LANDSCAPE PERMEABILITY AND WILDLIFE CROSSINGS

Enhancing the Reintroduction of Tule Elk in California

SENIOR CAPSTONE PROJECT, 2018

CAMERON GEE

LANDSCAPE PERMEABILITY AND WILDLIFE CROSSINGS: Enhancing the Reintroduction of Tule Elk in California

by Cameron Gee

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Lastly, I wish to thank my parents for their relentless support.

ABSTRACT

The presence of roads in the landscape has negative effects on the ecological systems they intersect. Roads impede the flow of species, acting as a barrier that decreases habitat connectivity and landscape permeability. As a result, species that reside around roads experience habitat loss and habitat fragmentation, reducing their potential for movement and reproduction. This project aims to explore ways in which wildlife crossings can be implemented along three highways in Northern California to mitigate the effects of roads on habitats for tule elk (*Cervus elaphus nannodes*). By gathering relevant data on tule elk distribution, as well as land cover and protected areas, optimal locations for potential wildlife crossings have been identified along Interstate-80, Highway 113, and Highway 12. Designs for these wildlife crossings consider the surrounding topography, future sea level rise, and necessary landscape elements for the species of concern. The methods carried out during this project are meant to serve as a guide for future large-scale transportation planning projects, and to encourage wildlife conservation practices in all aspects of road expansion or upgrade projects.

01 INTRODUCTION

SIGNIFICANCE

While tule elk populations are steadily growing, roads act as a barrier for potential colonization of suitable habitat. Vehicle-wildlife collisions are a threat to tule elk and other animals. To reduce the possibility of these collisions, wildlife crossings can be constructed to provide a safe means of travel for animals. The purpose of this project is to first explore ways in which landscape permeability and potential habitat connectivity can be modeled and analyzed. It attempts to identify variables that are critical in influencing tule elk habitat and movement patterns in northern California. By considering these variables, this project will determine optimal locations for wildlife crossings, with the goal of improving tule elk habitat connectivity between three identified terminuses.

STUDY AREA

This project focuses on the northern California region surrounding the existing tule elk habitat on Grizzly Island. Interstate-80, Highway 113, and Highway 12 all intersect adjacent potential habitat for the sub-species. Wildlife crossings along these three highways would allow for the safe movement of tule elk between areas of suitable habitat, improving the reintroduction of the sub-species in California.

LANDSCAPE PERMEABILITY

Landscape permeability can be defined as the quality of a heterogeneous land area to provide for the passage of animals. Landscape permeability is a measure of the resistance to animal movement and the potential for animal passage across landscapes (Singleton et al., 2002).

RESEARCH QUESTIONS

This project asks: How can landscape permeability for tule elk be assessed along highways to locate areas for potential and appropriate wildlife connectivity improvements to decrease roadway barriers?

This project also seeks to answer: What factors must be considered to model habitat suitability and potential habitat connectivity? How might the physical environment and needs of tule elk impact the design of a suitable wildlife corridor? How can wildlife crossings be implemented into transportation planning projects?

To answer these questions and devise appropriate designs, this project looks at past tule elk habitat suitability modeling and case studies of successful transportation projects that involve wildlife crossings.

02 TULE ELK

DISTRIBUTION HISTORY

Three sub-species of elk reside in California: Roosevelt (*Cervus elaphus roosevelti*), Rocky Mountain (*Cervus elaphus nelsoni*), and tule (*Cervus elaphus nannodes*). Of the three sub-species, tule elk are endemic to California, and once occupied much of the Central Valley (Greco et al., 2009). Tule elk are the most specialized elk sub-species in North America; they live in open country under semi-arid conditions, whereas the species as a whole typically occupies temperate climates and uses heavy cover at least seasonally (McCullough, 1969).

Figure 2-1 A pair of tule elk (Ron Wolf, 2012)

Figure 2-2 Tule elk crossing a stream (California State Parks, 2018)

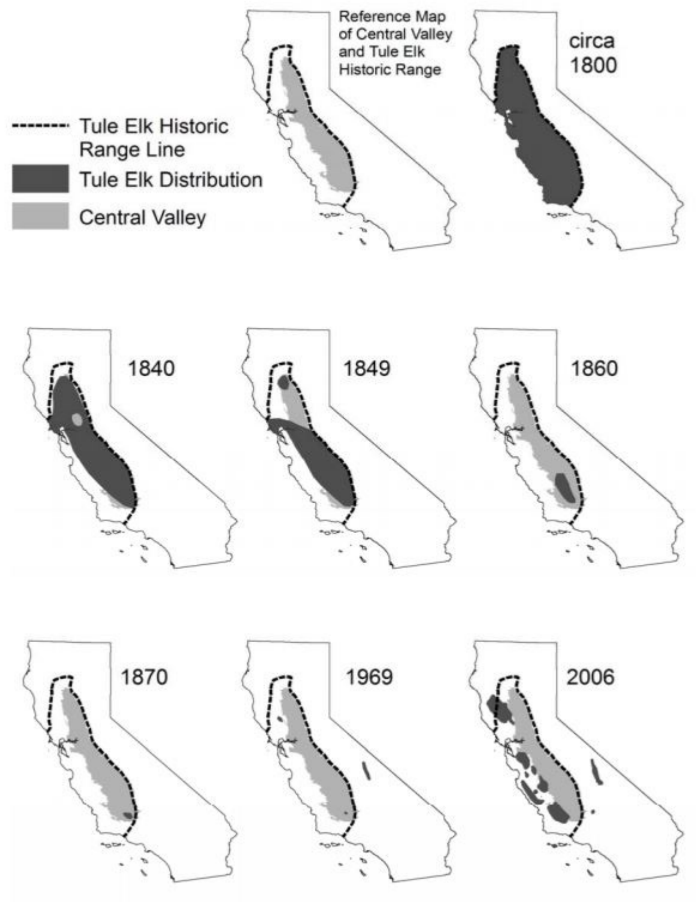


Figure 2-3 Historical distribution of tule elk (Greco et al., 2009; McCullough, 1969; Hickman, 1993)

The tule elk population in California was as large as approximately 500,000 individuals before the 19th century (Huber & Greco, 2012). The sub-species was found as far south as Buena Vista, as far east as the Sierras, and along the coast as far north as Mount Shasta (Phillips, 2013). However, as explorers settled in California region due to the gold rush in the mid-19th century, tule elk numbers began rapidly declining. Hide and tallow hunters, as well as habitat loss from the conversion of land to agriculture, reduced elk numbers significantly; by the 1870s only a handful of tule elk remained (Huber & Greco, 2012). DNA evidence indicates that there could have been as few as a single pair of tule elk (Greco et al., 2009). The last remaining tule elk were found on a ranch owned by Henry Miller, who decided to protect the elk in 1873 after hunting tule elk was finally banned (Huber & Greco, 2012).

REINTRODUCTION EFFORTS

Since then, reintroduction efforts have been attempted to restore the tule elk population in California. In the contemporary California landscape, tule elk herds can easily outgrow their environment, leading to overpopulation, habitat destruction, and stress (Greco et al., 2009). To combat this, managed relocation practices have been undertaken to minimize these effects. In the early 20th century, tule elk relocation techniques were not very effective; elk were causing property damage, and many individuals were killed during capture attempts or during transport (Greco et al., 2009). While most relocation efforts released herds within the tule elk's native range, many populations died out over time.

Several states where elk reintroductions have been carried out have also conducted feasibility studies to identify places where there is sufficient habitat to support elk populations (Greco et al., 2009). In California, potential reintroduction zones (PRZ) have been identified throughout the Central Valley Ecoregion, as only three of the current 24 herds are located within the valley (Huber & Greco, 2012).

Due to better care of tule elk during capture and the limiting of herd size at some locations, the general population of tule elk has gradually recovered. Currently there are 24 tule elk herds in California, with a total population surpassing 4,000 individuals (Phillips, 2013).

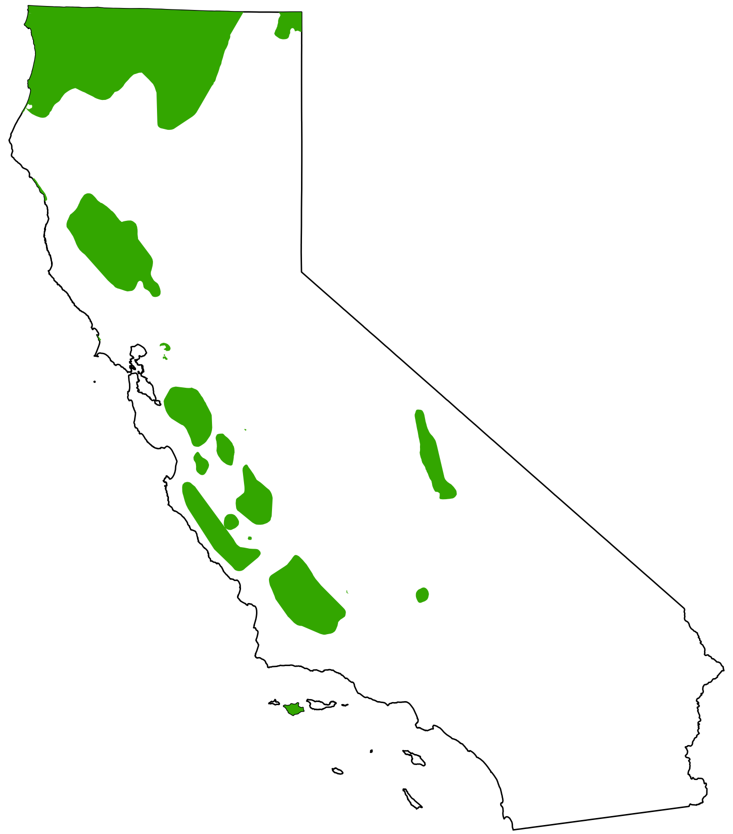


Figure 2-4 Elk species range using CWHR data from 2014 (Gee, 2018)

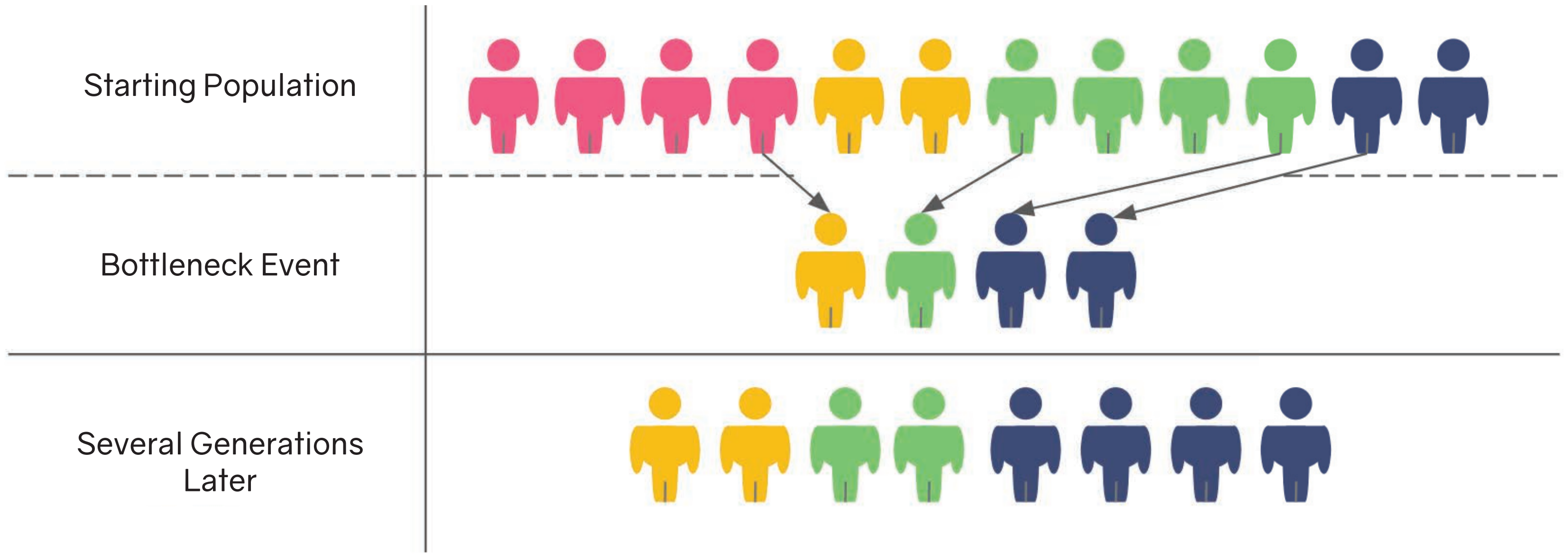


Figure 2-5 Genetic effects of a population bottleneck (adapted from Helix, 2017)

CURRENT THREATS TO THE SUB-SPECIES

One of the main threats to the tule elk population is disease. Because the current population is a result of genetic bottlenecking, there is minimal genetic variation within the sub-species (Greco et al., 2009). Transplants among all herds appear to be the most beneficial for improving their genetic variation (Greco et al., 2009).

Another threat to tule elk is human development and infrastructure. Like all species, habitat loss and fragmentation due to sprawling development and the construction of widespread transportation infrastructure has major impacts on habitat connectivity. In addition, a large portion of their current range is on unprotected private lands (Greco et al., 2009). Because these private lands are unprotected, there is a constant threat of development or subdividing of these properties (Greco et al., 2009).

03 LANDSCAPE ECOLOGY

PRINCIPLES

Landscape ecology is the study of the interactions among organisms and their local ecosystems (Forman, 1995). Landscapes exhibit three characteristics: structure, function, and change (Dramstad et al., 1996). "Landscape structure is the spatial pattern or arrangement of landscape elements...functioning is the movement and flows of animals, plants, water, wind, and energy through the structure...and change is the dynamics or alteration in spatial pattern and functioning over time" (Dramstad et al., 1996 p. 14). Within landscape structure are three universal elements: patches, corridors, and matrix.

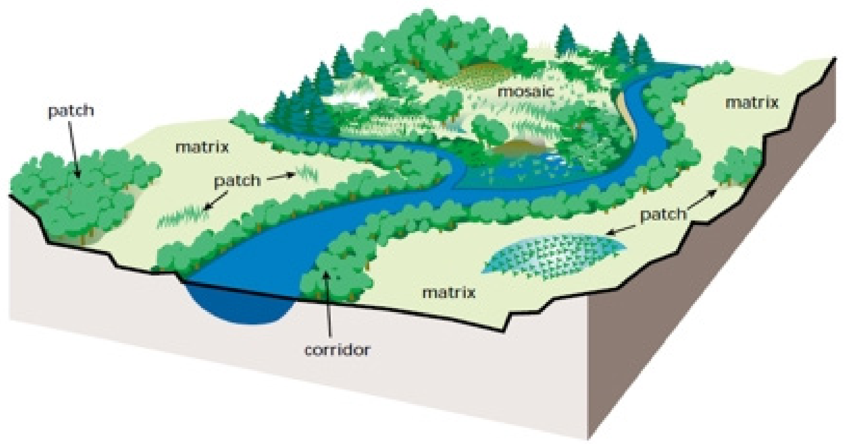


Figure 3-1 The different elements within a landscape structure (University of Arizona, 2006)

Patches: a relatively homogeneous area within a mosaic that differs from the landscape matrix. They are the smallest unit of the landscape and can change over time.

Corridor: linear areas of habitat that create connectivity to allow for species' movement.

Matrix: the predominant land cover type and background landscape where patches and corridors reside.

All landscapes involve a unique relationship and pattern between patches and corridors. Infrastructure such as buildings, roads, and canals can intersect natural patches and corridors, disrupting species' movement, reproduction habits, and other ecological systems.

Figure 3-2 The Trans-Canada Highway intersects surrounding natural patches and corridors (Richardson, 2012)

ROAD ECOLOGY

Road ecology describes the interaction of organisms and the environment linked to roads and vehicles (Forman et al., 2003). Roads exist in a variety of sizes and functions, from multilane highways to farmers' lanes. Roads have become the backbone of development, and the economic values associated with roads typically outweigh perceived environmental values (Spellerberg, 2002).

Roads can have numerous effects on the surrounding environment. Road construction changes the physical and chemical environment, affecting the distribution and productivity of nearby species (Trombulak & Frissell, 2000). Roads also exhibit a road-effect zone—the area "over which significant ecological effects extend outward from a road" (Forman & Deblinger, 2000 p. 37). Because of nature's varied spatial patterns on opposite sides of a road, the road-effect zone is highly asymmetric (Forman & Deblinger, 2000).

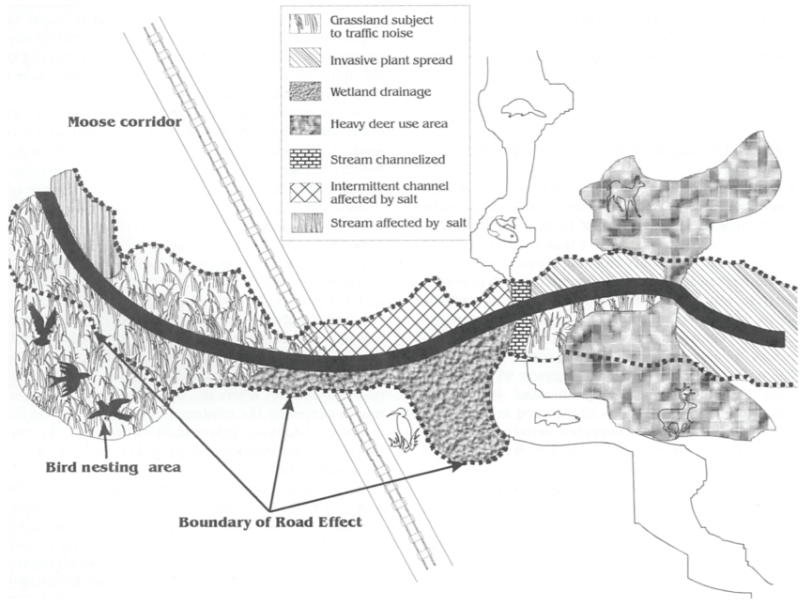


Figure 3-3 Diagram illustrating the varying road-effect boundary for different ecological features (Forman & Deblinger, 2000)

The presence of roads and other transportation corridors results in three consequences: reduced landscape permeability, habitat loss, and increased habitat fragmentation (Bennet et al., 2011). Figure 3-4 shows the decreasing amount of wilderness over time in Norway due to roads, railways, and regulated water sources. Transportation corridors affect the arrangement of patches and corridors necessary for species' movement across the landscape. Roads can have direct ecological effects, such as species mortality due to vehicle collisions, and indirect ecological effects, such as reduced reproductive rates as a result of habitat fragmentation (Bennet et al., 2011). In addition to reducing the amount of habitat available, roads also impact habitat quality. Habitat quality is expressed by a decrease in abundance or density of breeding individuals. A decrease in habitat quality therefore can lead to a reduction in habitat amount (Forman et al., 2003).

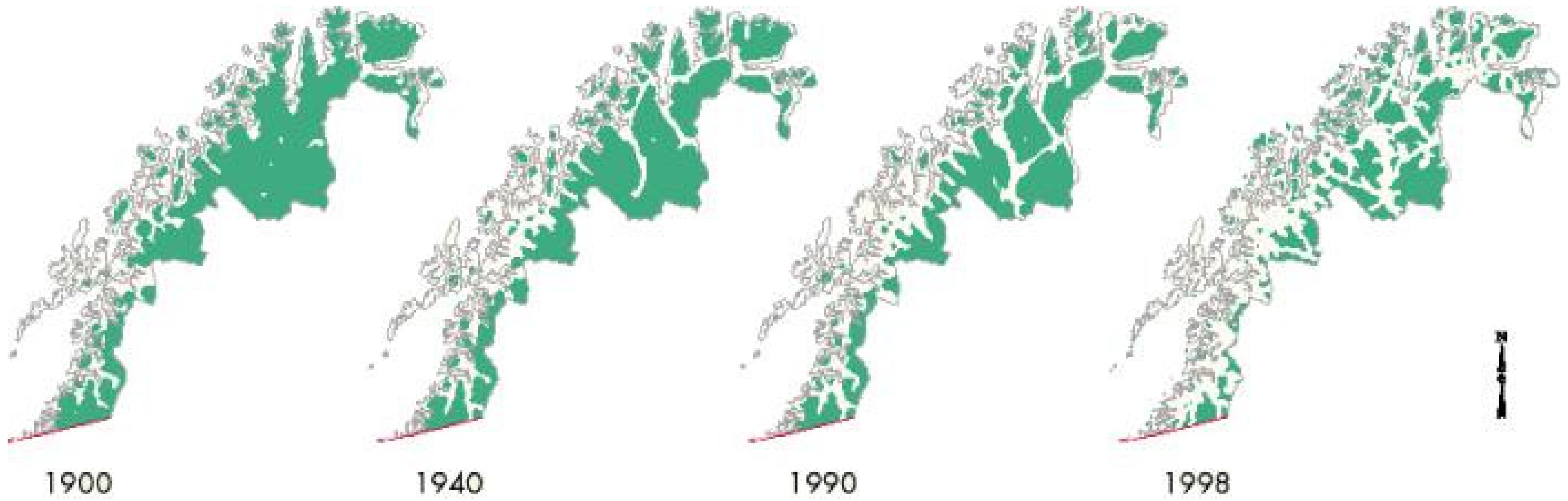


Figure 3-4 Decrease in wilderness areas in Norway (Norwegian Mapping Authority)

Vehicle speed and traffic volume influence wildlife collisions (Forman et al., 2003). Studies have shown that accidents decrease when there is a lower speed limit, a greater distance to wooded areas, and a greater minimum visibility distance (Forman et al., 2003). This suggests that proximity of habitat cover and wildlife movement corridors is another factor that contributes to wildlife-vehicle collisions.

TULE ELK AND ROADS

While some animals, such as reptiles, are attracted to roads as basking sites, others show behavioral avoidance of open habitats and noise, making them less vulnerable to road mortality (Forman et al., 2003). Large animals such as elk appear to avoid roads (Forman et al., 2003). However, because of their behavior, the presence of highways throughout northern California prevents necessary connectivity and circuitry between tule elk herds. Connectivity between herds is essential for a species that has experienced genetic bottlenecking to improve genetic diversity, thus reducing the threat of disease.

LANDSCAPE CONNECTIVITY

Landscape connectivity is defined as "the degree to which the landscape facilitates animal movement and other ecological flows" (Forman et al., 2003 p. 129). Barriers such as roads or other types of human development can significantly reduce landscape connectivity. High landscape connectivity allows multihabitat organisms to regularly move through the landscape to different habitat types for their needs. Animals need to be able to move efficiently within their home ranges to regularly access food and shelter. They also need to be able to move beyond their home ranges to maintain genetic exchange between metapopulations (Singleton et al., 2002). High landscape connectivity allows species to repopulate areas that have suffered local declines (Forman et al., 2003). In addition, connected populations also provide greater flexibility for a species to respond to climate change and other changing environmental conditions (Beckmann et al., 2010). As such, improving landscape connectivity is essential for the success of tule elk reintroduction in California.

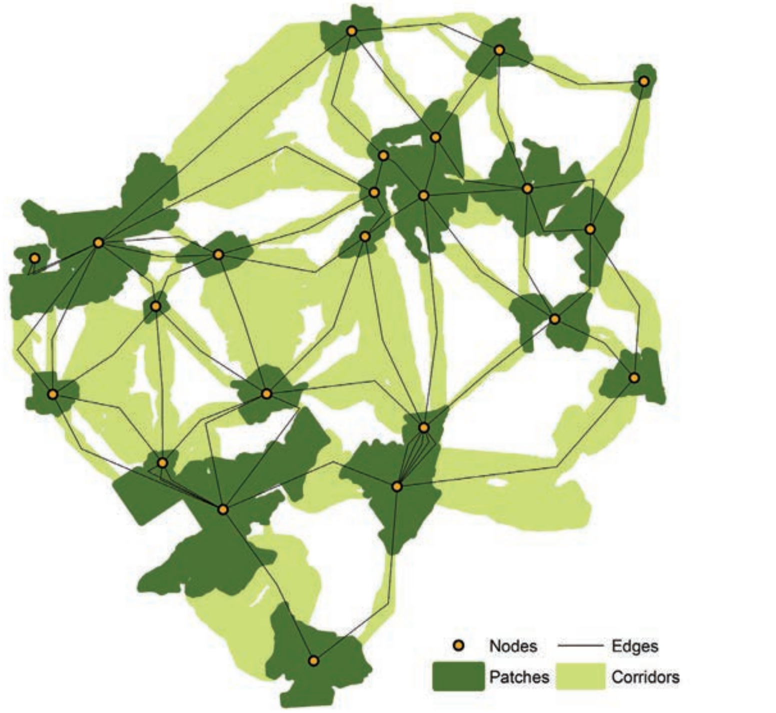
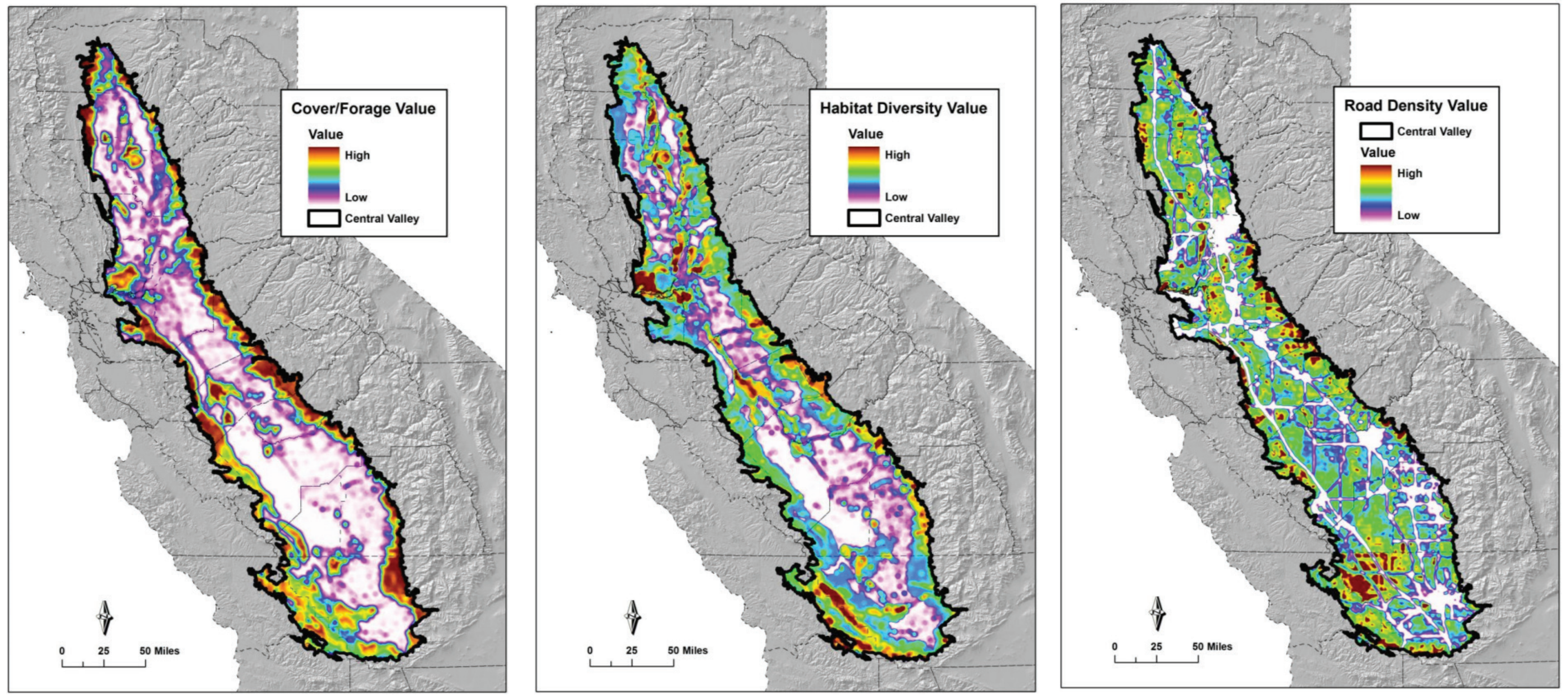


Figure 3-5 Habitat patches that have more connections between them reduce the negative effects of gaps and allow for more efficient movement (Rudnick et al., 2012)

MODELING HABITAT SUITABILITY

Habitat suitability modeling is a method used to locate critical habitats for threatened species. It is used to assess the quality of habitat within a study area and can inform management and conservation decisions. Raster-based layers such as land use, land cover, elevation, protected areas, and human disturbances are often gathered as factors that impact the quality of life for a species of concern. To identify areas where suitable habitat exists in the Central Valley Ecoregion, Huber & Greco used a model which considered preferred tule elk cover and forage, habitat diversity, and human impacts (Huber & Greco, 2012).



Figures 3-6, 3-7, 3-8 *(from left to right)* Areas in the Central Valley with high cover/forage, high habitat diversity, and low road density (Huber & Greco, 2012)

Values between 0.0 and 1.0 were given to each of the three components reflecting their suitability for tule elk, and then multiplied to create final suitability scores. Areas with high quality habitat scores were then identified as potential reintroduction zones (PRZ).

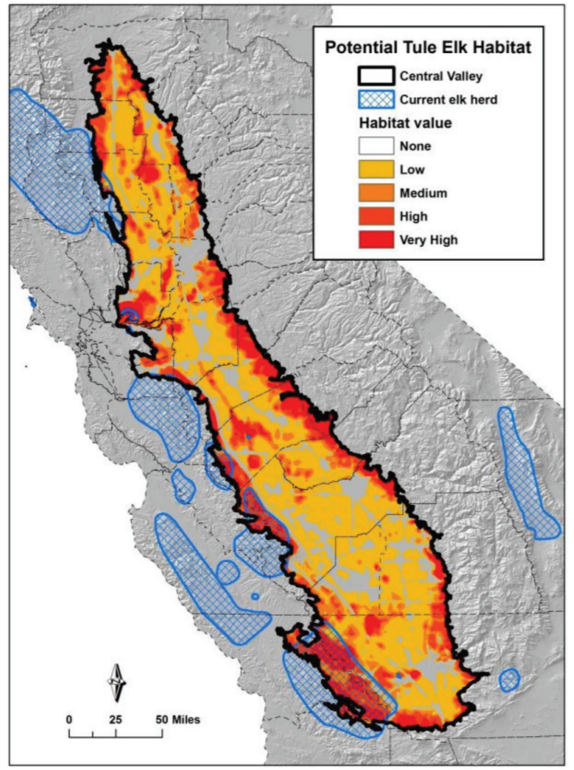


Figure 3-9 Final habitat suitability values for tule elk in the Central Valley (Huber & Greco, 2012)

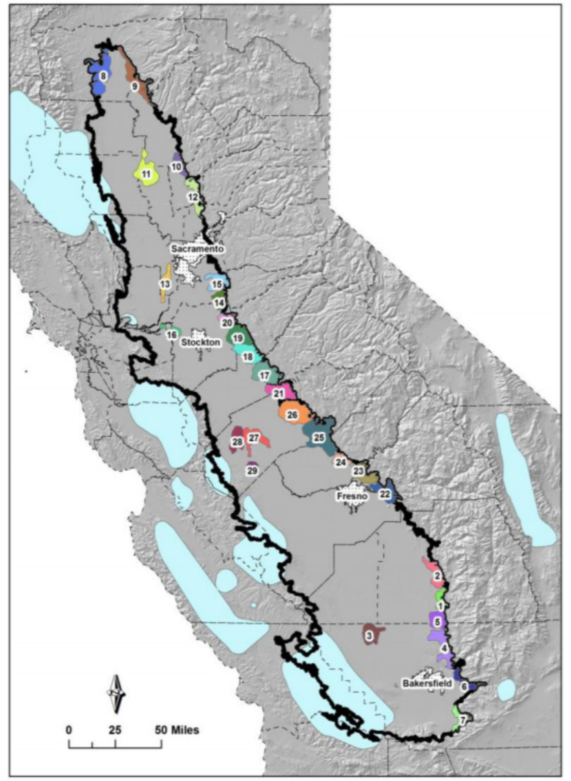


Figure 3-10 Potential reintroduction zones within the Central Valley (Huber & Greco, 2012)

While the report by Huber & Greco identifies numerous areas for potential tule elk reintroduction, it is also suitable for tule elk to naturally colonize these areas. The existing herd at Grizzly Island is in close proximity to two identified PRZs. It would be ideal if tule elk were to naturally disperse from Grizzly Island to the Yolo Bypass PRZ and the Delta PRZ. From a biological perspective, natural periodic interactions between the Grizzly Island herd, the Yolo Bypass PRZ, and the Delta PRZ would be best for allele exchange and genetic diversity of the sub-species (Huber & Greco, 2012). These colonizations can be assisted through planning projects to enhance wildlife connectivity through the construction of wildlife crossings.

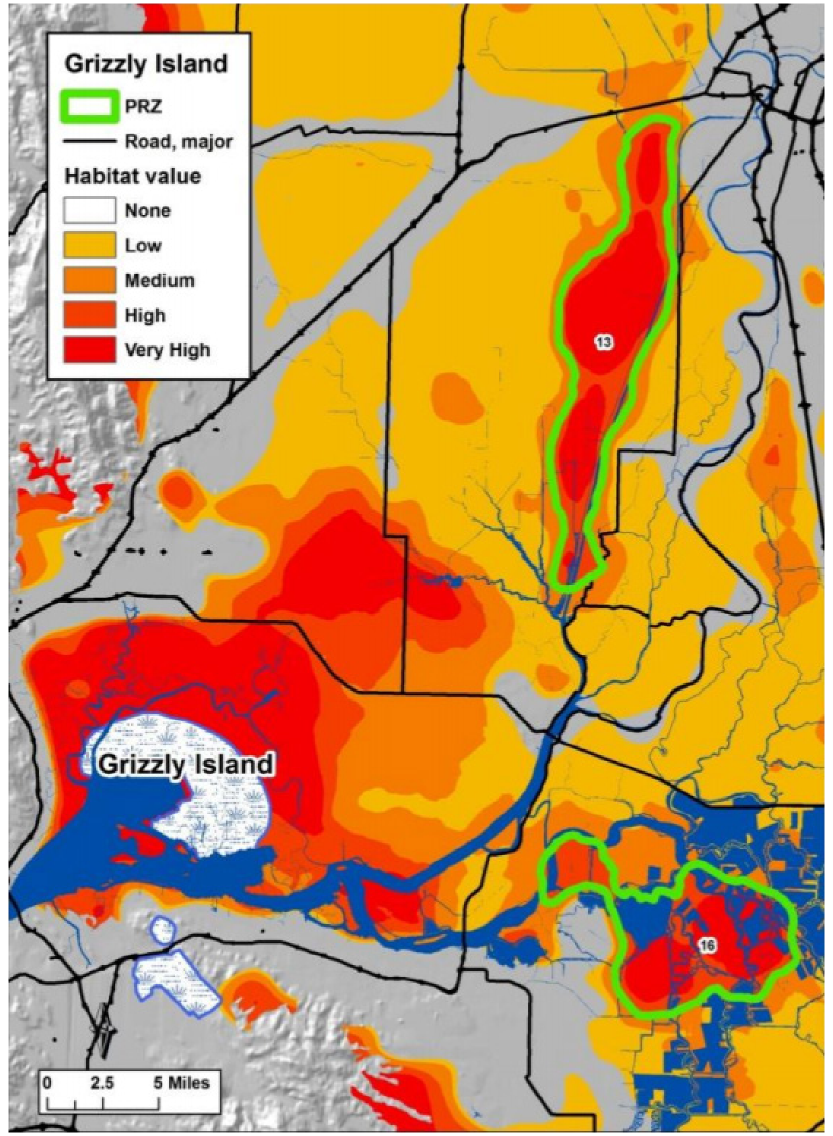


Figure 3-11 Potential expansion of tule elk habitat by the existing Grizzly Island herd (Huber & Greco, 2012)

04 WILDLIFE CROSSINGS

IMPORTANCE AND BENEFITS

Wildlife crossing structures can help mitigate the negative effects of roads on landscape connectivity. Wildlife crossings allow animals to cross roads while reducing hazards to both motorists and wildlife (Beckmann et al., 2010). According to Forman et al., the "overall objective of wildlife passages is to increase the permeability of a road corridor" (Forman et al., 2003 p. 161). As road networks continue to be constructed as a result of human population growth, wildlife crossings will become an essential part of transportation planning projects if habitat connectivity is to be maintained.

Wildlife crossing structures provide five ecological functions (Beckmann et al., 2010):

1. Reduced mortality and increased movement within populations
2. Meeting of biological requirements such as finding food, cover, and mates
3. Dispersal from maternal or natal ranges and recolonization after long absences
4. Redistribution of populations in response to environmental changes and natural disturbances
5. Long-term maintenance of metapopulations, community stability, and ecosystem processes

CLASSIFICATIONS

Wildlife crossings can be classified into more than “over-” and “under-” structures. There are eleven different wildlife crossing types, each with their own benefits for different types of animals (Beckmann et al., 2010).

Landscape Bridge:

- The largest wildlife crossing structure, typically more than 100 m (330 ft) wide
- Large size enables restoration of habitats on either side of the road
- Targets large mammals

Wildlife Overpass:

- Smaller than landscape bridges, generally 40-50 m wide
- Targets medium-sized fauna

Figure 4-1 Landscape bridge (Federal Highway Administration, 2011)

Figure 4-2 Wildlife overpass (Federal Highway Administration, 2011)

Mutli-use Overpass:

- Smaller in size than wildlife overpasses (15-25 m wide)
- Allow for both wildlife and human use
- Targets small- and medium-sized fauna

Figure 4-3 Multi-use overpass (Federal Highway Administration, 2011)

Canopy Crossing:

- Above-grade structures designed to link forest habitats
- For arboreal species whose movements are impacted by roads

Figure 4-4 Canopy crossing (Federal Highway Administration, 2011)

Viaduct or Flyover:

- The largest underpass type
- Keeps habitats underneath intact
- Commonly used for crossing wetland habitats

Figure 4-5 Viaduct (Federal Highway Administration, 2011)

Large Mammal Underpass:

- Small- and medium-sized mammals can utilize these if there is cover provided along the walls
- Generally at least 10 m wide and 4 m (13 ft) tall

Figure 4-6 Large mammal underpass (Federal Highway Administration, 2011)

Multi-use Underpass:

- Allows for both wildlife and human use
- Targeted at smaller, generalist species common in human-dominated environments

Figure 4-7 Multi-use underpass (Federal Highway Administration, 2011)

Underpass with Water Flow:

- Accommodates moving water as well as wildlife
- Generally located in wildlife movement corridors due to their association with riparian habitats

Figure 4-8 Underpass with water flow (Federal Highway Administration, 2011)

Small- to Medium-Sized Mammal Underpass:

- Targets small- to medium-sized mammals
- Needs sufficient cover and protection aligned within their habitats

Figure 4-9 Small- to medium-sized underpass (Federal Highway Administration, 2011)

Modified Culvert:

- Designed for small and medium-sized wildlife associated with riparian habitats or irrigation canals
- Walkways can be constructed on the interior

Figure 4-10 Modified culvert (Federal Highway Administration, 2011)

Amphibian and Reptile Tunnel:

- Facilitates migration of amphibians or reptiles across roads
- Requires extensive fencing to guide species to the tunnel entrance
- Typically requires ample amounts of natural light, depending on the species

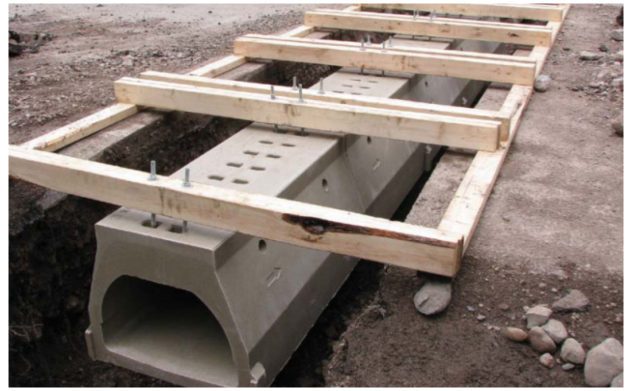


Figure 4-11 Amphibian and reptile tunnel (Federal Highway Administration, 2011)

FENCING AND ESCAPE STRUCTURES

In addition to the crossing itself, fencing is typically constructed to prevent wildlife from entering the road, and to funnel animals towards crossing structures. Fencing to prevent ungulates such as elk from entering the road ranges from 6.5 to 8 feet high (Arizona Department of Transportation). However, wildlife can become trapped inside fenced areas; jump-outs or earthen ramps are common structures to encourage trapped animals to escape (Beckmann et al., 2010).

Figure 4-12 Wildlife escape ramp with concrete retaining wall (Arizona Department of Transportation)

Figure 4-13 Wildlife escape ramp, front view (Arizona Department of Transportation)

Figure 4-14 Wildlife escape ramp, rear view (Arizona Department of Transportation)

Figure 5-1 One of six wildlife overpasses at Banff National Park, Canada (Conservation 2020)

05 CASE STUDIES

In order to create a successful design, past wildlife crossing projects can be examined as case studies to get a better understanding of design techniques and implementation decisions.

U.S. 93 NORTH WILDLIFE PASSAGES, MONTANA, 2004-2008

Ninety-seven kilometers of U.S. Highway 93 were reconstructed in 2004 in response to concerns important to Tribal people relating to wildlife habitat. The highway intersects the Flathead Indian Reservation in Montana, 1.25 million acres in size. Goals of the project included restoring habitat areas that had been fragmented and creating a better understanding of the cultural significance of the place (Montana Department of Transportation et al., 2000). Deer, bears, turtles, small mammals, and birds had been observed as roadkill (Beckmann et al., 2010). These environmental issues combined with the safety problems and the need for reestablishing cultural significance in the area prompted the proposal to reconstruct a section of the highway. The redesign included a proposal of 23 culverts for wildlife crossing and seven bridges (Beckmann et al., 2010). Habitat areas and migration patterns were mapped, as well as road kill data and sightings to determine locations where wildlife crossed the highway (Montana Department of Transportation et al., 2000). A total of 41 wildlife crossing structures were constructed. Ongoing monitoring is being done to determine if there is a reduction in wildlife-vehicle collisions.

Figure 5-2 Wildlife overpass crossing U.S. 93 (Montana Department of Transportation et al., 2000)

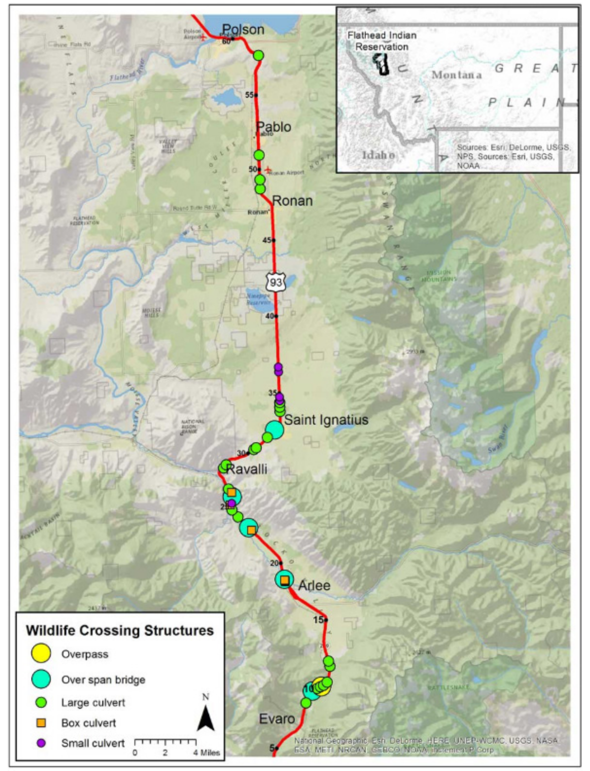


Figure 5-3 Wildlife crossing structures along U.S. 93 (Montana Department of Transportation et al., 2000)

Figure 5-4 Wildlife overpass crossing the Trans-Canada Highway (Segal, 2018)

Figure 5-5 Wildlife overpass at Banff National Park (Segal, 2018)

BANFF WILDLIFE CROSSINGS PROJECT, CANADA, 1988-2011

The Banff Wildlife Crossings Project began in 1988 because of increased commercial usage of the Trans-Canada Highway in the Banff National Park. Originally a low-volume, two-lane highway, the Trans-Canada Highway had little impact on wildlife in the 1950s (Beckmann et al., 2010). However, the highway became recognized as a source of mortality and a barrier for large mammal movement (Beckmann et al., 2010). The project involved expanding the width of the Trans-Canada Highway from two to four lanes. Thirty-one crossings have been constructed. As a part of the project, extensive monitoring was done to record the frequency of wildlife crossings. The data collected (from 23 crossing structures between November 1996 to March 2009) showed that the wildlife crossings were used over 185,000 times by large mammals alone, including black bear, grizzly bear, coyote, deer, and elk (Beckmann et al., 2010). Even though there was extensive use of the wildlife crossings, it was found that the crossings were not as frequent right after construction; it took time for animals to adapt to the new structures and use them as corridors (Beckmann et al., 2010).

INTERNATIONAL WILDLIFE CROSSING INFRASTRUCTURE DESIGN COMPETITION, 2010

Animal Road Crossing (ARC) is an interdisciplinary partnership that aims to facilitate new solutions for wildlife crossing structures. In 2010, ARC promoted an international competition that provided an opportunity for interdisciplinary teams to develop concept designs for a structure along Colorado's West Vail Pass along I-70. The goal of the competition was to raise awareness of the importance of wildlife in the construction and maintenance of road networks (ARC, 2018). Designs included planting palettes for the species that would be utilizing the crossing, as well as the consideration of adjacent landforms. Some designs featured modular structures that were cost-efficient and adaptable, while also attempting to be aesthetically pleasing to vehicles passing underneath. The ARC competition resulted in numerous designs that each had unique design considerations and landscape elements.

Figure 5-6 Rendered perspective of an overpass design by the Olin Studio (ARC, 2018)

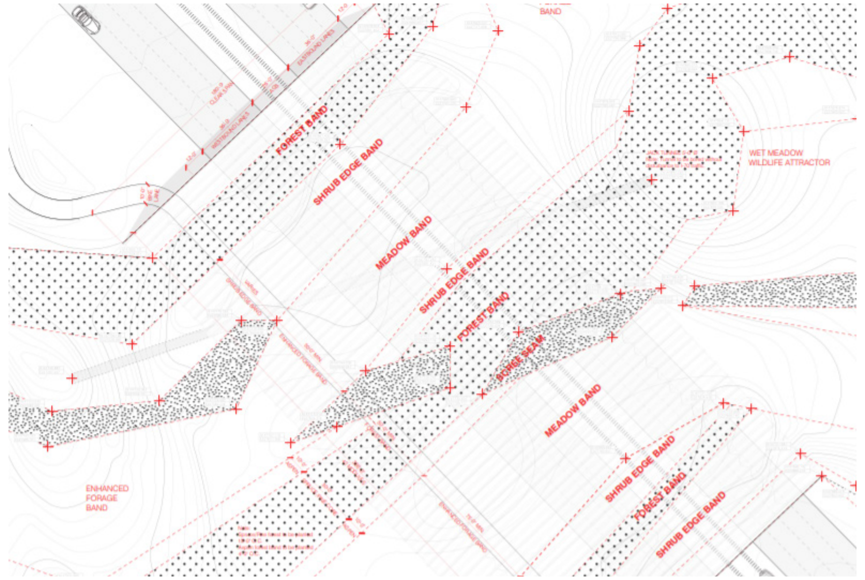


Figure 5-7 Planting arrangement of an overpass design by HNTB with Michael Van Valkenburgh & Associates (ARC, 2018)

EVALUATION

The U.S. 93 North Wildlife Passages in Montana are an example of a project that focuses on both natural and cultural aspects of wildlife crossings. The role of wildlife is important not only as a natural resource for the local ecology of the region, but also as a cultural resource for the Flathead Indian Reservation. Coordination between the tribes and the Montana Department of Transportation was required to design and implement the wildlife crossing structures. Ongoing monitoring has shown that the wildlife crossings are being used regularly.

The Banff Wildlife Crossings Project also monitors the genetic effectiveness of its wildlife crossings. Its success can be attributed to the diversity in wildlife crossing design. Wildlife researchers hope to determine the most cost-effective means of increasing wildlife movement. In addition, the Banff Wildlife Crossings Project relied on public education and outreach to obtain funding. It is important that the public understand the purpose of wildlife crossings, as well as the safety benefits to both wildlife and humans.

The International Wildlife Crossing Infrastructure Design Competition produced numerous design concepts utilizing unique elements such as planting arrangements and modular structures. While these proposals were not implemented, they provide innovative solutions to the standard wildlife crossing. They can be drawn upon as inspiration for more noticeable, cost-efficient crossing structures.

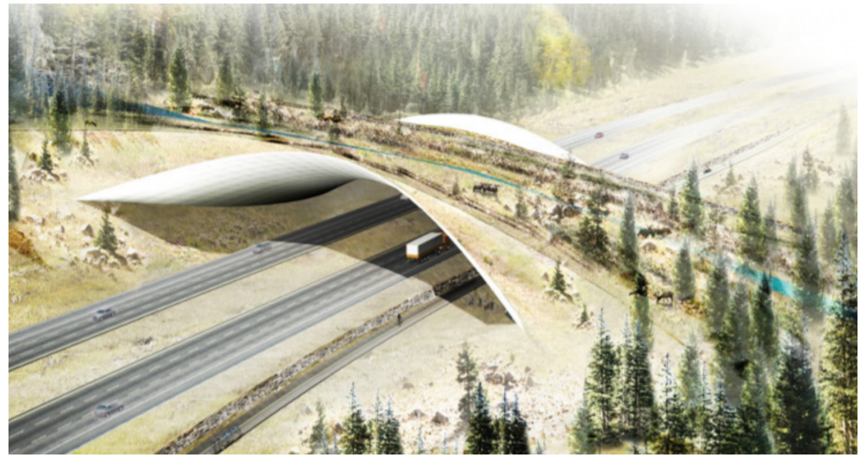


Figure 5-8 Rendered perspective of an overpass design by Zwarts & Jansma Architects (ARC, 2018)

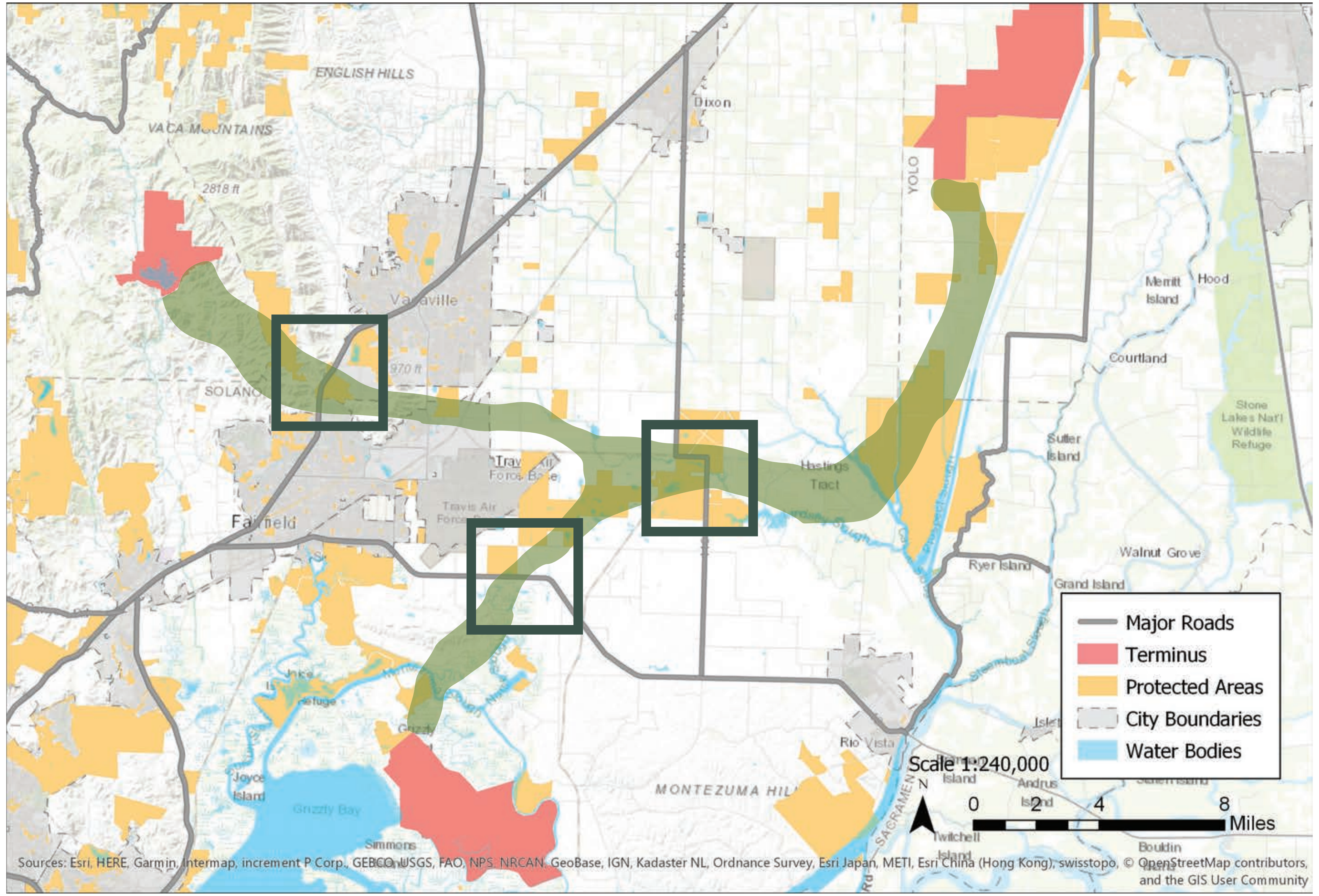
06 DESIGN SOLUTIONS

OPPORTUNITIES

The expert-based modeling provided by Huber & Greco is used as a foundation for the selection of wildlife crossing locations for tule elk in the region. According to Beckmann et al., mitigating roads for wildlife conservation is most economical during road expansion or upgrade projects (Beckmann et al., 2010). As such, it would be ideal to implement underpasses along highways 113 and 12 during a future road expansion project. Highways 113 and 12 are both two-lane roads that cross delta sloughs. Taking future sea level rise into consideration, utilizing these sloughs would be ideal for large mammal underpasses, as roads will eventually have to be raised. Sites were selected based on areas with suitable CWHR habitat types for tule elk, derived from Huber & Greco. These five habitat types are annual grassland, fresh emergent wetland, valley foothill riparian, perennial grassland, and saline emergent wetland. Nearby protected lands under conservation easements were also considered. Sites were selected at locations where existing protected lands intersected the highway.

Figure 6-1 Lindsey Slough, which eventually crosses Highway 113 (Gee, 2018)

Figure 6-2 *(across)* Study area showing potential corridors for tule elk movement in green (adapted from Huber, 2014)



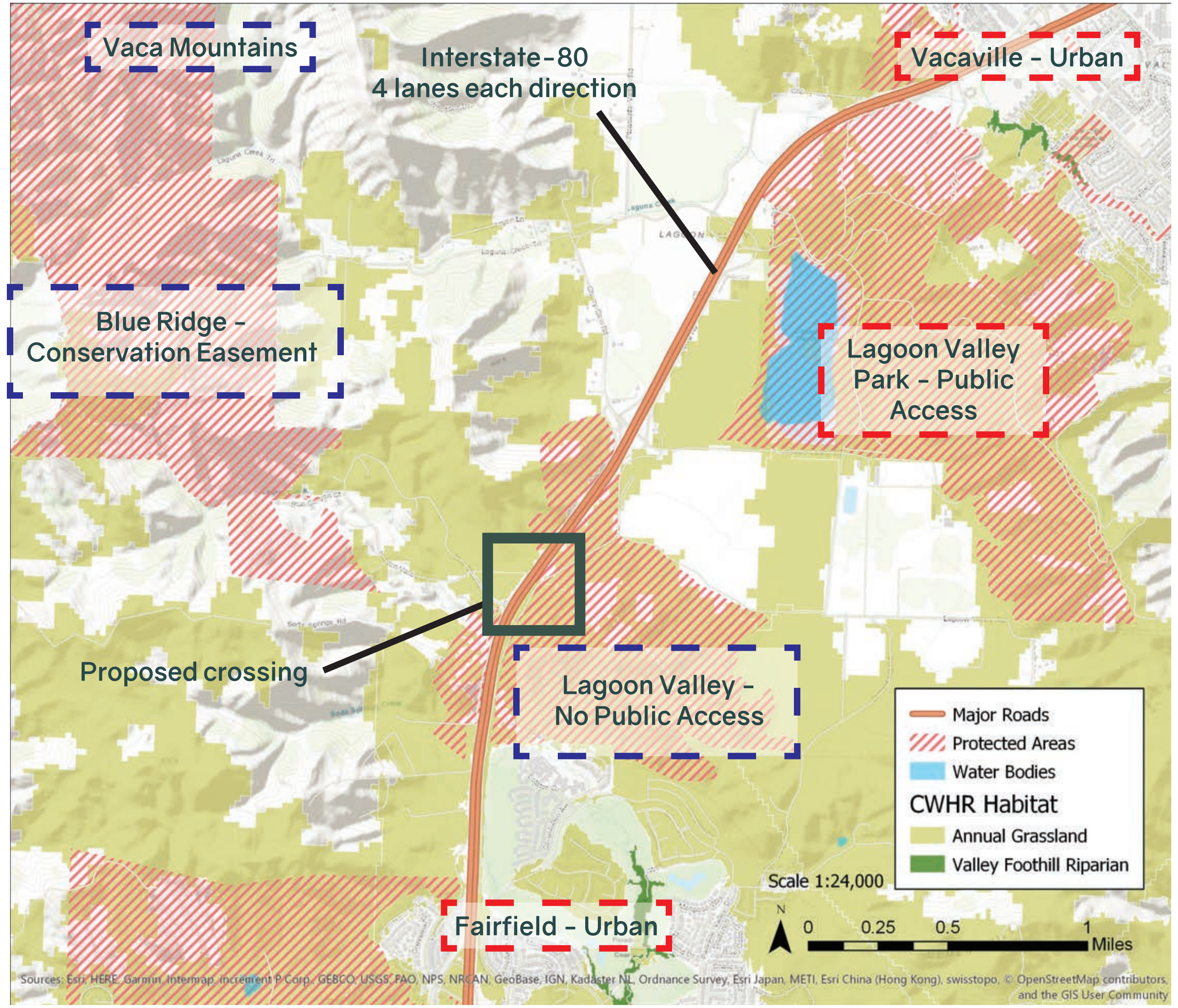


Figure 6-3
Existing conditions surrounding Interstate-80 (Gee, 2018)

INTERSTATE-80 EXISTING CONDITIONS AND ANALYSIS

Between Vacaville and Fairfield, Interstate-80 primarily runs North-South, adjacent to the Vaca mountains. The interstate itself is fairly flat, but is four lanes in each direction. Important protected areas that are closed to the public are Lagoon Valley—a park, and Blue Ridge, which is a conservation easement held by the Solano Irrigation District. The Lagoon Valley protected area crosses Interstate-80 and almost reaches Blue Ridge, making this location optimal for a wildlife crossing. Surrounding habitat consists entirely of annual grassland, with trees buffering the interstate.

A unique opportunity in this location is that the Vaca mountains, which run alongside the interstate, provide a vantage point for tule elk from the West. Likewise, tule elk from the East would be able to view the Vaca mountains even if a wildlife crossing was in place. To retain the prospect-refuge opportunity, a wildlife crossing that is flat but slanted in slope would be ideal for encouraging tule elk to cross.

Figure 6-4 Overlooking Interstate-80 facing South (Gee, 2018)

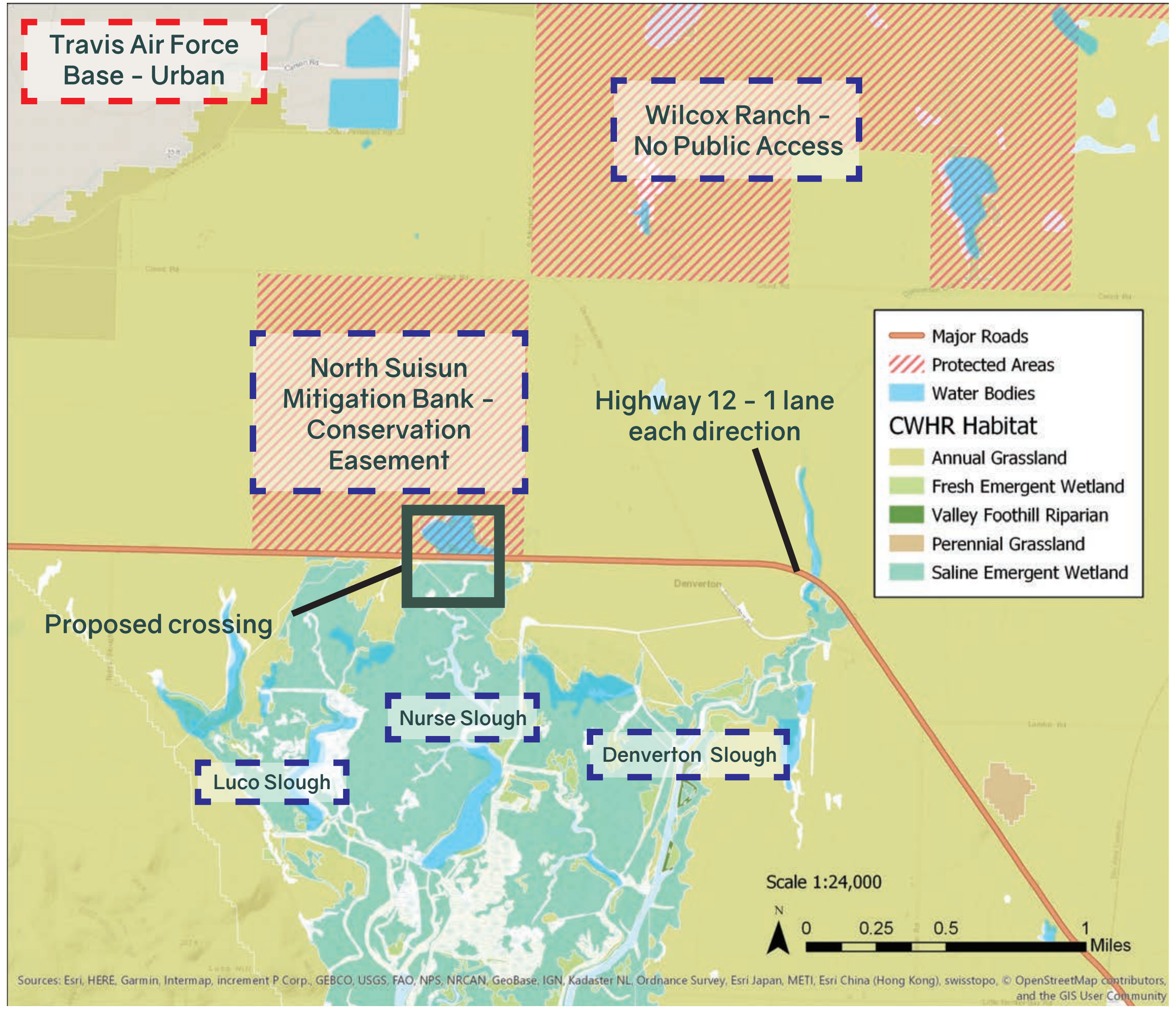


Figure 6-5 Existing conditions surrounding Highway 12 (Gee, 2018)

HIGHWAY 12 EXISTING CONDITIONS AND ANALYSIS

Highway 12 runs East-West, crossing Nurse Slough and Denverton Slough. The highway is one lane in each direction, elevated above the surrounding agricultural land. The North Suisun Mitigation Bank and Wilcox Ranch are protected areas to the north of the highway, leading in the direction of the potential corridors identified by Huber (see Figure 6-2). Surrounding habitat consists primarily of annual grassland and saline emergent wetland.

As sea levels rise, Highway 12 will eventually need to be raised. This foreseeable road upgrade provides an opportunity to construct one or more large mammal underpasses below the raised highway. This would allow tule elk and other riparian species to utilize the slough as a corridor. Underpasses for tule elk should be at least 12 feet high.

Figure 6-6 Highway 12, facing West (Gee, 2018)

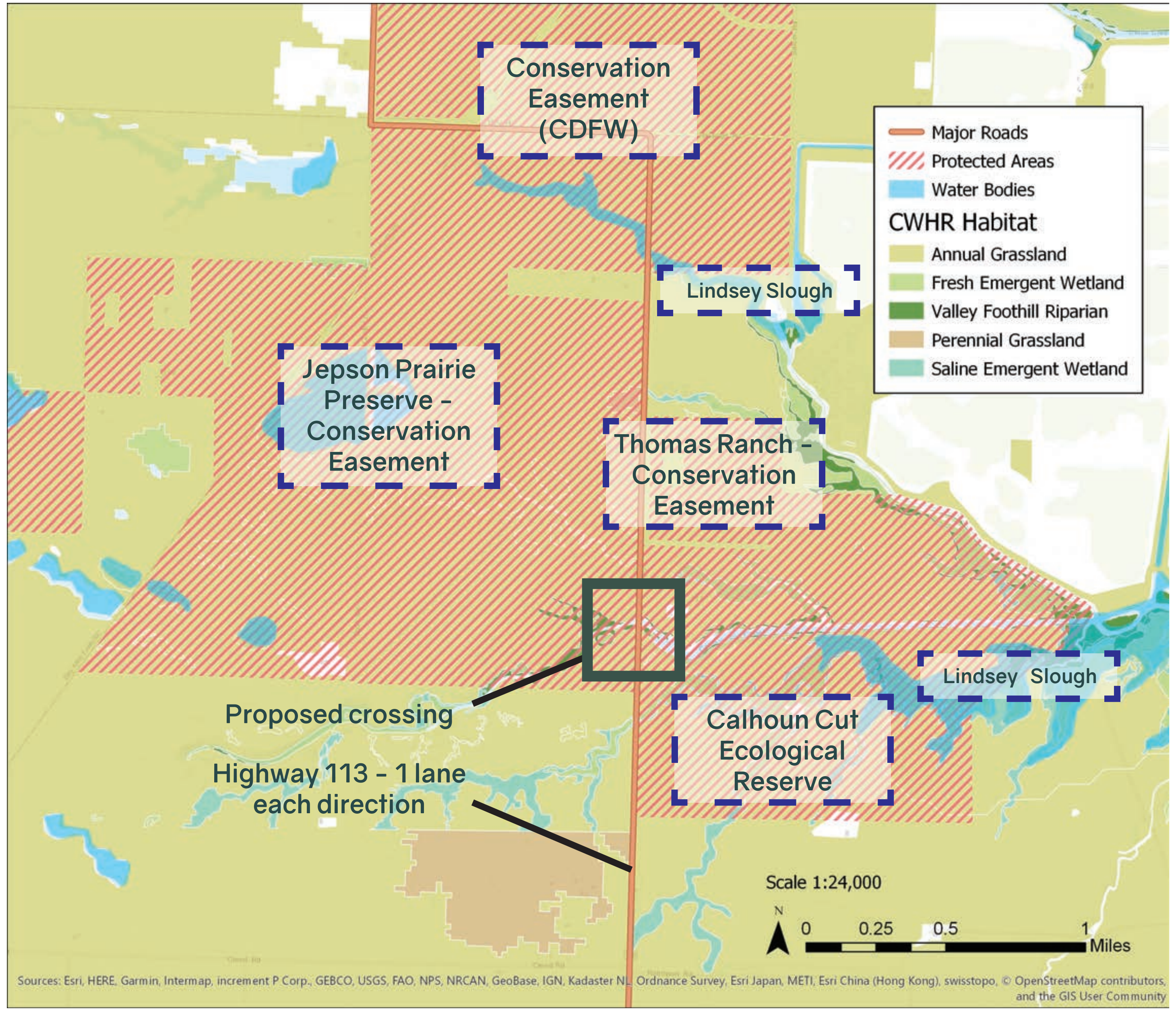


Figure 6-7 Existing conditions surrounding Highway 113 (Gee, 2018)

HIGHWAY 113 EXISTING CONDITIONS AND ANALYSIS

Highway 113 runs North-South, crossing Lindsey Slough. Like Highway 12, it is one lane in each direction. In addition, Highway 113 intersects a large amount of protected areas, namely Jepson Prairie Preserve, Thomas Ranch, and Calhoun Cut Ecological Reserve. The highway is raised over Lindsey Slough (see Figure 6-1), where a culvert is in place to let water flow underneath. Surrounding habitat is primarily annual grassland.

It is ideal for Highway 113 to also be fitted with one or more large mammal underpasses during the eventual road upgrade project in response to sea level rise. It should be noted that because Highway 113 runs North-South, it will be difficult during the day for sunlight to illuminate the underpass. To combat this, each direction of traffic should be separated as a part of the road upgrade. This will allow more light to enter the underpass, encouraging tule elk and other animals to utilize the crossing.

Figure 6-8 Highway 113, facing South (Gee, 2018)

DESIGN GUIDELINES

Based on the assessment of the three crossing locations, two types of structures are ideal: a landscape bridge across Interstate-80 and large mammal underpasses under Highway 113 and Highway 12.

Design guidelines for a landscape bridge, according to the Wildlife Crossing Structures Handbook (Federal Highway Administration, 2011):

- Maintain similar vegetative composition to adjacent habitats
- Reduce light and noise from vehicles by using earth berms and dense vegetation on the sides of the structure
- Bridge should be a heterogeneous environment; combine open areas with shrubs
- Provide cover, as well as mechanically stabilized fencing, on both ends of the structure to guide wildlife
- Adjacent lands should be managed as protected areas

For the overpass, an hourglass shape will be used. Compared to a rectangular design with an even width throughout, an hourglass shape provides animals with a clear line of sight to the other side of the crossing if they are standing off to the side. Earth berms with mixed shrubs will act as a visual barrier for tule elk to block their view of the cars below.

Design guidelines for large mammal underpasses:

- Utilize sloughs as crossing locations, as raising roads due to sea level rise will provide a natural crossing opportunity
- Provide ample natural lighting to promote the development of native vegetation, and to encourage ungulate movement
- Mirror habitat conditions on both sides
- Provide escape ramps or jump-outs in case ungulates become trapped between fencing and the highway

Figure 6-9 Landscape bridge site plan (Gee, 2018)

LANDSCAPE BRIDGE DESIGN

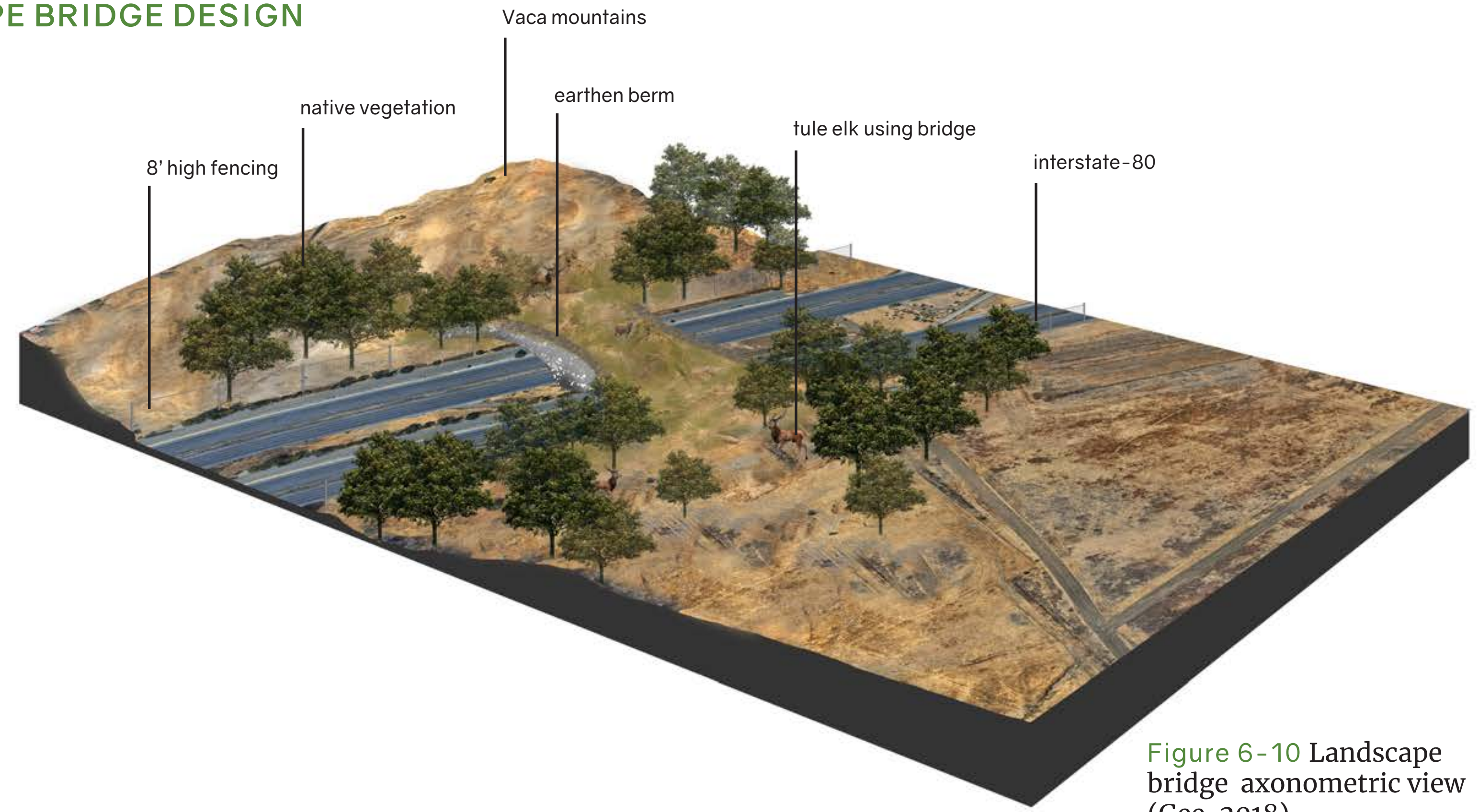


Figure 6-10 Landscape bridge axonometric view (Gee, 2018)

Figure 6-11 Landscape bridge section (adapted from ARC, 2018)

Figure 6-12 Large mammal underpass site plan (Gee, 2018)

LARGE MAMMAL UNDERPASS DESIGN

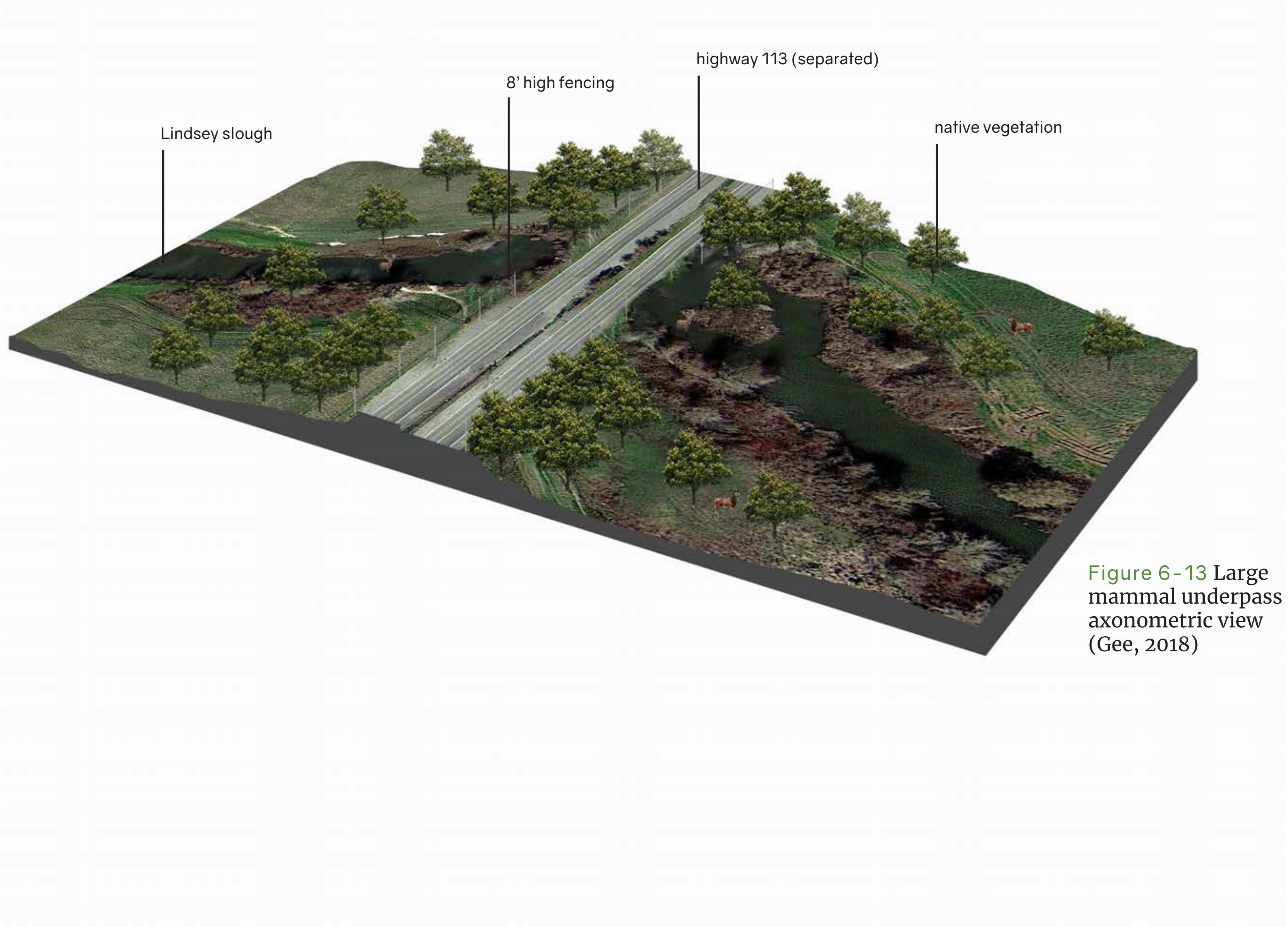


Figure 6-13 Large mammal underpass axonometric view (Gee, 2018)

07 IMPLEMENTATION

GENERAL PROCESS

In order to implement these proposed wildlife crossings, metropolitan planning organizations (MPO) must be made aware of their importance. In California, MPOs are responsible for developing regional transportation plans (RTP), which are long-term guides for future transportation projects within the MPO region. RTPs are conducted every five years, and provide a vision for the upcoming thirty. The wildlife crossings proposed in this report are within Solano County, which is a part of the Metropolitan Transportation Commission. Caltrans, who would ultimately construct the crossings, would need to be informed of the project purpose and need. A project initiation document (PID) is then required of the MPO before a project development team can be formed.

ADVANCE MITIGATION

Advance mitigation is simply mitigation in advance; it is a means of streamlining transportation projects at the regional scale to improve environmental outcomes. It anticipates compensatory mitigation needs by estimating the impacts of planned transportation projects (Caltrans, 2018) . The goal of advance mitigation is to identify higher-quality mitigation opportunities early in the planning process. Ideally, the ecological function of the proposed wildlife crossings with regards to habitat connectivity and wildlife movement would be studied as mitigation opportunities.

REGIONAL CONSERVATION INVESTMENT STRATEGIES

The Regional Conservation Investment Strategies Program under the California Department of Fish and Wildlife (CDFW) encourages public agencies to develop regional conservation planning documents. A regional conservation investment strategy (RCIS) identifies conservation priorities and actions for focal species and natural resources. Any public agency may develop an RCIS, which is valid for up to 10 years if approved (California Department of Fish & Wildlife, 2017). After approval of an RCIS, mitigation credit agreements (MCA) can be prepared as an advance mitigation tool to create credits (California Department of Fish & Wildlife, 2017). It would be ideal for an RCIS to be made that describes the installation of the proposed wildlife crossings.

NEXT STEPS

Taking a closer look at the lands adjacent to the wildlife crossings in this report can identify areas where conservation easements should be placed. Easements would prevent development from taking place on those lands, allowing for the implementation of wildlife crossing structures. Tools such as advance mitigation and regional conservation investment strategies can be utilized to push for the development of habitat connectivity projects.

08 CONCLUSION

Road ecology is being studied more by planners in response to the increasing number of wildlife-vehicle collisions and a greater understanding of road effects on animal populations. This project intends to evaluate road effects in conjunction with the population needs of tule elk. The goal of this project is to utilize landscape ecology principles and connectivity mapping to improve the habitat connectivity of tule elk between the Vaca mountains, the Yolo Bypass, and Grizzly Island. By reviewing existing models and analysis methods and relating them to the current conditions of the region and sub-species of interest, this project helps to conceive an effective method for locating wildlife crossings that will have the greatest impact.

This project is relevant in the current era of recognizing environmental degradation and global warming. Landscape architecture is a field that can greatly improve the relationship humans have with the environment through restoration and mitigation. Because of this, awareness of the potential of projects such as this one are crucial. As humans continue to develop outward from existing cities, surrounding habitat is constantly threatened. Wildlife conservation policies and techniques as they pertain to outward development are important for the survival of many species.

Results from this project may serve as a framework or guide for other projects of similar nature. The conclusions generated may offer a way to better visualize and understand how human development impacts habitat connectivity. Hopefully, this project provides a tool for landscape architects and planners to help prioritize habitat connectivity and conservation when assessing large-scale transportation projects.

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