2021

# Implications of Climate-Driven Fallowing for Ecological Connectivity of Species At Risk

Sofie HE McComb

Claire Powers

Forrest Melton

Ashley Larsen

# Implications of Climate-Driven Fallowing for Ecological Connectivity of Species At Risk

**Sofie HE McComb** ( shemccomb@gmail.com )
The University of British Columbia https://orcid.org/0000-0003-2237-1833
**Claire Powers**
University of Colorado Boulder
**Forrest Melton**
NASA Ames Research Center
**Ashley Larsen**
University of California Santa Barbara David Bren School of Environmental Science and Management

---

**Research Article**

**Keywords:** conservation planning, dynamic reserves, agricultural matrix, endangered species, Circuitscape, drought

**Posted Date:** June 7th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-529250/v1

---

## Abstract

# Context.

Climate change and agricultural intensification are modifying the configuration of natural lands within agricultural landscapes, further impacting species' ability to move freely between remaining natural areas. These working landscapes have inherently high opportunity costs, making the establishment of additional permanent reserves for species movement unlikely.

# Objectives.

Here we explore the potential for opportunistic and dynamic conservation reserves, in the form of temporary fallowed croplands, to increase connectivity in competing land use regions.

# Methods.

We evaluate the potential for fallowed lands to facilitate habitat connectivity for at-risk species in the San Joaquin Valley (SJV), an intensive agricultural landscape in California. We perform landscape connectivity analyses to examine how historic drought-induced fallowing from 2011 to 2017 in the SJV region impacted connectivity within Kern County for the endangered, endemic San Joaquin kit fox (Vulpes macrotis mutica).

# Results.

We found that an increase in temporary fallowing from 2011 to 2015/2017 in Kern County likely increased habitat connectivity for the kit fox. This finding was represented by reductions in average Cost-Weighted Distances (CWD), Effective Resistances, and CWD-to-Least Cost Path Ratios between core habitat areas, indicating that cumulative costs incurred by kit foxes travelling between primary habitats decreased.

# Conclusions.

Our findings highlight that strategic and cooperative, yet temporary, conservation actions have the potential to reduce the conflict between biodiversity preservation and agricultural production in working landscapes while increasing landscape connectivity. Fallowing-based, agri-environmental schemes could help working areas meet statewide groundwater management policy targets while improving species' mobility in the face of climate change.

## Introduction

Global environmental change is putting increasing pressure on agricultural production and on the natural resources that support and are affected by production, from groundwater to biodiversity (Norris, 2008; Tilman, 1999). Where agriculture overlaps areas of high biodiversity there are difficult trade-offs between economic benefits, resources needed to support human population growth, and ecological conservation (Dudley & Alexander, 2017; Fischer et al., 2017; Larsen et al., 2020; Shackelford et al., 2015). Given agriculture covers about 40% of ice-free land, understanding how to balance these inherent trade-offs is critical for the conservation of global biodiversity (Foley et al., 2005; Ramankutty et al., 2008).

Agricultural land conversion and intensification do not just affect habitat availability and quality, but also the spatial matrix of different land uses in the landscape (Bennett et al., 2006; Tscharntke et al., 2005). This spatial configuration, in turn, influences the movement of species and associated gene flow and migration that may be critical to species persistence (Doherty & Driscoll, 2018; Fahrig, 2002, 2007; Fraterrigo et al., 2009; Villard & Metzger, 2014). Particularly in intensive agricultural landscapes, connectivity between often rare and small patches of intact habitat may play key ecological functions (Baguette et al., 2013; Fischer & Lindenmayer, 2002; Herrera et al., 2017; Saura et al., 2014). However, creating such connectivity corridors presents major challenges in working landscapes where open land is scarce.

Historically, conservation initiatives have focused on separating nature from areas of human economic activity and resource use through the acquisition and protection of “untouched” wildland or land with restoration potential (Folke, 2006). More recently, the focus has been on the creation of permanent protected areas connected by fixed natural corridors through the landscape (Folke, 2006). However, both of these static conservation approaches are not always practical in (semi) urban or high value agricultural zones where setting aside land for conservation has high opportunity costs. Rather, more opportunistic and dynamic reserves may offer a feasible mechanism for provisioning habitat and enhancing connectivity in regions unlikely to be protected in perpetuity due to competing land-uses (D’Aloia et al., 2019; Reynolds et al., 2017).

California, US, presents a valuable opportunity to understand the potential conservation benefits of dynamic reserves in the form of temporary or persistent fallowed croplands. California is considered a biodiversity hotspot with ~ 1500 plant and ~ 60 vertebrate endemic species across its 13 distinct level III ecoregions, and is also home to some of the most valuable agricultural lands in the country, which underpin the economic and social fabric of many inland regions (Griffith et al., 2016; Harrison, 2013; Kelsey et al., 2018). From 2012 to 2016, California experienced its driest years of instrumental record, and the resultant water storage deficits led to billions in crop and livestock losses as well as a substantial increase in fallowed land (Berg & Hall, 2017; Bryant et al., 2020; Dong et al., 2019; Howitt et al., 2014; Medellín-Azuara et al., 2015; Stovall et al., 2019; Swain et al., 2014). In response, the California legislature passed the Sustainable Groundwater Management Act (SGMA), requiring groundwater basins to be managed such that they provide a reliable water supply able to withstand future climate change induced drought conditions by 2040, while providing multiple environmental and socioeconomic co-benefits (Roberts et al., 2021; California Water Code [CWC]. Division 6, Part 2.74. Sustainable Groundwater

Management., 2014). As the majority of groundwater in California is withdrawn for agricultural uses, forecasts suggest that more than 300,000 ha of agricultural land in the San Joaquin Valley might need to be retired to achieve basin sustainability by the SGMA 2040 deadline (Bryant et al., 2020; Hanak et al., 2017, 2018, 2019). This potential policy-driven fallowing could provide significant environmental and conservation co-benefits (Queiroz et al., 2014). In particular, fallowed lands, which we define here as land that does not produce a crop within a calendar year, could play a significant role as dynamic reserves in the San Joaquin Valley. The San Joaquin Valley is the agricultural powerhouse of California that is home to many endemic and endangered species greatly impacted by agricultural and urban development (Lortie et al., 2018; Stewart et al., 2019; Williams & Fitton, 1997). There have been an increasing number of studies examining the potential strategic retirement and restoration of these fallowed agricultural lands in the San Joaquin Valley for species habitat, often using the spatial distribution of historic drought-induced fallowing as an indication of likely policy-induced fallowing (Bryant et al., 2020; Kelsey et al., 2018; Lortie et al., 2018; Stewart et al., 2019). Yet, few studies have focused on the potential habitat connectivity benefits despite encroaching development (Lortie et al., 2018) and anticipated climate driven range shifts.

Here we consider the potential of fallowed lands to facilitate habitat connectivity in an intensive agricultural landscape. We focus on the highly productive and heavily ground-water reliant Kern County in the San Joaquin Valley. We select the endangered and endemic San Joaquin kit fox (*Vulpes macrotis mutica*) as our case study species, since it is considered an umbrella species for regional fauna, is disturbance sensitive, has well-studied historic distribution and ecology, and has designated high suitability core area in Western Kern (Cypher et al., 2000, 2013; Gerrard et al., 2001; Haight et al., 2004; Koopman et al., 2000; Nogeire et al., 2015; Williams & Fitton, 1997). Using a time series of field-level fallowing, we examine how changes to fallowed areas in Kern county from 2011 to 2017 influence connectivity between kit fox habitat areas. Beyond illustrating the connectivity benefits of fallowing for kit fox in this region, we discuss potential applications of these methods for future studies and collaborations around strategic fallowing and temporary connectivity corridors.

# Methods

## Overview

We examined how the fallowing of cropland in intensive agricultural areas as a result of widespread drought impacts species mobility throughout the landscape and what role it might play in increasing overall connectivity between critical species habitat. Our case study centered on the endangered San Joaquin kit fox within Kern County, the highest crop producing county in California (California Department of Food and Agriculture, 2019). Kern experienced increases in fallowed fields beginning in 2012 from widespread drought, which peaked in 2015. To examine species connectivity, we defined the core habitat areas of the San Joaquin kit fox and created resistance layers for the species across the landscape derived from land cover as well as barriers to movement such as roads and rivers. We then ran spatial connectivity analyses to measure how the spatial distribution of fallowing affected landscape connectivity through its effect on landscape resistance. We statistically compared connectivity between the years of analysis, with 2011 as the base year of our analysis, 2015 as the year of the maximum extent and intensity of the drought in California, and 2017 as the final year of analysis. All processing and analyses were performed in R Statistical Software v3.5.3 (R Core Team, 2019) and ArcGIS 10.7.1.

## Kit Fox Core Areas

We defined critical habitat of the kit fox using the California Wildlife Habitat Relationships (CWHR) Predicted Habitat Suitability raster (30m) (California Department of Fish and Wildlife California Interagency Wildlife Task Group, 2016), which depicts the mean habitat suitability score (0–1) for the kit fox based on the average value of expert defined reproduction, cover, and feeding scores for the species in the habitat type. We created polygons of the habitat area by aggregating the raster at 270 meters around the median, and then defined core habitat areas as > 5 ha polygons—to remove isolated fragments created by vectorizing the habitat data—with the highest possible suitability score (0.92) (SI Methods).

## Resistance Layers

To analyze how species mobility through the landscape changed annually from 2011 to 2017, we created resistance layers for each of the years derived from land cover, slope, and barrier (roads and rivers) datasets. Resistance surfaces reflect the “energetic cost, difficulty, or mortality risk” (B. H. McRae & Kavanagh, 2011, 2017) for the species to move across each cell. Land cover was defined from three land use datasets: annual, satellite-derived fallowed area data layers (30m rasters) for 2011 to 2017 from the NASA-USGS-USDA Fallowed Area Mapping (FAM) project (Boryan et al., 2011; Medellín-Azuara et al., 2015; Melton et al., 2015), statewide crop mapping shapefiles from Land IQ LLC and California Department of Water Resources (DWR) for 2014 and 2016 (California Department of Water Resources, 2017, 2019), and aggregate land cover layers (30m rasters) of 2011 and 2016 from the USGS National Land Cover Database (NLCD) (Homer et al., 2015; Jin et al., 2019). The annual FAM datasets were used to define fallowed areas for these analyses, defined as land that did not produce a crop within a calendar year. Non-irrigated lands exhibiting volunteer crop growth or evidence of a non-irrigated winter cover crop in January–February or November–December were considered fallow. After harmonizing the extent and spatial resolution of the three land use datasets, we combined them into one consolidated land use map for Kern county. As we wanted to evaluate how the change in fallow area, defined as a binary variable based on the annual FAM data, influenced the change in species connectivity across the years, we combined the FAM input in each year from 2011 to 2017 with the 2016 DWR dataset and the 2016 NLCD (Fig. 1). We later examined the impact of these static layers by comparing the connectivity results from the 2011 FAM data combined with the 2016 DWR and 2016 NLCD data to the results from the 2011 FAM data combined with the 2014 DWR and 2011 NLCD data. To combine the layers together we gave precedence to FAM, then DWR, and then NLCD. Resistance values for different land covers and crop types were based on the inverse of kit fox habitat suitability values presented in Cypher et al. (2013) (Table S1).

To capture additional resistance features, we also included the presence of primary and secondary roads (U.S. Census Bureau, 2019) and rivers (Buto & Anderson, 2020; United States Geological Survey (USGS), 2020) in our resistance layers, giving both a value of 1 (highest resistance) (Cypher et al., 2013; Koen et al., 2014; B. McRae et al., 2016). Lastly, we calculated percent slope, using 30m elevation raster files from the National Elevation Dataset (Gesch et al., 2018; United States Geological Survey (USGS), 2018). We calculated the final resistance surface using the equation $R = (H + 1)^{10} + s/4$ as detailed in Dickson et al. (2017), in which H is the maximum resistance value across combined resistance layers (land use, roads, rivers) and s is percent slope (Dickson et al., 2017). The 30 m resistance surface layers (for each year) were then aggregated to 270-meter resolution for input into spatial connectivity analysis software.

## Spatial Circuit and Connectivity Analyses

To examine how changes in fallowed areas impacted species movement through the landscape and overall landscape connectivity, we used Circuitscape and least-cost path approaches (B. H. McRae, 2013; B. H. McRae & Kavanagh, 2011, 2017; B. H. McRae & Shah, 2009). Both approaches model movement of an organism between core areas based on the resistance landscape. Circuitscape relies on circuit theory to model probabilistic species movement through the landscape as a function of current flow (B. H. McRae et al., 2008; B. H. McRae & Shah, 2009). In contrast, the least-cost path (LCP) identifies the single least-cost path an omniscient individual would take, or the pathway with the lowest cumulative cost of movement (Adriaensen et al., 2003; B. H. McRae et al., 2012; B. H. McRae & Kavanagh, 2017). Both tools can be combined such that Circuitscape is run through “least-cost” corridors spanning the least cost path to identify potential bottlenecks to species movements, or pinch points, using the Linkage Mapper toolbox (B. H. McRae et al., 2012; B. H. McRae & Kavanagh, 2011, 2017; WHCWG (Washington Wildlife Habitat Connectivity Working Group), 2010). We truncated corridors at 200 km and dropped corridors that intersected core areas, as we were interested in the change in movement between, and not through, core areas. For our analyses, we used Circuitscape 4.0 (B. H. McRae, 2013) and Linkage Mapper 2.0 (B. H. McRae & Kavanagh, 2011) through the ArcGIS Toolbox.

## Statistical Analyses

In addition to comparing the annual change in species mobility through the landscape visually, we performed statistical comparisons of our spatial connectivity analyses to examine if there were significant changes in species connectivity as fallow area increased from 2011 (start of drought) to 2015 (peak) to 2017 (drought subsides). We focused on measures of cost-weighted distance and effective resistance for our least cost paths. Cost-weighted distance (CWD) for least-cost paths is the amount of resistance accumulated by an individual when moving optimally between core areas, and is in units of cost-weighted meters (B. H. McRae et al., 2012). We used the metric Cost Weighted Distance to Least Cost Path Length, which is a ratio of the CWD to the actual distance covered on the least cost path, as well as examining the CWD and LCP Length metrics that compose it (converted to km). Effective resistance (ER), often referred to as resistance distance, is a measure of isolation between a pair of core areas, as it accounts for multiple pathways, and is in units of ohms (B. H. McRae et al., 2008; B. H. McRae & Shah, 2009).

Given that we had panel data (2011, 2015, 2017) with a paired design (from and to core pairs are constant), we used a within-estimator model (also known as fixed effects in causal inference terminology) predicting CWD, LCP Length, CWD to LCP Length Ratio, and ER as a function of year dummy variables absorbing core-to-core identifiers and clustering the standard errors at the same level. The coefficient in this model is equivalent to a paired-t test, though sample restrictions differ, and is more flexible with respect to the treatment of the standard errors (Table S2).

# Results

## Least Cost Paths

As expected, fallowed land within Kern increased from 2011 (~ 45 kha) to 2015 (~ 93 kha) and 2017 (~ 67 kha) (Fig. 2a-c). The total number of least cost paths links—the pathway between core areas with the lowest cost to an individual—fluctuated slightly between the years as pathways computed through core areas were dropped: there were 384 least cost path (LCP) links in 2011, 386 in 2015, and 391 in 2017 (Fig. 2d).

The increase in fallowed parcels from 2011 to 2015 altered current flow in the movement corridors, or the importance of the areas for preserving species probable movement, by opening up some alternative, independent routes to movement (Fig. 3) (B. H. McRae et al., 2008). Some areas show an increase in current between the years, where current is funneled through more narrow pathways that are important to keep intact for connectivity, while areas with a decrease, particularly in the south, show potential reasonable alternative routes opened by fallowing and increases in needed ecological redundancy.

Cost Weighted Distance (CWD) to Least Cost Path (LCP) Length Ratio, or the cost of movement encountered by an individual per km traveled on the least cost pathway, had an average value across all pathways of 74.94 ± 110.68 (+/-SD), in 2011, 59.03 ± 91.27 in 2015, and 65.68 ± 98.31 in 2017 (Table 1). Standard deviation was used for summary statistics of least cost paths to show the range of variability in pathways, but standard errors were used for statistical comparisons of pathways, as is common practice. The pathway averages highlight a decrease in mean ratio value from 2011 to 2015 by ~ 21% and from 2011 to 2017 by ~ 12%, and show an increase from 2015 to 2017 of 11%. CWD and Effective Resistance metrics displayed a similar trend in increasing and decreasing values between the years (Table 1). Conversely, the Least Cost Path Length (km), or the distance an individual travels following the least cost path from one core area to another, showed the opposite trend. Thus, while the paths became slightly longer in 2015 and 2017 relative to 2011 in terms of LCP Length, they were less costly and there was a lower resistance distance to individuals. However, while these summaries help illustrate overall trends in mobility across the landscape, averaging across all pathways does not account for the paired nature of pathways.

Table 1

The number of Least Cost Paths (LCPs) and average (Mean ± SD) cost-weighted distance (CWD), LCP length, CWD to LCP Length ratio, and effective resistance values for those LCPs each year, grouped from Core-to-Core. Distance measurements have been converted to km.

| Year | Least Cost Paths | Cost Weighted Distance (Accumulated cost) | LCP Length (km) | CWD to LCP Length Ratio (Accumulated cost per km traveled) | Effective Resistance (Ohms) |
|---|---|---|---|---|---|
| 2011 | 384 | 386.47 ± 649.88 | 7.85 ± 10.58 | 74.94 ± 110.68 | 33,218.15 ± 65,787.14 |
| 2015 | 386 | 324.19 ± 510.49 | 8.54 ± 12.17 | 59.03 ± 91.27 | 28,744.41 ± 56,821.16 |
| 2017 | 391 | 361.26 ± 550.72 | 8.41 ± 11.63 | 65.68 ± 98.31 | 31,867.57 ± 60,398.06 |

### Within-estimator Models

For our within-estimator models, which evaluate differences in core-to-core connectivity metrics, we see similar patterns between years (Table 2). The average CWD to LCP Length Ratio, which measures movement costs accumulated per km traveled on the LCP, was significantly ($p < 0.05$) lower in 2015 relative to 2011 (-14.25 ± 3.26 (+/-SE)). The CWD to LCP ratio was also significantly reduced in 2017 relative to 2011, but to a lesser degree (-9.39 ± 3.15). The difference between 2015 and 2017 was not significant based on a F-test. CWD (accumulated cost) and Effective Resistance (Ohms) showed similar patterns of significant decreases in values in 2015 and 2017 relative to 2011. CWD had a significant increase from 2015 to 2017 of 25.41 ± 11.63 accumulated cost, while the increase in Effective Resistances was not significant. LCP Length also showed a similar pattern as before, but the results were not significant on the whole. There was a marginally significant increase in distance traveled on the LCP from 2011 to 2015 of 0.36 ± 0.21 km ($p < 0.1$); there was a non-significant increase from 2011 to 2017 of 0.24 ± 0.16 km and a non-significant decrease from 2015 to 2017 of -0.12 ± 0.14 km. Mean difference estimates from paired t-tests are identical to within-estimator coefficients for the same sample (Table S2). Overall, the trends highlight that the decrease in cost weighted and effective distances was greatest for 2015—the height of the drought with the greatest peak in fallowed lands.

Table 2
Within-estimator model results for Cost-Weight Distance (CWD), Least Cost Path Length (km), CWD to LCP Length Ratio (km), and Effective Resistance (Ohms). 2015 and 2017 are compared to 2011 (base year) after removing core-to-core (Path ID) average and year shocks. 2015 and 2017 estimates were then compared by setting 2015 as the base year. Displaying coefficient with cluster robust standard error, clustered at the core-to-core Path ID. There were 1,161 observations across 413 clusters of Path ID. *p < 0.1; **p < 0.05; ***p < 0.01.

| Years | CWD | LCP Length | CWD to LCP Length Ratio | Effective Resistance |
|---|---|---|---|---|
| **2011–2015** | -56.31*** | 0.36* | -14.25*** | -4,376.32*** |
| | (15.74) | (0.21) | (3.26) | (1532.26) |
| **2011–2017** | -30.91*** | 0.24 | -9.39*** | -2726.50** |
| | (11.29) | (0.16) | (3.15) | (1320.27) |
| **2015–2017** | 25.41** | -0.12 | 4.86 | 1649.83 |
| | (11.63) | (0.14) | (3.27) | (1251.52) |

# Discussion

The global trend toward increasing farmland retirement offers potential opportunities for biodiversity preservation in working landscapes worldwide (Stewart et al., 2019). Here we sought to understand how landscape changes driven by drought-induced fallowing in Kern County, California, US impacted landscape connectivity for the endangered San Joaquin kit fox, an umbrella species in the region (Williams & Fitton, 1997). Our analysis found that habitat connectivity for kit foxes peaked in 2015 with the highest total area of fallowed land, then slightly decreased with fallowing in 2017. Increases in connectivity from 2011 to 2015/2017 were apparent in reductions in average cost-weighted distances and effective resistances between core habitat areas. Additionally, despite least cost path lengths increasing from 2011 to 2015/2017, CWD-to-LCP ratios decreased in those timeframes, indicating that cumulative costs incurred by kit foxes travelling along LCPs decreased. These findings highlight that fallowed parcels may provide important conservation value by increasing landscape connectivity through an intensive agricultural landscape. While our work focused on one species, the San Joaquin kit fox, our findings have implications for other species of interest under the implementation of groundwater management policy.

Effective habitat conservation for the many endangered and endemic species in intensive agricultural regions necessitates corridors between sparse protected areas. Improved connectivity between core habitat areas prevents isolation of individual populations, helping to prevent inbreeding depression and facilitating annual or climate-driven migration and range shifts (Lino et al., 2019; Norén et al., 2016; Runge et al., 2014; Schwartz & Mills, 2005). Connectivity is especially critical for highly mobile species like kit foxes and other small canids, as dispersal within metapopulations across a fragmented landscape is vital to maintaining critical levels of genetic diversity (Hanski et al., 1996; Koopman et al., 2000; Stacey et al., 1997). Small improvements to connectivity in an agricultural landscape could significantly impact recovery for regionally threatened species and facilitate gene flow for many others (Gilbert-Norton et al., 2010; Kelsey et al., 2018; Schloss et al., 2012; Stewart et al., 2019; Williams & Fitton, 1997). Indeed, we saw fallowing double in the region from 45 kha in 2011 to 93 kha in 2015, yielding notable increases in connectivity for the San Joaquin kit fox across multiple metrics. More specifically, we find that the cost-weighted distance, effective resistance, and CWD to LCP ratio all decrease from 2011 to 2015/2017. In combination, these results indicate that kit foxes likely experienced less resistance to travel across western Kern County in 2015 relative to 2011, and also had more options for low resistance travel between core areas. Given the potential increase in permanent or rotational fallowing under the Sustainable Groundwater Management Act and the increasing need for species' mobility in response to climate changes, such increases in connectivity present a promising conservation opportunity.

Conservation lands are often heavily skewed towards high elevation and poor soil areas (Aycrigg et al., 2013). The opportunity costs of developing permanent reserves or movement corridors in productive agricultural landscapes are high and far-reaching (Bourque et al., 2019) and cultural ties to farming often extend generations (Kelsey et al., 2018), making large-scale static conservation corridors in working landscapes implausible. Thus, strategic conservation in predominantly agricultural landscapes may require opportunistic options for increasing landscape connectivity, such as temporary corridors between established protected areas (Bengtsson et al., 2003). More specifically, temporary reserves that take advantage of ephemeral and semi-permanent land use changes, such as fallowing, may be a more viable solution for increasing conservation through connectivity in areas of high economic and ecological value (Ando & Hannah, 2011; Costello & Polasky, 2004; Moilanen et al., 2014). Besides being potentially more economically and socially viable, these dynamic corridors could also be more adaptive to temporal shifts in environmental conditions or species movement behavior, which is increasingly vital under compounding anthropogenic and climate stressors (D'Aloia et al., 2019; Jennings et al., 2020; Larsen & McComb, 2021; Zeller et al., 2020). Additionally, strategic placement of fallowed lands may have numerous co-benefits, including improved soil quality, increased water storage, increased yields post-fallowing, and reduced economic losses from forced fallowing (Bourque et al., 2019; Kremen & Miles, 2012; Larsen & Noack, 2021; Oliver et al., 2010). Collaboration between agricultural and conservation stakeholders with local Groundwater Sustainability Agencies (GSAs) could help provide spatially contiguous or connected habitat with temporary corridors composed of fallowed land, and help increase species mobility and recovery throughout working landscapes (Lortie et al., 2018; Maresch et al., 2008; Stewart et al., 2019), while also seeking to minimize or offset costs to farmers associated with implementation of SGMA.

Groundwater overdraft in the San Joaquin Valley has resulted in the largest groundwater deficit of any region in California (Hanak et al., 2018). In order to meet SGMA guidelines by 2040 it has been suggested that upwards of 300 kha of agricultural land may need to be fallowed, with a yet to be determined mix of rotational and permanent fallowing (Bryant et al., 2020; Hanak et al., 2018). It is anticipated that many farmers will have options to temporarily fallow some fields, bringing them into production as short-term climate conditions yield sufficient surface water supply. Strategic collaboration as to which fields different farmers choose to temporarily fallow could provide important dynamic habitat connectivity throughout the San Joaquin Valley. Furthermore, temporary corridors paired with increased protection and restoration of quality habitat, via permanently fallowed land, could create dynamic reserve networks that help achieve both short- and long-term conservation objectives (Bengtsson et al., 2003; D'Aloia et al., 2019). Incentives provided to farmers who temporarily or permanently fallow particular fields based on objectives of these dynamic reserves could offset opportunity costs they would incur by not selecting fields with the lowest economic value. Funding mechanisms that seek to capitalize on the biodiversity conservation potential of fallow land under SGMA while decreasing costs to farmers have grown in recent years. Broadly speaking, agri-environmental schemes for biodiversity conservation have been used successfully across the US and globally, including direct payments and subsidies to farmers who adopt environmentally beneficial practices and fallowing rotations (Bourque et al., 2019; Henderson et al., 2000; Herzon et al., 2010; Kuussaari et al., 2011; Oñate et al., 2007; Ribaudo et al., 2008, 2010; Sanz-Pérez et al., 2019; Tarjuelo et al., 2020; Toivonen et al., 2013). In California, conservation payments could tap into available funding mechanisms and environmental initiatives, such as USDA funded conservation initiatives, Sustainable Groundwater Planning Grant Program funding for projects that increase sustainable groundwater, and state funding from California's newly established Biodiversity Collaborative (Bourque et al., 2019; California Department of Water Resources, 2021; Office of Governor Gavin Newsom, 2020). In 2020, the California Department of Conservation (DOC) initiated a Watershed Coordinator Grant Program providing a total of $1.5 million in funding to five different Watershed Coordinators, some of whom are expected to use funding to incentivize retirement of agricultural land that will benefit wildlife (California Department of Conservation, 2019). More recently, Assembly Bill (AB 252) was proposed in California under which the DOC would be required to provide funding to GSAs that could then provide payments to farmers who agree to repurpose land for specific conservation and restoration projects (*AB-252 Department of Conservation: Multibenefit Land Repurposing Incentive Program: Administration*, 2021).

To derive the requisite benefits from tax payer funded agri-environmental schemes necessitates a thorough understanding of the socio-ecological system. Our study adds to understanding of how temporary reserves may function to improve connectivity in working landscapes, yet has several limitations of note. First, our case study focuses on one species in one agriculturally-dominated county. Second, we lack data on species movement to validate our connectivity models. Further examination of strategic fallowing and its potential co-benefits at a larger spatial scale and inclusion of ground-validation of species movement is needed to understand cost-effectiveness of opportunistic fallowing. Strategic corridors of fallowed lands could be functional for kit foxes, who have been historically documented living near and foraging in fallow and less intensive agriculture fields. Indeed, the species recovery plan suggests farmland areas periodically set aside for more than 2–3 years would be useful for maintaining connectivity corridors in our study region (Williams & Fitton, 1997). However, this schema may not be generalizable to other species or regions. More research is needed to understand how connectivity benefits and co-benefits scale with fallowing duration.

Strategic, yet temporary conservation actions have the potential to reduce the conflict between biodiversity preservation and agricultural production in agricultural landscapes. Here we show that an increase in temporary fallowing from 2011 to 2015/2017 in western Kern County likely increased landscape connectivity for the San Joaquin kit fox. These results illustrate the potential for co-benefits to be derived amidst significant land use changes associated with drought conditions and the impending implementation of SGMA. Though the opportunity costs of fallowing to farmers under SGMA will likely be high, those costs have the potential to be partially offset by tapping into the conservation potential of dynamic reserves comprised of permanent and temporary conservation corridors made available by such actions. Given the ubiquity and influence of productive landscapes on human and natural systems and the increasing preponderance of uncultivated land therein, strategic and coordinated fallowing paired with dynamic and opportunistic conservation may be key to biodiversity conservation in agricultural landscapes.

# Declarations

## Funding

No funding was received for conducting this study.

## Conflicts of interest

We declare no conflicts of interest.

## Ethics approval

No ethics approvals were required for conducting this study.

## Consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data and material

FAM data will be available upon request from reviewers, and will be posted to Github. All other data is publicly downloadable from the sources cited, and processed in the manner described in the Methods and SI Methods.

## Code availability

Code is available upon request from reviewers.

**Authors' contributions**

Sofie McComb and Ashley Larsen conceptualized and designed the study. Material preparation and data collection were performed by Sofie McComb, and supported by Forrest Melton with regards to supplying Fallow Area Mapping data. Sofie McComb, Ashely Larsen, and Claire Powers performed the formal analysis and investigation, and contributed to the first draft of the manuscript. All authors reviewed and edited previous versions of the manuscript, and read and approved the final manuscript.

# References

1. Adriaensen, F., Chardon, J., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H., & Matthysen, E. (2003). The application of 'least-cost'modelling as a functional landscape model. *Landscape and Urban Planning*, *64*(4), 233–247.
2. Ando, A. W., & Hannah, L. (2011). Lessons from finance for new land-conservation strategies given climate-change uncertainty. *Conservation Biology*, *25*(2), 412–414.
3. Aycrigg, J. L., Davidson, A., Svancara, L. K., Gergely, K. J., McKerrow, A., & Scott, J. M. (2013). Representation of Ecological Systems within the Protected Areas Network of the Continental United States. *PLoS ONE*, *8*(1), e54689. https://doi.org/10.1371/journal.pone.0054689
4. Baguette, M., Blanchet, S., Legrand, D., Stevens, V. M., & Turlure, C. (2013). Individual dispersal, landscape connectivity and ecological networks. *Biological Reviews*, *88*(2), 310–326.
5. Bengtsson, J., Angelstam, P., Elmqvist, T., Emanuelsson, U., Folke, C., Ihse, M., Moberg, F., & Nyström, M. (2003). Reserves, Resilience and Dynamic Landscapes. *AMBIO: A Journal of the Human Environment*, *32*(6), 389–396. https://doi.org/10.1579/0044-7447-32.6.389
6. Bennett, A. F., Radford, J. Q., & Haslem, A. (2006). Properties of land mosaics: Implications for nature conservation in agricultural environments. *Biological Conservation*, *133*(2), 250–264.
7. Berg, N., & Hall, A. (2017). Anthropogenic warming impacts on California snowpack during drought. *Geophysical Research Letters*, *44*(5), 2511–2518. https://doi.org/10.1002/2016GL072104
8. Boryan, C., Yang, Z., Mueller, R., & Craig, M. (2011). Monitoring US agriculture: The US department of agriculture, national agricultural statistics service, cropland data layer program. *Geocarto International*, *26*(5), 341–358.
9. Bourque, K., Schiller, A., Loyola Angosto, C., McPhail, L., Bagnasco, W., Ayres, A., & Larsen, A. (2019). Balancing agricultural production, groundwater management, and biodiversity goals: A multi-benefit optimization model of agriculture in Kern County, California. *Science of The Total Environment*, *670*, 865–875. https://doi.org/10.1016/j.scitotenv.2019.03.197
10. Bryant, B. P., Kelsey, T. R., Vogl, A. L., Wolny, S. A., MacEwan, D., Selmants, P. C., Biswas, T., & Butterfield, H. S. (2020). Shaping Land Use Change and Ecosystem Restoration in a Water-Stressed Agricultural Landscape to Achieve Multiple Benefits. *Frontiers in Sustainable Food Systems*, *4*, 138. https://doi.org/10.3389/fsufs.2020.00138

11. Buto, S. G., & Anderson, R. D. (2020). *NHDPlus High Resolution (NHDPlus HR)—A hydrography framework for the Nation* (Report No. 2020–3033; Fact Sheet, p. 2). USGS Publications Warehouse. https://doi.org/10.3133/fs20203033
12. California Department of Conservation. (2019). *Watershed Coordinator Program*. https://www.conservation.ca.gov/dlrp/grant-programs/watershed/Pages/Index.aspx
13. California Department of Fish and Wildlife California Interagency Wildlife Task Group. (2016). *Kit Fox Predicted Habitat—CWHR M148 [ds2599].* https://map.dfg.ca.gov/metadata/ds2599.html
14. California Department of Food and Agriculture. (2019). *California Agricultural Statistics Review 2018-2019.* https://www.cdfa.ca.gov/statistics/PDFs/2018-2019AgReportnass.pdf
15. California Department of Water Resources. (2017). *2014 California Statewide Agricultural Land Use*. https://gis.water.ca.gov/app/CADWRLandUseViewer/
16. California Department of Water Resources. (2019). *2016 California Statewide Agricultural Land Use*. https://gis.water.ca.gov/app/CADWRLandUseViewer/
17. California Department of Water Resources. (2021). *Sustainable Groundwater Management Grant Program*. https://water.ca.gov/Work-With-Us/Grants-And-Loans/Sustainable-Groundwater
18. Costello, C., & Polasky, S. (2004). Dynamic reserve site selection. *Resource and Energy Economics*, *26*(2), 157–174.
19. Cypher, B. L., Phillips, S. E., & Kelly, P. A. (2013). Quantity and distribution of suitable habitat for endangered San Joaquin kit foxes: Conservation implications. *Canid Biology and Conservation*, *16*, 25–31.
20. Cypher, B. L., Warrick, G. D., Otten, M. R., O'Farrell, T. P., Berry, W. H., Harris, C. E., Kato, T. T., McCue, P. M., Scrivner, J. H., & Zoellick, B. W. (2000). Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. *Wildlife Monographs*, 1–43.
21. D'Aloia, C. C., Naujokaitis-Lewis, I., Blackford, C., Chu, C., Curtis, J. M., Darling, E., Guichard, F., Leroux, S. J., Martensen, A. C., & Rayfield, B. (2019). Coupled networks of permanent protected areas and dynamic conservation areas for biodiversity conservation under climate change. *Frontiers in Ecology and Evolution*, *7*, 27.
22. Dickson, B. G., Albano, C. M., McRae, B. H., Anderson, J. J., Theobald, D. M., Zachmann, L. J., Sisk, T. D., & Dombeck, M. P. (2017). Informing Strategic Efforts to Expand and Connect Protected Areas Using a Model of Ecological Flow, with Application to the Western United States. *Conservation Letters*, *10*(5), 564–571. https://doi.org/10.1111/conl.12322
23. Doherty, T. S., & Driscoll, D. A. (2018). Coupling movement and landscape ecology for animal conservation in production landscapes. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1870), 20172272.
24. Dong, C., MacDonald, G. M., Willis, K., Gillespie, T. W., Okin, G. S., & Williams, A. P. (2019). Vegetation Responses to 2012–2016 Drought in Northern and Southern California. *Geophysical Research Letters*, *46*(7), 3810–3821. https://doi.org/10.1029/2019GL082137

25. Dudley, N., & Alexander, S. (2017). Agriculture and biodiversity: A review. *Biodiversity*, *18*(2–3), 45–49.
26. Fahrig, L. (2002). Effect of habitat fragmentation on the extinction threshold: A synthesis. *Ecological Applications*, *12*(2), 346–353.
27. Fahrig, L. (2007). Non-optimal animal movement in human-altered landscapes. *Functional Ecology*, *21*(6), 1003–1015.
28. Fischer, J., Abson, D. J., Bergsten, A., Collier, N. F., Dorresteijn, I., Hanspach, J., Hylander, K., Schultner, J., & Senbeta, F. (2017). Reframing the food–biodiversity challenge. *Trends in Ecology & Evolution*, *32*(5), 335–345.
29. Fischer, J., & Lindenmayer, D. B. (2002). Small patches can be valuable for biodiversity conservation: Two case studies on birds in southeastern Australia. *Biological Conservation*, *106*(1), 129–136.
30. Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., & Gibbs, H. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574.
31. Folke, C. (2006). The Economic Perspective: Conservation against Development versus Conservation for Development. *Conservation Biology*, *20*(3), 686–688. https://doi.org/10.1111/j.1523-1739.2006.00446.x
32. Fraterrigo, J. M., Pearson, S. M., & Turner, M. G. (2009). Joint effects of habitat configuration and temporal stochasticity on population dynamics. *Landscape Ecology*, *24*(7), 863–877.
33. Gerrard, R., Stine, P., Church, R., & Gilpin, M. (2001). Habitat evaluation using GIS: a case study applied to the San Joaquin kit fox. *Landscape and Urban Planning*, *52*(4), 239–255.
34. Gesch, D. B., Evans, G. A., Oimoen, M. J., & Arundel, S. (2018). *The National Elevation Dataset* (pp. 83–110). American Society for Photogrammetry and Remote Sensing; USGS Publications Warehouse. http://pubs.er.usgs.gov/publication/70201572
35. Gilbert-Norton, L., Wilson, R., Stevens, J. R., & Beard, K. H. (2010). A meta-analytic review of corridor effectiveness. *Conservation Biology*, *24*(3), 660–668.
36. Griffith, G. E., Omernik, J. M., Smith, D. W., Cook, T. D., Tallyn, E., Moseley, K., & Johnson, C. B. (2016). *Ecoregions of California* (Report No. 2016–1021; Open-File Report). USGS Publications Warehouse. https://doi.org/10.3133/ofr20161021
37. Haight, R. G., Cypher, B., Kelly, P. A., Phillips, S., Ralls, K., & Possingham, H. P. (2004). Optimizing reserve expansion for disjunct populations of San Joaquin kit fox. *Biological Conservation*, *117*(1), 61–72.
38. Hanak, E., Escriva-Bou, A., Gray, B., Green, S., Harter, T., Jezdimirovic, J., Lund, J., Medellín-Azuara, J., Moyle, P., & Seavy, N. (2019). Water and the future of the San Joaquin Valley. *Public Policy Institute of California: San Francisco, CA, USA*.
39. Hanak, E., Jezdimirovic, J., Green, S., & Escriva-Bou, A. (2018). Replenishing Groundwater in the San Joaquin Valley. *Public Policy Institute of California*, *36*.

40. Hanak, E., Lund, J., Arnold, B., Escriva-Bou, A., Gray, B., Green, S., Harter, T., Howitt, R., MacEwan, D., Medellín-Azuara, J., Moyle, P., & Seavy, N. (2017). Water Stress and a Changing San Joaquin Valley. *Public Policy Institute of California*, 50.
41. Hanski, I., Moilanen, A., & Gyllenberg, M. (1996). Minimum viable metapopulation size. *The American Naturalist*, *147*(4), 527–541.
42. Harrison, S. (2013). *Plant and Animal Endemism in California*. University of California Press. https://doi.org/10.1525/9780520954731
43. Henderson, I. G., Cooper, J., Fuller, R. J., & Vickery, J. (2000). The relative abundance of birds on set-aside and neighbouring fields in summer. *Journal of Applied Ecology*, *37*(2), 335–347.
44. Herrera, L. P., Sabatino, M. C., Jaimes, F. R., & Saura, S. (2017). Landscape connectivity and the role of small habitat patches as stepping stones: An assessment of the grassland biome in South America. *Biodiversity and Conservation*, *26*(14), 3465–3479.
45. Herzon, I., Helenius, J., Kuussaari, M., Tiainen, J., & Mäkinen, T. (2010). *Agri-environmental programme in Finland serving biodiversity: Working forward.* 261–269.
46. Homer, C., Dewitz, J., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N., Wickham, J., & Megown, K. (2015). Completion of the 2011 National Land Cover Database for the conterminous United States–representing a decade of land cover change information. *Photogrammetric Engineering & Remote Sensing*, *81*(5), 345–354.
47. Howitt, R., Medellín-Azuara, J., MacEwan, D., Lund, J. R., & Sumner, D. (2014). *Economic analysis of the 2014 drought for California agriculture*. Center for Watershed Sciences University of California, Davis, CA.
48. Jennings, M. K., Zeller, K. A., & Lewison, R. L. (2020). Supporting Adaptive Connectivity in Dynamic Landscapes. *Land*, *9*(9), 295.
49. Jin, S., Homer, C., Yang, L., Danielson, P., Dewitz, J., Li, C., Zhu, Z., Xian, G., & Howard, D. (2019). Overall methodology design for the United States national land cover database 2016 products. *Remote Sensing*, *11*(24), 2971.
50. Kelsey, R., Hart, A., Butterfield, H. S., & Vink, D. (2018). Groundwater sustainability in the San Joaquin Valley: Multiple benefits if agricultural lands are retired and restored strategically. *California Agriculture*, *72*(3), 151–154.
51. Koen, E. L., Bowman, J., Sadowski, C., & Walpole, A. A. (2014). Landscape connectivity for wildlife: Development and validation of multispecies linkage maps. *Methods in Ecology and Evolution*, *5*(7), 626–633. https://doi.org/10.1111/2041-210X.12197
52. Koopman, M. E., Cypher, B. L., & Scrivner, J. H. (2000). Dispersal Patterns of San Joaquin Kit Foxes (Vulpes Macrotis Mutica). *Journal of Mammalogy*, *81*(1), 213–222. https://doi.org/10.1644/1545-1542(2000)081<0213:DPOSJK>2.0.CO;2
53. Kremen, C., & Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. *Ecology and Society*, *17*(4).

54. Kuussaari, M., Hyvönen, T., & Härmä, O. (2011). Pollinator insects benefit from rotational fallows. *Agriculture, Ecosystems & Environment*, *143*(1), 28–36. https://doi.org/10.1016/j.agee.2011.03.006
55. Larsen, A. E., Farrant, D. N., & MacDonald, A. J. (2020). Spatiotemporal overlap of pesticide use and species richness hotspots in California. *Agriculture, Ecosystems & Environment*, *289*, 106741. https://doi.org/10.1016/j.agee.2019.106741
56. Larsen, A. E., & McComb, S. (2021). Land cover and climate changes drive regionally heterogeneous increases in US insecticide use. *Landscape Ecology*, *36*(1), 159–177. https://doi.org/10.1007/s10980-020-01130-5
57. Larsen, A. E., & Noack, F. (2021). Impact of local and landscape complexity on the stability of field-level pest control. *Nature Sustainability*, *4*(2), 120–128. https://doi.org/10.1038/s41893-020-00637-8
58. Lino, A., Fonseca, C., Rojas, D., Fischer, E., & Pereira, M. J. R. (2019). A meta-analysis of the effects of habitat loss and fragmentation on genetic diversity in mammals. *Mammalian Biology*, *94*(1), 69–76.
59. Lortie, C. J., Filazzola, A., Kelsey, R., Hart, A. K., & Butterfield, H. S. (2018). Better late than never: A synthesis of strategic land retirement and restoration in California. *Ecosphere*, *9*(8), e02367. https://doi.org/10.1002/ecs2.2367
60. Maresch, W., Walbridge, M. R., & Kugler, D. (2008). Enhancing conservation on agricultural landscapes: A new direction for the Conservation Effects Assessment Project. *Journal of Soil and Water Conservation*, *63*(6), 198A-203A. https://doi.org/10.2489/jswc.63.6.198A
61. McRae, B. H. (2013). *Circuitscape ArcGIS toolbox*. https://circuitscape.org/downloads/
62. McRae, B. H., Dickson, B. G., Keitt, T. H., & Shah, V. B. (2008). Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology*, *89*(10), 2712–2724.
63. McRae, B. H., Hall, S. A., Beier, P., & Theobald, D. M. (2012). Where to Restore Ecological Connectivity? Detecting Barriers and Quantifying Restoration Benefits. *PLoS ONE*, *7*(12), e52604. https://doi.org/10.1371/journal.pone.0052604
64. McRae, B. H., & Kavanagh, D. M. (2011). Linkage mapper connectivity analysis software. *The Nature Conservancy, Seattle WA*.
65. McRae, B. H., & Kavanagh, D. M. (2017). *User Guide: Linkage Pathways Tool of the Linkage Mapper Toolbox. Version 2.0*.
66. McRae, B. H., & Shah, V. B. (2009). Circuitscape user's guide. *The University of California, Santa Barbara*.
67. McRae, B., Shah, V., & Edelman, A. (2016). *Circuitscape: Modeling landscape connectivity to promote conservation and human health*. https://doi.org/10.13140/RG.2.1.4265.1126
68. Medellín-Azuara, J., MacEwan, D., Howitt, R. E., Koruakos, G., Dogrul, E. C., Brush, C. F., Kadir, T. N., Harter, T., Melton, F., & Lund, J. R. (2015). Hydro-economic analysis of groundwater pumping for irrigated agriculture in California's Central Valley, USA. *Hydrogeology Journal*, *23*(6), 1205–1216.
69. Melton, F., Rosevelt, C., Guzman, A., Johnson, L., Zaragoza, I., Verdin, J., Thenkabail, P., Wallace, C., Mueller, R., & Willis, P. (2015). Fallowed area mapping for drought impact reporting: 2015 assessment

of conditions in the California Central Valley. *NASA Ames Research Center: Mountain View, CA, USA*.

70. Moilanen, A., Laitila, J., Vaahtoranta, T., Dicks, L. V., & Sutherland, W. J. (2014). Structured analysis of conservation strategies applied to temporary conservation. *Biological Conservation*, *170*, 188–197. https://doi.org/10.1016/j.biocon.2014.01.001
71. Nogeire, T. M., Lawler, J. J., Schumaker, N. H., Cypher, B. L., & Phillips, S. E. (2015). Land use as a driver of patterns of rodenticide exposure in modeled kit fox populations. *PloS One*, *10*(8), e0133351.
72. Norén, K., Godoy, E., Dalén, L., Meijer, T., & Angerbjörn, A. (2016). Inbreeding depression in a critically endangered carnivore. *Molecular Ecology*, *25*(14), 3309–3318.
73. Norris, K. (2008). Agriculture and biodiversity conservation: Opportunity knocks. *Conservation Letters*, *1*(1), 2–11.
74. Office of Governor Gavin Newsom. (2020). *Governor Newsom Launches Innovative Strategies to Use California Land to Fight Climate Change, Conserve Biodiversity and Boost Climate Resilience*.
75. Oliver, Y. M., Robertson, M. J., & Weeks, C. (2010). A new look at an old practice: Benefits from soil water accumulation in long fallows under Mediterranean conditions. *Agricultural Water Management*, *98*(2), 291–300.
76. Oñate, J. J., Atance, I., Bardají, I., & Llusia, D. (2007). Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. *Agricultural Systems*, *94*(2), 247–260.
77. Queiroz, C., Beilin, R., Folke, C., & Lindborg, R. (2014). Farmland abandonment: Threat or opportunity for biodiversity conservation? A global review. *Frontiers in Ecology and the Environment*, *12*(5), 288–296.
78. R Core Team. (2019). *R: A language and environment for statistical computing. R Foundation for Statistical Computing.* https://www.R-project.org/.
79. Ramankutty, N., Evan, A. T., Monfreda, C., & Foley, J. A. (2008). Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000: GLOBAL AGRICULTURAL LANDS IN 2000. *Global Biogeochemical Cycles*, *22*(1), n/a-n/a. https://doi.org/10.1029/2007GB002952
80. Reynolds, M. D., Sullivan, B. L., Hallstein, E., Matsumoto, S., Kelling, S., Merrifield, M., Fink, D., Johnston, A., Hochachka, W. M., & Bruns, N. E. (2017). Dynamic conservation for migratory species. *Science Advances*, *3*(8), e1700707.
81. Ribaudo, M., Greene, C., Hansen, L., & Hellerstein, D. (2010). Ecosystem services from agriculture: Steps for expanding markets. *Ecological Economics*, *69*(11), 2085–2092.
82. Ribaudo, M., Hansen, L. T., Hellerstein, D., & Greene, C. R. (2008). *The use of markets to increase private investment in environmental stewardship*.
83. *AB-252 Department of Conservation: Multibenefit Land Repurposing Incentive Program: Administration*, (2021) (testimony of Robert Rivas). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB252

84. Roberts, M., Milman, A., & Blomquist, W. (2021). The Sustainable Groundwater Management Act (SGMA): California’s Prescription for Common Challenges of Groundwater Governance. In J. Baird & R. Plummer (Eds.), *Water Resilience: Management and Governance in Times of Change* (pp. 41–63). Springer International Publishing. https://doi.org/10.1007/978-3-030-48110-0_3
85. Runge, C. A., Martin, T. G., Possingham, H. P., Willis, S. G., & Fuller, R. A. (2014). Conserving mobile species. *Frontiers in Ecology and the Environment*, *12*(7), 395–402.
86. Sanz-Pérez, A., Giralt, D., Robleño, I., Bota, G., Milleret, C., Mañosa, S., & Sardà-Palomera, F. (2019). Fallow management increases habitat suitability for endangered steppe bird species through changes in vegetation structure. *Journal of Applied Ecology*, *56*(9), 2166–2175.
87. Saura, S., Bodin, Ö., & Fortin, M. (2014). EDITOR’S CHOICE: Stepping stones are crucial for species’ long-distance dispersal and range expansion through habitat networks. *Journal of Applied Ecology*, *51*(1), 171–182.
88. Schloss, C. A., Nuñez, T. A., & Lawler, J. J. (2012). Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. *Proceedings of the National Academy of Sciences*, *109*(22), 8606–8611.
89. Schwartz, M. K., & Mills, L. S. (2005). Gene flow after inbreeding leads to higher survival in deer mice. *Biological Conservation*, *123*(4), 413–420.
90. Shackelford, G. E., Steward, P. R., German, R. N., Sait, S. M., & Benton, T. G. (2015). Conservation planning in agricultural landscapes: Hotspots of conflict between agriculture and nature. *Diversity and Distributions*, *21*(3), 357–367.
91. Stacey, P. B., Taper, M. L., & Johnson, V. A. (1997). Migration within metapopulations: The impact upon local population dynamics. In *Metapopulation biology* (pp. 267–291). Elsevier.
92. California water code [CWC]. Division 6, part 2.74. Sustainable Groundwater Management., (2014).
93. Stewart, J. A. E., Butterfield, H. S., Richmond, J. Q., Germano, D. J., Westphal, M. F., Tennant, E. N., & Sinervo, B. (2019). Habitat restoration opportunities, climatic niche contraction, and conservation biogeography in California’s San Joaquin Desert. *PLOS ONE*, *14*(1), e0210766. https://doi.org/10.1371/journal.pone.0210766
94. Stovall, A. E. L., Shugart, H., & Yang, X. (2019). Tree height explains mortality risk during an intense drought. *Nature Communications*, *10*(1), 4385. https://doi.org/10.1038/s41467-019-12380-6
95. Swain, D. L., Tsiang, M., Haugen, M., Singh, D., Charland, A., Rajaratnam, B., & Diffenbaugh, N. S. (2014). The extraordinary California drought of 2013/2014: Character, context, and the role of climate change. *Bull. Am. Meteorol. Soc*, *95*(9), S3–S7.
96. Tarjuelo, R., Margalida, A., & Mougeot, F. (2020). Changing the fallow paradigm: A win–win strategy for the post-2020 Common Agricultural Policy to halt farmland bird declines. *Journal of Applied Ecology*, *57*(3), 642–649.
97. Tilman, D. (1999). Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences*, *96*(11), 5995–6000.

98. Toivonen, M., Herzon, I., & Helenius, J. (2013). Environmental fallows as a new policy tool to safeguard farmland biodiversity in Finland. *Biological Conservation*, *159*, 355–366.
99. Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecology Letters*, *8*(8), 857–874.
100. United States Geological Survey (USGS). (2018). *National Elevation Dataset*. The National Map. https://viewer.nationalmap.gov/advanced-viewer/
101. United States Geological Survey (USGS). (2020). *National Hydrography Dataset: NHDPlus High Resolution (NHDPlus HR)*. https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products
102. U.S. Census Bureau. (2019). *TIGER/Line Shapefiles (machinereadable data files): California, Primary and Secondary Roads*.
103. Villard, M., & Metzger, J. P. (2014). Beyond the fragmentation debate: A conceptual model to predict when habitat configuration really matters. *Journal of Applied Ecology*, *51*(2), 309–318.
104. WHCWG (Washington Wildlife Habitat Connectivity Working Group). (2010). *Washington Connected Landscapes Project: Statewide Analysis*. Washington Departments of Fish and Wildlife, and Transportation. http://waconnected.org/statewide-analysis/
105. Williams, D. F., & Fitton, S. (1997). *Draft recovery plan for upland species of the San Joaquin Valley, California*. Region 1, US Fish and Wildlife Service.
106. Zeller, K. A., Lewsion, R., Fletcher, R. J., Tulbure, M. G., & Jennings, M. K. (2020). Understanding the Importance of Dynamic Landscape Connectivity. *Land*, *9*(9), 303.

# Figures

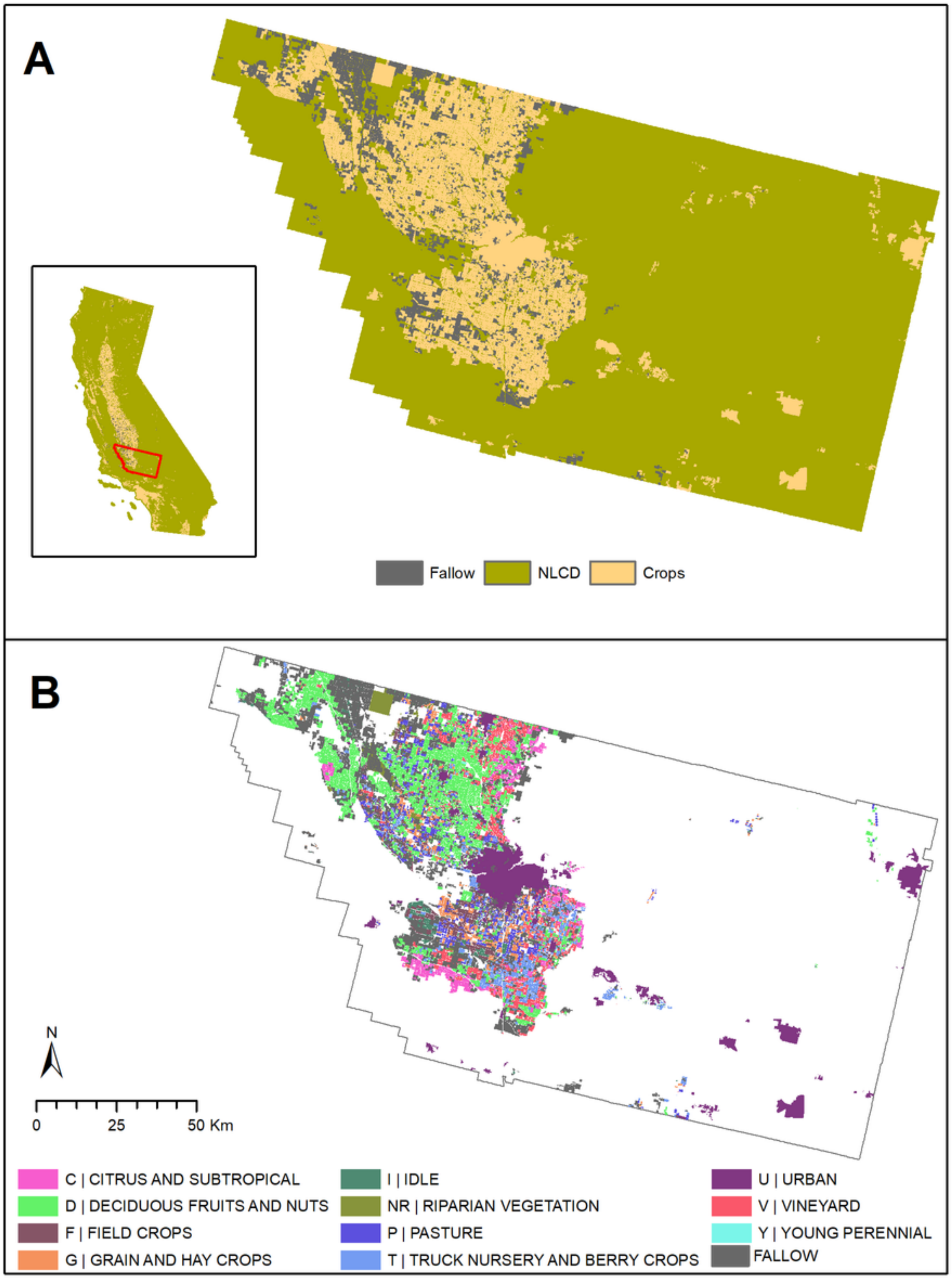

**Figure 1**

Land cover map of Kern County. Panel A shows the land cover in Kern for 2014 from 2014 FAM fallowing data, 2016 LandIQ LLC Crop Data, and 2016 NLCD data. The same data are shown for the entire state of California, with Kern county outlined in red. Panel B shows the breakdown of the 2014 Crop Data in the Department of Water Resources Categories, plus 2014 FAM Fallowing Data.

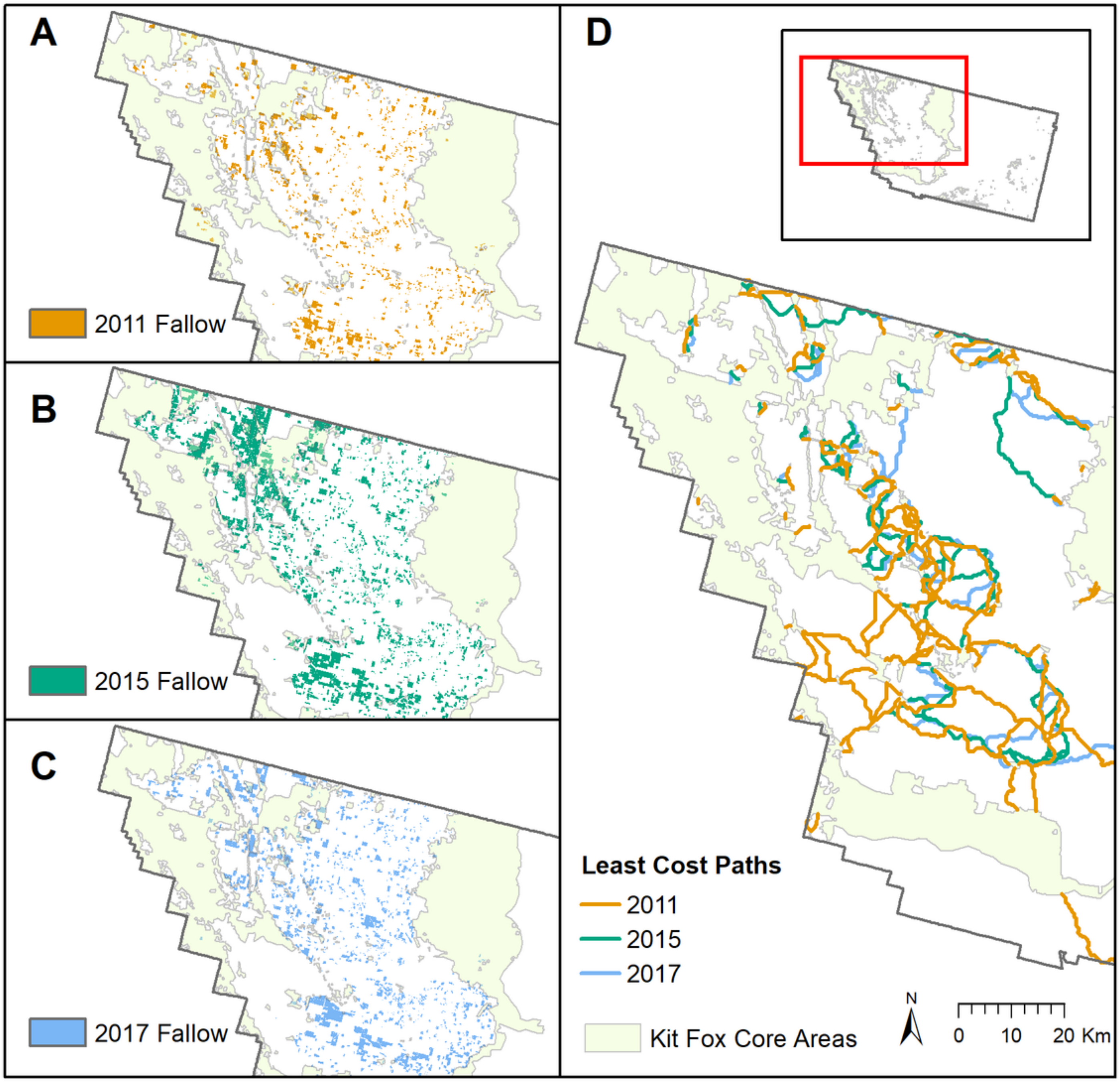

**Figure 2**

San Joaquin kit fox Core Areas and Least Cost Paths within West Kern County, with Fallowed Areas for 2011, 2015, and 2017. On the left is the amount of fallowed land in A) 2011, B) 2015, and C) 2017. Figure D shows the Least Cost Paths between kit fox Core Areas for each year, where 2011 least cost paths have visualization precedence over 2015 and 2017, and 2015 over 2017; therefore, only additional pathways can be seen and not the removal of pathways.

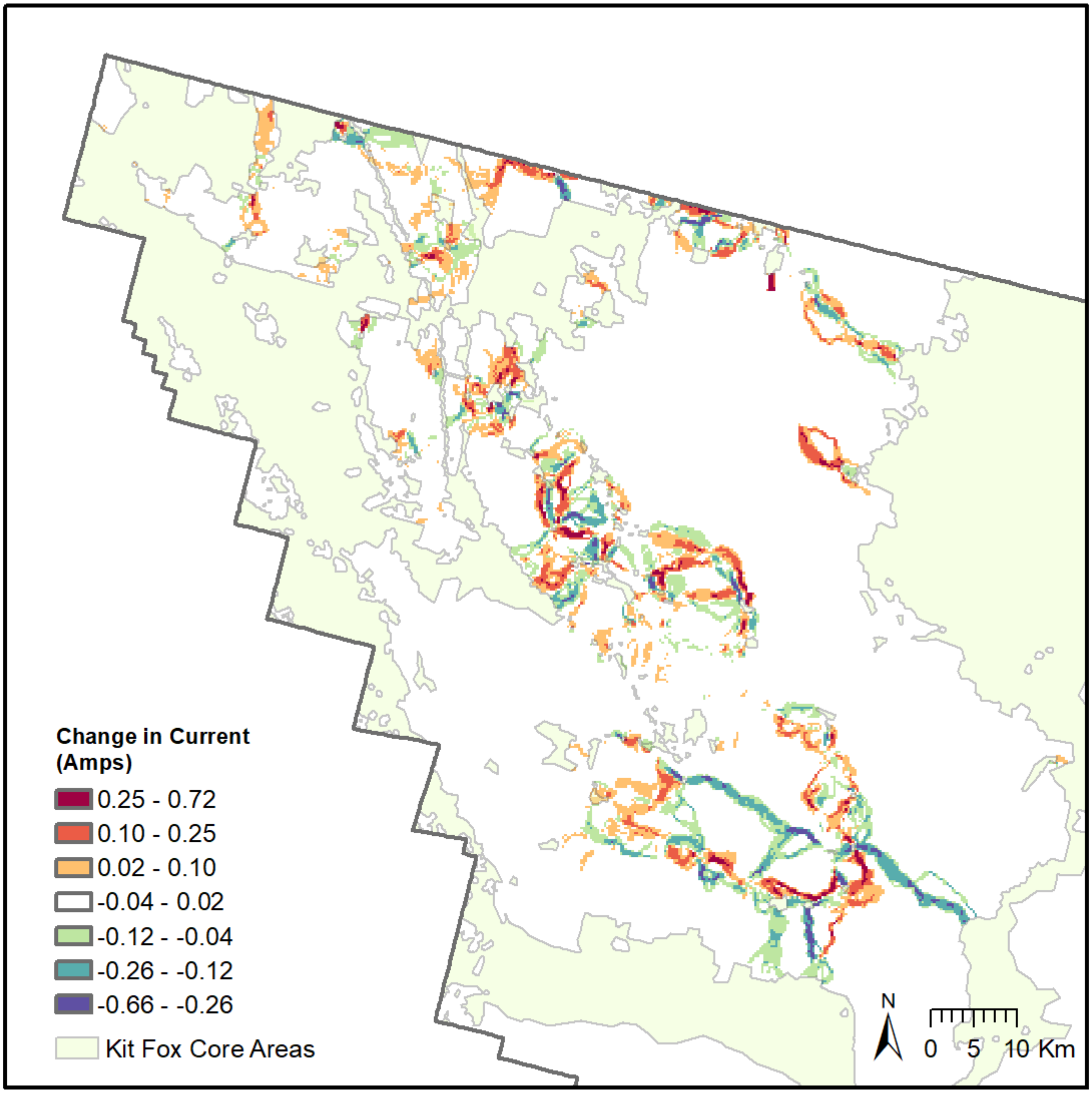

**Figure 3**

Difference in Current Flow Output between 2011 and 2015. The change in current in amps from 2011 to 2015 is depicted using Natural Jenks for breaks. Increase in current (amps) shown in orange to red colors, and a decrease in green to purple. Amps ranged from 0 to about 0.8 in the study period.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryInformation051421.docx