CLIMATE-WISE
LANDSCAPE CONNECTIVITY:
WHY, HOW, AND WHAT'S NEXT

A Report for:

California's Fourth Climate Change Assessment

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PREFACE

California's Climate Change Assessments provide a scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. These Assessments contribute to the advancement of science-based policies, plans, and programs to promote effective climate leadership in California. In 2006, California released its First Climate Change Assessment, which shed light on the impacts of climate change on specific sectors in California and was instrumental in supporting the passage of the landmark legislation Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), California's Global Warming Solutions Act. The Second Assessment concluded that adaptation is a crucial complement to reducing greenhouse gas emissions (2009), given that some changes to the climate are ongoing and inevitable, motivating and informing California's first Climate Adaptation Strategy released the same year. In 2012, California's Third Climate Change Assessment made substantial progress in projecting local impacts of climate change, investigating consequences to human and natural systems, and exploring barriers to adaptation.

Under the leadership of Governor Edmund G. Brown, Jr., a trio of state agencies jointly managed and supported California's Fourth Climate Change Assessment: California's Natural Resources Agency (CNRA), the Governor's Office of Planning and Research (OPR), and the California Energy Commission (Energy Commission). The Climate Action Team Research Working Group, through which more than 20 state agencies coordinate climate-related research, served as the steering committee, providing input for a multisector call for proposals, participating in selection of research teams, and offering technical guidance throughout the process.

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. It includes research to develop rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health.

The Fourth Assessment includes 44 technical reports to advance the scientific foundation for understanding climate-related risks and resilience options, nine regional reports plus an oceans and coast report to outline climate risks and adaptation options, reports on tribal and indigenous issues as well as climate justice, and a comprehensive statewide summary report. All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor and relevance to practitioners and stakeholders.

For the full suite of Fourth Assessment research products, please visit www.climateassessment.ca.gov. This report advances understanding of designing and implementing climate-wise connectivity strategies to mitigate and help species adapt to climate change.

ABSTRACT

Scientists predict significant shifts in species distributions in response to climate change. Wildlife corridors have been shown to facilitate species movement in fragmented landscapes and, in the hope they will facilitate range shifts in the face of climate change, are the go to solution to enhance climate resilient landscapes. While habitat connectivity has been studied for over four decades, the design of climate-wise connectivity to mitigate and help species adapt to climate change is a relatively new challenge. With species already shifting their ranges due to climate change, and habitat loss and fragmentation continuing at harrowing speed, there is an urgent need to speed up the rate of corridor implementation, but little information is available on how to efficiently implement corridors on-the-ground. We reviewed the literature, conducted a workshop, and interviewed conservation professionals to evaluate climate-wise connectivity modeling, and to understand the challenges and opportunities encountered during connectivity project implementation. We identified 13 approaches to design climate-wise connectivity, based on either focal species or landscape structure. Concepts that will increase climate adaptation include linking climate analogs and focusing on climate refugia and areas of low climate velocity. We offer guidance for selecting methods for climate-wise connectivity planning depending on conservation objectives. Opportunities to achieve climate-wise connectivity through corridor implementation include developing a common vision of connected landscapes, accounting for the multiple benefits of corridors, building partnerships between stakeholders, involving the public, introducing laws and regulations to guide resource agencies, and promoting incentive programs for private landowners. Scientific data on climate change velocity, refugia, and animal movement paths can be important for siting and justifying connectivity projects with climate resilience objectives. Research is needed that compares different approaches to designing climate-wise connectivity, addresses how wide corridors need to be, and quantifies the impact of natural and anthropogenic barriers on possible range shifts. To ensure expedient corridor implementation, California should advance policies and funding mechanisms aimed at increasing connectivity conservation, integrate habitat connectivity objectives into local land use planning, and develop incentive programs to increase private landowner participation.

Keywords: climate-wise, connectivity, conservation, corridor implementation, corridors, focal species, implementation framework, lessons learned, refugia, structural connectivity, wildlife

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HIGHLIGHTS

- Climate-wise connectivity is an emerging area of conservation science focused on maintaining and restoring resilient landscapes to facilitate species movement required for range shifts expected with climate change.
- Increasing the amount of habitat throughout the landscape is one of the most effective strategies to help California's species adapt to climate change. Additionally, the protection of climate refugia, elevation and other geographic gradients that may help slow the rate of climate change that species may experience, and movement corridors will help facilitate persistence and range shifts.
- 13 approaches to design climate-wise connectivity, based on either focal species or landscape structure, were identified and each approach aligns with different conservation objectives, start and end points, and input data.
- Structural connectivity approaches based on land use/land cover are a good proxy for species movement patterns and are recommended as a first start for statewide corridor modeling in combination with climate information, particularly on refugia (areas where today's climate will persist into the future and places with low climate velocity); where possible, empirical data on species movement should be used for model validation and local planning.
- Riparian corridors should be included in connectivity planning because of their importance as natural movement corridors, climate gradients, and refugia, and also because they provide co-benefits to protecting water resources and hazard mitigation.
- Robust scientific data, especially animal movement paths, camera trap data, and roadkill surveys, in combination with climate change assessments and connectivity models, can help with siting and justifying connectivity projects.
- Opportunities for successful corridor implementation include creating a common vision of connected landscapes, accounting for the multiple benefits of corridors, partnerships between stakeholders, close collaboration with scientists, climate-wise connectivity planning, communication among partners and with the public, laws and regulations focused on conserving connectivity to guide resource agencies, and incentive programs for private landowners.
- A framework to guide corridor implementation is proposed based on the literature and interviews with conservation professionals in California that includes: the role of partnerships; planning; data and analysis; opportunities and challenges; and various strategies producing conservation outcomes.
- California should advance policies and funding mechanisms aimed at increasing connectivity conservation, integrating habitat connectivity objectives into local land use planning and infrastructure upgrades and maintenance, and developing incentive programs to increase private landowner participation.
- In sum, California can make rapid progress towards creating climate-resilient landscapes by using appropriate modeling approaches to design corridors that will help animals and

plants move in response to climate change, protecting climate refugia, continuing to conduct scientific field research on species movement, and following the framework developed here to guide on-the-ground connectivity implementation.

WEB LINKS

http://ucanr.edu/sites/merenlender/Research_Areas/Corridors_as_Adaptation_to_Climate_Change/

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1: Introduction

California's large area harbors a wide variety of topographic and physical features that contain variations in elevation, temperature, rainfall, and soil type and result in a high level of endemism (DeNevers et al. 2013). The diversity of these factors produces California's 10 distinct bioregions, and variation in soil type, slope, aspect, temperature, and topography has led to the evolution of many endemic species with restricted ranges (Thorne et al. 2009). This variability and associated endemism explains why human-induced disturbance may have broad implications for the flora and fauna of California, and why California is a hotspot for endangered species. This diversity of ecosystems and species also makes conservation and connectivity planning across the state complex and necessitates exploring approaches that are suitable for the varied ecoregions and communities that exist within them. The decisions made today about land and water protection and habitat connectivity will profoundly influence the conservation of California's biodiversity into the future.

Many species and ecosystem functions are dependent on extensive, well-connected habitats (Hilty et al. 2006). In the face of rapid climate change, many species face difficulties in shifting their ranges to new, suitable habitats and climates. This is due to several factors, including highly modified landscapes such as roads, intensive agriculture, and residential development (Opdam & Wascher 2004; Kitzes & Merenlender 2014); and, increasingly, to the velocity of changing climate with its associated direct and indirect ecological effects (Loarie et al. 2009). In response, protected area planning has focused on advancing habitat connectivity through identification and protection of linkages in the form of corridors, ecological networks, greenbelts, and other landscape features (Heller & Zavaleta 2009).

Connectivity is the extent to which movements of genes, propagules (e.g., pollen and seeds), individuals, and populations are facilitated by the structure and composition of the landscape (Hilty et al. 2006). Connectivity can result from the opportunistic movement of wildlife in response to environmental cues over various time frames. A species can undertake several types of movement events, which generally take place at different spatial and temporal scales at various life history stages. Daily movement can occur in the procurement of food, water, shelter, or other resource requirements. Seasonal movement, or "migration," might generally occur at a much larger spatial scale. Long distance juvenile dispersal or other colonization events might take place once in an individual's life or even less frequently, occurring only after a lapse of several generations. Further, connectivity is increasingly recognized as being critical to allow for species ranges to shift and increase the resilience of populations in the face of future climate change. These various types of movement, coupled with inter-specific biological differences, lead to numerous ways in which to measure a landscape's connectivity. Understanding the factors that contribute to landscape connectivity for specific populations, species, or communities – while challenging – is urgent in considering the expected impacts of climate change.

The destruction and degradation of natural habitats on which all organisms rely -- including humans -- is occurring at an unprecedented rate across most regions of our planet (Sanderson et al. 2002). This process changes not only the size of habitat patches but also habitat patch configuration and result in habitat fragmentation that can threaten species persistence (Laurance 1990; Mills 1996; Lidicker 1998). Human-caused disturbances often occur on shorter timeframes and over larger areas than do natural disturbances, so ecological communities face challenges to adapt and respond to novel rates and scales of disturbances that are quite different from those with which they may have evolved (Hannah et al. 2007; Merenlender 2015). Current human-induced fragmentation of habitats has been modeled for California (Girvetz et al. 2008) and can be considered as a future threat to existing natural areas and linkages. Models of how land use will affect California's habitats have also been produced (Beardsley et al. 2009; Huber et al. 2012; Thorne et al. 2012). These models can be used with projections of future climatic conditions to develop optimal conservation linkage designs for California. Understanding these threats to existing and future connectivity needs is key to helping prioritize corridor conservation.

Conserving connectivity in this context requires identifying, maintaining, and possibly enhancing the linkages between patches of habitat in the landscape. Corridors, which are generally features that facilitate movement between patches, are frequently used as a tool for conserving or enhancing linkages (Bennett 1999; Rudnick et al. 2012). However, landscape connectivity is highly diverse and species-specific, and other forms of connectivity may be relevant to organisms; for example, a linked mosaic of vernal pools may be required for fairy shrimp; whereas coastal riverine corridors that support old growth redwood and Douglas fir are important for marbled murrelet conservation (Rudnick et al. 2012). The challenge of matching connectivity patterns to ecological requirements becomes even greater when we expand our thinking to consider maintaining or restoring connectivity for multiple species or entire communities, as is often the goal for regional and statewide conservation planning efforts.

To make landscapes climate resilient, the number and size of protected areas and corridors should be increased, and connectivity should now be designed to specifically facilitate animal and plant movement in response to climate change. Conserving a diversity of geological features, considering the velocity of climate change in an area, identifying climate refugia, and taking into account animal and plant population dynamics at the leading and trailing edges of ranges are some approaches to plan for climate-wise connectivity (Pearson & Dawson 2005, Carroll et al. 2017). The addition of climate considerations to connectivity design augments the connectivity potential beyond what is otherwise attainable, thereby reducing the likelihood that connectivity projects will fail to promote species movements into the future.

While the concept of increasing connectivity to facilitate persistence will increase climate resilience for those taxa that have time and opportunities to persist in a refugia or shift their ranges, the question remains what happens to climate-sensitive species when connectivity is planned and implemented through habitat with extremely high velocity and climate change extremes? Will improving connectivity benefit biodiversity, increase resilience or promote adaptation at the end of this century? Evidence to answer these questions at this time is scarce (Heller et al. 2015). However, if climate change is not considered in today's connectivity planning efforts there is a risk of investing in conservation today that is not optimal in the future. To reduce species vulnerability to climate change, protected area land networks need to be as resilient to climate change as possible; incorporating climate-wise connectivity while growing the protected area land networks is a useful strategy.

In addition to adding a climate-wise component to connectivity planning, with species habitat loss and fragmentation continuing at harrowing speed there is an urgent need to speed up the rate of corridor implementation. Even though many local, regional, or national connectivity plans and prioritizations exist (e.g. Merenlender et al. 2010; Spencer et al. 2010, Jongman et al. 2010), implementing these plans has been slow.

To address these issues, this project analyzed methods used to integrate connectivity and climate science and explored barriers and opportunities related to corridor implementation. We used information gained from existing scholarship to address fundamental questions about the theory, methods, and utility of migration corridors as an adaptation strategy to climate change in California. Based on this information, we provide guidance on how to select the most appropriate climate-wise connectivity approaches depending on conservation objectives and available data. We also propose a framework outlining the key elements of on-the-ground connectivity implementation to help future projects be successful.

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2: Planning for Climate-wise Connectivity

2.1 Introduction

Climate change presents a fundamental threat to biodiversity. Widespread biotic responses have already been documented, including severe range contractions, local and global extinctions, shifts in phenology causing disruptions of species interactions, but also adaptations to warmer conditions, shifts in species distributions, and changes in resource use and dispersal capabilities at the leading edges of range margins (Parmesan 2006). In the face of climate change, many existing obstacles to species range shifts become increasingly problematic. These include landscape fragmentation from roads, intensive agriculture, residential development (Opdam & Wascher 2004; Kitzes & Merenlender 2014); and, increasingly, the velocity of changing climate and associated direct and indirect ecological effects (Loarie et al. 2009) and mismatches with dispersal capabilities (Schloss et al. 2012).

Conservation planning has focused on advancing landscape connectivity through identification and protection of linkages in the form of corridors, ecological networks, greenbelts, and other landscape features (Heller & Zavaleta 2009) to facilitate movements of genes, propagules (e.g., pollen and seeds), individuals, and populations, and to maintain ecological processes (Hilty et al., 2006; Heller & Zavaleta 2009). However, while habitat connectivity has been studied for over four decades, the design of climate-wise connectivity – connectivity that specifically facilitates animal and plant movement in response to climate change – is a relatively new challenge (Box 2.1).

There are considerations related to climate change that cross methodological approaches. Here we review three key concepts related to climate considerations for terrestrial ecosystems: climate velocity (Box 2.2), range dynamics particularly at the leading and trailing edges of ranges (Box 2.3), and climate refugia (Box 2.4). We identify approaches to modeling climate-wise connectivity, summarize studies comparing connectivity design approaches, discuss how refugia are incorporated into climate-wise connectivity designs, and give a brief overview of modeling tools. We then synthesize empirical studies and simulations that assess habitat connectivity for climate adaptation. We conclude with a critical look at approaches to designing climate-wise connectivity and make recommendations.

Box 2.1. Habitat vs. Climate-wise Connectivity

Historically, habitat connectivity aimed to functionally connect suitable habitats such that individual organisms can move within their current range. The species that most often required improvements in habitat connectivity tended to be wide-ranging or exist as meta-populations (Beier et al. 2008). Climate-wise connectivity expands the need for connected landscapes: it aims to also connect current habitat to habitat that will become suitable in the future (Hodgson et al. 2011). Furthermore, connectivity to facilitate range shifts will likely be essential for all species that can adapt to the changing climate by shifting their ranges (Heller & Zavaleta 2009; Mawdsley et al. 2009; Krosby et al. 2010; Hannah 2011). Because range shifts will likely occur over generations, climate-wise connectivity needs to provide sufficient habitat for individuals to live in and find resources throughout their entire life cycles, not just for daily, dispersal, or migratory movements which can occur through habitat that may only be suitable for movement or feeding (Hannah 2011). Further, as species shift their ranges toward future suitable climate conditions, climate-wise connectivity is directional, following temperature and moisture gradients (Parmesan 2006; Killeen & Solorzano 2008). Finally, climate-wise connectivity should include geophysical features that create a diversity of microclimates that can buffer the effects of climate change, giving species with short dispersal distances time to track the changing climate (Hannah et al. 2014; Anderson et al. 2015). Despite these added needs for climate-wise connectivity, the implementation tools remain the same: common strategies are protecting, restoring, and managing land in the corridors, as well as ‘softening’ the matrix to make landscapes more permeable.

Box 2.2. Climate Velocity

The concept of climate velocity is to quantify the rate of climate change over time in relation to spatial gradients of climatic heterogeneity across a landscape (Loarie et al. 2009). For temperature, climate velocity expresses the speed at which a population would have to move to keep up with the changing climate on the landscape; velocity is calculated as the ratio of rate of climate change (°C/year) divided by the spatial gradient (°C/year ÷ °C/km = km/year). Global studies of animal diversity show greater diversity of narrow range species in areas with low velocity (mainly mountainous regions; Sandel et al. 2011), supporting the view that rugged topography could help buffer the biotic impacts of climate change by allowing species to move shorter distances, thereby mitigating changing conditions (Ackerly et al. 2010). On the other hand, an analysis of montane environments revealed that shortest distance paths connecting present and future suitable climate may often traverse climatically dissimilar landscapes, presenting potential barriers to movement and offsetting the value of heterogeneous topography (Dobrowski & Parks 2016). Some have suggested that connectivity should be designed to limit the rate of climate change along a designated linkage to “slow” the experience of climate change for individuals on the move (Anderson et al. 2014; Heller et al. 2015; Anderson et al. 2016). Since the initial introduction of the velocity concept, several methodological developments have extended the velocity calculations to multiple climate variables and expanded the spatial domain to consider isolated climate refugia that may not be revealed by local analysis of landscape heterogeneity (Hamann et al. 2015; LoPresti et al. 2015).

Box 2.3. Range Dynamics: Trailing and Leading Edges

For many species and habitat types, a changing climate is expected to reduce climatic suitability for some locations or populations, and increase it in others. These declining and improving locations are referred to as trailing and leading edges, respectively. Along temperature gradients, when the climate is warming, trailing edges will generally be found at warmer (southern or lower elevation) locations, while leading edges will occur at cooler (northern, coastal, or high elevation) locations where new populations may have a chance to establish beyond a species' current distribution (Thomas 2010). In heterogeneous landscapes, trailing- and leading-edge populations may occur in less obvious locations. For example, conditions may deteriorate on south-facing slopes, while new populations might establish in valley bottoms due to warming of cold-air pools and enhanced moisture availability (Ackerly 2003; Morin & Lechowicz 2008). Connecting trailing edges to the main range and leading edges to future suitable habitat by improving landscape connectivity may be essential to facilitating migration and the adaptation of native species to climate change. Locations with similar climates across current conditions and future scenarios are referred to as climate analogs (Veloz et al. 2012); when modeling structural connectivity, corridors can be designed to connect one area to another estimated to be a climate analog in the future.

Box 2.4. Climate Refugia

The concept of refugia has first been explored in paleoecology with strong evidence for the importance of Pleistocene refugia -- areas of endemism -- that provided source populations for future species range expansions when the climate began warming (Keppel et al. 2012). With respect to modern day climate change, climate refugia are places of lower climate velocity relative to the surrounding (Bennett & Provan 2008). The importance of refugia to buffer species and communities against deleterious effects of climate change has been recognized as one approach to guide protected area planning for climate change resilience (Keppel et al. 2012; Keppel & Wardell-Johnson 2012; Hannah et al. 2014; Keppel et al. 2015). Different types of refugia have been identified. The literature distinguishes between microrefugia and macrorefugia depending on geographic scale; therefore, the resolution of climate data appropriate for modelling them differs (Ashcroft 2010). Microrefugia that can facilitate species range shifts are sometimes referred to as stepping stones and are integrated into corridor planning theory (Hannah et al. 2014). Microclimate refugia are microsites with a lower rate of climate change. They can play a role in promoting long-term persistence by slowing climate velocity that is experienced by species. These refugia are expected to be more common in areas with high topographic diversity (Anderson et al. 2016). In-situ refugia are locations that will remain, at least temporarily, suitable for a species under climate change either because 1) the climate will minimally change compared to the surrounding, 2) because the temperatures are cooler than the surrounding, 3) because precipitation patterns buffer increasing temperatures (Ashcroft 2010; Maher et al. 2017), or 4) because climate change is within the range of suitable climate for the species in that location (Carroll et al. 2017). Ex-situ refugia are refugia that are currently outside a species' range (Ashcroft 2010). Models that spatially and temporally link current habitat to ex-situ refugia while taking species' dispersal capabilities into account are one way to address the need for temporal connectivity (Williams et al. 2005; Phillips et al. 2008). Less frequently identified types of refugia are drought refugia (areas in arid and semi-arid regions characterized by relatively high plant abundance; Rouget et al. 2003), evolutionary refugia (areas where certain organisms are able to persist despite long-term climate changes; Klein et al. 2009), and hydrologic refugia (areas of high relative water availability; McLaughlin et al. 2017). Epps et al. (2006) defined genetic refugia as in-situ refugia that are well connected and thereby promote the maintenance of high genetic diversity.

It is important to note that refugia of any kind are not entirely immune to climate change over a century, and hence refugia should not imply permanence in the face of climate change (Hannah et al. 2014). However, sites where the velocity of change is slower could buy some species more time to adapt (Heller et al. 2015), making them important to include in a protected area network for increased climate resilience.

2.2 Literature Search Methods

We systematically searched the online databases ISI Web of Science and Scopus (articles published until September 20, 2017) with a combination of climate-related and connectivity-related terms to find papers at the intersection of connectivity and climate change (Pullin & Stewart 2006):

((“climat* change” OR “climate velocity” OR “velocity of climate” OR climat* OR “global warming” OR “global change”) AND ((corridor* AND connectivity) OR (“range shift*” AND connectivity) OR (“conservation planning” AND connectivity) OR (“land facet*”) OR (linkage* AND connectivity) OR (“coarse filter approach” AND connectivity) OR (wildlife AND (connectivity OR linkage OR corridor OR “stepping stone”)) OR (riparian AND (connectivity OR linkage OR corridor OR “stepping stone”)) OR (“trailing edge*”) OR (refugia AND (connectivity OR linkage OR corridor OR “stepping stone”)))). The above search terms were iteratively tested and modified using a list of references (Appendix A). When reading the papers included in the review from the database search, we looked for additional relevant studies in the citations and included them in the review.

We included all research papers, reviews, and essays that integrate climate and connectivity in their methods and results sections. We filtered the resulting references on three criteria to determine their relevance to our research questions. First, based on the titles and abstracts, Annika Keeley assigned papers to one of 3 categories: include, exclude based on no inclusion of climate and connectivity in the methods or results sections, or possibly include. Second, titles and abstracts of papers in the 3rd category were reviewed by Adina Merenlender and David Ackerly. If either investigator considered a paper relevant, it was included in the next step. Third, we performed full text filtering to remove references that may have appeared relevant from the abstract but upon closer inspection did not meet the inclusion criteria. We estimated the comprehensiveness of the database search by calculating the proportion of papers that we obtained through the bibliographies but missed in the database search.

We developed a data extraction spread-sheet to collect metadata from each paper (Appendix B). Using a subset of the metadata, we conducted a hierarchical cluster analysis (R Core Team 2014) to facilitate grouping the papers based on the metadata collected. To arrive at a useful solution, we iteratively studied the results of the cluster analysis and adjusted the set of metadata categories included in the final cluster analysis (Appendix C) helping us to recognize commonalities between studies. We studied the subgroups to develop climate-wise design approach categories (Table 2.1). We assigned papers that did not fall into distinct, meaningful subgroups to one of the final categories based on the objectives, input, output, corridor end points, and temporal planning horizon.

Table 2.1. Studies designing climate-wise connectivity organized by connectivity design approach.

Connectivity based on focal species	
Finding climate-stable corridors	McKelvey et al. 2011 Howard&Schlesinger 2013 Wasserman et al. 2013 Giannini et al. 2015 Drake et al. 2017 Leonard et al. 2017
Connecting current to future ranges: large species groups	Lawler et al. 2013 Choe et al. 2017
Connecting current to future habitat: one or a few focal species	Razgour 2015 Coristine et al. 2016 Dilts et al. 2016 Gonçalves et al. 2016
Temporal corridors	Williams et al. 2005 Phillips et al. 2008 Rose&Burton 2009 Hannah et al. 2012a Pellatt et al. 2012 Fleishman et al. 2014
Conservation network planning	Vos et al. 2010 Faleiro et al. 2013 Alagador et al. 2014 Rüter et al. 2014 Alagador et al. 2016 Hodgson et al. 2016 Rayfield et al. 2016 Albert et al. 2017 Brambilla et al. 2017
Paleo-connections	Fan et al. 2017 Mokany et al. 2017 Wu et al. 2017
Structural connectivity	
Riparian corridors	Krosby et al. 2014
Environmental gradients	Rouget et al. 2003 Nuñez et al. 2013 McGuire et al. 2016 Jewitt et al. 2017
Naturalness-based corridors	Theobald et al. 2012 Krosby et al. 2015 Belote et al. 2016 Dickson et al. 2016 McRae et al. 2016 Belote et al. 2017 Littlefield et al. 2017
Land facet corridors	Brost&Beier 2012a Brost&Beier 2012b

Table 2 continued.

Lattice corridors	Kilbane 2013 Townsend&Masters 2015
Conservation network planning	Cowling et al. 2003 Rouget et al. 2006 Klein et al. 2009 Game et al. 2011 Anderson et al. 2014 Heller et al. 2015 Anderson et al. 2016 Fung et al. 2016
Carbon stock corridors	Jantz et al. 2015

2.3 Results and Discussion

The literature search returned 1333 papers, 103 of which we considered relevant (Appendix D). We added an additional 12 papers that we obtained through the bibliographies. Of the additional papers, four are reports or book chapters that would not have been encountered in the formal literature search. Without these, the proportion of journal articles that we obtained through the bibliographies but missed in the database search is 6.9%. Of the 115 papers included in the review, 84 were original studies and 31 were review papers or essays. While the first paper designing climate-wise connectivity dates from 1996, the majority of papers has been published since 2011. Most studies were conducted in North America, with 40% of the papers coming from California. Studies using a focal species approach explored connectivity for animals (28), plants (18), both (7), or simulated species (7) (Appendix E). The final cluster analysis split the papers into two main groups: those that explore how to design climate-wise connectivity networks (Fig. 2.1) and those that assess patterns and processes related to habitat connectivity as a climate change adaptation strategy (Fig. 2.2). In both clusters, the papers were then grouped by whether they focus on focal species connectivity or on structural connectivity. Focal species connectivity is based on information about a single or a set of focal species; structural connectivity describes the physical characteristics of a landscape that are generally understood to facilitate species movement. Within the design cluster, we identified 13 climate-wise design approach categories: six categories capture the studies taking a focal species approach, and 7 categories organize the papers taking a structural connectivity approach (Table 2.1). Within the assessment cluster (Fig. 2.2), although there are distinct splits, we did not recognize intuitive categories beyond the structural/focal-species-based connectivity groups. Below, we organize our review assessment based on these two major categories.

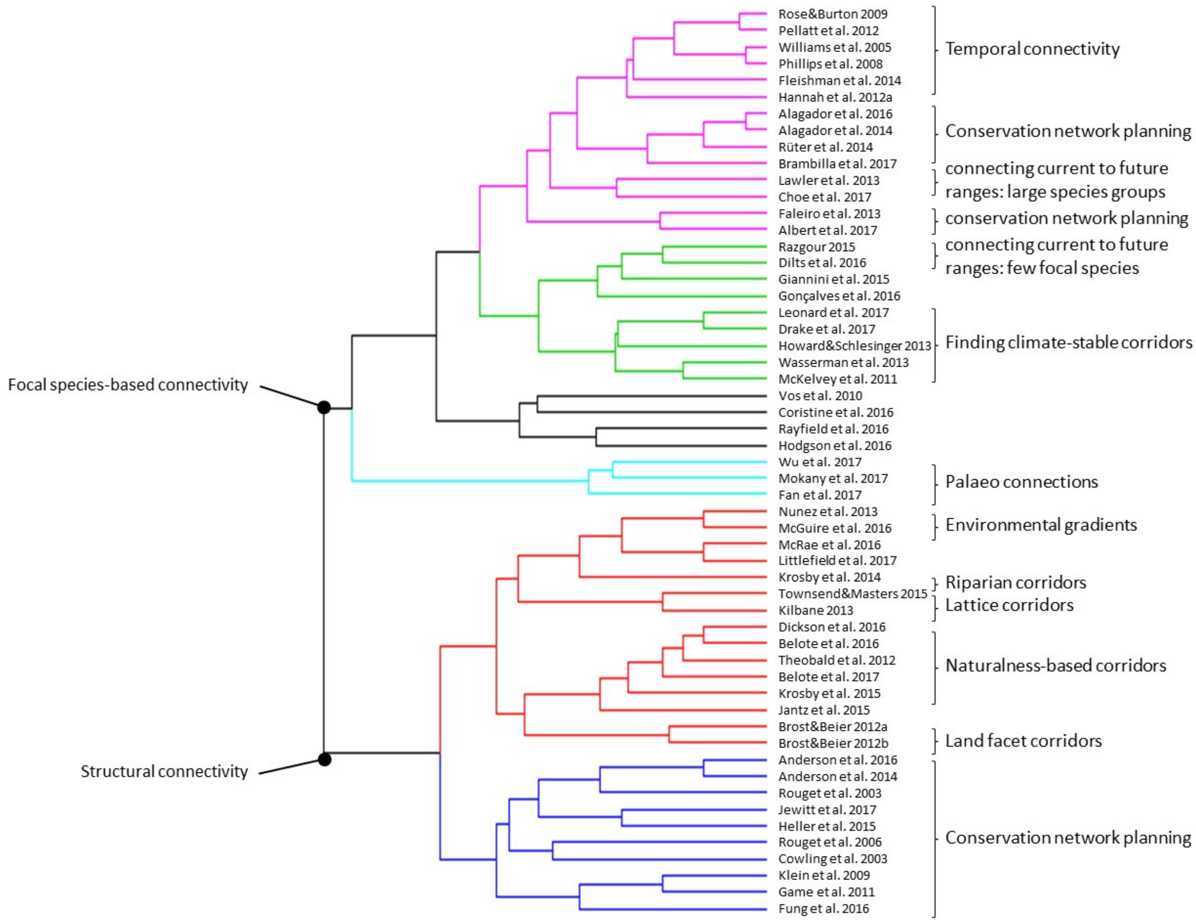

Figure 2.1. Results of the cluster analysis: Studies designing climate-wise connectivity.

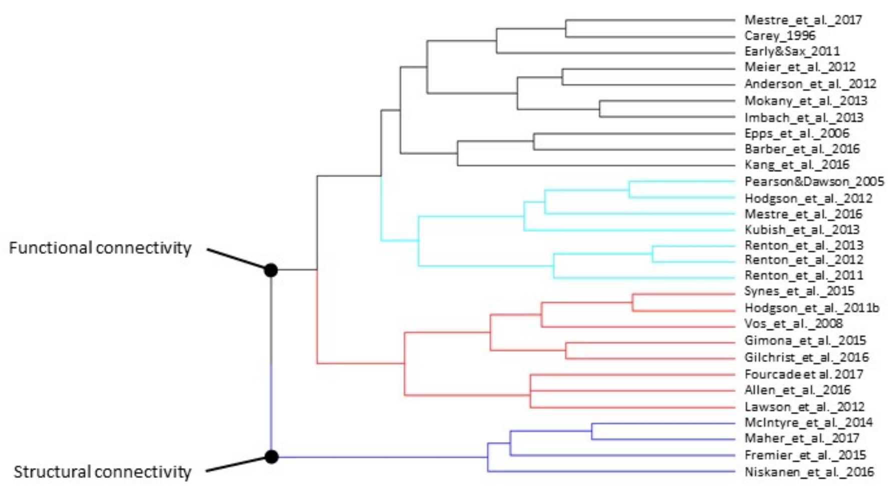

Figure 2.2. Results of the cluster analysis: Studies assessing connectivity at the leading edge.

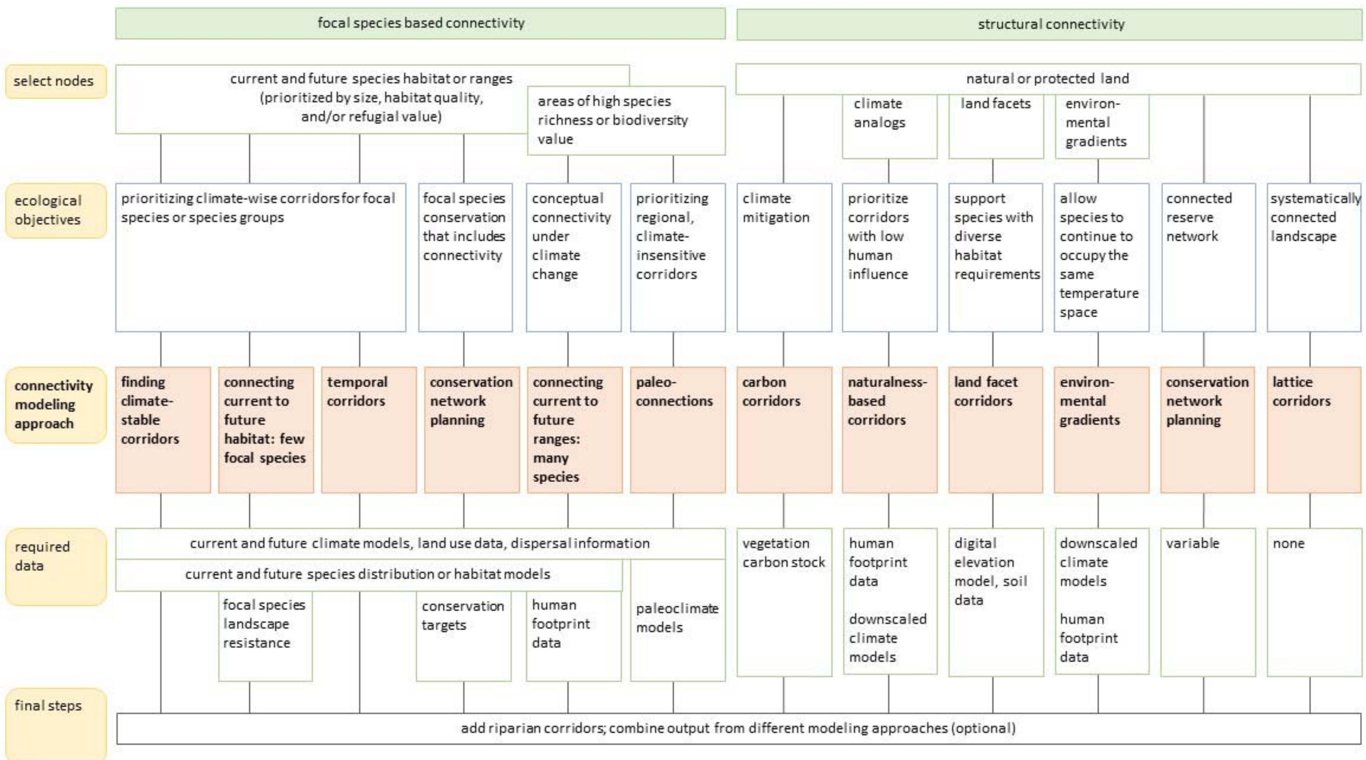

Figure 2.3. Flow chart to select connectivity modeling approaches for on-the-ground climate-wise connectivity planning.

2.3.1 Climate-wise Connectivity Conservation Objectives

As this review demonstrates there are many different and creative approaches to climate-wise connectivity planning under exploration. While for overview purposes we grouped the approaches into separate categories, many of the methods are not mutually exclusive to specific approaches but may be more prominently identified in a cluster of research papers falling under a single approach category even though research papers under another approach category allude to the same methods. Some variation in approach reflects different conservation objectives (Fig. 2.3). Species recovery, a common conservation objective, is the focus of studies designing corridors or protected area networks for focal species. Many other approaches aim to facilitate the general movement of species that are projected to respond to climate change with range expansions or range shifts. These designs seek to ensure connectivity for a large group of species, a suite of carefully selected focal species, or focus on structural connectivity. While we distinguish between connectivity designs based on focal species from designs that take a structural approach, some studies contain elements of both. One effort tries to leverage carbon mitigation to identify lands that will maximize both the amount of carbon sequestered and provide species corridors. Depending on the objectives, the spatial scale of connectivity planning varies from local to continental, resulting in outputs ranging from corridor designs at the parcel level ready for on-the-ground implementation (e.g. Howard & Schlesinger 2013) to conceptual movement flow patterns across continents (e.g. Lawler et al. 2013).

2.3.2 Connectivity Based on Focal Species

Approaches to connectivity based on focal species all include models of species distributions for at least two points in time with most focusing on current and future distributions, but a few reaching back to the historic record. Some focus on how present-day connectivity for a species can also contribute to movement for climate adaptation. Others identify connectivity between current and future ranges across the present landscape or habitat suitability as it changes through time.

2.3.2.1 Finding climate-stable corridors

Several studies characterize how connectivity is changing for focal species under predicted climate scenarios (McKelvey et al. 2011; Howard et al. 2013; Wasserman et al. 2013; Giannini et al. 2015; Drake et al. 2017; Leonard et al. 2017). A common conclusion was that suitable habitat area will decrease and fragmentation will increase as a result of climate change and land-use change. However, these studies also reveal regions of relatively minor difference between current and future connectivity value that, if protected or restored, could continue to facilitate movement despite climate change. Drake et al. (2017) propose management of the habitat network modeled under future conditions to promote native species persistence and inhibit invasive species movement.

2.3.2.2 Connecting current to future ranges

Another climate-wise connectivity approach is to model current and predicted species distributions or suitable habitat and, if spatially disconnected, find the best connection between them. Studies applying this approach identify factors that could either limit movement (such as anthropogenic land uses) or facilitate movement (such as species-specific habitat suitability). These studies parameterize models to preferentially move through areas with the least impediments to reach future suitable areas. Some studies summarize this information for large groups of species. Lawler et al. (2013) modeled current and predicted species distributions for 2,903 vertebrate species in the Americas and found areas with projected high densities of climate-driven movements. Based on species distribution models of 2297 plant species, Choe et al. (2017) generated climate meta-corridors for species groups with similar distribution patterns that will facilitate range shifts of multiple species. A corridor's suitability can then be assessed by how many species' ranges it intersects. Other studies focus on single species or a small suite of focal species, which makes it possible to also incorporate fine-scale variables such as human population density, land cover type, topography, and species dispersal distances into the species distribution models (Razgour 2015; Coristine et al. 2016; Dilts et al. 2016; Gonçalves et al. 2016).

2.3.2.3 Temporal corridors

To ensure that species can actually reach the new climatically suitable areas, several studies model how a species' climatic envelope (suitable temperature and moisture regime) moves across a landscape over several periods of simulated climate change. The predicted corridor is the chain of locations that are quantified during the simulation to be contiguous for enough time to support range shifts, with new populations becoming established in locations that transition into the envelope while other populations go extinct (Williams et al. 2005; Phillips et al. 2008; Rose & Burton 2009; Hannah et al. 2012; Pellatt et al. 2012; Fleishman et al. 2014). The approach therefore considers temporal connectivity in addition to spatial connectivity. To account for temporal connectivity in conservation planning, Phillips et al. (2008) recommended increasing the size of protected areas to encompass adjacent areas important for continued species persistence; Alagador et al. (2014, 2016) conversely suggest to instead shift the location of protected areas as focal species of conservation concern are shifting their ranges.

2.3.2.4 Conservation network planning

Systematic conservation planning approaches integrate climate-wise connectivity by (1) extending reserve selection algorithms to account for shifting habitat while minimizing cost and maximizing persistence of corridor targets (Alagador et al. 2014, 2016), (2) minimizing the geographic distance between current and future species distributions according to focal species' dispersal ability (Faleiro et al. 2013), (3) designing habitat networks that account for short-range and long-range connectivity by giving priority to pixels of high quality that contribute to local and regional connectivity (Rayfield et al. 2016; Albert et al. 2017), and (4) optimizing the spatial arrangement of habitat for range expansion by retaining habitat patches characterized by high movement flow and adding patches that will alleviate bottlenecks in the habitat network, taking into account a species' dispersal ability (Hodgson et al. 2016).

Some have argued that existing plans for reserve networks need to be vetted for climate change (Vos et al. 2010; Rüter et al. 2014). To do so, they developed metapopulation models that take into account current and future suitable habitat, species-specific dispersal and colonization abilities, species-specific landscape permeability, and carrying capacity for a suite of species. The purpose is to identify locations in existing networks that need to be strengthened to maintain spatial cohesion under climate change. By focusing on climate adaptation zones, benefit for species adaptation is maximized and the amount of land required to be protected is minimized (Vos et al. 2010). Similarly, Brambilla et al. (2017) took the approach of prioritizing habitat areas with more stable climate space (in-situ refugia) and adding habitat areas predicted to become suitable (ex-situ refugia) as well as connectivity areas for a set of alpine bird species to ultimately protect areas that will support these species into the future.

2.3.2.5 Paleo-connections

Instead of modeling connectivity areas based on current and future species distributions, the paleo-connections approach identifies regions that likely functioned as biodiversity corridors under past climates. While there is a large body of literature about pathways of migration following the ice ages (e.g. Hewitt 2000; McLachlan et al. 2005), three papers that resulted from the systematic literature search argue that the areas that connected populations under past climate regimes will also be important under future climate changes. In the case of Wu et al. (2017), current bird distribution data were used to describe current patterns of diversity and these patterns were compared with simulated species richness patterns under paleoclimate models. This comparison allowed them to assess changes in species richness over time and delineate areas that bridged major biotas in the past. A different approach relies on a landscape genetic framework to identify dispersal corridors of a set of plant species in the late Quaternary (Fan et al. 2017). Past, current, and future refugia for the paleoendemic flora also provided the basis for identifying overlapping areas of spatiotemporal connectivity (Mokany et al. 2017).

2.3.3 Structural Connectivity

Planning for structural connectivity aims to accommodate the movement needs of a wide range of species, making it an efficient planning process. The modeling approaches incorporate different concepts of climate-wise connectivity, and range in design from simple to complex.

2.3.3.1 Riparian corridors

Riparian corridors are commonly used as movement corridors by many species of animals and plants (including terrestrial and aquatic species), support important ecological processes, provide cooler and moister microclimates than the immediate surrounding (especially important in summer or dry seasons), and tend to span climatic gradients as they are oriented along elevational gradients (Beier 2012; Krosby et al. 2014). In addition, riparian areas often enjoy popular support for water quality and recreation benefits, and do not require modeling, making them easy to convey for community conservation efforts (Townsend & Masters 2015). In many places, riparian zones often already have some legal protection (Fremier et al. 2015), though the legal requirements may not be wide enough to support a full suite of species that could potentially benefit from the corridors.

For all of these reasons, riparian corridors are often a priority for climate change resiliency. Applying fixed buffers around riparian areas that connect desired termini has been suggested as a simple method to design riparian corridors (Rouget et al. 2003; Brost & Beier 2012b). In cases where no specific termini need to be connected, Krosby et al. (2014) developed a method for prioritizing riparian areas for climate adaptation based on the temperature gradient the river spans, the width of the riparian area, and the levels of canopy cover, solar insolation, and human modification. The information is combined in an index of climate-corridor quality to estimate the climate adaptation potential for each of the different segments from the headwaters to downstream reaches.

2.3.3.2 Environmental gradients

Environmental gradients influence the distribution of plants and animals (Lawler 2009). Therefore, designing corridors to follow temperature and precipitation gradients may assist individuals tracking suitable climates regardless of the magnitude of climate change (Pearson & Dawson 2005). For topographically diverse areas, climate gradient corridors have been designed that connect presently warm to cool areas in a unidirectional way, prioritizing gradual change in temperatures as well as areas of high naturalness (Nuñez et al. 2013; McGuire et al. 2016). Mapping connectivity between protected areas to maintain floristic diversity under climate change was done in one case based on land cover permeability and weighted by areas of high species turnover which reflect temperature, precipitation, and soil gradients (Jewitt et al. 2017). Another example of mapping environmental gradients included edaphic interfaces, upland-lowland interfaces, and macroclimatic gradients as surrogates for key ecological and evolutionary processes that will ensure resilience to climate change (Rouget et al. 2003).

2.3.3.3 Naturalness-based corridors

Naturalness refers to the level of human impact on landscape elements. Naturalness-based corridors for climate change prioritize corridors in areas with the least amount of human development, reasoning that species that are sensitive to human disturbance will be able to more easily traverse such areas (Belote et al. 2016). Connectivity is either modeled between protected areas, or on a continuous landscape. Several studies prioritize connectivity between climate analog sites to account for the tendency of species to move towards areas that will provide suitable climates in the future (Nuñez et al. 2013; McGuire et al. 2016; Littlefield et al. 2017). While the focus is on human modification, additional information such as slope (Dickson et al. 2016), an index of wildness (Belote et al. 2016), ecological integrity, ecosystem representation, and biodiversity priority (Belote et al. 2017) may also be included.

2.3.3.4 Lattice-work corridors

Ensuring the persistence of a regular crisscrossed array of corridors (lattice-work corridor systems), is an approach to provide comprehensive connectivity without the need of developing complex models. Kilbane (2012) solicited community involvement to modify a systematic trans-continental network of corridors across Australia to match local conditions. Townsend & Masters (2015) also recommended involving stakeholders in delineating and protecting connectivity in tropical mountain ecosystems by protecting elevational connectivity along rivers (which can enable range shifts to higher elevations) and promoting population viability in perpendicular elevational bands through conservation-friendly land uses. These approaches are simple in design, which makes involvement by the local communities easier, an essential component for successful connectivity conservation (Keeley et al. in prep).

2.3.3.5 Land facet corridors

The land facet corridor approach defines landscape units (called land facets, enduring features, geophysical settings, or ecological land units) by topography and soil and aims to maximize in the corridors the continuity and diversity of landscape units found in the neighboring natural areas (Beier & Brost 2010; Brost & Beier 2012b). The rationale behind this concept is that the corridors will support movement by species associated with particular land facets, and even if the suites of species in an area change with a change in climate, biodiversity will remain because the diversity of landscape units is protected, a concept commonly referred to as 'conserving nature's stage' (Beier et al. 2015; Lawler et al. 2015).

2.3.3.6 Conservation Network Planning

Climate-wise connectivity has been incorporated into systematic conservation planning approaches in different ways. To include a climate-wise connectivity component into a reserve network design that maximizes representation of geophysical settings as surrogates of biodiversity, microclimatically diverse and locally connected grid cells in each geophysical category were prioritized (Anderson et al. 2014, 2016). Local connectivity was defined by the degree of similarity between a focal cell and its neighboring cells with respect to land cover and degree of development based on a resistance kernel analysis (Anderson et al. 2014). Anderson et al. (2016) further prioritized regional movement pathways that increase in altitude and latitude by favoring upslope and south-to-north movements.

Taking advantage of the innate connective properties of streams (see discussion above), other systematic conservation models have approached the climate-wise connectivity goal by prioritizing land units that are located near streams while factoring in the acquisition cost (Klein et al. 2009). Temporal connectivity can also be incorporated into systematic conservation planning by prioritizing spatial vicinity between different – cooler and warmer, or drier and moister – habitats, a proxy thought to facilitate species persistence through time. Game et al. (2011) accomplished this using the conservation planning software Marxan by requiring a high boundary length modifier which minimizes the difference between topo-edaphic and climate variables in adjacent areas. Heller et al. (2015) instead used Marxan to maximize hydro-climate diversity in the reserve network, thereby capturing the diversity of climate types in the planning region.

Alternatively, climate-wise corridors can be incorporated into systematic conservation plans by specifying surrogates for key ecological and evolutionary processes such as upland-lowland and macroclimatic gradients as conservation targets (Cowling et al. 2003). To capture these gradients in regional-scale corridors, Rouget et al. (2006) combined least-cost path analysis with a systematic conservation planning approach. This approach targeted ecosystem representation, suitable wildlife areas, and irreplaceable vegetation types and considered current and future land-use patterns.

While expert-defined corridors are commonly found in habitat connectivity plans (e.g. Penrod 2001), experts were asked to site climate-wise corridors in only two studies (Vos et al. 2010; Fung et al. 2017). Avoiding the challenge of siting corridors in a systematic conservation modeling framework and including the benefit of familiarity with the socio-economic environment, stakeholders were asked to designate climate-wise pathways based on extensive data generated in the reserve modeling effort, including information on climate velocity (Fung et al. 2017), and potential for international connectivity (Vos et al. 2010).

2.3.3.7 Carbon stock corridors

While all the connectivity design approaches so far address climate adaptation, carbon stock corridors, aiming to maximize the amount of biomass contained in the corridor, are a climate change mitigation strategy (Jantz et al. 2014). With funding available for climate change mitigation projects in the Reducing Emissions from Deforestation and Forest Degradation (REDD+) framework (Jantz et al. 2014) and in Cap and Trade programs (e.g. Balmes 2014), carbon stock corridors add biodiversity conservation benefits by guiding the spatial arrangement of climate change mitigation projects.

2.3.4 Comparisons between Climate-wise Design Approaches

As demonstrated above, there are many different approaches to climate-wise connectivity planning; however, very few studies compare the results of two models to each other. Several papers that compare the results of older and newer methods show that, based on study-defined criteria, the new methods are often an improvement (Rouget et al. 2006; Alagador et al. 2014; Heller et al. 2015; Drake et al. 2017). Useful comparisons across methods are presented in Brost & Beier (2012a) and Krosby et al. (2015), who compare focal species connectivity designs to land facet and naturalness-based corridors, respectively. In general, the naturalness and land facet corridors represented connectivity for focal species reasonably well, although small species with poor dispersal capabilities or species with narrow distributions were not served well. On the other hand, focal species linkages did not capture connectivity for the land facets well. Both studies concluded that structural connectivity approaches are a good proxy for species movements. However, if data are available for a suite of representative species (Beier et al. 2008), corridors based on functional connectivity may better capture movement needs of all species (Krosby et al. 2015), while the land facet corridors should be designed as a complement to the focal species corridors (Brost & Beier 2012a).

2.3.5 Including Refugia in Climate-wise Connectivity Design

Several approaches have been developed to incorporate refugia into connectivity designs. An early-adopted approach was to identify different types of refugia, e.g. riparian, drought, or evolutionary refugia, and include them as targets in systematic conservation planning efforts (Cowling et al. 2003; Klein et al. 2009). Game et al. (2011) took a different approach to systematic conservation planning and classified sites based on topographic and climatic factors. Grid cells with minimal difference between current and future conditions were categorized as in-situ refugia and assigned a high probability. When running the systematic conservation planning algorithm Marxan, cells with high probability values were more likely to be included in the reserve network.

A different way to include refugia when designing climate-wise connectivity is to identify in-situ refugia and model connectivity between them. Maher et al. (2017) applied this approach to mountain meadows, characterizing connectivity based on distance, topography, watercourses, and roads. Alternatively, refugia can be integrated into climate-wise corridor modeling with protected areas as the termini by parameterizing a resistance map based on the vulnerability of cells to climate change, or their value as in-situ refugia. Coristine et al. (2016) determined the climate vulnerability by assessing the change and variability of several climate variables relevant to pollinator species over the past decades. Grid cells with lower rates and reduced climatic variability (refugia) were assigned lower resistance values than cells with higher rates and increased variability of climate change. Jewitt et al. (2017) gave lower resistance values to climatically stable cells as well. By prioritizing sites characterized by high topographic diversity and elevation gradients and connected by natural cover, Anderson et al. (2014) integrated microclimate refugia and connectivity into conservation planning.

For species-specific connectivity models, refugia can be identified based on environmental variables meaningful for the focal species. To determine areas where wolverines are predicted to persist in the western United States and Canada, McKelvey et al. (2011) modeled persistent spring snow pack, an environmental condition critical to the wolverine's life cycle, under future climate scenarios and found the least cost paths between the refugia. Bioclimatic envelope modeling has been applied to predict geographic ranges of organisms as a function of climate (Rose & Burton 2009; Pellatt et al. 2012). When these models are combined with dispersal models, connections to ex-situ refugia can be modeled for particular species (Vos et al. 2008). Identification of these refugia can support the prioritization of sites for protected areas, as well as guide management decisions with respect to increasing connectivity to facilitate colonization of new habitat or optimizing networks of in-situ refugia (Vos et al. 2008; Pellatt et al. 2012; Brambilla et al. 2017).

Extending the timeframe to also include past refugia, Mokany et al. (2017) studied communities of the paleoendemic flora in Tasmania and identified refugia based on generalized dissimilarity modeling of compositional turnover. Taking dispersal into account, they used an index of spatiotemporal connectivity to quantify connectivity in refugia in the past, present, and future. Overlapping areas are deemed to be important for persistence regardless of whether the climate is getting colder or warmer.

2.3.6 Existing Resources for Future Climate-wise Connectivity Planning in California

Ten of the studies collected in the systematic review of climate-wise connectivity modeling were conducted for part or all of California or included California as part of a larger study area (Table 2.2). Six of the studies model naturalness-based corridors but vary in node selection, input data, and algorithms used. Some model connectivity between protected areas, while others model continuous core-free connectivity, essentially finding the value of each cell to landscape connectivity. While climate change resilience is often an objective, not all use climate data to address climate change explicitly. All naturalness-based corridor studies include a human modification layer; some combine this layer with other data such as slope, wildness, or species dispersal capabilities. The connectivity algorithms that have been applied in California are cost-weighted paths and circuit theory. The output maps are spatially comprehensive and depict major flow routes of connectivity or current flow. Other studies modeled temperature gradients corridors between climate analog protected areas using Climate Linkage Mapper (McGuire et al 2016) and temporal corridors for native plants throughout California (Hannah et al. 2012). Several reports integrated land facet corridors into the linkage designs (e.g. Krause et al. 2015, Penrod et al. 2012). Finally, one study used conservation network planning to improve an existing conservation lands network in the greater Bay Area by capturing the full range of climatic diversity in the region as a way to improve resilience to climate change.

The published studies represent recent advances made in modeling climate-wise connectivity; however, this early work does not provide a solution set for California's connectivity requirements. Limitations differ between the approaches published to date. Several naturalness-based approaches find areas of high flow through areas of the State that contain low density development without considering differences in habitat type or quality or climate change (Theobald et al. 2012, Belote et al. 2016, McRae et al. 2016, Dickson et al. 2016). In other words, the methods are more useful in urban areas where connectivity is an emergent property of the built environment. Also, because of edge or boundary effects, continuous core-free connectivity modeling approaches cannot detect high levels of connectivity along the coast even if it exists (e.g. McRae et al. 2016). Studies that model connectivity across large extents (the entire U.S. or the western U.S.) apply climate models that do not reveal local variation that may be important in determining regional movement patterns. The published naturalness-based approaches also do not account for fine-scaled topoclimatic features which can play an important role as climate microrefugia. At the same time, pathways on the maps may traverse climatic conditions that are not likely to be suitable for some species in the future or even cross geographic barriers to movement. Finally, these studies do not take into account that the human footprint will continue to grow, and land use patterns will change. Other California climate-wise studies are limited in that they were only conducted for a small region of California (Heller, et al. 2015, Krause et al. 2015), only studied one focal species (Dilts et al. 2016), or are conducted at a coarse grain with simplistic model parameters to achieve computational feasibility (Hannah et al. (2012) and Roehrdanz et al. (unpublished report).

Most studies present a new method with recommendations for model improvements and climate-wise connectivity modeling continues to proceed in CA. These are a few examples we are aware of. The Nature Conservancy is in the process of creating a map of naturalness-based connectivity throughout California with the goal of setting climate-wise connectivity conservation priorities at the state-wide scale (Richard Cameron and Carrie Schloss, pers. comm.). The connectivity model integrates the concepts of connecting climate analogs and prioritizing flow through grid cells containing high topoclimatic diversity. Using Omniscape at a resolution of 75 m, ecological flow is mapped between all-natural pixels, avoiding the need to subjectively select start and end points.

The "Building Habitat Connectivity for Climate Adaptation" project funded by the California Landscape Conservation Cooperative has been conducted for 10 counties in the Mayacamas to Berryessa Coast Ranges in northern California. Integrating components of climate benefit, landscape heterogeneity, and high-resolution data (30x30m), the study identified regional terrestrial and riparian linkages at the parcel scale between protected areas, then evaluated them with respect to the climate benefit they will provide under future scenarios using summer and winter temperatures by quantifying the cooling effect of moving through a linkage to an adjacent protected area. The average potential net cooling from linkages between protected areas was 1.8 °C for summer maximum (range: 0.0 – 13.5 °C) and 0.8 °C for winter minimum (range: 0.0 – 6.8 °C) temperatures. The results show distinct spatial trends and climate benefit predictions for seasonal temperatures, suggesting that seasonal temperature extremes can be important for connectivity planning in Mediterranean-climate landscapes. Stakeholder involvement during the modeling process has made the study especially important and relevant for on-the-ground implementation action, starting with six focal linkages co-developed using the open-access spatial data products (databasin.org). Climate-wise corridors need to be implemented especially in areas that are currently not protected and where the current climate space is shrinking (Gray et al. 2018).

The Conservation Biology Institute has developed an ArcGIS tool, Linkage Priority (LP), that helps quantify the relative conservation priority of each linkage in a landscape based on criteria determined by the planner and potential input from stakeholders (Gallo & Greene 2018, https://doi.org/10.6084/m9.figshare.5673715). Linkage priority can be based on the climate signature difference between two core areas (i.e. prioritizing for climate gradients to allow range shift, or climate-analog areas to optimize networks). Linkage Priority can also consider the climate refugia value of the cores being connected, in addition to 'classic' core area values such as shape, size, and proximity. LP is part of the version 2.0 release of Linkage Mapper. To test the tool prototypes, it has been applied to prioritize climate-wise corridors in three regions in California (West Mojave, Sacramento Valley, and Modoc Plateau) based on the potential of linkages to facilitate species range shifts, the quality of the core areas as climate refugia, and the microclimate diversity within cores and linkages. Output maps are already available on databasin.org; reports and publications are forthcoming.

San Diego State University is developing corridor maps for the South Coast Ecoregion by combining ensemble species distribution models with dynamic metapopulation models while accounting for climate change, land-use shifts, and uncertainty (http://www.conservationecologylab.com/climate-resilient-connectivity-for-the-south-coast-ecoregion.html).

Table 2.2. A systematic search of studies modeling climate-wise connectivity revealed ten studies that were conducted for part or all of California or included California as part of a larger study area.

Connectivity design approach	**Study**	**Study area**	**Nodes**	**Input data**	**Algorithm** O	**utput**
Naturalness-based corridors	Theobald et al. 2012	entire U.S., including California	continuous core-free connectivity	human modification	least cost path: betweenness centrality	pathways or flow “routes” depicting connectivity of natural landscapes
	Dickson et al. 2016	western U.S., including California	protected area centroids	human modification, slope	electrical circuit theory: current flow centrality	cumulative current flow between protected area centroids
	McRae et al. 2016	northwestern U.S. including northern California ecoregions	continuous core-free connectivity	human modification	circuit theory: Omniscape	current flow for terrestrial connectivity among all natural and semi-natural pixels within 50 km of one another
	Littlefield et al. 2017	western quarter of U.S., including California	continuous core-free connectivity	human footprint resistance map with species’ dispersal capabilities	circuit theory: Omniscape	potential species’ movements (measured as current flow) between areas of historical climates and their 2080s climate analogs
	Belote et al. 2016	entire U.S., including California	protected areas	human modification, wildness index	cost-weighted paths	composite corridor value between large protected core areas
	Belote et al. 2017	entire U.S., including California	protected areas	human modification, connectivity, ecosystem representation priority index, biodiversity priority index	summing of normalized indices	composite map of wildland conservation value, including connectivity value

Environmental gradients	McGuire et al. 2016	entire U.S., including California	natural areas	human modification, protected area database	Climate Linkage Mapper: connecting climate analogs in a unidirectional way	margin of success or failure at achieving climate connectivity with and without corridors; corridor efficiency at achieving climate connectivity
Conservation network planning	Heller et al. 2015	San Francisco Bay Area	currently protected areas	historical and future hydro-climate projections	Marxan	climate priority spots for conservation investment within Conservation Lands Network
Temporal corridors	Hannah et al. 2012 and Roehrdanz et al. unpublished report	California	current and future species habitat	current and future climate models, species distribution models, soil parameters	Network Flow	areas required to form temporal corridors through 2050
Connecting current to future habitat: one or a few focal species	Dilts et al. 2016	part of the western Mojave Desert	current and future species habitat	current and future climate models, species distribution models, land use scenarios, habitat suitability	graph theory, least cost paths, circuit theory, lattice grid	change in key connectivity areas between current and future conditions; least-cost paths and cumulative current for range expansion of focal species
Land Facet corridors	Krause et al. 2015	northern Sierra Nevada Foothills	protected areas	digital Elevation Map, slope layer	least cost paths	land facet corridors between protected areas

2.3.7 Tools for Climate-wise Connectivity Modeling

There are numerous software programs available for connectivity modeling (for prominent examples refer to conservationcorridor.org). Here, we present a brief (and by no means complete) overview of tools that have been applied to or developed specifically for climate-wise connectivity modeling.

In many of the reviewed studies that modeled either focal species based or structural connectivity, least cost path and circuit theory-based analyses were used to identify linkages (e.g. Brost & Beier 2012b; Belote et al. 2016; Coristine et al. 2016). Based on a GIS layer of termini (e.g. nodes of current and future suitable habitat, climate-analog areas) and resistance surfaces, which specify the degree to which a grid cell facilitates or inhibits movement, these algorithms highlight areas estimated to have relatively high probability of use as movement corridors. A variety of variables have been used to parameterize resistance surfaces, including habitat suitability, climate vulnerability, land facets, and human footprint. Several software programs are available such as Circuitscape (McRae 2006), the CorridorDesigner ArcGIS toolbox in ArcGIS (Majka et al. 2007), and Linkage Mapper (http://www.circuitscape.org/linkagemapper) to assist with these types of spatial analyses. The latter also now includes a module called Climate Linkage Mapper which operationalizes the climate gradient corridor approach (Nuñez et al. 2013). The new software Gflow (Leonard et al. 2016) extends the utility of Circuitscape to compute connectivity in large-extent and high-resolution landscapes by computing circuit theory-based connectivity simultaneously on a large number of processors, and new advances in Circuitscape now include the ability to connect climate analogs and climate gradients (Littlefield et al. 2017).

Both algorithms (least cost corridor and circuit theory) have been adapted to model continuous core-free connectivity, meaning that the core areas/termini do not need to be specified (Anderson et al. 2012; Theobald et al. 2012; Anderson et al. 2014; Koen et al. 2014; Pelletier et al. 2014; McRae et al. 2016; Littlefield et al. 2017). Using Circuitscape with a novel moving window algorithm (Omniscape) to create a continuous map summarizing movement probabilities across the landscape, Littlefield et al. (2017) integrated a human footprint resistance map with species' dispersal capabilities by choosing different moving window radii. This resulted in flow patterns connecting climate analogs that may be accessible for the taxa in question in the next few decades.

Unicor (Landguth et al. 2012) is a program that prioritizes corridors that promote species persistence by predicting the importance of locations across the landscape for providing long-distance dispersal connectivity among core habitat patches (Wasserman et al. 2013). Based on the principles of graph theory, the packages Conefor (Saura & Torne 2009), Graphab (Foltête et al. 2012), and IGRAPH (Csardi & Nepusz 2006) use the principles of graph theory to rank the importance of core areas and linkages to maintain or improve connectivity across a network (Dilts et al. 2016; Kang et al. 2016; Rayfield et al. 2016, respectively). The new Linkage Priority Mapper module in ArcGIS (Gallo & Greene 2017) is designed to prioritize linkages between core areas that also contain high topographic heterogeneity and therefore may provide microclimatic variation that has potential to serve as climate refugia.

Metapopulation models, especially the habitat network assessment tool LARCH (Landscape Ecological Rules for the Configuration of Habitat, Verboom & Pouwels 2004) have been applied to evaluate landscape connectivity for focal species in fragmented landscapes and design a network of existing and proposed areas that will facilitate focal species range shifts (Vos et al. 2010). These models take into account habitat quality, species' traits such as dispersal distance, reproductive potential and life span, and the effects of barriers and stepping stones.

For systematic conservation planning, software programs commonly adjusted to include climate-wise components are Zonation (Moilanen et al. 2005) and Marxan (Ball et al. 2009). Zonation retains the most valuable cells for multiple species while also accounting for connectivity. Papers in this review that have applied Zonation include, for example, Fleishman et al. (2014) and Albert et al. (2017). Marxan, applied among others by Fung et al. (2017) and Heller et al. (2015), designs cost-effective reserve systems based on the principles of comprehensiveness, representativeness, and adequacy.

2.3.8 Assessing Connectivity Strategies for Climate Change Adaptation

For range shifts to occur, individual organisms need to physically move to suitable habitat beyond the current distribution (Lawson et al. 2012; Fourcade & Öckinger 2017). Several studies assess the effects of landscape configuration on range shifts at the leading edge (Table 2.2). A simulation study examining the effectiveness of different conservation strategies to promote range expansion in a real landscape found that increasing the amount of habitat throughout the landscape is one of the most effective strategies (Serra-Diaz et al. 2015; Synes et al. 2015). However, concentrating habitat in few large areas reduces the capacity for rapid range shifts (Hodgson et al. 2012). Several simulation and empirical studies have also shown that adding corridors between natural or protected areas can be an effective strategy to facilitate range expansion, but the effectiveness depends on the size and the elevational gradient in the corridor (Imbach et al. 2013), the degree of landscape fragmentation (Renton et al. 2012; Mokany et al. 2013; Gimona et al. 2015), the amount of available habitat (Collingham & Huntley 2000; Hodgson et al. 2011; Synes et al. 2015), climate velocity (Renton et al. 2012), species' dispersal ability (Meier et al. 2012; Kubisch et al. 2013; Mokany et al. 2013; Gimona et al. 2015), and habitat preferences (Hodgson et al. 2011).

In more intact landscapes, for strong dispersers the quantity of suitable habitat may be more important than the spatial arrangement of suitable habitat for determining successful dispersal (Pearson & Dawson 2005; Renton et al. 2012). However, in highly fragmented landscapes where less than 20% of the habitat remains, species may not be able to shift their ranges even with strong dispersal capabilities and under moderate climate change scenarios (Renton et al. 2013). Conserving or restoring connectivity between suitable habitat to facilitate range expansion is likely most effective for species with medium dispersal capabilities in moderately fragmented landscapes with lower climate velocity (Pearson & Dawson 2005; Meier et al. 2012; Renton et al. 2013; Gimona et al. 2015).

Corridors that cover large areas and have high altitudinal gradients were found to benefit the greatest number of species (Imbach et al. 2013), whereas small stepping stones embedded in the matrix are beneficial only to a few species (Collingham & Huntley 2000; Lawson et al. 2012; Synes et al. 2015; Gilchrist et al. 2016). If habitats are naturally isolated (e.g. vernal pools or microrefugia), they need to exist at sufficient density to keep the distance between them short enough to enable dispersal (Epps et al. 2006; McIntyre et al. 2014; Niskanen et al. 2017). The effectiveness of both increasing the amount of habitat in the landscape and adding small but critical corridors often creates a trade-off in conservation strategies because of the commonly high costs of critical corridors (Hodgson 2011).

Table 2.3. Advantages and disadvantages of strategies to improve climate-wise connectivity.

Strategy	Advantages	Disadvantages
Increasing the amount of habitat throughout the landscape	Increases speed of range shifts in fragmented landscapes; benefits most species	
Concentrating habitat in few, large areas	Increases species persistence for some species	Slows speed of range shifts
Adding corridors between natural or protected areas	Increases speed of range shifts in fragmented landscapes	Trade-off with increasing protected area system Most effective for species with medium dispersal capabilities in moderately fragmented landscapes with lower climate velocity
Creating small stepping stones embedded in the matrix	Increases speed of range shifts in fragmented landscapes	Benefits few species
Increasing the size of existing protected areas	Increases in-situ and ex-situ species short-term persistence; improves temporal connectivity for some species	
Improving the matrix	Increases speed of range shifts in fragmented landscapes; benefits many species	
Maintaining naturally isolated habitats at sufficient density to enable dispersal	Ensures species persistence in naturally isolated habitats if positioned along a climate gradient and/or in vicinity of macro refugia	

Other strategies of improving landscape connectivity include specifically increasing the size of existing protected areas, adding new protected areas, and enhancing and diversifying the matrix (Donald & Evans 2006; Groves et al. 2012; Allen et al. 2016; Donaldson et al. 2017). Simulation studies designed to compare the effectiveness of these different strategies in facilitating range shifts differed in their conclusions. While Synes et al. (2015) concluded that creation of new habitat adjacent to existing small patches gives the most consistent benefit across species, Hodgson et al. (2011) found that adding new habitat to cells chosen at random and adding new habitat to cells with high dispersion and low connectivity provided the most consistent increases in the speed of predicted range expansion. Mokany et al. (2013) determined that the best strategy depends on a species' dispersal ability and the region and recommended implementing a mix of landscape configuration strategies. Because different species have different ecological requirements with respect to landscape configuration, landscapes containing large protected areas connected through linkages, or stepping stones embedded in a permeable matrix will promote population persistence and facilitate range expansion at the leading edge for the greatest number of species (Collingham & Huntley 2000; Donald & Evans 2006; Synes et al. 2015).

2.3.9 Caveats

All climate-wise modeling approaches have advantages and disadvantages (Table 2.3). In general, models can be conceptually sound but depend on other highly uncertain data or modeled outcomes, including projections of future carbon emissions, how the atmosphere and oceans respond to these emissions, climate model downscaling, landcover change projections, climate envelope models for the focal species, and dispersal abilities of these species (Beier et al. 2009; Rudnick et al. 2012). Also, inherent to most models is that they cannot account for all factors driving the response. For example, even models designing corridors for individual plants to shift their ranges do not account for specific factors such as soil type, seasonally varying soil properties like wetness (Pellatt et al. 2012), or the habitat requirements and dispersal characteristics of animals that disperse the plants. Perhaps the most challenging aspect of these models is that, under climate change, novel types of climates are predicted, and forecasting how suitable these novel climates will be for existing species cannot be reliably determined (Capinha et al. 2014). Because the models are predicting species' potential climate space or refugia in the future, it is not possible to validate modeled events by empirical tests.

Studies modeling species distributions into the future make several assumptions. Current distributions of species are assumed to be in equilibrium with climate, and bioclimatic envelopes are assumed to be constant, meaning that species cannot evolve to tolerate new climates. Species are anticipated to move towards locations with analogous climates. Species-specific models of range shifts at the leading edge expect that species disperse, survive, and reproduce in each generation and consider extinction rates as negligible, assuming that newly suitable patches will become occupied within one timestep (Hodgson et al. 2016). These assumptions oversimplify reality, adding uncertainty into the results.

Bioclimatic envelope models often omit several aspects of biology that would affect model results. Because species' capacity for plastic or genetic response to climate change is generally not known, models do not take into account species' adaptation potential (Razgour 2015), even though empirical studies indicate that some species can adapt to the changing climate (Parmesan 2006). Bioclimatic envelope models are also simplistic in that they do not consider species' interactions. While species-specific climate-wise connectivity models can be useful for informing conservation action on endangered species (e.g. California Desert Biological Conservation Framework 2016), they have high data requirements. Generally, a lack of realistic biological information decreases model accuracy. However, the species-specific approach is increasingly taking advantage of newly available, fine scale climate data and georeferenced individual detection rates for a wide variety of species. These data sets allow for very detailed modeling of the relationships between physical variables and species occurrences that could be used to provide detailed guidance for species conservation and recovery planning (Midgley et al. 2010; Schumaker et al. 2014; Pérez□García et al. 2017).

Species-focused models assume that species will disperse more successfully through suitable habitat. This may be valid for many species; however, studies have shown that during dispersal and mating-related movement, many animals readily cross land cover types avoided during daily movements (Keeley et al. 2017). Another assumption is that plant movement can be promoted by maintaining habitat connectivity. Rare long-distance movements of poor dispersers have been documented that indicate that there may be chance events that move species beyond their current range without habitat connectivity. Similarly, wind-dispersed species may be able to jump across unsuitable habitat (Pearson & Dawson 2005; Anderson et al. 2016). Simultaneously, poorly dispersing specialist species may not be able to shift ranges as there may not be suitable habitat nearby.

Structural connectivity approaches assume that areas with minimal human impact facilitate species range shifts. While high human modification will limit movement for species moving in response to changes in climate, the influence of naturalness on resistance to movement likely varies greatly between species (Krosby et al. 2015). Hence, structural connectivity modeling may not address the connectivity needs of all species or may miss opportunities in the landscape to protect connectivity because species' responses to land-use are oversimplified.

Coarse resolution of input data, which is often associated with studies that cover a large geographic extent, can limit the usefulness of model outputs for conservation planning and implementation (e.g. Hannah et al. 2012; Alagador et al. 2014; Gonçalves et al. 2016). In many cases, to maintain computational feasibility, spatial resolution of the data is limited, resulting in underestimating the likelihood that many climate limited species will persist in cooler microhabitats (McGuire et al. 2016).

Table 2.4. Advantages and disadvantages of climate-wise connectivity modeling approaches.

	Advantages	**Disadvantages**
All focal-species based approaches	• can take advantage of newly available, fine scale climate data and georeferenced individual detections for a wide variety of species • can provide detailed guidance for species conservation and recovery planning by modeling relationships between physical variables and species occurrences	• based on uncertain species habitat preferences, life history characteristics, and climate models • often forecast species distributions for novel climates for which no empirical data can be incorporated in the original model – violating model assumptions for extrapolation • can oversimplify species requirements and miss variables that may be correlated with those included in the model (e.g. soil type, competition, symbiotic species)

		• intensive data requirements • to maintain computational feasibility, spatial resolution of data is frequently limited resulting in underestimating likelihood of species to persist
Finding climate-stable corridors	• finds areas for conservation action that will remain valuable even with climate change	• relies on the assumption that habitat conditions will exist to allow for species occupancy
Connecting current to future ranges: large species groups	• results in conceptual movement flow patterns	• relies on species ability to move through unsuitable climate space to reach final destination
Connecting current to future habitat: one or a few focal species	• useful for endangered species conservation	• does not account for gradual changes in climate
Temporal corridors	• accounts for changes in climate through time and thereby ensures that species can actually reach the new climatically suitable areas	• not applicable for connecting protected areas
Conservation network planning	• protected area networks are designed to function for focal species into the future • useful for vetting existing reserve network plans for climate change	• network designed to protect focal species, unclear how the rest of the community will use the resulting network
Paleo-connections	• long time perspective	• high uncertainty due to modeling past and current climates, and past species distributions • connections that facilitated movements during past climate changes may not be able to play that role during current climate change to conditions hotter than before
Structural connectivity	• good proxy for movement patterns of a wide range of species which	• may not address the connectivity needs of all species

	makes it an efficient planning process • low levels of model uncertainty • low cost approach because input data are often readily accessible	• may miss opportunities in the landscape to protect connectivity because species' responses to land-use are oversimplified
Riparian corridors	• commonly used as movement corridors by many species of animals and plants • support important ecological processes • provide cooler and moister microclimates than the immediate surrounding • tend to span climatic gradients as they are oriented along elevational gradients • enjoy popular support for water quality and recreation benefits, • do not require modeling • method has been developed to prioritize riparian corridor for conservation • can easily be applied in combination with other approaches • resulting corridor designs are ready for on-the-ground implementation	• only covers one type of land facet and may not suffice alone for habitat connectivity demands especially in areas such as deserts where water ways are extremely ephemeral
Environmental gradients	• climate-gradient corridors accommodate the need for gradual change in temperatures • the climate-gradient corridor approach has been operationalized (Climate Linkage Mapper) • environmental gradients are surrogates for key ecological and	• climate-gradient corridors are not applicable in landscapes with little topography or landscapes in which termini cannot be connected without reversals in the climate gradient (e.g. a "cool" mountain range cannot be connected to a "colder" mountain range without

	evolutionary processes that will ensure resilience to climate change • resulting corridor designs are ready for on-the-ground implementation	movement across a "hot" valley)
Naturalness-based corridors	• flexible with respect to termini (either protected areas or node-less approach) • can incorporate different additional concepts (e.g. climate analogs, slope, wildness, ecological integrity, ecosystem representation) • human land use map exists for entire United States; software to operationalize the approach exists and is being improved • resulting corridor designs can guide on-the-ground implementation	• influence of naturalness on resistance to movement likely varies greatly between species • when operationalized using circuit theoretical algorithm, interpretation of dispersed flow in highly permeable area is difficult; output can be difficult to explain to stakeholders
Land facet corridors	• does not require climate modeling • corridors will support movement by species associated with particular land facets even if the suite of species in an area changes with climate change • based on globally available data (digital elevation and soil data) • represents connectivity for focal species reasonably well • applies least cost path algorithm which is intuitive, generates a value for every pixel and is a reliably scaled metric • resulting corridor designs are ready for on-the-ground implementation	• few studies have applied land facets and approach output is not well studied • small species with poor dispersal capabilities or species with narrow distributions may not be served well
Lattice corridors	• does not require a GPS, or modeling	• relies on stakeholder input

	• intuitive, easy to convey to stakeholders and therefore conducive to implementation • comprehensive coverage that includes connectivity at all scales	• may miss important linkages
Conservation network planning	• landscape-wide conservation planning: prioritizes protected areas in addition to delineating corridors • flexible with respect to ways of incorporating climate-wise connectivity • resulting network designs can be ready for on-the-ground implementation	• complex approach • Marxan & Zonation (the dominant software tools) reward compactness and penalize fragmentation which only sometimes results in corridors. Therefore, siting corridors in a systematic conservation modeling framework is challenging
Carbon-stock corridors	• approach for climate mitigation • can take advantage of funding sources tied to climate mitigation • resulting corridor designs are ready for on-the-ground implementation	• not focusing on facilitating range shifts

2.4 Conclusions and Next Steps

Selecting the best methods for connectivity design depends on the objectives, available data, and the landscape (Fig. 2.3). By combining results from structural connectivity and species-focused approaches, entire ecosystems can be addressed as well as particular focal species of interest. Riparian corridors should be included in all connectivity plans because of their importance as natural movement corridors, climate gradients, and refugia (Beier 2012). To accommodate species range shifts over generations, climate resilient areas that facilitate persistence of biodiversity under climate change, such as climate analog core areas and refugia, need to be identified, protected, and connected (Vos et al. 2008; Hodgson et al. 2011; Carroll et al. 2017). It is important to provide live-in habitat in the corridors (Beier et al. 2008; Mackey et al. 2008; Beier 2012), implying that wide landscape linkages (e.g. > 1 km) will be more functional than narrow corridors. Making corridors as wide as possible is a simple way to ensure that they contain a diverse topography that provides micro-refugial sites for species persistence (Jewitt et al. 2017). Empirical studies are urgently needed to inform how wide a corridor must be and how much human disturbance (e.g. recreation, ranching) can be allowed within the corridor without compromising functionality for various ecosystems and contexts. Quantifying the impact of natural and anthropogenic barriers on possible range shifts could inform management strategies within corridors.

Even though many different approaches to climate-wise connectivity modeling have been explored, only a few studies compare methods and fewer evaluate how much wildlife will use the resulting networks. An increased effort in this direction could highlight similarities, differences, and complementarities between approaches and help guide conservation planners when choosing connectivity models. While structural climate-wise connectivity models make fewer assumptions than species-focused models and have less uncertainty, studies evaluating their effectiveness in facilitating range shifts of different species types are needed. Because structural connectivity is designed to facilitate future range shifts, simulation studies that take advantage of data-intensive species models may be an option. It is important to note that most approaches to climate-wise connectivity modeling depend on high resolution GIS data layers characterizing the landscape based on, for example, human influence, current climates, downscaled climate models, climate velocity, topographic diversity, and geodiversity. While these layers are available for some regions, increasing coverage of higher resolution data across California and into Mexico, and standardizing methodologies to facilitate cross-border connectivity planning are vital.

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3: Implementing Habitat Connectivity

3.1 Introduction

Ongoing conversion of natural areas for human use leads to progressive habitat loss and fragmentation, species declines, and ecosystem degradation (Haddad et al. 2015). For over four decades, wildlife corridors that mitigate the impact of habitat fragmentation have been an important tool for maintaining landscape connectivity, resulting in a variety of corridors, linkages, and wildlife-friendly road crossings all around the world (Hilty et al. 2012). There are also many ambitious efforts to connect protected areas at the continental scale including the Yellowstone to Yukon Conservation Initiative in North America, the Gondwana Link in Australia, and the Mesoamerican Biological Corridor (Shadie & Moore 2008). However, with habitat loss and fragmentation continuing rapidly (Theobald et al. 2016), and climate change driving species range shifts (Hannah 2011), there is an urgent need to speed up the rate of habitat connectivity implementation.

Many local, regional, or national connectivity plans and prioritizations exist (e.g. Merenlender et al. 2010), but implementation has been slow (Tiemann & Siebert 2008). The failure to translate plans into conservation action is a phenomenon often referred to as “the research-implementation gap” or “planning-implementation gap.” This gap can potentially be bridged by scientists engaging with conservation practitioners throughout an entire project, from the initial study questions through project implementation and monitoring (Knight et al. 2008, Beier et al. 2016). Because academic norms do not often promote such long-lasting engagement, Cook et al. (2013) suggested that applied conservation science should be conducted by scientists working within resource management agencies or environmental organizations, or involve formal agreements between practitioners and academic scientists to ensure comprehensive collaboration. However, Toomey et al. (2017) note that “conservation is a social process that engages science, not a scientific process that engages society” and argue that we need to re-conceptualize the planning-implementation gap as a space that needs to be filled by a diversity of social processes to achieve effective conservation implementation. Here, we examine the available literature, as well as the personal experiences from practitioners working on a diverse array of projects in California to investigate the challenges and opportunities that arise in connectivity implementation efforts. Currently few climate-wise connectivity projects have been implemented, therefore we rely on lessons learned when implementing habitat connectivity and corridor projects throughout California. We argue that implementing climate-wise connectivity differs from implementing habitat connectivity mostly in the planning stage, where appropriate climate-wise models (see section 2 of this report) need to be applied to assess the benefits of various options for on-the-ground intervention that are likely to increase climate resilience and climate adaptation. We qualify the challenges and opportunities and propose a framework outlining the key elements of successful on-the-ground connectivity implementation. The components of the framework constitute the social processes necessary to enable successful implementation. While there will never be a single solution for connectivity restoration or conservation, this thorough analysis of the challenges and successes encountered in a variety of implementation projects can improve future project success.

3.2 Methods

Although corridor science is a well-studied field, published literature on corridor implementation in limited. We define "corridor" as spatially constrained habitats that provide connectivity between larger habitat areas. We found 27 peer-reviewed papers, 13 reports, and five book chapters that included information on implementation and corridors in Web of Science and the top 100 Google search results in May 2017 (Appendix F).

To improve our understanding of factors that may increase or jeopardize success of connectivity implementation projects, we conducted 30 interviews with practitioners in conservation organizations and public agencies. The interview protocol was approved by the Committee for Protection of Human Subjects of the University of California, Berkeley (Permit Number: 2016-09-9118). We also convened scientists and practitioners from resource agencies and organizations to brainstorm ways to best plan and implement connectivity in the face of continued human land use and climate change. The interviews and workshop were conducted with practitioners in California where connectivity projects span a diversity of socio-ecological contexts and institutional participation. Interview questions were formulated to obtain information on the interviewee's role with respect to connectivity conservation, background on the project, the type of information used for planning, and perceived challenges and opportunities encountered during implementation (Appendix G).

3.3 Results, Discussion, and Recommendations

Our review found that the challenges of and opportunities for corridor implementation are varied and context-specific (e.g. dependent on: land ownership patterns, intensity of development and fragmentation, socio-economic factors, institutional capacity, and the regulatory framework) (Worboys & Lockwood 2010; Fitzsimons et al. 2013; Brodie et al. 2016). Challenges can be based on customs, values, or belief that projects will have negative impacts on the rights and economic opportunities of landowners. They can stem from historical factors such as ingrained land use patterns, or a lack of alignment among project partners. Lack of funding and lack of political will causes challenges as will insufficient project or political leadership (Naumann et al. 2011). In the literature and interviews, opportunities and strategies to overcome these challenges have been suggested, explored, and evaluated (Appendix H, I). We discuss these strategies in seven broad categories that reflect the diversity of perspectives in the field.

3.3.1 Build Partnerships

Building partnerships is a key strategy for corridor implementation in regions with diverse landownership. Public-private partnerships are a powerful model for accomplishing on-the-ground implementation, because the two can complement each other (Naumann et al. 2011; Gleason et al. 2013). In some situations, private landowners refuse to deal with public agencies due to previous negative experiences with laws and regulations, but the door may be open to non-governmental organizations (NGOs). Private landowners and NGOs can often respond quickly to specific project needs. They can also attract and manage private charitable foundation funds, which are more flexible than agency funds (Gleason et al. 2013). Public agencies manage public lands and public funds, the transportation network, and natural resources, and therefore are essential partners in connectivity conservation.

Involving agencies at the right levels and engaging people in the right position of the agency hierarchy can be challenging. While for some high-profile agency-led projects involvement of agency leaders may be advantageous, for many projects, such as road wildlife mitigation projects, agency staff can address connectivity aspects in their routine work. For the latter to occur, agencies need to be required to address the issue of landscape fragmentation and have policies mainstreaming connectivity considerations in everyday decision-making (Morrison & Boyce 2008).

While many projects are started by one individual with drive, energy, passion, and commitment who inspires others to participate (Fitzsimons et al. 2013; Pulsford et al. 2015), a collaborative team is key to maintaining momentum and ensuring succession of leadership (e.g. Tiemann & Siebert 2008). Involving diverse stakeholders as equal partners from the beginning and maintaining regular communication is key to success. Early participation improves understanding of the need for and approach to connectivity conservation, increases buy-in, and encourages continued involvement (Rottle 2006; Jongman 2008). Ongoing dialogue and information exchange gives partners and communities a sense of ownership and responsibility (e.g. von Haaren & Reich 2006). In general, an atmosphere of cooperation promotes productivity and success, but as relationships get complicated, professional moderators may need to be engaged on a regular basis (Tiemann & Siebert 2008). While seen to be more effective in the long-term, collaborative efforts with multiple partners also take longer to develop. When there are many partners, organizing leadership into a core team may be necessary.

Diverse private landownership can pose a challenge to connectivity implementation (e.g. Naumann et al. 2011). Involving landowners as critical partners, who have defined rights and responsibilities in the connectivity project, and, if necessary, entering into formal agreements to manage land across property boundaries are avenues that can lead to success. Specifying realistic timelines for completing the various phases of a connectivity project is necessary to avoid delays and potential failure (Tiemann & Siebert 2008).

3.3.2 Develop a Common Vision

A vision of a connected landscape will engage different interests, facilitate collaboration between stakeholders, and spur policies promoting or mandating connectivity conservation (Beunen & Hagens 2009; Goldman 2009; Wyborn 2015). To address challenges due to customs, values, or beliefs, establishing a common vision of success that integrates social, ecological, and economic outcomes proposed by partners and stakeholders is essential. This vision can result from multi-partner regional planning processes, generate energy and enthusiasm among stakeholders, and create a momentum for project implementation. Once a shared vision is established, priority areas for restoration or conservation can be determined by the participating stakeholders (Beunen & Hagens 2009).

In Australia, the conservation community recognized that it could slow species loss and the effects of climate change by facilitating species movements. This shared vision of connected landscapes to conserve biodiversity in the face of climate change resulted in a social movement (Pulsford et al. 2012) and has led to a National Wildlife Corridors Plan and connectivity initiatives in every state of Australia (Wyborn 2015).

In several European countries, despite a strong vision for a connected landscape resulting in planning efforts at multiple scales and policies at the European and national levels, little progress beyond planning has been made (Beunen & Hagens 2009), indicating that a vision alone may not be sufficient for successful implementation. Lack of public engagement, no deadline for network completion, deficiencies in legal definitions, and a history of conflict between resource agencies and landowners were offered as explanations for implementation failures (Tiemann & Siebert 2008).

3.3.3 Be Transparent and Tell Stories of Success

Regular meetings of project partners, conferences, and webinars facilitate coordination and uphold interest (Rottle 2006; Tiemann & Siebert 2008). This is vital when unconventional partners with different interests are involved, such as counties, business communities, and developers. To retain stakeholder interest and promote a feeling of progress, defining a set of measurable criteria for success, developing a transparent strategy for monitoring progress, and agreeing on a regular review process for approved projects can help (Dettman 2006; Tiemann & Siebert 2008). Clearly communicating the goals and objectives of a connectivity project, openly discussing a project's implications for the landowners, and acknowledging and addressing the financial realities of conservation on private land are important aspects of building trust. For larger, complex projects, early success can lead to greater acceptance in the community. Thus, starting out with easy steps, such as visible small stewardship projects, is recommended (e.g. Rottle 2006).

Outreach campaigns are an important strategy for building public support, which can be critical for implementation success (Dettman 2006; Naumann et al. 2011). Depending on the goal, the audience can be the public, specific communities, private landowners in priority areas, or for the longest time horizon, children. The objectives can be short-term -- sharing information about a specific project, or long-term -- educating the public about the effects of habitat fragmentation and the resulting need for landscape connectivity. Outreach campaigns serve to broaden the base of support for implementation among private landowners and enhance trust between NGOs and/or agencies and local communities. The adoption of charismatic flagship species can play an important role in communicating the concept and need for connectivity conservation among local communities (Tiemann & Siebert 2008). Wildlife studies can be a good tool to engage with the public, because photos, videos, and movement paths of charismatic animals can inspire people. For high-profile projects, a formal public outreach strategy with in-depth and widespread media coverage on implementation progress can enable successful implementation (Schlotterbeck 2012).

Forms of communication can include websites and social media, newspaper columns, newsletters, public presentations, workshops, school visits, field trips, volunteer days, and one-on-one communications with landowners (Fitzsimons et al. 2013). When communicating with the public, the use of stories and non-technical, evocative language are most effective.

3.3.4 Base Implementation on Sound Science

All projects rely on a combination of empirical data such as animal movement (e.g., from telemetry studies, camera traps, roadkill surveys, and/or genetic studies), connectivity and prioritization models, and expert input to aid in planning, prioritizing, and validating connectivity zones and corridors. Coarse-scale analyses are important to inspire and guide connectivity action, but individual projects need to be informed by detailed, fine-scale plans (Beier et al. 2011). To account for the effects of climate change on biodiversity, climate-wise connectivity concepts need to be considered in the planning stage (climate refugia, microclimates diversity and climate velocity, Conserving Nature's Stage, and climate analogs, see section 2). Having animal movement data for a specific linkage can help convince stakeholders of the need for implementation (White & Penrod 2012) and can garner political support and funding (Naumann et al. 2011). While scientists are needed to collect data and conduct analyses, partners should be involved in the discussion about methods, input parameters, and focal species. The process should be transparent and inclusive and consider partners' perspectives and local knowledge (Beier et al. 2008).

In addition to the need for scientific data for planning effective corridors, interviewees noted that the level of project staff expertise (e.g. with respect to land acquisitions and habitat management) affects the efficiency of project implementation. Training for project managers and agency staff on landscape fragmentation effects, the interpretation and use of connectivity data, and guidance on how to select relevant models among a profusion of those available can help mainstream connectivity conservation.

3.3.5 Seek to Create Multiple Benefits

Multiple benefits can emerge from land protection and restoration, including increased potential for species to adapt to climate change, carbon sequestration, improved water quality, recreation, and preservation of open space and working lands. Promoting these benefits in addition to protecting wildlife and biodiversity can be an effective strategy to increase support for connectivity projects in areas with diverse landownership (e.g. Jongman et al. 2008; Beunen & Hagens 2009). Coalition building by involving multiple partners whose objectives align with these co-benefits, including nontraditional conservation actors such as water districts, planning agencies, and recreation departments, is an opportunity for increasing advocacy, tapping a greater variety of funding sources, and improving the odds of overcoming barriers toward implementation.

In some regions, finding means of integrating conservation and economic development, e.g. by developing sustainable forestry or extensive farming practices in corridors, can be essential for successful connectivity implementation (Bennett 2004). However, in some cases, the biological corridor implementation effort was combined with the goal of advancing economic development, which detracted from the original purpose of biodiversity conservation (Dettman 2006). Hence, associating a corridor project with multiple benefits can be a double-edged sword when it comes to operationalization (Naumann et al. 2011). Effective communication of the primary ecological objectives and creation of baseline ecological data and a monitoring program are critical to ensure project goals are met. Specifying how other benefits are synergistic with primary objectives and providing guidelines on how to manage or restore land in corridors will help reconcile conflicting objectives as more stakeholders and goals are bundled into single projects (Dettman 2006).

3.3.6 Diversify Funding

Funding for on-the-ground efforts is a pre-requisite for successful implementation. An array of funding strategies was listed by interviewees including: conducting fundraising from individuals, applying for public funds, creating public-private partnerships, planning multi-benefit projects, linking to climate adaptation funding, using seed money to grow successful projects, developing partnerships with businesses, and taking advantage of volunteers (see also Bennett 2004).

A specific challenge arises when a pinch point corridor needs to be protected where key lands may be relatively small but very expensive and slated for city development. Often, these small parcels do not harbor listed species, rare habitat types, or other statewide priority resources for conservation, and thus can be harder to fund with sources that focus on threatened and endangered species. Agency resource professionals also noted that while local land use policies and state initiatives may pay homage to the benefits of habitat connectivity, real regulatory requirements and funding mechanisms are mostly absent, making it difficult to retroactively incorporate connectivity measures into existing highways. They argue that a funding source specifically for habitat connectivity projects would make project implementation in this and many other instances more feasible. Funding through climate change adaptation programs is increasingly available and strengthens the practice of "climate-wise" connectivity conservation.

3.3.7 Create Incentives

Some interviewees cautioned against promoting connectivity through laws that regulate private landowners, and emphasized the need for strong, voluntary incentive programs with cost-sharing for compatible land uses, and consensus-based approaches, to increase acceptance and willingness to participate (see also e.g. Rottle 2006; Morrison & Boyce 2008). This is in part because concerns about additional regulations can interfere with landowners' willingness to participate in connectivity implementation.

In contrast, binding regulations for agencies are an important foundation for success in widespread, systematic connectivity implementation (Lausche et al. 2013), even though in some countries land policy regulations have become so complex that potential players avoid becoming involved (Beunen & Hagens 2009). A legal framework requiring agencies to consider and prioritize connectivity conservation would ensure early internal and external coordination of connectivity projects between agencies with different mandates (Shadie & Moore 2008). Without such a framework, action is left to motivated employees who act without the support of the agency's bureaucracy, resulting in piecemeal connectivity implementation.

3.3.8 Policies Related to Habitat Connectivity Conservation in California

Policies related to wildlife connectivity fall into several major categories including regulatory, fiscal, and advisory. Regulatory policies include measures that prevent or reduce impacts to connectivity or require offsets for impacts that do occur. They can also include provisions for increasing connectivity from current conditions. Fiscal policies are those that provide funding for implementation efforts to enhance the connectivity of landscapes. Finally, advisory policies are those that encourage or enable government agencies to include connectivity in current planning processes without explicitly regulating this or providing funding to do so.

Policies influencing connectivity planning have existed as part of federal and state policy in California for more than 40 years (see Table 3.1 for a list and Appendix J for more details). Groundbreaking legislation such as the National Environmental Policy Act and the National Environmental Quality Act set the early stage to enable public agencies to engage in planning for wildlife connectivity. Federal regulations were established by agencies such as the Environmental Protection Agency and U.S. Fish and Wildlife Service as well as those related to infrastructure that the Federal Highway Administration (FHWA) enacted. However, there is relatively little regulatory language at the federal level for obligatory protection or enhancement of wildlife connectivity. Those regulations that do exist generally consider connectivity during environmental assessment of proposed federal projects.

Similarly, policies can be enacted at the state level to direct state regulatory and infrastructure agencies. For California, agencies that have some influence over habitat connectivity statewide include the Department of Fish and Wildlife, Caltrans, and the Department of Water Resources. Some statewide efforts in California were linked to efforts at the federal level to encourage implementation of wildlife connectivity projects across the U.S. For example, when Congress passed SAFETEA-LU and the subsequent MAP-21 the importance of habitat connectivity was explicitly included in the mitigation framework for impacts from California's ground transportation projects. The Department of the Interior also developed guidelines for the inclusion of connectivity in land use planning. While SAFETEA-LU and the associated IEF were the first efforts at the federal level to incorporate wildlife connectivity into infrastructure planning, MAP-21 more explicitly provided regulatory language to provide for conservation of connectivity. Finally, local jurisdictions such as cities and counties control land use in California and it is these actions that drive levels and patterns of fragmentation. With careful thought, land use plans can avoid impacts to habitat, and provide incentives to conserve open space and habitat connectivity. For example, local land use regulations offer many opportunities to foster infill development, protect open space, and insist on the maintenance and restoration of habitat connectivity as part of the development process. Policies at the three levels of government that are moving California towards the preservation and enhancement of wildlife connectivity and establishment of habitat corridors can be found in Table 3.1.

The passage of Natural Community Conservation Planning (NCCP) legislation in 1991 provided some momentum to implement connectivity strategies for the reserve networks associated with these endangered species recovery plans. Beginning with the creation of the San Diego Multiple Species Conservation Plan in 1998, at least five NCCPs have been established to date that not only explicitly plan for wildlife connectivity but provide a financial mechanism for implementation. In addition, as of September 2016, 22 more NCCPs were in the planning phase and some may include explicit wildlife connectivity and corridors for future implementation. While NCCPs call for connectivity implementation, similar language does not appear in the federal Endangered Species Act, specifically Section 10 that deals with Habitat Conservation Plans (HCPs). In California, many HCPs are also part of NCCPs, but by no means all of them. Therefore, many of these local conservation plans have no explicit call for conservation of connectivity.

After NCCP legislation was passed in 1991, there has been very little attention paid to connectivity policy development until the adoption of the Standard Environmental Reference and subsequent pieces of legislation. Several bills were signed into law during 2008-2016 related to habitat connectivity that were largely enabling or advisory in scope (e.g. AB 2785, AB 498, and AB 2087). The California Department of Fish and Wildlife as well as Caltrans also developed policies that encourage the consideration of wildlife connectivity in project design and execution. Recently in California this issue is becoming more visible and of greater importance to State wildlife interests. For example, in 2016 the Wildlife Corridor Working Group was established as a lobbying body to work with legislators on bills related to connectivity.

Taken together, federal, state, and local policies provide very few regulations, guidance, and even less funding for connectivity planning and implementation across California. What little public funding is available today is associated with endangered species recovery and mitigation of impacts associated with transportation infrastructure. While Caltrans staff at the district levels are exploring potential uses of transportation funds for implementation of wildlife crossings and other measures, relatively little state or federal money can be used for these types of projects. The rather limited implementation efforts to date indicates that there are still policy gaps that if filled could make connectivity a key planning element for State agencies focused on wildlife, transportation, water management, and climate change.

The importance of maintaining and restoring habitat connectivity cannot ride solely on the backs of endangered species recovery planning such as NCCPs. California will not see substantial progress unless we rapidly adopt other policies and funding mechanisms to plan for and implement wildlife corridors. One possibility could be through funding a substantial grant program run by the Wildlife Conservation Board, for example, to support acquisition or restoration of important linkage areas. Such incentive programs could aid progress across private lands that make up the matrix surrounding many of our essential core public protected areas. This in conjunction with accelerating efforts to mitigate habitat loss and fragmentation resulting from development and transportation through the establishment of well-functioning wildlife corridors across California would go a long way to making California's landscapes more resilient to the rapid changes impacting biodiversity across the State.

Table 3.1. Federal, State, and local policies advancing wildlife connectivity and corridors in California.

Federal examples		
Policy	Policy family	Policy focus
Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)	advisory	Federal transportation spending legislation
Moving Ahead for Progress in the 21st Century Act (MAP-21)	fiscal	Federal transportation spending legislation (successor to SAFETEA-LU)
Department of Interior (DOI) Manual, Chapter 523 DM 1	policy directive	Guidelines for project impact assessment
National Fish, Wildlife and Plants Climate Adaptation Strategy	advisory	Federal inter-agency policy for conservation of species under climate change
Department of Interior Manual 600 DM 6	policy directive	Manual establishing new mitigation policy
State examples		
California Environmental Quality Act (CEQA)	regulatory	Addresses environmental impacts from projects
California Proposition 117/Habitat Conservation Fund (1990)	fiscal	Creates the Habitat Conservation Fund, including money for wildlife corridors
Natural Communities Conservation Plan legislation (first passed in 1991)	policy directive	Regional conservation plans that identify future reserves and address expected mitigation needs for multiple species
General Plan Guidelines	advisory	Framework for the development of general plans by local governments

Standard Environmental Reference	policy directive	Caltrans document for use by staff in environmental assessment
AB 2785	policy directive	Calls for the development of a statewide corridor/linkage database
AB 498	advisory	Enables the conservation of wildlife corridors in California
State Wildlife Action Plan	advisory	Establishes the state's conservation priorities
AB 2087	policy directive	Framework for integrated regional conservation plans
Transportation Plan 2040	fiscal	Statewide transportation plan
Examples from local jurisdictions		
San Diego Multiple Species Conservation Program	fiscal	Plan to protect species and ecosystems and provide for mitigation for impacts
East Contra Costa County Habitat Conservation Plan	fiscal	Plan to protect species and ecosystems and provide for mitigation for impacts
Coachella Valley Multiple Species Habitat Conservation Plan	fiscal	Plan to protect species and ecosystems and provide for mitigation of impacts
Measure M2	fiscal	A sales tax to support the Orange County Transportation Authority's transportation program
Santa Clara Valley Habitat Plan	fiscal	Plan to protect species and ecosystems and provide for mitigation of impacts

3.4 Proposed Evidence-based Framework for Connectivity Implementation

In light of these findings, we propose a framework intended to guide on-the-ground climate wise connectivity implementation (Fig. 3.1). This framework shows how many of the evidence-based elements listed above are related to the implementation process including: the role of partnerships, climate-wise planning, data and analysis, opportunities and challenges, and various strategies to produce conservation outcomes. We illustrate the framework's content using three case studies (Fig. 3.2, Boxes 3.1-3.3), a highway crossing project (Hwy 17 in Santa Cruz County, 'highway project'), a pinch point corridor project (Sonoma Valley Wildlife Corridor, 'Sonoma project'), and a landscape zoning project (Desert Renewable Energy Conservation Plan, 'desert project').

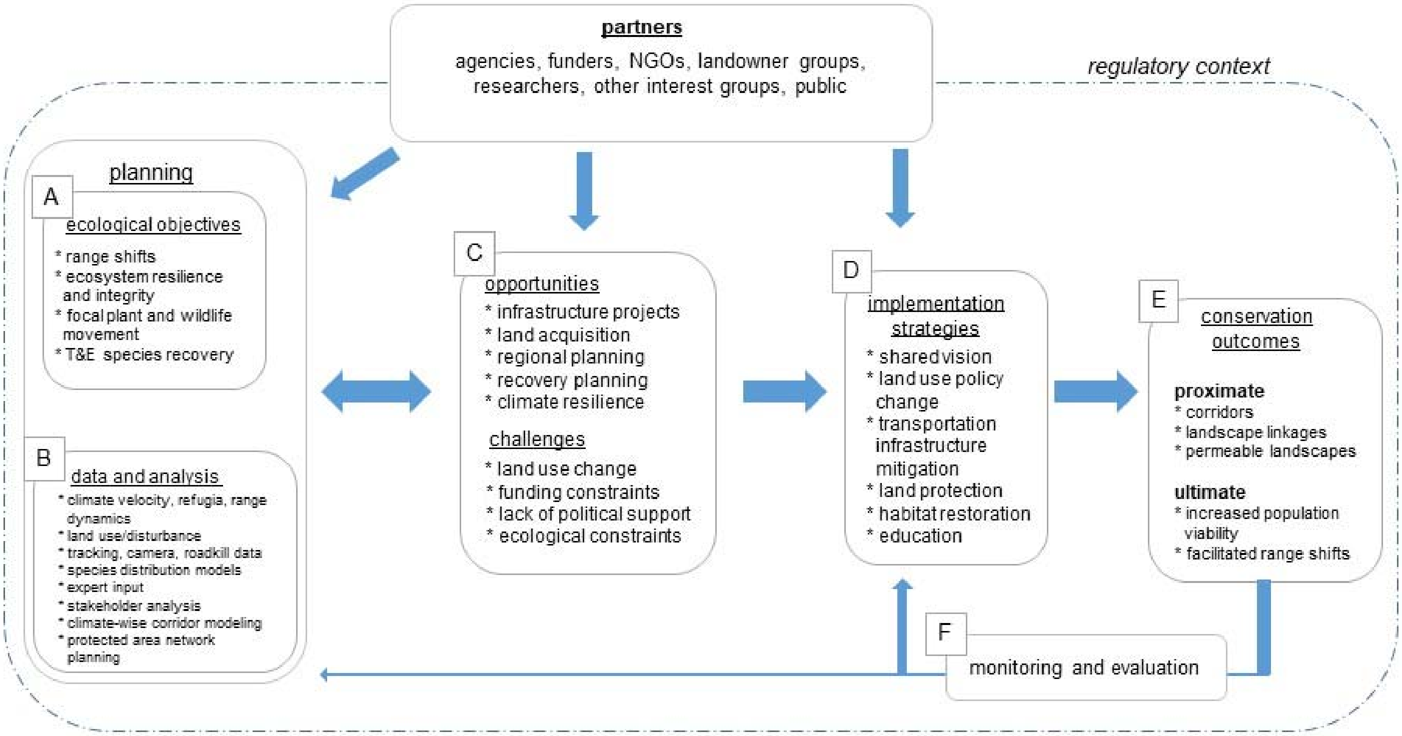

Figure 3.1. A framework for climate informed connectivity implementation

The three projects differ in their ecological objectives (Fig. 3.1-A). Desired proximate conservation outcomes (Fig. 3.1-E) are a corridor (highway project), a landscape linkage (Sonoma project), and a permeable landscape (desert project). The projects all focus on increasing population viability by facilitating plant and animal movement; the Sonoma and desert projects also aim to facilitate range shifts with climate change.

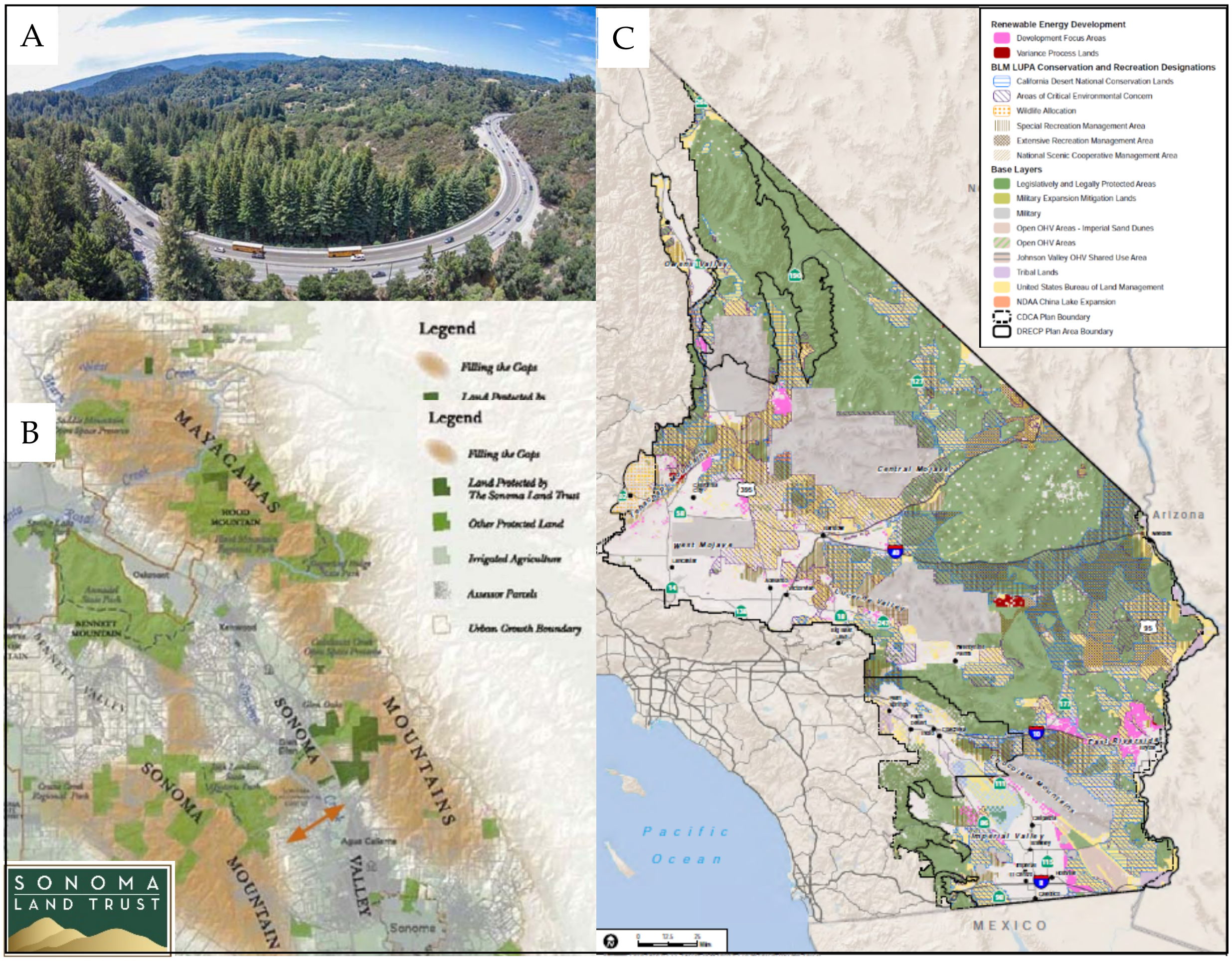

Figure 3.2. The location for the planned wildlife crossing structure under Highway 17 in Santa Cruz County, California (A); the Sonoma Valley wildlife landscape linkage just above the orange arrow in Sonoma County, California (B); the zoning map of the Desert Renewable Energy Conservation Plan, in southeastern California. Source: U.S. Bureau of Land Management 2016. Record of Decision. BLM/CA/PL-2016/03+1793+8321 (C).

Box 3.1: Hwy 17, Santa Cruz County

Information provided by Nancy Siepel: Caltrans
http://pathwaysforwildlife.com/hwy_17_wildlife_connectivity_improvement_project

Objective and justification

- Create a safe passageway across a busy, congested 4-lane highway that poses a barrier to wildlife movement.

Partners

- Land Trust of Santa Cruz County
- Santa Cruz County Regional Transportation Commission
- California Department of Transportation
- California Department of Fish & Wildlife
- University of California, Santa Cruz Puma Project

Intended conservation outcomes

- Provide connectivity for multiple species to prevent genetic isolation and population fragmentation

Planning: Data and analysis

- Camera trap data
- Mountain lion telemetry data
- Road kill data
- Regional wildlife linkage models

Opportunities

- Public-private partnership
- Media campaign to generate public support
- Land trust engaging lobbyists to generate agency support
- Pilot agreement between Caltrans and CDFW created advanced mitigation credits for wildlife connectivity
- Sufficient biological data for project planning
- Safety concern for humans (agency desire to decrease animal-car collisions)
- Significant economic savings due to roadkill/car accident prevention

Challenges

- Funding
- Lack of precedence for funding model

Implementation Strategies

- Crossing structures
- Conservation easements

Box 3.2: Sonoma Valley Wildlife Corridor

Information provided by Bob Neal and Tony Nelson (Sonoma Land Trust); https://sonomalandtrust.org/pdf/WildlifeCorridorOnline.pdf

Objective and justification

- Maintain and restore a regional scale wildlife corridor across Sonoma Valley, California, that encompasses approximately 10,000 acres, and stretches from the top of Sonoma Mountain across Sonoma Creek and the valley floor to the Mayacamas Mountains to the east. The Corridor is part of a much larger network of proposed linkages connecting habitats from the coast through the coastal mountains providing a vital connection for wildlife movement within the northern San Francisco Bay Area.

Partners

- Sonoma Land Trust
- Other local conservation organizations
- County and state parks
- Landowners
- Academia

Intended conservation outcomes

- Facilitate wildlife movement and range shifts under climate change

Planning: Data and analysis

- Wildlife camera grids and underpass monitoring and analysis of species detection rates
- Parcel scale mapping
- Landscape permeability analysis
- Climate analysis comparing maximum summer and winter minimum temperatures between corridor termini

Opportunities

- Interest by locals in wildlife
- Long-standing positive relationship between partners
- Large parcel of public hospital land closing and up for repurposing

Challenges

- Lack of funding for stewardship and cost sharing with landowners to improve habitat condition and corridor function
- Private and public land (state hospital) in corridor threatened by intensive agricultural and residential development
- Busy roadways and increasing recreation pressure
- Lack of mechanisms and opportunities for organizations to work together
- Initial lack of species presence and movement data, vegetation maps
- Uncertainty of climate predictions
- Not clear how to measure success for the project given limited capacity and funding

Implementation Strategies

- Public engagement and development of a shared vision
- Conservation easements in the corridor
- Removal and mitigation of barriers to animal movement
- Riparian area restoration
- Land management for permeability
- Sharing best management practices with landowners
- Manage recreation to minimize impacts to wildlife
- Wildlife monitoring

Box 3.3: Desert Renewable Energy Conservation Plan

Information provided by Jim Weigand and Vicki Campbell (Bureau of Land Management); http://www.drecp.org/

Objective and justification

- The plan prescribes land use allocations on public land in the desert region of California that aim to balance natural resource conservation including landscape connectivity with renewable energy development. For private lands, it provides a vision for biological conservation to inform conservation planning and investments.

Partners

- California Energy Commission
- California Department of Fish and Wildlife
- Bureau of Land Management
- United States Fish and Wildlife Service
- Other state and federal agencies, tribal and local governments, NGOs, private entities

Intended conservation outcomes

- Landscape-scale system of connected conservation areas
- Ecologically functional natural communities
- Conservation of viable self-sustaining populations of focal species

Planning: Data and analysis

- Resource distribution in the planning area
- Data on species occurrences, movement, dispersal, and population structure and trends
- Species habitat models
- Maps of natural communities
- Expert knowledge of the resources
- Climate modeling and climate change resiliency plans

Opportunities

- Politically motivated integration of sensitive biological resource conservation with renewable energy development
- High-level (Secretary of Interior, California Governor) political support
- Financial and staff support from federal and state agencies

Challenges

- Incredible complexity of project
- Very large number of stakeholders
- Integrating biological data collected at different scales
- Ensuring that most of the sensitive species in the desert were considered
- Staff inexperience with large project development

Implementation Strategies

- Land use allocation
- Required management action (habitat restoration; land acquisition; mitigation, avoidance, and minimization action)

3.4.1 Highway 17 Crossing

The highway project was triggered by frequent vehicle-wildlife collisions on a busy highway. Although California's regulatory context encourages agencies to consider wildlife connectivity in new project designs (CA-AB498), retrofitting existing highways was not part of standard procedures and was lacking funding sources. However, concern for human safety presented an opportunity (Fig 3.1-C) for the Department of Transportation to engage with conservation organizations concerned about the barrier effect of the highway and work on a wildlife crossing project. Other stakeholders that became involved in this public-private partnership included a local land trust, California Department of Fish and Wildlife, and university researchers. The local land trust raised funds to protect land on either side of the proposed highway crossing. Researchers collected extensive biological data and modeled regional wildlife connectivity to determine the best location (Fig 3.1-B), which led a media campaign to generate public and agency support (Fig 3.1-F). The main challenge that remained after garnering public and agency support, deciding on the best site and design for a wildlife tunnel, and securing the surrounding properties, was funding for the structure itself. Realizing that the need for mitigating existing highways was not limited to this location, the partners developed a pilot agreement for using advanced mitigation credits to fund connectivity projects that, if successful, can be applied throughout California. Implementation of the crossing structure (Fig 3.1-D) is slated for completion in 2020.

3.4.2 Sonoma Valley Wildlife Corridor

The Sonoma Valley Wildlife Corridor contains open land in an otherwise highly utilized valley between two mountain chains, making it a critical location for wildlife movement. Because it was identified as an important state and regional linkage (Spencer et al. 2010, Bay Area Open Space Council 2011, Fig. 3.1-B), the Sonoma Land Trust took the lead to permanently preserve it. They partnered with scientists to document the corridor's significance for daily wildlife movement and range shifts, and then took advantage of three main opportunities (Fig 3.1-C) – the interest of the local community in wildlife, the positive relationship between landowners and the Trust, and the upcoming repurposing of land in the critical linkage – to develop a comprehensive implementation strategy (Fig. 3.1-D). Land protection and management are the keys to preserving the corridor, which the Trust is achieving through communication with the public and key participating landowners. Continued monitoring (Fig. 3.1-F) is valuable not just for adaptive planning and management but also to maintain interest from the public.

3.4.3 Desert Renewable Energy Conservation Plan

The Desert Renewable Energy Conservation Plan (desert plan) was created out of the need to balance development of renewable energy projects on public lands with natural resource conservation in California's deserts. Partners from state and federal agencies, industry, and conservation organizations (Fig. 3.1-A) developed a vision of a permeable landscape that also accommodates new renewable energy projects. Because renewable energy development has been a political and economic priority in California, the Plan received extensive political and financial support. Due to ambitious ecological objectives, which included efforts to recover the endangered desert tortoise (Gopheru s agassiz ii) and increase ecosystem resilience and integrity, considerable data acquisition, mapping, and species and climate modeling (Fig. 3.1-B) was conducted. Integrating the varied biological data collected at different scales was challenging (Fig. 3.1-C). The high-level political support presented an opportunity for developing land use allocation prescriptions to maintain a connected landscape, but the project also came with challenges. Balancing energy development and conservation needs, the large extent of the project area, and the resulting complexity of aligning stakeholder objectives were cited as primary challenges. Whereas the previous examples considered individual corridors, the large landscape of the desert plan required a different implementation strategy (Fig. 3.1-D). The project resulted in land use allocations that promote either natural resource conservation or energy development. Ongoing development of management guidelines, habitat restoration, and private land planning will be completed in future phases.

3.5 Conclusion

While the process of connectivity implementation from planning to monitoring outlined in the framework appears linear, many of the activities overlap in time. There are also feedback loops between the major actions pointing out steps where adjustments may be needed to accommodate opportunities or challenges that arise. The different categories of opportunities, such as community visioning, communication, science, partnerships, and laws and regulations are elements that are needed to fill the planning-implementation space. When operating in this space, interviewees emphasized that flexibility, creativity, transparency, and persistence are necessary for success in accomplishing on-the-ground connectivity conservation.

While detailed implementation recommendations need to be project-specific, our research revealed overarching recommendations that are relevant in most contexts (Table 3.1). These and other suggestions discussed in this study can serve as a template to ensure that existing planning efforts translate into climate-wise connectivity, conservation and restoration.

Table 3.2. These overarching recommendations and best practices for governments, public agencies, and conservation organizations are relevant in most implementation contexts. Detailed recommendations necessarily need to be project specific as the socio-ecological context affects the whole process of connectivity implementation.

Recommendation	Justification
Programs and policies	
Create clear regulations and policies for public agencies.	This is important for spurring government agencies to address connectivity conservation.
Create voluntary incentive programs for private landowners.	Private landowners likely respond better to incentive programs than to regulations.
Offer incentives to diversify agricultural lands and cityscape.	This would increase general landscape permeability.
Use zoning with incentives to promote land conservation.	Especially in landscapes where development is sprawling, zoning can keep key areas open for wildlife, averting the need to purchase land for connectivity conservation in the future.
Funding	
Create connectivity-specific funding sources.	This would enable connectivity projects that may otherwise fall through the cracks, e.g. because conservation legislation focuses on endangered species, which may not be present in all corridors. It would also mainstream connectivity conservation, which is necessary for rapid, landscape-wide implementation.
Planning	
Conduct climate-wise connectivity planning.	Integrating climate considerations (climate velocity, refugia, range dynamics at the leading and trailing edges) should be considered to facilitate species' movements in response to climate change.
Use the level of threat of land use conversion to development and intensive agriculture as a basis for identifying the most critical locations for corridors.	This will focus connectivity conservation in high-risk areas.
Avoid planning at parcel scale in private lands without landowner engagement.	Landowners will often feel targeted by what are perceived as new regulations or restrictions on rights.
Focus connectivity programs within regions with similar ecological and social attributes.	Implementing connectivity in ecologically and socially similar regions may be more successful than spanning diverse areas.
Data collection	
Coordinate and facilitate the collection of solid biological baseline data (Wildlife agencies).	These data are vital for justifying corridor projects to stakeholders and the public, as well as for determining the best location for a corridor in priority connectivity areas.
Implementation	
Phase land acquisition to complete a minimum viable linkage.	If linkage implementation involves multiple private properties, this strategy ensures a continuous corridor that can be widened with time to allow for redundancy and possibly greater functionality into the future.
Set clearly-defined spatial priorities and implementation timelines where possible and appropriate.	This ensures that connectivity goals are being met.
Education and outreach	
Run state/country-wide and regional public campaigns.	Public outreach galvanizes support and participation.
Offer training for conservation practitioners on how to interpret and use connectivity data.	This ensures that science is used to maximum benefit.

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4: Conclusions and Future Directions

Here, we draw conclusions on the chapters on planning for climate-wise connectivity and implementing connectivity and provide an outline of future research needs.

4.1 Conclusions

4.1.1 Planning for Climate-wise Connectivity

Planning for climate-wise connectivity needs to accommodate all species that can respond to climate change by shifting their ranges. Increasing the amount of habitat throughout the landscape is a base strategy to help species adapt to climate change. Adding climate-wise corridors between natural or protected areas can be an effective strategy to facilitate species persistence and range shifts. Therefore, climatic considerations should be incorporated into corridor designs.

Structural connectivity approaches based on land use/land cover are a good proxy for species movement patterns and are recommended as a first start for statewide corridor modeling, in combination with climate information, particularly on refugia. Approaches that can be applied universally include corridor designs based on land facets or geodiversity that aim to conserve nature's stage, naturalness approaches that prioritize areas with low human modification while considering climate-related concepts such as climate analogs and topoclimatic diversity, and climate gradient corridors that connect current to future suitable habitat while avoiding drastic changes in climate along the corridor. Species movement information should be used, where possible, for validation and local planning.

Riparian corridors are natural movement corridors, climate gradients, and refugia and therefore should be included in all connectivity plans. Because they are often already protected, where rivers and creeks flow through a matrix of agriculture and developed lands, they tend to be hotspots of biodiversity. In Mediterranean climates, the significance of riparian corridors for connectivity is increased by the contrast between the dense, heterogeneous, and highly productive riparian vegetation and the surrounding, typically xeric, woodlands, shrublands, and grasslands. This contrast elevates the services these riparian areas offer with respect to microclimate and structural habitat for fish and wildlife. Many of the wildlife species from the more xeric ecosystems will use Mediterranean riparian areas during a portion of their life history which suggests that they will use them as corridors.

While traditional wildlife corridors mostly needed to accommodate daily and dispersal movements, climate-wise corridors need to be designed to facilitate range shifts over several decades. Therefore, corridors need to be wide enough to provide live-in habitat for slow moving species and should contain diverse topography that provides micro-refugial sites for species persistence.

4.1.2 Implementing Connectivity

To ensure that the planning efforts will be translated into meaningful connectivity conservation and restoration, we developed a framework to guide on-the-ground connectivity implementation. Opportunities for successful implementation include building partnerships, developing a common vision of a connected landscape, being transparent and telling stories of success, basing implementation on sound science including climate information, seeking to create multiple benefits of wildlife corridors, diversifying funding, and creating incentives for participation. Based on a review of federal, state, and local policies relevant to wildlife connectivity in California, we suggest strengthening or adding specific components to the policy framework to advance the establishment of well-functioning wildlife corridors across California. While detailed implementation recommendations need to be project-specific, our research revealed overarching recommendations that are relevant in most contexts, including:

- voluntary incentive programs for private landowners
- incentives to diversify agricultural lands and cityscape
- zoning with incentives to promote land conservation
- setting clearly-defined spatial priorities and implementation timelines where possible and appropriate
- state/country-wide and regional public campaigns
- coordination and facilitation of the collection of solid biological baseline data by wildlife agencies
- training for conservation practitioners on how to interpret and use connectivity data
- creating connectivity-specific funding sources.

Increasing landscape connectivity such that animals and plants can move in response to climate change following the suggested approaches will contribute to creating climate-resilient landscapes in California. Following our framework for on-the-ground connectivity implementation will increase the efficiency and success of corridor projects.

4.2 Future Research and Extension for Connectivity Conservation

Fundamental to future improvements in habitat connectivity across California is the need for sound science and improved mechanisms for corridor implementation, such as incentive programs and regulations that will drive investment in connectivity implementation. The following areas of investigation will improve our understanding of: how species adapt to climate change, the effect patterns of land use and cover have on permeability, and the relationship between permeability and facilitation of range shifts. At the same time, improving our ability to maintain and conserve connectivity areas requires increased investigation into the effect of community-based conservation strategies.

These areas in need of research span more than one ecosystem and reflect the review of the scholarship conducted as part of this study. The following specific topics are divided into corridor ecology, ecosystems and climate response, and extension and implementation.

4.2.1 Corridor Ecology

- Research how well existing connectivity areas function and potential impacts of various activities within and around the corridor.

- How permeable are various types of working landscapes for animal movement and facilitating range shifts?
- How does corridor width and length influence functionality?
- Compare climate-wise connectivity analysis methods in the same landscape context.
- Advance methods to efficiently collect and analyze species movement data in important connectivity areas.
- Employ multiple types of sensors to detect corridor use to improve planning for connectivity, e.g. camera traps, tracking, collaring animals, drones.

4.2.2 Ecosystems and Climate Response

- Establish a network of "sentinel" sites spanning protected areas and connectivity areas across bioregions and ecosystems in California, providing continuous monitoring and early detection of changes.
- Paleoecology and historical ecology to provide historical context on vegetation change across ecosystems and under climate change to determine responses to drought and the role of macro and micro refugia on dispersal and range shifts.
- Disturbance regimes and successional dynamics in nonstationary environments, including identification of leading and trailing edges of existing ecosystems and emergence of novel ecosystems.
- Interactions between climate, including extreme drought events, and disease.

4.2.3 Extension and Implementation

- Make implementation guidelines available to connectivity planners and set up mechanism for feedback to improve the process.
- Take advantage of UC Cooperative Extension to extend connectivity science and implementation strategies to those working with authority over land use and transportation infrastructure decisions at the county, region and statewide scales.
- Provide grants and other financial incentives for collaborative public/private landowner projects to protect or enhance connectivity through Resource Conservation Districts and other entities.
- Support public engagement, education, and communication efforts at a set level (e.g. 10%) as part of any funded connectivity conservation effort.
- Citizen monitoring of early detection of new arrivals and diseases; changes in flowering timing, seed set, and other life-cycle events in relation to environmental cues; citizen re-photography of historic photo points; and citizen supervision of monitoring instruments.
- Participatory research through improved usability of existing mobile and online applications for crowdsourced data acquisition; improved detection of local species

declines and extirpations; and new statistical approaches to weight-contributed data based on estimates of reliability (e.g., bird list length).

- Policies to advance city and county planning efforts at conserving open space and connectivity areas including CEQA oversight for agricultural development that results in habitat conversion of all native vegetation types.

4.3 Summary

The State of California recognizes the need for connectivity conservation to conserve its diverse biodiversity in the face of climate change and a growing human population. This report summarizes the available science for planning and implementing climate-wise connectivity. It provides the first state-wide assessment of approaches to advance habitat connectivity and climate change resilience landscapes. It also provides direct guidance on how to successfully implement connectivity conservation including proposed adjustments to policy.

APPENDIX A: Papers Used to Test the Search Terms.

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APPENDIX B: Categories in Data Extraction Sheet.

Reviewer
ID
Year of Publication
Title
Publication type
Original study or review
Simulation, software
Study location
Addresses connectivity in methods and results; OR expressively in review/essay/opinion piece
Addresses climate in methods and results; OR expressively in review/essay/opinion piece
Designs climate corridors or designates connectivity areas (provides pathways to projected future range) -abiotic
Designs species/ community movement corridors, or designates connectivity areas -biotic
What is being connected? (e.g. protected areas, climate analogs)
Assesses connectivity for focal species
Assesses structural connectivity
Goal of connectivity assessment
Informs management decisions or conservation planning?
Comparing behavior of organisms with different functional traits (e.g. dispersal distance)
Considering varying levels/arrangements of landscape fragmentation
Studying connectivity strategies?
Landscape complexity
Input data (e.g. type of cost surface)
Type of species information used (e.g. habitat preferences)
Is dispersal included at all? (including modeled assumptions?)
How is dispersal included?
Are empirically informed movement data included?
Compares methods for identifying corridors/connectivity
Species specific objectives and if so how many species
Which species?
Do species use the pathways? (Demonstrated through empirical observation)
Do they address land use change or changes to the matrix that improve or reduce connectivity?
Uses one or more than one climate or atmospheric variable (e.g. MAT, precip.)
List the climate or atmospheric variables
Considers one or more measures/statistics of climate space (e.g. climate velocity, gradient, diversity)
Which measures/statistics of climate space are considered?
Evidence of past or ongoing distribution changes (e.g. leading/trailing edges, range contraction)

Addresses the role of refugia
Uses SDMs
Connects current and future species distributions
Spatial scale: minimum mapping unit
Spatial scale: planning unit
Spatial scale: extent of study area
Temporal scale
Method of corridor/connectivity design
Method of connectivity assessment
Uses vegetation information
Uses the built environment
Output type/ information
Biological realism: high (detailed field information); medium (some field information); low (models do not include species specific information)
Conceptional complexity: low (few, straight forward models); moderate (several models, or few complex models); high (many models, or very complex models)
Interpretability (easy, moderate, difficult)
Best used for…; planning objective
Levels of potential error, # of models included in analysis
Study limitations
Papers to include in our review (references)
Short summary of findings
Comments, questions

APPENDIX C: Input Categories for Cluster Analysis.

designs_structural_connectivity (y, n)
designs_focal_species_connectivity (y, n)
assesses_connectivity_for focal_species (y, n)
assesses_structural_connectivity (y, n)
simulation_software (n, software, simulation)
objective (linking suitable habitat at leading edge, linking current and future linking suitable habitat, linking suitable habitat, linking protected areas / natural areas, n/a, linking geomorphic features: land facets, linking desirable atmospheric conditions: climate-based SDMs, linking desirable atmospheric conditions through time: climate-based SDMs, linking geomorphic features: elevation, linking geomorphic features: streams/ riparian areas, linking geomorphic features: streams/ riparian areas, elevation)
termini (n/a, protected areas, protected or natural areas, suitable habitat, other, natural areas)
output (n/a, spatially comprehensive connectivity prioritization maps, linear corridors, multiple, lattice-work corridor network, habitat network)
focus (n/a, whole biota, focal species, carbon sequestration)
dispersal_included? (y, n)
number_species (0, 1, 2-10, 11-100, 101-500, >1000, flexible)
taxa_2 (animals, plants, both, simulated, n/a)
land_use_changes_addressed (y, n)
climate_variables (y, n)
climate_space_measures (y, n)
addresses_role_of_refugia (y, n)
uses_SDMs (y, n)
connects_current_future_species_distributions (y, n)
planning_scale (n/a, local/regional, regional, regional/landscape-scale, landscape-scale, local/regional/landscape-scale)
temporal_scale_2 (not-specified, current, future, 2015-2100, flexible)
connectivity_design_method (Circuit theory, environmental gradients, experts/shortest distance/linear elements, graph theory, LCC_LCP, SDM overlap, systematic conservation planning, multiple, n/a, other)
connectivity_assessment_method ("experts/shortest distance/linear elements, genetic, graph theory, individual/population/species modelling, multiple, n/a, other)
uses_vegetation_information (y, n)
uses_built_environment (y, n)
goal of connectivity assessment (evaluating connectivity for range shifts, evaluating range shift requirements, evaluating the forecasting of future range shifts, factors affecting distribution change, landscape use during range shifts, n/a, restoration/conservation strategy, role of corridors for range shifts)
informs management decisions or conservation planning? (y, n)
comparing behavior of organisms with different functional traits (e.g. dispersal distance) (y, n)
considering varying levels/arrangements of landscape fragmentation (y, n)
studying connectivity strategies? (y, n)
landscape complexity (land cover, n/a, other, protected areas, suitable/unsuitable)

APPENDIX D: References Included in the Systematic Review of Climate-wise Connectivity Modeling.

Design papers

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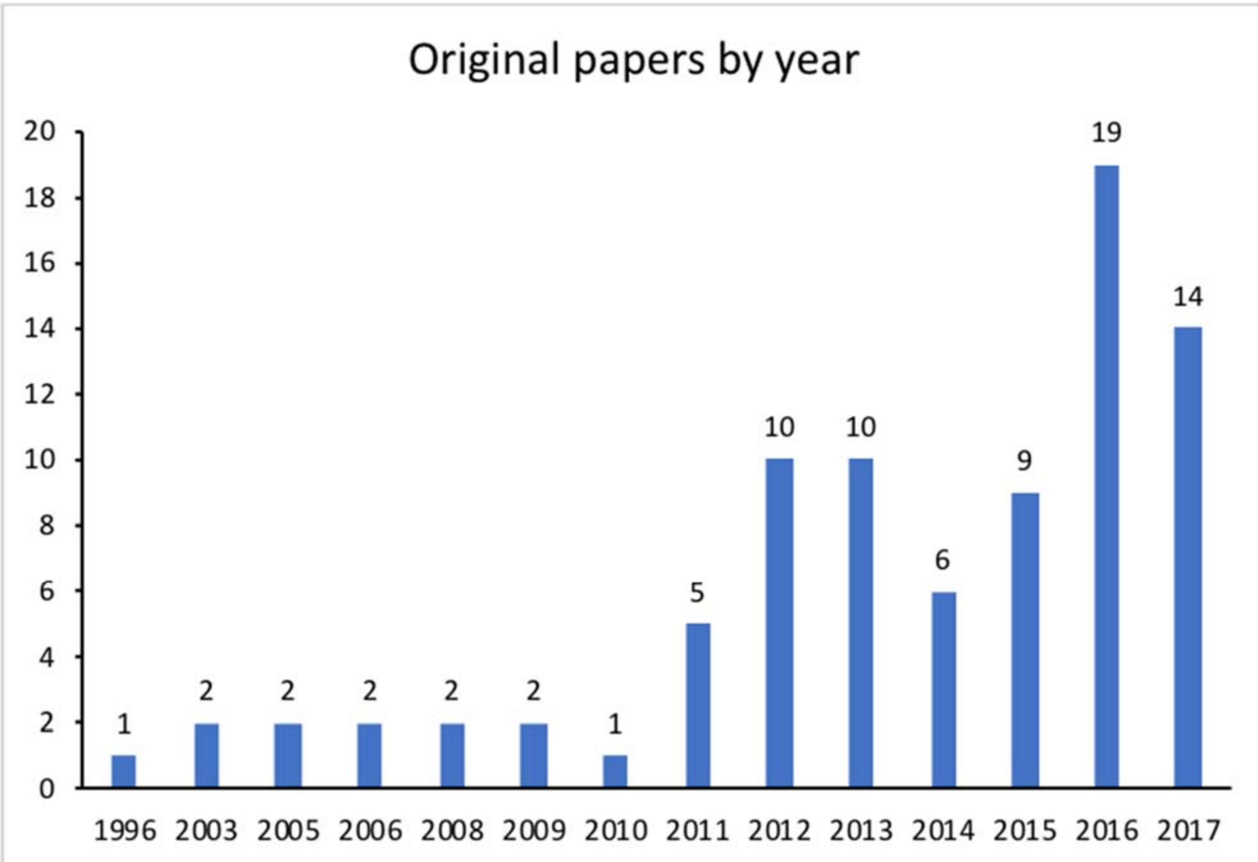
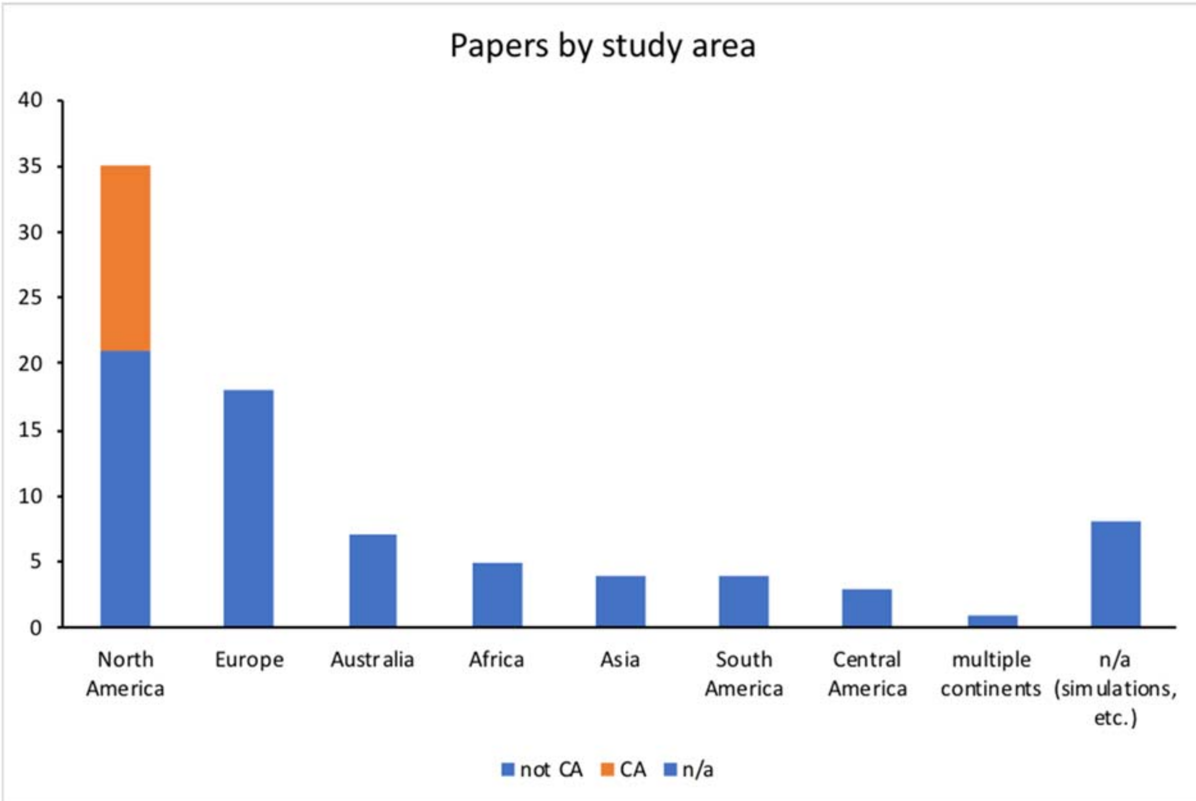
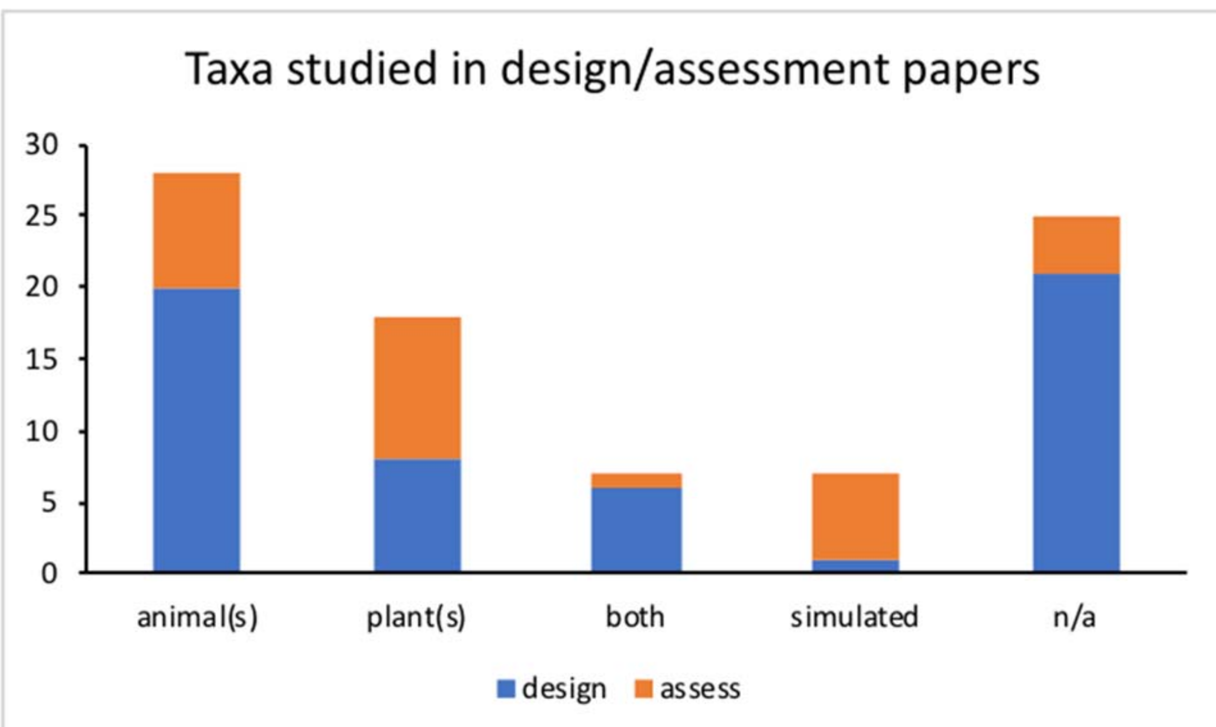
APPENDIX E: Graphs Summarizing the Reviewed Papers




Papers by study area
40
35
30
25
20
15
10
5
0
North America
Europe
Australia
Africa
Asia
South America
Central America
multiple continents
n/a (simulations, etc.)
not CA
CA
n/a


Taxa studied in design/assessment papers
30
25
20
15
10
5
0
animal(s)
plant(s)
both
simulated
n/a
design
assess

APPENDIX F: Literature search strategy and results.

We searched the peer-reviewed literature search using the data bases Web of Science and Scopus using 3 sets of search terms: (1) implement* AND (connectivity OR linkage OR corridor OR “stepping stone”) AND wildlife; (2) implement* AND lessons AND (connectivity OR linkage OR corridor OR “stepping stone” OR greenway OR “green infrastructure” OR “ecological network”) AND (conservation OR ecology); and (3) implement* AND “case study” AND (connectivity OR linkage OR corridor OR “stepping stone” OR greenway OR “green infrastructure” OR “ecological network”) AND (conservation OR ecology) (5/12/2017). For the 3 searches combined, Web of Science and Scopus yielded 268 and 364 references, respectively.

Because we expected to find valuable information in the grey literature in form of reports, we also conducted a Google search. We entered 3 search terms: (1) wildlife (corridor OR linkage OR paths) implementation report challenges (April 19, 2017); (2) wildlife (corridor OR linkage OR paths) implementation report lessons learned (April 19, 2017); (3) implementing ecological networks lessons learned (May 16, 2017). We scanned the first 100 results of each search.

To identify relevant material, in the first step we filtered all references based on titles and abstracts, or website description and content, respectively. In the second step, we performed full text filtering to remove references that may have appeared relevant from the abstract but upon closer inspection do not meet the inclusion criteria. We included papers, reports, or similar documents that included information on implementing connectivity based on real-life experiences. The search yielded 24 peer-reviewed papers, 15 reports, and 5 book chapters.

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Book

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APPENDIX G: Interview Questions.

I. BACKGROUND INFORMATION ABOUT THE INTERVIEWEE

1. How would you describe your position and role within your organization?
2. What is your role with respect to connectivity conservation?
3. How many connectivity projects have you worked on in the last 5 years?

II. PROJECT DETAILS

4. Please briefly describe the project.
5. How far along are you with the project (e.g. implementation, completed)?
6. Does it address a specific conservation objective?
7. Is it designed based on the needs of a specific focal species?
8. Where does the funding for the project come from?
9. Was the project or the funding motivated by the need for climate adaptation?
10. Does it involve active restoration, crossing structure implementation or improvement, and/or land purchases? Other?
11. Is the project based on/guided by local, state or federal laws or policies? Which ones?
12. How did you engage the public?

III. INFORMATION USE

13. What types of information or data (e.g. connectivity plans, aerial images, etc.) did you use in the planning phase? Were any of them climate-related?
14. Where did you access the data?
15. Which data sources do you wish you had had?
16. If existing connectivity plans were not useful, please explain why not.
17. Do you collaborate and/or communicate regularly with researchers about the project?

IV. CHALLENGES

18. What helped the project move forward?
19. What are the key challenges you have encountered?
20. Were you able to overcome those challenges? If so, how?
21. Can you name three things that would make it easier to implement the project?

V. CONCLUSION

22. Is there any additional information or data that you feel may be helpful to us in understanding better ways to support and enhance habitat connectivity on the ground?

APPENDIX H: Interview Quotes Illustrating the Components of the Connectivity Conservation Framework.

Reasons for success	"There were a small number of strong advocates in the right agencies and the right places to support the project."
	"We have a very strong leader in our organization."
	"We are being successful because we have really good staff."
	"She has been doing outreach to not just the environmental community but also to the city planning department and the mayor's office as well as the business community and developers."
	"If you can leave your Latin behind and talk to people about issues in plainer or more poetic language. We have to talk about creeks and birds and frogs and deer and our friend the beaver."
Opportunities	"We are to the point where something could be made as an example in California. […] this bigger effort to connect El Centro, California with Redding: continuous connectivity in CA, the most populous state in the union. I think this would be a really great headline/conservation effort that would be well received by a lot of folks."
	"The linkage is really a multi-benefit project."
	There were a small number of strong advocates in the right agencies and the right places to support the project.
	"When people are willing to work together then the partnership can be better than the sum of the parts."
	"Engaging with agencies that don't have wildlife corridors as the primary mission, but maybe they are more invested in another aspect such as groundwater recharge or public recreation."
	"It would be nice if there were some support from the counties for these efforts, so that they would incorporate wildlife linkage and corridor protection layers in their general plan."
	"There is a huge public interest to protecting wildlife. People love animals!"

"A well thought-out public relations plan to get the word out would have accelerated the project."

"If there was a funding source just for connectivity then obviously that would help."

"We need to have people in the conversation that have different perspectives and viewpoints."

Challenges

"Tons of thought have gone into it, but not a single penny has been spent on fencing or improvement to the underpass. But we have a plan!"

"The major problem that is going to be faced on a state-wide level is land ownership."

"It's tough because it's a balance between prioritizing habitat and connectivity for a species and economic or energy well-being for the people - it's a hard balance."

"With a large stake holder group coming to a consensus on conservation priorities is a challenge."

"There is no real regulation out beyond CEQA, section 7, or the California ESA that require you to do a full-blown wildlife corridor assessment. And without the regulation, it's to your discretion as an agency. It's a grey area."

"From the scientific community, there is a lot of studies […] to tell us what the proper mitigation would be and what agencies need to do in order to mitigate. But a source of funding is continuing to be difficult."

"One challenge was lack of data. "

"Our landscapes are so fractured in ownership – it's really hard to get any continuity or connectivity going across landscapes, especially in critical places like valleys."

Communication

"We are aware of at least one or two conservation easement deals we did that you can trace back perhaps to the fact that somebody's kid came out to a Nature Conservancy preserve and learned about what we are doing and let their parents know and then 15 or 20 years later we end up doing a conservation transaction with that family."

	Another challenge is how to share the information […] so that other land managers can pick up on it. There is a challenge in sharing not only data but also experience and management practices. "Through our volunteer program and outreach materials we are able to involve the local community in the wildlife corridors and educate them on why wildlife needs to move and how different wildlife moves. So it is as much a community outreach project as it is a land conservation project." "Community engagement can really boost the chances of success. The social dimension is really important."
Private Landowners	"Mainly, it was people like myself going out and talking to individuals at their kitchen tables and telling them what we were trying to do. We were not forcing anybody into anything." "Really clarifying the benefits and trade-offs for individual land owners is key." "If we had money available to do cost-sharing with land owners. That would be helpful."
Climate-wise approach	"We don't get beyond the notion of existing wildlife corridors in our planning." "There are several benefits to this particular linkage and one of them, a major one, that was part of our original planning is climate adaptation. That's probably the number one key component to it. And it resonated with all the funders."
Research	"Continuing to get good applied research, research that we can apply on the ground – is a real challenge." "…when you are developing a recovery strategy for an already listed species you want to think about what level of connectivity is required for a viable population." "Some of our common species we had to drop from our focal species list because we did not have enough data points to run models on."

	"Because we had done our homework we were able to say: we have the data, we have expert input, we have the plans, we have been thinking about the climate change dimension. […] We had that data in hand to say this looks like a high chance of success." "It would have been great if we had had a history of really good monitoring of animal movements. […] For other animals of conservation concern we have literally no clue."
Monitoring	"We encouraged them to do a monitoring study so that they could show the public that yes indeed [the crossing structures] were going to get used. […]. They have now gone from being sceptics to being advocates." "The other information that could have been helpful is […] a monitoring project […] but we were unable to locate funding to do this after project completed which was really really too bad. […] It would have been information that we would have been able to use for future projects."

APPENDIX I: Summary of Information on Ecological Objects, Data Used for Corridor Planning, and Implementation Actions Obtained from Interviews.

Project name	Interviewee's agency or organization affiliation	Primary ecological objective	Secondary ecological objective	Data used for corridor planning	Implementation action (with partners)
Berryessa Snow Mountain National Monument	federal agency	landscape linkage	climate resilience	n/a	habitat management, research, monitoring, public engagement
Desert Renewable Energy Conservation Plan	federal agency	mitigation	climate resilience	current and future species distribution models, climate models, current vegetation map, predicted shifts in vegetation	land status designations, zoning, management guidelines, land purchases, habitat restoration
North Coast Sea Level Rise Project	federal agency	climate resilience	endangered species	sea level rise models, known and predicted species occurrences, wildlife habitat models	land acquisition, habitat restoration, road crossing structures, monitoring
San Joaquin Valley BLM lands	federal agency	mitigation	endangered species	species occurrence records, species information, soil surveys	land acquisition, land swabs, wildlife and botanical research, habitat restoration, habitat management, public engagement
Santa Barbara County Tiger Salamander project	federal agency	endangered species	none	landcover maps, species occurrence data, climate change literature, landscape genetics work	habitat restoration, road crossing structures

Santa Barbara County Spine Flower project	federal agency	endangered species	none	landcover maps, species occurrence data, climate change literature, landscape genetics work	habitat restoration, road crossing structures
Caltrans projects in general	state agency	transportation	endangered species	telemetry data, camera trap data, roadkill data, connectivity models	road crossing structures, research, monitoring
Highway 50 in El Dorado County	state agency	transportation	none	roadkill data, animal migration information	road crossing structures
High Speed Rail: Bakersfield – Palmdale	state agency	transportation	none	n/a	road crossing structures
Hwy 17 in Santa Cruz County	state agency	transportation	mitigation	telemetry data, roadkill data, connectivity models	land acquisition, road crossing structure, public engagement
Sierra Foothills connectivity project	state agency	transportation	landscape linkage	land cover maps, habitat suitability models, connectivity models	road crossing structures, land acquisition, habitat restoration, public engagement
Coyote Valley, Santa Clara County	state authority	landscape linkage	climate resilience	telemetry data, genetic data, connectivity models	land acquisition, habitat restoration, road crossing structures, public engagement
Fisher Creek, Santa Clara County	regional agency	transportation	landscape linkage	connectivity model, site visits	habitat restoration, road crossing structures, monitoring
South Jacoby Creek, Humboldt County	city	landscape linkage	endangered species	hydrological modeling, GIS work	habitat restoration, monitoring, public engagement
Cosumnes River, Sacramento County	NGO	landscape linkage	climate resilience	land ownership information, expert knowledge, hydrological information, historical land use and land cover maps	land acquisition, restoration, public engagement

Lassen Valley to National Park, Lassen County	NGO	landscape linkage	climate resilience	n/a	land acquisition, easements, restoration, road crossing structures
Morongo Basin, Mojave County	NGO	landscape linkage	climate resilience	n/a	land acquisition, habitat restoration, habitat management, public engagement
Napa County	NGO	landscape linkage	climate resilience	telemetry data, land cover maps, climate models, climate-wise connectivity models	habitat restoration, land acquisition, easements, habitat management, highway crossing structures, public engagement
Pajaro River	NGO	landscape linkage	climate resilience	n/a	habitat restoration, land purchases, easements, road crossing structures, monitoring, public engagement
San Diego County	NGO	landscape linkage	climate resilience	telemetry data, land cover maps, connectivity models	land acquisition, zoning, road crossing structures
Santa Ana to Palomar Mountains	NGO	landscape linkage	climate resilience	telemetry data, land cover maps, connectivity models	land acquisition, zoning, road crossing structures
Sonoma County	NGO	landscape linkage	climate resilience	connectivity models, camera trap data, climate models, land cover maps, climate-wise connectivity models	land acquisition, habitat management, monitoring, outreach and education
Tehachapi linkage	NGO	landscape linkage	climate resilience	focal species habitat suitability models, land cover maps, connectivity models, property ownership, property sizes, roads, crossings	land acquisition, road crossing structures

APPENDIX J: Policies and Regulations Concerning Wildlife Connectivity in California

This appendix includes all the policies and regulations listed in Table 3.1. It provides information on the enacting and implementing bodies, the year of enactment, and the main purpose of the bill. Passages relevant to connectivity are quoted, and a short explanation of how the bill relates to connectivity conservation is provided.

Federal Policies

SAFETEA-LU (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users)

- Level of government – Federal
- Enacted by – U.S. Congress
- Year – 2005-2009
- Implemented by – Federal Highway Administration

SAFETEA-LU was a 2005 bill that funded and authorized federal transportation spending. Among the large number of provisions was Section 6001 which reads in part:

> "(b) PURPOSE.—Through the program under this section, the Secretary shall facilitate the planning, development, and implementation of strategies to integrate transportation, community, and system preservation plans and practices that address one or more of the following: … (2) Reduce the impacts of transportation on the environment."

This general provision led to, among other things, the development of the Integrated Ecosystem Framework (IEF; 2006). IEF enabled transportation agencies to develop conservation strategies around the country.

In California, one result of SAFETEA-LU and IEF was the California Essential Habitat Connectivity project (CEHC; Spencer et al. 2010), a multi-agency modeling effort designed to identify the most important wildlife linkages statewide. Because of its origins with federal transportation funding, a main purpose of CEHC was to provide Caltrans with information to enable prioritization of actions to decrease road impacts on wildlife and increase permeability of California's road network to wildlife movement. The spatial scale of the analysis is relatively coarse, so CEHC does not readily support implementable conservation actions. It does, however, serve as a statewide framework within which to do site-level modeling at the project scale.

MAP-21 (Moving Ahead for Progress in the 21st Century Act)

- Level of government – Federal
- Enacted by – U.S. Congress
- Year – 2012-present
- Implemented by – Federal Highway Administration

MAP-21 was the successor to SAFETEA-LU, passing in 2012. It also funded and authorized federal transportation spending. Some of its provisions include:

> "'(ii) reduce vehicle-caused wildlife mortality or to restore and maintain connectivity among terrestrial or aquatic habitats.''
>
> '''(iv) environmental mitigation in or adjacent to Federal land open to the public— (I) to improve public safety and reduce vehicle caused wildlife mortality while maintaining habitat connectivity; and ''(II) to mitigate the damage to wildlife, aquatic organism passage, habitat, and ecosystem connectivity, including the costs of constructing, maintaining, replacing, or removing culverts and bridges, as appropriate"
>
> ''(a) USE OF FUNDS.— ''(1) IN GENERAL.—Funds made available under the Federal lands access program shall be used by the Secretary of Transportation and the Secretary of the appropriate Federal land management agency to pay the cost of— ''(A) transportation planning, research, engineering, preventive maintenance, rehabilitation, restoration, construction, and reconstruction of Federal lands access transportation facilities located on or adjacent to, or that provide access to, Federal land, and— ''(i) adjacent vehicular parking areas; ''(ii) acquisition of necessary scenic easements and scenic or historic sites; ''(iii) provisions for pedestrians and bicycles; ''(iv) environmental mitigation in or adjacent to Federal land to improve public safety and reduce vehicle-caused wildlife mortality while maintaining habitat connectivity;"

This bill allows the use of federal transportation funds for connectivity enhancement projects. Some of this funding runs through the Federal Lands Transportation Program (FLTP), which includes yearly funding allocations for federal land management agencies. These agencies can use this funding on connectivity-focused projects.

Department of Interior (DOI) Manual, Chapter 523 DM 1

- Level of government – Federal
- Enacted by – Department of the Interior
- Year – 2012
- Implemented by – Department of the Interior

This chapter from the Departmental Manual establishes policy and guidelines for the Department of the Interior and associated bureaus. When assessing proposed projects, the chapter calls for avoidance of ecologically important features such as wildlife corridors. For example:

> “[f]ocus development activities in ecologically disturbed areas when possible, and avoid ecologically sensitive landscapes, culturally sensitive areas, and crucial wildlife corridors.”

This policy directive allows USFWS and other DOI entities to regulate impacts to wildlife connectivity. These regulations will occur during the environmental assessment process of proposed projects.

National Fish, Wildlife and Plants Climate Adaptation Strategy

- Level of government – Federal
- Enacted by – U.S. Fish and Wildlife Service
- Year – 2013
- Implemented by – U.S. Fish and Wildlife Service

This strategy was created by an inter-governmental working group. It is meant to provide policy at the federal level for conservation of species under the threat posed by climate change. Several relevant sections are:

> Strategy 1.4 recommends we “[c]onserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.”
>
> Strategy 1.4.6 urges “[p]rovid[ing] landowners and stakeholder groups with incentives for conservation and restoration of key corridor habitats through conservation programs such as those under the conservation title of the Farm Bill and landowner tools under the ESA as well as other mechanisms...”
>
> “[t]hrough the development of a comprehensive mitigation strategy, we can ensure that our national wildlife refuges, national parks, and other Federal lands and waters are managed for conservation purposes with sound stewardship and a commitment to conserve habitat and fish and wildlife migration corridors.”

This strategy includes a landscape connectivity approach to climate change adaptation. Examples of strategy implementation include the development of the Central Appalachian Landscape Essential Forests and Key Connectors plan and the National Fish Passage Program that has increased aquatic connectivity in California and elsewhere (National Fish, Wildlife and Plants Climate Adaptation Joint Implementation Working Group 2014).

Department of Interior (DOI) Manual 600 DM 6

- Level of government – Federal

- Enacted by – Department of the Interior
- Year – 2015
- Implemented by – Department of the Interior

This addition to the DOI manual established new mitigation policy, with a focus on taking climate change into consideration. It also has language regarding the conservation of existing wildlife migration corridors:

> "Focusing development activities in ecologically disturbed areas when possible, and avoiding ecologically sensitive landscapes, culturally sensitive areas, sensitive viewsheds, and crucial wildlife corridors."

This policy is not a formal rule so it could be changed or withdrawn by subsequent administrations.

State Policies

CEQA (California Environmental Quality Act)

- Level of government – State
- Enacted by – California Legislature
- Year – 1970, 2012
- Implemented by – California Department of Fish and Wildlife

CEQA is the state equivalent to NEPA, a law intended to address environmental impacts from proposed projects. Among the many regulations associated with CEQA, conservation of wildlife corridors is explicitly referenced in Environmental Checklist Appendix G:

> "d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?"

This checklist is used by CDFW to ensure that potential impacts to wildlife corridors are identified and appropriate mitigation measures are enacted to prevent, reduce, or offset the impacts.

NCCP (Natural Community Conservation Planning Act)

- Level of government – State
- Enacted by – California Legislature
- Year – 1991, 2003, 2011, 2012
- Implemented by – California Department of Fish and Wildlife

NCCPs are the California equivalent to federal Habitat Conservation Plans. These are regional plans that address the expected required mitigation needs for multiple listed species in advance of the impacts. These plans usually include spatially-explicit reserve designs that often incorporate linkages. Selected sections of the Act include:

> "Establishing one or more reserves or other measures that provide equivalent conservation of covered species within the plan area and linkages between them and adjacent habitat areas outside of the plan area."
>
> "Incorporating a range of environmental gradients (such as slope, elevation, aspect, and coastal or inland characteristics) and high habitat diversity to provide for shifting species distributions due to changed circumstances."
>
> "Sustaining the effective movement and interchange of organisms between habitat areas in a manner that maintains the ecological integrity of the habitat areas within the plan area."

One example of an NCCP that explicitly incorporates wildlife linkages is the County of Orange (Central/Coastal) NCCP/HCP. Two of the reserve habitat categories are:

- Habitat linkage: areas of natural habitat with coastal sage scrub and other habitats that are especially important as linkages.
- Special linkages: an area where proposed land uses are potentially compatible with connectivity functions.

These categories enable funds to be spent on preservation and enhancement of wildlife corridors in order to offset expected impacts associated with future developments within the plan area.

As of August 2015, 23 NCCPs had been completed or were in progress.

General Plan Guidelines

- Level of government – State
- Enacted by – Office of Planning and Research
- Year – 2003
- Implemented by – Cities and counties

The General Plan Guidelines (Governor's Office of Planning and Research 2003) provide the framework for local governments to use in the development of their general plans. The Guidelines call for the inclusion of a number of mandatory elements that must be included in any general plan, as well as a number of optional elements. One of the required elements is the Conservation Element. "Wildlife" is one specific issue that must be addressed in this element. The Guidelines provide ideas with which to assess the issues, one of which for Wildlife is:

> "Analyze the potential for development patterns to fragment plant and animal habitat."

While no explicit mention is made in the Guidelines of wildlife connectivity, a number of local governments have included connectivity and corridors in their plans. Some of these governments include (information provided by the Nature Conservancy):

- Castro Valley (Alameda County)
- Fresno County
- Marin County
- Mendocino County
- Mono County
- Nevada County
- Placer County
- San Diego County
- Sacramento County
- San Bernardino County
- Tehama County
- City of San Luis Obispo
- Town of Woodside
- City of Arcata
- City of Santa Cruz

California State Wildlife Action Plan (SWAP)

- Level of government – State
- Enacted by – California Department of Fish and Wildlife
- Year – Updated 2015
- Implemented by – California Department of Fish and Wildlife

The California State Wildlife Action Plan was updated in 2015. This document was created by CDFW in order to establish the state's conservation priorities. One of the goals in the current SWAP is the conservation and enhancement of wildlife connectivity in the state:

> *Goal 2.1 (Connectivity):* Maintain and improve connectivity vital for sustaining ecosystems (including those relevant to vegetation, wildlife corridors, genetic permeability, water flow, floodplains [longitudinal and lateral], and groundwater.)

Conservation strategies for many of the regional plan components call explicitly for conservation of connectivity in natural ecosystems. There is also extensive detail given to conservation of aquatic connectivity, especially for anadromous fish species. These goals and strategies will help guide CDFW actions for the coming decade.

A companion document, the Transportation Planning Companion Plan, provides guidance to transportation agencies on how to bring the goals and strategies developed in SWAP into early stages of infrastructure project planning. One of the guidelines is:

> "Identify high priority wildlife corridors, design wildlife crossing/passage structures, and incorporate their implementation into transportation projects."

If this guideline is followed by the agencies, implementation of infrastructure projects could provide a benefit to the conservation and enhancement of wildlife connectivity.

AB 2785

- Level of government – State
- Enacted by – California Legislature
- Year – 2008
- Implemented by – California Department of Fish and Wildlife, Caltrans

This California state bill directed CDFW to compile a database of the most critical wildlife corridors and linkages in the state, and to make them available to agencies and the public. The bill was sponsored by Assemblyman Ira Ruskin. Portions of it read:

> "Contingent upon funding being provided by the Wildlife Conservation Board from moneys available pursuant to Section 75055 of the Public Resources Code, or from other appropriate bond funds, upon appropriation by the Legislature, the department shall investigate, study, and identify those areas in the state that are most essential as wildlife corridors and habitat linkages, as well as the impacts to those corridors from climate change, and shall prioritize vegetative data development in these areas."
>
> "It is the intent of the Legislature that the Wildlife Conservation Board use various funds to work with the department to complete a statewide analysis of corridors and connectivity to support conservation planning and climate change adaptation activities."
>
> "Develop and maintain a spatial data system that identifies those areas in the state that are most essential for maintaining habitat connectivity, including wildlife corridors and habitat linkages. This data should include information essential for evaluating the needs of wildlife species, as defined in Section 711.2, that require habitat connectivity for their long-term conservation, including distribution and movement patterns."

There were no funds appropriated as part of this bill. Development of the database in contingent on funding from the Wildlife Conservation Board.

AB 498

- Level of government – State
- Enacted by – California Legislature
- Year – 2015
- Implemented by – Wildlife Conservation Board, California Department of Fish and Wildlife

AB 498 was authored by Assemblyman Marc Levine. It is meant to enable the conservation of wildlife corridors by California state agencies and to make it state policy to do so. It reads in part:

“This bill would declare that it is the policy of the state to encourage, wherever feasible and practicable, voluntary steps to protect the functioning of wildlife corridors through various means, as applicable.”

“This bill would include within the authorized purposes of a conservation bank the protection of habitat connectivity for fish and wildlife resources.”

“This bill would provide that the fact that a project applicant does not take voluntary steps to protect the functioning of a wildlife corridor prior to initiating the application process for the project shall not be grounds for denying a permit or requiring additional mitigation beyond what is otherwise required by law to mitigate project impacts.”

“Contingent upon funding being provided by the Wildlife Conservation Board from moneys available pursuant to Section 75055 of the Public Resources Code, or from other appropriate bond funds, upon appropriation by the Legislature, the department shall investigate, study, and identify those areas in the state that are most essential as wildlife corridors and habitat linkages, as well as the impacts to those wildlife corridors from climate change, and shall prioritize vegetative data development in these areas.”

“It is the intent of the Legislature that the Wildlife Conservation Board use various funds to work with the department to complete a statewide analysis of wildlife corridors and connectivity to support conservation planning and climate change adaptation activities.”

“It is the policy of the state to promote the voluntary protection of wildlife corridors and habitat strongholds in order to enhance the resiliency of wildlife and their habitats to climate change, protect biodiversity, and allow for the migration and movement of species by providing connectivity between habitat lands. In order to further these goals, it is the policy of the state to encourage, wherever feasible and practicable, voluntary steps to protect the functioning of wildlife corridors through various means, as applicable and to the extent feasible and practicable, those means may include, but are not limited to:
(A) Acquisition or protection of wildlife corridors as open space through conservation easements.
(B) Installing of wildlife-friendly or directional fencing.
(C) Siting of mitigation and conservation banks in areas that provide habitat connectivity for affected fish and wildlife resources.
(D) Provision of roadway undercrossings, overpasses, oversized culverts, or bridges to allow for fish passage and the movement of wildlife between habitat areas.”

“The fact that a project applicant does not take voluntary steps to protect the functioning of a wildlife corridor prior to initiating the application process for a project shall not be grounds for denying a permit or requiring additional mitigation

> beyond what would be required to mitigate project impacts under other applicable laws, including, but not limited to, the California Endangered Species Act (Chapter 1.5 (commencing with Section 2050) of Division 3) and the California Environmental Quality Act (Division 13 (commencing with Section 21000) of the Public Resources Code)."

While AB 498 is an advisory measure only, it does provide a policy basis for conservation of wildlife corridors where and when funding allows.

AB 2087

- Level of government – State
- Enacted by – California Legislature
- Year – 2016
- Implemented by – California Department of Fish and Wildlife
- Detail

Assemblyman Marc Levine authored this bill which was passed by the Legislature and signed into law in 2016. AB 2087 creates a framework from which the state can develop integrated regional conservation plans for use in mitigation and other conservation efforts. The bill calls for inclusion of wildlife connectivity as one ecological input in development of these plans. Portions of the text read:

> "In enacting this chapter, it is the intent of the Legislature to promote science-based conservation, including actions to promote resiliency to the impacts of climate change and other stressors. It is further the intent of the Legislature to create nonregulatory mechanisms to guide investments in conservation, infrastructure, and compensatory mitigation for impacts to natural resources, including impacts to threatened and endangered species, other sensitive species, natural communities, ecological processes, and connectivity."

> "The purpose of a regional conservation investment strategy shall be to inform science-based nonbinding and voluntary conservation actions and habitat enhancement actions that would advance the conservation of focal species, including the ecological processes, natural communities, and habitat connectivity upon which those focal species depend, and to provide nonbinding voluntary guidance for one or more of the following:"

> "A regional conservation investment strategy shall include all of the following: … Important resource conservation elements within the strategy area, including, but not limited to, important ecological resources and processes, natural communities, habitat, habitat connectivity, and existing protected areas, and an explanation of the criteria, data, and methods used to identify those important conservation elements."

> "Identify and summarize relevant regional pressures and stressors, including climate change vulnerability, conservation areas and habitat connectivity values, included in all of the following: … Analyses designed to identify areas for habitat connectivity."

There are currently four pilot projects underway to develop Regional Conservation Investment Strategies (RCIS) as test cases of the new policy. The locations of the pilots are: Santa Clara County, Alameda/Contra Costa County, Yolo Bypass, and Antelope Valley.

State funding for RCIS development is not needed because they will be developed in support of regional mitigation needs. As such, funding will be provided by project developers (e.g. infrastructure agencies).

California Transportation Plan 2040

- Level of government – State
- Enacted by – California State Transportation Agency
- Year – 2016
- Implemented by – Caltrans

The California Transportation Plan 2040 (CTP2040) includes a number of goals for transportation planning in California over the coming decades. One of the six major goals focuses on the environmental impacts associated with ground transportation projects. Goal 6 ("Practice Environmental Stewardship") includes four policies within it. Policy 1 is:

> "Integrate environmental considerations in all stages of planning and implementation"

Policy 2 is:

> "Conserve and enhance natural, agricultural, and cultural resources"

This goal coincides with Goal 6 ("Environmental sustainability") of the national MAP-21 legislation. CTP2040 refers back to the State Wildlife Action Plan for guidance on addressing environmental resources and includes a reference to supporting wildlife corridors in the transportation planning process.

Standard Environmental Reference

- Level of government – State
- Enacted by – Caltrans
- Year – 2007-2017
- Implemented by – Caltrans

The Standard Environmental Reference (SER) is used by Caltrans is an online document developed for state and local agency staff to use in their environmental assessment of transportation projects. Among the topics addressed in SER is wildlife corridors. Habitat connectivity and corridors are explicitly referenced in section 2-3.3 (“Biological Conditions in the Biological Study Area”). They are also mentioned in section 2-5.1 (“Habitats and Natural Communities of Special Concern”).

This document is meant to ensure that corridors are explicitly addressed as important biological features in any environmental assessment for transportation projects in California.

California Proposition 117/Habitat Conservation Fund (California Wildlife Protection Act)

- Level of government – State
- Enacted by – Voters
- Year – 1990
- Implemented by – Office of Grants and Local Services
- Detail

Proposition 117 was passed by California voters in 1990. This is one of the earliest state policies to explicitly call for protection of wildlife corridors. An introductory section of text reads:

> “Small and often isolated wildlife populations are forced to depend upon these shrinking habitat areas within the heavily urbanizing areas of this state. Corridors of natural habitat must be preserved to maintain the genetic integrity of California's wildlife.”

Implementation of wildlife protection through this Proposition is accomplished through the creation of the Habitat Conservation Fund. This Fund has a yearly allocation of $30 million. A $2 million portion of this is dedicated to conservation of wildlife corridors and urban trails. The Office of Grants and Local Services (OGALS) administers the grant program which allocates the money to cities, counties, and districts. This program requires a 50% match from grantees. Eligible projects include: nature interpretation programs to bring urban residents into park and wildlife areas, protection of various plant and animal species, and acquisition and development of wildlife corridors and trails. Priority is given to important corridor areas:

> “In areas where habitats are or may become isolated or fragmented. preference shall be given by the agencies expending money from the fund to projects which will serve as corridors linking otherwise separated habitat so that the genetic integrity of wildlife populations will be maintained.”

The Fund runs until July 1, 2020.

Local Policies

MSCP (San Diego Multiple Species Conservation Program)

- Level of government – City/County

- Enacted by – San Diego City and County
- Year – 1998
- Implemented by – San Diego City and County

The City and County of San Diego entered into an implementing agreement with state and federal wildlife agencies in 1998 on a plan to protect species and ecosystems and provide for mitigation for impacts as a result of development projects. The MSCP calls for the creation of a reserve network that includes spatially explicit and delineated corridors that will link core resource areas. Several relevant passages from the plan include:

> "The Multi-Habitat Planning Area delineates core biological resource areas and corridors targeted for conservation."
>
> "In addition to the high percentage of sensitive habitats and species included within the ERA, the final ERA design will provide a high degree of connectivity between reserved habitats…"

Acquisitions for MSCP have been occurring for the past several decades, some of which are for the purposes of wildlife connectivity.

East Contra Costa County HCP/NCCP

- Level of government – City/County
- Enacted by – Contra Costa County (and others)
- Year – 2007
- Implemented by – Contra Costa County (and others)

The East Contra Costa HCP/NCCP was enacted in 2007 and covers roughly 175,000 acres in the eastern portion of the county. The plan calls for the protection of 23,800-30,300 acres of land for multiple species. Signatories include Contra Costa County, several cities, and other organizations along with state and federal wildlife agencies.

> "Linkages were also considered so that habitat connectivity goals and objectives could be met."
>
> "These specialized habitat and linkage requirements and the goal to contribute substantially to the species' recovery in the inventory area were considered in the overall design of the Preserve System."
>
> "For example, habitat linkages will be acquired and protected to ensure that kit foxes can continue to move…"
>
> "New linkages will be created suitable for dispersal and colonization throughout the Preserve System and to existing parks and open space (Conservation Measure 1.1)."

Through the end of 2016, a total of 13,212 acres had been acquired, consisting of 32 properties. It is not clear how many of these properties are thought to be contributing to wildlife connectivity.

CVMSHCP (Coachella Valley Multiple Species Habitat Conservation Plan)

- Level of government – City/County
- Enacted by – Riverside County (and others)
- Year – 2008
- Implemented by – Riverside County (and others)

The CVMSHCP is an NNCP enacted in 2008 in a portion of Riverside County. Signatories include the county, a number of cities, Coachella Valley Water District, Imperial Irrigation District, Coachella Valley Association of Governments (CVAG), and Caltrans as well as state and federal wildlife agencies. Wildlife connectivity components of the plan include:

> "For each Conservation Area, Conservation Objectives are articulated for conserving Core Habitat for Covered Species, Essential Ecological Processes necessary to maintain Habitat viability, Biological Corridors and Linkages as needed, and the less common conserved natural communities."
>
> "The Plan includes certain requirements for Covered Activities in the Conservation Areas to avoid, minimize, and mitigate impacts to … Biological Corridors…"
>
> "Maintain Biological Corridors and Linkages among Core Habitat areas to sustain the effective movement and interchange of organisms between habitat areas inside and outside the Plan Area to the Maximum Extent Feasible."

The plan calls for 240,000 acres of conservation land, approximately 80,000 acres of which has been acquired to date.

Measure M2 (OCTA M2 NCCP/HCP)

- Level of government – County
- Enacted by – Orange County
- Year – 2010
- Implemented by – Orange County Transportation Authority

Tax Measure M2 was passed by Orange County voters in 2010. A sales tax was established to support the Orange County Transportation Authority's transportation program. Part of the funding provided by the tax goes towards advance mitigation of projected transportation project impacts as described in the OCTA M2 NCCP/HCP. The plan calls for, among other things, conservation of landscape connectivity within the plan area. Some of the plan's goals and objectives are:

"Landscape Goal 2: Protect and enhance natural and semi-natural landscapes important to maintain wildlife movement within the Plan Area."

"Landscape Objective 2.1: OCTA will acquire, protect, and manage natural landscapes that help to secure wildlife movement corridors and provide landscape connectivity."

"Landscape Objective 2.2: OCTA will restore or enhance habitat through restoration projects that improve habitat connectivity and wildlife movement through existing protected lands."

"Landscape Objective 2.3: OCTA will set forth policies and procedures requiring the planning and execution of covered freeway improvement projects in a manner that maintains and, if feasible, enhances wildlife connectivity through existing structures. OCTA will provide monitoring, when and where appropriate, to demonstrate this objective has been met. "

"Landscape Goal 3: OCTA will protect, enhance, and/or restore natural landscapes within a range of environmental gradients and contiguous to other protected areas to allow for shifting species distributions in response to catastrophic events (e.g., fire, prolonged drought) or changed circumstances (e.g., climate change)."

"Landscape Objective 3.1: OCTA will acquire and/or restore natural landscapes within elevation ranges (0–500; 500–1,000; 1,000–1,500; 1,500–2,000 feet). The conservation and restoration of Covered Species habitat in or contiguous with existing Preserve lands will benefit potential shifting species distributions in response to catastrophic events and changed circumstances."

"Landscape Goal 4: Protect and enhance habitat in geographically distinct areas across the Plan Area to conserve species by facilitating/promoting genetic exchange."

"Landscape Objective 4.1: OCTA will acquire and/or restore natural landscapes within most of the major watersheds (HUC8) and a majority of the core and linkage areas that are contributing to genetic exchange within these areas."

This plan is providing funding for connectivity conservation for current wildlife populations, for future climate change adaptation, and for genetic diversity. This plan was recently adopted, and to date 1,100 acres have been preserved.

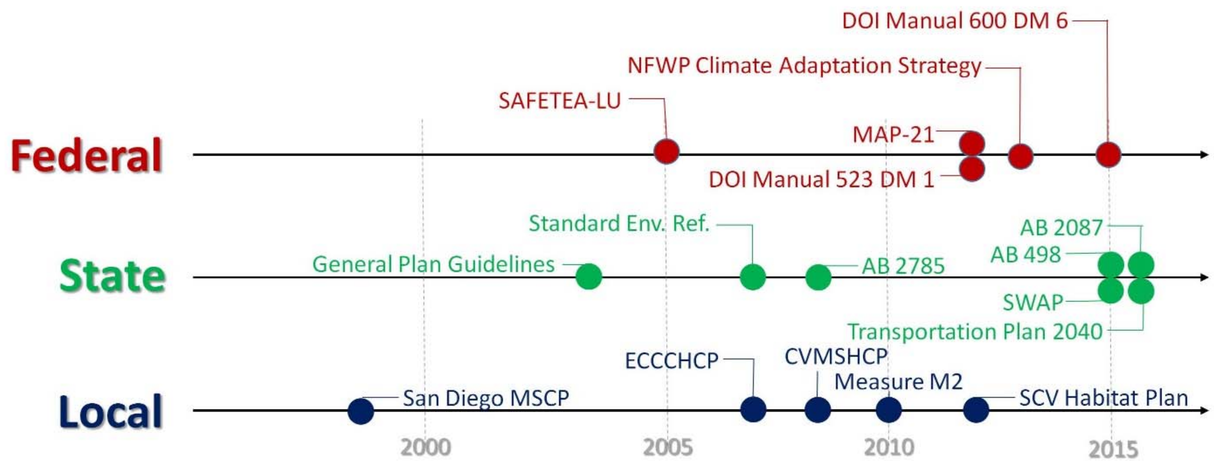
SCV Habitat Plan (Santa Clara Valley Habitat Plan)

- Level of government – County
- Enacted by – Santa Clara County (and others)
- Year – 2012
- Implemented by – Santa Clara County (and others)

The SCV Habitat Plan was enacted in 2012. There were six signatories to the plan: Santa Clara County, Santa Clara Valley Water District, Santa Clara Valley Transportation Authority, and the cities of Gilroy, Morgan Hill, and San Jose. The regulatory agencies that are participating are CDFW and USFWS. The plan calls for 46,496-46,920 of newly acquired acres in all, plus 13,291 acres of existing open space to be incorporated into the reserve system. Acquisition areas can be targeted for conservation of wildlife connectivity, with portions of the plan reading:

> “Linkages were also considered so that habitat connectivity goals and objectives could be met.”
>
> “The Reserve System will link existing protected areas and proposed reserves inside and outside the study area to maximize habitat connectivity.”

The first property to be enrolled in the reserve system is the Coyote Ridge Open Space Preserve, totaling 1,803 acres. The site contributes to two identified wildlife linkages, those between Coyote Ridge and higher elevation areas and Coyote ridge and Coyote Creek.



Appendix J, Figure 1. Timeline of policies enacted concerning wildlife connectivity. This timeline does not include the California Environmental Quality Act (first passed into law in 1970), California Proposition 117/Habitat Conservation Fund (1990), or Natural Communities Conservation Plan legislation (first passed in 1991) in order to enhance the clarity of the graphic. AB 2785, 498, 2087: California state bills; CVMSHCP: Coachella Valley Multiple Species Habitat Conservation Plan; DOI: Department of Interior; ECCCHCP: East Contra Costa County Habitat Conservation Plan; MAP-21: Moving Ahead for Progress in the 21st Century Act; MSCP: Multiple Species Conservation Program; NFWP: National Fish, Wildlife and Plants; SAFETEA-LU: Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users; SCV: Santa Clara Valley; SWAP: State Wildlife Action Plan.

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