# Respiratory disease, behavior, and survival of mountain goat kids

**Article** *in* Journal of Wildlife Management · October 2017

DOI: 10.1002/jwmg.21470

Nicholas Clark
United States Military Academy West Point
**9** PUBLICATIONS **32** CITATIONS
SEE PROFILE

Robert W. Klaver
Iowa State University
**96** PUBLICATIONS **1,825** CITATIONS
SEE PROFILE

Mike Cox
Nevada Department of Wildlife and WAFWA
**12** PUBLICATIONS **49** CITATIONS
SEE PROFILE

Peregrine Wolff
Nevada Department of Wildlife
**32** PUBLICATIONS **302** CITATIONS
SEE PROFILE

4-25-2018

# Respiratory disease, behavior, and survival of mountain goat kids

Julie A. Blanchong
*Iowa State University*, julieb@iastate.edu

Christopher A. Anderson
*Iowa State University*

Nicholas Clark
*Iowa State University*

Robert W. Klaver
*United States Geological Survey*, bklaver@iastate.edu

Paul J. Plummer
*Iowa State University*, pplummer@iastate.edu

*See next page for additional authors*

# Respiratory disease, behavior, and survival of mountain goat kids

**Abstract**

Bacterial pneumonia is a threat to bighorn sheep (*Ovis canadensis*) populations. Bighorn sheep in the East Humboldt Mountain Range (EHR), Nevada, USA, experienced a pneumonia epizootic in 2009–2010. Testing of mountain goats (*Oreamnos americanus*) that were captured or found dead on this range during and after the epizootic detected bacteria commonly associated with bighorn sheep pneumonia die-offs. Additionally, in years subsequent to the bighorn sheep epizootic, the mountain goat population had low kid:adult ratios, a common outcome for bighorn sheep populations that have experienced a pneumonia epizootic. We hypothesized that pneumonia was present and negatively affecting mountain goat kids in the EHR. From June–August 2013–2015, we attempted to observe mountain goat kids with marked adult females in the EHR at least once per week to document signs of respiratory disease; identify associations between respiratory disease, activity levels, and subsequent disappearance (i.e., death); and estimate weekly survival. Each time we observed a kid with a marked adult female, we recorded any signs of respiratory disease and collected behavior data that we fit to a 3-state discrete hidden Markov model (HMM) to predict a kid's state (active vs. sedentary) and its probability of disappearing. We first observed clinical signs of respiratory disease in kids in late July–early August each summer. We observed 8 of 31 kids with marked adult females with signs of respiratory disease on 13 occasions. On 11 of these occasions, the HMM predicted that kids were in the sedentary state, which was associated with increased probability of subsequent death. We estimated overall probability of kid survival from June–August to be 0.19 (95% CI = 0.08–0.38), which was lower than has been reported in other mountain goat populations. We concluded that respiratory disease was present in the mountain goat kids in the EHR and negatively affected their activity levels and survival. Our results raise concerns about potential effects of pneumonia to mountain goat populations and the potential for disease transmission between mountain goats and bighorn sheep where the species are sympatric.

**Keywords**

hidden Markov model, mountain goat, Mycoplasma ovipneumoniae, Oreamnos americanus, pneumonia, respiratory disease, survival

**Disciplines**

Animal Experimentation and Research | Natural Resources Management and Policy | Sheep and Goat Science | Statistics and Probability

**Comments**

This article is published as Blanchong, Julie A., Christopher A. Anderson, Nicholas J. Clark, Robert W. Klaver, Paul J. Plummer, Mike Cox, Caleb Mcadoo, and Peregrine L. Wolff. "Respiratory disease, behavior, and survival of mountain goat kids." *Journal of Wildlife Management*. (2018). DOI: 10.1002/jwmg.21470. Posted with permission.

**Authors**
Julie A. Blanchong, Christopher A. Anderson, Nicholas Clark, Robert W. Klaver, Paul J. Plummer, Mike Cox, Caleb Mcadoo, and Peregrine L. Wolff

The Journal of Wildlife Management; DOI: 10.1002/jwmg.21470

*Research Article*

# Respiratory Disease, Behavior, and Survival of Mountain Goat Kids

**JULIE A. BLANCHONG,**[1] *Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA 50011, USA*
**CHRISTOPHER A. ANDERSON,** *Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA 50011, USA*
**NICHOLAS J. CLARK,** *Department of Statistics, Iowa State University, Ames, IA 50011, USA*
**ROBERT W. KLAVER,** *U.S. Geological Survey, Iowa Cooperative Wildlife Research Unit, Iowa State University, Ames, IA 50011, USA*
**PAUL J. PLUMMER,** *Department of Veterinary Diagnostic and Production Animal Medicine and Department of Veterinary Microbiology and Preventive Medicine, Iowa State University, Ames, IA 50011, USA*
**MIKE COX,** *Nevada Department of Wildlife, Reno, NV 89511, USA*
**CALEB MCADOO,** *Nevada Department of Wildlife, Elko, NV 89801, USA*
**PEREGRINE L. WOLFF,** *Nevada Department of Wildlife, Reno, NV 89511, USA*

**ABSTRACT** Bacterial pneumonia is a threat to bighorn sheep (*Ovis canadensis*) populations. Bighorn sheep in the East Humboldt Mountain Range (EHR), Nevada, USA, experienced a pneumonia epizootic in 2009–2010. Testing of mountain goats (*Oreamnos americanus*) that were captured or found dead on this range during and after the epizootic detected bacteria commonly associated with bighorn sheep pneumonia die-offs. Additionally, in years subsequent to the bighorn sheep epizootic, the mountain goat population had low kid:adult ratios, a common outcome for bighorn sheep populations that have experienced a pneumonia epizootic. We hypothesized that pneumonia was present and negatively affecting mountain goat kids in the EHR. From June–August 2013–2015, we attempted to observe mountain goat kids with marked adult females in the EHR at least once per week to document signs of respiratory disease; identify associations between respiratory disease, activity levels, and subsequent disappearance (i.e., death); and estimate weekly survival. Each time we observed a kid with a marked adult female, we recorded any signs of respiratory disease and collected behavior data that we fit to a 3-state discrete hidden Markov model (HMM) to predict a kid's state (active vs. sedentary) and its probability of disappearing. We first observed clinical signs of respiratory disease in kids in late July–early August each summer. We observed 8 of 31 kids with marked adult females with signs of respiratory disease on 13 occasions. On 11 of these occasions, the HMM predicted that kids were in the sedentary state, which was associated with increased probability of subsequent death. We estimated overall probability of kid survival from June–August to be 0.19 (95% CI = 0.08–0.38), which was lower than has been reported in other mountain goat populations. We concluded that respiratory disease was present in the mountain goat kids in the EHR and negatively affected their activity levels and survival. Our results raise concerns about potential effects of pneumonia to mountain goat populations and the potential for disease transmission between mountain goats and bighorn sheep where the species are sympatric. © 2018 This article is a U.S. Government work and is in the public domain in the USA.

**KEY WORDS** hidden Markov model, mountain goat, *Mycoplasma ovipneumoniae*, *Oreamnos americanus*, pneumonia, respiratory disease, survival.

Bacterial pneumonia has been identified to be a major threat to the recovery and persistence of bighorn sheep (*Ovis canadensis*) in the western United States (Buechner 1960, Gross et al. 2000, Singer et al. 2000). Several pathogens have been implicated in pneumonia epizootics with transmission occurring through nose-to-nose contact (*Mycoplasma ovipneumoniae*), fomite contamination (*Mannheimia haemolytica*), and aerosolization (*M. haemolytica*) when animals are near each other (e.g., <18 m; Burriel 1997, Dixon et al. 2002, Clifford et al. 2009, Besser et al. 2014). As disease progresses, coughing, nasal discharge, head shaking, lethargy, anorexia, and ataxia are commonly reported (Marsh 1938, Onderka and Wishart 1988, Wild and Miller 1991, Dassanayake et al. 2010). Once clinical signs of pneumonia appear in lambs, generally at 6–9 weeks of age, lamb mortality rates also increase (Spraker et al. 1984, Coggins and Matthews 1992, Cassirer et al. 2013). Pneumonia epizootics have caused all-age die-offs and suppressed lamb recruitment in populations for many years (Singer et al. 2000, Monello et al. 2001, Miller

Received: 9 October 2017; Accepted: 28 February 2018

[1] *E-mail: julieb@iastate.edu*

2004, George et al. 2008) because at least some survivors become carriers and transmit pathogens to naïve animals (Foreyt 1990, Coggins and Matthews 1992, Besser et al. 2014, Fox et al. 2015, Plowright et al. 2017).

Rocky Mountain bighorn sheep in the Ruby and East Humboldt Mountain Ranges of northeast Nevada, USA, suffered an all-age die-off caused by bacterial pneumonia in winter 2009–2010. Nasal swabs from 31 live bighorn sheep that were sampled and lung tissue from the 7 mortalities recovered during this event were polymerase chain reaction (PCR)-positive for *M. ovipneumoniae* (McAdoo et al. 2010). The majority of pharyngeal and lung samples obtained from live animals, sick animals that were euthanized, and collected mortalities were culture-positive for *Bibersteinia trehalosi*, whereas *M. haemolytica* and *Pasteurella multocida* were also cultured but at lower rates (McAdoo et al. 2010). On the East Humboldt Mountain Range (EHR) >150 bighorn sheep died by 2011 out of an estimated summer population in 2009 of 170. In winter 2009–2010, the Nevada Department of Wildlife (NDOW) estimated that 13% of the mountain goat (*Oreamnos americanus*) population in the EHR had also died (NDOW, unpublished data). One mountain goat mortality was also recovered and was noted to have pneumonia on gross necropsy; however, no tissues were submitted for culture because of advanced autolysis. Subsequently, NDOW captured and sampled 5 mountain goats from the EHR and 12 from the adjacent Ruby Mountains and detected *M. ovipneumoniae, B. trehalosi*, and *M. haemolytica* (Washington Animal Disease Diagnostic Lab, accession numbers 2010-3330, 2012-1410, 2012-1464, 2012-1526).

Following the pneumonia epizootic, all surviving bighorn sheep in the EHR were captured and relocated by NDOW. Twenty bighorn sheep from Alberta were translocated to the EHR in January 2013. A population of 100–120 mountain goats continued to inhabit the EHR from 2013–2015 (NDOW, unpublished data). Prior to the 2009–2010 epizootic, mountain goat recruitment in the EHR was considered stable. An aerial survey in February 2009 recorded 30 kids/100 adults (Cox et al. 2009) with an average of 30 kids/100 adults during 2001–2009 (Cox et al. 2017). Following the die-off in bighorn sheep, annual winter aerial surveys from 2010–2013 documented an average of 8 kids/100 adults (NDOW, unpublished data). Because the mountain goat population in EHR experienced similarly poor kid:adult ratios, as is often observed in bighorn sheep populations for several years following a pneumonia event, managers were concerned that the mountain goat population might also be negatively affected by pneumonia.

Little is known about the occurrence or effects of respiratory disease in mountain goat populations (Garde et al. 2005). Mountain goats occur in ≥13 states or provinces in western United States and Canada (Myatt and Larkins 2010). Some populations are native, whereas many are introduced, and their status varies geographically ranging from increasing to stable to declining (Myatt and Larkins 2010). Long-term studies in Alberta, Canada suggest that mountain goat populations, at least in their native ranges, have slower growth rates compared to other ungulates (Festa-Bianchet and Côté 2007). Introduced populations, however, may have higher population growth rates perhaps because of more productive habitats or fewer competitors or predators (Houston and Stevens 1998). Mountain goat population dynamics have also been demonstrated to be more sensitive to environmental disturbance and harvest than some other species of ungulates (Hamel et al. 2006, Rice and Gray 2010). If mountain goats are vulnerable to bacterial pneumonia leading to mortality or detrimental effects on behavior that may reduce survival probability (e.g., nutritional intake), they may be at risk for prolonged negative effects following exposure to pathogens, and this consideration may be important with respect to setting appropriate harvest quotas. Additionally, if mountain goats are hosts for the bacterial pathogens associated with pneumonia epizootics, they may serve as a source of infection for bighorn sheep where the species are sympatric.

The detection of several of the bacteria implicated in bighorn sheep pneumonia epizootics in adult mountain goats coupled with low kid:adult ratios subsequent to the 2009–2010 bighorn sheep die-off led us to hypothesize that pneumonia was present and negatively affecting mountain goats, particularly kids, in the EHR. To address this hypothesis, from June–August 2013–2015 we observed mountain goat kids with marked adult females in the EHR to document signs of respiratory disease; identify associations between respiratory disease, activity levels, and death; and estimate weekly survival.

## STUDY AREA

Our study area included approximately 149 km$^2$ of Humboldt-Toiyabe National Forest and private land in the EHR (40° 55′ 16.68″ N, 115° 7′ 7.32″ W) in Elko County, Nevada. The EHR is a typical basin-range mountain that runs north south with a single spine ridgeline at over 3,050 m, with the valley floors at 1,700 m. The EHR has a glaciated steep east-faced escarpment with U-shaped canyons and a series of high-elevation cirque lakes that afford snow fields late into the summer months. Annual precipitation averages 89 cm with consistent snow cover at higher elevations from November–June. Mule deer is the dominant native ungulate in the EHR. A large portion of the EHR is designated wilderness with recreation and cattle grazing the primary land uses with ranching and farming in the surrounding valleys. Mountain goats were observed at elevations of 2,500–3,400 m in alpine and subalpine ecosystems commonly consisting of grasses (squirreltail [*Elymus elymoides*], spike fescue [*Leucopoa kingie*], meadow grasses [*Poa* spp.], and bluebunch wheatgrass [*Pseudoroegneria spicata*]), sedges (*Carex* spp.), forbs (arrowleaf balsamroot [*Balsamorhiza sagittata*], yellow Indian paintbrush [*Castilleja flava*], thistles [*Cirsium* spp.], sulfur buckwheat [*Eriogonum polyanthum*], round-leaved alumroot [*Heuchera cylindrical*], Watson's penstemon [*Penstemon watsonii*], and silky phacelia [*Phacelia sericea*], woody vegetation [snowbrush (*Ceanothus velutinus*], curl-leaf mountain mahogany [*Cercocarpus ledifolius*], wormwood [*Artemisia* spp.], yellow rabbitbrush [*Chrysothamnus viscidiflorus*], whitestem goldenbrush [*Ericameria discoidea*], currants [*Ribes* spp.], willows [*Salix* spp.], pines [*Pinus* spp.]), and succulents (*Echinocereus* sp. and *Opuntia polyacantha*).

## METHODS

As part of NDOW's population monitoring program, a subset of the adult female mountain goat population in the EHR is annually marked in winter with uniquely identifiable livestock ear tags. Some mountain goats also had collars (global positioning system [GPS] and very high frequency [VHF], satellite [SAT] and VHF, or VHF only). The capture and marking of mountain goats by NDOW personnel is conducted in accordance with procedures approved by the agency. From mid-May through mid-August in 2013 and mid-May through the end of August in 2014–2015, we used spotting scopes (20–60×) and attempted to locate and identify all marked adult females from a distance $\geq$1 time/week. We determined kid birth dates by locating marked adult females and recording the date when the adult female was first observed with a kid. Snow instability limited access in the early summer and therefore documenting the exact dates kids were born was not possible for most marked adult females. In instances where marked adult females had a kid on our first observation of that female in a year, we assigned the birth date as the median of known kid birth dates. Starting from 1 June, we attempted to create weekly re-sight histories for kids with marked adult females for 11 weeks in 2013 and 13 weeks in 2014 and 2015. Mountain goat kids prior to weaning in fall are dependent on their mothers. The kids of marked adult females could be readily linked to their marked adult females during the study period. Because mountain goat kids do not disperse before weaning (mid-Sep; Festa-Bianchet and Côté 2007), if we observed a marked adult female with a kid and later re-sighted the female without a kid, we assumed that the kid had died. Consultation with the Iowa State University Institutional Animal Care and Use Committee (IACUC) prior to the initiation of the project determined that because this was an observational study conducted at a distance with the use of spotting scopes, an IACUC protocol was not required.

We used bovine respiratory disease scoring methodology (Lechtenberg et al. 2011) as a model to create discrete respiratory health score categories (0–2) to assess respiratory health for all kids with marked females each time we observed them. We observed individuals for $\geq$20 minutes during each observation period. We assigned individuals exhibiting no clinical signs (e.g., alert, no evidence of droopy ears, and no coughing or head shaking) a score of 0, individuals with mild respiratory distress (e.g., coughing no more than once per 20 min, droopy ears, or head shake) a score of 1, and individuals with multiple severe signs (e.g., resting respiration rate greater than 30 breaths/min, nasal discharge, ataxia, or $>$1 cough/20 min) a score of 2.

We constructed behavioral activity budgets for kids with marked adult females weekly during summers of 2014 and 2015. We determined behavioral activity budgets by observing an individual kid and recording the time it spent in 8 discrete behavior categories: resting (head down and inactive), active bedding (head upright or ruminating while laying down), grazing, walking, standing, playing, nursing, and other. We attempted to collect a minimum of 20 minutes of behavior data for each individual kid with a marked adult female at each observation period. We created activity budgets that summarized the proportion of time during each 20-minute observation period that a kid spent in each of the behavior categories. In situations where we collected behavior data for a given kid $>$1 time/week, we averaged the data for that survey week.

We conducted a principal component analysis after performing an additive log-ratio transformation (ALR; Pawlowsky-Glahn and Egozcue 2006) to reduce the dimensionality of the behavior data. The ALR is a commonly used transformation for compositional data such as behavior data. It is a transformation from proportions, data between zero and one, to the real line. The ALR is completed by selecting 1 of the 8 categories ($x_d$) and computing $y_i = \ln x_i / x_d$ for the remaining $i = 1, \ldots, d-1$ categories.

We used a hidden Markov model (HMM) to determine if observed behaviors could be used to identify individual mountain goat kids at risk of dying (Fig. S1, available online in Supporting Information). An HMM is a flexible time series model where the distribution that generates the observed data depends on an unobserved, or latent, state that follows a Markov transition process (Zucchini et al. 2016). We fit a 3-state (corresponding to active, sedentary, dead) discrete HMM where observations could follow different beta distributions depending on state (Fig. S2, available online in Supporting Information). We used a Bayesian inferential methodology using Just Another Gibbs Sampler (JAGS; Plummer 2004). We forced the mean component, percentage of time active, of state 1 (active) to be higher than the mean component of state 2 (sedentary) to provide meaningful inference and avoid the common label switching issue that occurs during Bayesian analysis for HMMs. We also forced each kid to be in state 1 (active) at week 1 (see Supporting Information online for the complete statistical model and JAGS code).

The resulting HMM allowed us to capture several key characteristics of kid behavior. First, it allowed us to determine if a mountain goat kid's behavior changed prior to its death because we could determine the probable state that each of the observed kids was in each time it was observed. From here, we could further overlay the states with respiratory scores to see if there was an association between behavior and respiratory disease. Finally, the model offered insight, based on behavior, into the probability a kid would die in the next week.

We used weekly re-sight histories for kids with marked adult females to estimate weekly kid survival over the course of the summer using the Lukacs young survival from marked adults (YS) model (Lukacs et al. 2004) within Program MARK (White and Burnham 1999). The YS model is a likelihood-based extension to the Cormack-Jolly-Seber (CJS) model that estimates survival of dependent young when only the adult is marked and some young may not have been observed. If the young is always seen with the adult, the model is identical to the CJS model. The YS model estimates apparent survival ($\phi$) and detection probability ($p$). We ran 7 alternative models: 1) weekly and yearly differences in survival and detection, $\phi$(year × week) $p$(year × week); 2) weekly differences in survival and detection, $\phi$(week) $p$(week); 3) weekly differences in survival but constant detection, $\phi$(week) $p$(.); 4) both constant survival and detection, $\phi$(.) $p$(.); 5) a linear trend with differences among years in survival and constant detection, $\phi$(trend + year) $p$(.); 6) a linear trend in survival and constant detection, $\phi$(trend) $p$(.); and 7) a linear trend in survival starting in the ninth week of the study (i.e., the week we first observed signs of respiratory disease in kids) and constant detection, $\phi$(trend $1 = 9$) $p$(.). We conducted model selection using Akaike's Information Criterion corrected for small sample size ($AIC_c$; Akaike 1973, Burnham and Anderson 2002) and checked for non-informative parameters (Arnold 2010).

## RESULTS

Group size in the EHR was variable ($\bar{x} = 3.6 \pm 4.5$ [SD], range = 1–35) and group composition did not appear stable. The earliest we first observed a marked adult female with a kid was on 20 May and the latest on 5 June. Of the marked adult females, we observed 8 (of 13 in 2013), 11 (of 18 in 2014), and 12 (of 22 in 2015) with a kid. We observed 19 marked adult females with kids; we observed 5 adult females with kids in all 3 years, 2 adult females had kids in 2013 and 2014, and the remaining 12 adult females had a kid in only 1 year.

We recorded a respiratory score of 1 or 2 for 8 kids with marked adult females on 13 occasions (0 of 8, 2 of 11, and 6 of 12 kids in 2013, 2014, and 2015, respectively). Of marked adult females that had kids in multiple years, no more than 1 of an adult female's kids exhibited signs of respiratory disease. We first observed kids of marked adult females with signs of respiratory disease in late July or early August (ninth week of the study). Signs primarily included coughing and head shaking. We also occasionally observed nasal discharge, ataxia, and droopy ears. For subsequent analysis, we collapsed respiratory scores of 1 and 2 into a single category. By the end of the summer observation period, 6 of these 8 kids had died, 1 was still alive, and the fate of 1 was unknown because we did not observe the kid or its mother again in subsequent weeks. Mortality was similarly high for kids that we did not observe exhibiting signs of respiratory disease. By the end of the summer observation period, 16 had died, 3 were alive, and the fate of 4 was unknown. We did not recover carcasses for any kids with marked females. However, in each year we also observed signs of respiratory disease in kids whose adult females were not marked. We recovered 5 of these kids' carcasses in the EHR in 2014 and 2015, and all exhibited signs consistent with pneumonia at necropsy and *M. ovipneumoniae* was detected in all cases (P. L. Wolff, Nevada Department of Wildlife, unpublished data).

The first 2 axes of the ALR-transformed principal component analysis had eigenvalues >1 and accounted for 73% of the total variation (Table 1). The first eigenvector was relatively uninformative because the vector puts approximately equal weights on all of the behaviors, whereas the second eigenvector appeared to differentiate more active behavior (grazing and walking) from more sedentary behavior (resting and active bedding). Because we wanted to make use of as much of the behavior data as possible, we combined grazing, walking, playing, and nursing into a single categorical behavior (i.e., active behavior). Although grazing and walking had the highest loadings in the principal component analysis, literature suggests frequency of play and nursing also affect fitness. For instance, the frequency of play was reported to be positively related to pre-weaning kid survival in Canada (Theoret-Gosselin et al. 2015). We assumed that a higher percentage of these active behaviors was indicative of being in state 1 (an active state).

We used the percentage of time a kid was observed in active behaviors as the response variable in fitting the HMM. Of the 23 kids in the study in 2014–2015, 16 had ≥2 observations and could be included in this analysis. These 16 kids had a total of 91 kid-week observations, which we used to fit the HMM. The HMM required a burn-in of 5,000 iterations, which was followed by a draw of 50,000 samples from 3 separate chains in the posterior. This gave 150,000 samples to form the posterior distribution for the parameters. The Gelman–Rubin statistics were all <1.1 and our posterior plots revealed good mixing giving us no reason to believe the Markov chain Monte Carlo chains had not properly converged (Fig. S3, available online in Supporting Information).

The parameter estimates for the HMM (Fig. 1) indicated that during the 20-minute behavior observation period, kids in state 1 were engaged in active behaviors 60% of the time (95% CI = 51–71%), whereas kids in state 2 were active 39% of the time (95% CI = 21–55%). The probability of dying the next week decreased as the time spent engaged in active behaviors increased (Fig. 2). The probability that a kid in state 2 (sedentary) had died the next time its mother was observed was 0.20 (95% CI = 0.07–0.54) in contrast with 0.02 (95% CI = 0.001–0.09) if it was in state 1 (active). Kids with marked females were predicted to be in state 2 (sedentary) on 11 of the 13 occasions when we observed signs of respiratory disease (Fig. 3).

Of the 31 kids with marked adult females, 3 (of 8 in 2013), 10 (of 11 in 2014), and 9 (of 12 in 2015) were dead by the end

**Table 1.** The first 2 axes of the additive log-ratio (ALR) transformed principal component analysis of mountain goat kid behavior based on observations over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, June–August 2013–2015.

| Behavior | Eigenvector 1 | Eigenvector 2 |
|---|---|---|
| Resting | −0.34 | 0.49 |
| Active bedding | −0.34 | 0.49 |
| Grazing | −0.34 | −0.51 |
| Walking | −0.36 | −0.50 |
| Standing vigilant | −0.39 | |
| Playing | −0.41 | |
| Nursing | −0.45 | |

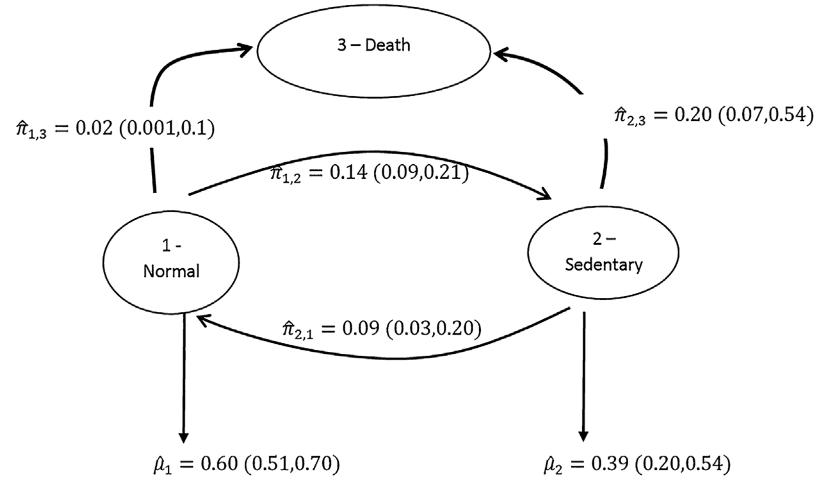

**Figure 1.** Hidden Markov model with mean and 95% confidence interval transition probabilities ($\pi$) between states and parameter estimates ($\mu$) of proportion time spent engaged in active behaviors (grazing, walking, playing, or nursing) by state based on mountain goat kid behavior observed over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, June–August 2013–2015.

of each year's observation period. One out of 8 kids for which we observed signs of respiratory disease and 3 out of 23 kids for which we never observed signs of respiratory disease were known to be alive at the end of the summer. Nine kids died in the 8 weeks prior to our first observing signs of respiratory disease and 13 kids died in the final 5 weeks of the observation period. The observation period was 11 weeks in 2013 compared to 13 weeks in 2014 and 2015. At week 11, 8 of 11 and 7 of 12 kids had died in 2014 and 2015, respectively. Comparison of survival models by $AIC_c$ indicated the most supported model was a linear trend in weekly survival with no difference among years and constant detection (Table 2). This model had 2.7 times the weight as the next ranked model that included an additive year effect for apparent survival. Furthermore, the coefficient for the year effect was not significant, indicating it was a

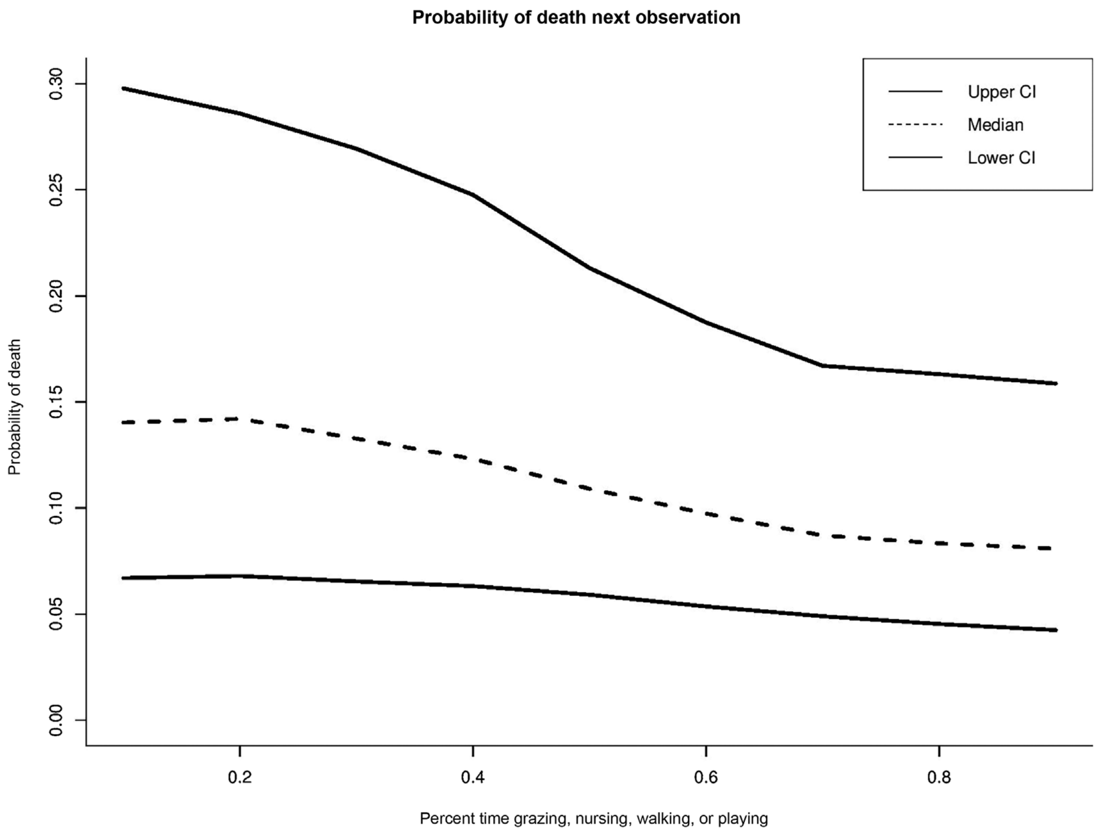

**Figure 2.** Mean probability and 95% confidence interval of mountain goat kids dying based on the proportion of time they spent engaged in active behaviors (grazing, walking, playing, or nursing) derived from a 3-state hidden Markov model based on observations over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, from June–August 2013–2015.

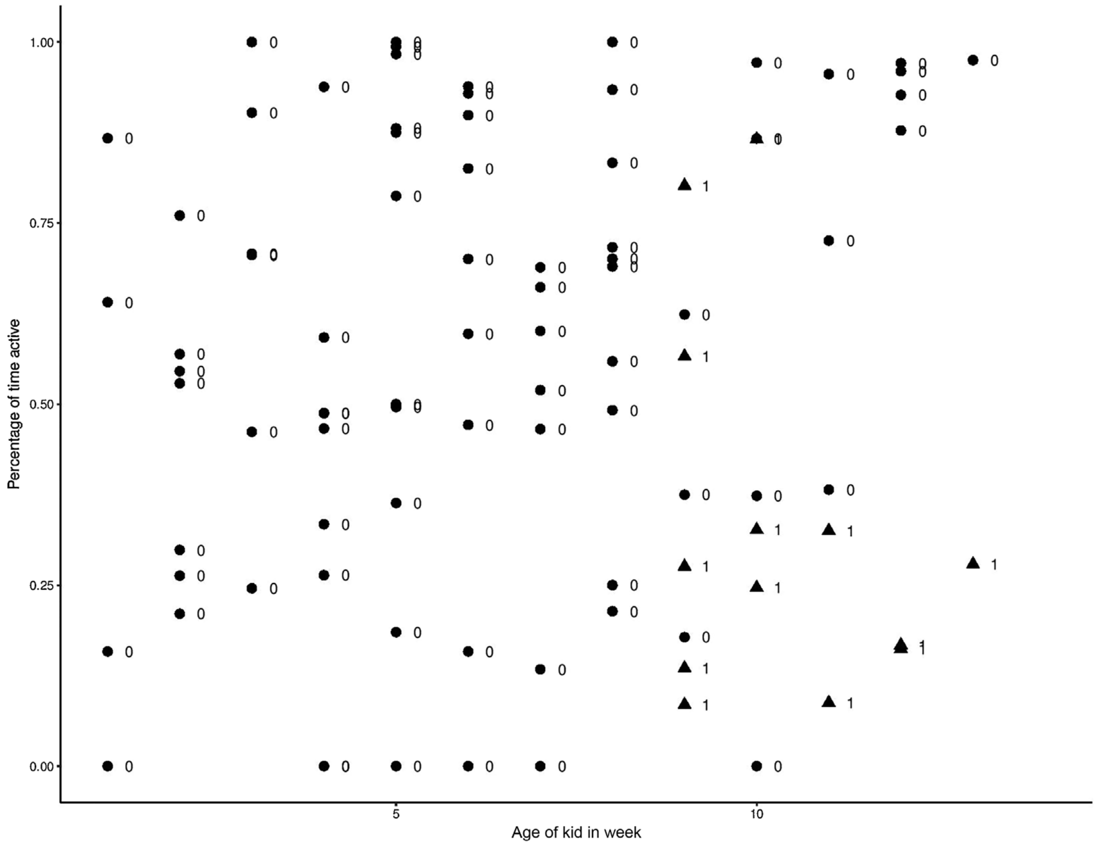

**Figure 3.** Proportion of time spent engaged in active behaviors (grazing, walking, playing, or nursing) in each observation of mountain goat kids over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, June–August 2013–2015. Circles indicate observations where kids were predicted to be in state 1 (active) and triangles indicate observations where kids were predicted to be in state 2 (sedentary) of a 3-state hidden Markov model. Numbers next to symbols represent observed respiratory disease state (0 = no sign of disease, 1 = signs of respiratory disease).

non-informative parameter (data not shown). The most supported model indicated there was a statistically significant negative trend in weekly survival from June–August ($\beta = -0.28$; 95% CI = −0.43 to −0.12; Fig. 4) with a probability of survival over the 13 weeks of 0.19 (95% CI = 0.08–0.38).

## DISCUSSION

Literature on respiratory disease in mountain goats is scarce. Our results indicate that respiratory disease was present in the mountain goat kids in the EHR and negatively affected their behavior and survival. We observed signs of respiratory disease that were similar to those that have been documented in bighorn sheep in 8 of 31 kids with marked adult females and in kids that did not have marked adult females. It is important to acknowledge that we did not test for disease and therefore it is possible that in some cases the signs we observed could have been explained by something other than bacterial pneumonia. However, during our study we did recover the carcasses of 5 kids (some of whom we observed with respiratory signs prior to their death) and all of them showed gross and histologic lesions consistent with pneumonia and were PCR-positive for *M. ovipneumoniae* (P. L. Wolff, Nevada Department of Wildlife, unpublished data), the bacterium considered by many to be primarily responsible for pneumonia epizootics in bighorn sheep (Besser et al. 2014).

The timing of the appearance of signs of respiratory disease in mountain goat kids tended to be later than what has been observed for bighorn sheep lambs (Cassirer et al. 2017). Signs of disease first appeared in kids during the ninth week of our study and continued through week 13 when our study ended. Examination of the dynamics of 8 bighorn sheep populations in Hells Canyon, Idaho, USA, by Cassirer and Sinclair (2007) documented that annually, lamb mortality was greatest from June through August with the highest rates occurring from 6–10 weeks of age. High rates of lamb mortality following pneumonia epizootics in bighorn sheep

**Table 2.** Lukacs young survival from marked adults models for 31 mountain goat kids with marked adult females observed over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, June–August 2013–2015. We assessed models of survival (ϕ) and detection ($p$) using difference in corrected Akaike's Information Criterion ($\Delta AIC_c$) and model weight ($w_i$) based on log likelihood (logLik).

| Model | $AIC_c$ | $\Delta AIC_c$ | $w_i$ | −2logLik |
|---|---|---|---|---|
| ϕ(trend), $p$(constant) | 125.2 | 0.0 | 0.65 | 121.1 |
| ϕ(trend + year), $p$(constant) | 127.2 | 2.0 | 0.24 | 118.9 |
| ϕ(trend 1 = 9), $p$(constant) | 128.8 | 3.6 | 0.11 | 124.7 |
| ϕ(week), $p$(constant) | 135.9 | 10.7 | <0.01 | 107.0 |
| ϕ(constant), $p$(constant) | 139.2 | 14.0 | <0.01 | 135.1 |
| ϕ(week), $p$(week) | 162.3 | 37.1 | <0.01 | 107.0 |
| ϕ(year × week), $p$(year × week) | 351.8 | 226.6 | <0.01 | 85.0 |

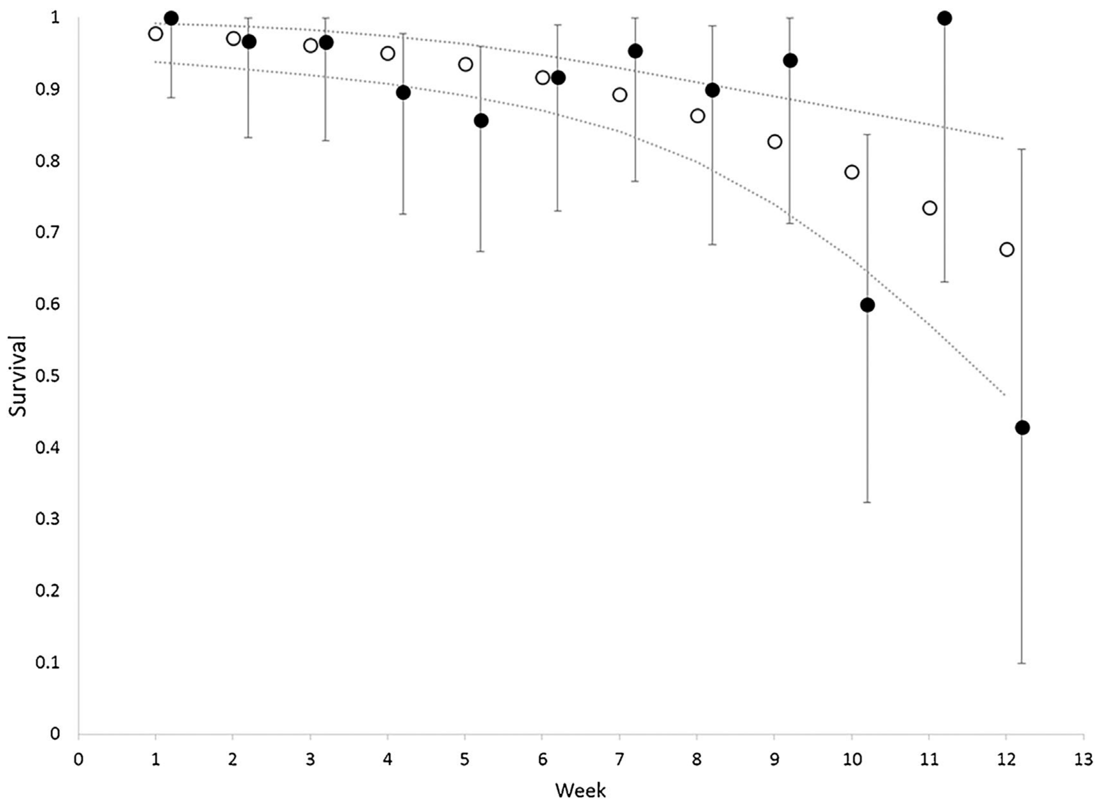

**Figure 4.** Predicted weekly survival rates (open circles) with 95% confidence intervals for a linear trend in survival and constant detection estimated using Lukacs young survival from marked adults and observed survival (closed circles) with 95% binomial confidence limits for 31 mountain goat kids with marked adult females observed over 13 weeks in the East Humboldt Mountain Range, Nevada, USA, June–August 2013–2015.

have led some to suggest that these young animals were less immunocompetent than adults (Monello et al. 2001).

In the majority of instances, where we observed kids showing signs of respiratory disease, kids were predicted to be in the sedentary state (i.e., less frequently engaged in active behaviors). Anorexia and lethargy have been associated with respiratory disease in bighorn sheep (Miller 2004, Besser et al. 2014, Cassirer et al. 2017). Kids predicted to be in the sedentary state had a higher probability of death than kids predicted to be in the active state. In 11 of 13 observations of kids showing signs of respiratory disease kids were also classified as sedentary, suggesting that respiratory disease was contributing to kid mortality in the EHR.

A benefit of using the HMM was that it allowed predictions of kid death based on single observations of kid behavior (whether or not signs of respiratory disease were present). Specifically, if we observed a kid for 20 minutes, we could predict the probability that the kid would die the following week (independent of possible cause). For instance, if we observed a kid engaged in active behaviors for the entire 20-minute period, the probability it would die the following week was 0.08. However, if we did not observe a kid in active behaviors during that time period, it was almost twice as likely that it would not be present the next time we observed its mother (Fig. 2). Because of the construction of the HMM, this is marginalized over the kid's age so it does not require an observer to know how old the animal is.

Death rates for kids with marked adult females in the EHR were high, particularly in 2014 and 2015. The best fitting model was a negative linear trend over time. This is in contrast to what is often observed in ungulates where pre-weaning survival increases with time (Galliard et al. 2000). The model representing decreasing survival starting when we first observed respiratory signs of disease in kids (ninth week of the study) was not well supported. This is not necessarily surprising because kids were subject to mortality prior to our first observation of disease. In addition, once clinical signs of disease appeared in the population, not all kids that died showed signs of disease, suggesting there were additional sources of mortality (e.g., predation, accidents, abandonment). Regardless of the cause of mortality, kid survival in the EHR during our study was low compared to mountain goats elsewhere and other ungulates. Across the 3 years, the probability of survival through August was estimated to be 0.19 (0.08–0.38). A study of mountain goat kids in Caw Ridge, Alberta from 1989–2002 reported kid survival averaged 87% to weaning (~15 Sep) and 64% to 1 year (~1 Jun; Festa-Bianchet and Côté 2007). Survival was variable from year to year but was never <60% to weaning (Festa-Bianchet and Côté 2007). Studies from other mountain goat populations also observed higher survival than we did. Specifically, kid survival to 1 year was estimated to be 56% (range = 46–78%) over 4 years in an introduced population in Colorado, USA (Adams and Bailey 1982) and was 67% and 71% in 2 years of a study of an introduced population in Montana, USA (Smith 1976). Kid survival in the EHR was also low compared to that reported for other ungulates. Average survival to 1 year for 23 ungulate species from 44 populations was estimated to be 50% (Galliard et al. 2000). The aerial surveys conducted by NDOW each February are consistent with our findings. Aerial surveys resulted in an estimated average of 7 kids/100 adults from 2011–2017 compared to the average of 30 kids/100 adults from 2001–2009 (Cox et al. 2017). In addition, aerial surveys have documented a decline in the number of adults over time (Cox et al. 2017). Continued monitoring of this population will help assess how long it takes this population to recover and whether there are significant sources of mortality in addition to respiratory disease that are contributing to the low kid survival in this population.

We must acknowledge some limitations that might have affected our conclusions due to small sample size and potential bias in collection. Our data relied on information from kids with marked adult females, which could be biased. However, we have no reason to believe that the marked animals were a biased subset of the population because helicopter capture by NDOW for population monitoring was based on encounter and so should have been relatively random. Another factor to consider is that our survival estimate could be overestimated if any of the marked adult females had kids that died before we could observe them. Also, similar to Festa-Bianchet and Côté (2007), we assumed that when we did not see kids, their absences were due to mortality even though we did not directly observe death. Finally, with respect to the behavior analysis, the percentage of time kids spent engaged in active behaviors was not statistically different between states likely because of our small sample size. A larger study that included age as a covariate, ensured that all observations took place at the same time of day, and longer observation periods might reduce some of the variability. However, even with the limitations, behavioral data offered insight into the probability a mountain goat kid would disappear. Despite these limitations, it is apparent that respiratory disease was present in mountain goat kids in the EHR and negatively affected their activity levels and survival.

## MANAGEMENT IMPLICATIONS

In the EHR of northeast Nevada, the detection of respiratory disease and low kid survival relative to other mountain goat populations has important implications for both mountain goat and bighorn sheep management. The low kid survival should be taken into consideration when determining the number of harvest tags to issue in the EHR, particularly because female mountain goats can be difficult to distinguish from males. Additionally, some of the bighorn sheep reintroduced to the EHR in 2013 died of pneumonia in fall 2015. Our documentation of respiratory disease in mountain goat kids during this time coupled with our field observations of the 2 species close to each other and evidence that the *M. ovipneumoniae* recovered from pneumonic bighorn sheep was a strain type match to that recovered from the EHR mountain goats (Wolff et al. 2016) suggests that mountain goats may have served as a source of infection. This raises concern about the potential for successful long-term reestablishment of bighorn sheep in the EHR. For range-wide conservation and management of mountain goats and bighorn sheep, it will be important to determine whether our findings are unique to the EHR or if mountain goat populations in other parts of their range also harbor and are negatively affected by bacterial pneumonia.

## ACKNOWLEDGMENTS

Any mention of trade, product, or firm names is for descriptive purposes only, and does not imply endorsement by the U.S. Government. We thank the United States Forest Service Jarbidge Ranger District for logistical support. Without the hard work of our field technicians, J. Hoffmann, W. McCammond, and C. Bleke, this work would not have been possible. We are grateful to S. Talley, T. Nall, and C. Morris for their support. Finally, thanks go to P. Dixon at Iowa State University for assistance with statistical analysis. Comments by R. Garrott, M. Festa-Bianchet, J. Wehausen, and 1 anonymous reviewer significantly improved this manuscript. Funding for this project was provided by the Elko Bighorns Unlimited, Nevada Bighorns Unlimited, the Nevada Department of Wildlife Heritage Trust Fund, and Iowa State University. This paper is a product of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. IOW05434 is sponsored by Hatch Act and State of Iowa funds.

## LITERATURE CITED

Adams, L. G., and J. A. Bailey. 1982. Population dynamics of mountain goats in the Sawatch Range, Colorado. Journal of Wildlife Management 46:1003–1009.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267–281 *in* B. N. Petrov and F. Csaki, editors. Proceedings of the second international symposium on information theory. Akademiai Kiado, Budapest, Hungary.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74:1175–1178.

Besser, T. E., E. F. Cassirer, K. A. Potter, K. Lahmers, J. L. Oaks, S. Shanthalingam, S. Srikumaran, and W. J. Foreyt. 2014. Epizootic pneumonia of bighorn sheep following experimental exposure to *Mycoplasma ovipneumoniae*. PLoS ONE 9:e110039.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:1–172.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York, New York, USA.

Burriel, A. R. 1997. News & Notes: isolation of *Pasteurella haemolytica* from grass, drinking water, and straw bedding used by sheep. Current Microbiology 35:316–318.

Cassirer, E. F., K. R. Manlove, R. K. Plowright, and T. E. Besser. 2017. Evidence for strain-specific immunity to pneumonia in bighorn sheep. Journal of Wildlife Management 81:133–143.

Cassirer, E. F., R. K. Plowright, K. R. Manlove, P. C. Cross, A. P. Dobson, K. A. Potter, and P. J. Hudson. 2013. Spatio-temporal dynamics of pneumonia in bighorn sheep. Journal of Animal Ecology 82:518–528.

Cassirer, E., and A. R. E. Sinclair. 2007. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71:1080–1088.

Clifford, D. L., B. A. Schumaker, T. R. Stephenson, V. C. Bleich, M. L. Cahn, B. J. Gonzales, W. M. Boyce, and J. A. Mazet. 2009. Assessing disease risk at the wildlife-livestock interface: a study of Sierra Nevada bighorn sheep. Biological Conservation 142:2559–2568.

Coggins, V. L., and P. E. Matthews. 1992. Lamb survival and herd status of the Lostine bighorn herd following a *Pasteurella* die-off. Biennial Symposium of the Northern Wild Sheep and Goat Council 8:147–154.

Cox, M., M. Dobel, L. Gilbertson, S. Kimble, K. Lansford, and D. Carter. 2009. Nevada Department of Wildlife 2008–2009 big game status. Nevada Department of Wildlife, Reno, USA.

Cox, M., C. McKee, C. Schroeder, P. Jackson, B. Wakeling, M. Scott, T. Donham, and S. Kimble. 2017. Nevada Department of Wildlife 2016–2017 big game status. Nevada Department of Wildlife, Reno, USA.

Dassanayake, R. P., S. Shanthalingam, C. N. Herndon, R. Subramaniam, P. K. Lawrence, J. Bavananthasivam, E. F. Cassirer, G. J. Haldorson, W. J. Foreyt, F. R. Rurangirwa, D. P. Knowles, T. E. Besser, and S. Srikumaran. 2010. *Mycoplasma ovipneumoniae* can predispose bighorn sheep to fatal *Mannheimia haemolytica* pneumonia. Veterinary Microbiology 145:354–359.

Dixon, D. M., K. M. Rudolph, M. L. Kinsel, L. M. Cowan, D. L. Hunter, and A. C. Ward. 2002. Viability of airborne *Pasteurella* spp. Biennial Symposium of the Northern Wild Sheep and Goat Council 13:6–13.

Festa-Bianchet, M., and S. D. Côté. 2007. Mountain goats: ecology, behavior, and conservation of an alpine ungulate. Island Press, Washington, D.C., USA.

Foreyt, W. J. 1990. Pneumonia in bighorn sheep: effects of *Pasteurella haemolytica* from domestic sheep and effects on survival and long-term reproduction. Biennial Symposium of the Northern Wild Sheep and Goat Council 7:92–101.

Fox, K. A., N. M. Rouse, K. P. Huyvaert, K. A. Griffin, H. J. Killion, J. Jennings-Gaines, W. H. Edwards, S. L. Quackenbush, and M. W. Miller. 2015. Bighorn sheep (*Ovis canadensis*) sinus tumors are associated with coinfections by potentially pathogenic bacteria in the upper respiratory tract. Journal of Wildlife Diseases 51:19–27.

Galliard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of Ecology and Systematics 31:367–393.

Garde, E., S. Kutz, H. Schwantje, A. Veitch, E. Jenkins, and B. Elkin. 2005. Examining the risk of disease transmission between wild Dall's sheep and mountain goats, and introduced domestic sheep, goats, and llamas in the Northwest Territories. Other Publications in Zoonotics and Wildlife Disease 29:1–139.

George, J. L., D. J. Martin, P. M. Lukacs, and M. W. Miller. 2008. Epidemic pasteurellosis in a bighorn sheep population coinciding with the appearance of a domestic sheep. Journal of Wildlife Diseases 44:388–403.

Gross, J. E., F. J. Singer, and M. E. Moses. 2000. Effects of disease, dispersal, and area on bighorn sheep restoration. Restoration Ecology 8:25–37.

Hamel, S., S. D. Côté, K. G. Smith, and M. Festa-Bianchet. 2006. Population dynamics and harvest potential of mountain goat herds in Alberta. Journal of Wildlife Management 70:1044–1053.

Houston, D. B., and V. Stevens. 1998. Resource limitation in mountain goats: a test by experimental cropping. Canadian Journal of Zoology 66:228–238.

Lechtenberg, K., C. S. Daniels, G. C. Royer, D. T. Bechtol, S. T. Chester, J. Blair, and R. K. Tessman. 2011. Field efficacy study of gamithromycin for the control of bovine respiratory disease in cattle at high risk of developing disease. Journal of Applied Research in Veterinary Medicine 9:184–192.

Lukacs, P. M., V. J. Dreitz, F. L. Knopf, and K. P. Burnham. 2004. Estimating survival probabilities of unmarked dependent young when detection is imperfect. Condor 106:926–931.

Marsh, H. 1938. Pneumonia in Rocky Mountain bighorn sheep. Journal of Mammalogy 19:214–219.

McAdoo, C., P. Wolff, and M. Cox. 2010. Investigation of Nevada's 2009–2010 East Humboldt Range and Ruby Mountain bighorn die-off. Biennial Symposium of the Northern Wild Sheep and Goat Council 17:7–11.

Miller, M. W. 2004. Pasteurellosis. Pages 330–339 *in* E. S. Williams and I. K. Barker, editors. Infectious diseases of wild mammals, Third edition. Iowa State University Press, Ames, USA.

Monello, R. J., D. L. Murray, and E. F. Cassirer. 2001. Ecological correlates of pneumonia epizootics in bighorn sheep herds. Canadian Journal of Zoology 79:1423–1432.

Myatt, N., and A. N. Larkins. 2010. Mountain goats in North America: a survey of population status and management. Biennial Symposium of the Northern Wild Sheep and Goat Council 17:1–7.

Onderka, D. K., and W. D. Wishart. 1988. Experimental contact transmission of *Pasteurella haemolytica* from clinically normal domestic sheep causing pneumonia in Rocky Mountain bighorn sheep. Journal of Wildlife Diseases 24:663–667.

Pawlowsky-Glahn, V., and J. J. Egozcue. 2006. Compositional data and their analysis: an introduction. Geological Society, London, Special Publications 264:1–10.

Plowright, R. K., K. R. Manlove, T. E. Besser, D. J. Paez, K. R. Andrews, P. E. Matthews, L. P. Waits, P. J. Hudson, and E. F. Cassirer. 2017. Age-specific infectious period shapes dynamics of pneumonia in bighorn sheep. Ecology Letters 20:1325–1336.

Plummer, M. 2004. JAGS: just another Gibbs sampler. http://www3.jouy.inra.fr/miaj/public/matrisq/Contacts/applibugs.07_11_08.plummer.pdf. Accessed 25 Apr 2016.

Rice, C. G., and D. Gray 2010. Effects of mountain goat harvest on historic and contemporary populations. Northwestern Naturalist 91:40–57.

Singer, F. J., E. Williams, M. W. Miller, and L. C. Zeigenfuss. 2000. Population growth, fecundity, and survivorship in recovering populations of bighorn sheep. Restoration Ecology 8:75–84.

Smith, B. 1976. Ecology of mountain goats in the Bitterroot Mountains, Montana. Thesis, University of Montana, Missoula, USA.

Spraker, T. R., C. P. Hibler, G. G. Schoonveld, and W. S. Adney. 1984. Pathologic changes and microorganisms found in bighorn sheep during a stress-related die-off. Journal of Wildlife Diseases 20:319–327.

Theoret-Gosselin, R., S. Hamel, and S. D. Côté. 2015. The role of maternal behavior and offspring development in the survival of mountain goat kids. Oecologia 178:175–186.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46: S120–S139.

Wild, M. A., and M. W. Miller. 1991. Detecting nonhemolytic *Pasteurella haemolytica* infections in healthy rocky mountain bighorn sheep (*Ovis canadensis canadensis*): influences of sample site and handling. Journal of Wildlife Diseases 27:53–60.

Wolff, P. L., M. Cox, C. McAdoo, and C. A. Anderson. 2016. Disease transmission between mountain goats and sympatric bighorn sheep. Biennial Symposium of the Northern Wild Sheep and Goat Council 20:79.

Zucchini, W., I. L. MacDonald, and R. Langrock. 2016. Hidden Markov models for time series: an introduction using R. CRC Press, Boca Raton, Florida, USA.

*Associate Editor: Robin Russell.*

## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.