The information presented here are preliminary results and do not represent any final conclusions.

Easygrants ID: 61055
National Fish and Wildlife Foundation NFWF Project ID: 0809.18.061055
Northern California Forests and Watersheds 2018 - Submit Interim Programmatic Report (New Metrics)
Grantee Organization: NCASI Foundation
Project Title: Developing a Pacific marten habitat connectivity model for Lassen National Forest (CA)
Submitted by Katie Moriarty on

Project Period	6/01/2018 - 5/31/2021
Project Location Description (from Proposal)	Lassen National Forest, California
Project Summary (from Proposal)	Develop a Pacific marten habitat connectivity model within the Storrie Fire boundary for Lassen National Forest in California. The project will develop a data-tested, flexible model that Lassen National Forest can use for future marten habitat restoration and management.
Project Status and Accomplishments	Field research efforts occurred on the Almanor Ranger District of the Lassen National Forest (December 2018–May 2019, September 2019–January 2020). Field activities have consisted of live-trapping of martens to deploy GPS collars and remote camera surveys. Our first trapping effort occurred from January–March 2019. Trapping during our first effort began subsequent to the end of the government shutdown and ended approximately 4 weeks prior to expected marten parturition, in accordance with CDFW permitting requirements. Our second trapping effort occurred from September 2019–January 2020. At captures, we estimated age of martens and classified each individual as juvenile/young-of-the-year (1 year old), subadult/yearling (1-2 years old) and adult (2 years old), with the intent of placing GPS collars (Litetrack 20g and 30g, Lotek Inc.) on all juvenile martens captured and tracking them through the dispersal process. Martens are highly capable of long-distance movements, and during dispersal, juvenile martens appear more likely to travel through lower-quality predicted habitat than adult martens. GPS movement paths of juvenile martens may indicate travel corridors and connectivity between areas of higher-quality habitat. As the Storrie Fire burned within marten habitat and through areas of predicted connectivity between patches of habitat, juveniles may travel through fire boundaries during dispersal movements. In addition to trapping/GPS collar activities, we have conducted remote camera surveys to investigate marten distribution. Prior to initiating live-trapping in December 2019, we installed 25 cameras to scout potential trap locations for juvenile martens. Cameras were placed along the northern perimeter of the Storrie Fire footprint, within 5 km of the Storrie Fire perimeter in areas where we have previously captured or detected juvenile martens, and in areas of predicted lower habitat suitability (e.g., outside of known adult marten territories; K. Moriarty, unpublished data) where dispersing juvenile martens could occur. Concurrent to our first trapping effort (January-March 2019), we conducted a broader-scale camera survey that replicated systematic camera surveys for martens conducted between 2006–2009. Surveys consisted of a grid of 20 sample units with each sample unit placed approximately 3 km from another sample unit (Zielinski et al. 2015). These surveys were intended to inform trapping locations for fall 2019 trapping efforts for juvenile martens. Each sample unit consisted of one camera at the original location used by Zielinski et al. (2015), and a second camera placed randomly within 150 m, following a protocol used for martens elsewhere (e.g., Moriarty et al. 2019). Sample units included a variety of vegetation types and varied in quality of predicted marten habitat. In December 2019, we deployed another remote camera survey grid to assess movement connectivity and test the predictive ability of connectivity modeling efforts by CBI. Surveys consisted of 21 sample units with 3 km spacing and cameras were installed using the protocol described above (e.g., a second camera placed within 150 m; Moriarty et al. 2019). This grid is an extension to the Zielinski et al. (2015) grid, with grid points located in a modeled movement corridor between our study area and Lassen Volcanic National Park. Cameras from this survey were retrieved in October 2020. We are processing 500,000 photographs now.

CBI has completed work on Task 2, habitat suitability modeling. After multiple efforts to fit mixed effects models using the glmmTMB package in R failed to yield an acceptable output across our entire area of interest, we reverted to a presence-only approach with MaxEnt (Phillips et al. 2006). Previously, we delineated our model calibration extent using an average daily movement distance (7 km) to buffer GPS detection points, expanding that out to the maximum daily movement distance (27.2, Moriarty et al. 2016) resulted in improved model projections across the larger study area extent. Detections were thinned to a minimum nearest neighbor distance of 1km to increase spatial independence and reduce spatial autocorrelation and model performance inflation (Veloz 2009, Boria et al. 2014).

Activities and Outcomes

Funding Strategy: Habitat Management
Metric: NorCal - Improved management practices - Acres under improved management
Required: Recommended
Description: Enter the number of acres under improved management except for those treated specifically for the benefit of California spotted owl. In the notes section, state how many acres are wetland/meadow, riparian, land, and/or other specific type and are not listed in the land/wetland acres metric. If applicable, state how many acres are for improved campsites, or for fuels reduction activities such as mechanical thinning, etc., but do not include acres from the prescribed burns.

Starting Value	0.00 Acres under improved management
Value To Date	27000.00 Acres under improved management
Target value	27000.00 Acres under improved management

Note:

The following pages contain the uploaded documents, in the order shown below, as provided by the grantee:

Upload Type	File Name	Uploaded By	Uploaded Date
NorCal Interim Report 2018	MoriartyEtAl_NorCal_2018_InterimReport_210429.pdf	Moriarty, Katie	04/29/2021

The following uploads do not have the same headers and footers as the previous sections of this document in order to preserve the integrity of the actual files uploaded.

Interim Programmatic Report Narrative

1. Project Status and Summary of Accomplishments for <u>NFWF funded and match project activities only</u>
Grant period of performance (09/25/18-**04/30/21**)
Grant reporting period (02/01/20-05/31/21)

We completed modeling and field efforts and are writing up the final report. Our last phase of connectivity modeling occurred over the past period of performance and is described herein. Our grant was approved 9/2018. We completed field research (12/2018–4/2019, 9/2019-1/2020), avoiding field work during the U.S. federal government shutdown and when female martens are raising dependent kits, complying with permitting requirements of California Department of Fish and Wildlife (CDFW). We deployed GPS collars on 10, and retrieved data from 6. We deployed xx remote cameras and processed photographs, describing marten locations in relation to our habitat and connectivity models.

2. Project Activities & Outcomes
Activities
Activity 1: Marten habitat suitability and connectivity modeling

Modeling efforts were completed by CBI. CBI filtered GPS data, removing locations with low accuracy. Our GPS dataset has 12,393 records (2010-2018) from 32 individuals (21M:11F; 37 to 1078 points/individual. Random points (25) were paired with locations within a 7 km buffer. CBI derived GIS predictor layers over the modeling extent (Lassen and Plumas National Forests, and Tahoe National Forest north of Interstate 80), which was expanded as a non-federal match to this project.

After multiple efforts to fit mixed effects models using the glmmTMB package in R failed to yield an acceptable output across our entire area of interest, we reverted to a presence-only approach with MaxEnt (Phillips et al. 2006). Previously, we delineated our model calibration extent using an average daily movement distance (7 km), but expanded to the maximum daily movement distance (27.2, Moriarty et al. 2016) resulting in improved model projections across the larger study area extent. Detections were thinned to a minimum nearest neighbor distance (1km) to increase spatial independence and reduce spatial autocorrelation and model performance inflation (Veloz 2009, Boria et al. 2014).

Using the highest performing spatial scale for each variable, we created 9 models which were "pruned" in an iterative, stepwise process to decrease model complexity and increase performance (Warren et al. 2014, Yiwen et al. 2016) by eliminating variables that least contribute to model performance (highest mean training gain without the variable). We selected the models with the fewest predictors having a mean training gain not significantly different than the full models. Pruned models were "tuned" by varying MaxEnt's regularization parameter from 0 to 5 in increments of 0.5 (default = 1) to constrain model complexity (Anderson and Gonzalez 2011, Warren and Seifert 2011, Radosavljevic and Anderson 2014, Warren et al. 2014). We selected the regularization parameter that produced the model with the lowest AICc (Akaike information criterion corrected for small sample sizes) calculated with ENMTools 'Model Selection' function (Warren et al. 2010). We ran MaxEnt with 10-fold cross validation with the selected regularization parameters to get final output grids using our multivariate tuned models. We used independent detection and non-detection survey data from multiple sources (130 detections from 2001-2012 and 118 non-detections from 2001-2010) for model evaluation. We also used all the GPS detections (n=12,383) to evaluate the models; while these data are not independent, they are helpful for describing model performance within the GPS study areas. For threshold-dependent model evaluation methods, we used the maximum training sum of sensitivity and specificity (MAXSS), a model-specific threshold shown to optimize discrimination between presence and absence (Liu et al. 2013) to classify model outputs into suitable and unsuitable habitat.

Our final model included 5 predictors: elevation (47% importance, live biomass 27%, slope 20%, tree density 5%, and canopy cover standard deviation 1%. Predictor scales ranged from fine (elevation, smoothed with a 30m radius moving window), moderate (tree density, 270m radius), to coarse (biomass, slope, and canopy cover standard deviation, 990m radius). This model had a 10-fold cross-validated test AUC of 0.94. Model sensitivity (True Positive/(True Positive + False Negative)) and specificity (True Negative /(False Positive + True Negative) using independent test data were 0.78 and 0.28. Model specificity measured using all GPS detections was 0.98.

CBI completed work on Activity 1, Part 2 (Habitat Connectivity). We used the multi-scale multi-variate habitat suitability model previously completed (Activity 1, Part 1) as the foundation for least-cost corridor modeling implemented with Linkage Mapper Toolkit (McRae and Kavanagh 2011) to analyze broad-scale, population-level connectivity for martens in the Lassen region as well as within and adjacent to the Storrie Fire perimeter. The habitat suitability model was the basis of the two input requirements of Linkage Mapper: core habitat areas and resistance or cost surface.

Habitat Connectivity: Delineating Core Habitat Areas

To delineate Pacific marten core habitat areas, defined as contiguous blocks of suitable habitat large enough to support at least five female home ranges, we first modified our habitat suitability model to account for conditions not reflected in the vegetation layers used as model predictors at coarser scales. Areas with high burn severity (2016-2020, U.S. Forest Service RAVG Thematic Percent Change in composite Burn Index (CBI-4)) post-model vegetation data (GNN 2016), no data due to vegetation data masking for non-forest land cover, and open water and developed land cover (U.S. Geological Survey NLCD 2016 Land Cover Conterminous United States) were converted to a suitability value of 0 and then smoothed by calculating the focal mean using a 3-km 2 circular moving window (approximate home range size, Moriarty et al. 2016).

While many thresholds are available to distinguish suitable from unsuitable habitat in MaxEnt models (Peterson et al. 2011), we often use the maximum sum of sensitivity and specificity (as we did for model evaluation) which has been shown to be robust and consistent (Cao et al. 2013, Liu et al. 2013, Liu et al. 2016). However, we found that threshold to be too inclusive for core area delineation in this case, and instead opted to use predicted-to-expected (P/E) ratio curve and associated 95% confidence intervals from the continuous Boyce index to inform our suitability threshold (Hirzel et al. 2006), with areas considered suitable at and above the value where the mean P/E and confidence intervals are > 1 (0.408).

Values in the smoothed layer greater than or equal to the suitability threshold (0.408) were extracted and areas of open water and developed land cover (U.S. Geological Survey NLCD 2016 Land Cover Conterminous United States) were assigned a suitability value of 0. We removed any potential cores areas with no known occupancy by marten along the eastern side of our area of interest by removing polygons in 8 ecoregional subsections: Big Valley Mountains, Blacks Mountain-Susanville Peak, Eagle Lake-Observation Peak, Honey Lake Basin-Pyramid Lake Basin, Fredonyer Butte-Grizzly Peak, Diamond Mountains-Crystal Peak, Frenchman, and Sierra Valley. Polygons with area less than approximately 5 female home ranges (15-km^2, Moriarty et al. 2016) were removed. This left 8 Pacific marten core habitat areas with a mean area of 66.2 km^2 (range of 15 to 260 km^2; Figure 1).

Habitat Connectivity: Resistance Surface

The selected habitat suitability model was also used as the foundation of the resistance surface for connectivity modelling. Habitat suitability values were transformed with a negative exponential function: $R = 100 - 99\ (1-exp(-c \cdot H) / (1-exp(-c)))$ where R = Resistance, H is suitability, and c determines the shape of the curves (Keeley et al. 2016). We used c= 8 based on previous work (Spencer et al. 2019) and expert opinion. The transformed surface was then rescaled from 1 to 1000 to accentuate resistance discrimination, based on expert opinion from previous projects and the literature (McRae and Kavanagh 2011). We further modified the resistance surface to account for factors that may affect movement costs but aren't adequately reflected in the underlying habitat suitability model, such as recent high severity fires and clearcuts, roads, and open water that may serve as barriers to movement. We based the additional costs for these factors on expert opinion from prior marten connectivity analyses (Spencer et al. 2019) and combined them with the rescaled transformed surface by taking the maximum cost (Figure 2).

Habitat Connectivity: Corridors and Pinchpoints

We then used the core habitat areas and enhanced resistance surface as inputs to Linkage Mapper (Version 2.0, McRae and Kavanagh 2017) to delineate likely potential marten movement corridors between core habitat areas with the Linkage Pathways tool. We used expert opinion and previous marten connectivity analyses to establish a minimum linkage width of 600,000 cost-distance units. This correlated to about 0.7 km as the minimum linkage width, with most roughly 3 km wide (Figure 3).

Narrow, constrained portions of linkages can be identified using the outputs of Linkage Mapper's Pinchpoint Mapper tool, which uses Circuitscape software (McRae et al. 2008) to create current density maps within corridors. Pinchpoints represent areas where movement would be funneled and thus may be particularly important to maintain or enhance suitable habitat conditions (McRae et al. 2008, McRae and Shah 2009, McRae 2012) and can be used to identify areas to prioritize for stand-level management prescriptions to improve connectivity. For the pointpoint analysis, we used the adjacent pairs option and removed current density values less than or equal to 1e-08 to constrain the output to within linkages (Figure 4). To highlight bottlenecks in the corridor network, we then reclassified the output, creating a pinchpoint map from current density values greater than or equal to the mean plus 2 standard deviations (Bleyhl et al. 2017; Figure 5). These areas represent places critical to facilitating movement between core habitat areas and where linkages are most susceptible to being severed, adversely impacting connectivity across the network.

Other Tasks

A group, ‘Pacific Marten Habitat Connectivity for Lassen National Forest’, has been created on Data Basin (https://databasin.org/groups/ac7f828b1b8e4fc9b2a680d48ef62806/), where all final output GIS layers, including continuous relative habitat suitability, habitat core use areas, and modeled corridors and pinchpoints will be available for viewing, use, and downloading. Currently, all predictors tested and used to develop the habitat suitability model as well as the habitat suitability model output are posted, with remaining connectivity layers to follow by May 1, 2021. Access to the group and data is limited to group members for now, but will become publicly available after project completion.

CBI has also created an easy to use tool and associated users’ guide document for updating the habitat suitability model in ArcMap when new vegetation layers become available. The model used three forest structure data layers, biomass, canopy cover, and tree density from the 2016 GNN dataset (LEMMA (Landscape Ecology, Modeling, Mapping, and Analysis) Lab, Oregon State University, https://lemmadownload.forestry.oregonstate.edu/). The Update Habitat Model Tool, a Model Builder Toolbox for ArcMap 10.6 assumes GNN data have been properly formatted (units, representation of no data, and adjustment for any scale factors used to minimize file size) before using.

The first series of tools process new GNN data layers for canopy cover, biomass, and tree density and create predictors for the marten habitat suitability model by smoothing layers with moving window statistics, extracting by mask to the area of interest, and adjusting layer minimum and maximum values (to account for MaxEnt process called ‘clamping’ by which predictors are constrained to remain within the range of values in the training data).

The second series of tools apply the complex model equations to the updated vegetation predictors (along with unchanged topographic predictors) to create a new habitat suitability layer reflecting the changed vegetation conditions. MaxEnt was run using 10-fold cross-validation (samples divided into replicate folds; each fold in turn used for test data), resulting in 10 replicates which are then averaged together to create the final habitat suitability layer. The model update tool will create the 10 replicate outputs, average them, and apply a land cover mask to convert the suitability value of low, medium, and high intensity development and open water (NLCD 2016) areas to 0.

Literature Cited

Bleyhl, B., M. Baumann, P. Griffiths, A. Heidelberg, K. Manvelyan, V.C. Radeloff, N. Zazanashvili, and T. Kuemmerle. 2017. Assessing landscape connectivity for large mammals in the Caucasus using Landsat 8 seasonal image composites. Remote Sensing of Environment 193: 193-203.

Cao, Y., R.E. DeWalt, J.L. Robinson, T. Tweddale, L. Hinz, and M. Pessino. 2013. Using MaxEnt to model the historic distributions of stonefly species in Illinois streams: The effects of regularization and threshold selections. Ecological Modelling 259: 30-39.

Hirzel, A.H., G. Le Lay, V. Helfer, C. Randin, and A. Guisan. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modeling 199: 142-152.

Keeley, A.T.H., P. Beier, and J.W. Gagnon. 2016. Estimating Landscape Resistance from Habitat Suitability: Effects of Data Source and Nonlinearities. Landscape Ecology 31 (9): 2151–62.

Liu, C., M. White, and G. Newell. 2013. Selecting thresholds for the prediction of species occurrence with presence-only data. Journal of Biogeography 40: 778-789.

Liu, C., G. Newell, and M. White. 2016. On the selection of thresholds for predicting species occurrence with presence-only data. Ecology and Evolution 6: 337-348.

McRae, B.H. 2012. Pinchpoint Mapper Connectivity Analysis Software. The Nature Conservancy.

McRae, B.H., B.G. Dickson, T.H. Keitt, and V.B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89:2712-2724.

McRae, B.H. and V. Shah. 2009. Circuitscape User Guide. University of California, Santa Barbara. http://www.circuitscape.org.

McRae B.H. and D.M. Kavanagh. 2011. Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle, WA. Available from http://www.circuitscape.org/linkagemapper.

Moriarty, K.M., C.W. Epps, and W.J. Zielinski. 2016. Forest thinning changes movement patterns and habitat use by Pacific marten. Journal of Wildlife Management 80(4): 621-633.

Peterson, A.T., J. Soberon, R.G. Pearson, R.P. Anderson, E. Martinez-Meyer, M. Nakamura, and M.B. Araujo. 2011. Ecological niches and geographic distributions. Princeton University Press, Princeton, NJ.

Spencer, W., J. Brice, D. DiPietro, J. Gallo, M. Reilly, and H. Romsos. 2019. *Habitat Connectivity for Fishers and Martens in the Klamath Basin Region of California and Oregon.* Conservation Biology Institute. https://doi.org/ 10.6084/m9.figshare.8411909

Figure 1. Pacific marten core habitat areas for habitat connectivity analysis (dark and light green).

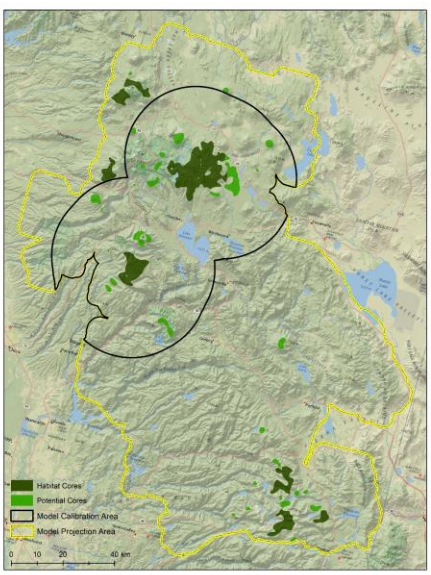


Figure 2. Reistance surface for marten habitat connectivity analysis.

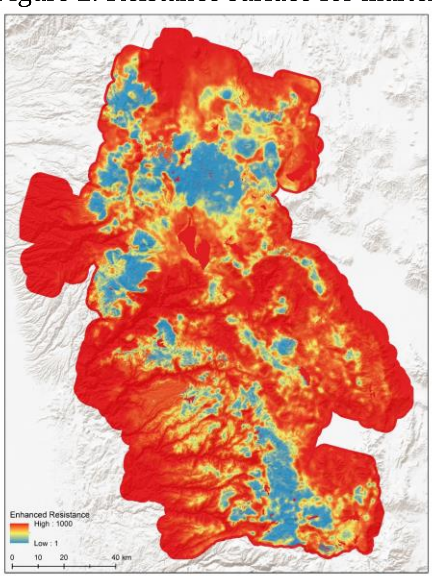


Figure 3. Pacific marten core habitat areas and least cost corridors.

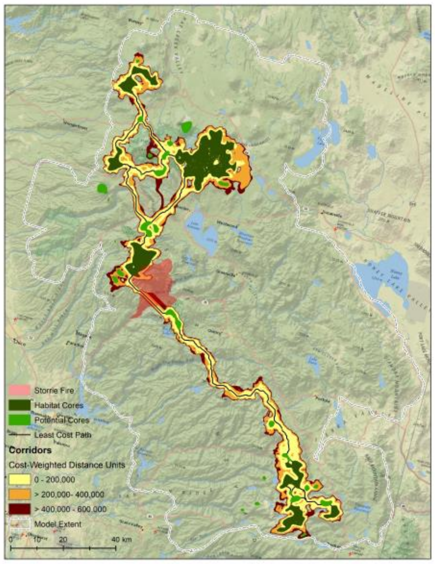


Figure 4. Pacific marten core habitat areas and current density within corridors. Higher values represent areas where corridors are more constricted.

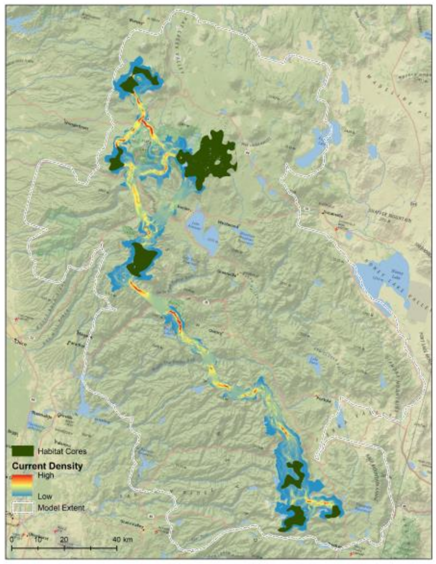
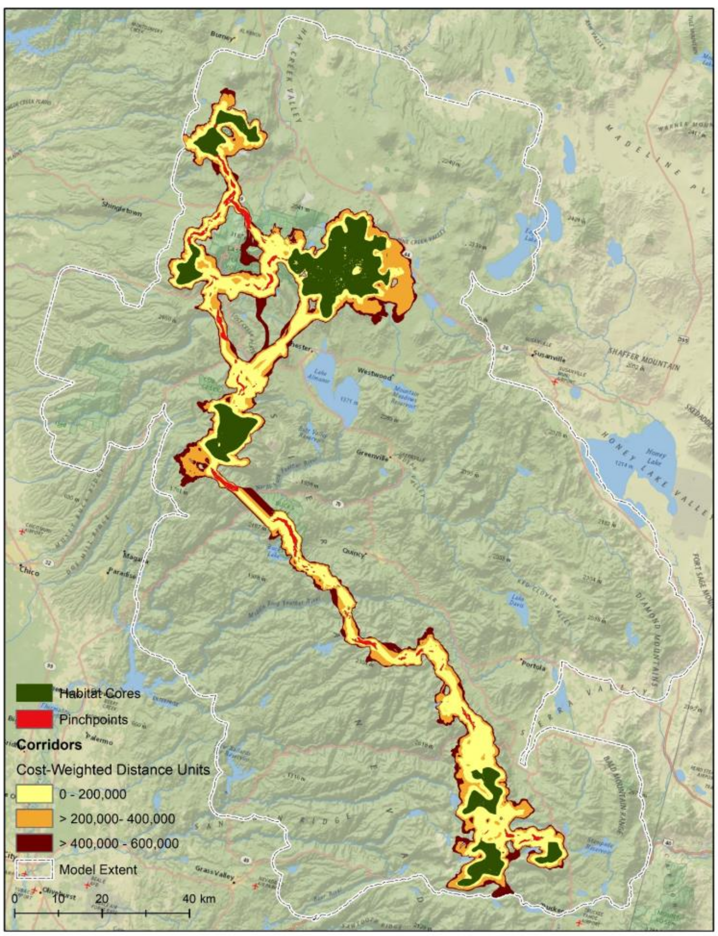


Figure 5. Pacific marten connectivity network in the Lassen region: core habitat areas (green), least cost corridors, and pinchpoints (red).



Activity 2: Field surveys to assess model predictive ability

Field research efforts occurred on the Almanor Ranger District of the Lassen National Forest (December 2018–May 2019, September 2019–January 2020). Field activities have consisted of live-trapping of martens to deploy GPS collars and remote camera surveys. Our first trapping effort occurred from January–March 2019. Trapping during our first effort began subsequent to the end of the government shutdown and ended approximately 4 weeks prior to expected marten parturition, in accordance with CDFW permitting requirements. Our second trapping effort occurred from September 2019–January 2020. At captures, we estimated age of martens and classified each individual as juvenile/young-of-the-year (< 1 year old), subadult/yearling (1-2 years old) and adult (> 2 years old), with the intent of placing GPS collars (Litetrack 20g and 30g, Lotek Inc.) on all juvenile martens captured and tracking them through the dispersal process. Martens are highly capable of long-distance movements, and during dispersal, juvenile martens appear more likely to travel through lower-quality predicted habitat than adult martens. GPS movement paths of juvenile martens may indicate travel corridors and connectivity between areas of higher-quality habitat. As the Storrie Fire burned within marten habitat and through areas of predicted connectivity between patches of habitat, juveniles may travel through fire boundaries during dispersal movements.

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Outcomes

Activity 1: Marten habitat suitability and connectivity modeling: completed (see above)
Activity 2: Field surveys to assess model predictive ability: completed (see above)

Challenges/Setbacks

We were delayed in receiving the grant, government shut downs, and the global pandemic. We have adjusted our timeline for both modeling and field research efforts accordingly.

We were awarded a no-cost extension to May 31, 2021.