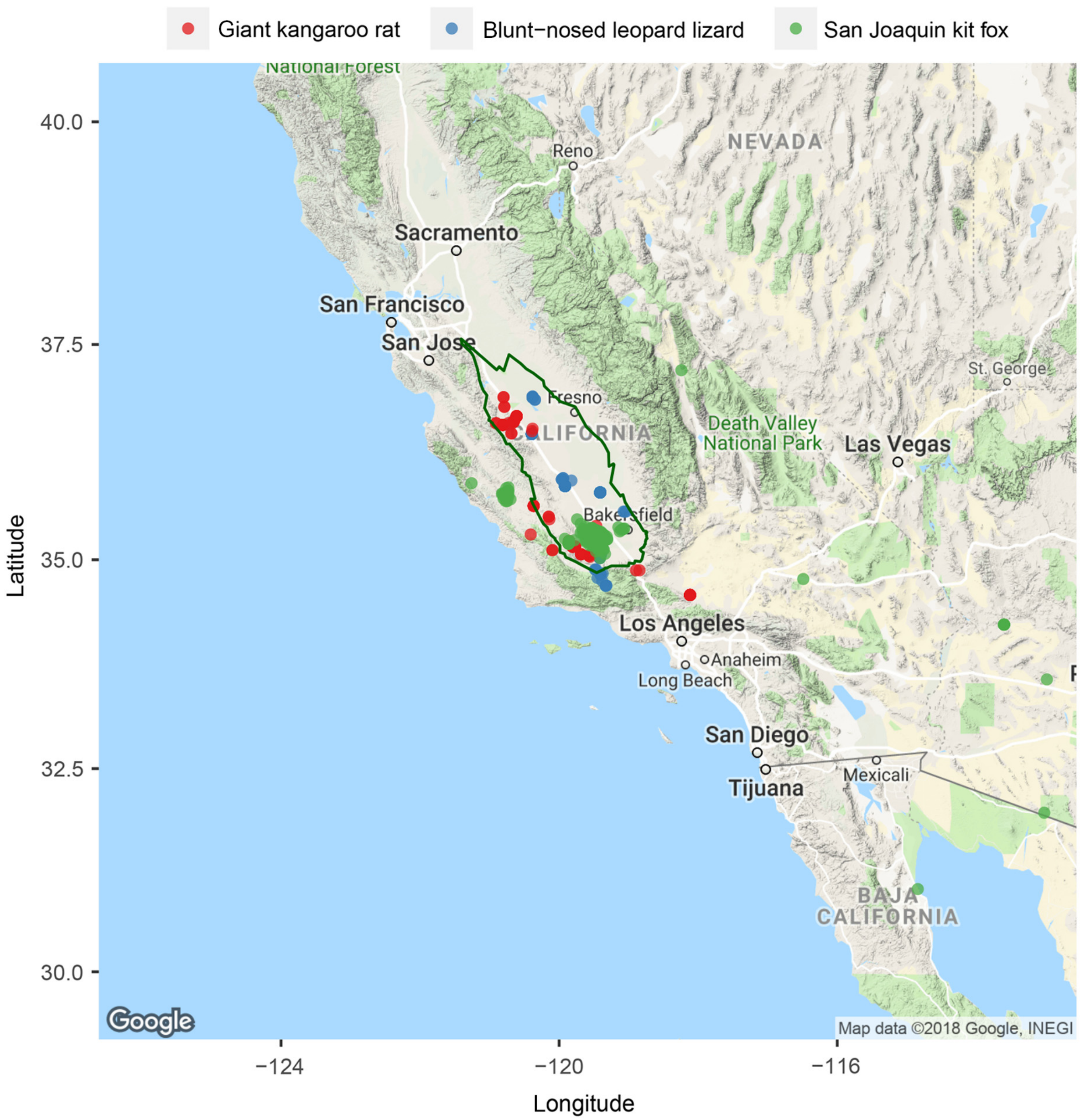


Fig. 1. Historical occurrence data sampled from Global Biodiversity Information Facility for three indicator animal species examined here. The solid line delineates the conventional extent associated with the San Joaquin Desert region.

multiple years (Bean et al. 2014). Other direct measures include surveys, telemetry, and walking transects, but these methods were used infrequently for this species. The most common techniques for surveying blunt-nosed leopard lizards included telemetry and transect sampling (Fig. 4). Recently, scat detection by dogs has been used to estimate presence of blunt-nosed leopard lizards (Filazzola et al. 2017), and camera traps can also be used to track this species at relatively fine scales within a habitat (Noble et al. 2016).

In addition to monitoring, active restoration for these indicator species onto retired agricultural lands can include translocations (i.e., introductions

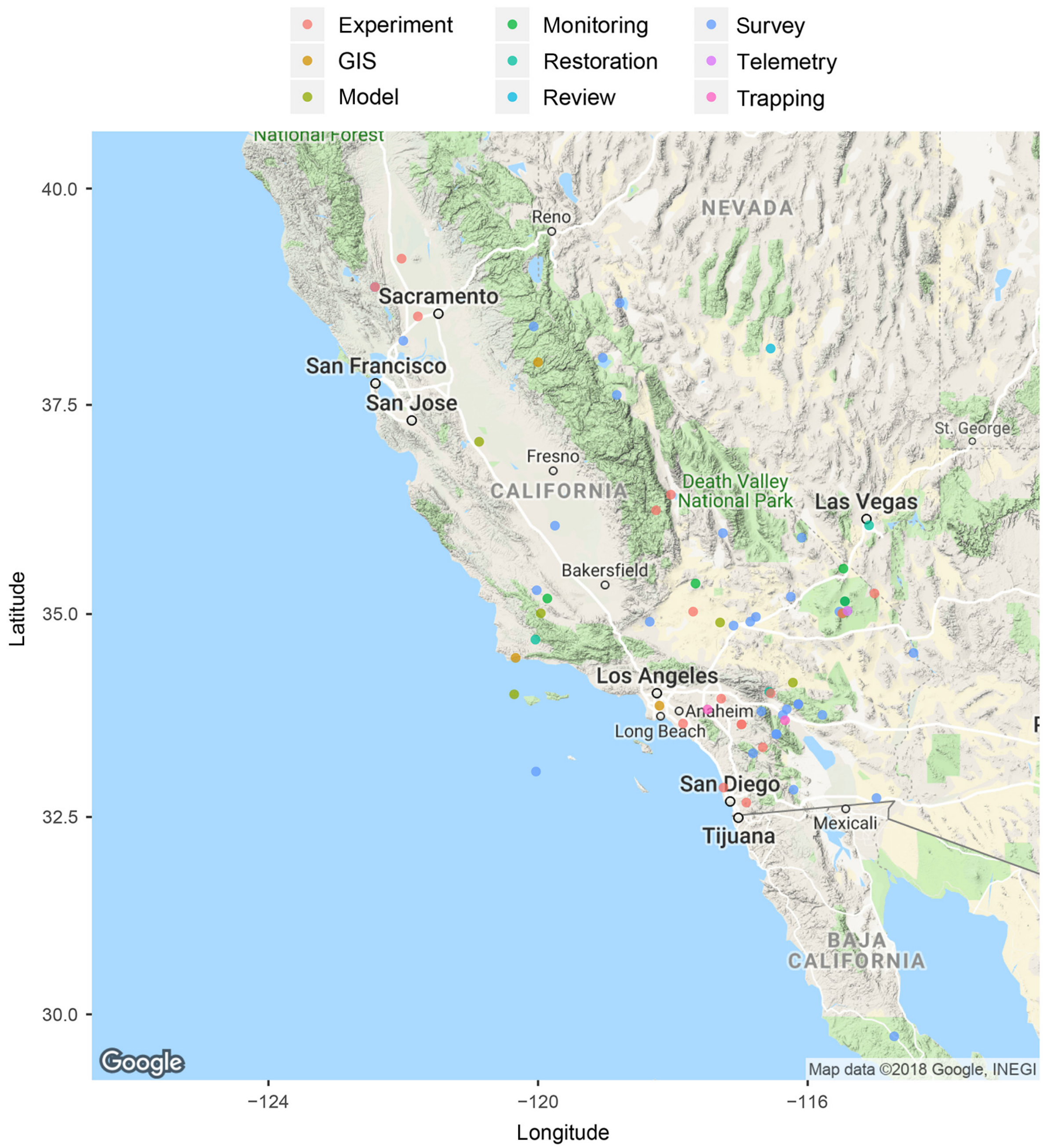


Fig. 2. A map showing the studies associated with restoration techniques and retired lands within the southwestern United States including the San Joaquin Desert (shown by green polygon). Various scientific tools were used to describe, summarize, and examine restoration of retired lands.

of individual animals to new locations) or habitat ameliorations. Translocation of San Joaquin kit foxes has had limited success because of lower survival of translocated individuals relative to free-ranging foxes (Scrivner et al. 2016). Other interventions for the San Joaquin kit foxes included installing artificial dens and providing escape cover by shrubs to reduce mortality from predators (Scrivner et al. 2016). Translocation efforts have been reported to the public through

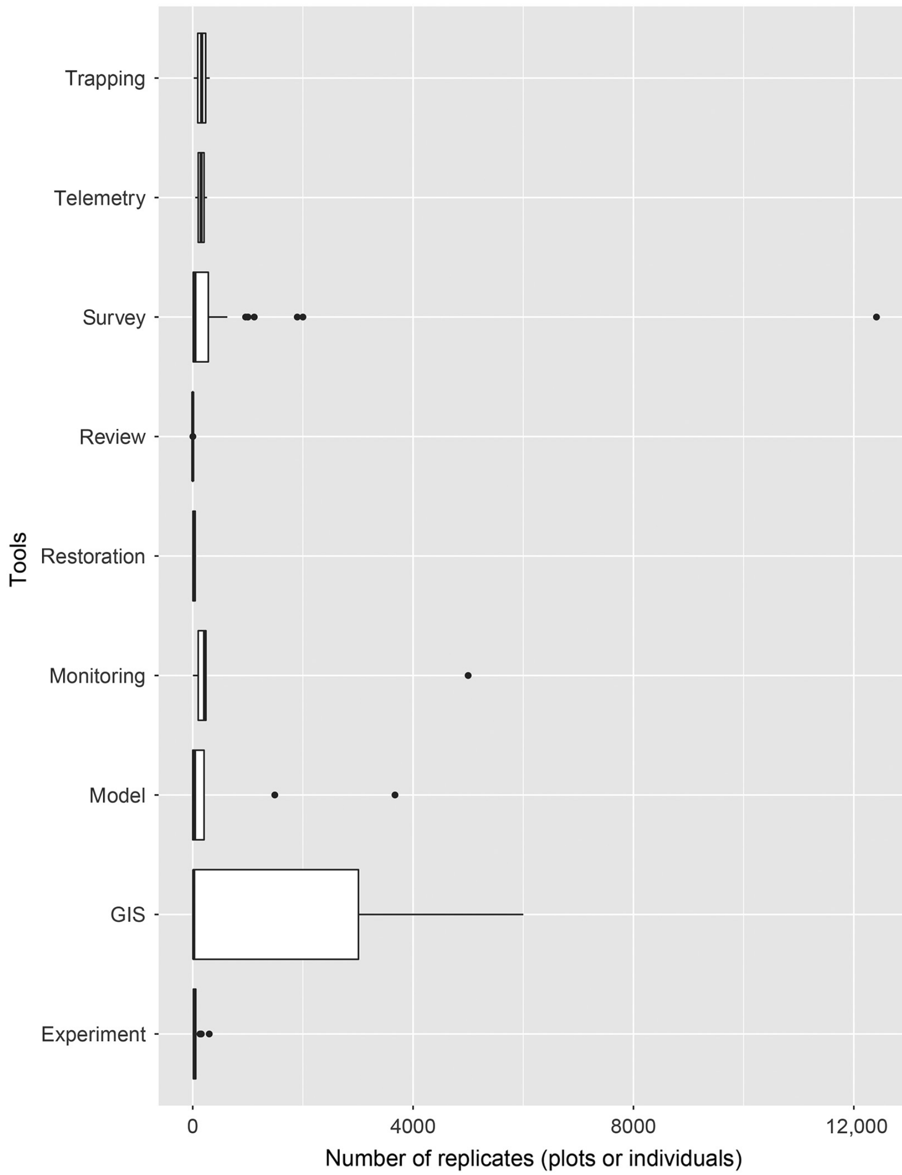


Fig. 3. The sampling effort for examination of restoration issues including management, monitoring, field surveys, and models for strategic land acquisition of retired or impacted lands within arid and semi-arid regions. The extent of replication summarized here from within studies included plots to individual plants to animal occurrence data.

online communication briefs for the giant kangaroo rat at mitigation sites for solar farms (e.g., Panoche Valley, Topaz Solar within the SJD), but the success of these direct interventions has not published in a report or in a peer-reviewed publication and they were unavailable for this synthesis. There were also no translocation studies for the blunt-nosed leopard lizard retrieved.

Restoration costs were also unreported in this set of literature. A flagship study nonetheless used an excellent protocol to measure and monitor shrub recovery following human disturbance and provided a good estimate of at least the extent of sampling needed—but not the economics (Stylinski and Allen 1999). Aerial photographs, transects for shrubs, gridded quadrat

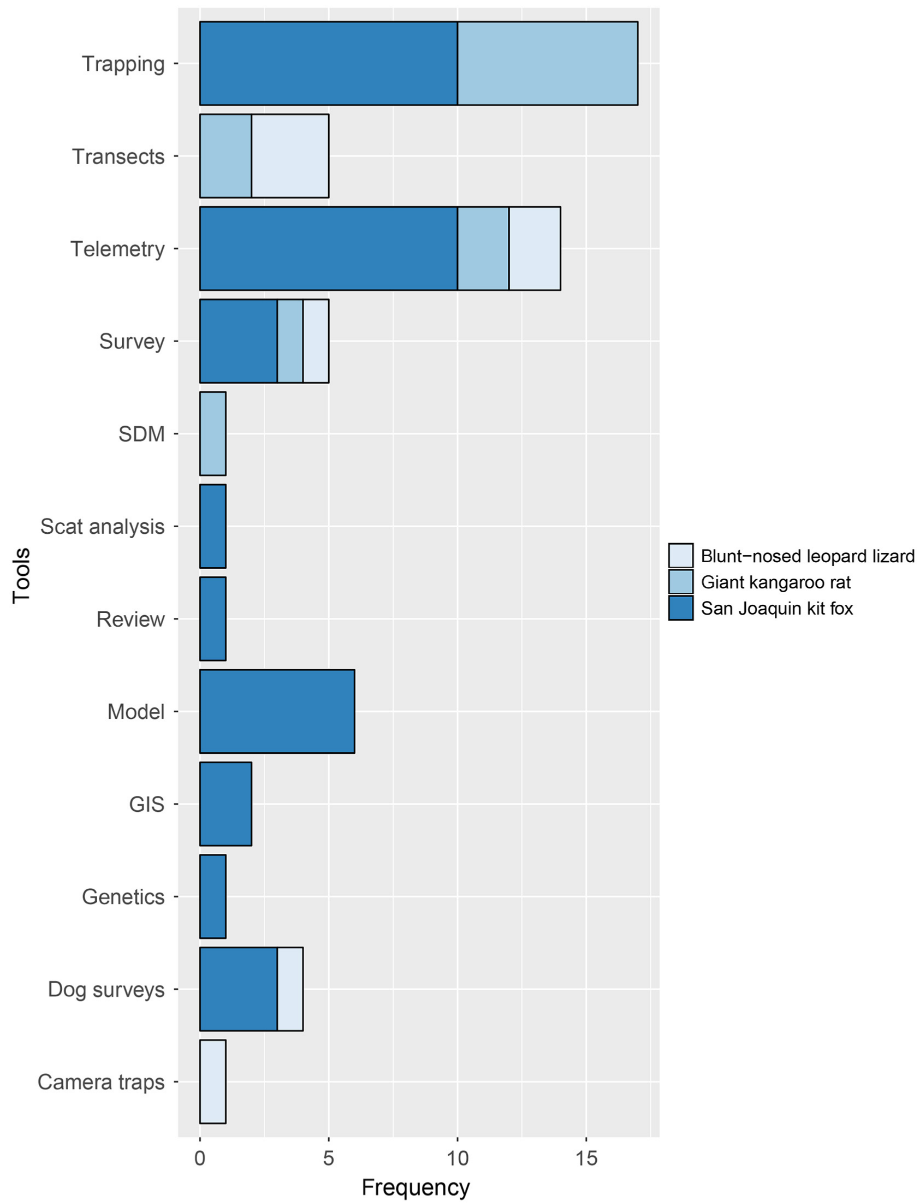


Fig. 4. Survey methods for San Joaquin kit fox, blunt-nosed leopard lizards, and giant kangaroo rats from literature review. Each of the tools described in full text (and SDMs refer to species distribution models). Frequency shows the total number of studies that examined a particular target species using a given tool.

frames for grasses and herbaceous vegetation, and soil samples were used to sample shrub and vegetation recovery at disturbance sites (Stylinski and Allen 1999). This study fit within the distribution of the extent of sampling reported in other SJD studies at a total of 25 sites with four replicate transects and sampling arrays at each site.

## Discussion

### *Synthesis*

Better late than never. Formal scientific syntheses are a reproducible, powerful form of hindsight into the known and insight into the unknown, that is, research gaps. Globally, a paradigm shift is needed for agricultural production that promotes better balance between human use and conservation. Restoration of agricultural lands for this balance also requires an ecosystem-level approach. For instance, a significant proportion of the lands within the San Joaquin Valley were previously suitable habitat for the three target San Joaquin species, but habitat loss and degradation has reduced suitable habitat to critically low levels. This synthesis suggests that restoration will require quantitative descriptions of the local environmental limitations, plant community, prey availability, and soil composition for the SJD. The research to date confirms that restoration programs must reduce the density of exotic plants, mediate drought, and if possible, use proximity to existing or previous habitat as critical criteria. Land assessment surveys to compare existing habitat with restoration of retired agricultural lands are an excellent fundamental starting point in quantifying these variables. Remote sensing assessments and GIS-based land cover classifications for retired lands have also been used effectively when coupled with species-specific data on reported occurrences. A detailed workflow should include the following steps for any region that must generally balance production/extraction with conservation: Determine species climatic needs with habitat, compile range maps and historical occurrence data, build occupancy models, use remote sensing and land cover classifications to match the niche for each species, check soils at each site, address limitations in water availability, and manage vegetation including addition of foundation native plant species associated with indicator animal species. This can be applied to any agricultural land retirement and restoration opportunity globally by five steps: (1) Identify suitable lands, (2) set goals for restoration, (3) restore, (4) evaluate efficacy, and (4) communicate findings with conservation partners—repeat as needed (Appendix S1: Fig. S2). Rules of thumb include "the closer to historic sites the better," presence of some woody native vegetation beneficial, less compacted soils are healthier and more useable by animals, water needed including recharged aquifers, and pressingly, proximity to human development and disturbance frequently correlates with negative impacts on animal species with limited dispersal in these ecosystems. These rules are common sense and likely held by many experts, but most importantly, the published scientific evidence to date strongly supports these principles in terms of frequency of reporting in the scientific literature. A "hope for the best" recovery for some lands and strategic acquisition of lands near former habitat is reasonable and can be successful based on this synthesis if several of the criteria are met. However, a more active restoration strategy addressing the capacity for soils, moisture, and native vegetation to support indicator desert animal species is recommended. Hope for the best passive restoration and recovery for acquiring lands near existing habitats also needs to be directly tested against more intensive and costly strategies. Other evidence gaps included the costs, scales, and duration of interventions needed to best mediate limitations associated with retired agricultural lands as novel conservation habitats. Action research that addresses these fundamental research gaps globally is needed given both the extent of agricultural lands and the relative scarcity of pristine lands in all ecosystems.

### *Implications from habitat studies*

We must accept that space is a critical limitation in most ecosystems and necessitates a novel conservation paradigm. Retired lands that were used for grazing can be suitable habitat for restoration if they previously supported an endemic species accustomed to areas with relatively high productivity such as giant kangaroo rats in California. Grazing has also been suggested as a method to reduce exotic grasses to improve habitat for the San Joaquin kit fox (Warrick et al. 1998). Retired agricultural lands can thus directly provide habitat if vegetation is managed appropriately but can further support species by facilitating movement between existing populations. The three indicator species examined here were sensitive to vegetation dynamics suggesting that restoration of retired lands must manage the vegetation for low densities of exotics and consider creating artificial dens or burrows that may have been lost through agricultural practices (Phillips and Cypher 2015, Westphal et al. 2016, Filazzola et al. 2017). Specific research is needed to identify vegetation targets or thresholds for restoration programs, but the good news identified in this synthesis is that species-specific needs can sometimes be aligned through the management of exotic plants and provision of shared dens/burrows. Restoration of native vegetation thus has the capacity to directly support many SJD animal species. Vegetation coupled to animal populations through key functions including provision of habitat but also resources and shelter is certainly a general lesson globally to inform restoration decisions for many threatened and endangered animal species.

Effective management strategies further need to both reduce invasive grass density and facilitate the re-establishment of native plants. Grazing can be effective but is controversial, and there is also evidence that while it reduces exotics, it can also negatively impact native vegetation restoration (Stahlheber and D'Antonio 2013). Fire management is another potential management strategy that has been proposed but is challenging. Native shrub species have been shown to successfully recover after fire or physical disturbance (Steers and Allen 2010, Lortie et al. 2018*c*), and herbicides are available that target annual grass but not perennial species (Huddleston and Young 2005). Other management techniques are available that focus on soil modification to promote native plant species such as activated carbon and soil amendments that can suppress invasive grass growth and improve water availability in favor of native re-vegetation efforts for shrubs and annuals (Walker and Powell 2001, McKinney and Cleland 2014). Successful interventions needed have been established, but fire, grazing, and soil mediation require continued maintenance because of the presence of exotics, sensitivity to invasion anew, and previous reductions in native shrub cover from agricultural practices. This research is currently decoupled from retiring and recovering agricultural lands from the perspective of habitat use.

### *Insights from historical evidence*

Baselines or historical reference conditions are useful for restoration. Evidence of the phyto-history and proposed examples of the former vegetation communities suggest that dramatically different communities are present today in California (Evett and Bartolome 2013). This is common in grasslands globally suggesting that restoration should focus on ecosystem function by identifying the specific functions that foundation plants can provide (Lortie et al. 2016) rather than on historic vegetation to support the endemic animal species within a region (Evett and Bartolome 2013). In this synthesis, restoration strategies should focus on establishing plants that directly address the needs of an animal species such foundation shrub species that provide shelter, refuge, and ameliorate harsh conditions (e.g., *Ephedra* spp. or *Atriplex* spp. depending on the specific site). Facilitation by foundation plant species is a well-established ecological process in many ecosystems (McIntire and Fajardo 2014, Silliman et al. 2015, Soliveres et al. 2015), and sites that retain some native vegetation and key animals species can be used to examine the function that foundation plant species provide. For instance in California, the Ciervo-Panoche Area and the Carrizo Plain have co-existing populations of the three target animal species and relatively well-established populations of dominant native plants (Germano et al. 2011, Bean et al. 2014, Richmond et al. 2017, Stewart et al. 2018). If restored to even intermediate densities, shrubs have been shown to be a better predictor of lizard abundances than precipitation in California (Barrows 2006). Shrubs can take 25–50 yr to reestablish fully (Lovich and Bainbridge 1999, Stylinski and Allen 1999), and sites with relatively lower resources need greater interventions, such as irrigation or shade shelters, to promote vegetative functions that support animals in the interim (Cortina and Vallejo 1999). This synthesis suggests the general lesson that when plants are established first, animals will follow (build it and they will come). This rule can be applied to restoration of agricultural lands, particularly given the challenges associated with translocation of threatened animal species. Finally, another promising research direction used natural habitat proxies such as existing scrubland, orchards, or other agriculture to provide connectivity and sometimes habitat as a contemporary analog for functions currently lacking to support indicator animal species (Geyer et al. 2010, Nogeire et al. 2013, 2015). Pristine is likely a thing of the past, at least in the central valley of California, and appropriately capitalizing on retiring land cannot be overstated as a critical mechanism to enhance ecological function for endangered animal species through vegetated habitat.

### *Opportunities in restoration research*

Resolving and compiling evidence from surveys vs. manipulative experiments is a common challenge in many ecological syntheses (Lortie and Bonte 2016). In this case study, there were a wide variety of mensurative tools describing the ecology and conservation biology of three endangered animal species in the SJD and relatively few direct manipulations. Nonetheless, the primary research literature for retired lands, even if it was not always explicitly designed to explore retired lands planning per se or manipulated key factors, supported evidence-based strategic planning similar to syntheses in conservation (Sutherland et al. 2004). We propose that habitat, endangered animal species as indicators, and associated restoration studies questions used here can be an effective synthesis structure to compile evidence, and perhaps even more importantly, identify gaps to inform critical action research. This is a key strength of scientific synthesis. The direct application of manipulative restoration practices to this region is sparse and thus a critical research gap not uncommon in other drylands (Svejcar and Kildisheva 2017). Nonetheless, matching the evidence compiled in the first two driving questions for habitat such as extant vegetation and historic range maps are valuable planning and management decision-making tools and can facilitate prioritization efforts for acquisitions (Darst et al. 2013). However, there is still the risk that the species will not be present or will not necessarily occupy a specific habitat if strategically acquired. Ideally, field-based surveys are matched with SDMs to ground truth the estimates of the relative likelihoods that a species can or will occupy a habitat class or site. Direct interventions to establish animal population through translocations (Baur 2014) and habitat restoration through vegetation and soils (Purkey David and Wallender Wesley 2001, Ren et al. 2008) in manipulative, replicated experiments are also needed to address fundamental biodiversity and ecology questions in many ecosystems experiencing anthropogenic land use pressures and changes (Turkington and Harrower 2016). The extent that an animal disperses within a region is important, and the number of sites surveyed or examined for potential occupancy should be balanced by the species biology described in the evidence summarized by the first focus question for each species. Combining survey techniques, such as camera traps and aerial surveys, is an underexplored opportunity but a clear path forward for both accurate and rapid assessment of animal populations to identify sites and for restoration interventions.

The most effective interventions have been identified from a large body of fundamental ecological research on plant–animal interactions, disturbance, and invasion biology. In a comprehensive review on this topic, three major drivers of change for retired lands that align with the species-level research were identified including disturbance and exotic species, low propagule availability to naturally recolonize habitats, and the harsh conditions in the local environment within these systems (Cortina and Vallejo 1999). These same challenges were consistently reported in this case study. The research for this region thus fits well with the following three themes of restoration interventions: (1) the mitigation of disturbance from humans directly and from indirect effects such as grazing; (2) the need for reductions in exotic plants and increases in native species (both translocations for animals and active planting for foundation plant species such as shrubs); and (3) the management of environmental conditions such as reductions in water loss (e.g., shelters, mulch, or wetter microsites) or through increased availability of water such as irrigation. Water was a key theme in this synthesis, and it is a critical challenge globally with drought and increasing variation in precipitation threatening the resilience of most terrestrial ecosystems. Analyses for California strongly suggested that short-term water solutions are needed to establish and support active restoration of retired lands in providing suitable habitat for foundation plants and dependent animals including use of reclaimed water and pumped groundwater (Nguyen et al. 2015). Collectively, these three general categories of restoration tools, mediation of disturbance, plants, and water, provide a clear roadmap for evidence-based strategic retirement and restoration planning on agricultural lands.

## Conclusions

We must advance from context-specific, single-case study thinking in restoration ecology and recognize costs to people. This synthesis clearly identified this paradigm shift for agricultural lands. Unfortunately, retiring agriculture will not necessarily overlap with existing population of endangered species. The restoration of habitat, the translocation of target species, and their continued maintenance will therefore be challenging and must be solved through the use of diverse sets of evidence from publications to open datasets to maps to expert knowledge. Solutions that include the general lessons and rules of thumb described herein are more likely to succeed. Utilizing lands that are in close proximity to protected government lands can increase species survivorship and reduce funding requirements (Haight et al. 2004). Monitoring is also another requirement of most restoration efforts in the United States and Europe, and a wide catchment of lands is critical for many endangered species. Restoration to support endangered species in agricultural regions will be expensive, but optimizing the location of lands to integrate with former and contemporary human land use patterns including grazing or desert tourism will further increase the likelihood of success and reduce net costs. The bottom line must balance the costs of protection of existing designated lands such as National Monuments in the United States with the strategic retirement and restoration of agricultural lands. The best buy on discounted lands should include an assessment of up-front vs. long-term costs on time horizons relevant to the restoration and recovery of the ecological functions of agricultural lands. A socioeconomic synthesis examining crucial and limiting needs of people in regions at the intersection between production and protection will further illuminate the capacity and likelihood for agricultural lands to meet the needs of the many and not just the few.

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## Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.2367/full