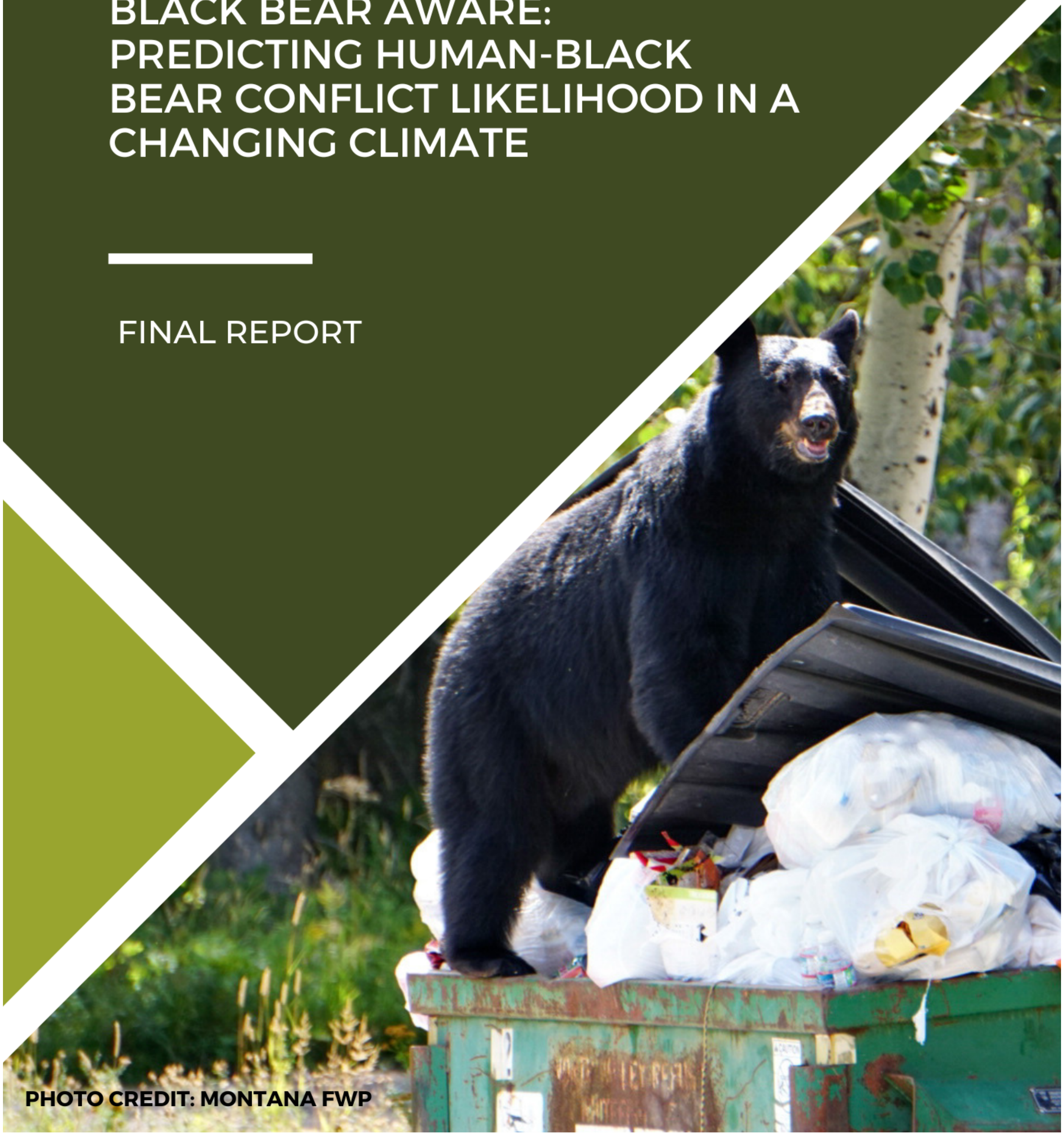
BLACK BEAR AWARE: PREDICTING HUMAN-BLACK BEAR CONFLICT LIKELIHOOD IN A CHANGING CLIMATE

FINAL REPORT



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CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

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ENVIRONMENTAL SCIENCE & MANAGEMENT
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Santa Barbara

Black Bear Aware:
Predicting Human-Black Bear Conflict Likelihood in a Changing Climate

A group project submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Science and Management
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Signature Page

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As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Sarah Anderson

Date

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Overview

Black Bears (*Ursus americanus*) are one of California's most charismatic, recognizable mammals. They are also a conflict-prone species, and human-bear conflict can lead to bear death, physical harm to humans, and damage to property. Conflict is typically characterized by bears utilizing human spaces and becoming habituated to easily accessible resources like trash, gardens, and chicken coops. These habituated bears, colloquially called "problem bears," often need to be relocated or euthanized to protect human property and safety. From 2016 to 2021, the California Department of Fish and Wildlife recorded 4,663 human-black bear conflict events, and between 2006 and 2018 3,430 depredation permits were issued to kill problem bears (CDFW). Resolutions that involve euthanasia are typically controversial with the general public, and alternatives such as relocation are costly and not always successful (Craven et al., 1998). Wildlife managers like the California Department of Fish and Wildlife can avoid costly and contentious mitigation efforts by proactively preventing conflict in regions where it is anticipated. They can also more effectively manage existing conflict if underserved communities can be identified for mitigation efforts. To efficiently implement these proactive measures, it is vital to establish a clear understanding of where conflict is likely to occur now and in the future. However, there is currently no tool that allows wildlife managers to estimate the likelihood of human-black bear conflict across California for more efficient management. Our project aims to develop a model to close this knowledge gap and provide CDFW with a tool to aid in black bear management efforts.

To create this model, we extended existing models of human-bear conflict with drought and fire extent and severity data and analyzed spatial data on suitable bear habitats and human settlement locations to develop a predictive model of human-black bear conflict. Drought and fire are included as they are climate change effects which may alter the resources and habitats available (and unavailable) to bears, thereby altering the spatial distribution of human-bear conflict.

We used this model to identify communities that may be currently under-reporting conflict, as well as communities that are likely to be prone to conflict in the future, to allow wildlife managers to more efficiently target current mitigation and anticipate where outreach efforts to human communities can prevent future conflict.

The primary objectives of the project are as follows:

1. Estimate a model of human-black bear conflict in California that incorporates the effects of fire and drought.
2. Predict future human-bear conflict on the basis of anticipated fire and drought conditions under climate scenarios.
3. Create a map of hotspots for current and future conflict-prone regions.

4. Identify locations to target management practices in order to effectively mitigate current conflict and prevent future conflict.
5. Create outreach materials to aid CDFW in educating identified at-risk communities

We found that communities currently under-reporting conflict are primarily located in the San Francisco Bay Area, particularly the southern Bay Area, and the southern coast between Long Beach and San Diego. Areas of under-reporting have a higher average proportion of historically underrepresented communities than areas of high reporting. We also found that conflict in the year 2030 shifts southward and slightly inland, with San Bernardino, Placer, San Diego, El Dorado, and Riverside Counties having the largest area of high conflict risk, in that order. A reduction in conflict risk is expected in northern California, and along the central coast near the Bay Area, while conflict is expected to be higher around the Sacramento area and the southern coast.

Background and Significance

Black bears and humans

Human-black bear conflict is characterized by humans and black bears coming into negative contact with one another (Belant et al., 2011). Conflict is most often caused by black bears pursuing human resources for food (Belant et al., 2011). The availability of garbage in urban areas presents an attractive, high-value, easy food source for bears, and this has led to an increase in black bear presence and instances of conflict with humans (Beckmann & Berger, 2003a). Other easy sources of food include gardens and chicken coops, and over time, bears can become habituated to moving through human-dominated spaces to access these resources (New Hampshire Fish and Game Department). In recent years media attention around black bear human conflict has become more prominent in the form of viral YouTube videos depicting incidents of conflict and even major motion pictures surrounding the topic (Banks, 2023; Coneley, 2021; Inside Edition; 2015). CDFW has a variety of management strategies in place for mitigating the effects of black bear conflict. Proactive measures include educating the public about behaviors that can prevent conflict events, like locking trash cans, securing livestock enclosures, and frightening bears away before they discover local resources. Others are more reactive, such as hazing, relocation, and euthanasia of bears. Euthanasia can be performed by CDFW, or by residents who are issued depredation permits to kill problem bears. Between 2006 and 2018, CDFW issued 3,430 such permits (CDFW). Relocation and euthanasia are more commonly used for particularly problematic or aggressive bears but are expensive and controversial with the general public (Witmer & Whittaker 2001; Heneghan & Morse, 2019). Despite being controversial, they remain common, largely because most management occurs after conflict with habituated bears has become an issue.

To identify conflict events, CDFW maintains an active reporting database (the Wildlife Incident Reporting System or WIR system) for the general public to report incidents of human-wildlife conflict. While this system is helpful for identifying communities that frequently report conflict, it does not allow for preventative measures. It is also an incomplete record of human-wildlife conflict in California, as we cannot assume that all conflicts will be reported to the WIR system. Under-reporting communities may not be receiving needed management interventions, which may be exacerbating the issue of problem bears. Current management techniques also do not account for the influence that climate change will have on black-bear human conflict. We focus on two specific climate effects here: fire and drought.

Wildfire Impacts

We hypothesize that wildfire-induced habitat destruction will alter bear behaviors in ways that increase human-bear conflict events. Changes in the spatial footprint and intensity of wildfires due to climate change will impact the distribution and intensity of these events. Wildfires can have a significant effect on the behavior and distribution of black bear populations (Bard & Cain, 2020; Cunningham, 2003; Cunningham & Ballard, 2019) because of habitat destruction and depletion of food sources (Cunningham, 2004). Black bears are primarily a forest-dwelling species, particularly preferring deciduous and coniferous forests (Garshelis et al., 2016). These forests are susceptible to the effects of wildfire, which can contribute to the death of important tree species (Bendix and Cowell, 2010; Borchert et al., 2002; Regelbrugge & Conard, 1993). Black bears will avoid severely burned areas (Stratman and Pelton, 2007; Crabb et al., 2022), and the destruction of vegetation from wildfires makes severely burned areas unsuitable for bedding and denning due to their high horizontal visibility (Bard & Cain, 2020). This habitat destruction also limits food resources for black bears. Black bears are omnivores, with a diet consisting of a combination of herbaceous vegetation, soft mast fruits, nuts, insects, fish, and mammals (Garshelis et al., 2016). The herbaceous vegetation that serves as a source of food for black bears has a higher-than-average ignition rate and is vulnerable to fire (Schwartz & Syphard, 2021). Loss of food sources increases conflict with black bears, as bears seek out urban areas during years when food is scarce (Baruch-Mordo et al., 2014). As bears' food sources are altered by wildfire events, they are likely to be driven toward urban centers in search of food.

Current research suggests that climate change is likely exacerbating wildfire impacts. Wildfires are expected to get larger, more severe, and more frequent in the future as climate change persists (Flannigan et al., 2000; Westerling et al., 2011). In northern California, wildfire-burned areas are predicted to increase by over 100% in many of the forested areas under several different climate projection scenarios (Westerling et al., 2011). These predicted trends are already being recorded; wildfires have been drastically increasing in both frequency and severity in California in recent years (Williams et al., 2019). 12 of the 20 largest wildfires in state history, and 15 of the 20 deadliest fires, have occurred since just 2015 ("Stats & Events," CalFire).

Drought Impacts

We also hypothesize that drought will have a significant impact on black bear-human conflict due to its impacts on food and water resources for black bears. Drought is characterized by prolonged periods of abnormally dry weather and lack of precipitation (Glossary of Meteorology, 1989). Unusually dry conditions have been found to increase human-black bear encounters, likely due to a lack of resources (Zack, Milne, & Dunn 2003). Drought directly reduces water availability for bears and can also lead to large-scale die-off of vegetation (Breshears et al., 2005). Many of the plant species that black bears eat are susceptible to being negatively affected by drought (Singer et al., 1989). For example, summer range grasslands were reduced by approximately 50% in Yellowstone as a result of drought impacts (Graber and White, 1983). This reduction of available food sources leads to a behavioral change in bears as they seek out new sources of food, which may lead to increases in conflict with humans (Baruch-Mordo et al., 2008; Zack et al., 2003).

As with wildfire, climate change is likely to exacerbate drought effects. Climate change is projected to cause shifts in precipitation patterns and evaporation rates, leading to more frequent and intense droughts in areas across California (Dai et al., 2018). Drought has been increasing in frequency and severity in California in recent years (Mann & Gleick, 2015), and drought conditions are expected to intensify in the near future in the absence of significant mitigation efforts (Cheung et al., 2016). Additionally, as temperatures rise, the demand for water resources is expected to increase, putting additional stress on water supplies and exacerbating drought conditions (Wang et al., 2016).

To develop a predictive model for human-black bear conflict in California that incorporates drought and fire, we adapted a model developed by Hagani et al. (2022) to predict human-black bear conflict in the Catskills region of New York. Hagani et al.'s model accounted for habitat suitability for black bears, biological relevance to black bears, and human influence. In this analysis, we replicate the Hagani et al. model within California, extend the model to incorporate fire and drought, and predict the possible impacts of climate change on the spatial distribution and intensity of human-black bear conflict.

Methods

Methodological foundation: Hagani et al. (2021)

Our model works to predict conflict probability given a changing climate. This study replicates and builds upon a paper by Hagani et al. (2021) which models human-black bear interactions in the Catskills region of New York. The Hagani et al. (2021) model predicts conflict likelihood using a set of environmental, landscape, and anthropogenic variables. Our study extends this model with the addition of climate variables, specifically fire and drought.

Hagani et al. used a resource selection probability function (RSPF) to model conflict. The RSPF is a common function in spatial ecology, often used to study large carnivore distribution, and evaluates how likely an animal or species is to use a resource unit based on environmental variables (Boyce et al., 2002; Hagani et al., 2021). Resource selection probability functions require use and availability data, as well as environmental variables that affect selection (Boyce et al., 2002). The RSPF function uses the given equation:

$$w(x) = \frac{\exp\left(\beta_0 + \beta_1 x_1 + \ldots \beta_n x_n\right)}{1 + \exp\left(\beta_0 + \beta_1 x_1 + \ldots \beta_n x_n\right)}$$

in which w(x) is the value of conflict at a location, x is the group of used covariates, and beta represents the parameters set by the model (Hagani et al., 2021).

Study area and data layers

To best inform state wildlife managers, our study was conducted for the entire state of California. We used conflict points from the California Department of Fish and Wildlife's (CDFW) online Wildlife Incident Reporting (WIR) system as our "use" data for the RSPF function. The general public can use this online database to report black bear interactions that fall into 4 categories: depredation, general nuisance, potential human conflict, or sightings. For this project, all reported types of interactions were treated as conflict, based on conversations with CDFW biologists. While a sighting may not indicate a direct conflict, reported sightings provide information about bears that are utilizing human spaces and are of sufficient concern to be reported to the state management agency. Reports from the WIR system include the latitude and longitude of the points and the date of the interaction, along with record numbers and the details of each event. The online WIR system has been active since 2016, and CDFW provided us with all WIR data from 2016 to February 2022. Over that time period, 4,663 human-black bear interactions were recorded. Conflict points were mapped, and erroneous points (i.e., those mislabeled as bear conflict or with incorrect geographic information) were removed from the data set. For the purposes of this analysis, we used conflict data through 2021.

To create our "availability" data, we buffered conflict points for each year by a 5 km radius as done by Hagani et al. (2021) due to the correspondence of that distance to typical black bear range (Wynn-Grant et al., 2018). We then randomly generated a sample of points from outside of these buffers equal to 5 times the number of conflict reports for that year. These were designated as non-conflict points, and were assigned a value of 0, while conflict points were assigned a value of 1.

For the environmental data required by the RSPF, we used rasters of environmental variables identified by Hagani et al. (2021) and our selected climate variables, fire and drought. The 12 environmental variables identified by Hagani et al. (2021) were: elevation, aspect, terrain ruggedness, human population density, land cover, road density, distance to roads, distance to streams, distance to urban areas, distance to recreation areas, distance to forest cover, and forest density. Distance layers were created in ArcGIS Pro using the Euclidean Distance tool. Land cover was reclassified from sixteen categories to twelve, using the classify function in the terra package in R, in order to reduce unnecessary categories. The road density layer was also created in ArcGIS Pro using the Line Density Spatial Analyst tool.

We obtained fire rasters from the Monitoring Trends in Burn Severity (MTBS) Agency, which tracks the severity and location of fires nationwide. These raster layers categorize fire severity on a scale of 0 (no fire) to 4 (high-intensity fire). We chose to keep only data about medium or high-intensity burns (3 or 4 on the intensity scale) due to the established effects of more severe fires on black bear behavior (Stratman & Peloton, 2007; Bard & Cain, 2020; Crabb et al., 2022). We created annual distance rasters that measured distance to fires 1 year prior to the year of a conflict, 2 to 3 years prior, and 4 to 5 years prior. 1-year post-fire results in little to no available vegetation necessary for bears among other wildlife to survive (Stratman & Pelton., 2007). The following years, 2-3, account for the necessary regrowth resulting in bears returning 4-5 years later to the burned area (Cerdá & Doer, 2005; Eby et al., 2014; Fredriksson et al., 2007).

We obtained shapefiles of weekly drought data for 2016 through 2021 from the US Drought Monitor (USDM), which measures drought on a scale of 0 to 4. These categories include abnormally dry (0, shows areas that may be going into or are coming out of drought), and four levels of drought: moderate (1), severe (2), extreme (3), exceptional (4) (NIDIS, 2022). The 0-4 severity-based scale is derived from the Palmer Drought Severity Index which measures drought on the basis of precipitation, temperature, soil characteristics, and evapotranspiration (NIDIS, 2022). Soil characteristics are specific to available water content, soil texture, and soil depth (Palmer, 1965). Shapefiles were converted to rasters, and values were averaged by year to produce rasters of the mean annual Palmer Drought Severity Index measure in a given area.

All data layers were converted to rasters if not already in that format, set to a 230-meter resolution, and reprojected to the NAD83 California Albers (2011) coordinate reference system (EPSG 6414) using the project function in terra. A shapefile of California from the TIGER database was converted to a raster using the rasterize function in terra, and used as the reference layer for all reprojections. This layer was also used to mask all data layers to the same extent, -380101.0666, 540047.238885548, -605327.054, 450346.970898149 (xmin, xmax, ymin, ymax). Data sources can be found in **Appendix Table 4**.

To prepare data for use in the RSPF model, environmental and climate rasters were stacked for each year using the terra package and the value of each variable was extracted at a given conflict or non-conflict point for that year, yielding a data frame. Where data for a given year were not available, the most recent year was used. For example, since no land cover data was available for 2017, we used the 2016 land cover data to model 2017 conflict. Due to this, there is some temporal mismatch between our conflict data and predictors. Yearly data frames were then merged to create a final data set that could be used within the rspf model function.

Model selection

Because high collinearity between independent variables can make the interpretation of model coefficients inaccurate and make the model overly sensitive to small changes in the data (Dormann et al., 2012), we assessed the correlation between covariates using the cor function in R prior to model creation. We adopted the Hagani et al.'s (2021) collinearity cutoffs for R^2 values above 0.7 or below -0.7. As none of our variables were beyond the acceptable collinearity threshold, all variables were retained. We then generated our models using the "rspf" function in the ResourceSelection package in R. We generated six potential "base" models (models that did not include fire or drought variables) as shown in **Table 1**; one included all "base" environmental variables, and the remaining five were identified by Hagani et al. (2021) as the most parsimonious models for predicting human-black bear conflict.

We used AIC values, which are commonly used to determine model quality (Burnham et al., 2011), to rank the base models. Of our base model options, Model 3 had the lowest AIC (**Table 1**). This model included 8 covariates: elevation, land cover, distance to forests, population density, distance to recreational areas, distance to streams, terrain ruggedness, and distance to urban areas (**Table 1)**.

Table 1. The six base models (excluding fire and drought variables) for human-black bear conflict probability in California. Models 1 through 5 were identified by Hagani et al. (2021) modeling human-black bear conflict in the Catskills. The most parsimonious model, model 3, is bolded.

	Model	**AIC**
All Variables	elevation + aspect + forest density + land cover + distance to forests + population density + distance to recreational areas + distance to streams + terrain ruggedness + road density + distance to urban areas + distance to roads	76615.45
1	elevation + land cover + distance to forests + population density + distance to recreational areas + road density + distance to urban areas	76984.38
2	elevation + forest density + land cover + distance to forests + population density + distance to recreational areas + road density + distance to urban areas	77861.75
3	**elevation + land cover + distance to forests + population density + distance to recreational areas + distance to streams + terrain ruggedness + distance to urban areas**	**76414.62**

4	elevation + forest density + land cover + distance to forests + population density + distance to recreational areas + distance to streams + distance to urban areas	78765.23
5	elevation + land cover + distance to forests + population density + distance to streams + terrain ruggedness + distance to urban areas	77071.41

After we determined our most parsimonious model, we expanded the model to include our climate variables for fire and drought. When compared to the base model (without climate variables), the model with drought and wildfire variables had an AIC that was lower by 4258.59 points, suggesting that the inclusion of the climate variables improves the fit of the model and that these variables are relevant indicators of conflict risk with black bears. Values for model coefficients and standard errors can also be found in **Appendix Table 5**.

We ran several robustness checks on our climate model to ensure we selected the best-fit model. These included 1) log-transforming population density and forest density, 2) including a squared population density term, 3) sampling non-conflict points only from within California's Wildland Urban Interface, 4) omitting bear sightings from conflict points, and 5) omitting distance to recreational areas. More information about the AICs of our robustness checks is available in **Appendix Table 1**. After running these checks, the model including a squared population density term was the only model with a significantly lower AIC than our selected model (model 3 + climate variables). As such, we opted to add this term into our final model. The variables selected for our final, best-fit model are displayed in **Figure 1**. Variables in the blue, green, and gray boxes were selected by Hagani et al. (2021) due to being often used in conflict or species distribution modeling, biologically relevant to black bears, or important for predicting human influence, respectively.

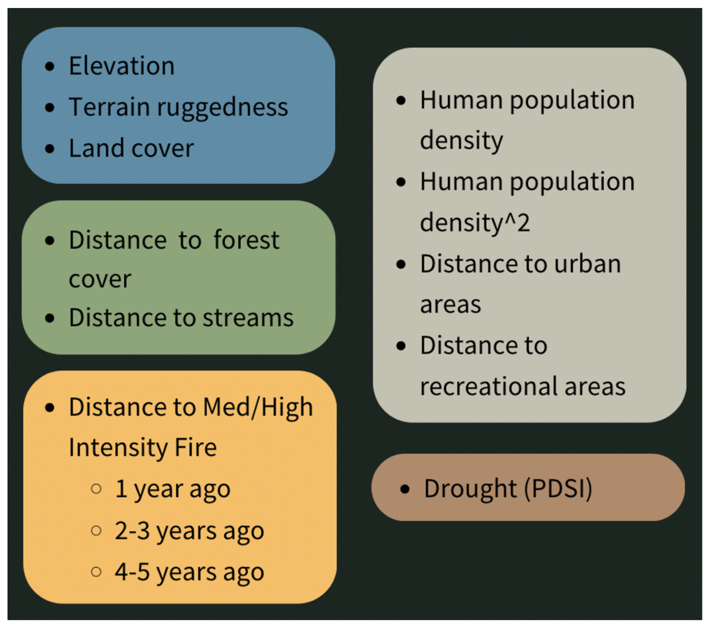

Figure 1. Model variables for our final resource selection probability function. This model predicts conflict risk with black bears throughout the state of California.

Current Conflict and Demographic Analysis

After model selection, we used the predict function in the terra package to develop a heatmap of conflict risk across California under current environmental and climate conditions, and overlaid WIR reporting points to identify areas of potential underreporting.

To analyze social factors affecting potential areas of underreporting, we ran several two-tailed t-tests to analyze the demographic differences between areas of high conflict with no reporting and areas of high conflict with reporting. High-conflict regions were defined as areas with a conflict risk greater than 70% (0.7). We buffered reported conflict points by a 5 km radius to establish regions of high conflict with reporting. Regions of high conflict with no reporting were those regions of high conflict outside of this buffer. We found the average population density of households within various ethnic and racial groups in both reporting and non-reporting regions. The population density data was drawn from Depsky et al. (2020) who developed high-resolution estimates of California's sociodemographics using 2020 census data. We ran two-tailed t-tests between the means of each of these demographic values in reporting versus non-reporting regions to determine if there was a statistically significant difference.

In addition, we also found the average social vulnerability index in both high conflict, reporting, and high conflict, non-reporting regions (i.e., underreporting regions). Social vulnerability index data was drawn from the Socioeconomic Data and Applications Center (SEDAC) which is part of NASA's Earth Observing System Data and Information System (EOSDIS). Social vulnerability index is measured on a scale of 0-1 and was developed by the Center for Diseases Control to measure vulnerability based on four factors - socioeconomic status, household composition & disability, minority status & language, and housing & transportation (Flanagan et al., 2018). We once again ran a two-tailed t-test to determine if there was a statistically significant difference in vulnerability between reporting and non-reporting communities.

Climate projections

To examine the impacts of climate change on conflict risk, we created a heatmap to display predicted conflict risk in the year 2030. Predicted drought conditions in 2030 were projected under representative concentration pathway (RCP) 4.5. This RCP is a moderate future emission scenario where greenhouse gas and aerosols reach their highest point in the year 2040, and then begin to decline (Cal-Adapt). Due to data availability constraints, projected wildfire data was modeled under RCP 8.5, which is considered the highest emissions scenario based upon assumptions including modest rates of technological change and energy intensity improvements, high population values, limited income growth, and limited change in climate policies (Riahi et al., 2011). However, RCP 4.5 and RCP 8.5 do not differ substantially for projections before 2050, and therefore we feel confident using this data for our analysis (Governor's Office of Planning and Research, 2018; Pierce et al., 2018).

The projected drought data was obtained by calculating the Palmer Drought Severity Index using projected values of precipitation and evapotranspiration in California from the Cal-Adapt database (Cal-Adapt). Initial values for precipitation and evapotranspiration were chosen for the month of January before being input into the PDSI equation as January represents the wettest of the early months within a year. This was important as January's precipitation and evapotranspiration values would be used to determine projected annual Palmer Drought Severity Index Values ("Current Results", 2023). We converted precipitation and evapotranspiration rasters to data frames and used the scPDSI package in R studio to calculate the PDSI value for each pixel. The data frame was then converted back into a spatial raster for use in the model. Projected wildfire data was obtained from Isaac Park based on his Generalized Additive Model for fire projection in California (Park et al., 2021). We kept fire probabilities above 0.003, which represents the upper half of fire probabilities.

Results

Human-Black Bear Conflicts

There is a substantial social component to any conflict data. Because "conflict" itself is defined by the person reporting it, it is often subjective — a sighting may be distressing enough for one person to define as conflict, while another might only report property damage or other, more drastic occurrences. Discussion with California Department of Fish and Wildlife biologists suggests many conflicts won't be reported at all.

Human-black bear conflict recorded in the WIR database is sorted into four types: depredation, general nuisance, potential human conflict, and sighting. These four conflict types are not clearly defined, and the type of conflict is often determined by the person who recorded the report or CDFW biologists, so there is a lack of consistency in sorting incidents into conflict types. For instance, general nuisance and potential human conflict tend to denote bear presence that is making community members uncomfortable, but the exact behavior of bears is not well sorted between these types. The depredation and sighting interaction types are the most well-defined, with depredation generally meaning some type of property damage by a bear has occurred, and sighting denoting presence without any negative behavior by the bear. If a California resident wants to receive a depredation permit to kill a destructive bear, they must first record the depredation in the WIR system, which can skew reporting towards higher depredation records. From 2016 to 2021, there were 4595 human-black bear interactions recorded. Of the 4595 reports, 59.2% (2718) were depredation, 24.2% (1110) were general nuisance, 11.2% (515) were potential human conflict, and 5.5% (252) were sightings. **Figure 2** below displays human-black bear conflict reports made to the WIR system from 2016 to 2021. Because the WIR system was launched in 2016, it is possible that the increase in conflict reports from 2016 to 2021 represents a wider knowledge of the WIR reporting system, rather than representing an actual increase in human-black bear conflicts. **Figure 3** below displays all recorded WIR human-black bear conflict counts by month. There is a clear seasonal variance, with July, August, and September having the highest number of conflict reports.

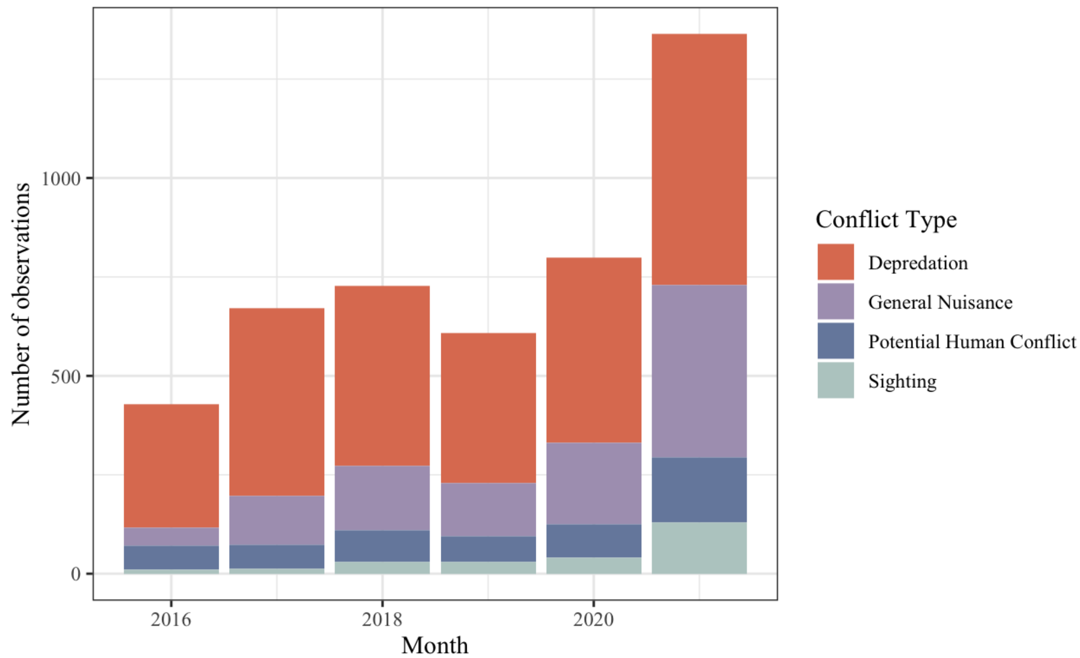

Figure 2. Counts of human-black bear conflict across California as recorded by the California Department of Fish and Wildlife (CDFW) from 2016 to 2021. Over that time period, 4,663 human-black bear interactions were recorded.

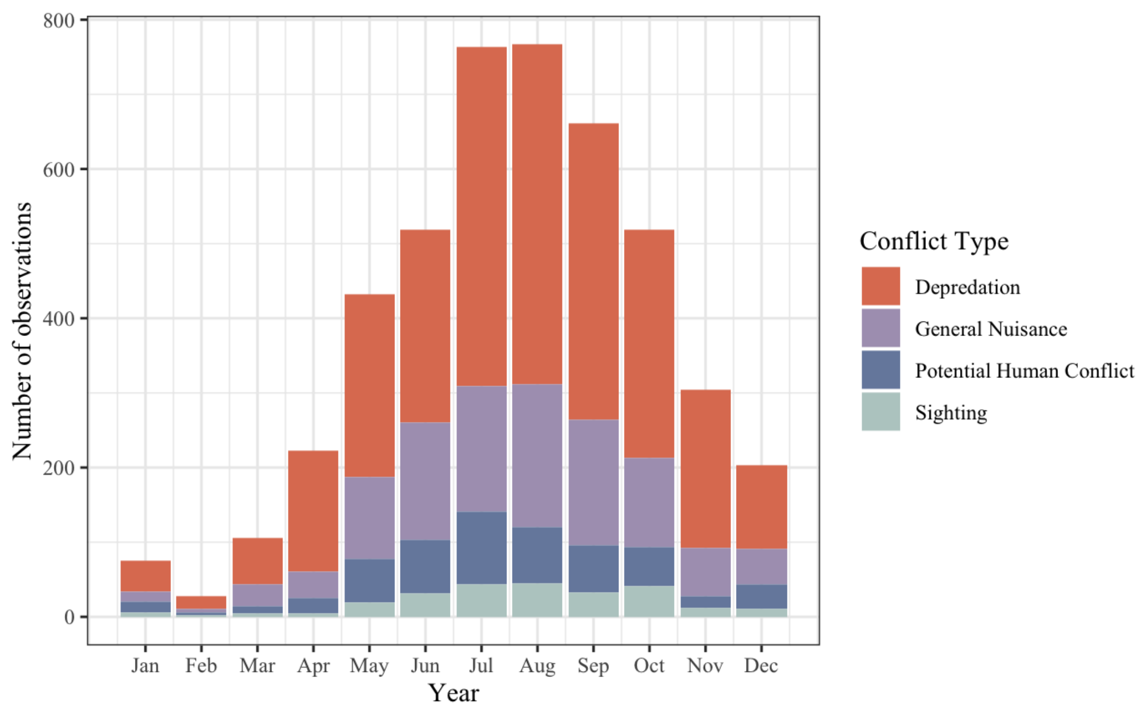

Figure 3. Counts of human-black bear conflict across California as recorded by the California Department of Fish and Wildlife (CDFW) from 2016 to 2021, displayed by month. Over that time period, 4,663 human-black bear interactions were recorded.

Model coefficients

All covariates except for open water and the intercept are significantly correlated with human-black bear conflict risk ($p < 0.05$). With the exception of land cover classes that are not perennial ice and snow, elevation, and human population density, all covariates are negatively correlated with conflict risk, indicating that as those variables increase, the log-likelihood of conflict decreases.

Distance from fire is negatively correlated with conflict risk. Moving one kilometer further from a fire burn scar decreases the odds of conflict by 0.38% for fires one year ago, 1.39% for fires two to three years ago, and 1.28% for fires four to five years ago (**Figure 2**). This can be thought about as closeness to fire: for every kilometer closer an area of land is to a medium or high-intensity fire burn scar, the odds of conflict in that area increased by 0.38% for burn scars from fires one year ago, 1.39% for fires two to three years ago, and 1.28% for fires four to five years ago. Time since the fire plays a role here, with fires two to three years ago having the strongest effect, followed by fires 4 to 5 years ago, and then fires one year ago. These differences suggest that for three land parcels equidistant to a fire, the parcel near a fire that happened two to three years ago would have the strongest increase in conflict risk, followed by the parcel near a fire 4 to 5 years ago and then a parcel one year ago.

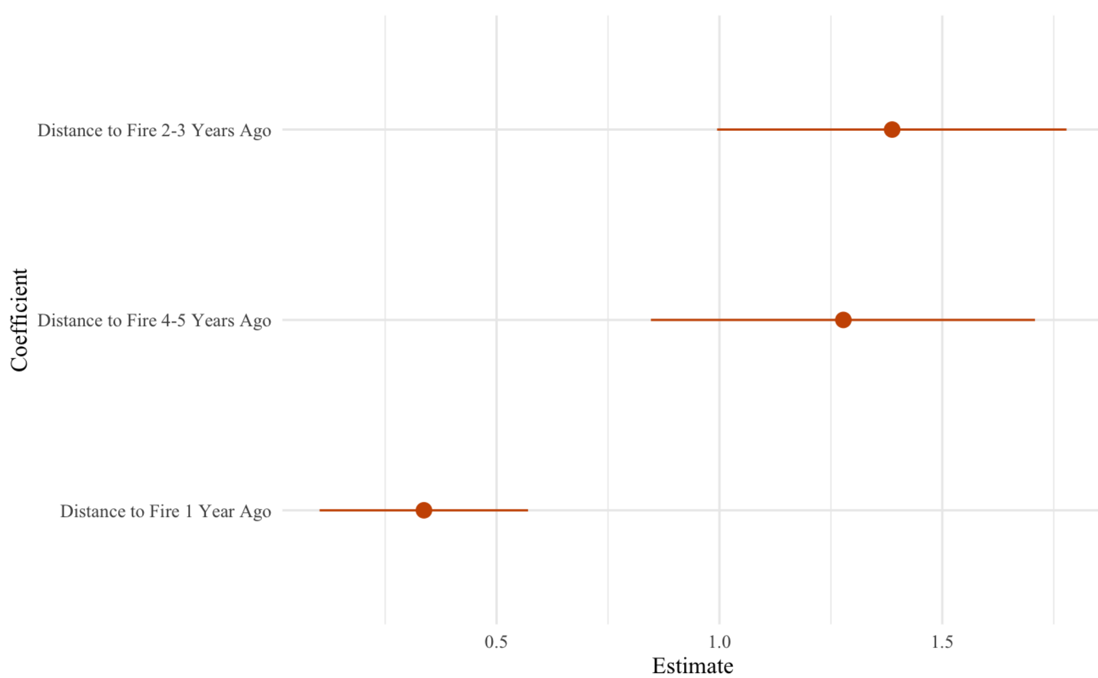

Figure 4. Transformed coefficients for a logistic regression function displaying the percentage change in the odds of human-black bear conflict for a 1 km increase in distance to fire, with a 95% confidence interval. Coefficients were estimated using a resource selection probability function.

Drought was also negatively correlated with the log-likelihood of conflict, indicating that areas of more intense drought had reduced conflict, or conversely that where water is more available, conflict is more likely. When the coefficient was transformed to show the effects of drought on the odds of conflict occurring, moving one class up on the Palmer Drought Severity Index decreased the odds of conflict by 15.95%.

Coefficients on land cover, with the exception of perennial ice and snow (uncommon in California), were positive, indicating a greater likelihood of conflict in most types of land cover relative to barren ground, the omitted reference category. When coefficients were transformed to show the effects of land cover on the odds of conflict occurring (relative to a reference land cover type of barren ground), low-intensity development had the most substantial effect on conflict probability, followed by developed open space (**Figure 3**). Low-intensity development has 2434.94% higher odds of conflict than barren ground, and developed open space has 1464.26% higher odds of conflict than barren ground. It is notable that the land cover types that most increase the odds of conflict are developed land cover classes and forest, with low intensity development and developed open space increasing the odds of conflict more than medium intensity or high intensity development.

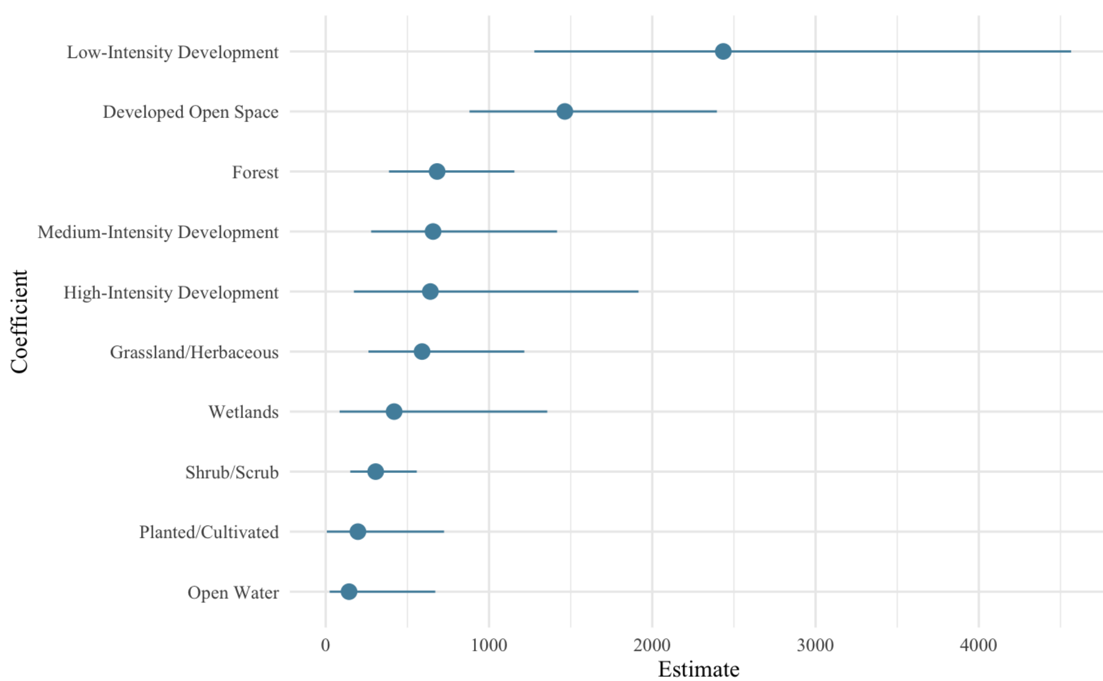

Figure 5. Transformed coefficients for a logistic regression function displaying the percentage change in the odds of human-black bear conflict by land cover type relative to barren ground, with a 95% confidence interval. Coefficients were estimated using a resource selection probability function. Perennial ice and snow is omitted here. It is negatively correlated with conflict and has a transformed coefficient of 99.95, indicating a 99.95% decrease in the odds of conflict relative to barren ground with a 95% CI of [99.29%, 100%].

All variables chosen to examine distribution of human influence were negatively correlated with conflict, with the exception of population density. Distance to urban areas had the strongest correlation with the odds of conflict, followed by population density and distance to recreational areas. An increase of one person per 52943.53 square meters increases the odds of conflict by 23.25%, moving 1 km farther from an urban area decreases the odds of conflict by 72.82%, and moving 1 km farther from a recreational area decreases the odds of conflict by 4.42% (**Figure 4**). This can be thought of conversely as moving closer to an urban area or recreational area will increase the odds of conflict by 72.82% and 4.42%, respectively. The population density coefficient suggests that as human populations increase, the likelihood of conflict also increases. However, due to the inclusion of population density squared as a variable, the relationship of population density and conflict risk may be best represented by a marginal effects plot (**Figure 5)** which shows the parabolic relationship between these two variables.

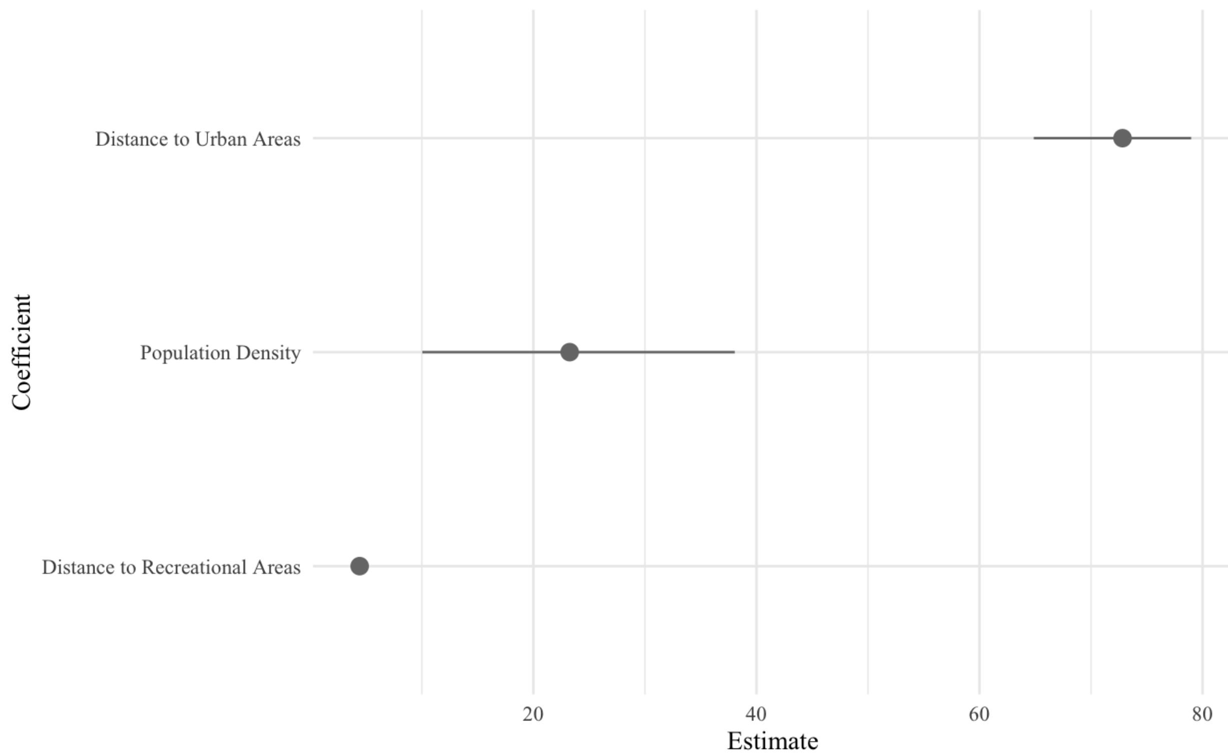

Figure 6. Transformed coefficients for a logistic regression function displaying the percentage effect of human impact covariates on the odds of human-black bear conflict, with a 95% confidence interval.CI for distance to recreational areas is not visible here but is [3.98%, 4.86%].

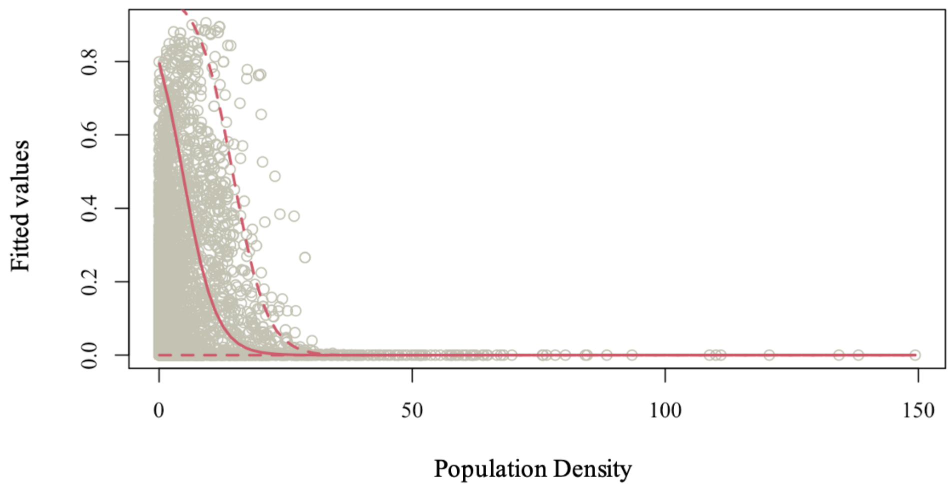

Figure 7. Marginal effects plot for the effect of population density on human-black bear conflict likelihood under a resource selection probability function.

Elevation was positively correlated with conflict risk, and each 1 km increase in elevation increased the odds of conflict by 166.28%. Terrain ruggedness was negatively correlated with conflict risk, with each one unit increase in the TRI (terrain ruggedness index) decreasing the odds of conflict by 5.27%. Distance to forest cover and distance to streams, both selected due to their biological relevance to black bear habitat, were both negatively correlated with conflict risk. Moving 1 km away from forest cover decreased the odds of conflict by 48.37%, and moving 1 km away from streams decreased the odds of conflict by 58.76%. Conversely, we can think of this as moving 1 km closer to forest or streams would increase the odds of conflict by 48.37% and 58.76%, respectively.

Current Modeled Conflict Risk

The model of current-day conflict risk shows areas of high risk throughout the Sierra Nevada mountains, northern California, and along the coast. Coastal areas of high conflict include the central coast near San Francisco Bay and the southern coast from Santa Barbara to San Diego (**Figure 8**). The Inland Deserts and North Central administrative regions of CDFW have the largest area of high conflict risk (i.e., conflict risk over 70 percent) under current conditions.
In regions identified as high conflict risk in California, we analyzed the land ownership type, as this will influence CDFW's management strategies. Land ownership fell into seven categories: city, county, federal, non-profit, special district, state, and private. We found that private land made up 75% of the total land included in the high-conflict risk regions, with federal land coming in second with 20% of the total land included in the high-conflict risk regions. All other categories made up the remaining 5% of high-conflict risk regions. **Appendix Table 2** displays all categories with respective percentage of area.

Figure 9 displays modeled black bear conflict risk throughout California, overlaid with black bear conflict reports from the WIR system. The San Francisco Bay Area, particularly the southern Bay Area, has high predicted conflict probability but low report numbers. The same is true of the southern coast, between Long Beach and San Diego. We conducted a difference of means analysis (**Table 2**) to determine if there were statistically significant differences between the demographics of underreporting regions and other high conflict regions. Our analysis indicated that there was a significantly higher average social vulnerability in underreported regions compared to reporting areas ($p < 0.05$). Additionally, there was a significantly higher average number of households with historically underrepresented ethnic backgrounds (Hispanic, Non-Hispanic Black, Non-Hispanic Asian, Non-Hispanic Native Hawian and Other Pacific Islander, Non-Hispanic White, and American Indian and Alaska Native) in underreporting regions compared to areas where there is reporting occurring ($p < 0.05$).

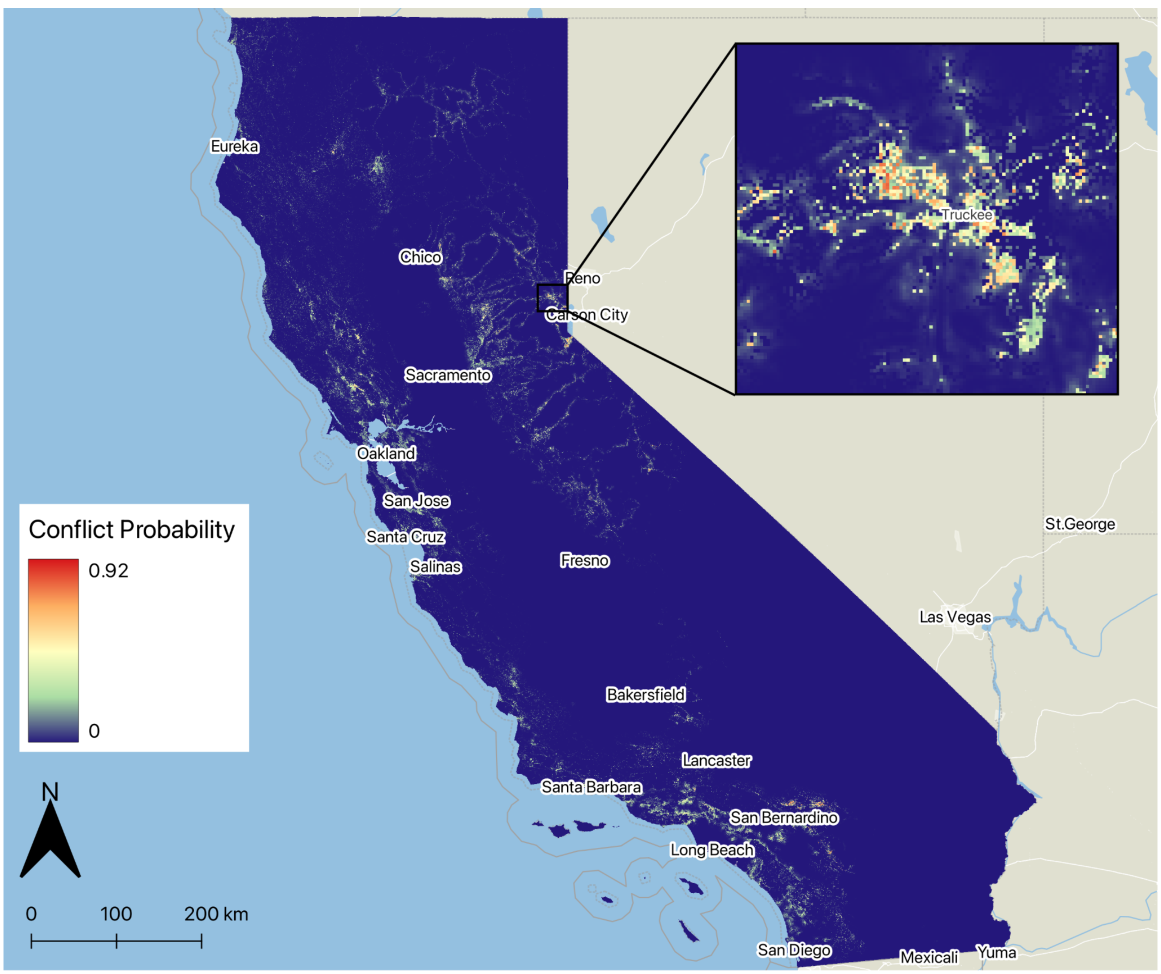

Figure 8. Modeled human-black bear conflict in the state of California under current conditions. A predictive map of human-black bear conflict based on a resource selection probability model, displaying modeled conflict probability as a function of the most recently available environmental, fire, and drought data.

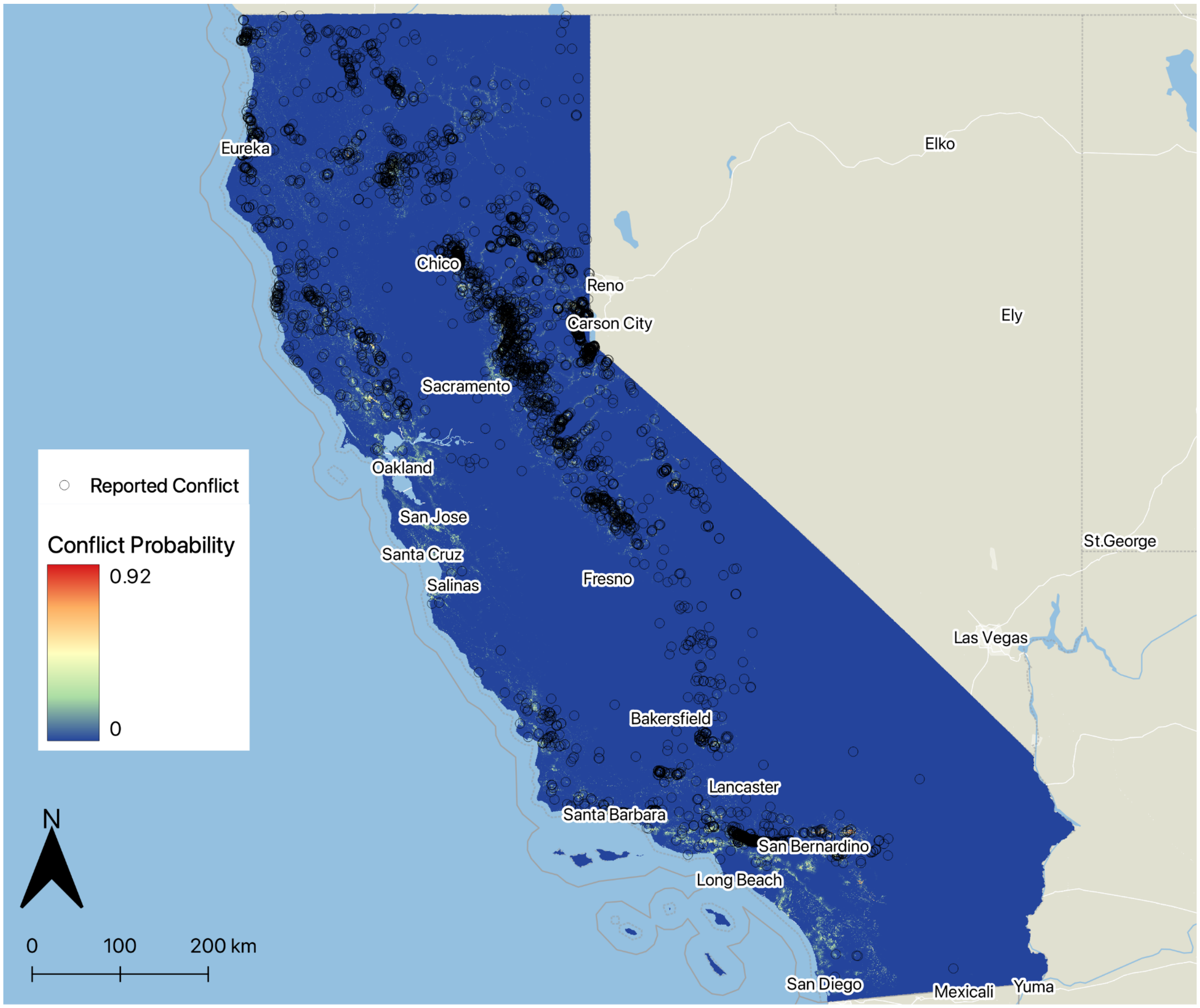

Figure 9. Modeled human-black bear conflict in the state of California under current conditions overlaid with conflict reports from the Wildlife Incident reporting (WIR) system. Conflict probability is modeled as a function of the most recently available environmental, fire, and drought data, using a new resource selection probability model.

Table 2. Average population density (people/10000m^2) and social vulnerability index in high conflict regions with reporting vs, no reporting. Social vulnerability index (SVI) is measured on a 0-1 scale, with a higher number indicating a higher level of social vulnerability. There is a statistically significant difference ($p<0.05$) between high conflict, reporting regions and high conflict, no reporting regions for several racial and ethnic groups tested. There is a statistically significant difference ($p<0.05$) in SVI between high conflict, reporting regions and high conflict, no reporting regions.

Ethnic or Racial Group	Region		p value
	High Conflict, Reporting	High Conflict, No Reporting	
Hispanic	1.936476	1.63793	0.04961954
Non-Hispanic Black	0.06228506	0.1616677	0.0006943373
Non-Hispanic Asian	0.187453	0.2852263	0.07275465
Non-Hispanic Native Hawian and Other Pacific Islander	0.01253714	0.01362763	0.7993745
Non-Hispanic White	5.844748	4.106572	5.339204e-19
American Indian and Alaska Native	0.3629799	0.260228	0.0002210685
Social Vulnerability Index	0.3341526	0.4884646	2.24324e-22

Projected Conflict Risk and Conflict Risk Change

When climate variables (drought and fire) were projected out to the year 2030 using the RCP 4.5 climate scenario, conflict risk became much higher around the Sacramento area and the southern coast, and became much lower throughout northern California communities and around the San Francisco Bay Area, while total conflict increased overall (**Figure 10**). **Figure 11** displays the change in conflict risk from baseline (current) model predictions to our 2030 model predictions. The largest and most clear area of increasing conflict is just north of Sacramento. Increasing conflict is also predicted along the southern coast between Santa Barbara and San Diego and inland toward San Bernardino. The top 5 counties with the largest projected area of high conflict risk are San Bernardino, Placer, San Diego, El Dorado, and Riverside, in that order. These counties are primarily governed by CDFW Regions 5 and 6 (South Coast and Inland Deserts Regions, respectively), but Placer and El Dorado counties are within Region 2 (North Central

Region) (**Figure 12**). **Table 3** shows the top 5 counties, metropolitan statistical areas, and CDFW administrative regions with the highest average projected conflict risk.

In regions identified as high conflict risk (i.e., conflict risk over 70 percent) in California under our projected 2030 conditions, we analyzed the land ownership type, as this will influence CDFW's management strategies. Land ownership fell into seven categories: city, county, federal, non-profit, special district, state, and private. We found that private land made up the majority (71%) of the total land included in the high-conflict risk regions, with federal land coming in second, containing 22% of high-conflict risk area. All other categories made up the remaining 6% of high-conflict risk regions. **Appendix Table 3** displays all categories with respective areas in km^2 and percentages of area.

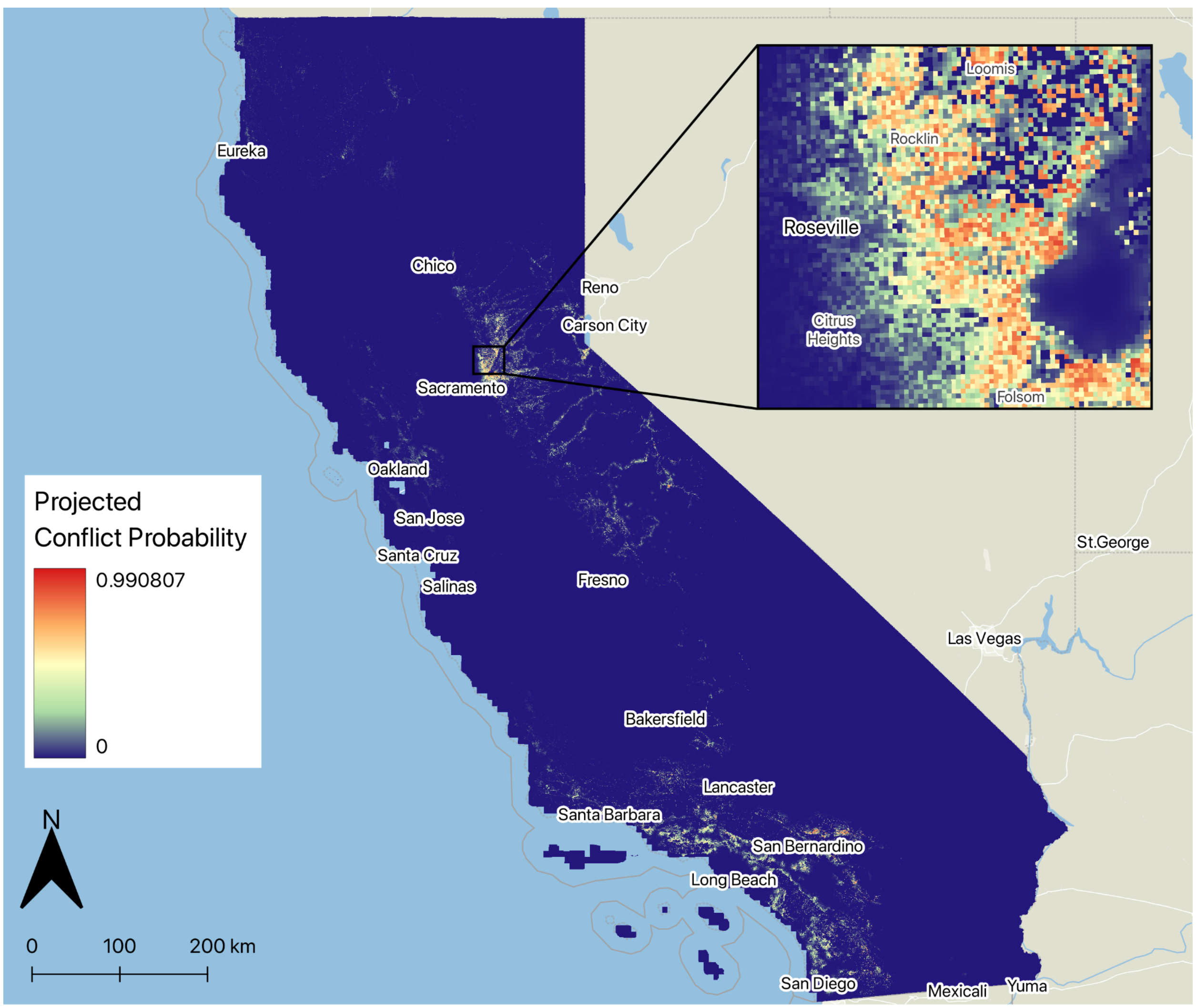

Figure 10. Modeled human-black bear conflict in the state of California under projected climate conditions. A predictive map of human-black bear conflict based on a resource selection

probability model, displaying modeled conflict probability as a function of environmental, fire, and drought data. Fire and drought were projected out to the year 2030 under the RCP 4.5 scenario.

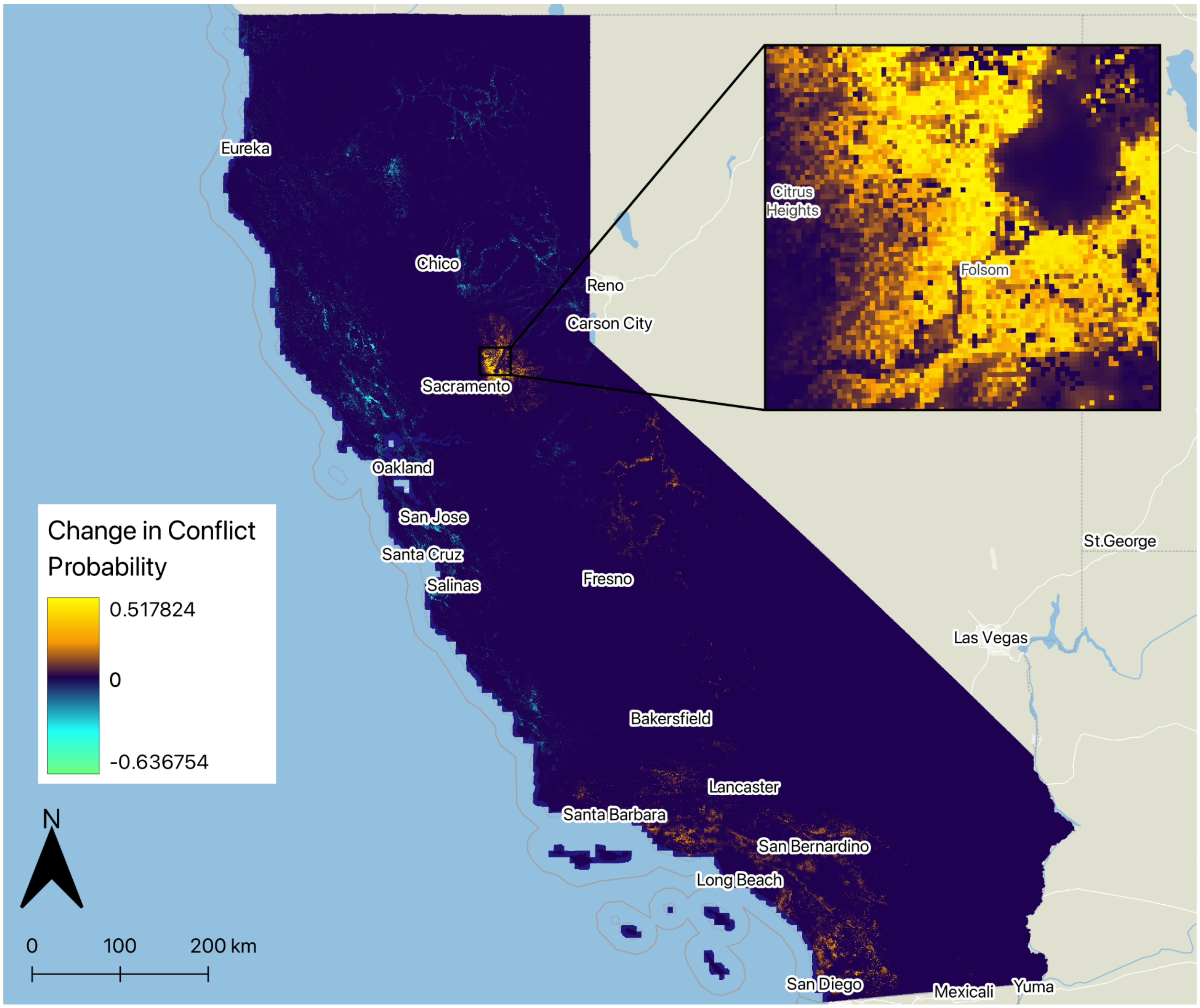

Figure 11. Chance in modeled human-black bear conflict probability in the state of California from current-day baseline to 2030. Conflict risk was predicted by a resource selection probability model, as a function of environmental, fire, and drought data. Fire and drought were projected out to the year 2030 under the RCP 4.5 scenario, and baseline (current-day) conflict risk was subtracted from projected conflict risk.

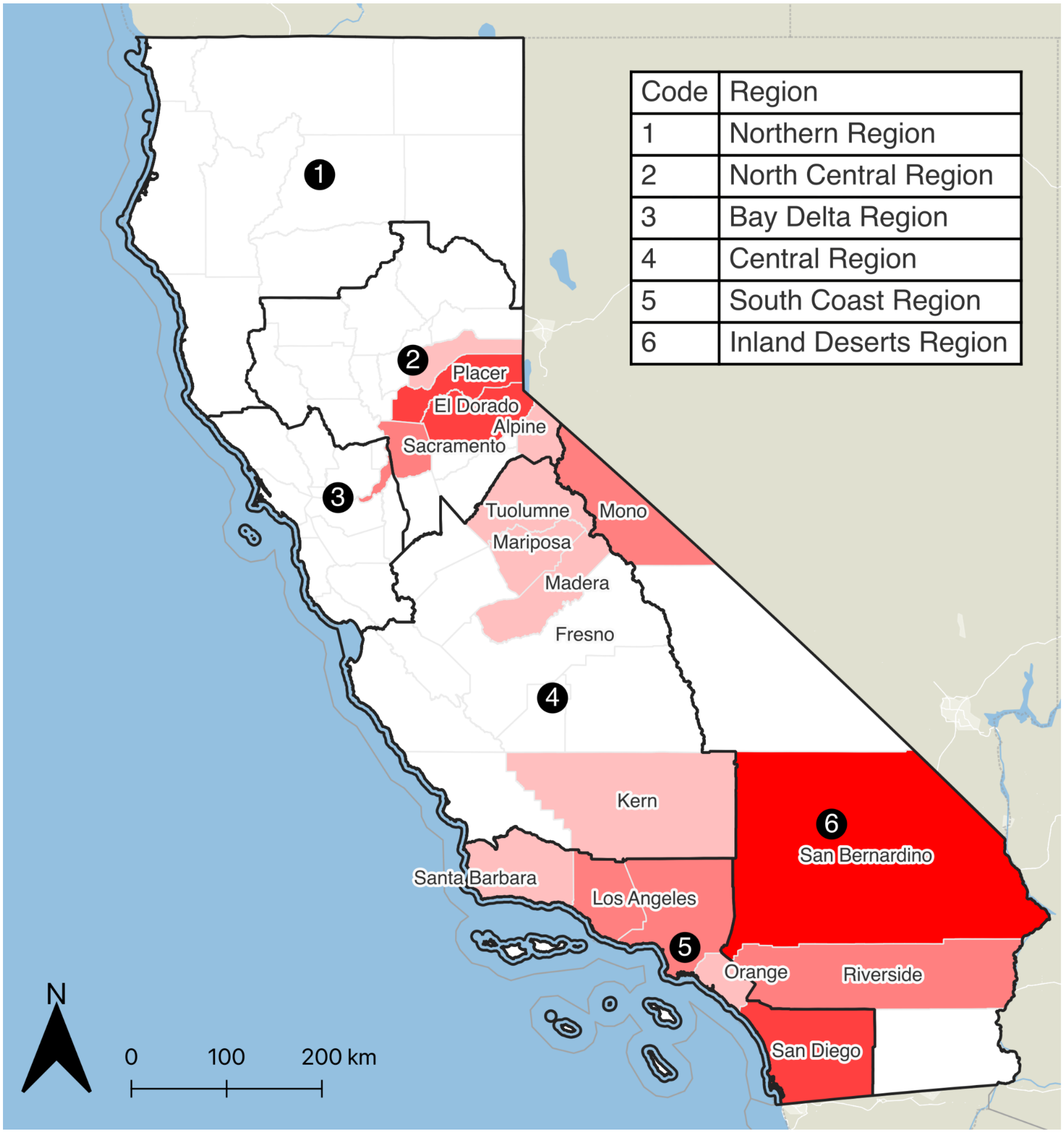

Figure 12. Counties and CDFW regions with the largest area of high projected human-black bear conflict risk in 2030. Area of high conflict risk (70% or higher probability of conflict) was calculated for each county. Counties with larger areas of high conflict risk are darker red; counties with the smallest area of high conflict risk are in pale pink. The top 5 counties with the largest area of high conflict risk are San Bernardino, Placer, San Diego, El Dorado, and Riverside, in that order. California Department of Fish and Wildlife administrative regions are overlaid for reference, excluding the Marine Region (Region 7).

Table 3. Top 5 counties, metropolitan statistical areas, and CDFW regions with the highest mean projected human-black bear conflict risk in 2030. Conflict risk is evaluated here as the probability of conflict occurrence; mean probabilities are in parentheses for reference.

Ranking	County	Metropolitan Statistical Area	CDFW Region
1	Placer (0.046)	Orange (0.044)	South Coast Region (0.030)
2	Orange (0.044)	Ventura (0.036)	North Central Region (0.013)
3	El Dorado (0.041)	Los Angeles (0.033)	Bay Delta Region (0.004)
4	Nevada (0.036)	San Diego (0.031)	Inland Deserts Region (0.004)
5	Ventura (0.036)	El Dorado, Placer, Sacramento, Yolo (0.030)	Central Region (0.003)

Discussion

This study aimed to investigate whether fire and drought impact human-black bear conflict risk, identify potential areas of under-reporting, and explore how climate change will affect the spatial distribution and intensity of human-black bear conflict. The general coefficient trends in our model are in line with current understandings of human-black bear conflict. We found that fire and drought (both impacted by climate change) do meaningfully impact human-black bear conflict in California, with fire increasing conflict risk and drought reducing conflict risk. We identified regions of potential conflict under-reporting in the coastal Bay Area and the southern coast. These communities are more socially vulnerable and are composed of significantly more people in several under-represented ethnic or racial backgrounds than reporting communities. We also found that climate change effects on fire and drought will alter the spatial distribution and intensity of conflict with black bears in the year 2030, with increases in conflict risk near Sacramento and along the southern coast, and decreases in northern California and the coastal Bay Area. Little research has been conducted on the relationship between climate change and human-wildlife conflicts thus far (LEDee et al., 2020), and we hope this study offers valuable insight for wildlife management agencies like CDFW to be better able to serve currently underserved communities and prevent future conflict in a shifting climate.

The strong positive effect seen in our model of low-intensity urban development, proximity to urban areas, and forest cover on the likelihood of conflict with black bears is in line with other studies suggesting that human-black bear conflict is most prevalent at the wildland-urban interface or WUI (Klees van Bommel et al., 2020). California has some of the highest numbers of WUI housing units in the United States (Radeloff et al., 2005), making this correlation particularly relevant for the management of human-black bear conflict in California. Our model also shows that conflict is more likely at higher elevations and closer to forest cover and streams, which is consistent with black bears' preferred habitat (Powell et al., 1997). In California, montane forests are often the site of low-density towns and vacation areas (Introduction to Montane Forests of the Southwest), leaving these areas particularly prone to conflict. Forested areas are also particularly susceptible to the impacts of climate change on fire, increasing further the conflict pressures present in these areas (Westerling et al. 2011).

While all of our fire coefficients suggested that being closer to a fire would increase the likelihood of conflict, we also noticed a temporal effect. Fires two to three years ago had the strongest effect on conflict, followed by fires four to five years ago and then fires one year ago. This may have to do with the regeneration of important food species in these burn scars; black bear use of burned areas in Florida was greatest in 3 and ≥5 year old burns, likely due to soft mast production (Stratman and Pelton, 2007). Drought had the opposite effect that we expected, with increasing drought intensity decreasing conflict risk. Measuring the distance to a drought area may be a more effective measurement for examining the impacts of drought, as bears are likely to leave areas where water is scarce (Hugie, 1979).

When climate variables were accounted for, our model of current-day conflict indicated that there are regions of California where human-black bear conflict is likely, but no WIR reports have been made. We specifically identified potential underreporting regions in the southern region of the San Francisco Bay Area and the southern coast between Long Beach and San Diego. It is possible these regions are experiencing conflict, but are unfamiliar with the WIR system, resulting in underreporting or no reported conflict. It is also possible that there are barriers to access preventing the use of the WIR system by these communities. Our results show these potential under-reporting communities have significantly larger populations of several ethnic and racial minority groups, and have a significantly higher social vulnerability, than reporting communities. This demonstrates a need to make conflict reduction resources and reporting frameworks more easily accessible. A possible actionable step that CDFW can take is to increase the linguistic accessibility of the WIR reporting system. The WIR system is currently only available in English and therefore inaccessible to those who speak English as a second language or who do not speak English at all. According to the Office of the Attorney General, nearly 44% of California households speak a language other than English at home, and nearly 19% of Californians report speaking English "less than very well" ("Limited English Proficient Consumers"). This is a substantial portion of the population that may not be able to utilize the reporting interface, even if they desire to do so. While not every person in one of the historically underrepresented groups that we analyzed is part of a limited English proficiency household, the proportion of LEP households is likely higher in these groups. Effective outreach and conflict management in these areas will require further examination of community demographics, and an ongoing effort to make reporting and management materials more accessible to everyone. It is our hope that identifying communities in need will aid CDFW in better managing conflict within these communities.

By identifying areas that are likely to experience higher rates of conflict in the future, our analysis can also equip CDFW to proactively prevent conflict within these communities. Our results show a probable southward shift in conflict-prone regions between now and 2030. The area north of Sacramento and the coastal zone south of Santa Barbara were regions identified as having the largest increases in conflict risk. Climate projections indicate that Southern California will experience highly variable precipitation events (Pathak et al., 2018), which will influence black bear food and habitat. Past studies on human-black bear conflict have confirmed that management will be most effective when integrating proactive management (Don Carlos et al., 2009). As human-black bear conflict zones shift due to climate change, CDFW has a window of opportunity to educate communities unfamiliar with bear interactions prior to conflict occurrences.

This analysis is the first step in establishing a relationship between human-black bear conflict and climatic variables in the context of climate change. However, future work is necessary to refine our model results and projections. Our model selection process compared the five models identified by Hagani et al. using our data. Hagani et al. utilized a “dredge” function (an iterative process that considers all possible model combinations) to select their most parsimonious models, but due to time and computing constraints, we were not able to conduct a dredge here. Future research in this area should attempt a dredge function using California data to determine if the top 5 selected models are significantly different from those identified by Hagani et al. The introduction of climate variables required us to make novel methodological decisions based on literature review and discussion with experts on fire and drought. Future research is needed to confirm the validity of these methodological decisions and should consider alternative approaches to quantifying and defining climate change variables in addition to those described here. The specific dynamics of climate change can be challenging to effectively model, which introduces much uncertainty. Our hope is that our model will be applied with expert knowledge, field surveys, and established methods for mitigating conflict events.

Understanding how climate impacts human-black bear conflict will provide CDFW with valuable information on producing management techniques that are cost-effective, prevent the need for costly reactive management, and lean on proactive education. Our model suggests that future research into human-wildlife conflict should consider climate variables. Our spatial analysis allows managers to identify current and future regions associated with a high conflict risk, which may serve as additional evidence to justify the allocation of resources to these regions. The findings of this project can be applied and adapted for wildlife managers interested in the relationship between climate change and human-wildlife conflict. Human-wildlife conflict is a continually-evolving area of study and will likely be exacerbated by climate change in the future. We anticipate that future work could build upon this early model, improving its precision and potentially its predictive capacity, to more accurately manage conflict with black bears under the ongoing effects of climate change.

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Appendix

Table 1: Robustness checks performed on the most parsimonious base model. Squaring population density (bolded) lowered the AIC of our model, and so that is the transformed model we elected to use for our analysis.

elevation + land cover + distance to forests + population density + distance to recreational areas + distance to streams + terrain ruggedness + distance to urban areas	76414.62
elevation + land cover + log(distance to forests) + log(population density) + distance to recreational areas + distance to streams + terrain ruggedness + distance to urban areas	76667.28
elevation + land cover + distance to forests + population density + population density^2 + distance to recreational areas + distance to streams + terrain ruggedness + distance to urban areas	**75295.23**
elevation + land cover + distance to forests + population density + distance to streams + terrain ruggedness + distance to urban areas	77071.41

Table 2. Land ownership types across California under present-day climate conditions

Land Ownership Type	Percent
City	0.2451839
County	0.5604203
Federal	19.8598949
Non Profit	0.3152364
Special District	0.2451839
State	4.0980736
Private	74.6760070

Table 3. Land ownership types across California under 2030 climate projections

Land Ownership Type	Percent
City	0.9926560
County	0.6537003
Federal	22.8310871
Non Profit	0.3147446
Special District	0.4519409
State	2.4049714
Tribal	1.2912598
Private	71.0596401

Table 4. Data sources

Usage	Data source
Base Model	
Elevation	WorldClim - Fick, S.E. and R.J. Hijmans, 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37 (12): 4302-4315.
Terrain Ruggedness	USGS EROS Archive - Digital Elevation - Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) USGS EROS Archive - Digital Elevation - Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010)
Land Cover	Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54
Forest Cover	Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54
Streams	California State Geoportal/ CDFW *California Streams | California State Geoportal*. (n.d.). Retrieved March 23, 2023, from https://gis.data.ca.gov/datasets/CDFW::california-streams/about
Human Population Density	Rose, A., Weber, E., Moehl, J., Laverdiere, M., Yang, H., Whitehead, M., Sims, K., Trombley, N., & Bhaduri, B. (2017). LandScan USA 2016 [Data set]. Oak Ridge National Laboratory. https://doi.org/10.48690/1523377 Rose, A., Weber, E., Moehl, J., Laverdiere, M., Yang, H., Whitehead, M., Sims, K., Trombley, N., Whitlock, C., & Bhaduri, B. (2018). LandScan USA 2017 [Data set]. Oak Ridge National Laboratory. https://doi.org/10.48690/1523376 Rose, A., Weber, E., Moehl, J., Laverdiere, M., Yang, H., Whitehead, M., Trombley, N., Sims, K., Whitlock, C., & Bhaduri, B. (2019). LandScan USA 2018 [Data set]. Oak Ridge National Laboratory. https://doi.org/10.48690/1523375

Recreation	California State Parks, State of California. "California State Parks GIS Data & Maps." *CA State Parks*, https://www.parks.ca.gov/?page_id=862.
Urban Areas	From Land Cover data
Climate Variables	
Wildfire	Data from Park (2021); not publicly available
Drought	"California." National Integrated Drought Information Systems (NIDIS), *Drought.gov*. https://www.drought.gov/states/california#state-documents.california; Pierce et al. (2018). Climate, drought, and sea level rise scenarios for California's fourth climate change assessment. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CNRA-CEC-2018-006. Long.Drought.Scenarios
Robustness Checks	
Wildland Urban Interface	Radeloff, Volker C.; Helmers, David P.; Mockrin, Miranda H.; Carlson, Amanda R.; Hawbaker, Todd J.; Martinuzzi, Sebastián. 2022. The 1990-2020 wildland-urban interface of the conterminous United States - geospatial data. 3rd Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2015-0012-3
Demographic Analysis	
Population Sociodemographics	Depsky, N. J., Cushing, L., & Morello-Frosch, R. (2022). High-resolution gridded estimates of population sociodemographics from the 2020 census in California. *PLOS ONE*, *17*(7), e0270746. https://doi.org/10.1371/JOURNAL.PONE.0270746
Social Vulnerability Index	"Socioeconomic Data and Applications Center." *SEDAC*, NASA - EARTHDATA, https://sedac.ciesin.columbia.edu/data/set/usgrid-us-social-vulnerability-index.
Other	

CA Outline for Raster	Bureau, U. C. (n.d.). *TIGER/Line Shapefiles*. Retrieved March 23, 2023, from https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

Table 5. RSPF model coefficients for a model predicting human-black bear conflict in California.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.9864321	1.0598788	-1.874207	0.0609019
dem	0.0009794	0.0000830	11.796554	0.0000000
lcdev_high_int	2.0023332	0.5005892	3.999953	0.0000634
lcdev_low_int	3.2327550	0.3049599	10.600589	0.0000000
lcdev_med_int	2.0244503	0.3473435	5.828381	0.0000000
lcdev_open_space	2.7499958	0.2335624	11.774137	0.0000000
lcforest	2.0568702	0.2365193	8.696416	0.0000000
lcgrassland_herbaceous	1.9311302	0.3230362	5.978062	0.0000000
lcopen_water	0.8862372	0.5780197	1.533230	0.1252192
lcperrenial_ice_snow	-7.5670993	1.3075517	-5.787227	0.0000000
lcplanted_cultivated	1.0881377	0.5107574	2.130439	0.0331354
lcshrub_scrub	1.4002012	0.2414984	5.797973	0.0000000
lcwetlands	1.6460346	0.5163768	3.187662	0.0014343
forest_dist	-0.0006610	0.0000770	-8.588441	0.0000000
popdens	0.2090701	0.0567005	3.687267	0.0002267
I(popdens^2)	-0.0093095	0.0030893	-3.013444	0.0025830
rec_dist	-0.0000452	0.0000023	-19.831012	0.0000000
streams_dist	-0.0008857	0.0001828	-4.845434	0.0000013
TRI	-0.0541707	0.0033481	-16.179514	0.0000000
urban_dist	-0.0013028	0.0001284	-10.143064	0.0000000
dist_fire_1yr	-0.0000034	0.0000012	-2.878344	0.0039977
dist_fire_23yrs	-0.0000140	0.0000020	-7.031017	0.0000000
dist_fire_45yrs	-0.0000129	0.0000022	-5.894989	0.0000000
drought	-0.1737500	0.0326271	-5.325323	0.0000001

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