Potential impacts of proposed solar energy development near the South Soda Mountains on desert bighorn sheep connectivity

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Summary
This report evaluates implications of the proposed renewable energy project in the vicinity of the Soda Mountains relative to conservation of desert bighorn sheep (*Ovis canadensis nelsoni*) in the Mojave Desert of California. The proposed solar array would straddle Interstate 15 and cover areas between the North and South Soda Mountains, on the northwest edge of the Mojave National Preserve. Although the exact footprint of the project is not yet clear, the intensity of development within such solar arrays would likely prevent movement of bighorn sheep through project areas. Past bighorn sheep movement between the North and South Soda has been blocked by Interstate 15. However, restoration of this movement corridor may be possible by either 1) modifying existing locations where the Interstate crosses washes via bridges to create potential underpasses for bighorn sheep by enticing bighorn sheep to those areas, or 2) construction of an overpass structure as has been implemented successfully over Highway 93 in Arizona. To determine the importance of the affected area for restoration of bighorn sheep connectivity, we used network analysis of an empirically-derived connectivity model for desert bighorn sheep to evaluate short- and long-term consequences of restoring the Soda Mountains connection for gene flow and recolonization by desert bighorn sheep. We also assessed potential underpass and overpass crossing sites using remotely-sensed data and site visits. The network analysis indicated that the North-South Soda Mountain connection is the most important restorable corridor for long-term demographic potential (i.e., population recolonization by ewes) across the entire southeastern Mojave Desert of California, as it would provide the best and only opportunity for movement between bighorn populations in the Mojave National Preserve and the large complex of populations to the north of Interstate 15, and would facilitate gene flow as well resulting in long-term (multi-step) connections with bighorn sheep populations in Death Valley National Park. We identified four existing underpasses in or near the affected area, and identified two specific locations where overpass structures might be built based on the distribution of bighorn sheep habitat. All potential crossing locations, including both existing underpasses and sites for potential overpass construction, are on or adjacent to the area proposed for renewable energy development. Therefore, the proposed development may negatively affect the potential to restore this extremely important movement corridor for bighorn sheep.

Introduction

Desert bighorn sheep (*Ovis canadensis nelsoni*) have strong cultural, ecological, and economic significance in the Mojave Desert of California. In this region this species exhibits a metapopulation structure: populations occupy numerous small mountain ranges that are separated by varying expanses of relatively flat desert (Fig. 1), with infrequent but continual crossing of those flats by individuals migrating between populations. Preserving and, where possible, augmenting connectivity among bighorn populations is an important conservation objective for genetic and demographic reasons. The relative isolation and small size of bighorn populations makes them very vulnerable to loss of genetic diversity from the pervasive force of genetic drift (Epps *et al.* 2005), but dispersal between mountain ranges counteracts this loss through gene flow and thereby works to maintain genetic diversity, and ultimately the ability of the species to adapt to changing environmental conditions. The high rate of past population extinction in this metapopulation (Torres, Bleich & Wehausen 1994) means that dispersal is also necessary for re-colonization of vacant habitat where extinctions have occurred (Epps *et al.* 2010). Numerous such re-colonization events have been documented in recent decades (Wehausen 2012, Epps *et al.* 2010).

Although core mountainous habitat where bighorn sheep reside, forage, and breed remains largely intact in the region, surrounding dispersal habitat has been fragmented over the past century by interstate highways, canals, urbanization, mining operations, and other anthropogenic developments (Epps *et al.* 2005). Ongoing and proposed renewable energy development in the Mojave Desert threatens to further reduce connectivity among bighorn populations by obstructing dispersal corridors. A proactive approach that focuses on restoring key dispersal corridors is an important option for managing desert bighorn populations in the region and is called for in the California Department of Fish and Wildlife draft conservation plan for these sheep (Wehausen 2012).

Here, we discuss potential impacts to bighorn connectivity of the proposed solar energy development between the North and South Soda Mountains (Fig. 1). We focus on this specific area because our recent analyses indicate that it could be especially important to efforts to restore metapopulation connectivity. Our comments are based on the results of an unpublished modeling study that addressed potential management actions to preserve and improve connectivity among bighorn populations in this region, which we describe briefly below.

Modeling genetic and demographic connectivity among populations

We combined an existing bighorn landscape resistance model (Epps *et al.* 2007) with a network theory approach to construct models of genetic connectivity and demographic connectivity in the Mojave Desert bighorn sheep metapopulation. We define genetic connectivity as the potential for gene flow among populations, and demographic connectivity as the potential for re-colonization of empty patches. Analyses of gene flow data by Epps et al. (2007) found that genetic connectivity among Mojave Desert bighorn populations is a function of a combination of geographic distance between populations and the slope of the intervening terrain, with bighorn sheep preferring more steeply-sloped terrain (>10%) that better allows them to escape predators. The combination of slope and distance that reflects the dispersal resistance differences of habitat of different slopes is termed "effective distance." Using genetic data and telemetry data, we estimated that the maximum effective distance over which individuals will disperse in this metapopulation (ED_{MAX}) is approximately 60 percent greater for rams than for ewes. This means that populations that are genetically connected may not necessarily be demographically connected because genes can be transmitted among populations by rams alone, but recolonization of empty patches requires both rams and ewes to disperse.

We used the Epps et al. (2007) landscape resistance model to predict the location and effective distance of the least-cost path (LCP) between all pairs of occupied habitat patches; these LCPs were assumed to represent likely dispersal corridors between populations, but do not represent all such corridors used by sheep. We then constructed two networks to represent existing connectivity within the metapopulation: 1) a genetic network including all dispersal corridors between patches separated by < ED_{MAX} for rams; and 2) a demographic network including those corridors < ED_{MAX} for ewes. Predicted paths that intersected a barrier feature (e.g., interstate highway, canal, urban area) were excluded from the network, as bighorn very rarely cross these barriers.

We identified 21 dispersal corridors that are currently interrupted by anthropogenic barriers but would otherwise connect populations within the estimated ED_{MAX} of rams (i.e., would provide genetic connectivity). Fifteen of these corridors were also within the shorter ED_{MAX} of ewes (i.e., would also provide demographic connectivity). These corridors were considered potential targets of management actions to mitigate barriers to restore connectivity. Examples of such actions are the building of wildlife crossing structures over freeways or using water to bait sheep to use existing freeway bridges as underpasses, as recommended in Wehausen (2012). In Arizona two such bridges recently constructed across Highway 93 for bighorn sheep received immediate use by the target species.

Prioritizing corridor restoration actions

We ranked restorable corridors according to their predicted influence on regional connectivity using two network metrics:

1. Effectively connected pairs (ECP) – a measure of short-term connectivity based on the number of pairs of patches that are linked by an effective distance within the dispersal range for a single dispersal event by an individual.
2. Mean weighted closeness (MWC) - a measure of long-term connectivity based on the average total effective distance between pairs of habitat patches along the shortest series of dispersal paths.

We added restorable corridors to the network model one at a time and recalculated connectivity metrics after each addition. Corridors whose addition resulted in the largest increases in network connectivity were inferred to be highest priority for restoration. We also calculated the proportional change in network metrics (Δ value) associated with each corridor addition. Results of this analysis are shown in Table 1.

Significance of the South Soda Mountains to metapopulation connectivity

The corridor linking the Avawatz Mountains and S. Soda Mountains was the highest-ranking restorable corridor in our analysis in terms of impact on long-term demographic connectivity (Table 1, right column; Fig. 2). This corridor is the most influential restorable corridor because if restored it would demographically link two major clusters of populations on either side of I-15. In fact, our model suggests that the Avawatz--S. Soda corridor is the only restorable corridor that is short enough to connect populations on either side of I-15 within the estimated maximum dispersal range of a ewe.

The proposed solar development along I-15 that lies between the North and South Soda Mountains (Fig. 2) has the potential to interfere with, if not preclude, future corridor restoration efforts in this location, including the building of one or more bridges for sheep. Although the footprint of the proposed development has not been finalized, the most recently-available estimate of that footprint would affect most of the area directly between the two mountain ranges. Given the intensity of proposed development in these areas and associated fencing, it is very unlikely that bighorn sheep would be able to move across any developed area.

The potential connection between the S. Soda Mountains and the habitat patches north of I-15 is a critical component of what we consider to be the most efficient management strategy for maximizing metapopulation connectivity: restoring one key dispersal corridor across each of the interstate highways that currently fragment the Mojave Desert (I-15, I-40, and I-10). Our model suggests that this strategy would increase connectivity by 46 to 93 percent, depending on the type of connectivity considered (genetic vs. demographic and short-term vs. long-term). We consider it important for regulatory agencies to give this issue adequate consideration when evaluating potential development projects so as to avoid actions that might limit or preclude future efforts to re-establish connectivity for bighorn sheep. Below are some pertinent details.

Restoring metapopulation connectivity across I-15 at the Soda Mountains

In this section we discuss our recommendations for restoring connectivity across Interstate 15 at the Soda Mountains. These recommendations are based on our observations from field and remote-sensing exploration of the area in the vicinity of the Soda Mountains, discussions with other experienced personnel who have investigated bighorn sheep activity in the area within the last 1-5 years, previous genetic studies (e.g. Epps et al. 2007), as well as the combined expertise of the contributing authors derived from decades of research on desert bighorn sheep.

In Figure 3 we identify what we consider to be two potential locations for the construction of structures for bighorn sheep to cross over I-15 (1 and 2 on Fig. 3). These locations were chosen because topographic features are most favorable for bighorn sheep use (e.g., Epps et al. 2007). Prior to the construction of Interstate Highway 15 bighorn sheep would have readily crossed between the North and South Soda Mountains at both locations. Currently there are differences between these two potential overpass sites. At location 1 there is a lack of steeper sloped habitat immediately adjacent to the where the overpass would begin on the south side of the freeway. Currently, evidence of bighorn sheep use ends in steeper habitat about 1.5 km south of where the overpass would begin. In contrast, at location 2 there is steep habitat right to where the overpass would begin and clear sign of current bighorn sheep use (observed February 2013) at the site where the overpass would begin and the adjacent habitat. Additionally, at this site there remain decades-old bighorn sheep trails from many sheep crossing at this location prior to the construction of Interstate Highway 15. The abundant water on the east edge of the South Soda Mountains readily explains the historic high use of this crossing point. Sheep would have moved between this water and the North Soda Mountains frequently in summer.

Figure 3 also includes the locations of four existing highway bridges across washes (A-D on Fig. 3) that have potential for use by bighorn sheep as freeway undercrossings. Wehausen (2012) recommended research into the use of supplemental water near potential undercrossings as a way to bait desert bighorn sheep to potential undercrossing. Given the social nature of bighorn sheep and their associated behavioral trait of learning about habitat patches from each other, the use of such an underpass will likely increase quickly once it begins.

These four potential undercrossings vary considerably in width from about 4.5m wide (A and C) to 22m for B and 27m for D. However, our site inspections in February 2013 found that none of these was too narrow for sheep use, and that there is no fencing across the underpass entrances that might inhibit use by bighorn sheep. All four locations lie outside of habitat with >10% slope, but C and D are closer to such habitat, especially the north side of D, where steep habitat is immediately adjacent (Fig. 3). However, the 10% slope cutoff used in our modeling is not an absolute habitat division. There is variation in adjacent intermountain habitat below a 10% slope cutoff and in the amount of bighorn sheep use it receives. Desert bighorn sheep regularly venture up to a few hundred meters out from the base of mountain ranges into intermountain habitat for short time periods, and in some situations have been known to move considerable distances across intermountain habitat regularly to obtain water. Dispersing sheep readily venture far out into intermountain habitat. The analysis of gene flow by Epps et al. (2007) indicates that bighorn sheep will disperse across as much as 16.4 km of intermountain terrain <10% slope when moving between core habitat areas. All four potential undercrossings fall well under the maximum dispersal distance for both sexes of desert bighorn sheep. For locations A and B (Figure 3) the distance is greatest, but at about 3.7 km between the North and South Soda Mountains in that area it is still a relatively short intermountain distance for desert bighorn sheep to cross. Considerable gene flow typically occurs across that distance in the absence of barriers (Epps *et al.* 2007); thus, all the intermountain habitat between the North and South Soda Mountains has potential to be used for dispersal.

Based on our field observations in the area, there is currently well-established bighorn sheep use of habitat on the south side of the proposed project site in the South Soda Mountains and between there and Cave Mountain, and these sheep may use undercrossings A-D occasionally. It would take years of monitoring to determine the extent of such use. In contrast, the North Soda Mountains no longer support a resident population of sheep. Prior to the construction of I-15, sheep would have moved readily between the North and South Soda Mountains and would have had access to the current excellent water on the east side of the South Soda Mountains. That very reliable water in the South Soda Mountains has allowed a recent natural colonization there to grow into a population of 50-100 sheep based on a ground count conducted in May 2012 by California Department of Fish and Wildlife. When the much larger and higher North Bristol Mountains were available, the total population was undoubtedly larger.

Wehausen (2012) recommended the development of water in the North Soda Mountains as a way to encourage more use of that range by sheep dispersing south from the Avawatz Mountains. Even if used only by dispersing rams, habitat patches like the North Soda Mountains can be very important to gene flow and connectivity in general. Increased use of the North Soda Mountains could lead to increased use of undercrossings locations A-D. Given the major migration barrier of I-15, it is important to retain these potential crossing locations at least until a freeway overpass for bighorn sheep can be built. The development of a solar power generation project between the North and South Soda Mountains would very likely preclude such use of some of these underpasses.

Acknowledgements

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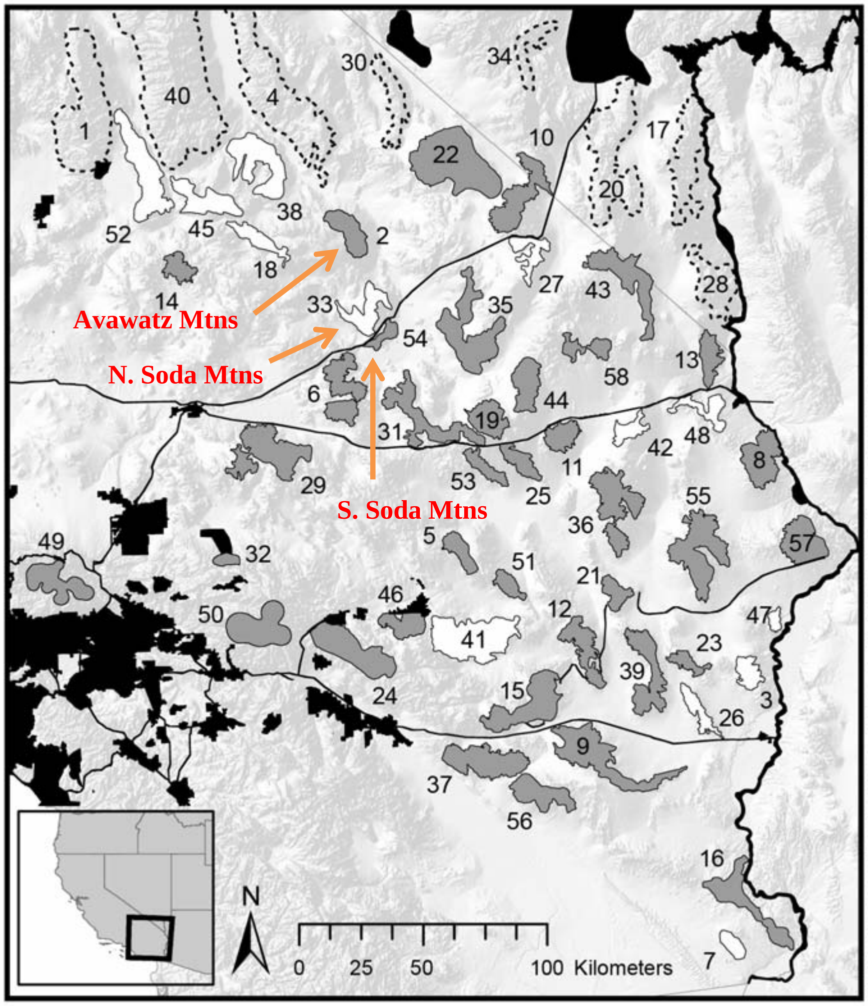

1-Argus Mtns (ARG); 2-Avawatz Mtns (AVA); 3-Big Maria Mtns (BMA); 4-Black Mtns/Greenwater Range (BGR); 5-Bullion Mtns (BUL); 6-Cady Mtns (CAD); 7-Cargo Muchacho Mtns (CAR); 8-Chemehuevi Mtns (CHE); 9-Chuckwalla Mtns (CHU); 10-Clark Mtns/S. Spring Range (CSS); 11-Clipper Mtns (CLI); 12-Coxcomb Mtns (COX); 13-Dead Mtns (DEA); 14-Eagle Crags (ECR); 15-Eagle Mtns (EMO); 16-E. Chocolate Mtns (ECH); 17-Eldorado Mtns (EDO); 18-Ft. Irwin Granite Mtns (FIG); 19-Granite Mtns (GRA); 20-Highland Range/McCullough Range (HMC); 21-Iron Mtns (IRO); 22-Kingston Mtns/Mesquite Range (KME); 23-Little Maria Mtns (LMA); 24-Little San Bernardino Mtns (LSB); 25-Marble Mtns (MAR); 26-McCoy Mtns (MCY); 27-Mescal Range/Ivanpah Mtns (MIV); 28-Newberry Mtns (NNV); 29-Newberry Mtns/Ord Mtns (NOR); 30-Nopah Mtns (NOP); 31-N. Bristol Mtns (NBR); 32-N. San Bernardino Mtns/-Cushenbury Mtns (NSB); 33-N. Soda Mtns (NSO); 34-N. Spring Range (NSP); 35-Old Dad Pk/Kelso Mtns/Marl Mtns/Club Pk/Indian Spring (OKM); 36-Old Woman Mtns (OWO); 37-Orocopia Mtns (ORO); 38-Owlshead Mtns (OWL); 39-Palen Mtns/Riverside Granite Mtns (PRG); 40-Panamint Mtns (PAN); 41-Pinto Mtns (PIN); 42-Piute Mtns (PIU); 43-Piute Range/Castle Pks/Castle Mtns (PCC); 44-Providence Mtns (PRO); 45-Quail Mtns (QUA); 46-Queen Mtn (QUE); 47-Riverside Mtns (RIV); 48-Sacramento Mtns (SAC); 49-San Gabriel Mtns (SGA); 50-San Gorgonio Mtns (SGO); 51-Sheephole Mtns (SHE); 52-Slate Range (SLA); 53-S. Bristol Mtns (SBR); 54-S. Soda Mtns (SSO); 55-Turtle Mtns (TUR); 56-W. Chocolate Mtns (WCH); 57-Whipple Mtns (WHI); 58-Woods Mtns/Hackberry Mtns (WHA)

Figure 1. Desert bighorn sheep habitat patches in the Mojave Desert region. Gray polygons are occupied patches, white polygons are unoccupied patches, and hollow dashed polygons are adjacent patches outside the study area considered in our analysis. Barriers to dispersal (interstate highways, urban areas, etc.) are shown in black.

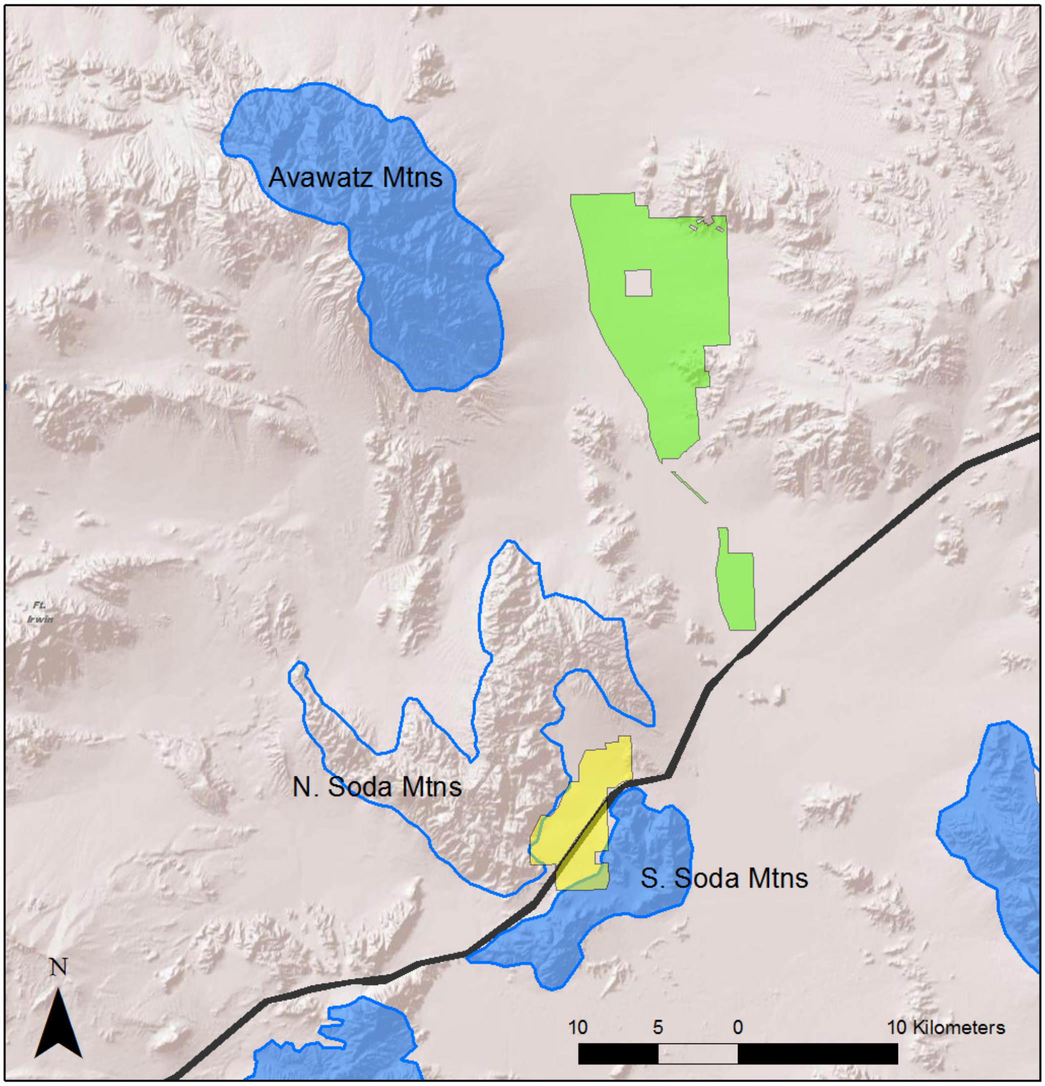

Figure 2. Proposed renewable energy developments near the South Soda Mountains. The filled blue polygons are mountain habitat currently occupied by desert bighorn sheep. The open blue polygon is currently vacant historic bighorn sheep habitat (with general boundaries inferred based on topography). The yellow polygon is the general region of the proposed solar energy facility, for which exact boundaries have not yet been established. Green polygons are proposed wind energy facilities in the vicinity. The thick black line represents Interstate 15.

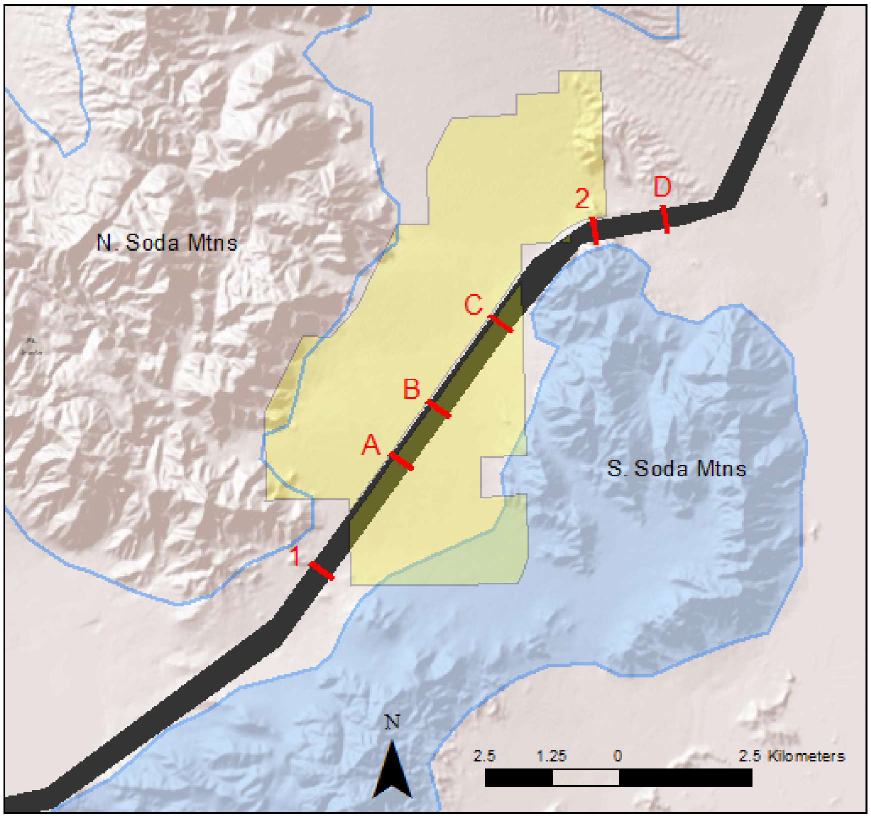

Figure 3. Potential locations for bighorn sheep to cross between the South Soda Mountains (filled blue polygon) and North Soda Mountains (open blue polygon). Red lines show locations of existing underpasses (A-D) and recommended sites for construction of wildlife overpasses (1, 2) across Interstate 15 (thick black line). Bighorn sheep sign and old trailing was observed in the immediate vicinity of location 2 on the south side of the interstate highway in February 2013. The yellow polygon reflects the general region of the proposed solar energy facility, for which exact boundaries have not yet been established.

Table 1. Prioritization of restorable corridors in the genetic and demographic networks based on ECP[a] and MWC[b]. The Δ value is the proportional increase in connectivity (as measured by ECP or MWC) when the specified corridor is restored to the network. Corridors are ranked from highest to lowest importance, with separate rankings for each combination of network type and network metric. Results for the Avawatz--S. Soda corridor (AVA-SSO) are highlighted in red. See Fig. 1 for patch name abbreviations.

Genetic network						Demographic network					
ECP			MWC			ECP			MWC		
Corridor	Δ value	Rank	Corridor	Δ value	Rank	Corridor	Δ value	Rank	Corridor	Δ value	Rank
GRA-MAR	0.246	1	GRA-MAR	0.342	1	GRA-MAR	0.231	1.5	AVA-SSO	0.196	1
NBR-SBR	0.197	2	NBR-SBR	0.308	2	NBR-SBR	0.231	1.5	GRA-MAR	0.196	2
EMO-ORO	0.123	3	CLI-PRO	0.280	3	LSB-SGO	0.108	3	NBR-SBR	0.185	3
CHU-EMO	0.115	4	BUL-CAD	0.225	4	EMO-ORO	0.092	4	CLI-PRO	0.110	4
CLI-PRO	0.090	5.5	BUL-NBR	0.217	5	CHU-EMO	0.077	5.5	EMO-ORO	0.101	5
LSB-ORO	0.090	5.5	CAD-NOR	0.205	6	LSB-NSB	0.077	5.5	CHU-EMO	0.096	6
ORO-QUE	0.066	7	AVA-CAD	0.171	7	LSB-ORO	0.062	7.5	LSB-SGO	0.094	7
AVA-CAD	0.049	8.5	AVA-SSO	0.166	8	ORO-QUE	0.062	7.5	COX-PRG	0.090	8
AVA-SSO	0.049	8.5	CHE-DEA	0.159	9	NSB-SGA	0.031	9.5	LSB-ORO	0.084	9
ORO-SHE	0.033	10	EMO-ORO	0.155	10	SGA-SGO	0.031	9.5	LSB-NSB	0.072	10
BUL-CAD	0.025	11.5	CHU-EMO	0.148	11	AVA-SSO	0.015	13	ORO-QUE	0.071	11
SGA-SGO	0.025	11.5	KME-OKM	0.147	12	CHE-DEA	0.015	13	COX-IRO	0.071	12
CAD-NOR	0.016	15.5	CSS-PRO	0.142	13	CLI-PRO	0.015	13	CHE-DEA	0.028	13
CHE-DEA	0.016	15.5	LSB-ORO	0.141	14	COX-IRO	0.015	13	NSB-SGA	0.020	14
CSS-PRO	0.016	15.5	CSS-WHA	0.141	15	COX-PRG	0.015	13	SGA-SGO	0.018	15
CSS-WHA	0.016	15.5	ORO-QUE	0.132	16						
KME-OKM	0.016	15.5	ORO-SHE	0.094	17						
NSB-SGA	0.016	15.5	CHU-PRG	0.081	18						
BUL-NBR	0.008	20	SGA-SGO	0.041	19						
CHU-PRG	0.008	20	NSB-SGA	0.039	20						
NOR-SGA	0.008	20	NOR-SGA	0.022	21						

[a] Effectively connected pairs, a measure of short-term network connectivity.
[b] Mean weighted closeness, a measure of long-term network connectivity.