Predicting Wildlife Use of Existing Highway Bridges and Culverts

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A Research Report from the Pacific Southwest Region University Transportation Center

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16. Abstract

Departments of Transportation (DOTs) are increasing attention to wildlife connectivity needs across highways, which is reflected in the inclusion of $350 million in new funding in the Bipartisan Infrastructure Law. There are over 600,000 bridges along US highways, approximately 75% of which are over waterways and could be useful for wildlife connectivity. The purpose of the proposed project was to develop an accessible model that DOTs could use to predict wildlife use of existing culverts and bridges and to look for cost-effective ways to increase wildlife use of existing structures. We collaborate with the DOTs and/or Departments of Fish and Wildlife/Parks (etc.) of AZ, CA, CO, FL, GA, ID, ME, MT, NV, OH, OR, and VA and the Alberta MOT to describe a predictive model for wildlife use of existing structures, based on evidence of use of these structures. Using camera trap data from CA, CO, ME, OR, VA, and WA, we developed a statistical model using structure and near-landscape characteristics, and evidence of wildlife use from camera traps. We are currently developing a website for state DOTs to use the model to predict which structures are likely to be useful for wildlife and which not. This will assist their planning and programming wildlife connectivity enhancements for areas not served by existing structures.

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About the Pacific Southwest Region University Transportation Center

The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

U.S. Department of Transportation (USDOT) Disclaimer

Disclosure

Principal Investigator Fraser Shilling, Analyst David Waetjen, and Graduate Student Noah Thoron conducted this research titled, "Predicting Wildlife Use of Existing Highway Bridges and Culverts" at the Road Ecology Center, Institute of Transportation Studies, University of California, Davis. The research took place from October 1, 2022 to September 30, 2023 and was funded by a grant from the USDOT in the amount of $118,758. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

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Abstract

Departments of Transportation (DOTs) are increasing attention to wildlife connectivity needs across highways, which is reflected in the inclusion of $350 million in new funding in the Bipartisan Infrastructure Law. There are over 600,000 bridges along US highways, approximately 75% of which are over waterways and could be useful for wildlife connectivity. The purpose of the proposed project was to develop an accessible model that DOTs could use to predict wildlife use of existing culverts and bridges and to look for cost-effective ways to increase wildlife use of existing structures. We collaborated with the DOTs and/or Departments of Fish and Wildlife/Parks (etc.) of AZ, CA, CO, FL, GA, ID, ME, MT, NV, OH, OR, and VA and the Alberta MOT to describe a predictive model for wildlife use of existing structures, based on evidence of use of these structures. Using camera trap data from CA, CO, ME, OR, VA, and WA, we developed a statistical model using structure and near-landscape characteristics, and evidence of wildlife use from camera traps. We are currently developing a website for state DOTs to use the model to predict which structures are likely to be useful for wildlife and which not. This will assist their planning and programming wildlife connectivity enhancements for areas not served by existing structures.

Predicting Wildlife Use of Existing Highway Bridges and Culverts

Executive Summary

Project Purpose

Recently, state DOTs, the public, and media have converged on the opinion that more wildlife connectivity is needed across state highways, to both treat legacy impacts of highways on nature, as well as mitigating future impacts from highway expansions. This is reflected in both individual state legislation (e.g., NM, CA, VA, OR) and the inclusion of new funds and requirements in the federal Bipartisan Infrastructure Law (HR 3684) for improved wildlife connectivity across road and rail infrastructure. The thinking reflected in all of these opinions and actions is that new crossings are needed to meet unmet wildlife connectivity needs. However, a large unknown in all states is how much existing culvert and bridge structures contribute to wildlife movement across the rights-of-way. The Road Ecology Center's camera trap projects over the years in California have been primarily at structures not built for wildlife movement and we have found varying, but often high levels of wildlife movement.

There are two critical impacts of transportation infrastructure on wildlife movement and connectivity that are relevant when thinking about existing bridges and culverts: 1) wildlife-vehicle collisions, potentially harmful to drivers and a source of mortality for wildlife, and 2) wildlife barrier effects, which can have deleterious impacts on populations and species, as well as communities of wildlife. Both of these types of impacts can cause major ecological changes, local or regional species extinction, genetic impacts, regulatory challenges for agencies, and future costs associated with mitigating impacts. Both types may also vary significantly depending on how many animals can and will go through existing bridges and culverts, rather than across the road surface. In addition, planning and environmental analysis for transportation and conservation investments could be strongly affected by their ability to predict how much connectivity need is already being met through these existing structures.

While most bridges may have originally been built for trucks, trains, and human mobility across a barrier (e.g., river), they also offer a way for wildlife to bypass the road without touching the road surface. For every state we are aware of, there is little current knowledge or way of predicting wildlife passage through existing structures. For the one state where a "passage assessment system" was developed to plan for wildlife passage, the system was not based on statistical modeling, nor was it statistically-validated using wildlife data (Kintsch and Cramer, 2011). There are two regular DOT activities at highway corridor scales where prediction of wildlife use of existing structures would be useful information. One is during environmental analysis for transportation projects in any wildlife habitat, especially associated with proposing new crossing structures. The other is bridge inspection for structural integrity and overall condition where there is usually no cursory or detailed evaluation of actual or potential wildlife passage. While wildlife movement might be a secondary concern for bridges in general, ensuring that existing bridges remain under-crossings for wildlife could save states many millions of dollars related to avoided costs from wildlife-vehicle-collisions and building new crossings.

Through this project we developed a first-of-its kind, evidence-based, predictive model for wildlife use of existing highway structures, in collaboration with multiple states. Because the model included validation using animal movement data from multiple states and agencies, it is more likely to be both accurate and acceptable to multiple states. Importantly, the model provided DOTs with a tool to more easily predict where wildlife may be safely crossing, or not crossing through existing structures at the corridor/project scale (Figure 1). At local and state scales, it could also expose gaps in information and systems of structures which could be filled through more detailed studies, or through constructing additional structures.

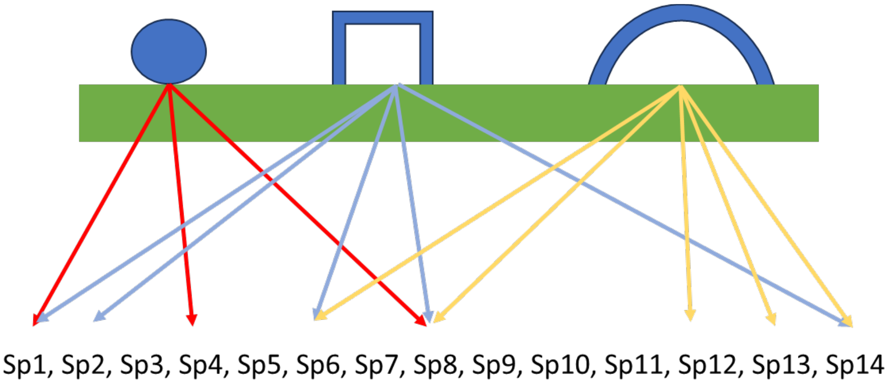


Figure 1. Use of different structure types by individual specie. The blue shapes represent culverts (blue circle), box culverts (blue square), and arch underpass/bridges (blue arch). Arrows represent structure-specific use, and "Sp1-14" represents 14 different species.

Approach

Our approach relied on four types of data: individual camera trap observations of wild animals, the dimensions of existing structures, the land cover surrounding the camera trap sites, and climatic conditions at the time of observation. Camera trap observations were aggregated in two ways: 1) by location for the occurrence or non-occurrence of each animal species and group of interest ("location model" dataset); and 2) by sum of the total number of occurrences of each animal species and group of interest, to find the frequency of appearance for each species ("animal-frequency model" dataset). The two aggregated datasets were used to create two models: 1) determination of whether or not a given species or group will use a given structure (location model) and 2) measurement of how often a given species or group will use a given structure (animal-frequency model). For both models, model development was guided by a combination of Akaike information criterion driven stepwise regression and human-driven variable selection. Stepwise regression was used to cut models down from all possible variables to a set of significant ones, while human intervention was used to ensure that the output model was reasonable.

Findings

For each of the statistical model types (location and animal-frequency) we developed predictive models for 26 species (e.g., bobcat) and species groups (e.g., deer). We also combined the coefficients for all variables for each species to make two determinations: 1) what structural conditions (dimensions and location) do individual species prefer and 2) given certain structural conditions, what is the likelihood of species or species group use of the structure. Model (1) can be used to inform planning and siting of new wildlife crossing structures that could suit particular species, or groups of species. Model (2) can be used to informs assessment of expected wildlife use of a network of existing structures, for example, all bridges and culverts in California.

Next Steps

We are using the model coefficients for each species to develop a website that anyone can use to plan new wildlife crossings, or assess existing structures for predicted wildlife use. The website will combine the predictions of wildlife use of existing structures with the features of an existing web tool to plan new wildlife crossings (https://wildlifecrossingcalculator.org) that we developed with support from Pew Charitable Trust.

Introduction

Most state Departments of Transportation have requirements to improve driver safety and reduce environmental impacts of constructing and operating state highway systems. Wildlife-vehicle collisions impact both safety and environmental aspects of project planning and delivery and are typically mitigated by building wildlife crossing structures and fencing parallel to the highway. When wildlife movement through culverts and bridges is monitored, there is variation in species use among structures and differences between disturbance-tolerant and sensitive species. Identifying structural attributes, thresholds for traffic disturbance and human use, and nearby environmental attributes (e.g., vegetation) would be useful for DOTs and sister agencies engaged in environmental analysis and mitigation planning.

The potential for wildlife use of existing structures not built for wildlife use has been considered and analyzed periodically over the last 20 years (Hunt et al., 1987; Foster and Humphrey, 1995; Rodriguez et al., 1996; Rodriguez et al., 1997; Rosell et al., 1997; Seiler, 2004; Mata et al., 2008; Seiler and Olsson, 2009), including on the now-iconic Trans-Canada Highway through Banff National Park (Waters, 1988). This literature base contributed to the development of a “Passage Assessment System” (PAS) by Washington State Department of Transportation to predict wildlife use of structures, based on structural and other attributes (Kintsch and Cramer, 2011). However, PAS was not developed based on statistical analyses and has not been scientifically tested for its ability to predict wildlife use of structures.

More recent studies have used statistical analyses to investigate the influence of individual and multiple variables on species and species groups’ use of culverts and bridges. Variables have included landscape (habitat and development), structural dimensions, and traffic volumes. As expected, there is reported variation in effectiveness of culverts and bridges (Chen et al., 2021; Denneboom et al., 2021; Lu et al., 2023) in passing wildlife. The combination of structural, location, and human use variables may be important in both planning for and predicting wildlife use of existing structures, or those planned for wildlife (Smith et al., 2015).

The federal Bipartisan Infrastructure Law includes many references to improving wildlife connectivity across linear infrastructure that could be a barrier or source of mortality for wildlife. For example, Sec. 21102 would update the National Freight Plan to include best practices to limit impacts to wildlife habitat of freight infrastructure and activity, while Sec. 11110 includes requiring analysis of wildlife collisions as a hazard. Sec. 11123 allocates $350 million to enhance wildlife crossing of highways. Sec. 11109 (Transportation Block Grants) includes support for “Projects and strategies designed to reduce the number of wildlife-vehicle collisions, including project-related planning, design, construction, monitoring, and preventative maintenance.” Sec. 11118 (Bridge Investment Program) requires consideration of whether the project will generate “environmental benefits, including wildlife connectivity.” Maybe of greatest relevance, under Sec. 11123 WILDLIFE CROSSING SAFETY, sub-section (e) WILDLIFE HABITAT CONNECTIVITY ANDNATIONAL BRIDGE AND TUNNEL INVENTORY AND INSPECTION STANDARDS.—“Section 144 of title 23, United States Code, is amended (6) determine if the replacement or rehabilitation of bridges and tunnels should include measures to enable safe and unimpeded movement for terrestrial and aquatic species.”

Methods

We used evidence of animal use of structures to create statistical models to predict structure use. This analysis relied on four types of data: individual camera trap observations at highway structures, the features of the structures, the biomes surrounding the camera trap sites, and the distance to the nearest building from the camera trap sites.

Animal Datasets

The camera trap observation data were from our own collaborative projects (AZ, CA, CO, NM, OR, UT), or provided by partners from ME, NC, VA, and WA (Figure 1) in the form of Excel or CSV spreadsheets, with each row representing a single observation of one or more animals at a camera trap. The data included the location of the camera trap, the date and time of the observation, and the species observed. Some datasets also included supplementary data, including number of individuals, sex, age, and other variables, but this data was not consistent across all datasets, so it was excluded. Thus, a single observation of a given species is not an individual animal of that species appearing at the location, but a single appearance of one or more animals of that species appearing at the location. Furthermore, there was no way of knowing if all appearances were definitely crossings. The data we used did not consistently measure whether or not an observation was of a successful crossing, or a refusal to cross. This was because not all data contributors used the same coding methods for animal use of structure; therefore we defined “use” as an observation of an animal recorded exiting or entering a structure.

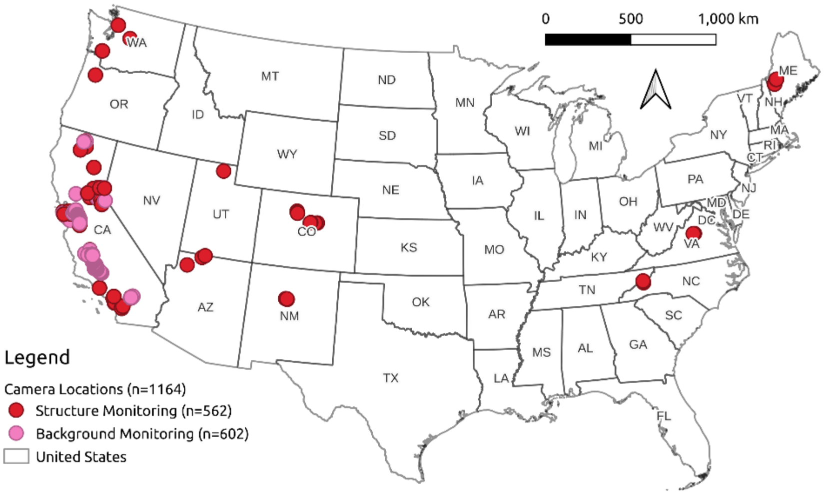


Figure 1. Locations of camera traps from which animal observation data were obtained.

Overall there were 185,881 observations at 662 monitoring locations of over 100 species. We did not use camera trap locations with less than 10 observations, leaving 190 total locations used. Of the over 100 species, 27 species and species groups had more than 30,000 observations and were used in statistical modeling. Species List: Black bear, Black-tailed jackrabbit, Bobcat, Brush rabbit, California ground squirrel, Coyote, Deer, Desert cottontail, Elk, Feral pig, Foxes, Gray fox, Ground squirrel, Mountain lion, Mule deer, Mustelids, Rabbits, Raccoon, Rats, Red fox, Striped skunk, Tree squirrel, Virginia opossum, Weasel, Western gray squirrel, White-tailed deer, and Woodrats.

Structural Attributes

The attributes of the camera trap structure locations were often provided by the partners. When those were unavailable, they were collected using Google Earth (e.g., structure length). Attributes included the type of camera trap location, be it a structure or wildlife trail, the type of structure (e.g., culvert, bridge), the dimensions of the structure in length, height, width, and calculated openness ratio from the animal's perspective (length being the distance that the animal needs to traverse to emerge on the other side of the crossing, the height being the furthest distance from the top of the structure to ground level, and the width being the maximum distance between the walls of the structure), and the location of the structure in latitude and longitude.

Spatial Datasets and Manipulations

We used the NAD83 Equal Area Albers CONUS (Continental United States) projection (EPSG:5070) across all spatial data. We incorporated animal data from many regional studies, and while regional or state data can be more accurate due to the smaller extent we only used data that is available nation-wide. We relied on Quantum GIS (QGIS, version 3.22) to run many of the spatial analyses, which include libraries from GDAL, GRASS, and third party plugins.

National Landcover Database (NLCD)

Land cover classifications for the biomes surrounding the camera trap locations were derived from the National Land Cover database (2019 version, accessed April 25, 2023; https://www.usgs.gov/centers/eros/science/national-land-cover-database, Figure 2). Specifically, twelve different types of land cover were used, as were five different measures of land cover density and adjacency. The land cover types were Developed, Developed (Open-Space), Barren, Forest, Scrub, Grassland, Farmland, Wetland, and Water-Wetland. We created new national maps which included select land cover classes and removed all other classes so those areas of the map become null or no-data values. We combined NLCD classes to provide a more general land cover type (Table 1).

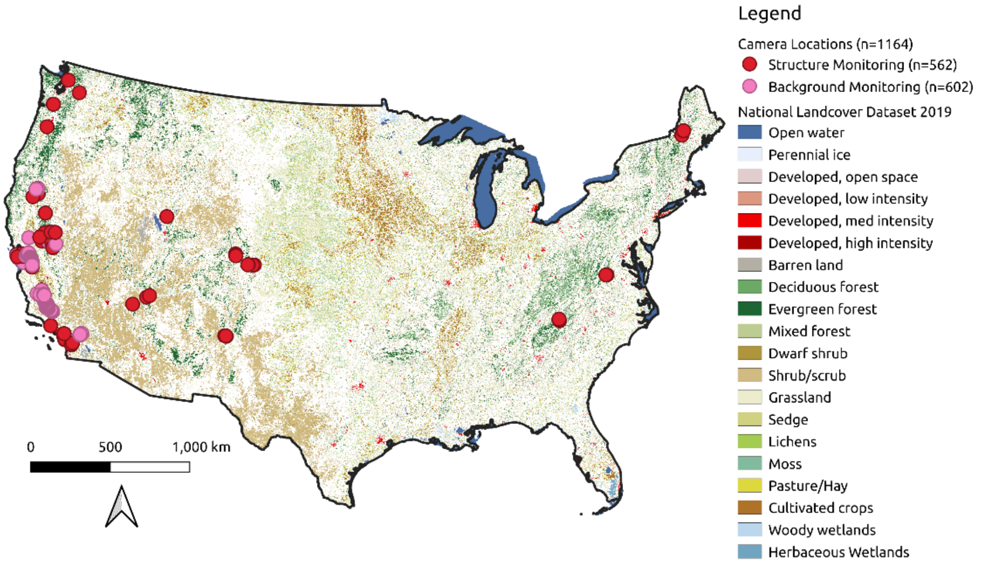


Figure 2. Land cover types from the National Landcover Dataset (2019) and camera trap locations.

Table 1. Land cover class combinations used. The “General Land Cover Classes” were the ones created using the “NLCD Classes” indicared.

General Land Cover Classes	NLCD Classes	Notes
Developed + Open	21, 22, 23, and 24	Developed Land, including developed open space.
Developed	22, 23 and 24	Developed Land, not including developed open space.
Barren	31	
Forest	41, 42, 43	Combined deciduous, evergreen and mixed forest classes.
Scrub	52	Class 51 (scrub) applies to Alaska only.
Grasslands	71	Classes 72, 73, and 74 (grasslands) relate to Alaska only.
Cultivated Crops	81 and 82	Pasture/hay and cultivated crops.
Wetlands	90 and 95	

The measures of land cover density and adjacency were 1) the distance from the camera trap location to the nearest raster cell of the land cover type.

Climate Data

We used climate data from the PRISM Climate Group to associate the minimum and maximum temperature (tmin, tmax) as well as precipitation (ppt) with each camera trap observation. We downloaded daily values at 4km resolution for the years we had observation data, including the provisional data through March 2023 (https://prism.oregonstate.edu/; accessed several times between Feb 27, 2023 and July 5, 2023). We used an R program to create a “raster stack” of average daily values and based on the date/time and location and from these we selected the climate attributes, pulling the appropriate values from the stack.

Waterway Data

We used the NHDPlus (National Hydrology Dataset, https://www.usgs.gov/national-hydrography/nhdplus-high-resolution, accessed on July 5, 2023) data to measure the distance from a structure location (or camera trap point) to the nearest water source. We converted the NHDPlus Water bodies layer from polygons to lines, and then combined the flow lines and water bodies data into a single lines layer. We then used the GRASS function, v.distance, to determine the distance of the structure and camera points to the closest water.

Distance to Buildings

The USGS has teamed with Microsoft’s Bing Maps to produce a raster layer of buildings and structures for the continental United States (https://www.usgs.gov/data/a-national-dataset-rasterized-building-footprints-us, accessed April 24, 2023). The raster grid is composed of 30 meter (equal area) cells whose value represent the number of building centroids found in that space. Similar to the NLCD data processing, we created a raster distance map where each cell value equaled the distance to the nearest building grid (centroid). We then estimated the distance from each camera trap locations to the nearest building.

Data Cleaning and Manipulation

The data cleaning process was conducted within the statistical analysis program, R (R Core Team, 2015). The process consisted of individually loading the datasets, and cleaning the data before merging. When merged, the data were scrubbed to remove potential duplicate observations, specifically observations of the same species at the same location of each other within ten minutes for structures and within one hour for background locations. Then, to create the "location-only" dataset, observations were aggregated by year and location for the occurrence or non-occurrence of each animal species and group of interest. If an animal appeared at any point during the year, that year's record was assigned a value of 1 for appearance. Otherwise, it was assigned a value of 0. Additionally, to create the "location+time+season" dataset, the observations were aggregated by year, location, time of day, and season, summing the total number of occurrences of each animal species and group of interest as well as the duration of total observation (how long cameras were active at a given location, measured from when a camera first detected a crossing of any species, to the final detection of any species), to find the frequency of appearance per day of observation. In both datasets, the aggregated observations were combined with land cover, distance to water, and distance to building data to create the final datasets.

Statistical Modeling

Two datasets and three models were created using R, one that measures whether or not a given species or group will use a given structure and another that measures how often a given species or group will use a given structure. These use the location-only aggregated dataset and the location+time+season aggregated dataset, respectively. For all three models, model development was guided by a combination of Akaike information criterion driven stepwise regression and human-driven variable selection. Forward (addition of variables) and backwards (subtraction of variables) stepwise regression was used to cut models down from all possible variables to a set of best fit variables, while human intervention was used to ensure that the output model was reasonable. For example, the structural dimension variables were strongly believed to have an effect on the outcome, as was distance to the nearest structure. As previously mentioned, distance to a given land cover type was automatically calculated in QGIS using the NLCD land cover dataset. This approach resulted in species and variable-specific coefficients that contributed to determining: 1) the likelihood that a species would use a structure and 2) the frequency at which a species might use a structure. Models generally followed this structure, with variables added to the equation.

$$\mathrm{Logit}(P) = A_o + A_T + A_{forest} + A_{length} + A_{height}$$

The three models were designed to address three different questions: what purely structural features influenced animals to use a structure, what features influenced how often a structure was used, including time of day and season, and what features influenced how often a structure was used, including weather conditions as well as time of day and season. The first question was best answered by a logistic regression model, as the outcome of interest was not frequency of use but use or no use of a structure by a given species or animal group. A logistic regression's predicted outcome of 0 or 1 made it preferable for this question. The second and third questions were best answered by linear regressions, as the outcome of interest is frequency of use. The predicted continuous outcome was both useful and simple to explain and calculate.

The daily and animal focused models are very similar in design. Both are interested in what temporal and seasonal features, as well as locational and structural features, impact an animal's behavior, examined through the frequency of entering and exiting a structure on a daily basis. The two main differences are on how the training data is segmented and the inclusion of weather data. The structural focused model is the most unique of all models, as it is aggregated differently and excludes any seasonal or temporal factors, as well as predicting appearance on an annual basis.

The daily model takes into account time of day, daily weather conditions, and season. It is trained on data aggregated at a day-to-day level, so each datapoint represents the number of animals who appeared over one day. It provides the number of a given animal that is predicted to enter and exit the structure during a given time of day on a given day.

The animal focused model takes into account time of day and season. It is trained on data aggregated at a seasonal basis, so each datapoint represents the daily average number of animals who appeared over the course of a season and time of day. It provides the number of a given animal that is predicted to enter and exit the structure during a given time of day and season.

The structure focused model takes into account only locational and structural features. It is trained on data aggregated at an annual basis, so each datapoint represents whether or not a given species entered or exited the structure in the course of a year. It provides the probability of a given animal entering and exiting a given structure.

The R packages tidyverse, stringr, readxl, broom, and lubridate were all used to help import and clean the data. The R packages questionr and MASS were used to help construct the models. The R package moonlit was used to determine the time of day. The R packages ggplot2 and graphics were used to make charts.

AIC was used to guide the stepwise regression in finding the model with the best fit. Significance of the individual variables was not used, as that would have changed the overall fitness of the model. Including or excluding variables on their statistical significance would have been akin to p-hacking.

Results

We developed three primary types of model: 1) an animal-centered model, predicting the frequency of animal use of structures, based on their location and dimensions, and upon the time of day and time of year; 2) a daily count model, which builds upon the animal-centered model to predict the estimated number of times a species will use a structure per day, based n structure dimensions and location, and the climatic conditions on the day in question; and 2) a structure-centered model, predicting likelihood of species use on an annual basis, based on the structural dimensions and location. Importantly, the model only predicts use if the species are expected to be present based upon their distribution.

Animal-Centered Model

Influence of Individual Variables

No single dimensional or locational structure variable exists without the others. However, it can be illustrative to examine the relationship between individual parameters and likelihood of species use and compare the relationship with what is known about species' behavior. For example, for mule deer, bobcat, and California ground squirrel, the relationships between likelihood of use and structure length were statistically-significant, but varied in slope direction (Figure 3). These curves indicate that mule deer and bobcat prefer, or will tolerate structures that are not as long and California ground squirrel prefer, or will tolerate longer structures.

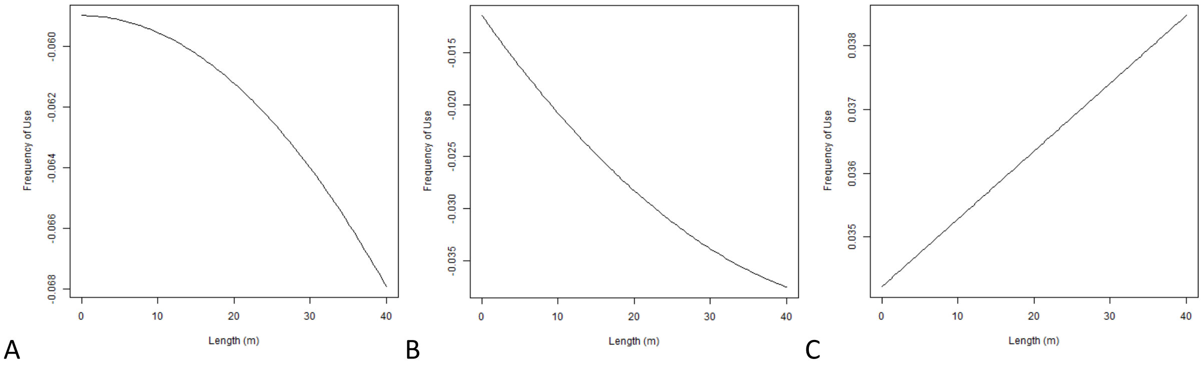
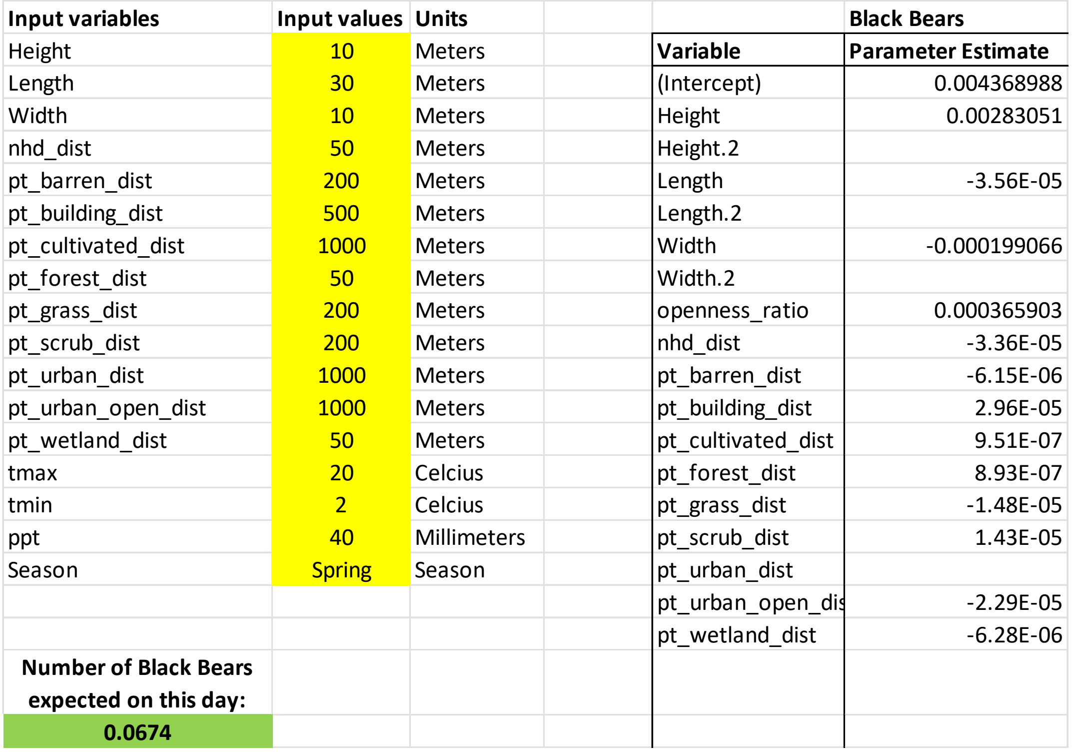


Figure 3. Relationship between frequency of use of structures and structure length for (A) mule deer, (B) bobcat, and (C) California ground squirrel.

Predictive Modeling

Combining the estimates for statistically-significant variables for individual species allows the determination of the probability of use of a certain structure by the species. We created a spreadsheet combining the various coefficients for probability of use and allowing entry of structure dimension and locational attributes to predict probability of use (Table 2).

Table 2. Spreadsheet showing use of statistically-significant parameter estimates to predict frequency of black bear use (green cell) of a structure with certain input variable* values (yellow highlight).



Input variables	Input values	Units			Black Bears
Height	10	Meters		**Variable**	**Parameter Estimate**
Length	30	Meters		(Intercept)	0.004368988
Width	10	Meters		Height	0.00283051
nhd_dist	50	Meters		Height.2	
pt_barren_dist	200	Meters		Length	-3.56E-05
pt_building_dist	500	Meters		Length.2	
pt_cultivated_dist	1000	Meters		Width	-0.000199066
pt_forest_dist	50	Meters		Width.2	
pt_grass_dist	200	Meters		openness_ratio	0.000365903
pt_scrub_dist	200	Meters		nhd_dist	-3.36E-05
pt_urban_dist	1000	Meters		pt_barren_dist	-6.15E-06
pt_urban_open_dist	1000	Meters		pt_building_dist	2.96E-05
pt_wetland_dist	50	Meters		pt_cultivated_dist	9.51E-07
tmax	20	Celcius		pt_forest_dist	8.93E-07
tmin	2	Celcius		pt_grass_dist	-1.48E-05
ppt	40	Millimeters		pt_scrub_dist	1.43E-05
Season	Spring	Season		pt_urban_dist	
				pt_urban_open_dis	-2.29E-05
				pt_wetland_dist	-6.28E-06
Number of Black Bears expected on this day:					
0.0674					

* -- “nhd_dist” = distance to stream, “pt_barren_dist” = distance from structure point to barren land cover, “pt_building_dist” = distance from structure point to nearest building, “pt_cultivated_dist” = distance from structure point to cultivated land cover, “pt_forest_dist” = distance from structure point to forest land cover, “pt_grass_dist” = distance from structure point to grassland land cover, “pt_scrub_dist” = distance from structure point to scrubland land cover, “pt_urban_dist” = distance from structure point to urban developed land cover, “pt_urban_open_dist” = distance from structure point to urban open space land cover, “pt_wetland_dist” = distance from structure point to wetland land cover, “tmax” = maximum temperature on day selected, “tmin” = minimum temperature on day selected, “ppt” = average precipitation on the day selected.

Structure-Centered Model

Influence of Individual Variables

We developed predictive models from the perspective of the structure, asking the question: given certain dimensions and location, what would the likelihood be of use by individual species, assuming it is present in the landscape? Although the variables do not function independently from each other in the model, the influence of individual parameters on likelihood of use can be illustrative (Figure 4). For these diverse species, structure height would result in greater likelihood of use (Figure 4).

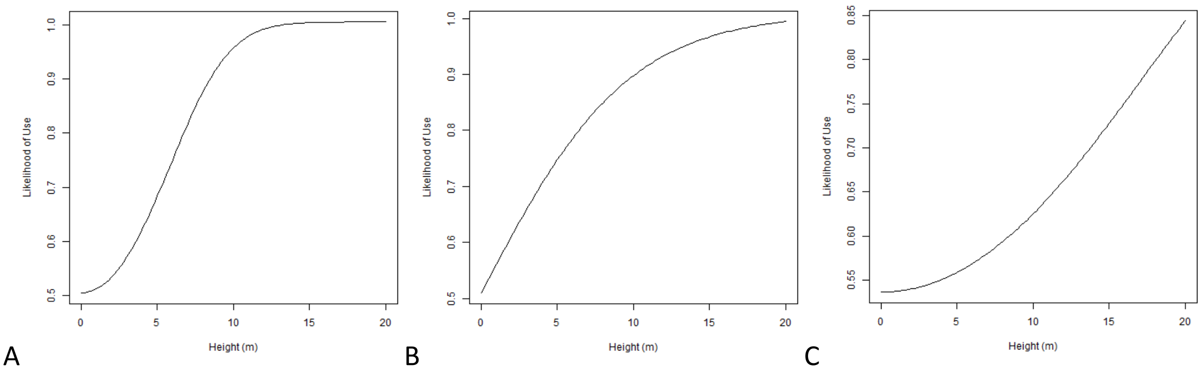


Figure 4. Relationships between likelihood of species use and structure height, for (A) mountain lion, (B) tree squirrel species, and (C) fox species.

Predictive Modeling

Combining the estimates for statistically-significant variables for individual species allows the determination of the probability of use of a certain structure by the species, assuming the species is present in the landscape. We created a spreadsheet combining the various coefficients for probability of use and allowing entry of structure dimension and locational attributes to predict probability of use (Table 3). This spreadsheet could be used for any location in the US to predict use by the species and species groups for which we developed predictive models. It also illustrates the information that could be input through a web-system for individual existing or proposed structure locations and the probability of wildlife use.

Table 3. Spreadsheet showing use of statistically-significant parameter estimates to predict probability of bobcat use on an annual basis (green cell) of a structure with certain input variable* values (yellow highlight).

Input variables	Input values	Units			Bobcat
Height	3	Meters		**Variable**	**Parameter Estimate**
Length	30	Meters		(Intercept)	-1.223754724
Width	3	Meters		Height	
nhd_dist	1000	Meters		Height.2	-0.008606683
pt_barren_dist	100	Meters		Length	
pt_building_dist	1000	Meters		Length.2	4.70E-05
pt_cultivated_dist	1000	Meters		Width	
pt_forest_dist	100	Meters		Width.2	4.92E-05
pt_grass_dist	1000	Meters		openness_ratio	0.019553076
pt_scrub_dist	1000	Meters		nhd_dist	-0.000848757
pt_urban_dist	100	Meters		pt_barren_dist	-0.000525233
pt_urban_open_dist	1000	Meters		pt_building_dist	-0.002455114
pt_wetland_dist	100	Meters		pt_cultivated_dist	0
				pt_forest_dist	0
				pt_grass_dist	0.002390974
Probability of Bobcat using this structure on an annual basis:				pt_scrub_dist	0.005075232
52.4%				pt_urban_dist	0.11751348
				pt_urban_open_dist	
				pt_wetland_dist	0.001008663

* codes are same as in Table 2.

Discussion/Conclusions

Predicting where wildlife might be crossing roadways safely using the existing system of culverts and bridges is useful information for Departments of Transportation assessing wildlife-vehicle conflicts and planning new wildlife crossings. We developed a series of predictive models of species tolerances for different structural variables, including structure dimensions, location environment, and climatic variables (for use at different times of year).

In a recent meta-analysis of available global literature on wildlife use of different culvert and bridge types, Denneboom et al. (2021) concluded that there was significant variation among taxonomic groups (e.g., ungulates, small carnivores) in terms of preferences for different types of over and under-crossings. For the variables that were comparable to our study, there was almost complete agreement between their study and the present one. For example, for ungulates both found a negative relationship between use and structure length and a positive relationship between use and structure width and a natural bottom. Similarly, both found a [positive relationship between small use and structure length. We did not have data for many of their variables: structure shape, overpasses, presence of fencing, and human use.

Our results were also consistent with geographically-limited studies on a few species in Europe, Asia and the US. Consistent with Denneboom et al. (2021), Myslajek et al. (2020) found that ungulates (e.g., deer) and large carnivores preferred large underpasses over small underpasses, whereas hares only had a slight preference for large underpasses over small underpasses. Similarly, Wang et al. (2021) compared wildlife use of bridge underpasses and culverts and found that ungulates preferred bridges, while badgers and weasels preferred culverts. Finally, Ng et al. (2003) found that mule deer, coyote, and bobcat had negative relationships between length and structure use, while small carnivores had positive relationships between use and length.

There are two primary advantages of our study over previous work: 1) Compared to general and qualitative guidance for constructing wildlife crossings (Clevenger and Huijser, 2011), or predicting wildlife use based upon structure dimensions (Kintsch and Cramer, 2011; Kintsch et al., 2015), our predictive models allow quantitative prediction of wildlife use; and 2) The multiple location and structure variables that we included in our modeling allow for prediction of wildlife use for any existing or proposed new wildlife crossing, for example through a web-system. These advantages will allow for prediction of wildlife use of individual or sets of existing or proposed culverts and bridges.

Next Steps

1) The animal and structure-specific coefficients we have developed in the current studies will be used with cooperating states to predict wildlife use of existing culverts and bridges. Examples of bridges are shown in Figure 5 for AZ and CA. ADOT has agreed to share their culvert locations and attributes and Caltrans is considering the request. The structure attributes, surrounding land cover types, distance from water, and distance from buildings can all be used to predict which wildlife are likely to use the structures, giving an indication along specific highway corridors where wildlife have and don’t have existing permeability and safe passage.

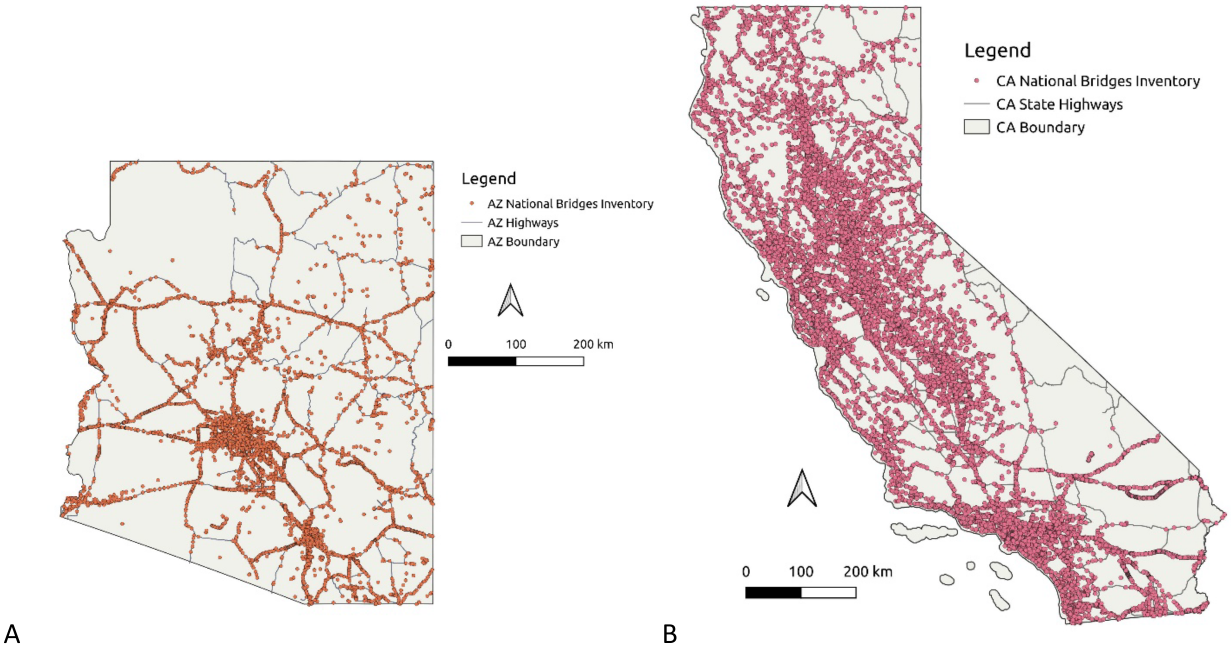
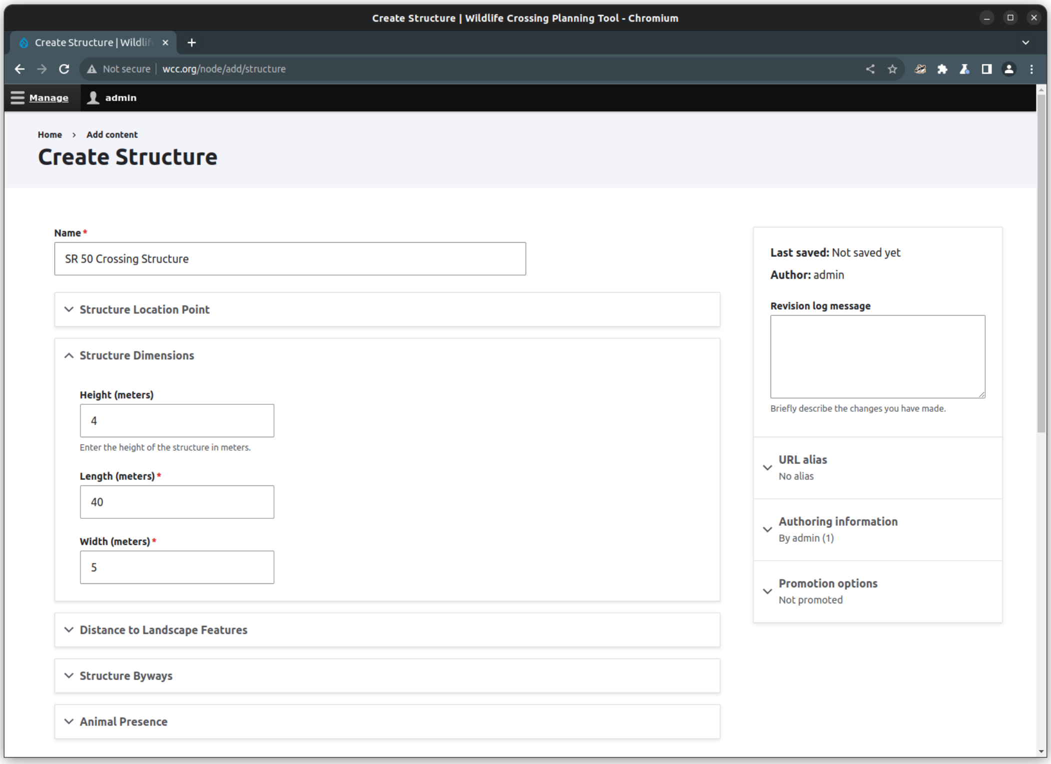


Figure 5. Maps of bridges along state highways in (A) Arizona and (B) California.

2) We are currently developing a web-system where state agency staff can enter structural attributes and locations for existing, or planned structures and find out which wildlife would be predicted to use the structures (Figure 6). This will be useful for both assessment of predicted wildlife use and planning new wildlife crossing structures.



Create Structure

Name *

SR 50 Crossing Structure

Structure Location Point

Structure Dimensions

Height (meters)

4

Enter the height of the structure in meters.

Length (meters) *

40

Width (meters) *

5

Distance to Landscape Features

Structure Byways

Animal Presence

Last saved: Not saved yet

Author: admin

Revision log message

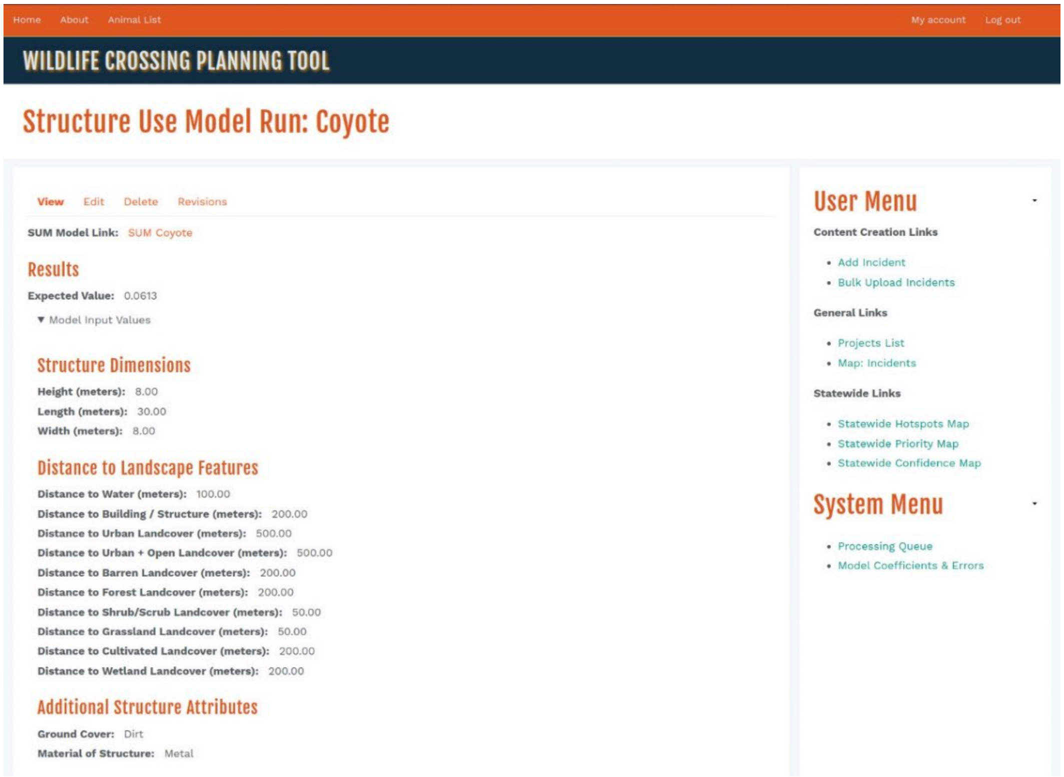
Briefly describe the changes you have made.

URL alias
No alias

Authoring information
By admin (1)

Promotion options
Not promoted

A



Structure Use Model Run: Coyote

SUM Model Link: SUM Coyote

Results

Expected Value: 0.0613

▼ Model Input Values

Structure Dimensions

Height (meters): 8.00
Length (meters): 30.00
Width (meters): 8.00

Distance to Landscape Features

Distance to Water (meters): 100.00
Distance to Building / Structure (meters): 200.00
Distance to Urban Landcover (meters): 500.00
Distance to Urban + Open Landcover (meters): 500.00
Distance to Barren Landcover (meters): 200.00
Distance to Forest Landcover (meters): 200.00
Distance to Shrub/Scrub Landcover (meters): 50.00
Distance to Grassland Landcover (meters): 50.00
Distance to Cultivated Landcover (meters): 200.00
Distance to Wetland Landcover (meters): 200.00

Additional Structure Attributes

Ground Cover: Dirt
Material of Structure: Metal

B

Figure 6. User interface for web-system for users to A) enter location and dimension information in order to predict wildlife use of culverts and bridges and B) receive reporting on structure conditions and use.

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Data Management Plan

Products of Research

The data that were collected and used for the study included camera trap data from several states and partners and spatial datasets.

Data Format and Content

Describe the format, or file type, of the data, and the contents of each file.

A) Camera trap data were obtained in spreadsheet format (e.g., Excel .xls) from partners. The data fields were: i) location code, ii) date, iii) time, iv) latitude and longitude, v) animal species, vi) structure dimensions (e.g., length). B) National Land Cover Datasets are in raster format, National Hydrography Dataset is in vector format, and distance to building is in raster format.

Data Access and Sharing

Camera trap data for CA and OR can be requested from fmshilling@ucdavis.edu. Camera trap data for other states can be requested from the states directly.

Reuse and Redistribution

Data can be used by the recipient and may not be redistributed.