TACCIMO Literature Report

Management Options Literature Report – Annotated Bibliography Format
Report Date: May 22, 2013

Content Selections:
FACTORS – Animal Communities
CATEGORIES – General Impacts, Amphibians, Birds, Mammals
REGIONS – All Western Regions
KEYWORDS – Rana sierrae, Empidonaz traillii, Centrocercus urophasianus, Martes americana, Martes pennant, Ovis canadensis

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest & Western Wildland Environmental Threat Assessment Centers, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

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Management Options by Source

Wednesday, May 22, 2013

RESOURCE AREA (FACTOR): ANIMAL COMMUNITIES

GENERAL SPECIES APPROACHES

Barbour, E. & Kueppers, L. M. (2011). Conservation and management of ecological systems in a changing California. Climatic Change, DOI 10.1007/s10584-011-0246-y, 1-

"Still, certain basic principles hold promise going forward: (i) following robust approaches to reserve design and prioritization, (ii) implementing adaptive management including ongoing experimentation with adaptive strategies, (iii) emphasizing co-benefits for climate change mitigation and adaptation, and (iv) enhancing ecosystem and economic health simultaneously through coordinated action."

"For example, biologists promote large, continuous reserves for multiple species as more sound than piecemeal strategies addressing species' needs individually (Christensen et al. 1996; Groves et al. 2002). In the face of climate change, systems of reserves encompassing climate variation in the landscape (e.g., topographic variation) and corridors connecting reserves (e.g., high-low elevation and north–south latitudes) will enable species to migrate shorter distances, or through more hospitable terrain (Ackerly et al. 2010; Heller and Zavaleta 2009). Protection of reserve boundaries and genetically diverse, evolutionary "hotspots" will reduce external pressures and maximize species capacity to adapt to change. Thus, robust design principles include strengthening fixed elements (reserves) as well as connectivity among reserves, and limiting external pressures, such as pollution, that will act synergistically with climate change (Hannah and Hansen 2005)."

AMPHIBIANS

GENERAL

Early, R. & Sax, D.F. (2011). Analysis of climate paths reveals potential limitations on species range shifts. Ecology Letters, 14, 1125-1133.

"First, constraints imposed by climatic variability, limited dispersal and low persistence may mean that even habitat corridors through high-quality habitat may not in themselves make range shifts possible. Additionally, corridors for species that show high uncertainty between climate paths under different GCMs are less likely to be effective. Where corridors are appropriate, their effectiveness will depend on how well the corridor landscape facilitates population persistence in addition to dispersal. Species' range shifts along corridors could be expedited by assisting or augmenting populations that 'naturally' establish themselves along the corridor. Given current uncertainty in climate modelling, predictions of climate paths many decades into the future may be an inadequate basis for corridor planning. However, the predicted directionality of range shifts in the short term (10–20 years) should be immediately incorporated into land use planning."

"Second, for species facing unpredictable or discontinuous climate paths (due to physical barriers or climatic variability), the controversial strategy of 'managed relocation' may be more effective than corridors in achieving conservation objectives (Richardson et al. 2009). The efficacy of corridors vs. managed relocation could be informed by climate-path analyses that consider measurements of the intrinsic lifehistory traits that will determine species' range-shift ability (discussed above) and by regular population monitoring. If analyses suggest that an insurmountable gap will arise in the climate path, then the deterioration in viability within the species' current range and suitability of conditions on the other side of the gap should be monitored concurrently. The combination of modelling and observation should then be used to inform decisions about whether to engage in managed relocation, as well as to determine the timing and location at which this approach would be most effective. "

"Third, species' range shifts and survival in situ could be aided by assisting extant populations to persist under future climatic variability. This could be achieved by mitigating against the impacts of climate change (e.g. via irrigation), by removing non-climatic stressors (such as predators or competitors), by improving habitat quality or connectivity (Grant et al. 2010), and through captive breeding programmes or translocations of individuals to augment population size or genetic composition (Semlitsch 2000)."

SIERRA NEVADA YELLOW-LEGGED FROG, RANA SIERRAE

Lacan, I., Matthews, K. & Feldman, K. (2008) Interaction of an introduced predator with future effects of climate change in the recruitment dynamics of the imperiled Sierra Nevada yellow-legged frog (Rana sierra). Herpetological Conservation and Biology, 3 (2), 211 – 223.

"This and other studies (Bradford 1989; Knapp and Matthews 2000) have demonstrated that an introduced predator (trout) has confined most frog breeding to exactly those lakes that are the most likely to dry out during the summer, and has eliminated a potential refuge of larger lakes during dry years by preventing the breeding there. A conservation strategy should recognize this interaction between the introduced predator and the likely future effects of climate change, and aim to expand the breeding habitat of R. sierrae [Sierra Nevada yellow-legged frog, Rana sierrae] to a greater fraction of the frog's former range, including large, permanent lakes."

Matthews, K. R. & Preisler, H. K. (2010). Site fidelity of the declining amphibian Rana sierra (Sierra Nevada yellow-legged frog). Canadian Journal of Fisheries and Aquatic Sciences, 67, 243 – 255.

"Under current disturbances in high-elevation Sierra Nevada lakes (exotic trout, climate change), site fidelity is problematic because frogs [Rana sierrae, Sierra Nevada yellow-legged frogs] return to lakes subject to drying or those with fish rather than dispersing to other lakes. Future recovery of declining species will need to focus efforts towards restoring habitats when animals maintain strong site fidelity even when their habitats deteriorate."

Stephens, S. L., Millar, C. I., & Collins, B. M. (2010). Operational approaches to managing forests of the future within a context of changing climates. Environmental Research Letters, 5 (024003), 1-10.

"Sierra Nevada yellow-legged frog (Rana sierrae) is a rare species of concern in the forests of the Sierra Nevada that has declined throughout its range. A possible management option would be to designate networks of high elevation lakes that have connectivity among them, exotic trout removed, and native frogs introduced (Lacan et al 2008)."

BIRDS

GENERAL

Russell, R. E., Royle, J. A., Saab, V. A., Lehmkuhl, J. F., Block, W. M. & Sauer, J. R. (2009). Modeling the effects of environmental disturbance on wildlife communities: avian responses to prescribed fire. Ecological Applications, 19(5), 1253 – 1263.

"Fuel reduction treatments potentially reduce the risk of future severe wildfires and may be a practical management tool [for birds] along the urban-wildland interface. Prescribed fire treatments, however, will likely not substitute for stand replacement fires in creating habitat for all fire-associated species. We recommend fire management plans that allow for natural wildfire events to burn in areas not likely to impact human developments or other areas of high economic or social value, thus, allowing for a mosaic of conditions that support diverse communities of avian species."

Bruzgul, J. & Root, T. L. (2010) Temperature and long-term breeding trends in California birds: Utilizing and undervalued historical database. California Energy Commission, PIER Energy-Related Environmental Research Program, CEC-500-2010-002.

"By helping resources managers in California to be able to expect that such a mismatch could occur [As the globe has warmed some species have been adapting to that change by shifting their phenology in the spring, fall or both], then they could take anticipatory steps. For example, providing supplementary food, much like refuge managers provide to waterfowl, could be planned before there is a crisis. "

WILLOW FLYCATCHER, EMPIDONAX TRAILLII

Hatten, J. R., Paxton, E. H. & Sogge, M. K. (2010). Modeling the dynamic habitat and breeding population of Southwestern Willow Flycatcher. Ecological Modelling, 221, 1674 – 1686.

"Specifically, our models suggests that careful manipulation of lake levels at the right time of the year, over a period of years, could result in the creation and maintenance of critical habitat necessary to sustain flycatcher [Southwestern Willow Flycatcher, Empidonax traillii] populations. The ability to create and manage riparian habitat for populations of flycatchers and other riparian obligate species will become increasingly important if predictions of climate change do result in a drier, hotter climate in the Southwest (Seager et al., 2007) and reduced stream flows (Ellis et al., 2008a)."

Galatowitsch, S., Frelich, L., & Phillips-Mao, L. (2009). Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. Biological Conservation, 142, 2012-2022.

"For example, if drought increases livestock grazing pressure on shrubs through premature drying of herbaceous forage, livestock could be taken off of the grazing allotment when shrub browse exceeds a certain percent as determined in collaboration with permit holders. Such standards should allow recruitment of riparian deciduous shrubs (that provide willow flycatcher [Empidonax traillii] nesting substrate) and are consistent with current management directions in the Sierra Nevada (SNFPA ROD 2001, p. A-59)."

Green, G. A., Bombay, H. L. & Morrison, M. L. (2003). Conservation assessment of the willow flycatcher in the Sierra Nevada. Sacramento, CA: US Forest Service Region 5.

"As reviewed in this document, [Sierra Nevada] meadows have been negatively impacted by a variety of factors that, together, have apparently caused a decline in habitat conditions for breeding and foraging flycatchers [Empidonax traillii]. Thus, management should be instituted that leads to an improvement in the stature (height and foliar cover) and recruitment of willow and maintains wet conditions throughout the flycatcher breeding cycle."

"Because of limited funding, a priority list of meadows that are candidates for restoration should be developed. Initially, efforts should be focused within willow flycatcher [Empidonax traillii] dispersal distance towards or near those meadows already supporting a high percentage of the Sierra Nevada willow flycatcher population."

SAGE-GROUSE, CENTROCERCUS UROPHASIANUS

Dzialak, M. R., Webb, S. L., Harju, S. M., Olson, C. V., Winstead, J. B. & Hayden-Wing, L. D. (2013). Greater sage-grouse and severe winter conditions: Identifying habitat for conservation. Rangeland Ecology and Management, 66 (1), 10 – 18. http://dx.doi.org/10.2111/REM-D-11-00223.1

"Results of this analysis [collecting landscape-level animal occurrence data in south-central Wyoming during severe winter conditions and estimation and validation of a resource selection function] indicate that occurrence of sage-grouse [Centrocercus urophasianus] during a severe winter was characterized by selection for large patches of big sagebrush [Artemisia spp.], tall shrubs, a favorable thermal environment, and avoidance of bare ground and anthropogenic features. A conservation plan based on this information, as a component of a larger strategy that addresses other important habitats (sensu Dzialak et al. 2011), should aim to retain big sagebrush throughout large areas and constrain human activity to the greatest extent feasible within patches that have been identified as critical habitat (Figs. 4C and 5; Walker et al. 2007; Doherty et al. 2008; Harju et al. 2010; Holloran et al. 2010)."

"Another potentially important implication of these results is that topographically variable expanses of sagebrush [Artemisia spp.] (i.e., sagebrush on steep or rough terrain, or within drainages) may become increasingly important as the severity of winter conditions intensifies. The distribution of snow will be relatively homogenous throughout flatter areas where sagegrouse [Centrocercus urophasianus] tend to congregate under average winter conditions and, at a sufficient snow depth, such areas will be rendered unavailable to sage-grouse. In contrast, steeper and more variable terrain results in considerable variability in snow deposition and thus resource availability. Wind-driven snow deposition and its effect on resource availability is an issue that needs to be addressed quantitatively as part of animal occurrence models on rangelands."

"Conserving critical seasonal habitat alone, such as severe winter areas for sage-grouse [Centrocercus urophasianus], is not sufficient as a basis from which to assume long-term population persistence; rather, comprehensive planning that considers habitat needs during all life-history phases is needed (sensu Dzialak et al. 2011). Yet, such critical seasonal habitat is important for many animal populations (Sawyer et al. 2006) because, as a temporary resource bottleneck, it can influence population size even if there is no shortage in resources during more typical climatic conditions. If an increase in climatic variability accompanies global climate change, as has been predicted in some regions (Parmesan and Yohe 2003), place-based, quantitative investigations will be important components of efforts to sustain valued human uses of the land that have not always found compatibility such as development of energy resources and conservation of animal populations and their habitat (Wu 2008)."

Schrag, A., Konrad, S., Miller, S., Walker, B. & Forrest, S. (2011). Climate-change impacts on sagebrush habitat and West Nile virus transmission risk and conservation implications for greater sage-grouse. GeoJournal, 76, 561 – 575.

"This assessment suggests that high-elevation sagebrush [Artemesia spp.] habitat in southwestern Wyoming (dark blue areas; Fig. 4) is of the highest conservation concern and should be the primary focus of resources for protecting current sagebrush habitat [for greater sage-grouse, Centrocercus urophasianus]. These areas currently have sagebrush and are likely to be highly suitable for sagebrush and have a low risk of WNv [West Nile virus] transmission in the future. Neighboring areas of southwestern Wyoming and Montana are good candidates for maintaining current sagebrush populations and limiting competing threats (e.g., energy development) into the future (medium blue areas; Fig. 4). Restoration projects have the highest potential for success in western Wyoming in most models and in northcentral and northwestern Montana in some models. Some portions of these areas do not currently have robust sagebrush habitat but likely will have climatic conditions necessary for sagebrush establishment in the future (light blue areas; Fig. 4). "

"Cumulative impacts of predicted climate change on sagebrush [Artemesia spp.] habitat and West Nile virus transmission are likely to reduce suitable sage-grouse [Centrocercus urophasianus] habitat in the northern Great Plains and northern Rockies. However, we can identify two conservation priorities for greater sage-grouse. The spatial representations of the ‘‘best available’’ habitat for the sage-grouse, both currently and twenty years in the future, indicate that areas in southwestern Wyoming will serve as important core refugia for sage-grouse populations, due to persistent sagebrush habitat, but will also experience elevated risk for West Nile virus transmission. Areas in north-central Montana are considered important fringe populations because they are located near the northern extent of the bird’s range and currently contain intact sagebrush habitat. Dispersal pathways (e.g., intact sagebrush habitat) that connect these populations and the core population in southwestern Wyoming should be protected."

"Greater sage-grouse [Centrocercus urophasianus] in some parts of our study area [Montana, Wyoming, North Dakota and South Dakota] migrate long distances ([60 km) between seasonal habitats (Connelly et al. 2004; Tack 2006). Thus, protecting not only those core areas with the highest probability of persistence, but also those areas that will maintain connectivity between core areas will be an important management strategy for this species (Tack 2006)."

"We recommend increased emphasis on conservation and protection of areas with a high probability of suitable sagebrush [Artemesia spp.] habitat [for greater sage-grouse, Centrocercus urophasianus] in the future, including both core and peripheral areas. Within those areas, proactive management of anthropogenic water sources will be required to reduce the spread of mosquitos that transmit West Nile virus. In addition, restoring converted areas back to native sagebrush-steppe and preventing widespread loss of sagebrush habitat to new development (energy, urban, residential, agricultural, etc.), particularly along the range periphery (Aldridge et al. 2008), will be important. We may also promote long term resilience to change by maintaining habitat within dispersal corridors between fringe and core populations. Finally, to determine the effectiveness of these measures, regional monitoring programs should be implemented that can identify when thresholds are about to or already have been surpassed in order to prompt appropriate conservation or regulatory action."

Wisdom, M. J. & Chambers, J. C. (2009). A landscape approach for ecologically based management of Great Basin shrublands. Restoration Ecology, 17 (5), 740 – 749. doi: 10.1111/j.1526-100X.2009.00591.x

"An effective strategy to reduce the risk of future loss of sagebrush [Artemesia spp.] to cheatgrass [Bromus tectorum] and to woodlands, and thus maintain Sage-grouse [Centrocercus urophasianus] habitats, could be based on establishing a comprehensive set of landscape-based spatial priorities and objectives compatible with the scale of Sage-grouse requirements (Meinke et al. 2009). Given limited resources for management, an efficient approach to establish and implement spatial priorities could focus on maintaining the largest areas of Sage-grouse habitat that require mostly passive management (little or no active resource inputs, see Step 5; also see Meinke et al. (2009) for a similar approach). In this case, the 100,000-ha blocks dominated by larger areas of sagebrush with higher resistance and resilience (lower risk of loss) would have high priority for management. Less focus would be placed on blocks with smaller areas of sagebrush of lower resistance and resilience."

MAMMALS

MARTEN, MARTES AMERICANA

Wasserman, T. N., Cushman, S. A., Littell, J. S., Shirk, A. J. & Landguth, E. L. (2012). Population connectivity and genetic diversity of American marten (Martes americana) in the United States northern Rocky Mountains in a climate change context. Conservation Genetics, DOI 10.1007/s10592-012-0336-z

"To implement such an approach most effectively, managers should prioritize corridors [for American marten, Martes americana] in the current landscape based on their importance to maintaining network connectivity, and evaluate the importance of corridors as climate change progresses. Our predictions of current and future corridor locations could guide this prioritization. Once key corridor locations are identified, conservation and restoration efforts should be focused in these areas and the adjacent population core areas to enhance habitat quality by reducing road density, increasing canopy closure and protecting late seral forest."

Wasserman, T. N., Cushman, S. A., Littell, J. S., Shirk, A. J. & Landguth, E. L. (2012). Population connectivity and genetic diversity of American marten (Martes americana) in the United States northern Rocky Mountains in a climate change context. Conservation Genetics, DOI 10.1007/s10592-012-0336-z

"However, even though the formal connectivity model that is most empirically supported based on genetic differentiation is climate driven, there may be landscape-scale conservation and restoration strategies that might enhance the viability of local core populations [of American marten, Martes americana] and connectivity among them. Habitat suitability of American marten in the study area is highly related to canopy cover, road density and extent of late-seral forest at broad landscape extents (Wasserman et al. in press). Landscape level habitat suitability of marten could be enhanced by management strategies that reduce road densities, increase average canopy cover within watersheds, and protect late seral forests. Increased habitat suitability might result in denser populations and a larger number of dispersing individuals in each core population, which could partly balance the effects of increased isolation on successful inter-core dispersal."

FISHER, MARTES PENNANTI

Zielinski, W. J., Truex, R. L., Schmidt, G. A., Schlexer, F. V., Schmidt, K. N. & Barrett, R. H. (2004). Resting habitat selection by fishers in California. Journal of Wildlife Management, 68(3), 475 – 492

"Because large live trees and large snags are less abundant in the Sierra Nevada and the Pacific Northwest than historically (McKelvey and Johnson 1992, U.S. Forest Service and U.S. Department of the Interior 1994, Bouldin 1999), every management activity designed to favor fishers [Martes pennanti] should be evaluated as to whether it enhances or reduces the availability or development of large live and dead trees and large logs. Management actions that are designed to reduce fuels and the possibility of catastrophic fire and to treat tree diseases should be especially careful about protecting legacy or residual woody structures (Hunter and Bond 2001), as well as trees with mistletoe infections that are used by fishers for resting (Mazzoni 2002)."

Purcell, K. L., Mazzoni, A. K., Mori, S. R. & Boroski, B. B. (2009). Resting structures and resting habitat of fishers in the southern Sierra Nevada, California. Forest Ecology and

Management, 258, 2696 – 2706.

"Our results suggest that large trees and snags are probably limiting to fishers [Martes pennanti]. Large trees, especially pines [Pinus spp.] and oaks [Quercus spp.], are less abundant than they were historically, and large trees and snags are beneficial to a wide variety of wildlife species (e.g., Verner et al., 1992; Noss et al., 2006; Purcell, 2007; Bagne et al., 2008). We encourage management practices that retain large trees, snags, and logs and support the growth of greater numbers of large trees while maintaining dense cover and a complex vertical and horizontal forest structure. Trees with decadence or poor growth form are sometimes removed if deemed to pose a hazard risk. Trees with defects such as multiple tops, rot, and cavities often result from injury and there is no genetic reason for removal (North et al., 2009). "

Truex, R. L. & Zielinski, W. J. (2013). Short-term effects of fuel treatments on fisher habitat in the Sierra Nevada, California. Forest Ecology and Management, 293, 85 – 91. http://dx.doi.org/10.1016/j.foreco.2012.12.035

"Land managers [in the Sierra Nevada] faced with balancing the challenges of maintaining habitat for fisher [Martes pennanti] and reducing the threat of catastrophic fire can take relatively simple steps to mitigate the effects of vegetation management projects on fisher habitat. First, to mitigate the anticipated reduction of canopy closure managers can plan actions that will maintain other habitat elements important to fisher (e.g., presence of large diameter hardwoods). Second, if conditions permit, early season burns appear to be preferable to late season burns in terms of the short-term impacts on fisher habitat, but should occur after the fisher denning period (mid-March through mid-May). If conditions necessitate burning earlier than mid- May, efforts should be made to avoid treating areas that have high density of structures likely to be used by females for denning (Zielinski et al., 2004; Purcell et al., 2009; Zhao et al., 2012). "

"Whenever possible, managers [in the Sierra Nevada] should plan vegetation management activities in a manner that disperses treatments over space and time to minimize impact on individual fishers [Martes pennanti]. We recognize, however, that this goal can contradict the guidelines for installing effective fuels treatments (i.e., Finney, 2001). Lastly, managers must be willing to commit to long-term monitoring efforts to better understand the impacts of vegetation management activities on fishers and other species of wildlife. Monitoring should include both a habitat component, such as the approach described herein using predictive models, as well as a population monitoring component (e.g., Zielinski et al., 2013)."

Zielinski, W. J., Kucera, T. E. & Barrett, R. H. (1995). Current distribution of the fisher, Martes pennanti, in California. California Fish and Game, 81(3), 104 – 112.

"Although the fisher [Martes pennanti] always has occurred in the southern Sierra Nevada, the apparent current isolation renders this population vulnerable to catastrophic events in the short term and, possibly, inbreeding depression in the long term. This population is crucial to the restoration of the fisher in California because it is the one most likely to recolonize the remainder of the Sierra Nevada. Moreover, it is a likely source for transplants should reintroduction to the central and northern Sierra Nevada be considered. Although research on the habitat associations of fisher elsewhere in California may help explain why the fisher is uncommon in the northern and central Sierra Nevada, studies of remnant populations are an insufficient conservation strategy. It is more important that forests in the Sierra Nevada and southern Cascades be managed to encourage the natural dispersal of fishers into the area we currently believe is occupied."

BIGHORN SHEEP, OVIS CANADENSIS

Epps, C. W., Palsboll, P. J., Wehausen, J. D., Roderick, G. K. & McCullough, D. R. (2006). Elevation and connectivity define genetic refugia for mountain sheep as climate warms. Molecular Ecology, 15, 4295 – 4302. doi: 10.1111/j.1365-294X.2006.03103.x

"Because the size of desert bighorn sheep [Ovis canadensis] populations in both high- and low-quality habitat appears to be very variable (Epps et al. 2005b), and current estimated population sizes are not correlated with genetic diversity (Epps et al. 2005a), the role of these areas [high elevations] as genetic refugia was not obvious from population census data alone. However, it should also be recognized that desert bighorn sheep may experience different habitat conditions in some of the high-elevation mountain ranges in the southwestern United States that are not considered desert habitat. Dense tree cover or heavy snow in ranges such as the San Gabriel Mountains of California may in fact decrease habitat quality for desert bighorn because of increased risk of predation and poorer forage in wooded areas."

"Although habitat conditions affected by climate are not amenable to manipulation (with the possible exception of maintaining perennial waterholes), connectivity could be improved. Epps et al. (2005a) demonstrated that fenced interstate highways and other human-made barriers are reducing genetic diversity in this metapopulation [of desert bighorn sheep, Ovis canadensis] by limiting migration. Thus, loss of genetic diversity due to climate variation is exacerbated by human disruption of population connectivity for desert bighorn sheep. However, the reduction of genetic diversity as the climate changes might be offset, at least in the short term, by finding solutions to restore connectivity. Possible solutions include widening and improving accessibility to culverts under interstate highways, creating overpasses, translocating desert bighorn sheep between populations, and ensuring that any additional highways are designed to permit movement of wildlife. Maintaining and restoring connectivity between fragmented populations should be a conservation priority, particularly in habitats vulnerable to the effects of rapid climate change."

Epps, C. W., McCullough, D. R., Wehausen, J. D., Bleich, V. C. & Rechel, J. L. (2004) Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology, 18 (1), 102 – 113.

"Our results have important implications for management actions. For future reintroductions of desert bighorn sheep [Ovis Canadensis], managers should consider expected precipitation and elevation within the mountain range of consideration. We do not advocate abandoning all efforts in mountain ranges that are at high risk: some may serve as valuable "stepping stones" for gene flow or demographic "rescue" (Bleich et al. 1990), and the extinction model may not be correct for all locations at all times. However, knowledge of climate-based risk of extinction may allow managers to focus further efforts on locations with the highest probability of success"

"Understanding which populations [of of desert bighorn sheep (Ovis Canadensis)] are under the most climate-related stress could also be critically important in coming decades (Fig. 3). Because of regionally correlated environmental conditions, whole regions of populations and subsequent opportunities for gene flow or recolonization may be lost (Fig. 3). Heightened monitoring of population size, condition, and water availability, with appropriate action, may be necessary to conserve populations of desert bighorn sheep in the future."

Epps, C. W., Palsboll, P. J., Wehausen, J. D., Roderick, G. K. & McCullough, D. R. (2006). Elevation and connectivity define genetic refugia for mountain sheep as climate warms. Molecular Ecology, 15, 4295 – 4302. doi: 10.1111/j.1365-294X.2006.03103.x

"Populations [of desert bighorn sheep, Ovis canadensis] generally maintained the highest genetic diversity when isolation was low (that is, connectivity with other populations remained) and suitable habitat conditions persisted (i.e. elevation was high). Therefore, maintaining connectivity between populations in more favourable habitats is particularly important. These areas seem to serve as refugia for genetic diversity in the event of long drought periods or increased aridity as climate changes, and will therefore act as source populations in periods of more favourable climate. "