A Review and Synthesis of Ecological Connectivity Assessments Relevant to the Cascade-Siskiyou Landscape in Southwest Oregon and Adjacent California

Selberg Institute LLC
1000 Benson Way #101, Ashland, OR 97520

by

Evan Frost MSc, Ecologist
Wildwood Consulting, Ashland, OR

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Cover photos: Top: Landscape view from the crest of the eastern Siskiyou Mountains east toward Pilot Rock in the Cascade-Siskiyou National Monument, by Pepper Trail. Bottom left: Roosevelt elk foraging in harm's way, northern California, by James McGillis. Bottom right: Camera trap photo of a fisher (*Peckania pennanti*), reclusive forest carnivore in the Klamath-Siskiyou Ecoregion, from California Department of Fish & Wildlife.

EXECUTIVE SUMMARY

The Cascade-Siskiyou landscape in southwest Oregon and adjacent California is widely recognized for supporting outstanding levels of biodiversity, and ecological connectivity has been frequently identified as a key attribute associated with creating and sustaining this diversity. However, to date no systematic attempt has been made to compile existing evidence demonstrating the area's connectivity values, or identify the location of specific areas that most contribute to maintaining this important ecological function across the landscape. The primary goal of this report is to synthesize all readily available, spatially-explicit evidence concerning ecological connectivity in and adjacent to a 4,500 mi^2 (~11,700 km^2) focus area, loosely centered around the Cascade-Siskiyou National Monument. A thorough search of published and unpublished literature identified 22 relevant studies from 1999-2018 that analyzed ecological connectivity in some way across all or portions of southwest Oregon and adjacent California. Short summaries are presented for each of these 22 papers, covering: 1) primary study goals, 2) geographic extent, 3) focus or overall approach to connectivity assessment, 4) essential aspects of analytical methods, and 5) map-based results relevant to the Cascade-Siskiyou focus area.

The primary goals of reviewed studies were to identify high-priority conservation areas, develop strategies for increasing resilience to climate change, and/or design potential linkage zones between existing reserves or core habitat patches for focal species. The geographic extent of assessments varied from national to ecoregional, with most (N=16) occurring at the multi-state or state level. Spatial resolution also varied considerably, with 50% (N=11) of papers reflecting a relatively "coarse-grained" analysis (i.e., minimum mapping unit > 0.5 km^2). A diversity of different modeling tools and approaches were used to assess connectivity, including modeling applications based on circuit theory, least cost path/distance, and individual, species-based distribution models. Eight (36%) of the 22 reviewed papers explicitly addressed how patterns of connectivity across the Cascade-Siskiyou landscape may be affected under climate change.

Despite the wide range of goals, approaches and analytical methods used, a high degree of agreement existed among studies regarding the most ecologically important connectivity zones in the Cascade-Siskiyou focus area. Based on a qualitative synthesis of all map-based data, six primary landscape-level linkages were identified. The two areas most frequently identified for their outstanding connectivity values are the east-west, inter-regional linkage and junction point between the eastern Siskiyou and Cascade Ranges [referred to as the "Cascade-Siskiyou land bridge"], and a north-south trending pathway that essentially follows the Southern Cascades in Oregon. The Siskiyou Crest (moving west from the land bridge / national monument), and the Southern Oregon Cascades into California -- were also frequently identified as being important linkages in this landscape.

The robust nature of these findings underscores the importance of increasing conservation efforts in these high priority linkages -- particularly in critical bottlenecks (i.e., where key movement pathways are most vulnerable), and/or where large connectivity gains can be made with targeted, strategic investment (e.g., mitigating known movement barriers such as the Interstate 5 highway). In particular, the Cascade-Siskiyou land bridge stands out as unique in that the area not only represents a critical connectivity bottleneck, but also:

- facilitates movement between otherwise disjunct ecoregions,
- has national significance for the conservation of special-status species dependent on inter-regional forest connectivity (e.g., northern spotted owl and fisher),
- is likely to be relatively resilient to climate change impacts, and
- supports high levels of both biodiversity and ecological intactness.

While significant steps have been taken to protect specific portions of this key inter-regional linkage, additional actions will be required across multiple ownerships in order to safeguard the area's outstanding ecological values. Future research should focus on site-specifically delineating the spatial extent (length/width), ecological condition and configuration of primary linkage areas broadly identified in this review, and also evaluate the potential tradeoffs between alternative approaches aimed at protecting and/or restoring connectivity in this nationally significant hotspot of biodiversity.

INTRODUCTION

Maintaining landscape connectivity -- generally defined as "*the degree to which a specific landscape facilitates or impedes movement of organisms*"(Taylor et al. 1993) -- has become a topic of rapidly growing interest in ecology and conservation over the last three decades. Connectivity is recognized as increasingly important because maintaining or restoring it partially compensates for the numerous adverse impacts associated with habitat fragmentation, helps maintain the flow of key ecological processes and, in the face of climate change, provides potential movement pathways that many species will require if they are to track suitable conditions (Cross et al. 2011). Landscape strategies that aim to maintain connectivity among habitat patches, and between protected areas over larger spatial scales, are now widely considered critical to conserve biodiversity and ecosystem function (Correa Ayram et al. 2016, Rudnick et al. 2012, Merelander 2007, Dobson et al. 1999). The term "connectivity conservation" has been adopted to describe this emerging consensus among scientists and conservation practitioners (Worboys et al. 2010, Crooks & Sanjayan 2006).

While connectivity is an essential attribute of almost all terrestrial ecosystems, some areas or even entire landscapes stand out as being exceptional in terms of their ecological connectivity functions and attributes. For example, regions in North America recognized for their outstanding connectivity values include the Tehachapi Mountains in Southern California (White & Penrod 2012, Penrod et al. 2003), several strategically-located sections of the Rocky Mountains (Jones et al. 2004, Tabor 1996), and the Cascade-Siskiyou landscape of southwest Oregon and adjacent California (this review). The last of these examples is named after and largely defined by the intersection of major mountain systems that trend both east-west (Siskiyous) and north-south (Cascades). Outside of the Cascade-Siskiyou landscape, very few if any other areas in the Pacific States functionally connect major coastal and inland mountain systems by relatively undeveloped and intact natural habitats (DellaSala 2000).

Federal biologists began to recognize the regional and even national importance of connectivity values associated with the Cascade-Siskiyou area in the early 1990's, particularly for species like the Northern Spotted Owl (*Strix occidentalis caurina*) that depend upon mature and old-growth forests (see Table 1). In 1994, the Record of Decision for the Northwest Forest Plan highlighted "*the special biological qualities of this unique area and directs the BLM to evaluate carefully the values of the Soda Mountain* [i.e., Cascade-Siskiyou] *area as a biological connectivity corridor and propose any additional management actions necessary...to protect those values*" (USDA FS/USDI BLM 1994). The Cascade-Siskiyou National Monument was established and later expanded under the Antiquities Act in part to protect connectivity as an "Object of Scientific Interest," because it was understood that this ecological function has helped to create and is essential to sustain the area's outstanding biological diversity (USDI 2000).

The national monument's 2017 proclamation recognized that "*the Cascade-Siskiyou landscape provides vital habitat connectivity*" and that "*supporting the biodiversity of the monument requires habitat connectivity corridors for species migration and dispersal*" (USDI 2017). However, no attempt has yet been made to collect the growing scientific evidence documenting the area's connectivity values, or identify the location of specific areas that most contribute to sustaining this key ecological function across the greater monument landscape. Given the increasing importance of connectivity for conserving biodiversity, there is an obvious need for a synthesis of knowledge on this topic in the Cascade-Siskiyou area, where connectivity values are known to be exceptionally high and numerous opportunities exist to better align land management with achieving connectivity goals across multiple ownerships.

GOALS, METHODS AND FOCUS AREA

The primary objective of this literature review and synthesis is to provide an overview of ecological and landscape connectivity assessments from the scientific literature that pertain to the Cascade-Siskiyou focus area. In order to develop this review, a targeted search of the literature was conducted to identify papers that analyzed connectivity in some way across all or portions of southwest Oregon and adjacent California. Although connectivity issues for aquatic species and ecosystems are an equally important topic, this review only includes studies that address the terrestrial environment. Upon review, literature resulting from the initial search was narrowed down to 22 relevant studies (see Table 2). While many appear in peer-

Table 1. Quotes from federal land management agencies regarding the importance of ecological or habitat connectivity in the greater Cascade-Siskiyou landscape, southwest Oregon and adjacent California. Original sources cited below. Bracketed words or phrases added to provide clarification only.

“***The Soda Mountain area is more than just botanically interesting; it is an important link for species migration, dispersion, and the process of evolution in the Northwest.***”

~ Tom Atzet Ph.D., former Area Ecologist for Southwest Oregon, US Forest Service (1994)

"***The Mt. Ashland Late-Successional Reserve*** [LSR] ***links the high elevation Siskiyou Range of the Klamath Physiographic Province with the Southern Oregon Cascades. This link is a critical node in the LSR network of SW Oregon and NW California. It allows flow to and from all legs and arms of the LSR network, a process important to the region as a whole.***"

~USDA Forest Service. 1996. Mt. Ashland Late-Successional Reserve Assessment, Rogue River-Siskiyou NF

“***The*** [Cascade-Siskiyou] ***area is one of the few places within the range of the Northern Spotted Owl where relatively intact forested habitat bridges the gap between the Klamath Mountains and the Interior Cascade Mountain Range, and thus provides a higher potential for east-west genetic exchange.***”

"***Because of topography, the pattern of current and potential LS/OG habitat and land ownership, the*** [Jenny Creek Late-Successional Reserve] ***area is key to wildlife connectivity across the landscape between the Southern Oregon Cascades and the Klamath Mountains of Oregon and California.***"

"***The*** [Cascade-Siskiyou] ***connectivity corridor must be protected and maintained in a condition that animals will use for movement, food, breeding and migration. Private lands in the area should be considered for acquisition, conservation easements and/or cooperative management agreements to provide dispersal habitat for uninterrupted passage by native plants and animals.***"

~USDI BLM. 1999. Jenny Creek Late-Successional Reserve Assessment, Medford District BLM. Medford, OR

“***The southern portion of the Upper Bear Creek watershed provides the only high-elevation connection between coastal and inland mountains in the western United States.***”

~Rogue Valley Council of Governments. 2001. Upper Bear Creek Watershed Analysis. Medford, OR.

“***This link*** [between the Siskiyous and Cascades] ***is a critical node in the overall migratory patterns of the Pacific Northwest. It allows flow to and from all legs and arms of the 'H',*** [the 'H' is comprised of the parallel Coast / Cascade Ranges, with the Siskiyous as connecting crossbar] ***a process important to the region as a whole for the last 60 million years...The maintenance of late-successional habitat within this area is important for maintaining species migration and dispersal.***”

"***This*** [Cascade-Siskiyou] ***area provides the single most important link connecting the Oregon Cascades to the Klamath Mountains across the Ashland/I-5 Area of Concern. By straddling the crest, this provides important east-west connectivity for the southern Oregon Cascades, and is the key link from Oregon to California south of Highway 66.***"

~ USDI FWS. 2006. Biological Opinion -- Potential Impacts to Listed Species from Proposed Forest Management Activities, FY 2006-2008. Medford District BLM. Medford, OR

"***Specifically, the Mount Ashland Late-Successional Reserve*** [LSR] ***acts as a critical east-west link in the LSR network and provides migration, travel and dispersal corridors for spotted owl, fisher, and other late successional species between the Siskiyou and Cascade Ranges.***"

~USDA Forest Service. 2008. FEIS, Ashland Forest Resiliency Project. Rogue River-Siskiyou NF. Ashland, OR

“***Habitat fragmentation and the loss of connectivity threaten the biological integrity of the Cascade-Siskiyou National Monument in the short term.***”

~ USDI BLM. 2008. Resource Management Plan, Cascade-Siskiyou National Monument. Medford District BLM. Medford, OR.

"***This*** [Cascade-Siskiyou] ***area does provide a crucial link, along with the Mt. Ashland LSR, between the Western Cascades and Klamath Provinces in the Ashland / I-5 Area of Concern. At least one spotted owl migration from west of the Applegate District to this area has been confirmed. However, forest connectivity here remains a concern.***"

~ USDI BLM. 2008. District Analysis / Biological Assessment of Forest Habitat, Medford District BLM. Medford, OR reviewed journals, ten studies currently available only as unpublished or online reports are also included because they met selection criteria and provide results relevant to our focus area.

The majority of this report is comprised of short summaries of these 22 studies, with a focus on how their findings pertain to connectivity and land use planning in the Cascade-Siskiyou focus area. Despite their common theme, each of these studies was completed with differing goals, approaches, spatial scales and analytical methods. In the following sections the studies are grouped according to spatial scale, which varies from national (contiguous U.S.), to macro-regional (multi-state), to regional (state/ecoregion), to the range of an individual focal species. Each narrative summary covers the following topics: 1) primary study goals, 2) geographic extent, 3) focus or overall approach to connectivity assessment, 4) essential aspects of analytical methods, and 5) map-based results relevant to the Cascade-Siskiyou focus area.

The greater Cascade-Siskiyou landscape is somewhat loosely defined in this report by the convergence of major mountain systems and ecoregions that occurs in southwest Oregon and adjacent California, which over evolutionary time has created an ecological mixing zone or "biological crossroads" that is unique in western North America (USDI BLM 2008, 2000). Given that any hard boundary around this landscape would be somewhat arbitrary, and in order to facilitate easy comparison of spatial results between maps, a simple rectangular focus area centered around the Cascade-Siskiyou National Monument was adopted for the purposes of conducting this review. Focus area boundaries encompass roughly 4,500 square miles (~11,700 km^2), extending east-west from the edge of the Modoc Plateau and Klamath Basin to the central Klamath-Siskiyou Mountains, and north-south from the northern end of Oregon's Rogue Valley to the Shasta and Scott Valleys in California.

Figure 1 locates the Cascade-Siskiyou focus area in relation to the boundaries of level III and IV ecoregions (from Cleland et al. 2007) and the distribution of public lands. The focus area includes portions of four major ecoregions (Klamath Mountains, Southern Cascades, Western Cascades and Modoc Plateau) and 22 ecoregion subsections. Elevations range from over 7,400' along the Siskiyou Crest to ~1,200' on the lower reaches of the Rogue and Klamath Rivers. Roughly half of lands within focus area boundaries are publicly owned and, in addition to the national monument, include portions of two national forests (Rogue River-Siskiyou and Klamath NFs) and three BLM Districts (Medford, Lakeview and Ukiah). Human population and developed infrastructure are concentrated in lower-elevation valleys, particularly the Rogue, Applegate (Oregon) Shasta, Scott and Butte Valleys (California).

Where data are available, maps specific to the Cascade-Siskiyou focus area were constructed using DataBasin (www.databasin.org), a web-based platform that provides access to a wide variety of spatial datasets and analysis tools. These maps, which appear as figures throughout this report, allow presentation of results from reviewed studies at more appropriate and comparable spatial scales. In most cases, additional lands surrounding the Cascade-Siskiyou focus area are also presented to provide important geographic context for interpreting patterns of connectivity and adjacent results. In cases where spatial data were not publicly available, figures were excerpted from maps as presented in the original papers.

RESULTS AND DISCUSSION

Table 2 summarizes primary attributes of the 22 studies included in this review, allowing comparison of stated goals, overall approaches, spatial resolution and analytical methods. Most papers analyzed connectivity to help identify high-priority conservation areas, develop strategies for increasing resilience to climate change, and/or design potential linkage zones between existing reserves or core habitat patches for focal species. These goals were largely based on the recognition that connectivity has been greatly reduced in many landscapes, and that maintaining or enhancing this ecological function is essential if long-term biodiversity conservation goals are to be achieved.

The geographic extent covered by studies included in this review varied from national to ecoregional, with most (16) occurring at the multi-state or state level. Twelve papers did not analyze connectivity across the entire focal landscape -- either because particular areas are located outside the study's geographic extent and/or habitat of a particular focal species was largely absent from portions of the Cascade-Siskiyou landscape. Spatial resolution, as reflected by the size of minimum mapping unit, also varied considerably between studies. Eleven (50%) of 22 papers reflect a relatively "coarse-grained" analysis

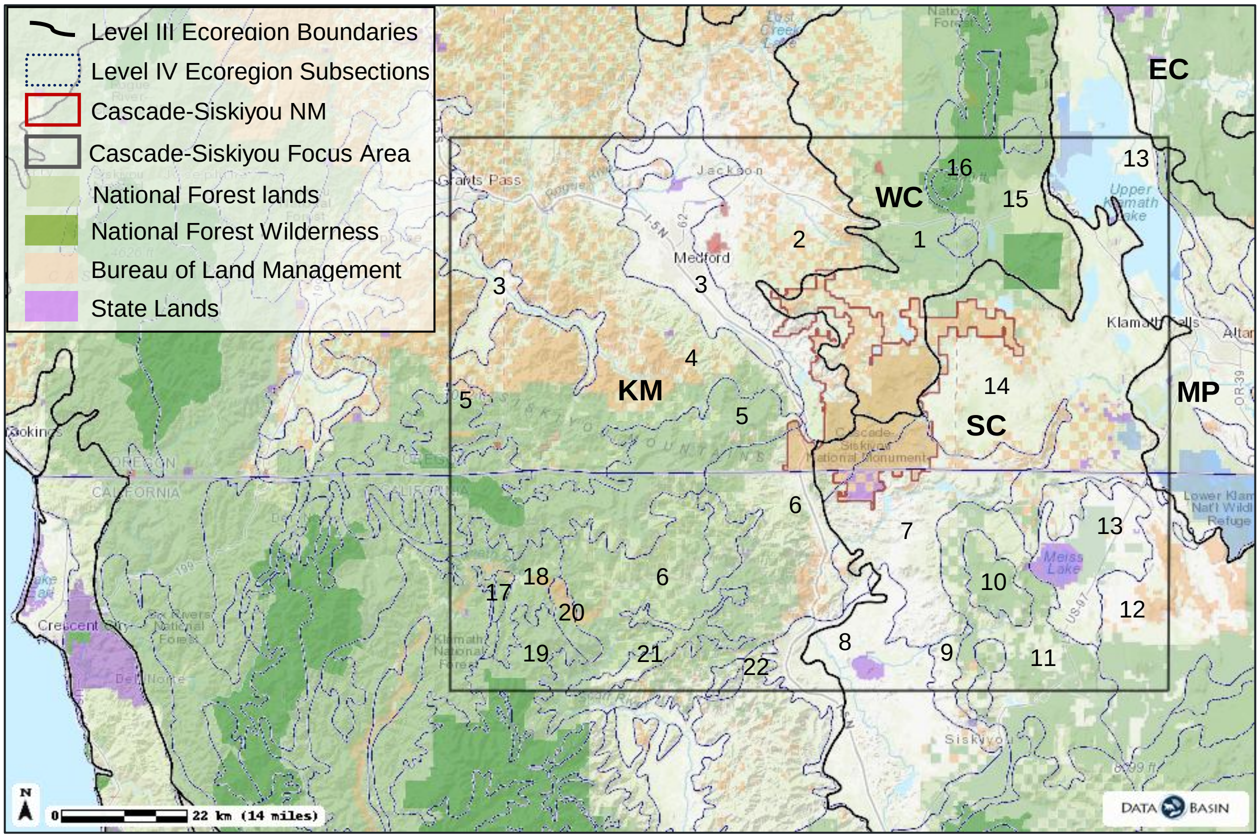

Figure 1. Map of Cascade-Siskiyou focus area in southwest Oregon and adjacent California (black line rectangle), showing public land ownership, Level III ecoregions (thick black lines) and Level IV ecosections (dashed blue lines). Ecoregion names abbreviated as follows: KM - Klamath (-Siskiyou) Mountains, WC - Western Cascades, SC - Southern Cascades, MP - Modoc Plateau, and EC - Eastern Cascades. Ecosections numbered as follows: 1) Low Southern Cascades Mixed Conifer Forests, 2) Oak Savannah Foothills, 3) Rogue-Illinois Valleys, 4) Inland Siskiyous, 5) High Siskiyous, 6) Klamath River Ridges, 7) Old Cascades, 8) Shasta Valley, 9) California Cascades Eastside Conifer Forests, 10) High Southern Cascades Montane Forests, 11) Low Southern Cascades Mixed Conifer Forests, 12) Modoc Lava Flows and Buttes, 13) Klamath-Goose Basins, 14) Southern Cascades Slope, 15) High Southern Cascades Montane Forests, 16) Cascades Subalpine/Alpine, 17) Western Klamath Montane Forests, 18) Western Klamath Low Elevation Forests, 19) Salmon Mountains, 20) Serpentine Siskiyous, 21) Eastern Klamath Montane Forests, and 22) Duzel Rock.

(i.e., minimum mapping unit > 0.5 km^2), eight are moderate to fine-grained (< 270 m^2), and three either did not report this information or it was not relevant (e.g., linkages were expert-drawn).

A diversity of different modeling tools and approaches were used to assess connectivity, the most common include applications based on circuit theory (CircuitScape, OmniScape), least cost path/distance and other metrics based on graph theory (network centrality), and individual, species-based distribution models (HexSim, MaxEnt). Each of these methods has unique strengths and weaknesses, a discussion of which is beyond the scope of this review. Suffice it to say here that a diverse array of connectivity analysis methods and tools have recently been developed, and all are in theory capable of identifying specific areas that are important to connectivity in complex landscapes. For an in-depth comparison and details concerning the various GIS-based analysis tools utilized by these studies, see Keeley et al. (2018a), Correa Ayram et al. (2016), Wade et al. (2015) and Singleton & McRae (2013).

Eight (36%) of 22 reviewed papers explicitly addressed how patterns of connectivity across the Cascade-Siskiyou landscape may be affected under climate change. While methodological approaches varied, most of these papers modeled changes to connectivity and/or shifts in suitable habitat across a range of scenarios constructed from downscaled climate projections (usually in terms of mean annual temperature). The interaction between connectivity and climate change is a relatively new and fast-growing area of

Table 2. Comparison of primary attributes across all 22 ecological connectivity and focal species assessments included in this review, summarizing the broad range of goals, spatial scales, methodological approaches and analytical methods. Studies are grouped by spatial scale as described in the text. The last six entries report on connectivity-related issues for three different focal species (northern spotted owl (3), gray wolf (1) and fisher (2); eight studies (36% of total) evaluated the potential impacts of climate change on connectivity in some capacity.

STUDY	GEOGRAPHIC SCALE	CONNECTIVITY GOAL	FOCUS OF ANALYSIS	ANALYSIS METHOD(S)	MIN. MAPPING UNIT	CLIMATE CHANGE ADDRESSED?
National Scale Assessments						
Belote et al. 2017	Coterminous U.S.	Integrate ecological connectivity into mapping of wildland values	Assess 'wall-to-wall' wildland values, calculated as a function of biodiversity, connectivity, ecological integrity and ecological representation	Calculate Index of Wildland Value as the sum of four spatial data layers per each grid cell	1 km^2	No
Belote et al. 2016	Coterminous U.S.	Map the most natural / structurally intact linkages between existing large protected areas	Compare connectivity results using different resistance surfaces and varying assumptions regarding animal movement	Least cost paths using Linkage Mapper; composite corridors represent areas of agreement across several differing models	1 km^2	No
McGuire et al. 2016	Coterminous U.S.	Map climate connectivity -- the capacity of landscapes to allow species movement in the face of changing climate	Compare degree of climate connectivity between natural areas with and without the presence of corridors	CircuitScape and Climate Linkage Mapper used to assess % success or failure of natural areas to achieve climate connectivity	1 km^2	Yes
Theobald et al. 2012	Coterminous U.S.	Identify most effective network of connectivity paths based on relative naturalness / intactness	Analyze connectivity as a function of overall landscape permeability	Map network centrality of permeability scores to calculate relative importance to overall connectivity	270 m^2	No
Macro-Regional Scale (Multi-State) Assessments						
DIckson et al. 2017	Western U.S.	Identify specific areas that most contribute to connectivity between existing large protected areas	Evaluate relative contribution of specific federal land areas to connectivity between existing protected areas	Combine two metrics -- effective resistance to movement and current flow centrality using CircuitScape	1 km^2	No
Littlefield et al. 2017	Western U.S.	Identify areas that are most likely to successfully facilitate climate-induced species' movements and range shifts	Map species' movement routes along climatic gradients, using data on landscape permeability, simulated corridors and several climate projection models	CircuitScape used to quantify species movement between historical climates and future analogs under several climate model projections	1 km^2	Yes
McRae et al. 2016	Pacific Northwest and California	Identify those areas most likely to facilitate ecological flow -- i.e., species' movement, dispersal and distributional range shifts	Model landscape connectivity using three metrics -- regional flow potential, current flow percentile and normalized current flow	OmniScape used to quantify flow among all natural and semi-natural lands up to a distance of 50 km	180 m^2	Yes (pilot analysis)
Buttrick et al. 2015	Pacific Northwest and California	Map sites resilient to climate change, defined as a function of local permeability to movement (i.e., connectivity) and topoclimate diversity	Assign permeability and topoclimatic diversity scores to each pixel as a function of: 1) resistance to movement within 3 km radius and 2) heat load / index of topographic complexity	Calculate relative index of resilience to climate change by combining permeability and topoclimate diversity scores	90 m^2	Yes

STUDY	GEOGRAPHIC SCALE	CONNECTIVITY GOAL	FOCUS OF ANALYSIS	ANALYSIS METHOD(S)	MIN. MAPPING UNIT	CLIMATE CHANGE ADDRESSED?
Theobald et al. 2011	Western U.S. (forests only)	Develop an approach to analyzing broad-scale connectivity that integrates structural and functional approaches and also provides quantitative estimates of the effects of land use change	Delineate large forest patches, compute metrics of connectivity, generate minimum linkage network and evaluate potential change to network assoc. w/ future land use scenarios	Map landscape connectivity networks using metrics and tools from graph theory, including least cost distance (FunConn application)	270 m^2	No
Western Governors' Association 2010	Western U.S.	Map locations of Large Intact Blocks (LIBs) of habitat important to wildlife and Important Connectivity Zones (ICZs) that link them across state and regional boundaries	Classify LIBs based on level of intactness and size, identify least cost paths between them and buffer primary linkage pathways to create ICZs	Least cost path analysis	1 mi^2	No
State and Ecoregional Scale Assessments						
Cameron et al. In prep.	California	Identify areas of structural connectivity across all lands in the state and assess how existing patterns of connectivity may be influenced by projected climate change	Model connectivity as a function of landscape naturalness and human-created barriers to movement; assess climate connectivity by identifying areas where natural grid cells are located proximal to cooler cells	OmniScape used to quantify ecological flow among all pixels within 50 km radius (similar to McRae et al. 2016)	180 m^2	Yes
Hannah et al. 2012	California	Identify broad-scale areas of relatively intact habitat that are most likely to facilitate plant species range shifts in response to climate change	Model suitable habitat for over 2,200 native plant species in ten-year time steps to identify "essential connectivity chains" in which species can disperse from currently suitable habitat to future suitable habitat	Heuristic algorithm developed to map clusters of essential connectivity chains that meet minimum suitable area targets	4 km^2	Yes
Olson et al. 2012	Klamath-Siskiyou Ecoregion	Identify a provisional set of mesorefugia that, if protected, would increase the capacity of the landscape to conserve biodiversity in the face of climate change	Map mesorefugia based on large-scale biophysical features, zones of species endemism and relict taxa dependent on cool and/or mesic habitats	Expert-drawn	n/a	Yes
Spencer et al. 2010	California	Design a functional network of Natural Landscape Blocks and Essential Connectivity Areas capable of ensuring the continued persistence of the state's native biodiversity	Identify all Natural Landscape Blocks, model least cost corridors between them and delineate Essential Connectivity Areas from the top 5% of pixels in each least cost path	Least cost path analysis between Natural Landscape Blocks based on state-wide resistance layer	30 - 100 m^2	No
Hatch et al. 2008	Oregon	Evaluate human-created barriers to wildlife movement and identify priority linkage areas across the state	Utilize regional expert workshops to collect info. on location of barriers to movement associated with specific wildlife groups and road segments; rank all identified barriers with standardized set of 6 criteria to identify priority linkages.	Using information from expert workshops, sum prioritization scores across all roads and then map by road segment	n/a	No

STUDY	GEOGRAPHIC SCALE	CONNECTIVITY GOAL	FOCUS OF ANALYSIS	ANALYSIS METHOD(S)	MIN. MAPPING UNIT	CLIMATE CHANGE ADDRESSED?
Noss et al. 1999	Klamath-Siskiyou Ecoregion	Develop plan to conserve special elements, representative ecosystems and viable populations of focal species via an interconnected network of reserves on public lands	Identify locations of important inter- and intra-regional linkages that provide connectivity between proposed core reserves	Systematic conservation planning, not specific to connectivity (supplemental connectivity analysis proposed)	n/a	No
Species-Level Assessments						
USDI BLM 2015	Range of Northern Spotted Owl in western Oregon	Utilize a simulation model and data on forest conditions to evaluate the range-wide distribution of habitat blocks, dispersal habitat and dispersal flux for the Northern Spotted Owl	Map NSO habitat blocks, estimate the distribution of dispersal-capable habitat and aggregate movement pathways of simulated NSO movements over time to create maps of dispersal flux	HexSim - spatially explicit species demographic model	214 acres	No
Carroll 2010	Range of NSO in WA, OR and CA	Investigate the potential effects of climate change on the distribution and connectivity of the Northern Spotted Owl	Develop model that incorporates data on locations of owl nest sites, the proportion of NSO habitat and down-scaled projections of climate change based on different climate simulations for current and two future time periods	MaxEnt used to model predicted NSO distribution from a landscape grid of environmental / climate data and species occurrence records	1 ha and 1 km^2	Yes
Carroll & Johnson 2008	Range of NSO in WA, OR and CA	Identify areas where habitat connectivity between sub-populations of Northern Spotted Owls may be most important to prevent barriers and genetic bottlenecks across the species' range	Create landscape network of hexagonal cells based on NSO habitat and occupancy, calculate and map the connectivity value of each hexagon independent of habitat value using graph theory metrics	Calculate Integral Index of Connectivity -- a metric based on graph theory derived with the software program Sensinode	24 km^2	No
Carroll et al. 2012	Range of gray wolf in Western North America	Determine specifically where it might be possible to increase natural dispersal between extant gray wolf populations, as well as into suitable but currently unoccupied habitat	Apply 3 linkage-mapping methods (shortest path, current flow, and minimum-cost/maximum-flow) to spatial data representing wolf habitat and compare potential patterns of connectivity	Range of centrality metrics corresponding to three linkage-mapping methods calculated using the Connectivity Analysis Toolkit	10 km^2	No
USDI FWS 2016	Range of fisher in WA, OR and CA	Develop spatial models to help understand the current status of the fisher relative to the amount and distribution of habitat in the Pacific States	Utilize vegetation data and verified fisher detections to construct expert model of suitable habitat; then map habitat with known fisher occurrences onto landscape grid, overlay results of recent detection surveys	MaxEnt used to model potential fisher habitat suitability; Landscape grid of hypothetical fisher home ranges and suitable habitat overlaid with results of fisher detection surveys	90 m^2 - MaxEnt model 1,000 ha - fisher home range / landscape grid	No
USGS-GAP 2014	Range of fisher in United States	Construct a fine-scale distribution map for fisher using a deductive model that identifies lands most suitable for occupation across the species' range	Create a species-habitat database including all relevant literature on the current distribution and habitat associations of the fisher in each occupied region	Correlate species-habitat database with land cover / vegetation, forest structure and other spatial data layers to create fisher distribution map	30 m^2	No

research, a result of the emerging consensus that increasing connectivity is likely the most effective strategy for mitigating the adverse impacts of climate change on biodiversity (Keeley et al. 2018a, Schmitz et al. 2015, Krosby et al. 2010, Heller & Zavaleta 2009). Landscape connectivity is thought to be critical for maintaining ecosystem resilience during periods of rapid change because it creates opportunities for species to shift their distributions and thereby successfully adapt to new conditions (Cross et al. 2015). While more research will undoubtedly add to our understanding, available evidence from the climate-related studies included in this review is clear on the highest priorities for connectivity conservation in the Cascade-Siskiyou focus area.

Montane portions of the focus area, specifically less-developed lands along the crest of the Siskiyou and Cascade Ranges (see Table 3 and Figure 2), were frequently identified as "mesorefugia," "climate corridors," and/or conservation priorities for climate change adaptation. A smaller proportion of climate change-related studies provide supporting evidence for linkages that traverse lower elevations, or that connect lowland to montane portions of the Cascade-Siskiyou landscape. These results are consistent with the understanding that, as temperatures rise, most species ranges will likely need to move upward in elevation (Littlefield et al. 2017). In addition, montane areas in our focus area tend to exhibit the most topographically complex and varied environments, which may also confer greater resilience to climate change impacts (Buttrick et al. 2015, Carroll et al. 2010). However, irrespective of whether connectivity was assessed under current conditions or across time with a warming climate, the same movement pathways within the Cascade-Siskiyou landscape were most frequently identified for their high connectivity values.

In an attempt to integrate findings across all 22 studies included in this review, map-based results of each paper were grouped according to where specific linkages or vectors of relatively high connectivity were located within the Cascade-Siskiyou focus area. In some cases, individual linkages were explicitly identified by authors as conservation priorities, whereas in others, analyses were presented without recommendations for connectivity planning or design. In the latter case, an attempt was made to determine whether or not specifically-defined linear features exhibited relatively high connectivity values by visually inspecting and scoring each paper's mapped results. The product of this synthesis, Table 3, is a summary of all papers that provide supporting evidence for one or more of the six primary linkage zones that were identified. Once scoring was completed, the six most commonly identified Cascade-Siskiyou linkages or connectors were then prioritized according to the proportion of papers that both analyzed the area and provided supporting evidence.

The two areas most frequently identified for their outstanding connectivity values are the east-west, inter-regional landscape linkage and junction point between the eastern Siskiyou and Cascade Ranges [hereafter referred to as the "Cascade-Siskiyou land bridge" - after DellaSala (2000)], and a north-south trending pathway that essentially follows the Southern Cascades in Oregon. Two additional connectivity zones clearly important in this landscape -- the Siskiyou Crest (moving west from the land bridge / national monument), and the Southern Oregon Cascades into California -- were identified only slightly less often using this approach (85-90% compared to74% of papers). All six linkages are mapped in Figure 2 as arrows indicating the general location and primary direction(s) of movement among core areas. More detailed, fine-scale analyses will be necessary in order to delineate their spatial extent (length/width) and configuration.

Despite the wide range of goals, approaches and analytical methods used among the 22 papers included in this review, considerable agreement exists in terms of the most important linkages in the Cascade-Siskiyou focus area. The robust nature of these findings underscores the ecological importance of increasing conservation efforts in these high priority areas -- particularly in critical bottlenecks (i.e., where key movement pathways are most vulnerable), and/or where large connectivity gains can be made with targeted, strategic investment (e.g., mitigating known movement barriers such as Interstate 5). Out of the six primary linkages identified, the Cascade-Siskiyou land bridge stands out as unique in that the area not only represents a critical connectivity bottleneck in this landscape, but also:

- functionally connects otherwise disjunct ecoregions (USDI 2017, DellaSala 2000, Noss et al. 1999)
- has national significance for the conservation of special-status species dependent on inter-regional forest connectivity (e.g., Northern Spotted Owl and fisher; USDI BLM 2015, USDI FWS 2016)
- is likely to be relatively resilient to climate change impacts (Littlefield et al. 2017, McGuire et al. 2016, Buttrick et al. 2015, Olson et al. 2012)
- supports high levels of both biodiversity and ecological integrity (Belote et al. 2016, 2017)

While significant steps have been taken to protect portions of the Cascade-Siskiyou land bridge (e.g., 2017 expansion of the national monument), additional actions will be needed across multiple ownerships in order to safeguard this area's outstanding ecological values. Recognizing this need, the final section of this report offers a set of recommended next steps that, if implemented, are most likely to further advance opportunities for science-based connectivity conservation in this region.

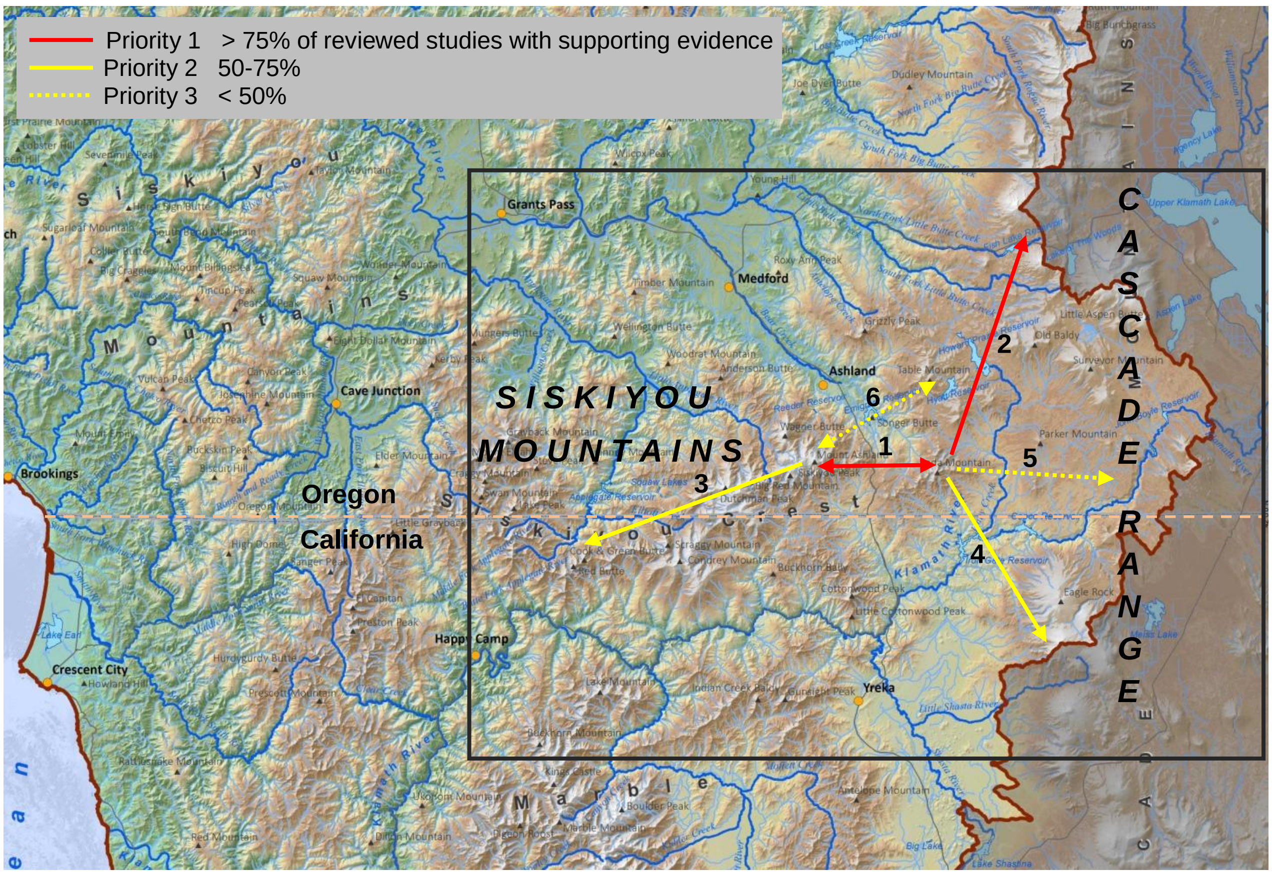

Figure 2. Generalized locations and prioritization of connectivity pathways in the Cascade-Siskiyou focus area (black rectangle) identified by studies included in this review. Linkages are classified into three priority classes based on the proportion of reviewed literature with supporting evidence for each pathway, and numbered from highest to lowest priority as follows: 1) Cascade-Siskiyou Land Bridge, 2) Southern OR Cascades; Cascade-Siskiyou NM to Rogue River-Siskiyou NF, 3) Siskiyou Crest; Mt. Ashland to western Siskiyous, 4) Southern OR Cascades; Cascade-Siskiyou NM to Klamath NF, 5) Klamath River Canyon; Cascade-Siskiyou NM to Klamath Falls BLM, and 6) Bear Creek Valley; Southern OR Cascades to Eastern Siskiyous. See Table 3 for scoring details used to assign prioritization.

Table 3. Summary of studies included in this literature review that provide supporting evidence for the ecological importance of specific connectivity segments in the Cascade-Siskiyou focus area, southwest Oregon and adjacent California. Cells are shaded dark in cases where study results do not address a particular linkage path, either because it is located outside of the study's geographic extent and/or is beyond the range of analyzed focal species. Linkage areas supported by fewer than five papers were not included. Abbreviations in linkage location names as follows: C-S NM = Cascade-Siskiyou National Monument, NF = National Forest, BLM = Bureau of Land Management.

	STUDIES WITH SUPPORTING EVIDENCE / PRIORITIZATION OF TERRESTRIAL LINKAGES IN CASCADE-SISKIYOU FOCUS AREA					
	Cascade-Siskiyou Land Bridge	**Southern OR Cascades -- C-S NM to Rogue River NF**	**Southern Cascades -- C-S NM to Klamath NF**	**Bear Creek Valley -- Cascades to Siskiyous**	**Siskiyou Crest -- Mt Ashland to Western Siskiyous**	**Klamath River Canyon -- C-S NM to Klamath Falls BLM**
LINKAGE ORIENTATION	East/West	North	South	East/West	West	East
Belote et al. 2017	X	X	X		X	
Belote et al. 2016	X	X	X		X	X
McGuire et al. 2016	X	X	X	X	X	
Theobald et al. 2012		X	X			
Dickson et al. 2017	X	X	X		X	
Littlefield et al. 2017	X	X	X		X	
McRae et al. 2016	X	X	X	X	X	
Buttrick et al. 2015	X	X	X		X	
Theobald et al. 2011	X	X	X		X	
Western Governors' Assoc. 2010		X	X	X		X
Cameron et al. In prep.			X		X (California portion)	X (California portion)
Hannah et al. 2012	X				X	
Olson et al. 2012					X	
Spencer et al. 2010		X	X			X
Hatch et al. 2008	X	X				
Noss et al. 1999	X					X
USDI BLM 2015 (N. Spotted Owl; NSO) Dispersal flow	X				X	
Habitat blocks/dispersal	X	X		X	X	
Carroll 2010 (NSO)	X	X		X	X	
Carroll & Johnson 2008 (NSO)	X	X	X		X	
Carroll et al. 2012 (gray wolf)		X	X			
USDI FWS 2016 (fisher)	X	X			X	
USGS-GAP 2014 (fisher)	X	X			X	
RELATIVE PRIORITY (% of all reviewed papers)	**85%** (17/20)	**90%** (18/20)	**74%** (14/19)	**24%** (5/21)	**74%** (17/23)	**31%** (5/16)
CLIMATE CHANGE PRIORITY (% of climate change papers)	**100%** (5/5)	**100%** (5/5)	**67%** (4/6)	**25%** (1/4)	**100%** (7/7)	**17%** (1/6)

I. <u>NATIONAL SCALE CONNECTIVITY ASSESSMENTS</u> (Coterminous U.S.)

Belote, T.R., M.S. Dietz, C.N. Jenkins, P.S. McKinley, G.H. Irwin, T.J. Fullman, J.C. Leppi and G.H. Aplet. 2017. ***Wild, Connected, and Diverse: Building a More Resilient System of Protected Areas***. Ecological Applications 27(4): 1050-1056.

The current system of protected areas are likely insufficient to sustain biodiversity in the face of ongoing climate change and habitat loss. Consequently, numerous calls have been made to expand the nation's conservation reserves so that the future network: 1) better represents ecosystems, 2) increases connectivity which in turn facilitates movement of the biota in response to stressors such as climate change, and 3) sustains biodiversity within functional landscapes. Toward these ends, the authors conducted a 'wall-to-wall' assessment of existing conservation values across the contiguous United States by integrating geospatial data on ecological integrity (from Theobald et al. 2013), landscape connectivity (from Belote et al. 2016), representation of ecosystems (from Aycrigg et al. 2013), and a mapped index of biodiversity based on representation of range-limited species (from Jenkins et al. 2015). Prior to further analysis, these four map layers were normalized and then displayed with a uniform grid cell size of 1 km^2 across the coterminous U.S.

The four indices listed above were summed to produce a single composite map of conservation values (Figure 3). Individual grid cells were assigned a higher value if they: 1) maintained a high degree of ecological integrity and/or low degree of human modification; 2) included ecosystem types that are less well represented within existing protected areas; 3) scored relatively high in terms of ecological connectivity, thereby helping to maintain functional linkages between protected areas; and 4) supported relatively high numbers of endemic species and/or species with limited geographic distributions that are currently not well-represented in protected areas. Grid cells exhibiting maximum conservation values represent locations where the highest values across all indices overlap. Belote et al. also produced six bivariate maps to evaluate the four value layers in pair-wise comparisons.

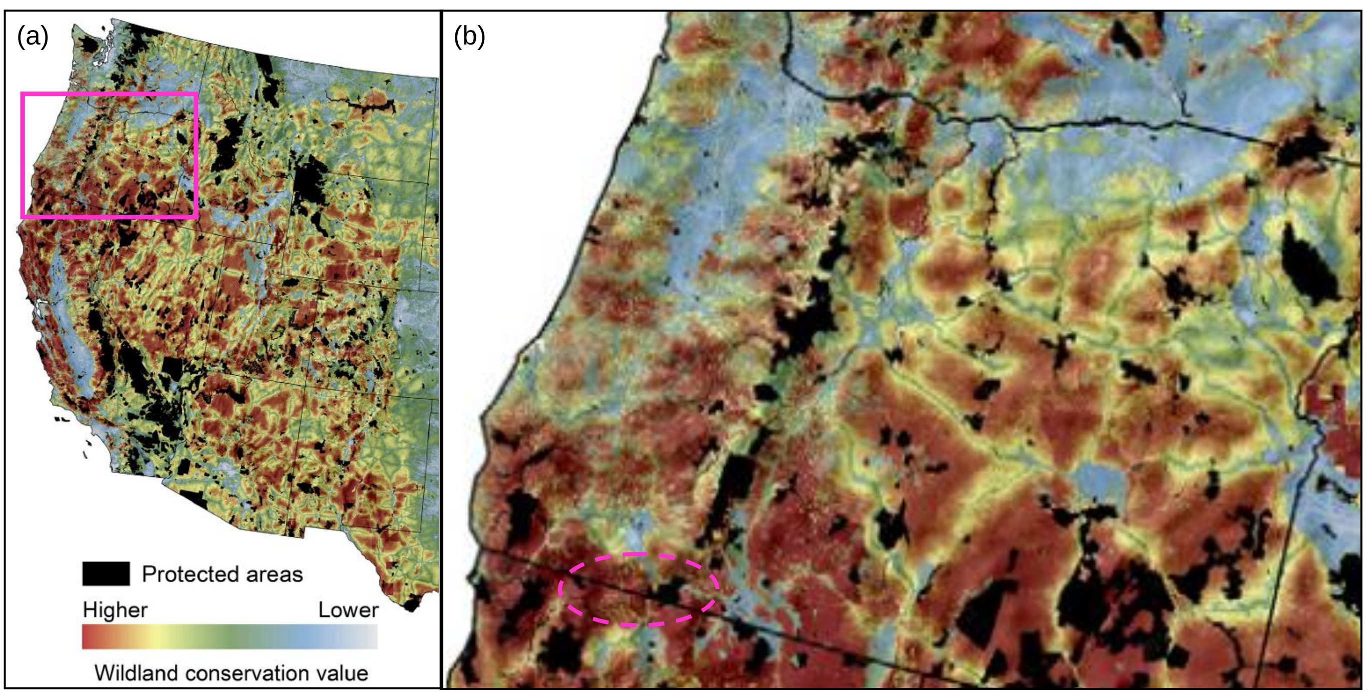

Figure 3. Composite map of wildland conservation value from Belote et al. (2017), based on the sum of ecological integrity, connectivity, ecosystem representation and biodiversity (number of range-limited species) across (a) the western U.S. and (pink insect box, b) Oregon and adjacent California. High-value lands in the immediate vicinity of the Cascade-Siskiyou National Monument highlighted by pink dashed-line oval in (b). Lands within existing protected areas (GAP status 1 and 2) are shown in black.

The composite map reveals high-value areas concentrated throughout the western U.S., where lands tend to be less modified by humans and most existing large protected areas exist. In Oregon, the majority of lands with high conservation value are located east of the Cascades and in the southwestern quadrant of the state. In the Cascade-Siskiyou focus area, a well-defined area of high value covers a large portion of the Siskiyou Mountains and extends east to include the Cascade-Siskiyou National Monument and surrounding lands (pink dashed-line oval, Figure 3b). Inspection of bivariate maps for this specific area indicates high composite scores are primarily attributable to high levels of connectivity, biodiversity and ecological integrity combined with moderate levels of ecosystem representation (Figure 4). The authors recommend these results be used to help evaluate the national significance of local or regional lands so that future conservation efforts are most likely to maximize protection of the nation's biological heritage.

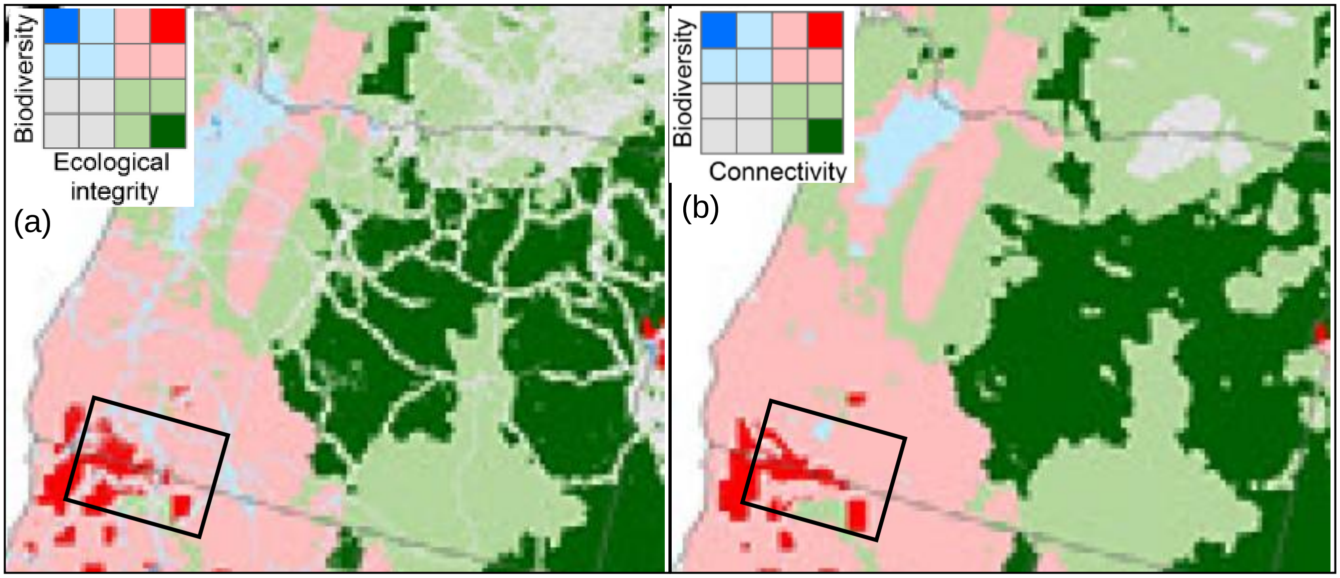

Figure 4. Bivariate maps showing pair-wise relationships between indices of (a) biodiversity and ecological integrity; and (b) biodiversity and connectivity across Oregon and adjacent California, from Belote et al. (2017). Values on each axis represent natural breaks in the index such that red areas represent lands where high priorities overlap, blue and green areas where only one priority is high and the other low, and gray areas score low in both priorities. Black rectangles approximate location of the Cascade-Siskiyou focus area.

Belote, R.T., M.S. Dietz, B.H. McRae, D.M. Theobald, M.L. McClure, G.H. Irwin, P.S. McKinley, J.A. Gage and G.H. Aplet. 2016. ***Identifying Corridors among Large Protected Areas in the United States***. PLoS ONE 11(4) | DOI: 10.1371/journal.pone.0154223.

Recognizing the importance of connectivity for sustaining biodiversity in the current era of rapid climate change, the authors of this study developed a national-scale connectivity model to identify the most "natural" (least human-modified) corridors between existing, large protected areas in the contiguous United States. Corridors were delineated with Linkage Mapper (McRae and Kavanagh 2012), a modeling tool that requires as inputs a set of core areas to connect and a "resistance surface" (i.e., a mapped index reflecting cost or risk of movement). Core protected areas used in this analysis were those greater than 10,000 acres with GAP 1 or 2 status in the Protected Area Database, as these lands include legislative or management direction to maintain biodiversity and prohibit most development. Resistance surfaces were derived from previous efforts to quantify and map anthropogenic alterations to ecosystems across the U.S. Multiple connectivity models were run with different assumptions, and then aggregated to create a composite map identifying areas of broad agreement regarding the optimal location of connectivity corridors.

According to Belote et al.'s map of composite corridor values, landscape connectivity is highly variable across the western U.S. (Figure 5). In western Oregon and adjacent California, only three primary east-west corridors were identified, the southern-most of which is essentially analogous to the Cascade-

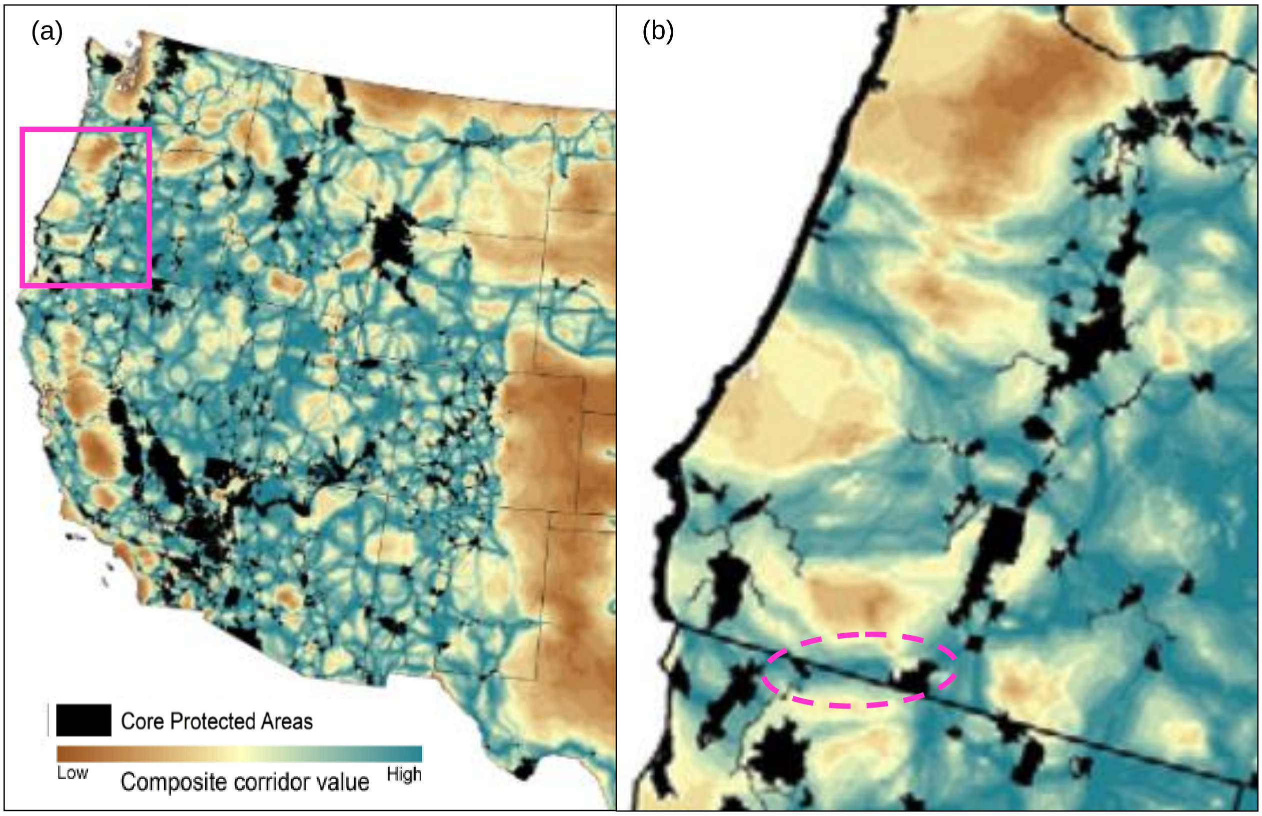

Figure 5. Maps of composite corridor values between large protected areas in (a) the western U.S. and (b) western Oregon (pink inset box), from Belote et al. (2016). Dashed pink oval in (b) highlights the high-value east-west corridor connecting the Cascade-Siskiyou National Monument with protected areas located further west in the Klamath-Siskiyou Ecoregion.

Siskiyou land bridge. While appearing slightly narrower in width than other east-west / coastal-inland flow paths in western Oregon, the Cascade-Siskiyou connectivity corridor exhibits slightly higher composite scores (shown in dark green, Figure 5b), assumedly because it is less human-modified and relatively more intact than those located further north. The authors conclude that corridors identified in this study may be among the most important areas on which to focus future conservation efforts, because they offer the best opportunities for maintaining a connected, nation-wide network of protected areas.

McGuire, J.L., J.J. Lawler, B.H. McRae, T.A. Nunez and D.M. Theobald. 2016. ***Achieving Climate Connectivity in a Fragmented Landscape***. Proceedings of the National Academy of Sciences 113(26) DOI: 10.1073/pnas.1602817113.

The overarching goal of this analysis was to quantify and map climate connectivity -- defined as the capacity of landscapes to allow species movement in the face of a changing climate -- across the contiguous United States. First, to identify natural lands or core areas, the authors used a spatial layer developed by Theobald (2013) that combined data on land use, land cover and roads to map human impacts across the contiguous U.S. A minimum human impact level (equivalent to GAP status 1 and 2 lands in the Protected Area Database) was then applied with the Core Mapper Tool of the CircuitScape software package (McRae et al. 2013) to delineate all high-integrity natural lands greater than 10 km^2.

Once core area patches were identified, the differential impact of changing climate on species movement across the contiguous U.S. was analyzed by: 1) partitioning natural lands into temperature subunits to create climate gradients; 2) creating a network of climate-gradient corridors using Climate Linkage Mapper (Kavanagh et al. 2013), which identifies movement routes among patches that follow temperature gradients while simultaneously minimizing cumulative resistance to movement created by human development; and 3) calculating the margin of success or failure at achieving climate connectivity for each core area patch, with and without the presence of corridors. Climate connectivity was achieved when core areas are connected to sufficiently cool patches such that the future temperature of the destination patch is the same as or cooler than the current temperature of the origin patch -- meaning that organisms could successfully track preferred temperatures through adjacent patches, given projected climate change.

At the national level, McGuire et al.'s analysis found that only 41% of existing natural areas (and less than 2% in the eastern states) retain enough connectivity to allow plants and animals to maintain climatic parity as temperatures rise. Introducing corridors to facilitate movement through human-dominated areas increased the proportion of climatically connected natural lands from 41 to 65%. Within the Cascade-Siskiyou focus area, the large majority of low- to mid-elevation natural areas exhibited some degree of successful climate connectivity, particularly when corridors are included (Figures 6-7). However, higher elevation lands generally failed to achieve climate connectivity, because no upslope areas exist that would allow species' movements to track equivalent temperatures as the climate warms (i.e., "climatic cul-de-sacs"). These findings demonstrate that landscape connectivity is critical for allowing species to colonize suitable habitats during an era of rapid climate change, and can be used at local or regional scales to help identify the most strategic locations for increasing connectivity as part of climate-smart conservation planning.

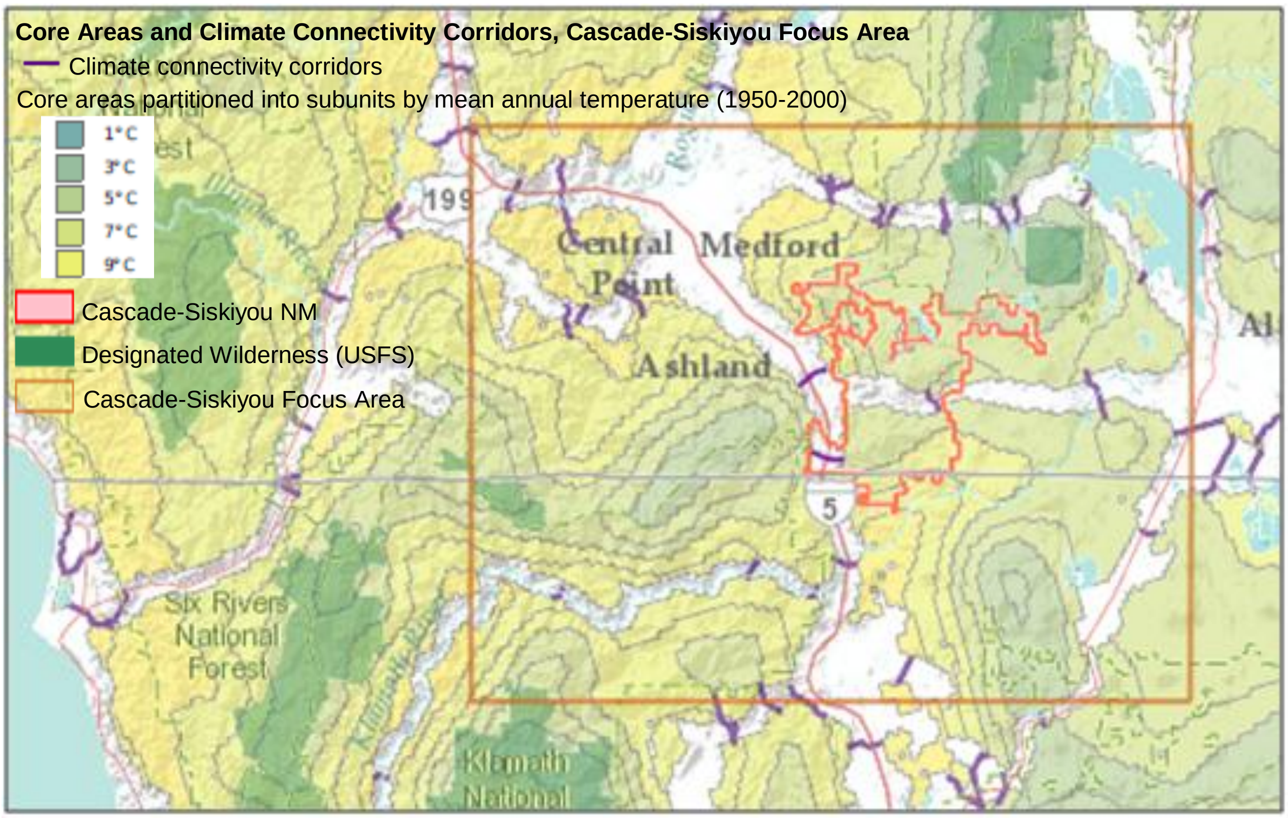

Figure 6. Mapped results from McGuire et al. (2016) showing core area patches (colored polygons) partitioned into temperature subunits (uniformly-colored sections of each polygon stratified by mean annual temperature,1950-2000) and climate connectivity corridors (purple lines) in the greater Cascade-Siskiyou focus area. Note location of east-west climate connectivity corridors in the Siskiyou Mountains (three, traversing Interstate 5 in OR and CA) and north-south, inside the Cascade-Siskiyou National Monument (one).

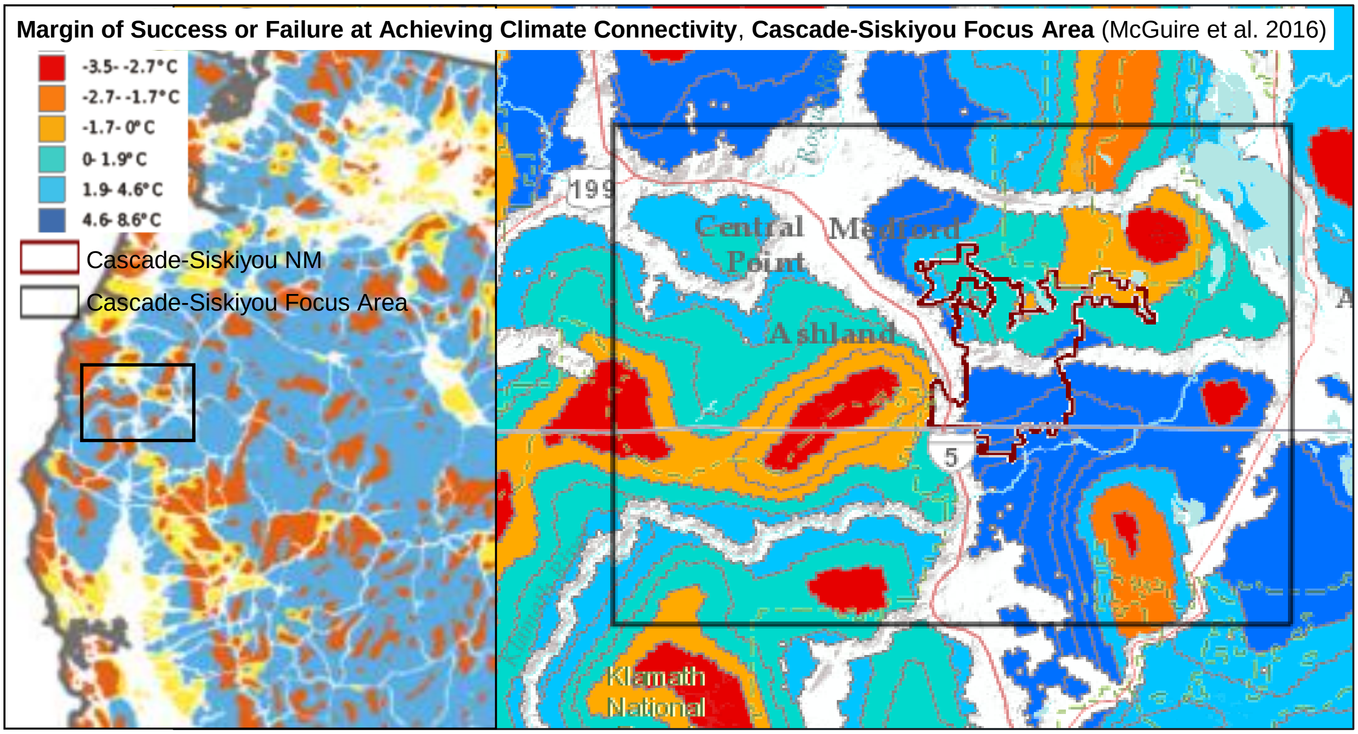

Figure 7. Map depicting the margin of success or failure at achieving climate connectivity across the Pacific Northwest (left) and the Cascade-Siskiyou focus area (black inset box, right) with corridors included. This margin is calculated as the current temperature of the origin patch minus the future temperature of the destination patch, in degrees Celsius. Negative temperatures (yellow to red colors) indicate a failure to achieve climate connectivity, and positive temperatures (light to dark blue) indicate success. Note that the coolest temperature patches, associated with higher elevations (e.g., Siskiyou Crest, High Cascades) generally fail to achieve climate connectivity because there are no adjacent cooler patches in the landscape that would allow for upslope dispersal.

Theobald, D.M., S.E. Reed, K. Fields and M. Soule. 2012. ***Connecting Natural Landscapes using a Landscape Permeability Model to Prioritize Conservation Activities in the United States***. Conservation Letters 5: 123-133. [See also: Fields, K., D.M. Theobald and M. Soule. 2010. ***Modeling Potential Broad-Scale Wildlife Movement Pathways within the Continental United States***. Research White Paper, Available from the Wildlands Network, Seattle, WA. 6 pp.]

The authors present a novel, robust modeling approach to identify the most functionally connected movement pathways across lands of the coterminous U.S. In comparison with other studies, Theobald et al.'s analysis is based on estimation of a continuous metric of permeability rather than attempting to distinguish discrete corridors or linkages. The gradient-based approach to mapping connectivity presented in this study followed a four-step process: 1) quantify "naturalness" as an integrated function of land cover types, housing density, presence of roads, and effects of highway traffic; 2) calculate variable resistance to wildlife movement using the inverse of the "naturalness" surface as a proxy for permeability; 3) map permeability across the landscape by averaging numerous model iterations that determine the degree of resistance between all cells (270 m resolution); and 4) calculate a metric of network centrality so as to display the relative importance of each cell to the overall pattern of landscape connectivity.

The product of this analysis is a map displaying a branching system of pathways that represent the most efficient patterns of movement if following lands of least resistance (Figure 8). Thicker lines (shown in blue) represent areas of high potential flow that most contribute to maintaining connectivity, as a function of both local naturalness values and the respective cells' position within the broader landscape network. The authors recommend that these results be used to help identify and conserve lands that are most important for maintaining connectivity and inform climate change adaptation at regional and national scales.

Focusing in on lands along the Oregon-California border, a conspicuous connectivity convergence or junction point can be seen at the intersection of the Siskiyou and Cascade Ranges (shown in maroon dashed-line oval, Figure 8b), with flow paths extending from here to lands located north in Oregon's High Cascades, southwest to the Klamath Mountains, and east to the Modoc Plateau in California. Given that the 'Cascade-Siskiyou connectivity path' intersects and is adversely impacted by a primary highway with high traffic volume (identified by red arrow, Figure 8c), the area may be a high priority for developing wildlife crossing structures or other actions to help maintain or restore connectivity.

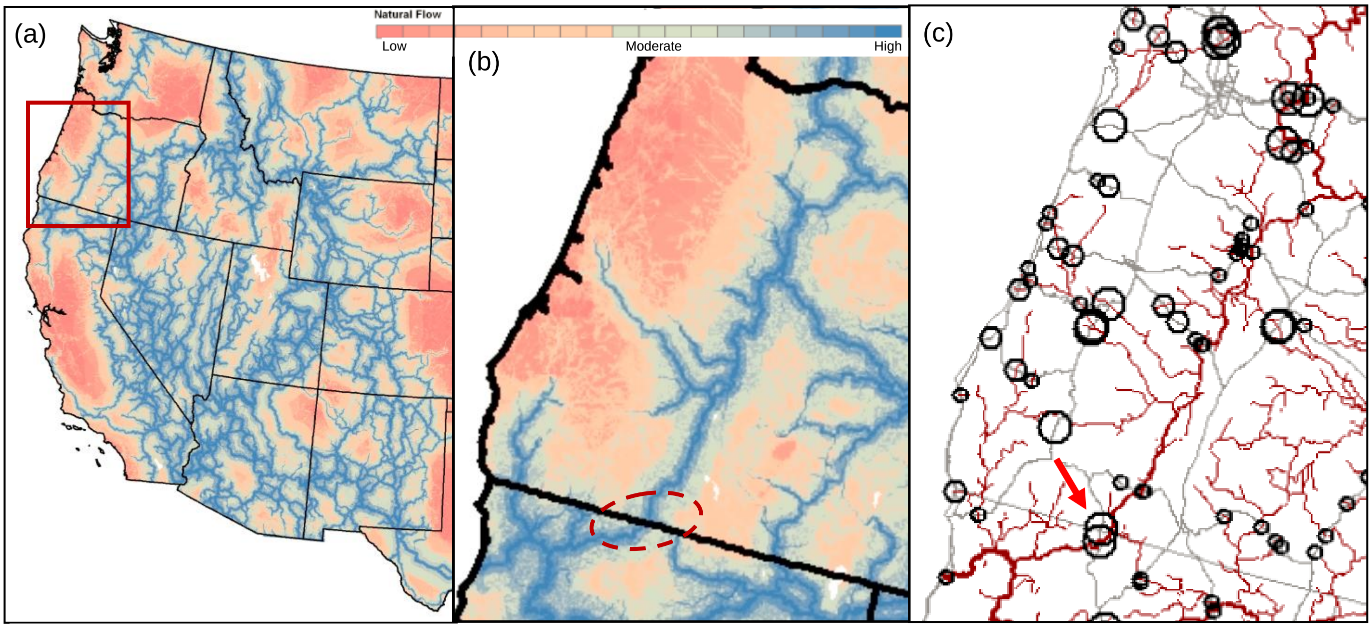

Figure 8. Primary pathways of ecological flow or landscape connectivity across (a) the western U.S. and (b) western Oregon as identified by Theobald et al. (2012). Dashed red oval in (b) highlights junction point where three primary connectivity paths intersect in the Cascade-Siskiyou focus area. (c) displays the location of important connectivity paths (maroon lines) relative to major highways (gray lines) in western Oregon. Circles represent the intersections of highways with connectivity paths, and larger circles signify higher vehicle traffic volume. Red arrow indicates intersection of Cascade-Siskiyou connectivity paths with Interstate 5.

II. <u>MACRO-REGIONAL SCALE CONNECTIVITY ASSESSMENTS</u> (Multiple States)

Dickson, B.G., C.M. Albano, B.H. McRae, J.J. Anderson, D.M. Theobald, L.J. Zachmann, T.D. Sisk and M.P. Dombeck. 2017. ***Informing Strategic Efforts to Expand and Connect Protected Areas Using a Model of Ecological Flow, with Application to the Western United States***. Conservation Letters 10(5): 564-571.

The goal of this study was to estimate patterns of ecological flow among existing protected areas (hereafter PAs), so as to identify specific areas of federal land that most enhance connectivity across the western United States. Toward this end, a spatial model was developed that incorporates two complementary estimates of how an area contributes to ecological connectivity and integrity: 1) <u>effective resistance</u>, which quantifies the relative isolation of specific sites or populations; and 2) <u>current flow centrality</u>, which identifies those lands most important for maintaining connectivity among protected areas and can be used to predict movement probabilities for wide-ranging animals at regional scales.

The subset of U.S. PAs used in this analysis were selected from the U.S. Protected Area Database, specifically those that are relatively well-protected (identified by IUCN categories I-IV) and at least 20 km^2 in size. As a first step to modeling connectivity, a "wall-to-wall" landscape resistance layer was created by combining a range of spatial data on human modifications to the landscape using methods from Theobald

(2013). Next, an ecological connectivity (i.e., current flow) layer was developed using CircuitScape (McRae et al. 2013), a software tool based on the principles of electronic circuit theory. The resultant data layer -- displaying the sum of all circuits that connect PAs -- was used as a proxy for current patterns of ecological flow across the western U.S. The final step of the analysis combined landscape resistance and current flow data for each pixel so as to identify areas of federal land that score high in both ecological integrity (low resistance) and connectivity (high flow centrality).

Results of ecological connectivity / current flow for Oregon (inset) and the Cascade-Siskiyou focus area are mapped in Figure 9. At the broad scale, ecological connectivity as modeled in this study is highest in eastern Oregon, but patches of moderate to high connectivity are also identified in southwestern Oregon and adjacent California. Three primary connectivity flowlines apparent within the greater Cascade-Siskiyou area converge in the Monument -- oriented east-west along the Siskiyou Crest, north to Oregon's High Cascades, and southeast to the California Cascades and Modoc Plateau (dotted yellow arrows, Figure 9). Dickson et. al.'s "wall-to-wall", flow-based model can be used to inform new conservation strategies and critical land use decisions by identifying those areas on both public and private lands that are best positioned to maintain and enhance ecological connectivity across the western U.S.

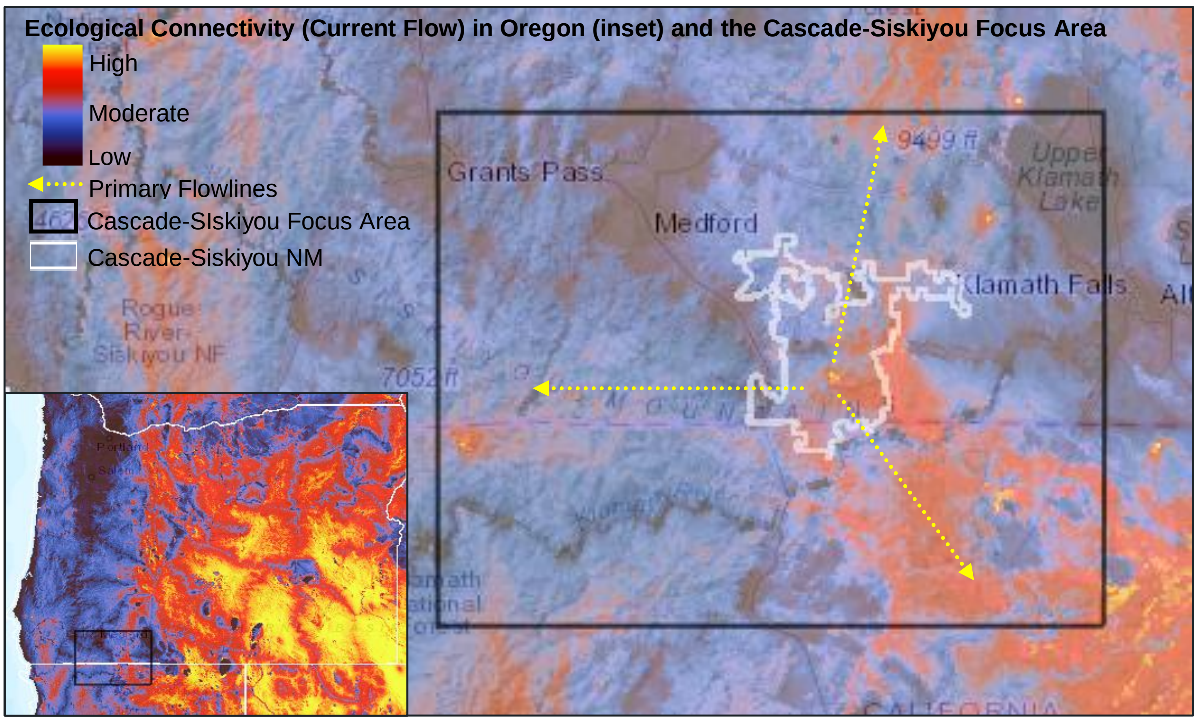

Figure 9. Ecological connectivity (current flow) in Oregon (inset box, lower left) and the Cascade-Siskiyou focus area, excerpted from Dickson et al. (2017). Dotted yellow arrows indicate three primary flowlines of movement apparent from display of current flow data that converge inside the Cascade-Siskiyou National Monument. Relative to lands east of the Cascades, connectivity across western Oregon is generally low, which further underscores the importance of moderate to high connectivity areas that remain in this part of the state.

Littlefield, C.E., B.H. McRae, J. Michalak, J.J. Lawler and C. Carroll. 2017. ***Connecting Today's Climates to Future Analogs to Facilitate Species Movement under Climate Change***. Conservation Biology 31(6):1397-1408.

Increasing connectivity has been identified as the most important strategy for facilitating species range shifts and maintaining biodiversity in the face of climate change. To date, however, few researchers have included future climate projections in efforts to prioritize areas for increasing connectivity. The goal of this study was to identify key areas likely to facilitate climate-induced species' movement across western North America. Using historical climate data sets and future climate projections, the authors mapped potential species' movement routes that link current climate conditions to analogous climate conditions in the future (i.e., future climate analogs) with a novel moving-window analysis based on electrical circuit theory. In addition to tracing shifting climates, this approach also incorporated data on landscape permeability and empirically-derived species' dispersal capabilities.

First, analogs between historic and future climates were spatially identified by comparing historical climate data (1961-1990) with future climate projections (2040-2071), calculated with three different global circulation models for each 1-km grid cell in the western U.S. The authors then used CircuitScape (McRae et al. 2013) to quantify potential species' movement (measured as current flow) between historical climates and their future analogs. CircuitScape estimates connectivity on the basis of electrical circuit theory, treating landscapes as conductive surfaces. Patterns of electrical current predict the movements of random walkers across a landscape, where walkers are proportionately more likely to move through intervening low-resistance cells than high-resistance cells. The final result is a continuous map of current flow across all possible routes -- in this case, across all possible routes between two climate analogs. Patterns of potential movement were also limited by a resistance layer based on human modification of the landscape, using methods developed by Theobald (2013, 2016).

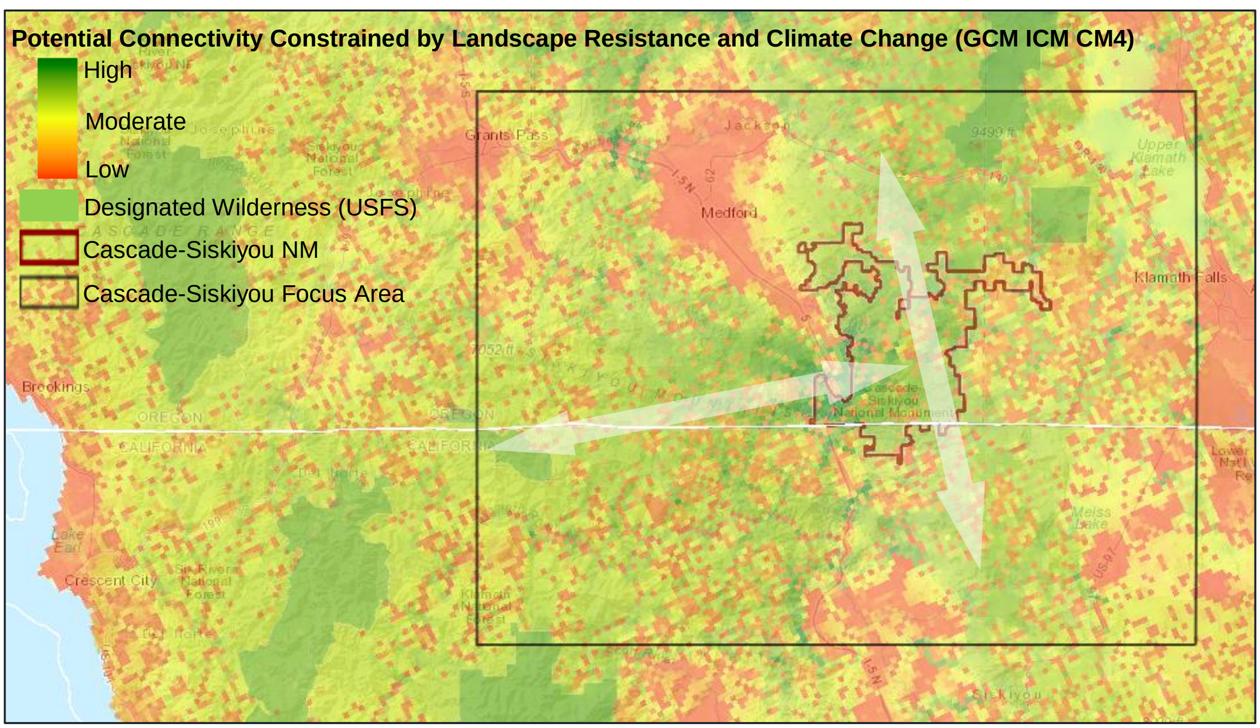

Figure 10. Potential connectivity (measured as current flow) across the Cascade-Siskiyou focus area from Littlefield et al. (2017), incorporating effects of both landscape resistance and climate change as predicted by global circulation model INM CM4 (note: compared with two other GCM models used in this analysis, ICM CM4 predicts the least climate change). Color shading reflects normalized values of potential movement, and white arrows indicate major east-west (Cascade-Siskiyou) and north-south (Oregon-California Cascades) pathways between analogous historical and future climates.

Figure 10 is a map of the Cascade-Siskiyou focus area depicting potential connectivity between areas of historical climates and their 2080s climate analogs. Consistent with other studies included in this review, primary movement pathways can be identified that follow mountainous terrain along both east-west (connecting Cascades-Siskiyous) and north-south (Oregon and California Cascades) trajectories (white arrows, Figure 8). Littlefield et al. (2017) found that mountainous physiographic features consistently exhibited high levels of connectivity between analogous historical and future climates, and are therefore predicted to be key pathways for facilitating climate-mediated species' movements. In contrast with many other portions of the western U.S., movement routes needed for species to track changing climatic conditions in the Cascade-Siskiyou landscape are relatively similar to existing patterns of connectivity (as defined by human-created barriers to movement). Incorporating future climate projections into connectivity modeling can help identify areas of high conservation importance, and "is a necessary step toward facilitating successful species movement and population persistence in a changing climate."

McRae, B.H., K. Popper, A. Jones, M. Schindel, S. Buttrick, K. Hall, R.S. Unnasch and J. Platt. 2016. ***Conserving Nature's Stage: Mapping Omnidirectional Connectivity for Resilient Terrestrial Landscapes in the Pacific Northwest***. The Nature Conservancy. Portland, OR.

The landscape connectivity analysis reported in McRae et al. (2016) identifies those areas likely to facilitate ecological flow -- particularly movement, dispersal, gene flow, and distributional range shifts for terrestrial plants and animals -- over large distances across the Pacific Northwest and northern California. Relative connectivity values across this broad region were delineated spatially with OmniScape (Pelletier et al. 2014) using a modified moving-window algorithm to quantify flow among all natural and semi-natural lands up to a distance of 50 km. CircuitScape treats landscapes as resistive surfaces, where high-quality movement habitat has low resistance and barriers have high resistance. The algorithm incorporates all possible pathways between movement sources and destinations and identifies areas of high flow via low-resistance routes, i.e., routes presenting relatively low movement difficulty because of lower human modification, and thus lower mortality risk.

The results of this analysis identified broad, relatively intact areas where movement of terrestrial organisms is largely unrestricted by human modifications to the landscape, as well as constricted areas where fragmentation has reduced movement options and further habitat loss could isolate remaining natural lands. Results of McRae et al. (2016) were presented via three different map products reflecting different facets of modeled landscape connectivity -- 1) regional flow potential, 2) current flow percentile, and 3) normalized current flow. Each of these analyses are briefly summarized below and presented with the excerpted map sections covering the Cascade-Siskiyou focus area.

Regional Flow Potential

Regional flow potential represents the pattern of ecological connectivity across the regional landscape in the absence of barriers to movement. As such, it serves as a baseline, or null model, against which the actual, more restricted flow patterns created by finer-scale patterns of human development and other landscape features can be compared. Pixels surrounded by large natural areas have the most lands to connect within 50km, and thus the highest flow potential (shown in bright yellow, Figure 11). In contrast, heavily modified areas include numerous barriers to movement and therefore exhibit very little or no connectivity potential (shown as blue). Pixels intermediate between these two extremes that still support some degree of ecological flow (shown in orange to red) cover the largest percentage of the state. According to this analysis, the Cascade-Siskiyou land bridge (roughly highlighted by black dashed-line oval in Figure 11) includes the fewest movement barriers and exhibits the greatest potential for landscape connectivity in the state of Oregon between coastal and inland mountain systems.

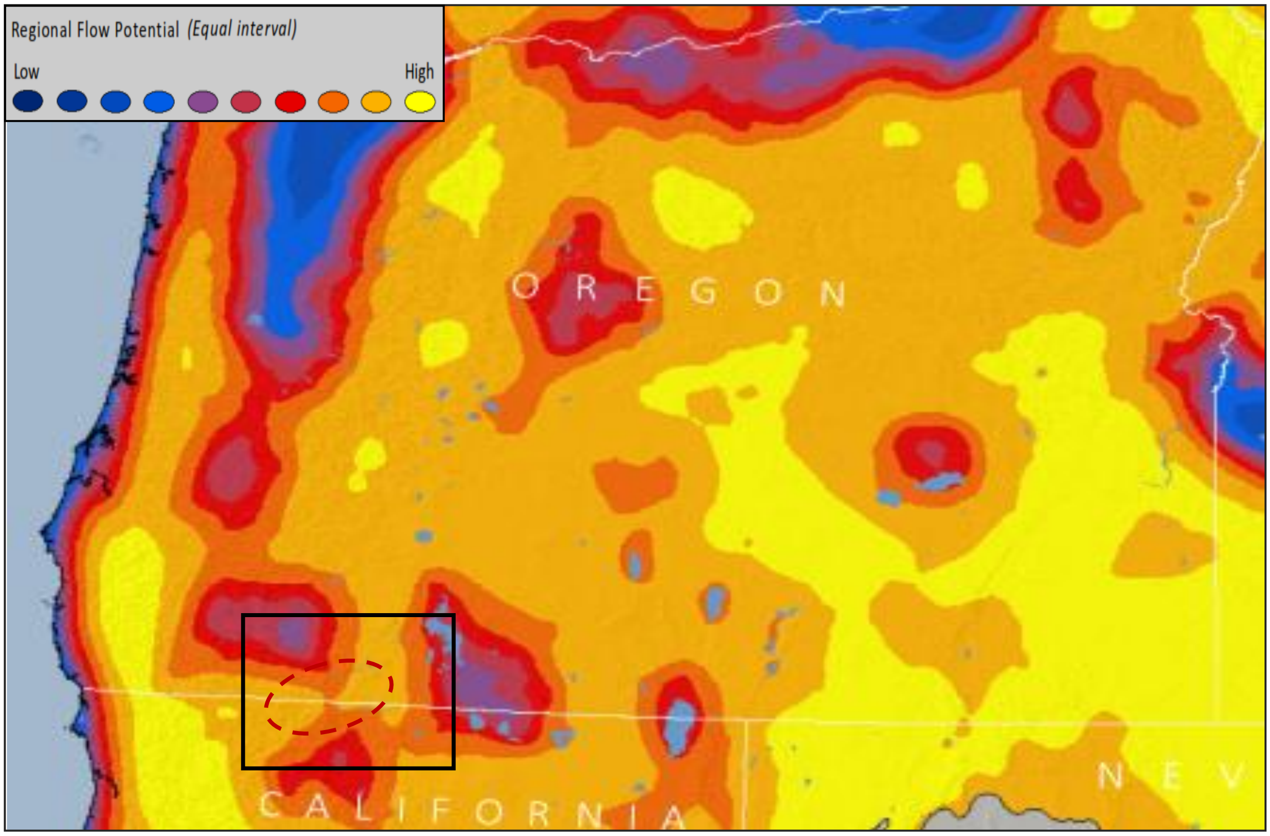

Figure 11. Regional flow potential across Oregon and adjacent California, defined by McRae et al. (2016) as the pattern and relative degree of connectivity that exists in the absence of barriers. Grid cells surrounded by highly natural areas have the most available land to connect within the programmed search radius, and thus the highest flow potential. Black rectangle approximates location of the Cascade-Siskiyou focus area, and dashed maroon oval identifies east-west band of high flow potential associated with Cascade-Siskiyou linkage.

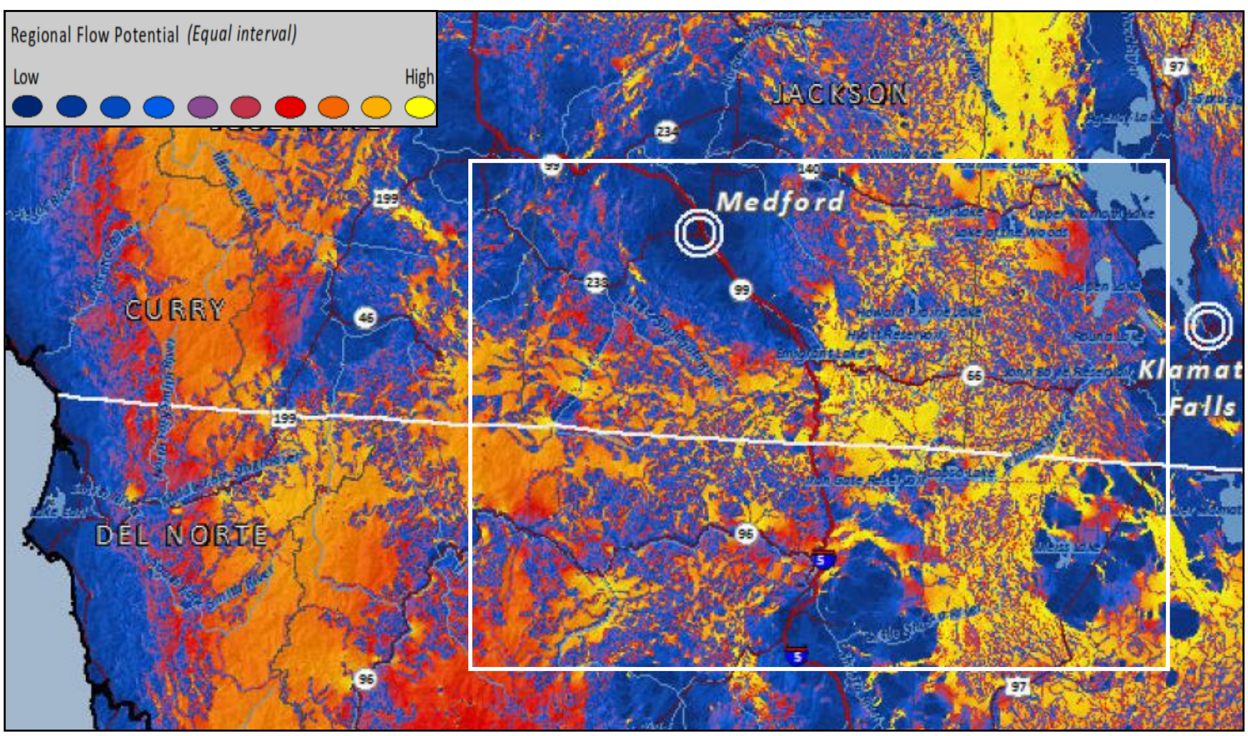

Figure 12. Map of current flow percentile or terrestrial connectivity within the Cascade-Siskiyou focus area (white rectangle) among all natural and semi-natural lands, developed by McRae et al. (2016). Current flow is highest (orange/yellow colors) between lands with high source weights (most natural / least human-modified) and along flow paths of low resistance (most permeable with few barriers to movement).

Current Flow Percentile

McRae et al. used CircuitScape with a moving window algorithm to quantify ecological flow among all pixels up to a distance of 50 km. The resulting map product depicts current flow as a percentile, and illustrates how existing patterns of flow across the landscape may become diminished, redirected, or concentrated through certain areas due to the spatial arrangements of cities, towns, farms, roads, open water and other natural features (Figure 12). Areas that exhibit the highest current percentile flow (yellow pixels in Figure 12) essentially represent 'pinch points' -- where the movement of terrestrial organisms is channeled or concentrated so as to avoid barriers such as developed lands or open water.

A clearly identifiable east-west 'bridge' of relatively high connectivity (red/orange/yellow pixels) parallels the crest of the eastern Siskiyou Mountains and extends downslope in elevation to include the rugged Klamath River canyon in California. This zone of high connectivity continues east to include the Cascade-Siskiyou National Monument, and then pivots north/south to follow the primary axis of the Southern Cascades. The width of the Cascade-Siskiyou land bridge is constrained by large areas with little or no connectivity (light to dark blue pixels) associated with heavily developed lands of the upper Rogue (north, in Oregon) and Shasta and Scott Valleys (south, in California). Connectivity also declines dramatically east of the Cascades where mountainous terrain grades into relatively flat valley bottom lands developed for agriculture across the upper Klamath Basin.

Normalized Current Flow

In this analysis, current flow percentile was divided by regional flow potential to generate a normalized display of current flow. Normalizing the ecological flow data helps to reveal the underlying mechanism associated with different landscape patterns created by the CircuitScape model. Areas where flow is higher than expected (i.e., pixels where current flow > regional flow potential) tend to occur where barriers are channeling movement and/or creating pinch-points in heavily fragmented landscapes. Conversely, diffuse patterns of flow are characteristic of areas where barriers are minimal and numerous options exist for unobstructed movement across the landscape.

The resulting map of normalized current flow (Figure 13) was stratified into four differing landscape connectivity classes: 1) diffuse -- relatively intact areas where many options for movement through mostly natural lands exist, 2) intensified -- areas where connectivity options are moderately restricted by human development, 3) channeled -- channeled areas or narrow pinch-points where connectivity options are strongly limited and further habitat loss could isolate remaining natural areas, and 3) impeded -- areas where flow is eliminated or impeded by barriers.

McRae et al.'s map of normalized current flow indicates that most of the Cascade-Siskiyou focus area exhibits relatively high habitat connectivity (Figure 13). An estimated ~80% of the focus area can be classified as moderately diffuse flow (i.e., largely unobstructed by development), with the largest, most contiguous areas associated with steep, mountainous terrain in the eastern Siskiyous and Southern Cascades. Smaller, more scattered patches classified as intensified flow are concentrated in the Rogue and Shasta Valley foothills, and in the southern and western portions of the Cascade-Siskiyou National Monument. Areas with very little or no connectivity are associated with extensive areas of developed land in the Rogue and Shasta Valleys and, east of the Cascades, agricultural lands in the upper Klamath Basin.

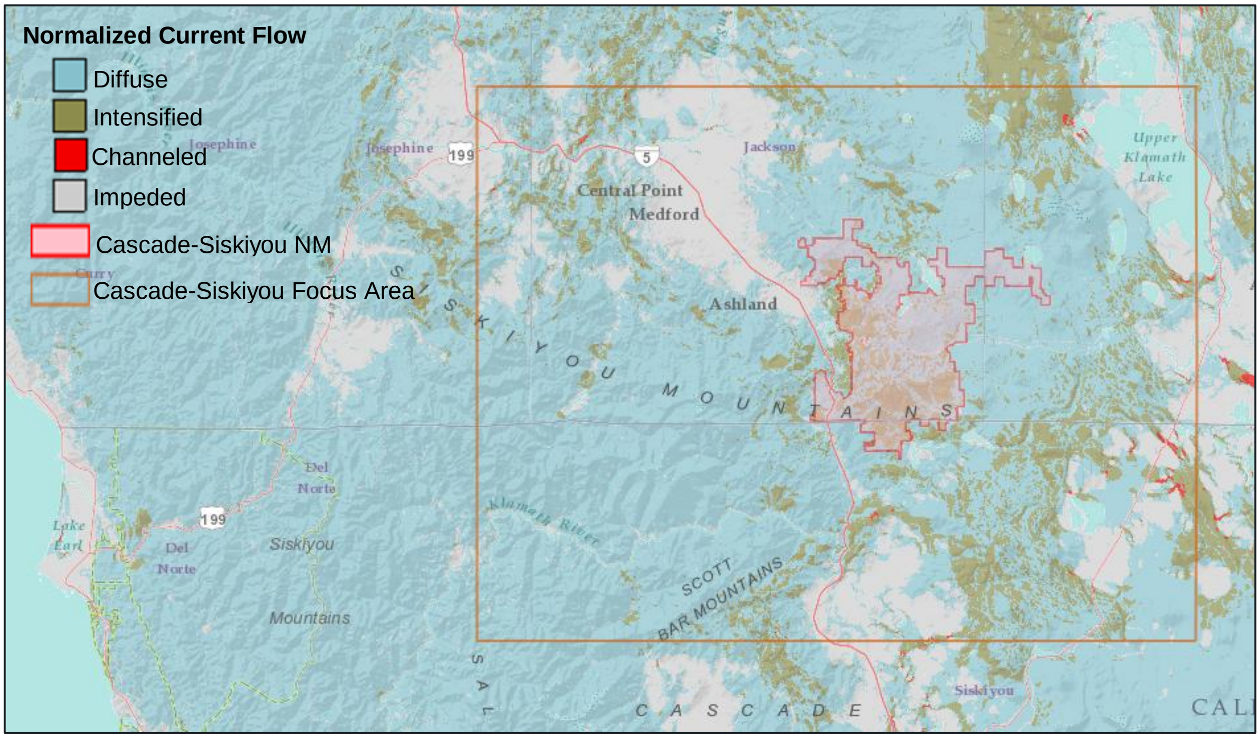

Figure 13. Normalized current flow from McRae et al. (2016) for the Cascade-Siskiyou focus area, created by dividing current flow by regional flow potential across all grid cells. Normalized data were then stratified into four terrestrial connectivity classes, identifying where: 1) many options exist for movement through mostly natural / undeveloped lands (diffuse), 2) movement options are significantly restricted by development (intensified), 3) connectivity is severely constrained to form bottlenecks or pinch points (channelized), and 4) movement is largely blocked by barriers (impeded).

Buttrick, S., K. Popper, M. Schindel, B. McRae, B. Unnasch, A. Jones and J. Platt. 2015. ***Conserving Nature's Stage: Identifying Resilient Terrestrial Landscapes in the Pacific Northwest***. The Nature Conservancy, Portland, OR.

The primary objective of this broad-scale analysis was to spatially identify those areas across the Pacific Northwest and Northern California that have the greatest potential to collectively and individually sustain native biodiversity, even as the changing climate alters species' distribution patterns. To achieve this goal, the authors focused on mapping sites likely to be resilient to climate change, which they defined as a function of local permeability to movement (i.e., connectivity) and topoclimate diversity. Sites that were both locally permeable and topoclimatically diverse were considered most resilient to climate change because they have the highest potential to allow organisms to access climatically suitable habitats by moving short distances. Results of this analysis in terms of landscape permeability and resilience to climate change, particularly as they apply to the Cascade-Siskiyou focus area, are briefly summarized below.

Landscape Permeability

Buttrick et al. (2015) defined permeability as "a measure of the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms." A method to map landscape permeability as a continuous surface was developed by integrating spatial information on the relative hardness of barriers to movement, the degree of connectedness between various land cover types, and the physical arrangement of natural and human-modified habitats. This surface was created by evaluating the capacity for ecological flow outward from every 90 meter-sized cell into its local neighborhood, up to a

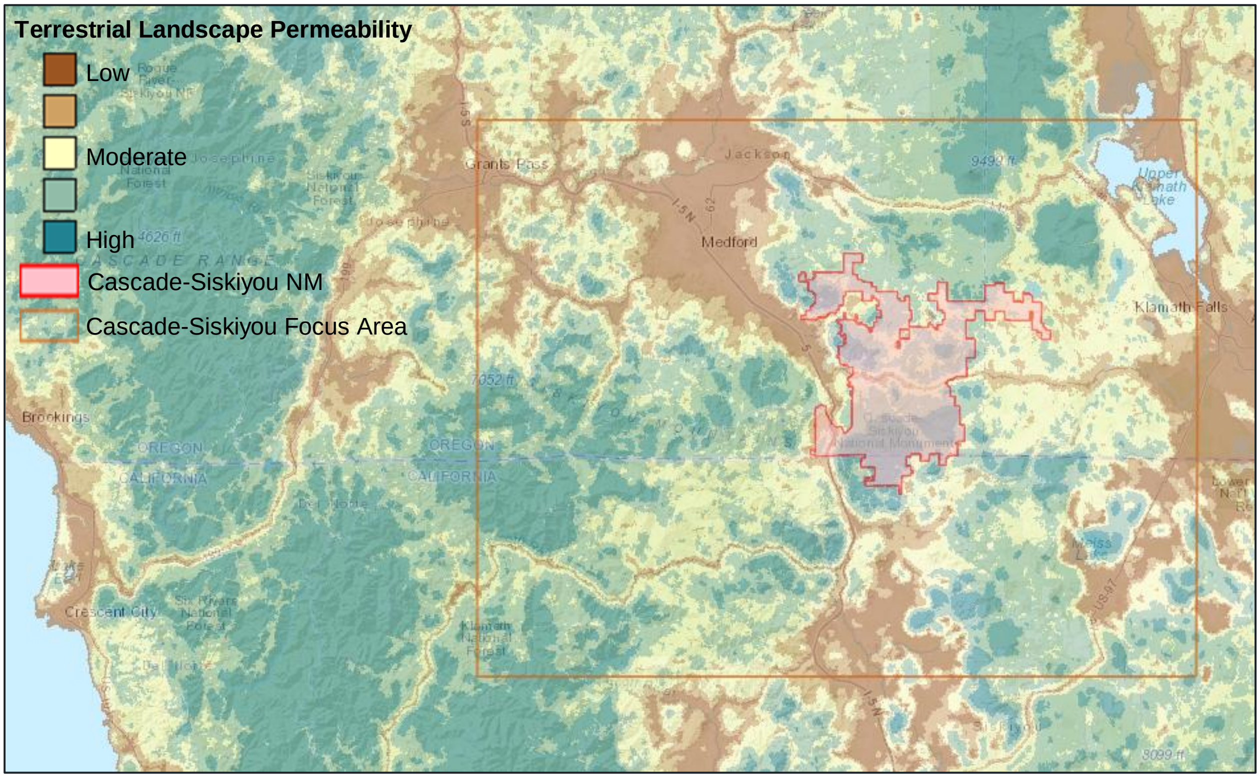

Figure 14. Map of terrestrial landscape permeability for the Cascade-Siskiyou focus area (orange rectangle), from Buttrick et al. (2015). Permeability is defined as the degree to which a landscape sustains ecological processes and supports movement of many species by virtue of it structural connectedness. Buttrick et al.'s analysis calculated the capacity for ecological flow outward from each 90-m focal cell into its local neighborhood up to a maximum distance of three kilometers.

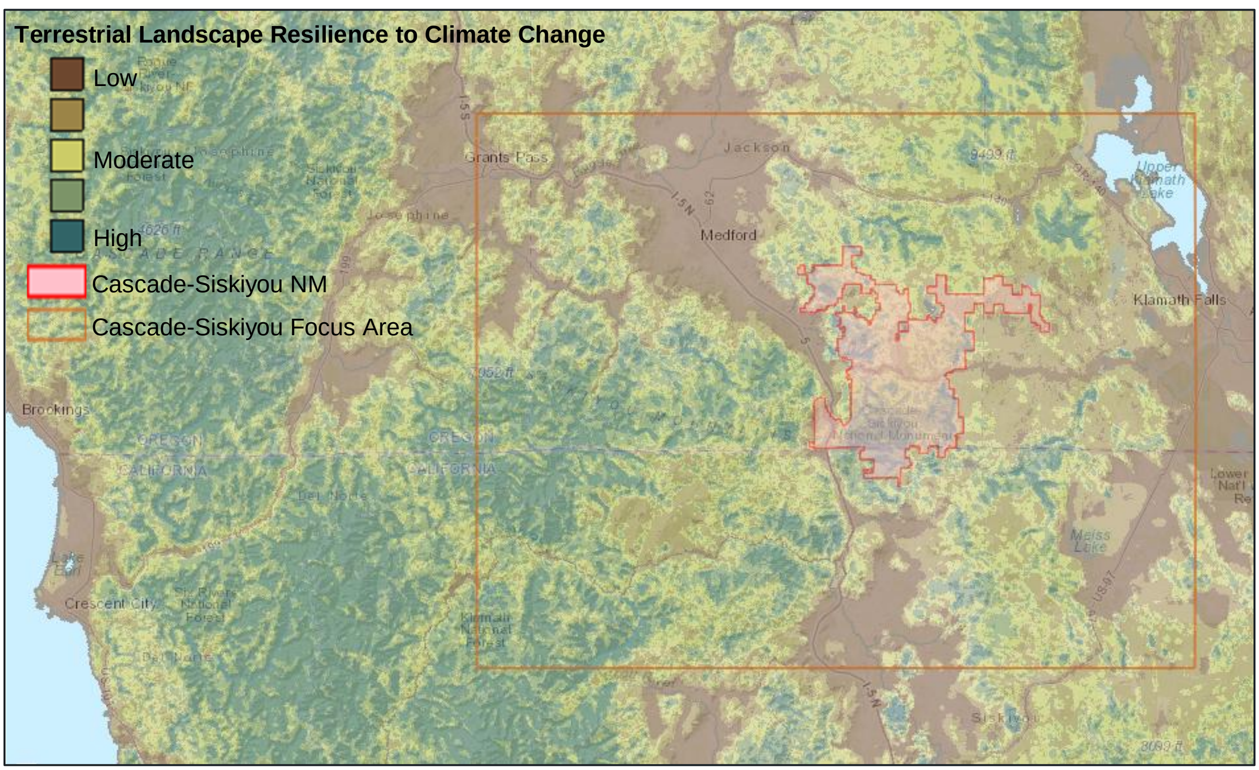

Figure 15. Buttrick et al.'s mapped results of terrestrial resilience to climate change for the Cascade-Siskiyou focus area (orange rectangle), calculated by multiplying data on topoclimate diversity and landscape permeability, then stratifying scores by ecoregion and geophysical setting to create the final product. High values -- generally correlated with topographically diverse areas -- indicate a specific site is more resilient to climate change impacts than lower values.

maximum distance of 3 km. Each cell was assigned a standardized permeability score (0-100 scale) based on how much resistance to movement existed within its given neighborhood.

According to final maps of landscape permeability presented by Buttrick et al. (2015), local permeability within the Cascade-Siskiyou focus area is highly variable (Figure 14). Areas of very low permeability (shown in yellow to brown) are primarily associated with lower-elevation lands intensively developed for agriculture and residential development in the upper Rogue (north) and Shasta/Scott Valleys (south) and the upper Klamath Basin (east). Primary highway corridors, such as Interstate 5 (north-south), CA State Highway 96 (east-west) and OR Highway 66 (east-west), also scored low on permeability and likely act as significant barriers or filters to movement for many species. High permeability areas (shown in light to dark green) are primarily associated with steeper terrain in the Siskiyou (east-west) and Cascade (north-south) Ranges, the large majority of which are under federal ownership.

Landscape Resilience

Buttrick et al. (2015) defined landscape resilience as a function of both an area's diversity of topoclimates and ability to support terrestrial species movement, or permeability. The authors posit that topoclimates provide species localized refugia from the direct effects of a changing climate, whereas landscape permeability reflects the ability of a site to facilitate terrestrial species movement to and between suitable topoclimates as they shift in response to climate change. To calculate terrestrial landscape resilience, topoclimate data were combined with landscape permeability scores to generate a discrete, standardized resilience value for every 90-meter cell across the large project area. Higher values indicate a specific site is relatively more resilient to climate change impacts than lower values. These results were then stratified by ecoregion and by geophysical setting to identify the portions of each landscape more likely to be resilient to the adverse effects of climate change.

Results of the landscape resilience analysis in the Cascade-Siskiyou focus area roughly correlate with patterns of landscape permeability described above. The large majority of area within the east-west montane land bridge, where the eastern Siskiyous intersect with the Southern Cascades, exhibits moderate to high resilience scores (shown in light to dark green, Figure 15). Denser patches of high resilience are located in the southern section of the Cascade-Siskiyou NM, along the primary east-west axis of the Siskiyou Mountains in Oregon, and in steeper sections of the Klamath River canyon in California. These areas are the most likely to conserve biodiversity in the face of climate change by providing resident species the maximum opportunity to move short distances and successfully find suitable habitat. In contrast, relatively low resilience areas are associated with large inland valleys, some lower foothill settings and primary highway corridors. The authors discuss how these results can be used to guide future land use planning and conservation initiatives.

Theobald, D.M., K.R. Crooks and J.B. Norman. 2011. ***Assessing Effects of Land Use on Landscape Connectivity: Loss and Fragmentation of Western U.S. Forests***.
Ecological Applications 21(7): 2445-2458.

The overall goal in this study was to develop a comprehensive approach to analyzing landscape connectivity that can provide quantitative estimates of the effects of land-use change and to illustrate its application on a broad, regional expanse of the western United States. Toward these ends, the authors: 1) identified relatively undeveloped, contiguous areas of forest that could be considered high-quality patches (data derived from LANDFIRE vegetation classification, minimum patch size of 100 km^2); 2) computed the effective distance between forest patches that reflects the effect of land use and land cover types in the intervening matrix; 3) quantified connectivity among forest patches using two graph-theoretic metrics calculated with the software tools application FunConn (Theobald et al. 2006): and 4) used connectivity metrics to rank the relative importance of forest patches and delineate a minimum network of landscape-level linkages that effectively connects all high-quality forest patches across the West (aka "backbone" of a network or minimum spanning tree).

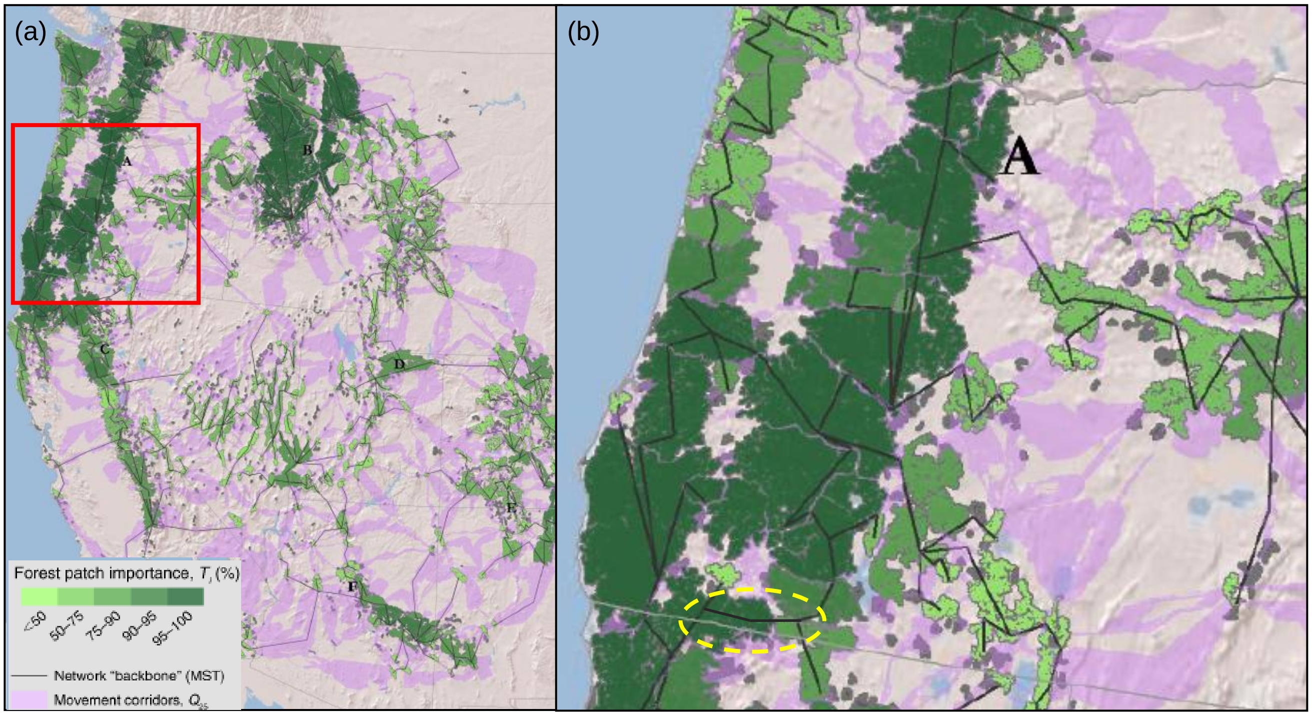

Figure 16. The relative importance of high-quality forest patches displayed across a) the western United States and b) Oregon and adjacent California (red rectangle inset), using a minimum patch size of 100 km^2. Also shown are identified movement corridors (purple) as well as the 'minimum spanning tree' for landscape connectivity (black lines); i.e., the minimum set of linkages that effectively connects all patches. The line vector representing east-west linkage in the Cascade-Siskiyou focus area is highlighted (yellow dashed-line oval).

Forested lands in the western U.S. were found to occupy over 1.7 million km^2, and between 25-30% of these lands were identified as high-quality forest patches that are integral to the existence of a region-wide forest network. Incorporating the effects of land uses such as residential development and transportation infrastructure resulted in a 4.5% decline (~20,000 km^2) in total area of high-quality patches. Several of the large forest patches located in southwest Oregon and adjacent California were ranked within the highest 10-20 percentile classes in terms of their relative importance in contributing to a connected network. An east-west linkage or corridor identified as part of the minimum spanning tree connects high-quality forest patches located just north of the California-Oregon border in the Cascade-Siskiyou focus area. This linkage vector essentially parallels the crest of the Siskiyou Mountains and intersects a north-south trending connectivity zone that follows the Cascade Range in the vicinity of the Cascade-Siskiyou National Monument (Figure 16). The authors recommend that results of this analysis be used to identify regionally important zones of landscape connectivity and to prioritize those most in need of more detailed, local-scale corridor assessments and plans.

Western Governors' Association (WGA). 2010. ***Western Regional Wildlife Decision Support System: Definitions and Guidance from State Systems***. Western Governors' Association, Denver, CO. [See also: Western Governors' Wildlife Council (WGWC). 2013. ***Western Wildlife Crucial Habitat Assessment Tool (CHAT): Vision, Definitions and Guidance for State Systems and Regional Viewer***. White Paper, v.3. https://www.adfg.alaska.gov/static/maps/chat/pdfs/wgwc_whitepaper_final.pdf; and Western Association of Fish and Wildlife Agencies. 2018. ***Western Governors' Crucial Habitat Assessment Tool: Mapping Fish and Wildlife Across the West***. http://www.wafwachat.org].

In response to growing recognition of the importance of and accelerating risks to landscape connectivity to maintaining wildlife populations in the western U.S., the Western Governors' Association approved development of the Western Regional Wildlife Decision Support System, a set of analytical tools that integrates a range of geospatial data to identify important wildlife corridor and crucial habitat values across the western states. The main objective of this west-wide effort was to provide individual states with information on current landscape conditions, as well as the mapped locations of Large Intact Blocks (LIBs) of habitat important to wildlife and Important Connectivity Zones (ICZs) that link them across state and regional boundaries. The Western Regional Wildlife Decision Support System (later revised and renamed as the Crucial Habitat Assessment Tool; CHAT) has since migrated from the Western Governors' Association to the Western Association of Fish and Wildlife Agencies, who are managing its implementation (see Western Governors' Wildlife Council 2013, 2018).

The Large Intact Blocks dataset was developed using NatureServe's Landscape Condition Class model to map areas greater than 1,000 hectares that are relatively intact or exhibit low levels of human impacts. Once identified, LIBs were stratified into three levels of importance based on the relative level of intactness and total area. Important Connectivity Zones represent linear landscape paths that were identified by using a human footprint / landscape condition layer as a "cost" surface that influences wildlife movement. ICZ paths or flowlines were mapped by analyzing every pixel for a least cost path to every other pixel. Pixels and paths that were repeatedly identified as the most efficient or least cost movement routes formed a network of primary flowlines. For each flowline that intersected one or more LIBs, start/end points were determined and a one-mile buffer on each side of the least cost path was designated to create the final ICZ dataset (maps published in December 2013).

Figure 15 presents results of this analysis within the Cascade-Siskiyou focus area as well as adjacent portions of southwest Oregon and adjacent California. Large Intact Blocks (shown in blue, Figure 17) are widely distributed, with the largest, most contiguous LIBs associated with national forest lands in the Klamath-Siskiyou Mountains (to the west) and the High Cascades east of the Rogue Valley in Oregon. An intersecting network of ICZs connect these intact habitat blocks, a large proportion of which are immediately adjacent to and/or pass through the Cascade-Siskiyou National Monument (dotted black lines, Figure 17). The primary ICZs within this network are several, roughly parallel paths located along a northeast-southwest orientation that functionally link LIBs in the eastern Siskiyous with lands in the Cascade Range (#1-4). Several other ICZs in the Cascade-Siskiyou Monument area trend north-south, linking areas of intact habitat in the Cascades across the state border (#5-6).

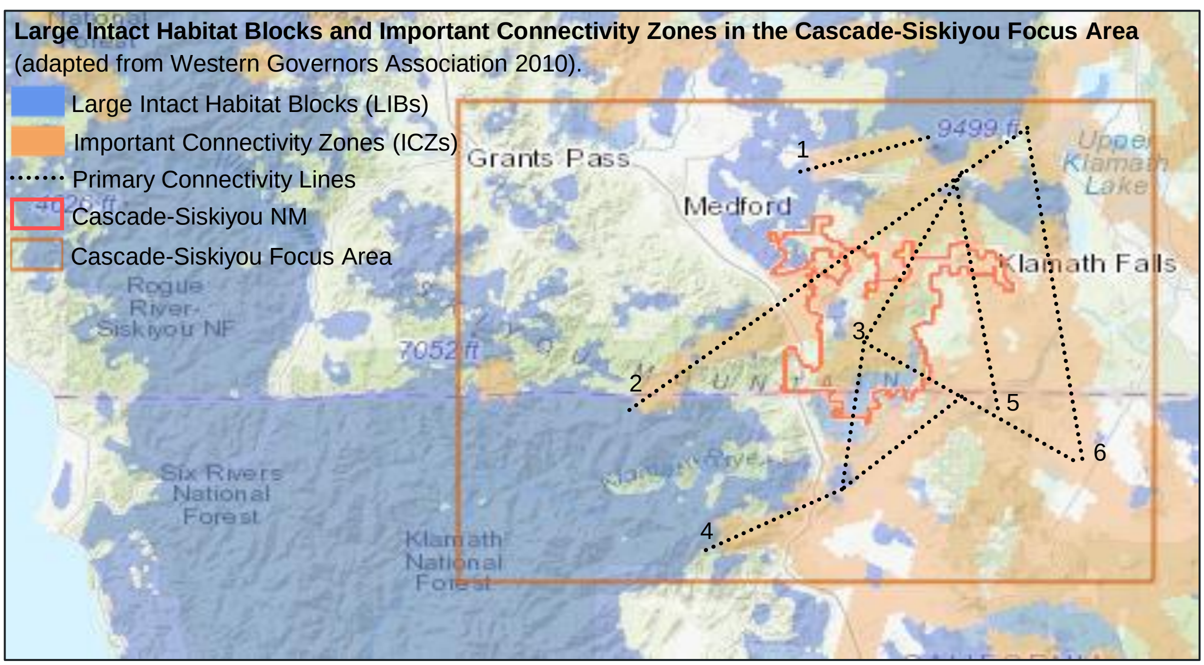

Figure 17. Large Intact Blocks of habitat and Important Connectivity Zones (ICZs) in the Cascade-Siskiyou focus area, using data from Western Governors' Association (2010). Highlighted ICZs (dotted black lines) link large natural areas in the Siskiyou Mountains and the Cascade Range (#1-4), and connect habitat blocks in the Cascades across the Oregon-California border (#5-6).

III. STATE AND ECOREGIONAL SCALE CONNECTIVITY ASSESSMENTS

Cameron D.R., C. Schloss, B. McRae and D.M. Theobald. In prep**. *Habitat Connectivity Assessment for California.*** The Nature Conservancy, Sacramento, CA.

Cameron et al. (in prep.) have completed the most current and comprehensive landscape connectivity assessment in California for plant and animal species whose movement is inhibited by human development. As with other connectivity analyses utilizing a similar methodology (e.g., Dickson et al. 2017, McRae et al. 2016), this study focused on structural connectivity of relatively undeveloped lands, with resistance to movement modeled as a function of landscape naturalness. The author's used a modified version of CircuitScape (Pelletier et al. 2014, McRae et al. 2013) with a moving-window algorithm to quantify ecological flow among all pixels within a 50km radius. CircuitScape treats landscapes as resistive surfaces, where high-quality movement habitat has low resistance and barriers have high resistance. The algorithm incorporates all possible pathways between movement sources and destinations and identifies areas of high flow via low-resistance routes, i.e., routes presenting relatively low movement difficulty because of lower human modification, and thus lower mortality risk.

To investigate how patterns of landscape connectivity may be affected by climate change, an additional analysis integrated results of the connectivity analysis with current climate data. A spatial layer depicting mean annual temperature (from 1961-1990) was generated for the state (180 m resolution), and then queried to determine where spatial connectivity exists between grid cells with temperature profiles that differed by > 1^o C and < 5^o C. Areas important for climate connectivity were delineated by connecting each natural and semi-natural grid cell to cooler cells (if available) within 50 km. The resulting map suggests which portions of the existing California landscape could best promote species' movement across significant climate gradients. Patterns of potential flow were diminished in areas with fewer options for moving to significantly cooler areas within 50 km (generally areas with less topographic relief).

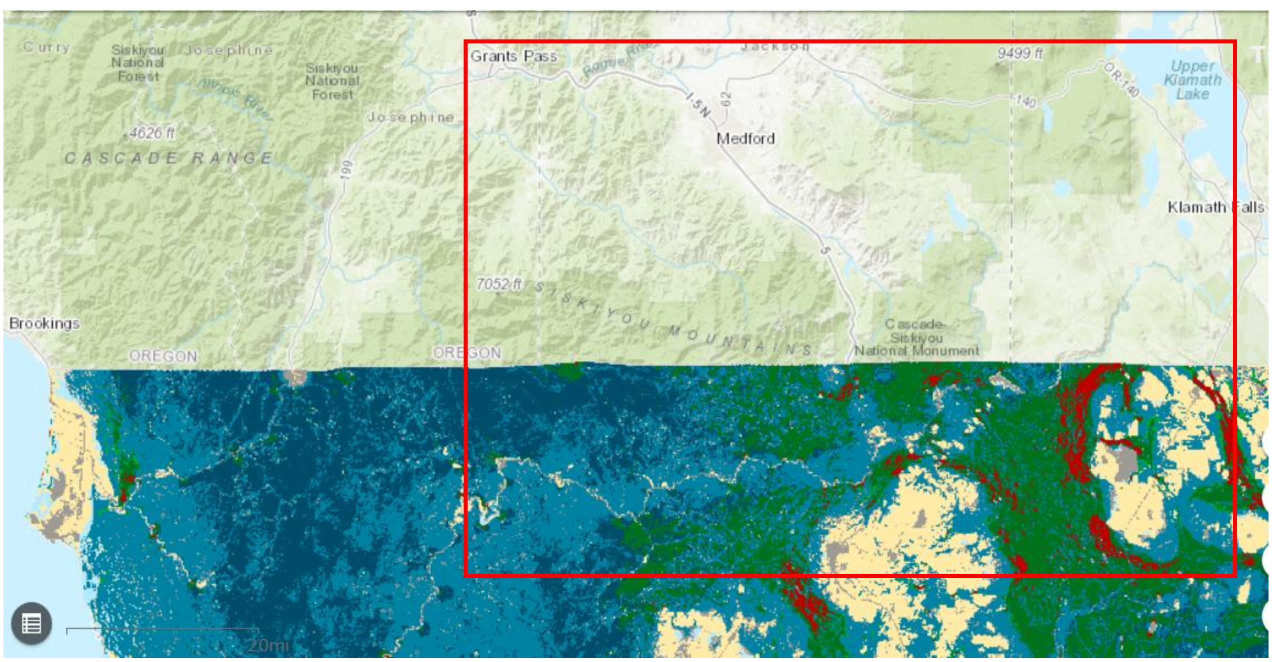

Figure 18. Current flow within the California portion of the Cascade-Siskiyou focus area (red rectangle) from Cameron et al. (In prep.), a measure of landscape connectivity calculated by combining patterns of naturalness (flow potential) with anthropogenic barriers to movement (resistance). Grid cells with connectivity were further stratified into one of three classes: diffuse - many options for movement through mostly natural lands with fewer fragmentation barriers (blue); intensified - movement options significantly restricted by human development (green); and channelized - an area where connectivity options are severely constrained (maroon).

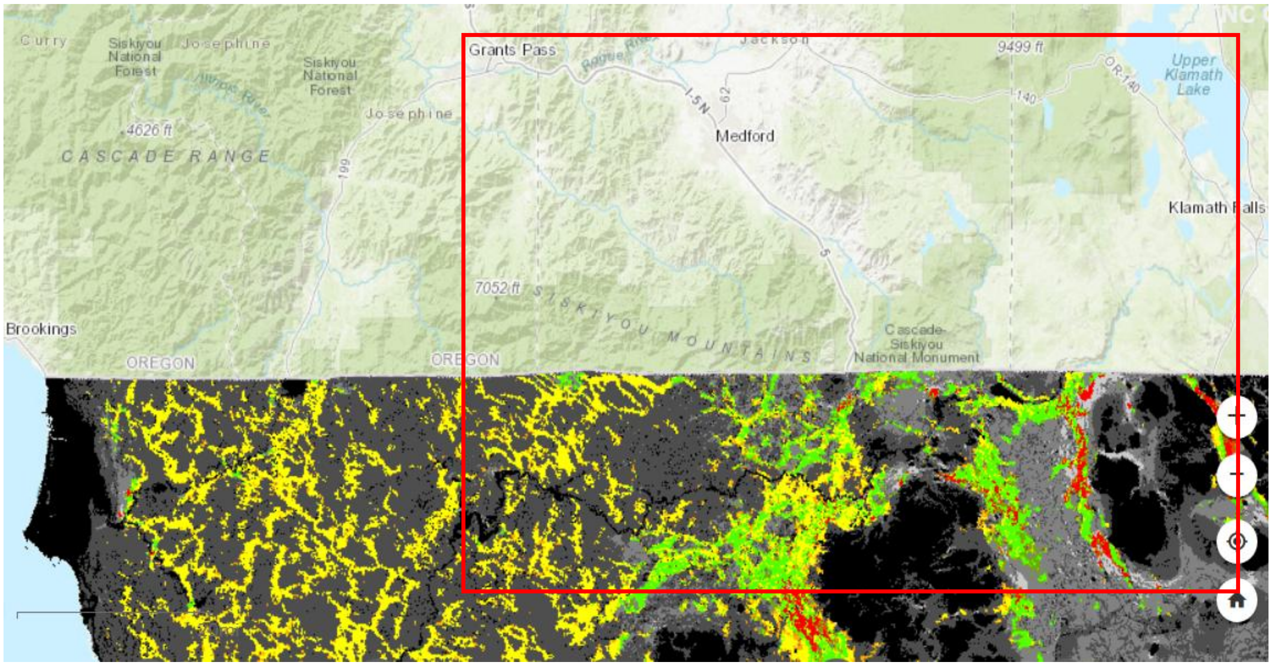

Figure 19. Results of Cameron et al.'s analysis of connectivity and climate, displaying in color those portions of the landscape most likely to facilitate successful movement across climate gradients (e.g., natural land grid cells adjacent to cooler temperatures). Climate-connected areas are color-coded as follows: yellow = diffuse, green = intensified, and red = channelized connectivity. No data available for the Oregon side of the Cascade-Siskiyou focus area (red rectangle).

Since this analysis was restricted to California, Cameron et al.'s results do not include connectivity values associated with adjacent lands in southwest Oregon. Nevertheless, their results indicate that the California portion of the Cascade-Siskiyou focus area currently supports relatively high connectivity. The primary connectivity classes, in order of decreasing area, are intensified (movement options significantly restricted by human development), diffuse (many options for movement through mostly natural lands with fewer fragmentation barriers), and channelized (an area where connectivity options are constrained; often the last remaining option for connectivity between natural areas through a modified environment; see Figures 18 and 19). Areas that act as barriers or significantly impede movement are relatively uncommon, largely restricted to developed lands immediately adjacent to the Klamath River, the Interstate 5 highway corridor and further south, in the Shasta Valley.

Hannah, L., M. Rebecca Shaw, P. Roehrdanz, M. Ikegami, O. Soong and J. Thorne. 2012. ***Consequences of Climate Change for Native Plants and Conservation***. California Energy Commission. Publication number CEC-500-2012-024. Sacramento, CA.

Recognizing the need to identify areas of landscape connectivity that can facilitate species movements in response to climate change, Hannah et al. (2012) developed an analytical approach called Network Flow Analysis (NFA) and presented initial coarse-scale results for the state of California. The NFA approach is based on modeling spatial projections of suitable habitat for over 2,200 native plant species in ten-year time steps to identify "chains" of habitat that are most likely to be connected in time. An Essential Connectivity Chain is formed by a continuous path or a set of pixels in which a species can successfully disperse from currently suitable habitat through all time steps to future suitable habitat. A heuristic algorithm then selects and maps areas that form chains of suitable habitat meeting minimum suitable area targets. The resultant outputs represent specific areas required to ensure both spatial and temporal connectivity of suitable habitats for a large number of native plant species through time (Figure 20).

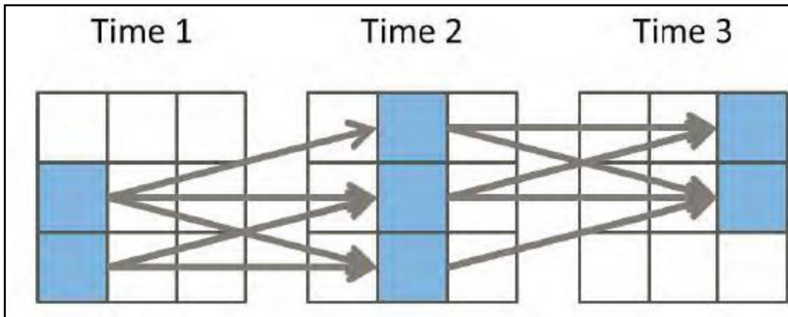

Figure 20. Conceptual illustration of Chains of Suitable Habitat, from Hannah et al. (2012). Areas shaded blue represent suitable habitat in each time step on 3 x 3 grid. Grey arrows represent possible chains within a species dispersal capability necessary to retain suitable habitat across all time steps.

The final result of Hannah et al.'s Network Flow Analysis is a map of California delineating Essential Connectivity Chains of suitable habitat (shown in maroon, Figure 21a), i.e., those areas most likely to be successfully utilized by native plants to shift their local distributions as climate changes. Many of these essential connectivity areas are adjacent to existing protected lands, as the algorithm preferentially selected areas to connect both within and between areas currently managed for conservation. Narrowing in on results of this analysis near the Oregon-California border (Figure 21b), Essential Connectivity Chains were identified in the Cascade-Siskiyou focus area along an east-west axis, essentially following the crest of the Siskiyou Mountains and linking with the Cascade-Siskiyou National Monument (shown in orange dashed-line oval, Figure 21b). Broader areas of high connectivity were also mapped within the Monument and in the eastern Siskiyous.

The results of Hannah et al. (2012) are reported as preliminary, the authors recognizing that further refinements in this NFA approach will be required before final state-wide recommendations for habitat and climate connectivity can be generated. However, the essential connectivity chains delineated in this study "provide some indication of possible conservation priorities under climate change", and help identify those focal areas most important to protect for adapting the state's conservation portfolio to projected climate change.

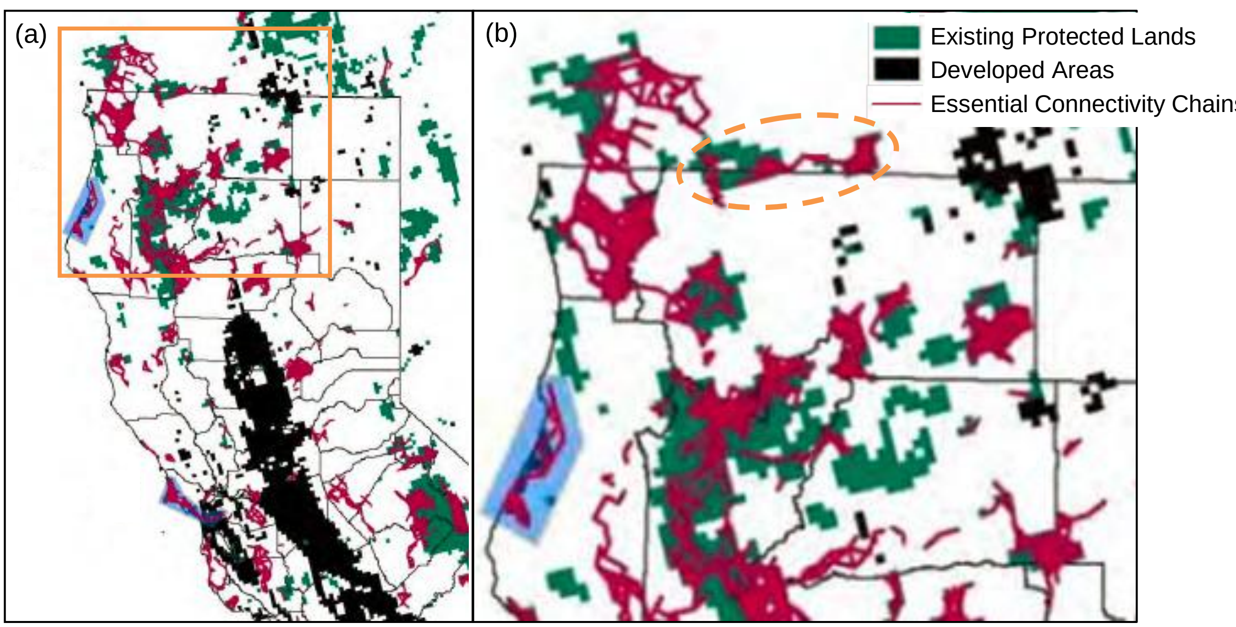

Figure 21. Map showing clusters of Essential Connectivity Chains identified by Hannah et al. (2012) in (a) northern California and (b; orange inset box) northwest California and adjacent Oregon, including portions of the Cascade-Siskiyou landscape. Essential Connectivity Chains represent those areas most likely to be successfully utilized by native plant species to shift their distributions as climate changes. The dashed orange oval in (b) highlights location of cluster of Essential Connectivity Chains correlated with the 'Cascade-Siskiyou land bridge'.

Olson, D., D.A. DellaSala, R.F. Noss, J.R. Strittholt, J. Kass, M.E. Koopman and T.F. Allnut. 2012. ***Climate Change Refugia for Biodiversity in the Klamath-Siskiyou Ecoregion***. Natural Areas Journal 32(1): 65-74.

The Klamath-Siskiyou (K-S) Ecoregion in southwest Oregon and northern California has been recognized as an important refuge for many species during past climate change events, but current anthropogenic stressors may compromise its effectiveness to act as a refugium for this century's projected changes. To address this concern, the authors developed an ecoregional planning framework for increasing the capacity of the landscape to conserve biodiversity in the face of climate change impacts. One of the central tenets of this framework is identification of a provisional set of mesorefugia that currently occur mostly outside of existing protected areas and, if protected, would increase opportunities for vulnerable species to persist into the future. The authors define mesorefugia as "large areas that contain nested clusters of microrefugia with similar species assemblages that have functioned as refugium over past millennia."

In this study, nine mesorefugia were provisionally identified across the K-S Ecoregion, based on large-scale biophysical features and locations that predict effective refugia -- e.g., coastal mountains with complex topography and/or areas of high precipitation. Areas with concentrations of range-restricted (i.e., local endemic) species or relict taxa dependent on cool or mesic habitats were also evaluated to refine candidate mesorefugia locations and boundaries. These included the distribution of Brewer spruce (*Picea*

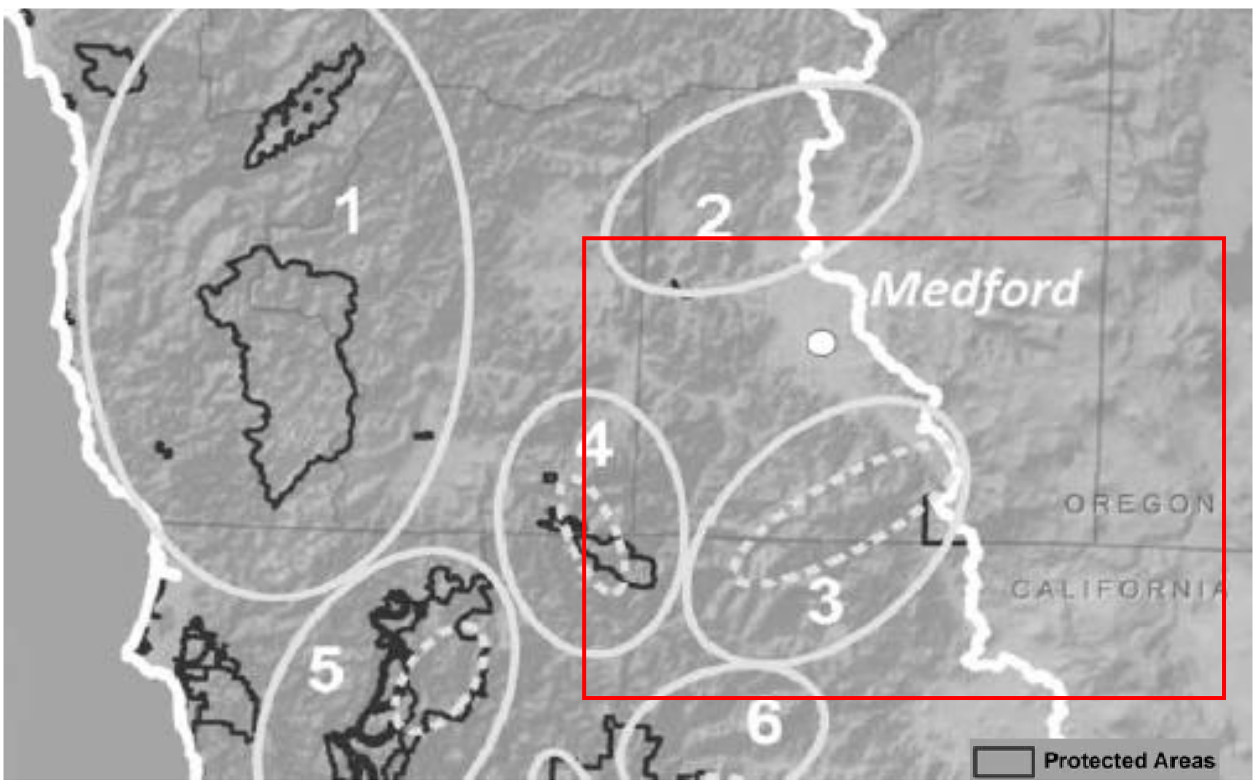

Figure 22. Subset of high-priority mesorefugia (gray ovals) identified by Olson et al. (2012) within the Klamath-Siskiyou Ecoregion, based on large-scale predictors of climate stability and an overlay of the distribution of mesophilic, range-restricted species, endemism zones for vascular plants and relict conifers. Dashed ovals represent high-elevation refugia that are more likely to conserve species and ecological functions under climate change. Numbers refer to named mesorefugia as follows: 1) Kalmiopsis, 2) North Siskiyous, 3) East Siskiyous, 4) North of the Southern Bend of the Klamath River, 5) West Siskiyous and 6) Lower Scott Bar River [additional mesorefugia not shown]. Note the East Siskiyou mesorefugia (3) is located within the Cascade-Siskiyou focus area (red rectangle) and contiguous with the Cascade-Siskiyou National Monument [not shown, just west of the ecoregional boundary (thick white line)].

breweriana), Engelmann spruce (*Picea engelmannii*), foxtail pine (*Pinus balfouriana*), Plethodon and Dicamptodon salamander species and numerous other plant and invertebrate species groups. Most of the high-priority mesorefugia occur outside of existing protected areas and will therefore require additional safeguards to increase the likelihood that these lands can continue to support many climate-vulnerable species into the future.

Of the nine identified mesorefugia, two are located partially or entirely within the Cascade-Siskiyou focus area, labeled in Figure 22 as 'East Siskiyous' and 'North of the Southern Bend of the Klamath River'. Of particular interest here are the 'East Siskiyous', which essentially encircle the eastern terminus of the range and connect with the Cascade-Siskiyou National Monument (located just outside the study's ecoregional boundary). The authors identified the Eastern Siskiyous as a high-priority climate mesorefugia largely because of the area's diverse terrain that spans a broad range of elevations, soils, microclimates and other environmental gradients, which in turn is more likely to allow species to move and successfully adapt to shifting habitats. "Protection [of these mesorefugia] will greatly improve the chances for persistence of a large portion of the ecoregion's diverse biota, even if we are uncertain of the magnitude, timing, and distribution of changes in temperature and precipitation at sub-regional scales."

Spencer, W.D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi and A. Pettler. 2010. ***California Essential Connectivity Project: A Strategy for Conserving a Connected California***. Prepared for CA Dept. of Transportation, CA Dept. of Fish & Game, and Federal Highways Administration. Sacramento, CA.

The CA Department of Transportation and CA Department of Fish & Game (now CA Department of Fish & Wildlife) commissioned the California Essential Habitat Connectivity Project (CEHCP) to design a functional network of connected natural areas capable of ensuring the continued persistence of California’s native biodiversity in the face of human development and land use change. The primary product of CEHCP's interdisciplinary assessment is a state-wide map delineating: 1) large, relatively natural habitat blocks important for supporting biodiversity (Natural Landscape Blocks) and 2) linkages essential for maintaining ecological connectivity between them (Essential Connectivity Areas). Essential Connectivity Areas were defined as portions of the landscape that most effectively connect Natural Landscape Blocks and represent the lowest relative resistance or "least cost" to a wide variety of ecological movements and flows (e.g., species migration, dispersal and gene flow). The CEHCP maps depicting connectivity are broad in scale, not based on the needs of any particular species, and focus on identifying natural areas that are likely most important for maintaining ecological integrity and functional connectivity across the state.

Within the Cascade-Siskiyou focus area, Spencer et al. (2010) identified a contiguous polygon that includes and is immediately adjacent to the California portion of the Cascade-Siskiyou National Monument as a Natural Landscape Block, which the authors named Wadsworth Flat (total area = 26,560 acres). Essential Connectivity Areas were identified emanating in four directions from Wadsworth Flat, including north of the California-Oregon border through the Cascade-Siskiyou Monument and beyond to the southern Oregon Cascades (see Figure 23). Other Essential Connectivity Areas connect Wadsworth Flat with Natural Landscape Blocks in the Siskiyou Mountains (west), California Cascades (south) and Modoc Plateau (east). Federal, state and local agencies are using data from CEHCP to conduct finer-scale connectivity assessments and support a range of land use and development planning efforts.

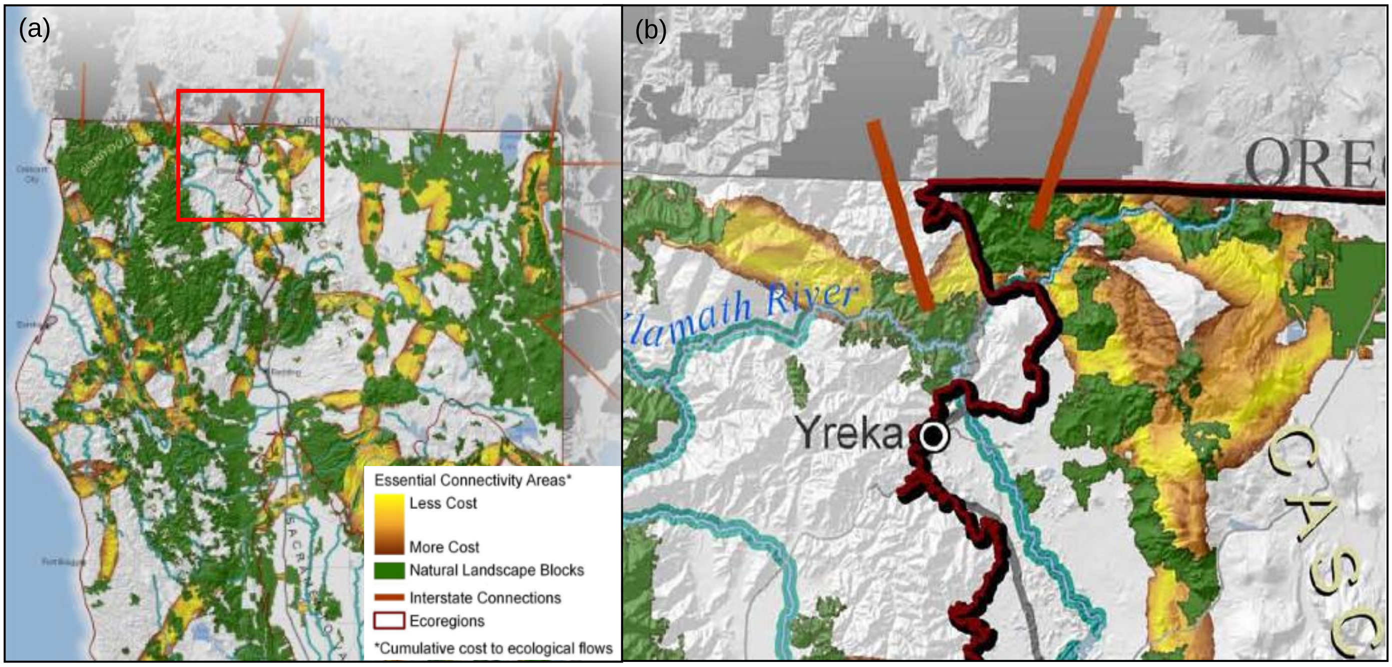

Figure 23. Essential connectivity map from Spencer et al. (2010), depicting large, relatively natural habitat blocks that support native biodiversity (Natural Landscape Blocks) and areas essential for ecological connectivity between them (Essential Connectivity Areas) in (a) northern California, and (b) the California portion of the Cascade-Siskiyou focus area. Essential Connectivity Areas are color-scaled to display gradation from the least (yellow) to most (brown) relative resistance or "cost" to a wide variety of ecological movements and flows. Adjacent connectivity values in Oregon were not analyzed in this study.

Hatch, A., S. Wray, S. Jacobsen, M. Trask and K. Roberts. 2008. ***Oregon Wildlife Linkage Project, Final Report***. Oregon Department of Fish and Wildlife, Salem, OR.

The Oregon Wildlife Linkage Project was created to evaluate human-created barriers to wildlife movement at a broad scale across the state of Oregon. The analysis was centered around data collected from a series of expert workshops held in 2007 throughout the state by the Oregon Department of Fish and Wildlife to help identify linkages, defined as key movement areas for wildlife. Workshops convened biologists, transportation planners, and others – including the public, private and non-profit sectors – to identify these locations on the landscape. Participants used personal knowledge as well as spatial information on vegetation, road networks, wildlife habitat and land ownership to identify important linkages for three groups of terrestrial species that are adversely affected by paved roads -- big game mammals, small mammals and reptiles/amphibians. The final result of these workshops was mapped information about the location of important barriers to wildlife movement associated with specific road segments across Oregon.

Using data collected from the workshops, working group authors identified state-wide priority linkage areas by ranking specific road segments using six criteria: 1) areas that are also identified in the Oregon Conservation Strategy as Conservation Opportunity Areas; 2) areas that are associated with high rates of wildlife mortality due to collisions with motor vehicles (according to OR Dept. of Transportation data); 3) areas that are in proximity to public lands; 4) areas that affect more than one focal species group; 5) areas that were identified at the workshops as providing movement pathways for focal species; and 6) areas that were identified at the workshops as facing significant threats. All ranks were compiled and normalized to produce a state-wide map of priority wildlife linkages (Figure 24a).

Connectivity values for wildlife across major roads in southwest Oregon and the Cascade-Siskiyou focus area are highly variable. The two highway segments identified in this study as the most significant barriers to wildlife movement are located along: 1) the southern-most section of Interstate 5 from Ashland to the California border, and 2) Highway 140 where it traverses the High Cascades through the Rogue River-

Siskiyou National Forest, just south of the Sky Lakes Wilderness (Figure 24b). Data are not available to determine which of the six criteria listed above used in ranking road segments were most significant in identifying these areas as high priority linkages/barriers. However, the authors note that wildlife vehicle collision data reported more deer/motor vehicle collisions in southwest Oregon on Interstate 5 than for any other segment of highway in the entire state. These results can be used to prioritize additional research on areas identified as important wildlife linkage/barriers, and develop mitigation projects such as wildlife crossing structures that can reduce the adverse impacts of primary roads at key locations.

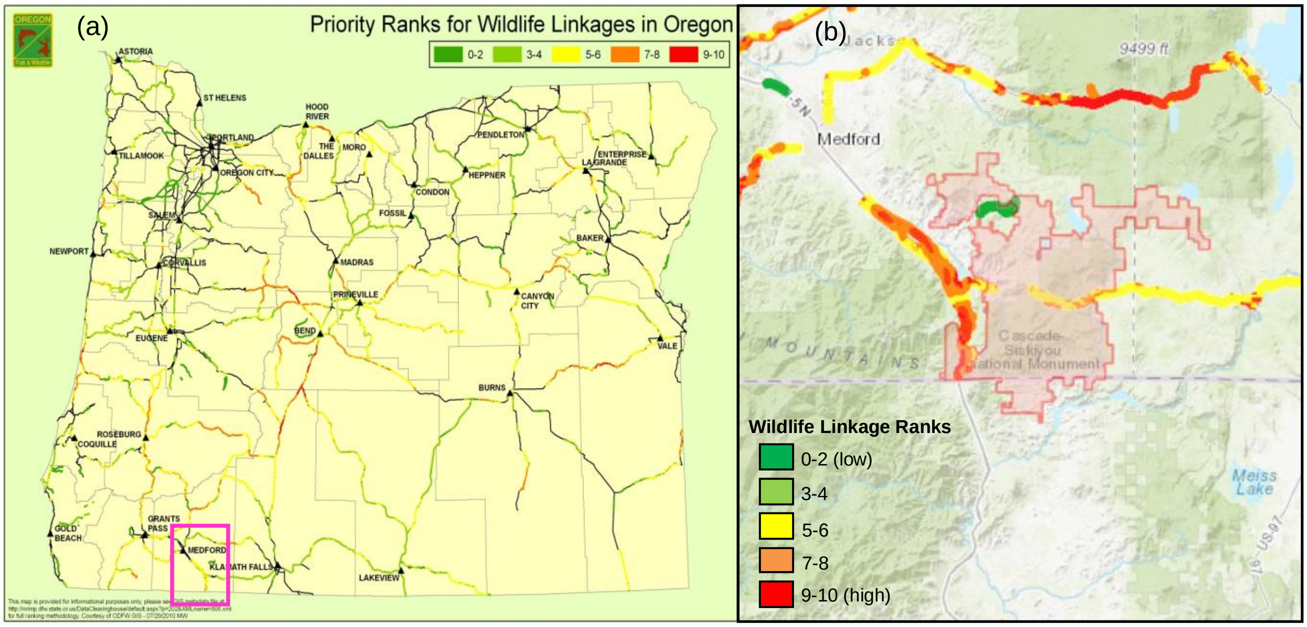

Figure 24. Priority ranks for wildlife linkages across major roads in (a) Oregon and (b; pink inset box) the vicinity of the Cascade-Siskiyou National Monument, from Hatch et al. (2008). Ranks were assigned based on information collected from a series of expert workshops, data on wildlife-vehicle collisions and several other criteria.

Noss, R.F., J.R. Strittholt, K. Vance-Borland, C. Carroll and P. Frost. 1999. ***A Conservation Plan for the Klamath-Siskiyou Ecoregion***. Natural Areas Journal 19: 392-411.

The authors present results of a conservation planning and reserve design process for the Klamath-Siskiyou Ecoregion in southwest Oregon and northwest California that was developed to satisfy three parallel objectives: (1) protection of special elements, such as rare species hotspots, old-growth forests and key watersheds; (2) representation of physical and vegetative habitat types; and (3) maintenance of viable populations of focal species (e.g., fisher). These three complementary goals were used to develop a variety of GIS-based spatial analyses that were integrated to form the basis for designing a proposed regional conservation reserve network.

Although detailed analysis of ecological connectivity was beyond the scope of this work, Noss et al. (1999) emphasized the importance of maintaining connectivity, both between individual protected areas as well as with lands in adjacent ecoregions. Based on their three-track criteria, the author's proposed ecoregional conservation plan broadly identifies those areas deemed most important for maintaining both terrestrial (T) and aquatic (A) connectivity (shown as broad arrows, Figure 25). Within the Cascade-Siskiyou focus area, two zones of important connectivity are highlighted in this study: 1) for terrestrial connectivity, an east-west vector that follows the eastern Siskiyou Mountains in Oregon and is essentially analogous to the Cascade-Siskiyou land bridge as previously defined, and 2) for both aquatic and terrestrial organisms, the east-west trending Klamath River Canyon to the south in California. The authors conclude that connectivity and linkage design is an important topic that warrants further analysis and is critical to ensure long-term persistence of wide-ranging animals such as large carnivores.

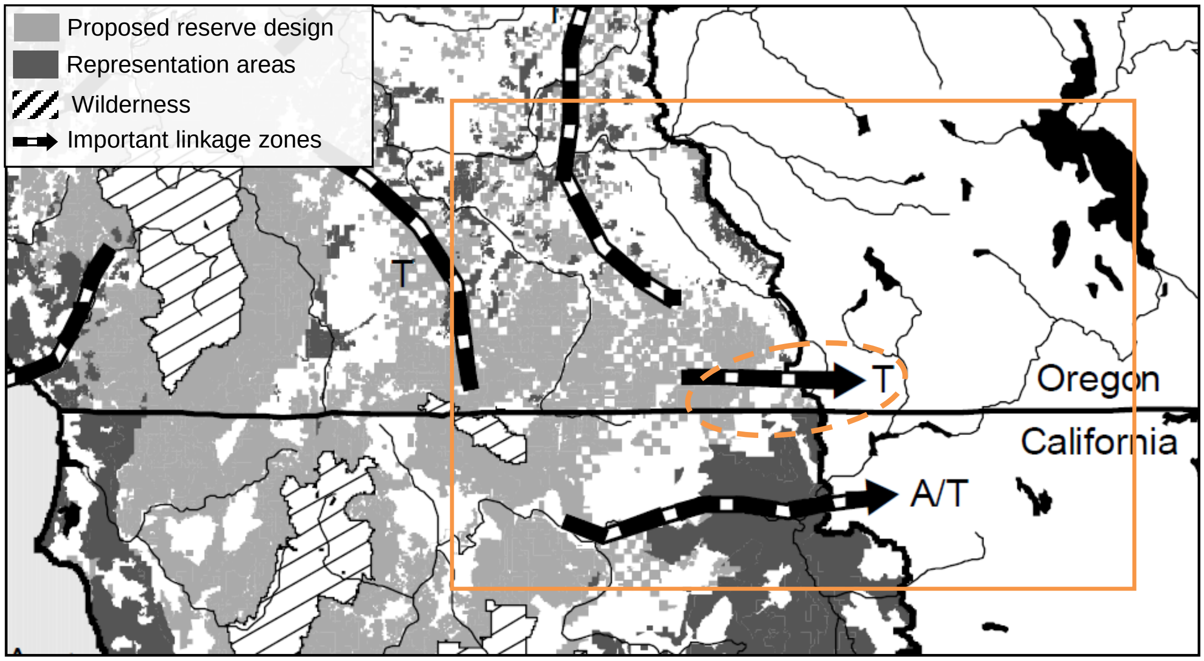

Figure 25. Proposed conservation reserve design developed by Noss et al. (1999) for a portion of the Klamath-Siskiyou Ecoregion that includes the greater Cascade-Siskiyou focus area (orange rectangle). Arrows identify important linkages (A = aquatic, T = terrestrial, and A/T = both aquatic and terrestrial), and dashed orange oval highlights the linkage connecting the eastern Siskiyou Mountains with the southern Cascade Range along the Oregon-California border (i.e., the 'Cascade-Siskiyou land bridge').

IV. SPECIES-LEVEL CONNECTIVITY ASSESSMENTS

A. Northern Spotted Owl (*Strix occidentalis caurina*)

USDI Bureau of Land Management. 2015. ***Draft Environmental Impact Statement for the Revision of the Resource Management Plans of the Western Oregon Bureau of Land Management Districts***. Portland, OR. Available online at: http://www.blm.gov/or/plans/wopr/deis/index.php [See also: Schumacker, N.H., A. Brookes, R. Dunk, B. Woodbridge, J.A. Heinrichs, J. Lawler, C. Carroll and D. LaPlante. 2014. ***Mapping Sources, Sinks and Connectivity Using a Simulation Model of Northern Spotted Owls***. Landscape Ecology 29(4): 579-592]

As part of recovery planning and critical habitat designation for the federally threatened Northern Spotted Owl (NSO) the U.S. Fish & Wildlife Service developed HexSim, a demographic simulation model to evaluate the distribution and metapopulation dynamics of the species across California, Oregon and Washington (USDI FWS 2011). The HexSim model was built around spatially explicit maps of habitat conditions displayed in a grid of 214-acre hexagons, plus data on probabilistic NSO life cycle events including survival by age class, reproduction and dispersal. The BLM used a modified version of HexSim to map dispersal-capable habitat conditions and then to aggregate the movement pathways of simulated NSOs over time across the landscape of western Oregon (USDI BLM 2015, Schumaker et al. 2014). The results of this analysis were decadal maps of dispersal flux -- defined as the number of times, during 100 replicate simulations, that an individual owl passed through each 214-acre hexagon during a decade. Because the HexSim model also predicts NSO survival (including the survival of dispersing young) as a function of individuals interacting with a range of habitat conditions, the dispersal flux metric reflects both NSO movement and survival.

Dispersal Flux

Results of simulated NSO dispersal flux across western Oregon and the Cascade-Siskiyou focus area are presented in Figure 26. At the sub-regional scale, predicted owl survival and movement appears highest in the eastern Siskiyou Mountains and the High Cascades portion of the Rogue River National Forest (Figure 26b). Consistent with this pattern, Schumaker et al. (2014) found that the net flux of owls over 100 HexSim simulations was greatest between the "Oregon Klamath" (i.e., Siskiyou Mountains) and "Cascades South" (i.e., southern Oregon Cascades) modeling sub-regions. These results suggest that dispersal or export of owls moving primarily from west to east across the Cascade-Siskiyou land bridge may be particularly critical for persistence of the NSO population as a whole. Given the very limited options that currently exist for NSO movement between coastal and inland sub-populations, it follows that safeguarding habitat connectivity along the Cascade-Siskiyou dispersal pathway may be more important to long-term survival of the owl than equivalent actions taken in other, less strategic portions of the species' range.

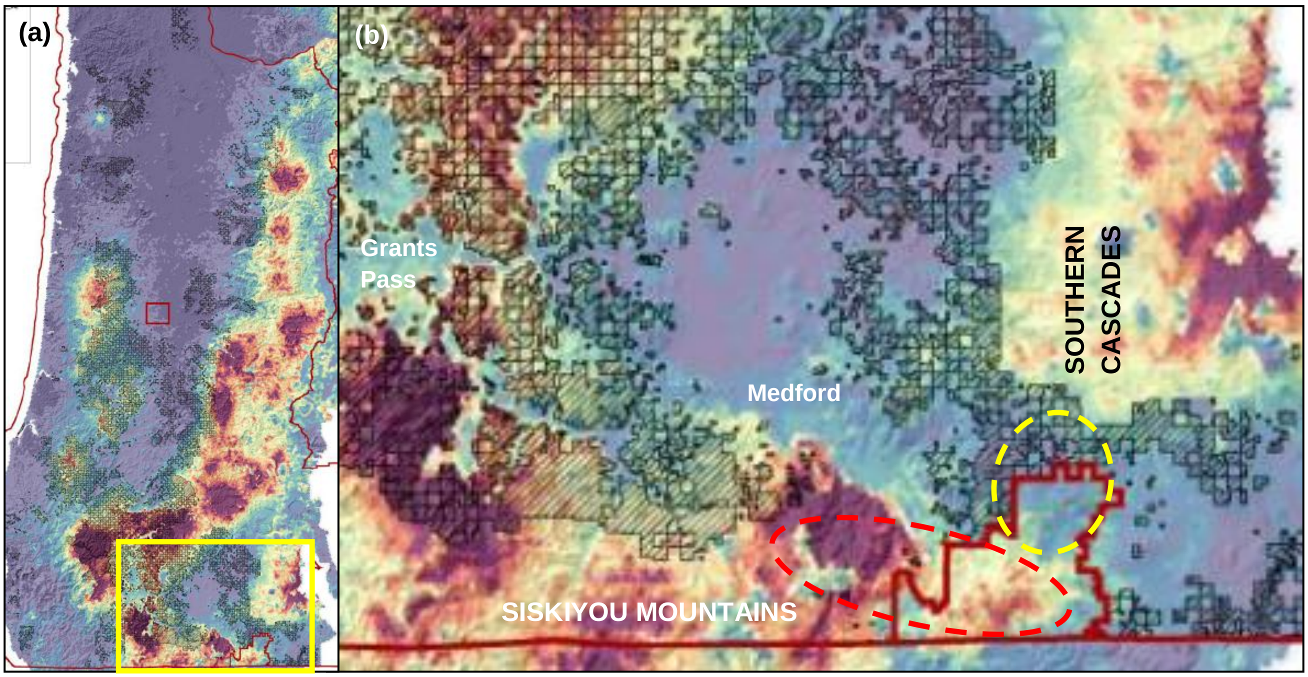

Figure 26. Map showing potential Northern Spotted Owl dispersal flux across (a) western Oregon and (b; yellow inset box) the portion of Cascade-Siskiyou focus area in southwest Oregon, based on 100 HexSim model simulations from 2013-2023 (USDI BLM 2015). The color of each 214-acre hexagonal pixel reflects the number of dispersal events occurring over the decadal simulation. Areas colored dark and light purple indicate essentially no or marginal NSO movement and survival. Increasing levels of NSO movement and survival color shaded from yellow (moderate) to maroon (high). Dashed line ovals highlight areas of relatively robust east-west connectivity (red) and restricted north-south flow (yellow) in the vicinity of the Cascade-Siskiyou National Monument (original boundary). Other BLM lands are shown in black outline.

NSO Large Habitat Blocks and Dispersal Habitat

In order to assess the potential impacts of proposed resource management plans on the Northern Spotted Owl, the BLM mapped patches or blocks of NSO nesting-roosting habitat across all land ownerships in western Oregon. This analysis involved moving a 500-acre circular window over a habitat suitability map of the analysis area, and calculating the acres of nesting-roosting habitat on all lands within the circle. Where the amount of nesting-roosting habitat met or exceeded the minimum acreage required for a NSO home range, the patch was identified as a habitat block capable of supporting a pair of reproducing owls. Adjacent habitat blocks were then aggregated, and where combined patches of nesting-roosting habitat were large enough to support at least 25 pairs of owls, they were classified as "large habitat blocks". Other patches of nesting-roosting habitat not meeting this criteria were defined as "small habitat blocks."

To evaluate the potential for movement and dispersal of owls across western Oregon, the BLM identified all habitat considered capable of supporting NSO dispersal, defined according to the "50-11-40 rule" -- at least 50% of the land area within a 15.5-mile radius supports forest with an average tree diameter of 11" dbh or greater and at least 40% canopy closure (Davis et al. 2011). The final maps produced from this analysis depict: 1) all large and small NSO habitat blocks, each surrounded by 6-mile wide buffers in order to visually determine if large and small blocks are sufficiently close to allow interaction between adjacent sub-populations of owls, and 2) dispersal-capable NSO habitat (Figure 27).

Results of BLM's analysis indicate that "current habitat conditions support limited east-west movement between the Oregon Coast Range and Oregon Klamath with the Oregon Cascades provinces." Two primary east-west NSO movement pathways in southwest Oregon have been identified -- lands that broadly traverse the upland divide the between Rogue and Umpqua River watersheds, and further south, a narrower forested 'bridge' that connects the Siskiyou Mountains and southern Cascades, located adjacent to and overlapping with the Cascade-Siskiyou National Monument (Figure 27b and d).

In its final rule on critical habitat designation, the U.S. Fish & Wildlife Service (USWFS) identified east-west connectivity through these areas as essential to the overall persistence and recovery of the Northern Spotted Owl (USDI FWS 2012). The Cascade-Siskiyou corridor was specifically recognized as the "Ashland/I-5 Area of Concern" (Forsman et al. 2002, USDI FWS 1994, Tweten 1992) because of the critical inter-regional connectivity function associated with this habitat "bottleneck". In making this determination, the U.S. Fish & Wildlife Service recognized that the Cascade-Siskiyou area "*provides the single-most important link connecting the Oregon Cascades to the Klamath Mountains Province...and is also the key link from the Oregon Cascades to California south of Highway 66...Without adequate dispersal across this area of concern, risk of isolation of* [NSO sub-populations between] *the Klamath and Cascades Provinces is increased*" (USDI FWS 1994).

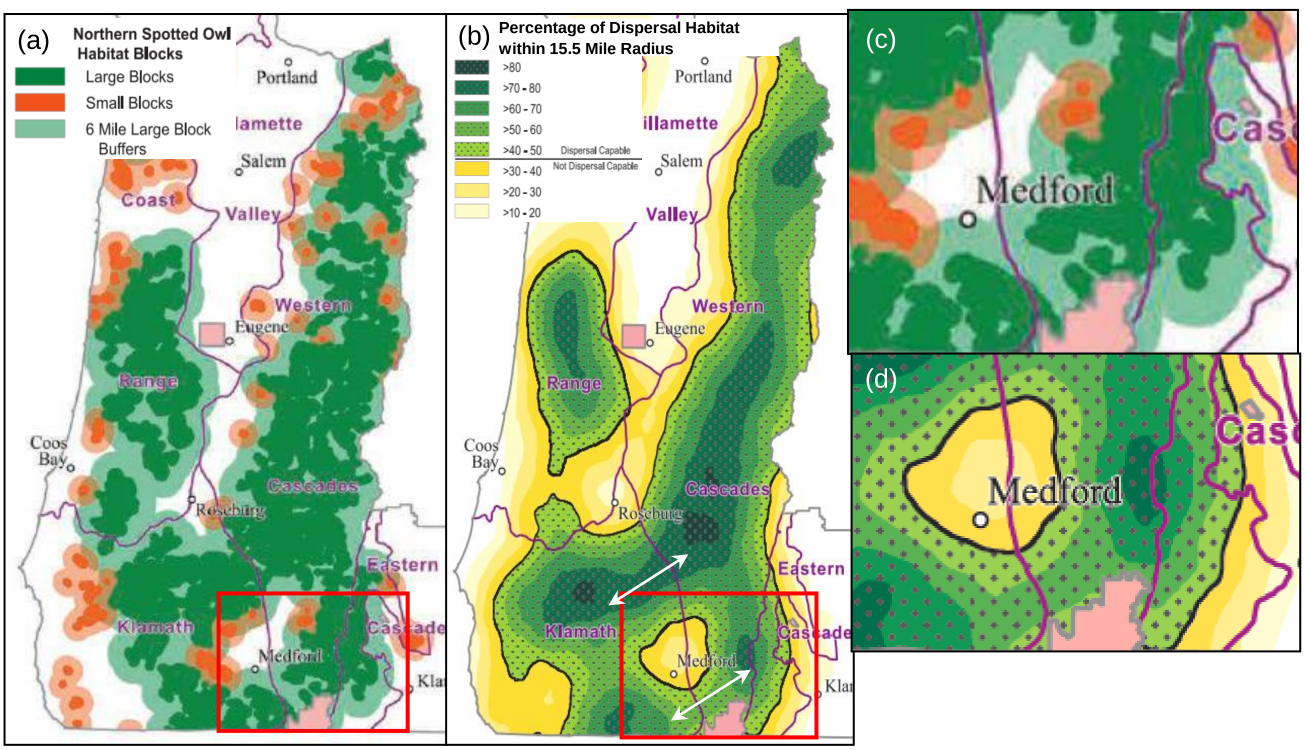

Figure 27. Maps of (a) the distribution of large and small NSO habitat blocks, and (b) dispersal-capable NSO habitat according to the "50-11-40 rule" across western Oregon, from USDI BLM (2015). The two primary east-west movement pathways discussed in the text are identified with white arrows in (b). Red rectangles in broad-scale maps identify location of the Cascade-Siskiyou focus area, enlarged in (c) and (d) to highlight NSO habitat and connectivity values in the vicinity of the Cascade-Siskiyou National Monument (pink polygon, original boundary).

Carroll, C. 2010. ***Role of Climatic Niche Models in Focal-Species-Based Conservation Planning: Assessing Potential Effects of Climate Change on Northern Spotted Owl in the Pacific Northwest, USA***. Biological Conservation 143(6): 1432-1437.

Well-studied and threatened vertebrates such as the Northern Spotted Owl (NSO) are often used as focal species in regional conservation plans, but range shifts associated with climate change may adversely affect the ability of existing plans to maintain species viability in the future. To investigate the potential effects of climate change on NSO abundance and distribution, Carroll et al. (2010) developed a 'climate niche' approach to modeling using MaxEnt (maximum entropy model; Phillips et al. 2006) that incorporates data on known locations of owl nest sites and activity centers, the proportion of mature and old-growth forest habitat at two spatial scales (1 ha and 1 km^2), and spatially explicit, down-scaled projections of climate change (e.g., temperature and precipitation) based on three different model simulations across current and two future time periods (2011-2040 and 2061-2090).

Under the model that best simulated changes to both owl habitat and climate, NSO habitat suitability declined under future climate scenarios, particularly in coastal Oregon. NSO populations in coastal areas are already at risk due to their small size and isolation amid a landscape with low proportion of older forests, and climate change can be expected to accelerate these threats. The best climate-only model suggested that the distribution of high suitability NSO habitat in the future will move northward and to higher elevations. In southwest Oregon and adjacent California, such a climate-induced species' range contraction may eventually lead to loss of habitat connectivity and greater isolation between coastal (i.e., Siskiyou) and inland (southern Cascades) NSO sub-populations (Figure 28). Carroll (2010) concludes models that integrate climate projections with spatial data on current habitat conditions can inform conservation planning by providing less-biased estimates of potential range shifts than do models based on either set of factors alone.

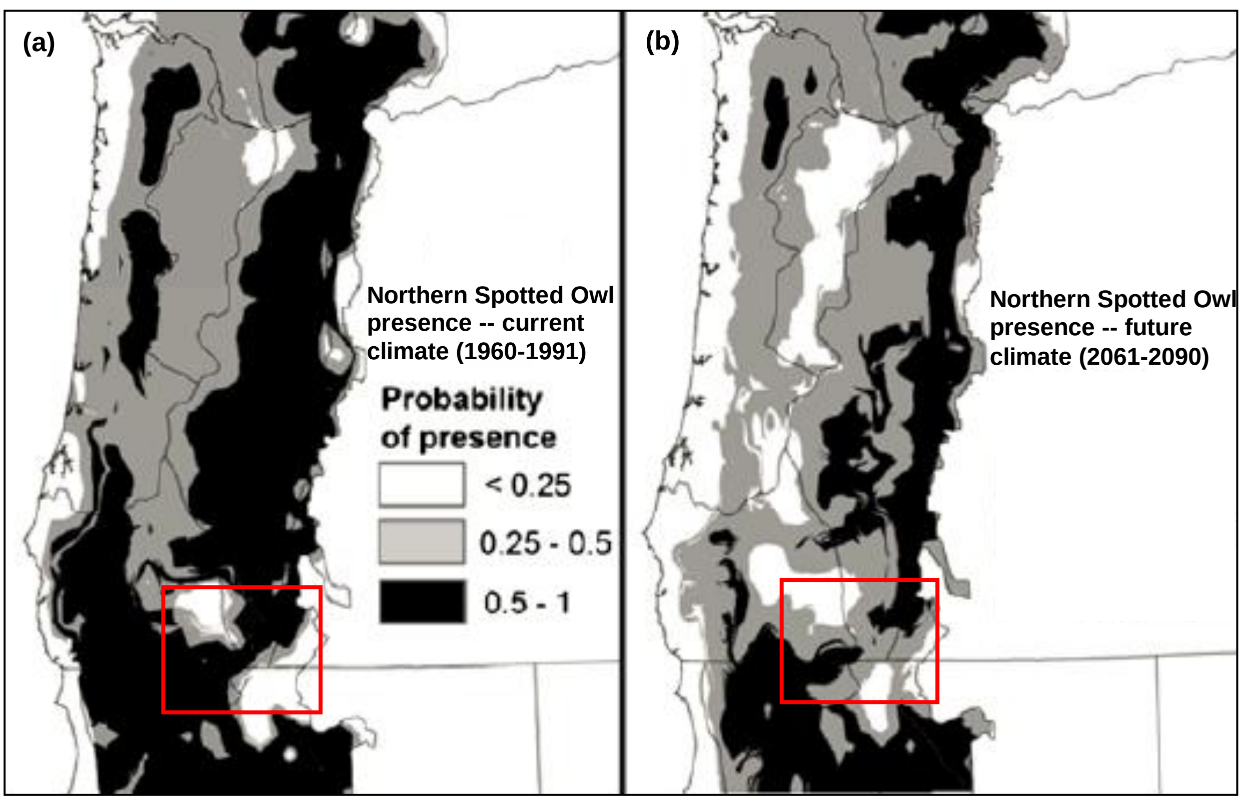

Figure 28. Mapped results of Carroll's (2010) analysis of habitat suitability for Northern Spotted Owl across western Oregon and adjacent California, based on output from Maxent models constructed using climate data but no vegetation data. (a) shows predicted probability of NSO presence under current climate (1961-1990), and (b) under representative projections of future climate (2061-2090). Note the general contraction of suitable NSO habitat (black) under future climate change scenarios, including potential loss of connectivity within the Cascade-Siskiyou focus area (red rectangles).

Carroll, C. and D.S. Johnson. 2008. ***The Importance of Being Spatial (and Reserved): Assessing Northern Spotted Owl Habitat Relationships with Hierarchical Bayesian Models***. Conservation Biology 22(4): 1026-1036. [See also: Carroll, C., D.C. Odion, C.A. Frissell, D.A. DellaSala, B.R. Noon and R.F. Noss. 2009. ***Conservation Implications of Coarse-Scale versus Fine-Scale Management of Forest Ecosystems: Are Reserves still Relevant?*** Unpublished report available from Klamath Center for Conservation Research, Orleans, CA at: http://www.klamath conservation.org/ docs/ForestPolicyReport.pdf]

The goal of this study was to use Bayesian spatial modeling techniques to assess the relationship between the distribution of older coniferous forest and the abundance of Northern Spotted Owls (NSO) in northern California, Oregon and Washington. The authors utilized a modeling framework which overlays a seamless grid of 24 km^2 hexagonal cells across the study area. Each cell was considered a sample unit with paired data on the proportion of mature and old-growth conifer forest and known NSO nest and activity site locations. Bayesian spatial modeling results support the conclusion that NSO distribution is strongly correlated with the amount of mature and old-growth forest, and that the specific nature of this correlation varies between different subregions across the species' range. Areas of high predicted NSO abundance occurred in low- to mid-elevation valleys of the southern subregion (northwest CA and southwest OR), the southern Oregon Coast Range and portions of the Oregon and Washington Cascades (Figure 29). The authors conclude that the existing system of Late Successional Reserves may need to be strengthened to facilitate recovery of the species.

In an extension of this initial study, Carroll et al. (2009) used the Bayesian modeling techniques referenced above to identify areas where habitat connectivity between owl sub-populations may be most important to prevent barriers and genetic bottlenecks from forming across the species' range. Important NSO habitat connectivity areas were spatially identified by displaying the Integral Index of Connectivity (IIC) -- a metric based on graph theory and calculated using the software program Sensinode -- across the network grid of 24 km^2 hexagons from Carroll & Johnson (2008). To analyze the relative importance of each hexagon to connectivity, centroids were treated as nodes in a region-wide network, and the amount of flow between

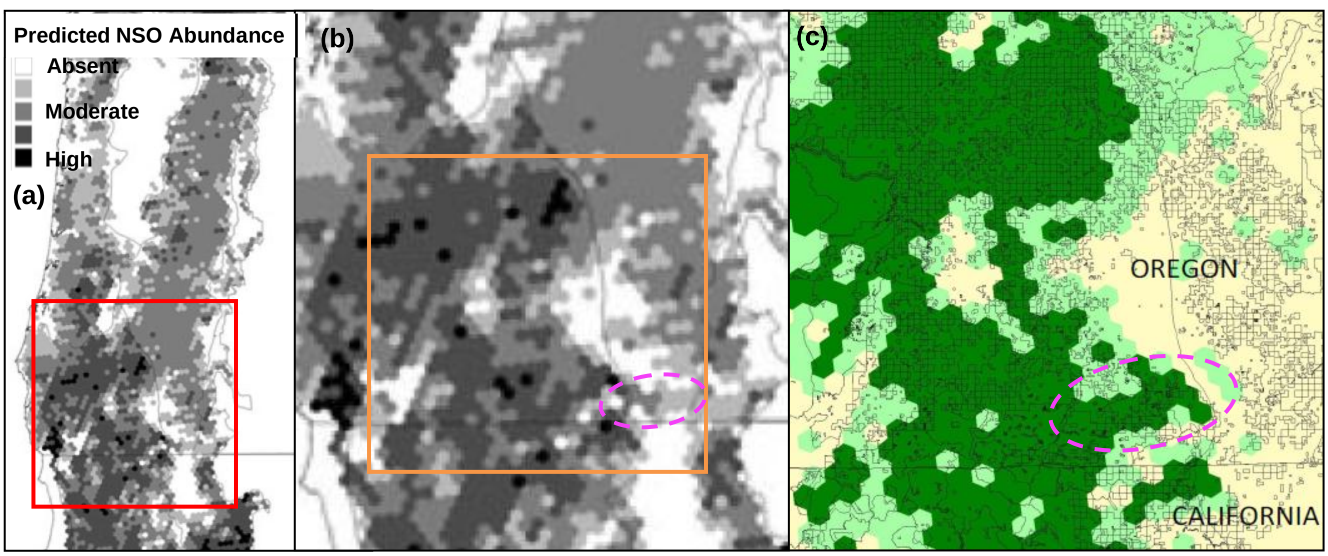

Figure 29. Maps of predicted Northern Spotted Owl abundance based on output of Bayesian models that integrate spatial data on the distribution of conifer forest age classes and known locations of NSO nest and activity sites, covering (a) western Oregon and adjacent northern California, and (b, red inset box in (a)) southwest Oregon in the Cascade-Siskiyou focus area. Predicted NSO abundance is displayed for each hexagon along a gray scale ranging from white (absent) to gray shades (moderate) to black (highest abundance). (c, orange inset box in (b)): spatial results of connectivity analysis in a portion of the Cascade-Siskiyou focus area, identified by mapping the Integral Index of Connectivity (IIC; see text). Hexagons supporting high connectivity values are colored dark green, followed by those in light green (moderate) and tan (low). Dashed pink ovals in (b) and (c) highlight NSO habitat values and connectivity "bottleneck" where the Siskiyou Mountains and Cascade Range converge.

nodes was calculated in proportion to their NSO habitat value. IIC values were determined by dropping individual nodes from the graph, and then calculating resultant change to connectivity across the entire network. Based on model results, the authors conclude that "areas most important for maintaining range-wide connectivity are those that connect the Klamath Mountains region to both the Oregon Coast and Oregon Cascades... Particularly narrow and thus vulnerable habitat bottlenecks are found within southwestern Oregon, especially where public and private lands form a checkerboard pattern."

One of the areas in southwest Oregon identified as supporting high NSO connectivity values lies at the eastern terminus of the Siskiyou Mountains, located just north of the California border in the Cascade-Siskiyou focus area (Figure 29c). As suggested in the above quote, habitat connectivity is disproportionately important here because it increases the potential for successful dispersal and genetic exchange between NSO sub-populations in the Siskiyous and southern Cascades. While Carroll et al's analyses are relatively broad-scale and therefore preliminary at this resolution, they suggest that habitat linkages may be critical for conservation of the threatened NSO, and provide evidence that one such 'regional pinch-point' overlaps with what is referred to elsewhere in this review as the Cascade-Siskiyou land bridge.

B. Gray Wolf (*Canis lupus*)

Carroll, C., B.H. McRae and A. Brookes. 2012. ***Use of Linkage Mapping and Centrality Analysis Across Habitat Gradients to Conserve Connectivity of Gray Wolf Populations in Western North America***. Conservation Biology 26(1): 78-87.

Conservation of regional habitat connectivity has the potential to facilitate long-term recovery of the gray wolf, a threatened species distributed across several distinct subpopulations in the western United States that is currently recolonizing portions of its historic range. The authors note that analyses are needed to help determine specifically where it might be possible to increase natural dispersal between extant wolf populations as well as into currently unoccupied habitat. With this goal in mind, Carroll et al. (2012) applied three contrasting linkage-mapping methods (shortest path, current flow, and minimum-cost-maximum-flow) to spatial data representing wolf habitat across across the Pacific Northwest and southwestern Canada, and assessed the relevance of each method to connectivity planning for the species.

As baseline for this analysis, the authors adapted a previously-published spatial model that predicted wolf habitat suitability across the western U.S. using data on land cover, primary productivity, slope, and human-associated mortality factors (Carroll et al. 2006). The study region was then divided into a landscape grid of hexagons, each with an area of 10 km^2. A software application called the Connectivity Analysis Toolkit (Carroll 2010) was then developed that generated a range of centrality metrics from the landscape grid overlaid with wolf habitat data. Wolf habitat suitability index values were assumed to be inversely proportional to movement cost (i.e., low habitat suitability = high movement cost). Centrality metrics corresponding to each of the three linkage-mapping methods were calculated across the study area and used to compare patterns of potential connectivity across the landscape without reference to specific source and target patches.

Areas of high connectivity identified by Carroll et al.'s shortest-path analysis, which combined movement cost and habitat quality into a single aggregate index,, identify the minimal set of linkages whose loss would greatly reduce wolf dispersal across the region. In Oregon, primary lines of high connectivity are oriented north-south through the Cascade Range, and northeast-southwest through the Blue Mountains and Eastern Cascades, with both paths eventually joining in the south near the Cascade-Siskiyou focus area (Figure 30). Interestingly, modeled best-path linkages are in general agreement with actual movement routes that have been documented over the last ~8 years by individiual wolves dispersing from northeast Oregon (Figure 31). The presence of high-quality habitat in the Cascade-Siskiyou landscape, together with the area's strategic location at the convergence of primary regional movement pathways, has helped gray wolves to successfully re-establish residency in southwest Oregon (Figure 31, ODFW 2017). The authors recommend that results from this analysis be used to enhance connectivity via habitat protection and/or reduction of mortality for dispersing wolves within key linkage zones.

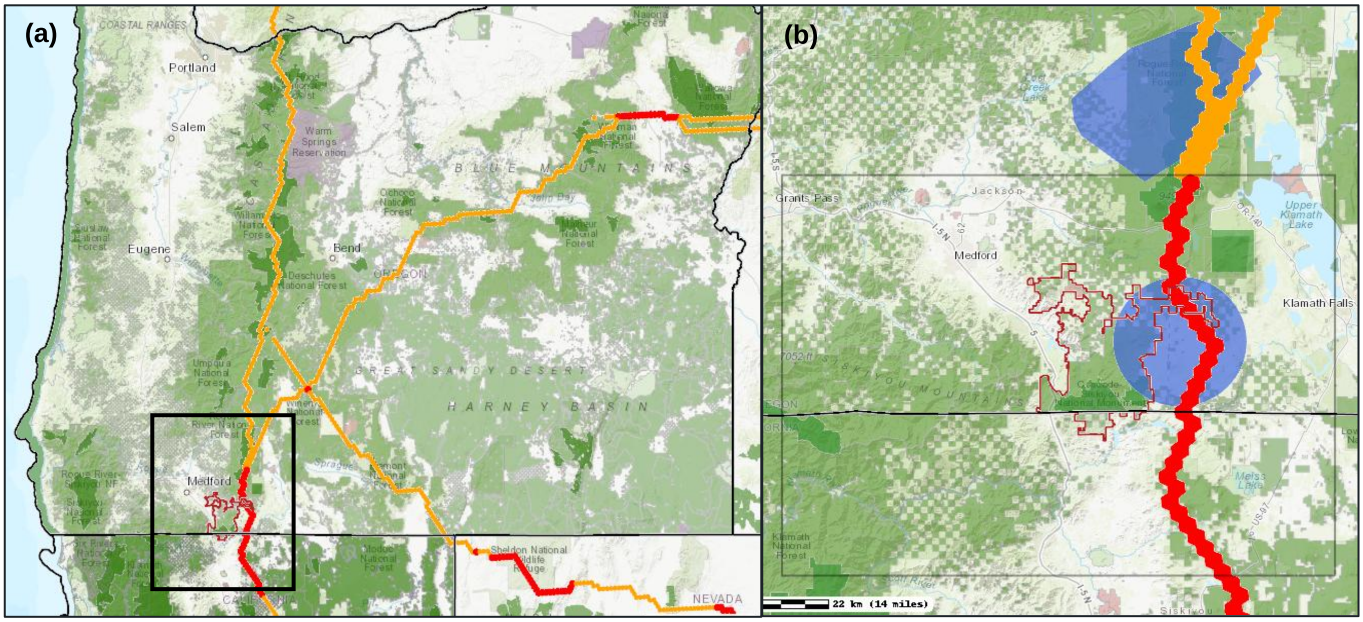

FIGURE 30. Maps developed using data from Carroll et al. (2012) of shortest-path / single best movement routes for gray wolves identified with the least-cost centrality metric across (a) Oregon, and (b, black rectangle in (a)) the Cascade-Siskiyou focus area in southwest Oregon and adjacent California. Least-cost centrality measures the relative value of each individual 10 km^2 grid cell to facilitating potential movement of wolves across the larger landscape. Red pathway segments indicate most suitable / shortest path areas, and orange segments are less optimal but best available. Blue-shaded polygons in (b) represent Known Wolf Use Areas as of 2016 in the vicinity of the Cascade-Siskiyou focus area, the northern-most polygon representing documented territory of the Rogue Pack (ODFW 2017).

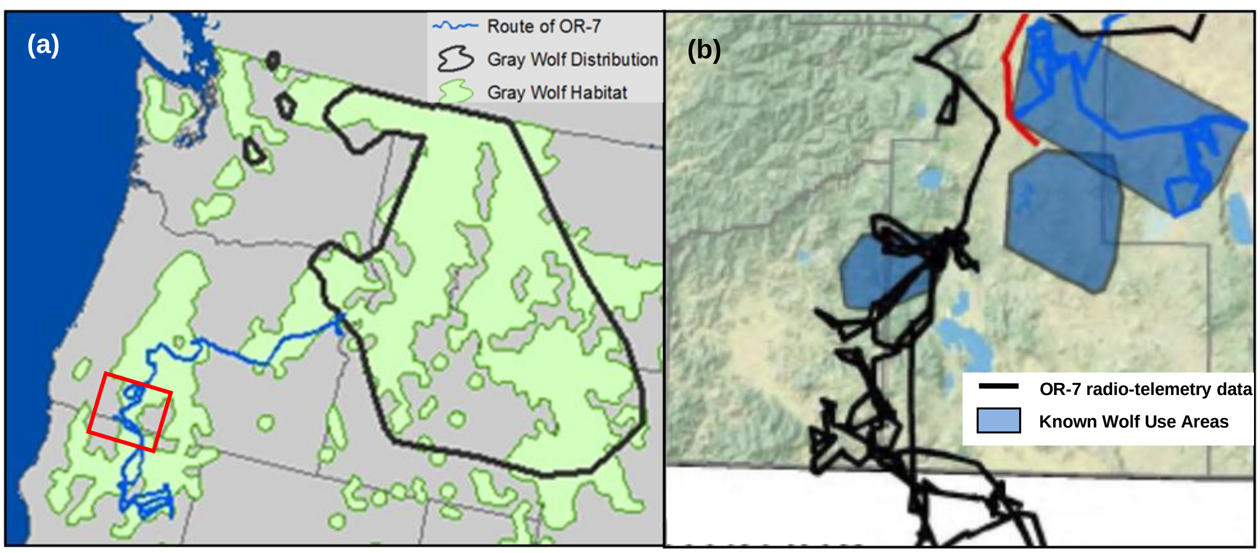

Figure 31. The (a) regional (b) and local (red rectangle inset from (a)) movement route constructed from radio-telemetry data used by the male gray wolf OR-7, who dispersed from northeast Oregon in 2011 and eventually established residency in the southern Oregon Cascades (now referred to as the Rogue Pack). OR-7's dispersal route generally followed the broad-scale connectivity pathway suggested by Carroll et al. (2012), including (b) repeated passage through portions of the Cascade-Siskiyou focus area that exhibit relatively high habitat connectivity. Data from Oregon Dept. of Fish & Wildlife (2016, 2017).

C. Fisher (*Pekania pennanti*)

USDI Fish & Wildlife Service. 2016. ***Final Species Report -- Fisher (Pekania pennanti), West Coast Population***. U.S. Fish & Wildlife Service, Yreka, CA. 327 pp. Available online: https://www.fws.gov/klamathfallsfwo /news/Fisher/Final/SpeciesRpt-FisherFinal-20160331.pdf [See also: Spencer, W. and H. Rustigian-Romsos. 2012. ***Decision-Support Maps and Recommendations for Conserving Rare Carnivores in the Interior Mountains of California***. Conservation Biology Institute, Corvallis, OR. Available online: https://consbio.org/products/ reports/decision-support-maps-and-recommendations-conserving-rare-carnivores-interior-mountains-california]

The fisher (*Pekania pennanti*) is a large member of the weasel family associated with mature, structurally complex, low- to mid-elevation forests. The species was once widely distributed across forested regions of North America, including large portions of the Pacific Northwest and California, but has experienced widespread decline throughout most of its former range. Remaining populations in the western U.S. are small, separated by large distances, and threatened by habitat loss and fragmentation. By the mid-2000's, fishers were believed to occupy less than half their historic range, after having apparently been extirpated from Washington, most of Oregon and the central and northern Sierra Nevada in California. The isolated fisher populations that remained in the Pacific states, collectively referred to as the West Coast Distinct Population Segment (DPS), were initially accorded special federal status in 2004 (USDI FWS 2004). In 2013, the U.S. Fish & Wildlife Service conducted an extensive analysis of current status and threats to assess whether listing of the West Coast DPS was warranted under the Endangered Species Act. Some of the Service's analyses are summarized below because they underscore the importance of habitat and connectivity in the Cascade-Siskiyou focus area.

Current Distribution in Southern Oregon and Northern California

The current population of fishers in southern Oregon and northern California are considered to be isolated from fishers elsewhere in the western U.S. This isolation precludes immigration and associated genetic interchange with other populations, increasing their vulnerability to extinction due to the adverse effects from a number of deterministic and stochastic factors. Fishers in Northern California / Southern Oregon (hereafter NCSO) have already been documented to exhibit lower genetic diversity than other fisher populations in North America, as well as high genetic divergence from the closest native populations located in California's Sierra Nevada and southern British Columbia (USDI FWS 2016). Despite its isolation, the NCSO population is the largest fisher population in the Pacific States and likely the largest in the western U.S. However, because of the great difficulty of accurately estimating the density and number of fishers, it is unknown precisely how many exist in the NCSO population but the general concensus is that the total population is relatively small (USDI FWS 2016).

Historically, fishers are thought to have occurred widely in forests of the Coastal, Klamath-Siskiyou and Cascade Mountains of southern Oregon and northern California (Aubry & Lewis 2003). The current range of the species is significantly reduced, occurring primarily in the central and northern Klamath Mountains on both sides of the OR-CA state boundary (Figure 32a). Reliable detections since 1993 indicate the species occupies portions of Josephine, Jackson, and Curry Counties in Oregon and extends further south through the Klamath Mountains and Coast Ranges of California (Figure 32b). A smaller, second fisher population occurs in a portion of the southern Oregon Cascade Range (Douglas, Jackson and Klamath Counties) and is descended from reintroduced animals that were translocated to Oregon from British Columbia and Minnesota between 1961-1981. Despite their relative proximity (~25 miles), until recently it was believed that the SOC and NCSO fisher populations were disjunct and geographically isolated from each other because of suspected barriers to dispersal (e.g., Interstate 5) and the lack of known genetic exchange.

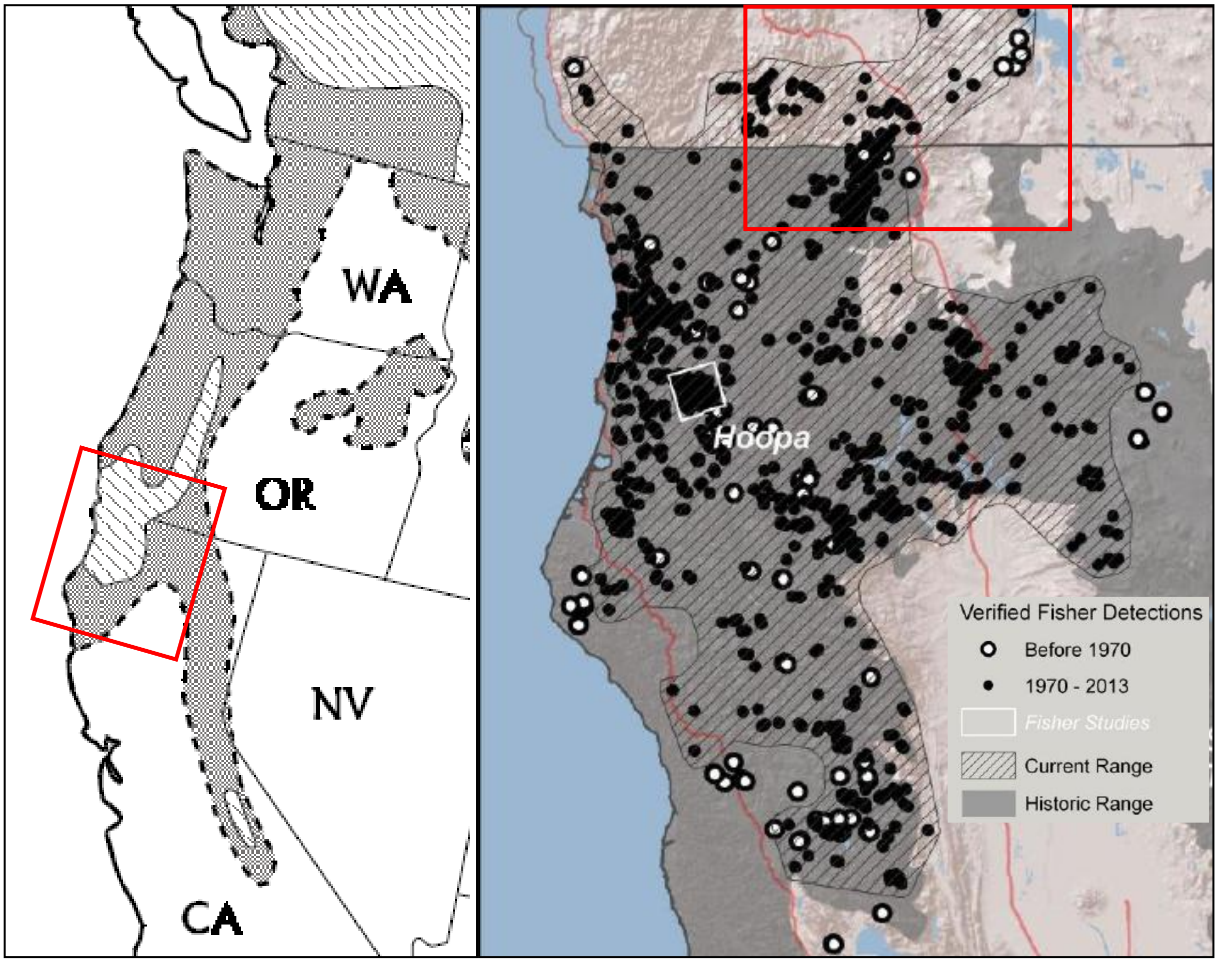

Figure 32. Presumed historic and current distribution of the fisher in (a) the Pacific States (from Lofroth et al. 2010) and (b, red rectangle in (a)) northern California and southern Oregon (Spencer et al. 2015). Documented fisher detections in (b) include only records considered highly reliable by US Fish & Wildlife Service, stratified into two groups dating before and after 1970 (USDI FWS 2016). Red rectangle in (b) highlights location of the Cascade-Siskiyou focus area. Note the narrow contiguous peninsula of the fisher's currently occupied range (lined cross-hatching) that connects the Klamath-Siskiyou and southern Oregon Cascades Ecoregions, in the Cascade-Siskiyou focus area.

Recent surveys conducted in the southern Oregon Cascades (Jackson County) have detected three individual fishers with genetic haplotypes that are associated with the native NCSO population. Two males and one female dispersing from the NCSO population were identified from hair samples at several locations east of Interstate 5 in the vicinity of the SOC population and within the Cascade-Siskiyou focus area in 2012 and 2014, respectively (Pilgrim & Schwartz 2012, 2014, 2015). The recent detections of native NCSO fishers in close proximity to the known range of the SOC reintroduced population "indicates that these two populations may be in the initial stages of convergence" (USFWS 2016). Because of this recent documented expansion, the Service now considers the NCSO and SOC fishers to constitute a single population connected by individuals that most likely are successfully dispersing across the Cascade-Siskiyou land bridge.

Fisher Habitat Suitability Model (Fitzgerald et al. 2016)

In order to better understand the current status of fisher relative to the amount and distribution of habitat, the U.S. Fish & Wildlife Service developed a spatial model using MaxEnt (Phillips et al. 2006) of potential habitat suitability for fishers across the Pacific States. Model development was based on 456 selected localities where fisher detections have been confirmed with high reliability since 1970, widely distributed across the current range of species. In addition to fisher distribution data, an array of 22 spatial layers of potential environmental predictor variables was developed including vegetation, climate, elevation, terrain, and LANDSAT-derived reflectance variables. Each environmental variable was averaged over a 10-km^2 moving window and then resampled to achieve a 90-m resolution. Models were then fitted to the data using MaxEnt, initially using all 22 environmental predictors for the three regions with verified fisher detection locations (Klamath-Southern Cascades, Southern Sierra Nevada, California Coast Range). Correlated and non-significant environmental variables were eliminated until the MaxEnt model contained the fewest combined significant predictors for each modeling region.

The modeling resulted in spatial representations of predicted fisher habitat suitability between 0 and 1, which was then stratified into three classes -- high, intermediate and low -- based on the strength of fisher habitat selection in each area populated by the species. Habitat was considered to be high quality if habitat with equal or higher value was used at a rate at least 1.5 times greater than expected based on availability. The model output values corresponding with these ranges varied between regions, so habitat was classified separately in each region. In regions where fisher location data were not available to calibrate the three habitat categories, habitat was classified using distance-weighted averaging so as to account for geographic variation and best approximate neighboring regions. Maps generated by the calibrated MaxEnt model can be interpreted as displaying the likelihood of fisher occurrence and/or as an index of fisher habitat suitability across the Pacific States (Figure 33).

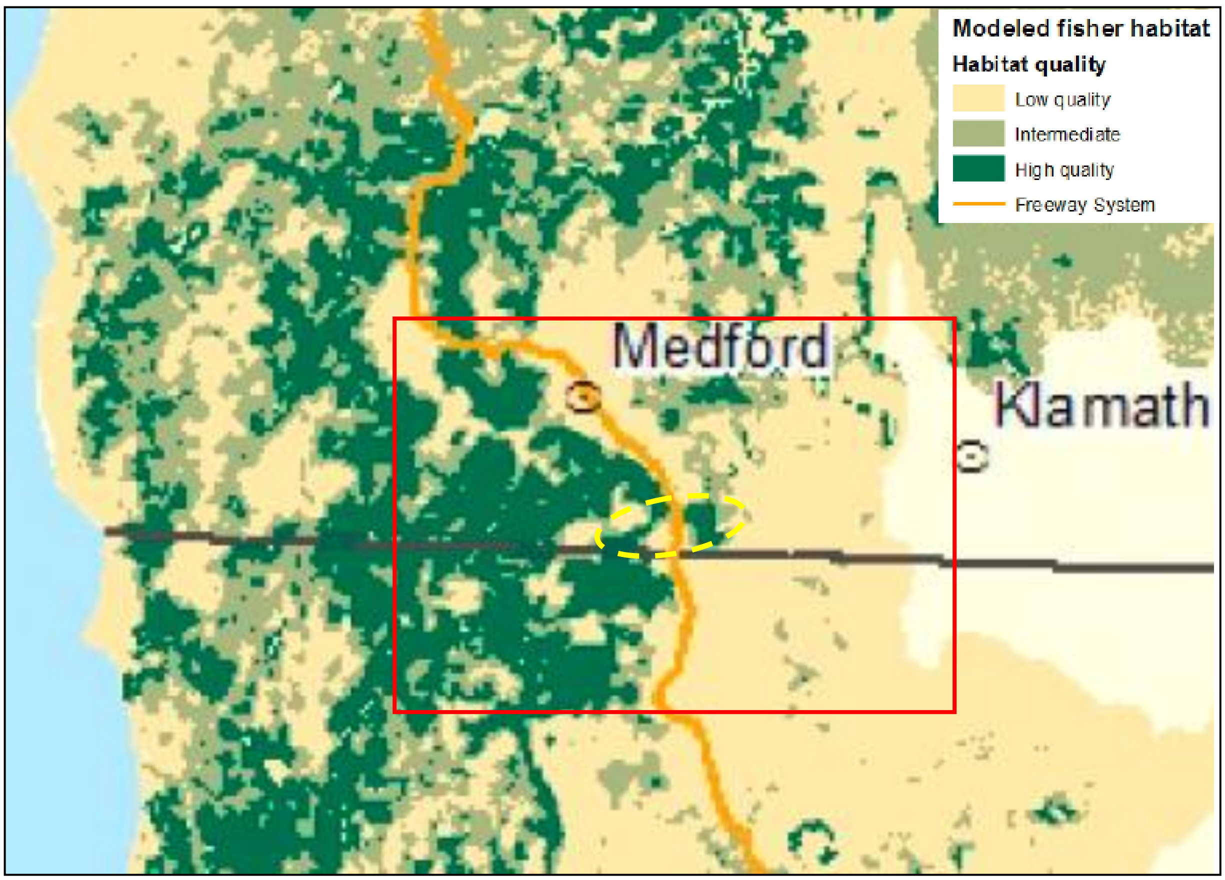

Figure 33. Spatial representation of habitat quality for fishers for a portion of southwest Oregon and adjacent California, based on the MaxEnt habitat suitability model developed by the U.S. Fish & Wildlife Service (Fitzgerald et al. 2016). Red rectangle identifies approximate boundaries of the Cascade-Siskiyou focus area. Note the relative contiguity of high quality habitat across the Oregon portion of the 'Cascade-Siskiyou land bridge' that traverses Interstate 5 (dashed yellow oval).

Integration of NCSO Fisher Habitat Quality with Detection Surveys

As a way of further investigating the relationship between known fisher distribution and potentially available habitat, the U.S. Fish & Wildlife Service mapped the database of recent fisher surveys onto a hexagonal, ~1,000-hectare grid depicting hypothetical fisher home ranges within the area occupied by the NCSO population. A two-way matrix of data were color coded for each hexagon and mapped across the region: 1) fisher habitat suitability from the MaxEnt model discussed above, and 2) results of fisher detection surveys from 2003-2013, categorized as positive, negative or unsurveyed (Figure 34). A positive survey result indicates that fishers were confirmed at a site somewhere within the hexagon, but a negative survey can result from either the absence of fishers or from a failure to detect fishers that were present. The large majority of the hexagons in the landscape grid remain unsurveyed.

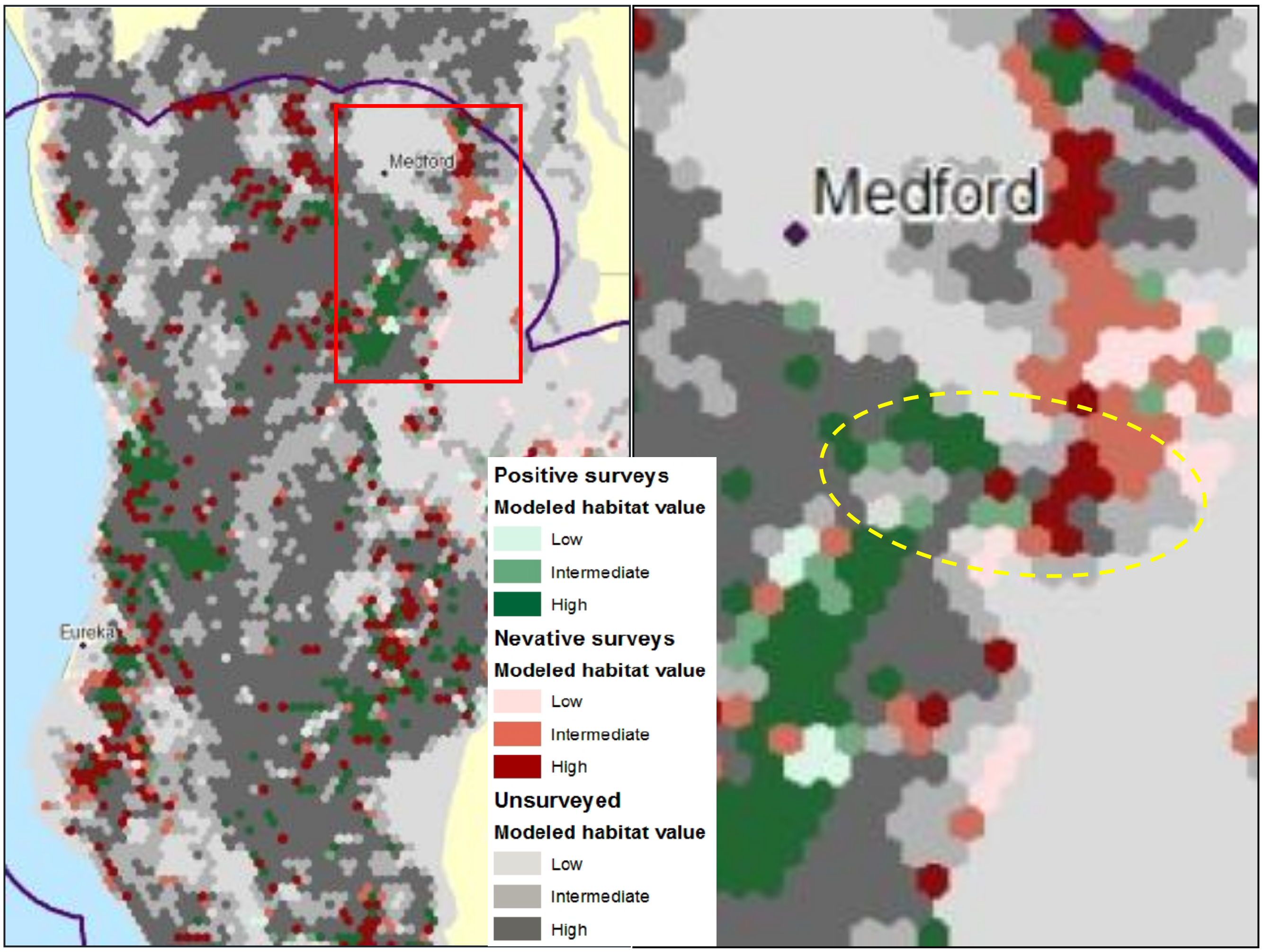

Figure 34. Range map of the Northern California / Southern Oregon (NCSO) fisher population at regional (left) and local (red rectangle inset, right) scales from USDI FWS (2016), classified into hypothetical 1000-ha hexagonal fisher home ranges that: 1) contain positive survey results since 2003 (light and dark green); 2) were surveyed since 2003 but contain only negative survey sites (red and pink); or 3) were not surveyed between 2003 and 2013 (gray). The purple outline buffers all positive detections of native fishers (e.g., not including the Southern Oregon Cascades reintroduced population) by 41 km to represent presumed maximum dispersal distance. Note the continuity of intermediate to high quality habitat and/or positive fisher detections within the 'Cascade-Siskiyou land bridge' that has recently been found to connect the NCSO and southern Oregon Cascade populations (yellow dashed oval, right).

There were 1,274 hexagons that contained at least one recent survey location; 34% of these hexagons contained at least one positive survey, whereas 66% included only negative surveys. Within high-value modeled habitat, the percentage of hexagons with at least one positive survey was higher, 47% (Figure 34). With an assumed detection probability of 60%, the Service estimated that fishers may have been present within approximately 56% of all surveyed hexagons and within 78% of hexagons with high habitat value (USDI FWS 2016). Fisher detection probabilities are affected by numerous variables, but given published detection levels, the Service believes that 60% detection probability is a conservative estimate that does not place undue confidence in the accuracy of negative results. An assumption of higher detection probabilities would give greater credibility to negative survey results and would therefore lead to estimates that fishers occupy less than 56% of the available habitat.

Inspection of the fisher habitat/detection maps in Figure 34 reveals several important insights. First, a significant proportion of high quality fisher habitat remains unoccupied within the current boundaries of the NCSO population. The Service offers several potential explanations for this, one being that many areas of suitable habitat are likely isolated from others by roads, rivers, areas of low quality habitat and other potential barriers to dispersal. These obstacles restrict connectivity between patches of otherwise suitable habitat, which may in turn depress fisher occupancy rates (USDI FWS 2016). Second, the Cascade-Siskiyou area stands out as disproportionately important because it is strategically located at the junction point between three portions of the fisher's regional distribution -- to the west, the Siskiyous link directly to the Coast Ranges; to the south, the central Klamath Mountains in California; and to the east, the southern Oregon Cascades via the narrow, forested 'bridge' straddling the Rogue and Klamath River watersheds.

The regional importance of habitat connectivity in the Cascade-Siskiyou focus area has been previously recognized by agency fisher experts Slauson and Zielinski (2002):

> "To give this [Klamath-Siskiyou] fisher population the best opportunity to recolonize adjacent areas of its former range, specific efforts to maintain, enhance and restore functional habitat connectivity [within strategic areas] will be required. ***Focus should be given to specific areas of forest connectivity including the Mount Ashland to Cascade-Siskiyou National Monument corridor (Jackson County, Oregon and Siskiyou County, California)***, the area from Dunsmuir south to Lake Shasta, and the Highway 199 corridor from Grants Pass [OR] southwest to Gasquet [CA]." (clarifying terms in brackets and bolded emphasis added)

Given the consensus of opinion that the greatest risk to fishers is the isolation of small populations and higher risk of extinction due to stochastic events, it follows that maintaining connectivity between and within populations may be of greatest long-term benefit to conservation of the species.

U.S. Geological Survey Gap Analysis Program (USGS-GAP). 2014. ***National Species Distribution Models -- Fisher***. Available online: https://gis1.usgs.gov/csas/gap/viewer/species/Map.aspx [See also: Csuti, B. and P. Crist. 2000. ***Methods for Developing Terrestrial Vertebrate Distribution Maps for Gap Analysis***. In: USGS-GAP. 2000. A Handbook for Conducting Gap Analysis. Idaho Cooperative Fish and Wildlife Research Unity, University of Idaho. Moscow, ID.

One of the primary goals of the USGS Gap Analysis Program (GAP) is to assess the conservation status of vertebrate wildlife species across the United States. In order to accomplish this task, GAP creates fine-scale maps of existing land cover (vegetation communities) and vertebrate species distributions, and then combines these layers in GIS along with data on land management for a specific region or state to identify species or communities at potential risk of endangerment because of "gaps" in conservation management. As part of this broad-scale effort, a national distribution map for the fisher was developed using a deductive model that identifies lands most suitable for fisher occupation across the species' geographic range. The model was created with a wildlife habitat relational database that includes all relevant peer-reviewed literature on the current distribution and habitat associations of fisher in each region, together with fine-scale spatial data on land cover, forest structure, elevation, terrain and other ancillary variables. Final results of the model are maps of predicted fisher distribution at a spatial resolution of 30 meters across the species' known range.

Figure 35 is a modeled distribution map for fisher in the vicinity of the Cascade-Siskiyou focus area, generated with USGS-GAP data. In comparison with the USFWS's fisher habitat/suitability maps for this area (Figure 33), the pattern of fisher occurrence predicted by the GAP model exhibits both similarities and differences. The USFWS analysis identifies considerably more suitable habitat, particularly in the Klamath-Siskiyou Ecoregion of southwest Oregon and adjacent California, than is suggested by GAP's proposed fisher distribution. There are likely several reasons for this difference (discussion of which is beyond the scope of this summary), but both approaches likely convey useful insights into potential fisher utilization of the landscape. Despite the use of different approaches and methodologies, both GAP and USFWS analyses highlight the importance of habitat in the eastern Siskiyou Mountains, including the relatively narrow, contiguous band of montane forest referred to throughout this review as the Cascade-Siskiyou land bridge. Both models also are in agreement that the Klamath River canyon, located just south of the Cascade-Siskiyou National Monument, likely serves as a significant barrier that prevents fishers from moving between the Oregon and California Cascades (also consistent with existing gap in fisher distribution, Figure 32b).

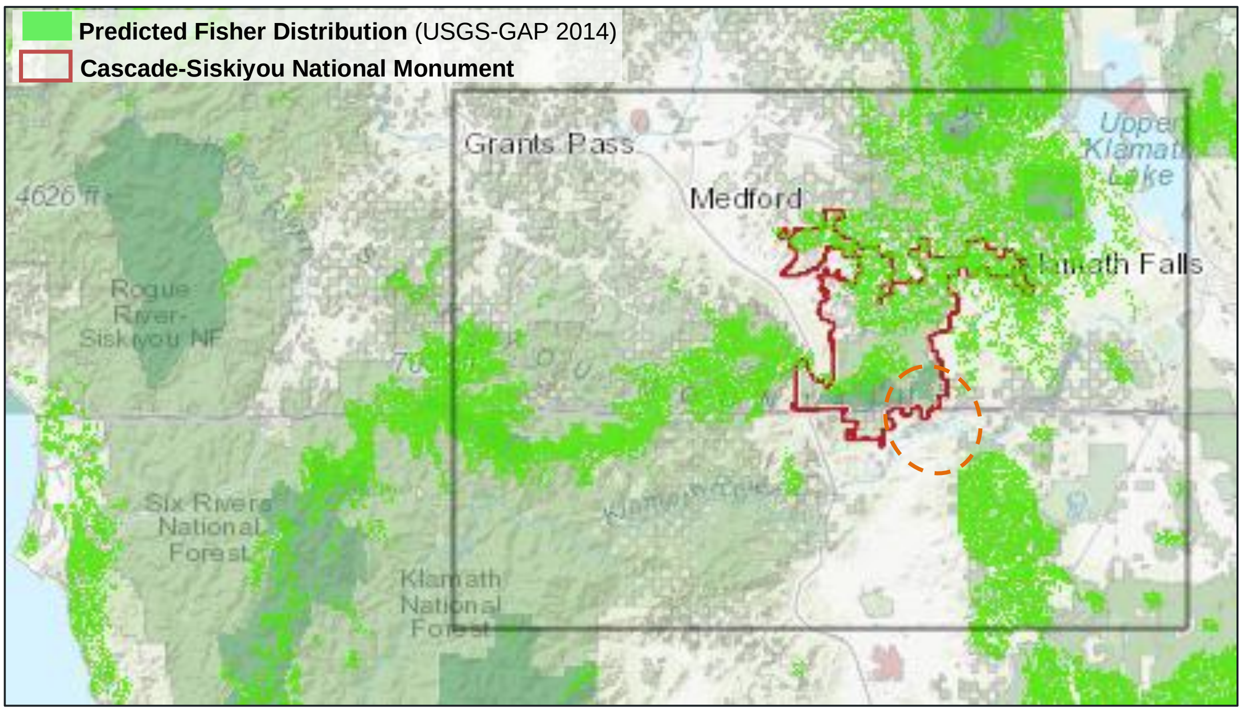

Figure 35. Map of areas where fisher are predicted to occur (bright green) in the Cascade-Siskiyou focus area (gray rectangle) according to a GAP species distribution model that incorporates data on land cover/vegetation, terrain, fisher habitat associations and other variables (USGS-GAP 2014). Note the relatively contiguous, east-west band of predicted fisher occurrence along the Siskiyou Mountains that links to the Cascades via the 'Cascade-Siskiyou land bridge', and the apparent gap in habitat connectivity between the Oregon and California Cascades due to the Klamath River Canyon (dashed orange oval; consistent with known fisher distribution, Figure 32b).

CONCLUSION AND NEXT STEPS

With the adverse effects of habitat loss and fragmentation continuing (Haddad et al. 2015, Stauss et al. 2002) and climate change increasingly shifting species ranges (Hannah 2011), there is an urgent need to speed up the rate of connectivity conservation (Keeley et al. 2018b). This review constitutes a first pass at synthesizing all known ecological connectivity assessments for the Cascade-Siskiyou focus area in southwest Oregon and adjacent California, a landscape widely recognized for its outstanding biodiversity and connectivity values. This report is not intended to act as a detailed prescription for linkage design, but rather to summarize the current state of knowledge regarding the most important priorities for connectivity conservation.

This review found that a considerable amount of published and unpublished research assessing ecological connectivity in the Cascade-Siskiyou focus area already exists. Despite the wide range of spatial scales and analytical methods used, the strong agreement among studies regarding the locations of key linkages should give planners confidence to build upon the priorities that have been identified here. Coarse-scale analyses are important to guide connectivity planning, but individual linkage designs will likely need to be informed by more detailed, fine-scale analysis (Beier et al. 2011). Ideally, this document will increase interest among biologists, conservation practitioners, land managers and others to those portions of the Cascade-Siskiyou focus area that are in greatest need of additional site-specific planning and conservation investment.

Ultimately, science-based assessments and maps are useful only to the extent that they can inform decision-making, guide management or otherwise be implemented (Keeley et al. 2018b). In order to advance a science-based connectivity conservation initiative in the greater Cascade-Siskiyou landscape, the body of literature synthesized in this document leads to the following points as recommended next steps:

- ***Identify specific opportunities and challenges to implementing connectivity-friendly management in the six broad-scale linkage zones highlighted in this report***. Each of the priority linkages identified in this document encompasses a different set of ecological issues, land use and development patterns that directly influence connectivity, and these need to be site-specifically evaluated in the context of future project design and implementation. Land management practices in some areas may already be generally consistent with achieving connectivity goals, whereas significant conflicts exist in others.

- ***Encourage research that seeks to document key movement pathways for a range of focal species using empirical data collected with radio telemetry, camera traps, roadkill surveys and/or genetic analysis***. Comparing results of modeling efforts to actual movements of target wildlife species would constitute an important test regarding the location and design of specific linkage zones and help improve the ability of connectivity projects to achieve specific, on-the-ground conservation goals. Using animal movement data to validate presumed linkages can also help convince stakeholders of the need for connectivity conservation and thereby garner political support and funding.

- ***Collect expert input from biologists and other specialists on a range of connectivity-related topics that then can then be used to further refine, prioritize and develop management goals for linkage zones in the Cascade-Siskiyou focus area.*** Experts with abundant local knowledge of the biological communities in this landscape can help address many important connectivity-related questions for which scientific research is not currently available. For example, which species are most in need of connectivity conservation, and which specific blocks of habitat are necessary to maintain or restore movement pathways under climate change? Since it may take many years (if ever) for formal studies on these topics to be conducted, and connectivity projects need to move forward as soon as possible, integrating expert knowledge into regional connectivity planning will be essential.

- ***Evaluate the most strategic, effective options for reducing impacts from known human-created barriers to animal movement in primary linkage zones, particularly the Interstate 5 (I-5) highway corridor within the Cascade-Siskiyou land bridge***. Several of the papers included in this review highlighted adverse impacts to connectivity associated with I-5 on both sides of the Oregon-California border (e.g., Buttrick et al. 2015, Theobald et al. 2012, Hatch et al. 2008). Opportunities for mitigating these impacts using a variety of wildlife crossing structures should be investigated in terms of their feasibility, optimal location and cost-benefit tradeoffs. (Clevenger 2012, Beckman et al. 2010).

- ***Increase education and outreach on the importance of ecological connectivity in the Cascade-Siskiyou landscape***. Connectivity conservation will move forward in this region largely to the extent that this issue is understood and seen as important by the people and agencies that are responsible for managing these lands. Increased cooperation is needed to help regulate land use activities that threaten wildlife movement across ownership boundaries, and also to generate greater appreciation for the importance of connectivity to sustaining the region's diverse biota, ecosystem services and quality of life.

- ***Lastly, all future work must recognize the importance of incorporating climate change into connectivity planning***. This can be accomplished by identifying connectivity paths along climatic gradients, evaluating the degree to which specific linkages are robust to different future climate scenarios, and incorporating climate refugia into connectivity design and implementation.

It is hoped that this review will help to spur these and other future actions aimed at protecting and restoring connectivity in this nationally significant hotspot of biological diversity.

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