

ARTICLE

Animal Ecology

Late season frosts and changing snowpack may exacerbate human–bear conflicts

Kevin T. Shoemaker¹  | Heather E. Reich^{1,2} | Perry J. Williams¹  |
 Megan J. Osterhout¹ | Joshua P. Vasquez¹ | Jon P. Beckmann³ |
 Carl W. Lackey² | Kelley M. Stewart¹ 

¹Department of Natural Resources and Environmental Science, University of Nevada, Reno, Nevada, USA

²Nevada Department of Wildlife, Reno, Nevada, USA

³Wildlife Conservation Society, Bozeman, Montana, USA

Correspondence

Kevin T. Shoemaker

Email: kevinshoemaker@unr.edu

Present address

Jon P. Beckmann, Kansas Department of Wildlife and Parks, 512 SE 25th Ave, Pratt, Kansas 67124, USA.

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Abstract

The North American black bear (*Ursus americanus*) is an opportunistic omnivore that depends on seasonal availability of fruits, nuts, grasses, and forbs for survival. Black bears on the urban–wildland interface also use anthropogenic food resources, especially when natural food resources are scarce. Consequently, natural food failure can exacerbate human–bear conflict, resulting in increases in human-caused mortality via vehicle strikes and management removal. Climate change is expected to increase the frequency and severity of extreme weather events, including drought or late frost. These climatic events may affect the spring growth resulting in loss of natural foods for bears and lead to heightened human–bear conflict in the future. In this study, we examined the effects of weather (snowpack and final freeze dates) on natural survival and cause-specific mortality (management removal and vehicle collision) of black bears in northwestern Nevada, using an extensive capture–recapture database (509 bears captured between 1998 and 2022). Our results indicated that late freeze dates were associated with a higher probability of conflict, increased probability of management removal, and reduced natural survival. Snowpack (snow–water equivalent) was weakly correlated with the probability of management removal, but the association was much weaker than the effect of late freeze dates. Anticipating the effects of late frost and snowpack on human–black bear conflict will help managers better anticipate and respond to potential high-conflict events.

KEYWORDS

Bayesian integrated analysis, black bear, climate change, human–bear conflict, multistate capture–recapture, snowpack, *Ursus americanus*, winter severity

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INTRODUCTION

Climate change is increasing the frequency and intensity of extreme weather events such as droughts, heat waves, and early or late frosts (Easterling et al., 2000; Niu et al., 2014; Orłowsky & Seneviratne, 2012; Walsh et al., 2020). In many cases, extreme weather or climatic events can have greater effects on ecosystems, plant populations, and wildlife populations than changes in climatic means (Niu et al., 2014; Ujvari et al., 2016; Walsh et al., 2020). Extreme events that severely reduce habitat quality or forage availability have the potential to exacerbate conflicts between humans and wildlife as animals seek alternative sources of food and shelter (Niu et al., 2014; Ujvari et al., 2016).

American black bears (*Ursus americanus*) are opportunistic omnivores whose diet primarily consists of mast production (nuts and berries), grasses, and forbs, and which is supplemented with insects, mammals, and fish when available (Graber & White, 1983). Availability of food resources affects home range size, survival, reproductive success, and the timing of denning (Beckmann & Berger, 2003a, 2003b; Doan-Crider & Hewitt, 2009; Johnson et al., 2018; Long et al., 2024; Vaughan, 2009). When natural food production fails, bears travel further in search of food and often resort to anthropogenic food sources such as garbage, domestic animal feed, fruit trees, chickens, and apiaries (Baruch-Mordo et al., 2014; Beckmann & Berger, 2003a; Hristienko & McDonald, 2007). Failure of natural foods often leads to an increase in human–bear conflicts, thereby increasing the number of bears killed (“removed”) by wildlife management agencies and the number of bears hit and killed by vehicles (Lewis et al., 2014; Ryan et al., 2007; Wynn-Grant et al., 2018). Conversely, human–bear conflicts are often documented to be lower in years of high natural food production (Beckmann & Berger, 2003a; Laufenberg et al., 2018; Vaughan, 2009).

Low availability of natural foods for bears has primarily been blamed on droughts (Doan-Crider & Hewitt, 2009; Honda & Kozakai, 2020; Niu et al., 2014). However, the impacts of drought may in some cases be less severe than the impacts of sudden drops in temperature (e.g., a late hard freeze event), especially if key forage plants are flowering or beginning to set mast (Niu et al., 2014). For example, Gu et al. (2008) found that early season warming (inducing plants to begin developing new growth, or “de-harden”; Niu et al., 2014) followed by a late frost could cause a devastating loss of flower, leaf, and fruit production of natural and agricultural plants. A late season frost could have important impacts on bears living on the urban–wildland interface, causing them to seek out anthropogenic sources of food

and thereby increasing rates of conflict. For example, Graber and White (1983) noted that an increase in property damage by black bears in Yosemite National Park was associated with a reduction in soft and hard mast production during a year with a particularly late frost.

Snowpack, often measured as snow-water equivalent (SWE), plays an important role in ecosystem productivity (Harpold, 2016; Tennant et al., 2017; Trujillo et al., 2012). Trujillo et al. (2012) established that hydrological changes from climate change, specifically changes in snow accumulation and melting, can have significant effects on the productivity of forests in the northern Sierra Nevada (Trujillo et al., 2012). Winter snowpacks are forecasted to change as climate change leads to increased warming and earlier melting; reduced snow cover or low snowpack can increase plant stress during summer (Harpold, 2016; Soderquist & Luce, 2021; Tennant et al., 2017; Trujillo et al., 2012). For instance, Harpold (2016) found that for every day of increased water stress in vegetation, their growing season shortened by 0.74 days. Reduced ecosystem productivity likely translates into decreased availability and quality of natural forage for bears and other species of wildlife and may exacerbate human–bear conflicts.

Increasing urbanization may interact with weather and climate to increase the likelihood of conflicts between humans and bears (Marley et al., 2017). In addition to expanding and intensifying zones of human–bear conflict, urbanization can have independent negative impacts on bear populations. For example, Schwartz et al. (2012) demonstrated that even low levels of urbanization in occupied grizzly bear habitat (e.g., one cabin within a square mile of habitat) reduced adult survival rates and could change source patches into sinks. Compounding urbanization with low availability of natural food resources during extreme weather events raises concerns that conflicts between humans and bears will increase as climate change and urbanization continue to escalate (Johnson et al., 2018).

In Nevada, black bears are thought to have been widely distributed at low densities across the state until their extirpation by the 1900s (Goodrich, 1990; Lackey et al., 2013). Following the reforestation of mountain ranges in western Nevada, black bears began reoccupying western Nevada from California in the late 1980s, and populations have been steadily increasing since then (Lackey et al., 2013; Sedinger, 2014, 2018; Sultaire et al., 2023). The Nevada Department of Wildlife (NDOW) began a long-term capture–recapture effort of black bears beginning in 1997, which continues to today (Beckmann & Berger, 2003a; Beckmann & Lackey, 2008, 2018; Lackey et al., 2013). This extensive database, coupled with records of management removal events

and vehicle-bear mortalities, allows for capture–mark–recapture (CMR) estimates of abundance (Lackey et al., 2013; Sedinger, 2014, 2018), and enables research into how acute climatic events may affect natural and anthropogenic sources of mortality for a population of black bears occupying an increasingly urbanized system. In this study, we assess how late frosts and variable snowpack have affected the rates of human–bear conflict and cause-specific mortality rates in Nevada. We hypothesized that the loss of natural food resources resulting from late frosts and/or low snowpack would result in increased human–bear conflicts, vehicle-bear mortalities, and rates of management removal.

MATERIALS AND METHODS

Study area

Our study area for the analysis of snowpack and late frost events extended from the Carson Range of the Sierra Nevada eastward to the Wassuk Range, and from Reno south to Topaz Lake (Figure 1). Because bears were captured in response to reported human–bear conflicts, captures generally occurred within developed areas in the Lake Tahoe Basin, Nevada, and the lower elevation urban centers of Reno, Carson City, Minden, Gardnerville, Hawthorne, and their associated valleys.

Our study area for natural survival, cause-specific mortality estimation, and abundance analysis included a smaller portion of this area. The area for that analysis is contained in an area referred to as the Carson Front (Lackey et al., 2013). This study area included the Carson Range of the Sierra Nevada eastward to the Virginia Range and Pine Nut Mountains, and from Reno south to Topaz Lake (Figure 1, Lackey et al., 2013). This subset of our total study area has been used historically by the Nevada Department of Wildlife to estimate the long-term demographics of the bear population in Nevada (Lackey et al., 2013; Sedinger, 2014, 2018).

Elevations in the study areas range from 1220 m in the valleys to 3050 m in the Sierra Nevada. The western edge of the study areas in the eastern Sierra Nevada includes stands of large pine species, including Jeffrey pine (*Pinus jeffreyi*) and ponderosa pine (*Pinus ponderosa*) along with various small shrubs found in western riparian zones (Andreasen et al., 2018; Grayson, 1993). The eastern edge of the study areas is in the rain shadow of the Sierra Nevada and is dominated by characteristic vegetation of the arid Great Basin, including single leaf pinyon pine (*Pinus monophylla*), juniper (*Juniperus* spp.), and sagebrush (*Artemisia* spp.) (Andreasen et al., 2018; Grayson, 1993).

Data collection and handling

We used an extensive CMR database maintained by NDOW, and our study focused on 25 years (1998–2022) of capture data. Individual bears entered the study following reports of human–bear conflict and were captured during spring, summer, and autumn when bears were active (e.g., not in dens). Bears were captured using culvert traps, Aldrich foot snares, or free-range darting (i.e., chemical immobilization delivery to an unconfined bear) (Beckmann & Berger, 2003a; Lackey et al., 2013). Although the database also includes wildland bears that were captured opportunistically or were trapped incidentally (e.g., in bobcat traps), we removed those individuals from our analyses because of the lack of information about survey effort (e.g., number and location of traps). All newly captured bears were assigned an ear tag with a unique identification code. Bears also received a corresponding tattoo of their identification tag in their upper lip on the same side as the tagged ear. In 2010, bears also began receiving passive integrated transponder (PIT) tags as a tertiary form of identification. Although ear tags alone are not perfectly reliable, the presence of secondary (lip tattoo) and tertiary (PIT) IDs assured that virtually all recaptured bears would be correctly identified throughout the 25-year study period. For all bears captured, recaptured, or recovered following mortality, NDOW biologists recorded date, age, sex, body condition, and capture location. Age of bears was determined subjectively by the biologist handling the animal based on tooth wear (Beausoleil et al., 2022), unless the bear was a dependent young (where age was known with certainty). We removed dependent young <1 year of age from our capture–recapture analysis, thereby restricting this analysis to those bears entering into conflict independent of the activities of the parent (Lackey et al., 2013).

This long-term database on black bears in this study area also includes known mortality events, including bears killed by vehicles and bears considered a public safety risk and thereby removed from the population (management removals). Although the database also includes unknown bears that were dead on their first handling (i.e., bears that were killed by vehicles and not previously marked) or were subjected to management removal at initial capture, those records were discarded prior to fitting capture–recapture models for survival estimation (see the following section).

Measuring snowpack and late frost events

We obtained two variables related to annual winter severity: a SWE metric based on Snowpack Telemetry

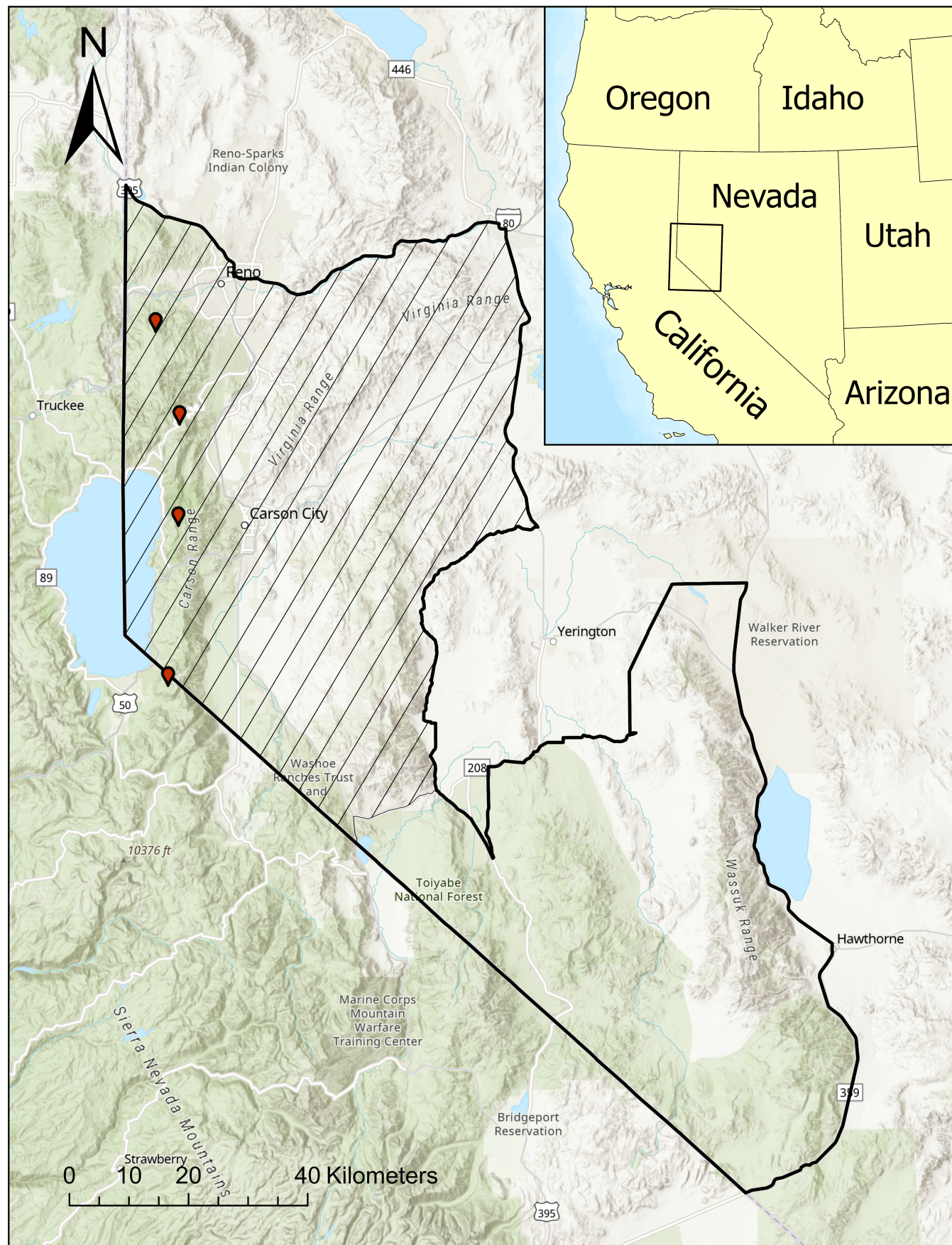


FIGURE 1 Legend on next page.

(SNOTEL; Serreze et al., 1999) monitoring stations, and the date of the final spring freeze based on daily temperature records. We obtained SWE data from all SNOTEL stations that were located within our study region ($n = 4$). The SNOTEL monitoring stations are overseen by the National Water and Climate Center (NWCC; part of Natural Resources Conservation Service; NRCS) and placed at numerous locations throughout the Sierra Nevada, including four stations covering higher elevation habitats within our northern Nevada study region. For each year of the study, we computed the average SWE on April 1 (across all four SNOTEL stations) as a metric of winter severity. We also generated a second metric of winter severity (final freeze date during spring), representing the ordinal date (day of the year, ranging from 1 to 365) of the last freeze of spring for each year. Here, a freeze was defined as $\leq -1.1^{\circ}\text{C}$. Raw daily temperature data were obtained from the National Oceanic and Atmospheric Administration (<https://xmacis.rcc-acis.org/>).

Natural survival and cause-specific mortality estimation

We used a Bayesian multistate CMR model to estimate natural survival probability and cause-specific mortality rates from the 25-year capture database for this population from 1998 to 2022. Each bear in the population was assumed to be alive in its initial year of capture (animals that were removed via management or found dead in the first year of capture were omitted from the analysis) and was assigned to one of four latent states for all subsequent years: 1, alive; 2, management removal; 3, vehicle-bear mortality; and 4, dead or previously removed (natural mortalities and individuals killed or found dead in previous years). The model also included four observation states: 1, not seen; 2, captured and released alive; 3, captured and removed via management; and 4, observed dead on road. The multistate likelihood was a compound function of four independent probabilities: capture, survival, vehicle-bear mortality, and management removal. Each of these probabilities was modeled as a logit-linear function of four covariates: sex, age, SWE, and final freeze date. For modeling purposes, we classified age into two

categories: juveniles (1–4 years) and adults (5 years of age or greater) (young-of-year were removed prior to analysis). All quantitative covariates (SWE and final freeze date) were centered and scaled prior to analysis.

Because all bears in this study were captured as a result of human–bear conflict (wildland captures and tag resightings were not considered in this model), the capture probability component of this model represents the probability of a bear being seen in or near a human settlement, and subsequently reported and captured by NDOW biologists or law enforcement. Annual detection probability (p_t) was modeled as:

$$\text{logit}(p_t) = \text{logit}(p_{0_t}) + \beta_{\text{sex}}^p \times \text{male}_t + \beta_{\text{juv}}^p \times \text{juv}_{i,t} + \beta_{\text{prev}}^p \times \text{prev}_{i,t} + \beta_{\text{freeze}}^p \times \text{last_freeze}_t + \beta_{\text{SWE}}^p \times \text{SWE}_t, \quad (1)$$

where p_{0_t} represents the baseline probability of detection at time t (i.e., probability of being reported in an urban setting and subsequently captured by NDOW), estimated separately for each year, β_{male}^p represents the difference in the log-odds of detection probability for males, male_t is a binary variable (0 for female, 1 for male), β_{juv}^p represents the difference in the log-odds of detection probability for juveniles, juv is a binary indicator variable (0 for adult, 1 for juvenile), β_{freeze}^p describes how the log-odds of detection changes with final-freeze date last_freeze_t (centered and scaled), and β_{SWE}^p describes how the log-odds of detection changes with SWE_t (centered and scaled). Based on the results of goodness-of-fit tests run in the U-CARE software (Choquet et al., 2009), we also allowed detection probability to vary depending on whether or not an animal had been detected in the previous year ($\text{prev}_{i,t}$).

The apparent survival process (ϕ), represents the per capita probability of surviving and remaining in the study area from one year to the next, discounting known human-caused mortalities such as vehicle-bear mortality and management removal (hereafter, “natural survival”). The annual probability of natural apparent survival (ϕ_t), road (vehicle-bear) mortality (rmort_t), and the probability of management removal (mgmt_t ; probability of being removed via management, conditional on being observed and captured in an urban setting) were each modeled as

FIGURE 1 Map of our northern Nevada study area for black bears (1998–2022). The black line denotes the study area outline for the larger study of snowpack and frost date analysis, red dots denote the locations of SNOTEL stations (used for estimating snowpack). The hashed area indicates the subset of the study area used for estimating abundance of black bears.

a logit-linear function of the same four covariates used for modeling detection probability:

$$\text{logit}(\phi_t) = \text{logit}(\phi_0) + \beta_{\text{sex}}^{\phi} \times \text{male} + \beta_{\text{juv}}^{\phi} \times \text{juv} + \beta_{\text{freeze}}^{\phi} \times \text{last_freeze}_t + \beta_{\text{SWE}}^{\phi} \times \text{SWE}_t, \quad (2)$$

$$\text{logit}(\text{rmort}_t) = \text{logit}(\text{rmort}_0) + \beta_{\text{sex}}^{\text{rmort}} \times \text{male} + \beta_{\text{juv}}^{\text{rmort}} \times \text{juv} + \beta_{\text{freeze}}^{\text{rmort}} \times \text{last_freeze}_t + \beta_{\text{SWE}}^{\text{rmort}} \times \text{SWE}_t, \quad (3)$$

$$\text{logit}(\text{mgmt}_t) = \text{logit}(\text{mgmt}_0) + \beta_{\text{sex}}^{\text{mgmt}} \times \text{male} + \beta_{\text{juv}}^{\text{mgmt}} \times \text{juv} + \beta_{\text{freeze}}^{\text{mgmt}} \times \text{last_freeze}_t + \beta_{\text{SWE}}^{\text{mgmt}} \times \text{SWE}_t. \quad (4)$$

We then used these four probabilities (p , ϕ_t , rmort_t , and mgmt_t) to define the multinomial likelihoods for the state transition process and the observation process. The state transition process was described by the row-stochastic matrix:

$$\begin{bmatrix} \text{Alive}_t & \text{Mgmt rem}_t & \text{Road mort}_t & \text{Dead}_t \\ \text{Alive}_{t-1} & \zeta & p_t \times \text{mgmt}_t & \text{rmort}_t & 1 - \phi_{t-1} \\ \text{Mgmt rem}_{t-1} & 0 & 0 & 0 & 1 \\ \text{Road mort}_{t-1} & 0 & 0 & 0 & 1 \\ \text{Dead}_{t-1} & 0 & 0 & 0 & 1 \end{bmatrix},$$

where ζ was computed as 1 minus the sum of the other probabilities in the row (to ensure multinomial state transition probabilities summed to 1). Similarly, the observation process was described by the row-stochastic matrix:

$$\begin{bmatrix} \text{Not seen} & \text{Seen and released} & \text{Seen and removed} & \text{Found dead on road} \\ \text{Alive}_t & (1 - p_t) & p_t & 0 & 0 \\ \text{Mgmt rem}_t & 0 & 0 & 1 & 0 \\ \text{Road mort}_t & 0 & 0 & 0 & 1 \\ \text{Dead}_t & 1 & 0 & 0 & 0 \end{bmatrix}.$$

We assumed that all cases of management removal involved capture via the same process by which all animals were captured in this study (i.e., via members of the public reporting a “problem” bear), and therefore all bears removed via management were assumed to be detected with probability p_t . For the detection matrix, we assumed perfect detection probability for vehicle-bear mortalities—that is, we assumed that all

bears killed by vehicles were reported and recorded by state agencies.

The multistate capture–recapture model was fitted in a Bayesian framework using a Markov Chain Monte Carlo (MCMC) algorithm using JAGS software (Plummer, 2022), which was called from the R programming environment (R Core Team, 2022) using the jagsUI package (Kellner, 2021). We assessed convergence to the joint posterior distribution using visual examination of marginal trace plots and ensuring that the potential scale reduction factor ($\hat{R}$) was less than 1.1 for all parameters (Brooks & Gelman, 1998). The R and JAGS code for implementing the above analyses are available from Zenodo (<https://doi.org/10.5281/zenodo.15793776>).

Abundance estimation

To examine black bear abundance dynamics in the study area, we used the same capture history database to fit Jolly-Seber-Schwartz-Arnason (JSSA) models, which are suitable for abundance estimation for open populations (Pledger et al., 2010; Schwarz & Arnason, 1996). We developed a suite of candidate models to investigate the effects of sex, year, and their interactions on detection probability, annual apparent survival, recruitment, and abundance. Yearly effects were modeled using polynomials, parameterized by four to six basis functions to flexibly capture temporal trends (Hefley et al., 2017). Candidate models were evaluated using Akaike information criterion (AIC), and only the model with the lowest AIC was retained for inference (Burnham & Anderson, 2013). All analyses were performed in R using the

openCR package, which implements JSSA models for capture–recapture data (Efford, 2024).

RESULTS

The long-term black bear capture history database compiled by NDOW (1998–2022) included 1465 total

detections of 699 unique black bears. After removing dependent cubs (young-of-year) and individuals found dead or removed from the population upon initial

capture, the final dataset for the multistate survival model consisted of 1135 observations of 509 unique individuals (Table 1), with total annual captures varying

TABLE 1 Summary of capture–recapture data for black bears in northern Nevada, 1998–2022.

Model	Total individuals	Males	Females	Recaptures
Multistate survival model	509	322	187	626
Abundance model*	537	328	209	682

*The abundance estimates used wildland bear captures in addition to bears captured in urban settings. Wildland captures were excluded from the multistate survival model.

TABLE 2 Description of parameters fitted in a Bayesian multistate model of black bear survival in northern Nevada, 1998–2022, with results summary.

Process	Parameter	Description	Estimate (CI)
Detection	p_0^a	Baseline probability of detection (adult females)	0.162 (0.016–0.424)
	β_{sex}^p	Effect of being a male on the log odds of the probability of detection	−0.86 (−1.18 to −0.58)
	β_{juv}^p	Effect of being a juvenile on the log odds of the probability of detection	−0.11 (−0.47–0.24)
	β_{freeze}^p	Effect of the final freeze date on the log odds of the probability of detection	0.11 (−0.53–0.87)
	β_{SWE}^p	Effect of snow-water equivalent on the log odds of the probability of detection	0.0031 (−0.709–0.822)
	β_{prev}^p	Effect of being captured in the previous year on the log odds of the probability of detection	0.76 (0.48–1.05)
Natural survival (ϕ)	ϕ_0	Baseline probability of apparent survival per year (adult females)	0.94 (0.91–0.96)
	β_{sex}^ϕ	Effect of being a male on the log odds of the probability of survival	−0.14 (−0.66–0.29)
	β_{juv}^ϕ	Effect of being a juvenile on the log odds of the probability of survival	−0.41 (−0.99–0.32)
	$\beta_{\text{freeze}}^\phi$	Effect of the final freeze date on log odds of the probability of survival	−0.30 (−0.79–0.17)
	β_{SWE}^ϕ	Effect of snow water equivalent on the log odds of the probability of survival	0.073 (−0.525–0.796)
Management removal	mgmt_0	Baseline probability of management removal per year (adult females)	0.125 (0.074–0.190)
	$\beta_{\text{sex}}^{\text{mgmt}}$	Effect of being a male on the log odds of the probability of management removal	1.02 (0.28–1.72)
	$\beta_{\text{juv}}^{\text{mgmt}}$	Effect of being a juvenile on the log odds of the probability of management removal	1.07 (0.17–1.90)
	$\beta_{\text{freeze}}^{\text{mgmt}}$	Effect of the final freeze date on the log odds of the probability of management removal	0.70 (0.31–1.14)
	$\beta_{\text{SWE}}^{\text{mgmt}}$	Effect of snow water equivalent on the log odds of the probability of management removal	0.23 (−0.15–0.67)
Vehicle-bear mortality	rmort_0	Baseline probability of vehicle-bear mortality per year (adult females)	0.017 (0.010–0.027)
	$\beta_{\text{sex}}^{\text{rmort}}$	Effect of being a male on the log odds of the probability of vehicle-bear mortality	0.33 (−0.23–0.89)
	$\beta_{\text{juv}}^{\text{rmort}}$	Effect of being a juvenile on the log odds of the probability of vehicle-bear mortality	0.24 (−0.42–0.91)
	$\beta_{\text{freeze}}^{\text{rmort}}$	Effect of the final freeze date on the log odds of the probability of vehicle-bear mortality	0.13 (−0.19–0.39)
	$\beta_{\text{SWE}}^{\text{rmort}}$	Effect of snow-water equivalent on the log odds of the probability of vehicle-bear mortality	0.017 (−0.242–0.278)

^aAveraged across all years.

from 22 to 91. The final dataset for the abundance model, which also included wildland captures, consisted of 537 unique individuals (Table 1).

Natural survival and cause-specific mortality

The multistate capture–recapture model indicated that the baseline probability of capture during the activity season (p_0) was 0.162 (0.016–0.424) (Table 2). Males had

a lower probability of detection than females, resulting in an average detection probability for males of 0.076 annually. Juvenile bears were slightly less likely to be detected than adults (Table 2). Baseline probability of natural survival (ϕ_0) was 0.94 (0.91–0.96). Males and juveniles tended to have slightly lower survival than adult females (Table 2). The baseline annual probability of management removal (conditional on being captured) was 0.125 (0.074–0.190; Table 2). Male and juvenile black bears had much higher probabilities of management removal conditional on capture, averaging 0.283 and

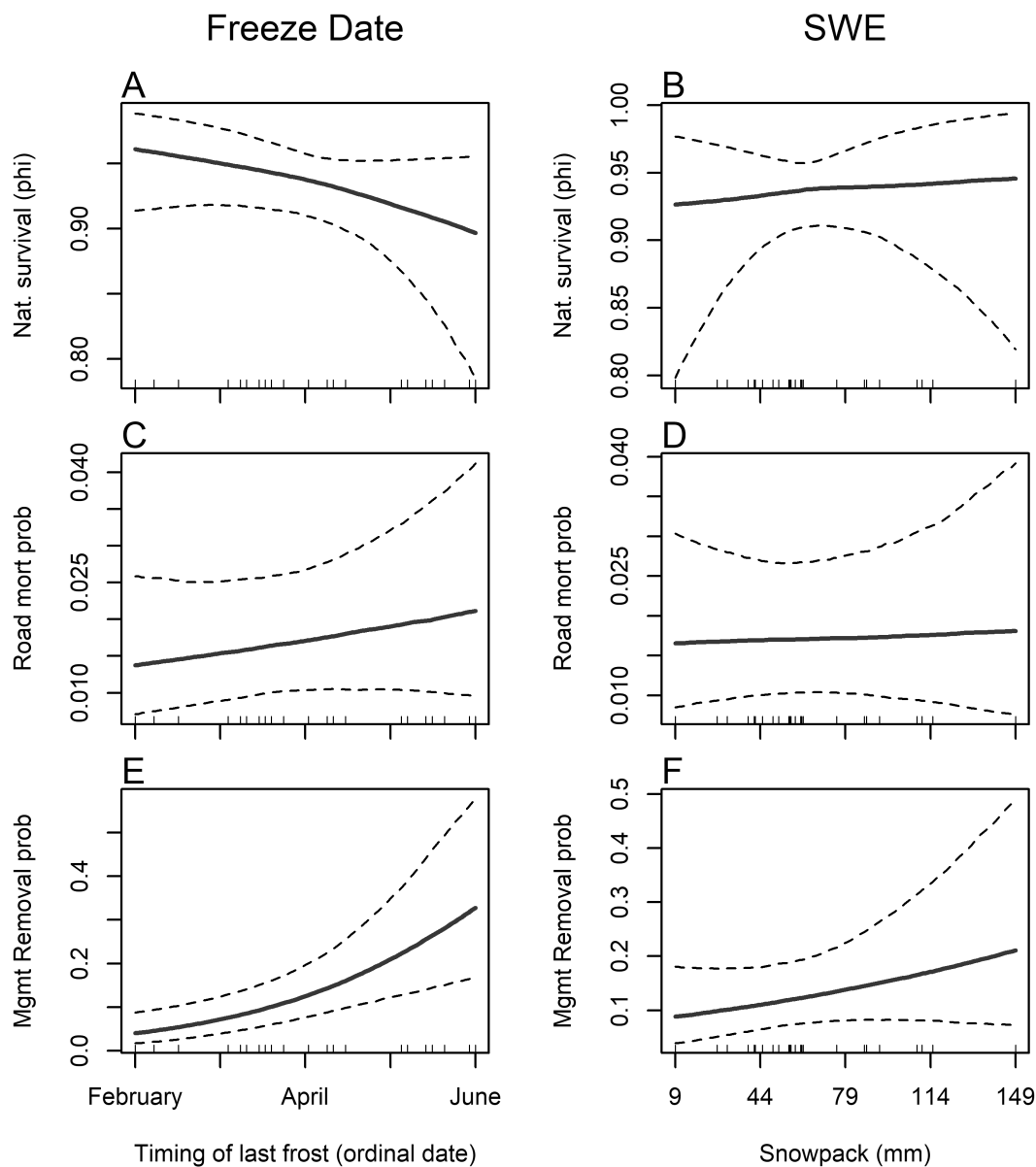


FIGURE 2 Partial dependence plots illustrating the estimated effect of (A, C, E) the final frost date and (B, D, F) snowpack (right column) on (A, B) natural survival rate of adult black bears (not including direct anthropogenic sources of mortality), (C, D) probability of vehicle–bear mortality (“Road mort.”), and (E, F) probability of a bear being removed from the population by a wildlife management agency (1998–2022). Predictions are derived from a Bayesian multistate capture–recapture model, with all other covariates held at their mean values. Solid lines indicate median responses, and dashed lines indicate a 95% credible interval. SWE, snow-water equivalent.

0.294, respectively (derived from coefficients in Table 2). Combining these additive effects, juvenile males had a 0.536 probability of management removal conditional on capture. The baseline probability of vehicle-bear mortality for female bears was 0.017 (0.010–0.027), with slightly higher rates for males and juveniles. The date of the final freeze had a strong positive effect on the probability of management removal, and a weakly negative effect on the probability of natural survival (Table 2; Figure 2). Snowpack (SWE) had no conclusive relationships with any of the modeled response variables, but had a weakly positive effect on the probability of management removal (Table 2; Figure 2).

Trends in black bear abundance and human–bear conflicts

The top model for estimating abundance (Table 3) suggests that the black bear population has increased substantially between 1997 and 2007, with about 72 (95% CI: 30–88) bears present in the population in 1998 and approximately 466 (95% CI: 368–592) in the population by 2022 (Figure 3). The population growth rate has slowed in recent years, but still appears to be increasing ($\lambda > 1$). The number of conflict calls reported to NDOW also generally increased throughout the study period (Figure 3) and was correlated with bear abundance estimates within the core study area ($\rho = 0.65$; $p = 0.0005$). There were fewer than 120 calls in 1998 and 1450 calls in 2022. There were large increases in conflict calls in 2007, 2014, and 2021. There were no general trends for the final freeze date or snowpack throughout the study (Figure 3). In the first half of the study, final freeze dates ranged from mid-April to the end of May. In the second half of the study, the final freeze dates ranged from the end of March to early May. The earliest final freeze was in 2019 and occurred in March. The latest final freeze was in 2010 and occurred at the end of May.

DISCUSSION

Our results indicated that years with late frosts were associated with increased natural mortality, reports of human–bear conflicts, and lethal removals resulting from human–bear conflicts in our study region. Those effects likely resulted from loss of key natural food resources (e.g., soft and hard mast) following late, hard frosts (Niu et al., 2014). Bears that remain in wildlands during times of food shortage can experience higher mortality, while bears that enter urban settings are at greater risk of being

TABLE 3 Model selection results from estimates of abundance of black bears in northern Nevada (1997–2022).

Model	Parameters	AIC
$p \sim 1$ phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5	15	6428.05
$p \sim$ bs1 + bs2 + bs3 + bs4 + bs5 phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ sex + year	16	6428.24
$p \sim$ bs1 + bs2 + bs3 + bs4 + bs5 phi $\sim$ sex + year $N \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5	16	6429.28
$p \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ year	16	6430.04
$p \sim$ year phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5	16	6430.53
$p \sim 1$ phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ bs1 + bs2 + bs3 + bs4 + bs5	14	6431.47
$p \sim$ sex phi $\sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5 $N \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5	16	6432.07
$p \sim 1$ phi $\sim$ sex + year $N \sim$ sex + bs1 + bs2 + bs3 + bs4 + bs5	11	6432.84

Abbreviation: AIC, Akaike information criterion.

involved in human–bear conflict, resulting in increased vehicle-bear mortalities and management removals (Laufenberg et al., 2018). In this way, climate change can place bears at the urban–wildland interface in a double bind between two unfavorable outcomes. We observed a freeze during late May of 2022, which resulted in loss of mast crops in the Sierra Nevada, which corresponded to high numbers of conflict calls (Figure 3). Worryingly, climate change models predict increasingly extreme fluctuations in temperature and precipitation (Orlowsky & Seneviratne, 2012; Soderquist & Luce, 2021), which may contribute to increasing resource scarcity especially resulting from late frosts.

Our study also indicated that higher SWE during spring had a weak positive effect on natural survival of bears in our study area. Higher snowpack likely increases soil moisture, as well as vegetation growth and survival, providing more food resources to bears (Walker et al., 1993). Indeed, during 2007 and to a lesser extent during 2014, peaks in conflict calls were consistent with the lowest estimates of SWE during the years of our study (Figure 3). The availability of plentiful natural foods can lead to a decrease in human–bear conflicts, because bears tend to select natural foods when available (Beckmann & Berger, 2003a; Laufenberg et al., 2018; Vaughan, 2009).

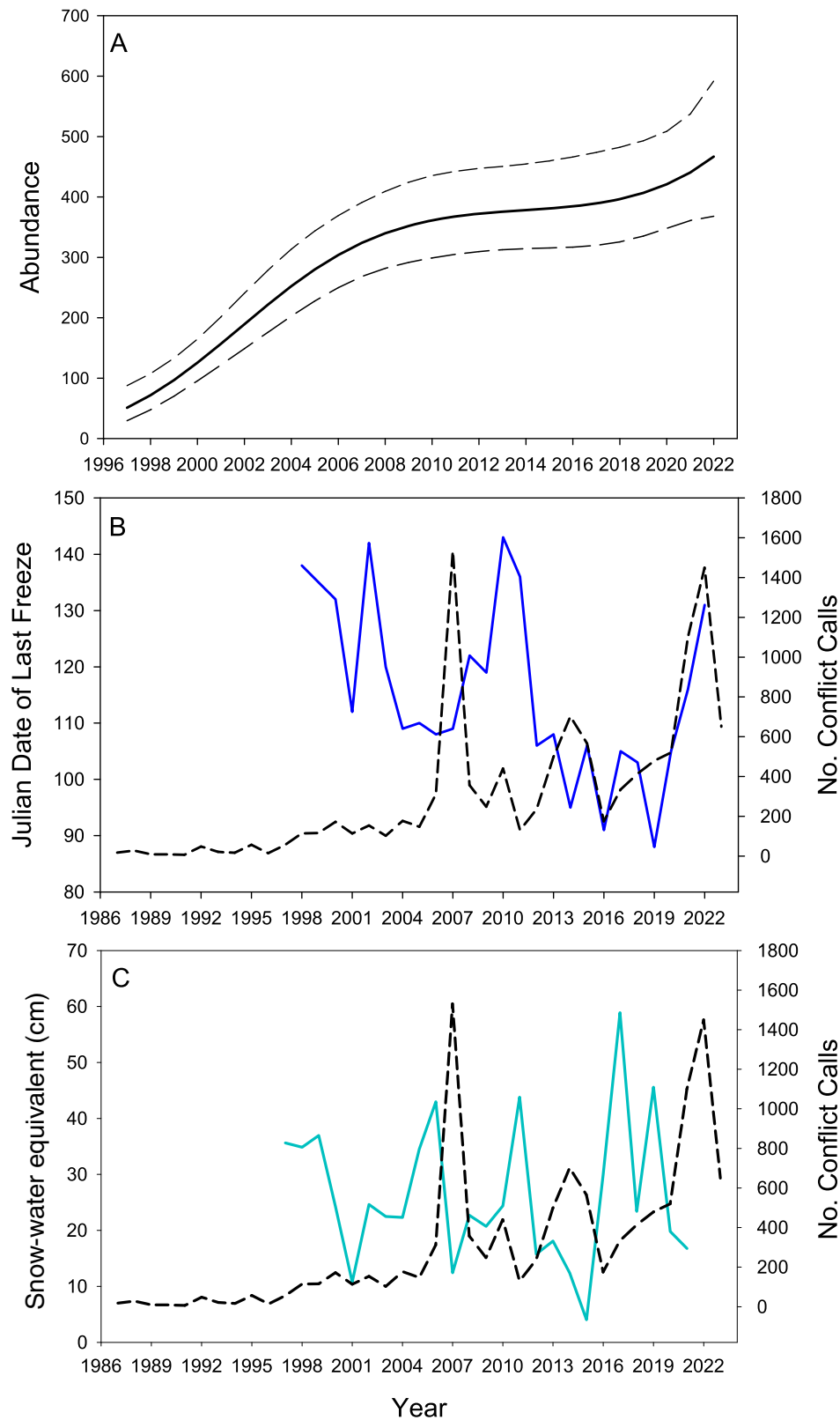


FIGURE 3 (A) Annual abundance estimates (dashed line indicates 95% CI) of black bears in the Sierra Nevada study area (1997–2022), based on the best-fit capture-recapture model, (B) the Julian date of the final freeze, and (C) snow-water equivalent measured on April 1 of each year (solid line) coupled with the number of calls to the Nevada Department of Wildlife reporting conflicts with black bears (dashed line).

The effect of SWE, however, was weak compared with the negative effects of late frosts on survival, human–bear conflicts, and rates of lethal removal (Figure 2). Therefore, our study provides little evidence for positive, or offsetting, impacts of climate change on black bears.

Our abundance estimate showed a growing population of black bears within the study area. Increasing abundance of black bears corresponds with increasing conflict calls over the duration of the study period (Figure 2). This trend, coupled with increasing human population in the area and the predicted higher fluctuations in climatic events in the future, indicates the potential for more conflicts between humans and bears in the future. While the decrease in survival during years with late frost did not affect the overall abundance of black bears within the study area, for areas with stable or declining populations, late frosts could negatively impact those populations. Aside from affecting population growth of black bears, climatic events that cause a decrease or failure of natural foods likely will result in a sharp increase in conflicts between humans and bears (Figure 2).

Recognition of the effects of extreme climate events—both on forage availability and the rate of human–bear conflict—is important for managing black bear populations along the wildland–urban interface. Wildlife managers are not able to predict late frosts until a frost warning is issued, and a spike in conflict is most likely inevitable once a mast failure occurs as a result of that event. Once a late frost is detected and food failure is likely, it would be advisable for wildlife management agencies and outreach organizations to put greater effort into educating the public on the anticipated increase of bear presence in urban areas and potential sources of conflict. Those efforts should include promoting bear-resistant garbage containers, electric deterrents, and other methods for securing anthropogenic bear attractants. Furthermore, bears with a lack of prior conflict history or low-level conflict history (e.g., accessing garbage cans or bird feeders as opposed to causing significant property damage) may be treated more leniently than bears that are already associated with high levels of conflict in years with low availability of natural foods.

AUTHOR CONTRIBUTIONS

Kevin T. Shoemaker: Conceptualization, methodology, formal analysis, visualization, writing—original draft, project administration. **Heather E. Reich:** Conceptualization, methodology, data curation, resources, writing—original draft. **Perry J. Williams:** Formal analysis, writing—original draft. **Megan J. Osterhout:** Conceptualization, methodology, data curation, writing—review and editing. **Joshua P. Vasquez:** Conceptualization, methodology, visualization, writing—review and editing. **Carl W. Lackey and Jon P. Beckmann:** Resource provision, data curation,

writing—review and editing. **Kelley M. Stewart:** Conceptualization, visualization, writing—original draft, supervision, project administration.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data and code (Shoemaker, 2025) are available from Zenodo: <https://doi.org/10.5281/zenodo.15793776>.

ORCID

Kevin T. Shoemaker  <https://orcid.org/0000-0002-3789-3856>

Perry J. Williams  <https://orcid.org/0000-0002-8439-1859>

Kelley M. Stewart  <https://orcid.org/0000-0001-9643-5890>

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