Estimating Mountain Lion Abundance in Arizona Using Harvest Records

F. Peck, A. Howard, M. Clement, E. Rubin

Arizona Game and Fish Department

INTRODUCTION

Monitoring the status of wildlife populations is an important component of wildlife management, especially for species managed for harvest. In many cases, it is possible and sufficient to monitor the status of a population using data on numbers, ages, and sex of individuals harvested. This approach has been used by the Arizona Game and Fish Department (AZGFD) in monitoring populations of mountain lions (*Puma concolor*) at a statewide scale. Managers collect age and sex data on harvested animals via mandatory check-in by hunters, and use these data to monitor the population to guide sustainable harvest. Anderson and Lindzey (2005) evaluated this approach experimentally in Wyoming and concluded that age and sex data on harvested mountain lions could be used effectively to inform an adaptive management framework for managing harvest thresholds.

Although AZGFD has effectively used this approach to guide decisions related to mountain lion harvest, harvest data have only been used to monitor mountain lion population trends, and not to generate absolute population estimates. However, to address additional management needs, such as those related to predator-prey relationships, and to address stakeholder questions about the number of mountain lions in the state, managers sought an absolute population estimate for mountain lions in Arizona.

Estimates of population size have previously been generated for mountain lions via a variety of techniques. A common approach for generating an absolute population estimate has been the application of mark-recapture techniques using actual capture of mountain lions (Lambert et al. 2006), or via genetic "marking" and "recapture" using tissue, scat, or hair samples (Russell et al. 2012, Davidson et al. 2014, Beausoleil et al. 2016). Other researchers have generated a minimum population estimate via genetic sampling of scat or hair (Gilad et al. 2011, Naidu et al. 2011, Sawaya et al. 2011), unique identification of tracks

(Germaine et al. 2000, Rosas-Rosas and Bender 2012), or identification of mountain lions via use of remote cameras (Smythe 2008, Rosas-Rosas and Bender 2012).

While these methods are well established, they are labor intensive and generally require extensive field work for data collection. Previous applications have typically focused on a limited geographic area (e.g., a mountain range) or population (Laundré et al. 2007, Kelly et al. 2008, Negrões et al. 2010). For long-term monitoring efforts across a large landscape, the costs and labor needs of these intensive methods are often prohibitive. These shortcomings make these methods impractical for our needs. In Arizona, mountain lions are found in nearly all parts of the state, and the AZGFD sought a method for estimating population size for the entire state. In addition, we sought a method that allowed population estimates to be updated annually, to maximize their use in guiding management decisions and setting yearly harvest thresholds.

To accomplish this goal, we applied virtual population analysis (VPA), also known as cohort analysis, in an age-structured population reconstruction method using harvest data from 2004 through 2016 to generate population estimates for lions in Arizona. VPA was first used in fisheries management where catch data are accessible but other traditional methods of abundance estimation are difficult to apply (Fry 1949, Gulland 1965, Skalski et al. 2005). In recent years, population reconstruction methods have been used to examine population trends in a variety of species such as greater sage-grouse (*Centrocercus urophasianus*; Broms et al. 2010), martens (*Martes americana*; Skalski et al. 2011), and turkeys (*Meleagris gallopavo*; Clawson 2015). When auxiliary data such as overall survival rates and information on cause of mortality have been incorporated into the analysis, these methods have also been used to generate absolute population estimates (Gove et al. 2002, Broms 2007, Clawson et al. 2013, 2016). The objective of this project was to generate absolute statewide population estimates for mountain lions in Arizona using available harvest data and information on survival and cause-specific mortality.

METHODS

Data

We used age-at-harvest data for mountain lions collected by AZGFD during 2004-2016. In Arizona, successful hunters are required to register harvested mountain lions within 10 days of harvest, at which time a premolar tooth is pulled. Hunters were required to mail teeth to AZGFD during 2004-2005 and to physically check-in animals with AZGFD during 2006-2016. Age-at-harvest was determined using cementum annuli analysis conducted by Matson's Laboratory (Manhattan, Montana). In addition, livestock operators are required to report depredation-related removals of mountain lions to AZGFD, although teeth are generally not collected from these animals. Mountain lions are occasionally removed due to public safety concerns, and these are also reported to AZGFD. Mountain lions killed by vehicles, recovered from poachers, or otherwise encountered after death are intermittently reported to AZGFD. For this project, we constructed the age-at-harvest data solely from hunter-harvested, depredation-related, and public-safety removal mountain lions because they are consistently reported to AZGFD. We excluded other mortality categories because they were not reliably reported and our analysis methods assume that harvested animals are reported accurately. Instead, we accounted for these additional categories of mountain lion losses by incorporating estimates of non-harvest mortality rates into our analyses.

We used data on the fate of mountain lions fitted with Global Positioning System (GPS) collars to generate estimates of non-harvest mortality rates. A total of 137 animals were monitored by AZGFD and other researchers between July 2003 and October 2017 during several independent studies in Arizona. Animals were collared in 8 of Arizona's 15 counties. When a collar emitted a mortality signal or GPS data indicated a mortality, researchers investigated to assign a cause of death to the animal.

We also obtained estimates of non-harvest mortality rates from published literature covering hunted mountain lion populations in the Southwest USA. We used scientific search engines to locate peer-reviewed papers that provided estimates of non-harvest mortality rates among hunted populations of mountain lions. We excluded studies of non-hunted populations because we were interested in populations in which mortalities were due to both harvest and non-harvest causes. Similarly, we excluded studies from outside Arizona, southern

California, Nevada, Utah, Colorado, New Mexico, and west Texas because mountain lion mortality causes and rates could differ substantially in dissimilar habitats.

Analysis

We used a virtual population analysis to estimate abundance from age-at-harvest data and survival estimates, using methods developed by Gulland (1965). Essentially, the population is divided into harvest-mortality and non-harvest-mortality animals, with the assumption that all harvest-mortality animals are reported to AZGFD, while non-harvest-mortality animals are typically unreported. We estimated abundance by summing the number of harvest-mortality animals, and then used survival estimates to adjust this tally to account for non-harvest-mortality animals.

Under this approach, harvest data were organized into a year by age-at-harvest table. From 2006 to 2016, 75% of animals were aged, while during 2004-2005, only 47% of animals were aged. We assumed that the unaged animals were a random sample of all animals, and therefore we completed the life table by assigning ages to the unaged animals according to the age distribution of the aged animals. We then summed harvest data within each cohort to obtain preliminary year- and age-specific abundance estimates that do not yet account for non-harvested animals.

For incomplete cohorts, it is necessary to estimate the number of animals alive in the most recent year (2016). To do this, we first estimated the harvest mortality rate for age class *j*,

$$\hat{M}_j = \sum_i h_{i,j} \Big/ \sum_i \hat{N}_{i,j}$$

where $h_{i,j}$ is the number of harvested animals in year *i* and age class *j*, and $\hat{N}_{i,j}$ is the estimated size of the cohort. For the incomplete cohorts, we then estimated cohort size using the known harvest data and the estimated harvest mortality rate, so that

$$\hat{N}_{last,j} = h_{last,j} \Big/ \hat{M}_j$$

where 'last' indicates the most recent year. Once cohort size is estimated for incomplete cohorts, annual abundance of harvest-mortality animals can be estimated by summing across cohorts within each year. These abundance estimates are often termed minimum known population estimates, but in this case, we excluded known individuals with mortality types that are not consistently reported, such as vehicle collisions and poached animals. Thus, these abundance estimates are less than the minimum known population.

The above abundance estimates are clearly lower than the true abundance because they are based only on harvested animals. Therefore, we adjusted the year by age-at-harvest table to account for additional mortality of non-harvested animals. For the oldest age class, we assumed that total mortality is 1 and we adjusted the harvest to estimate cohort size according to

$$\hat{N}_{i,old} = \frac{h_{i,old}}{\left(\dfrac{\mu_{H_{old}}}{\mu_{H_{old}} + \mu_N}\right)}$$

where 'old' indicates the oldest age class, μ_N is the instantaneous 'natural' (non-harvest) mortality rate, and μ_{H_j} is the instantaneous harvest mortality rate, which is estimated by $-\ln\left(1 - M_j\right)$. It should be evident that a higher non-harvest mortality rate yields a higher estimated cohort size. For all other age classes, $\mu_{H_{j-1}}$ is estimated (using numeric methods) from

$$\frac{N_{i,j}}{h_{i-1,j-1}} = \frac{\left(\mu_{H_{j-1}} + \mu_N\right) e^{-\left(\mu_{H_{j-1}} + \mu_N\right)}}{\mu_{H_{j-1}} (1 - e^{-(\mu_{H_{j-1}} + \mu_N)})}$$

and cohort size during the previous year, $N_{i-1,j-1}$, is estimated from

$$N_{i-1,j-1} = N_{i,j} e^{(\mu_{H_{j-1}} + \mu_N)}$$

Again, the larger μ_N, the more that the counts of harvested animals need to be adjusted to account for non-harvest mortality, resulting in a larger estimated cohort size. Again, for incomplete cohorts, the number of animals alive in the most recent year must be estimated from harvest and non-harvest mortality rates (see Skalski et al. 2005 for details). After generating year- and age-specific abundance estimates, annual abundance can be obtained by summing across cohorts.

These calculations required that we have an estimate of the non-harvest mortality rate. We obtained one estimate of the non-harvest mortality rate from the 137 mountain lions fitted with GPS collars in Arizona. We used a nest survival model to estimate daily survival rates for mountain lions (Johnson 1979, Rotella 2016). We then converted the daily survival estimate to an annual mortality rate and used this in the Gulland estimator described above. Because we were interested in non-harvest mortality, we right-censored harvested animals, as well as capture mortalities and animals removed to support a bighorn sheep reintroduction project. We estimated survival rates using the RMark package (Laake 2013) to interface with Program MARK (White and Burnham 1999) in Program R (R Core Team 2016). We also generated abundance estimates using survival rates and non-harvest mortality rates from previously published research on hunted populations in the Southwest USA.

RESULTS

During 13 years (2004-2016), 3,835 harvest mortalities were reported to AZGFD. Considering only these harvested animals and no non-harvest mortalities, the minimum abundance estimates averaged 1,299 animals during 2004-2016 and increased from an estimated 1,199 animals in 2004 to 1,422 animals in 2016, representing an average increase of 1.4% per year (Figure 1). However, this number excludes both a small number of reported mortalities due to vehicle strikes and poaching, and an unknown number of other non-harvest mortalities.

Using the nest survival analysis, we estimated that the annual non-harvest mortality rate for 137 animals with GPS collars was 19.1% per year (SE = 3.6%). Using –ln(1-0.191) for the Gulland estimator increased the estimate of the average population size to 2,683 (Figure 1).

Our literature search revealed four previous studies that provided mountain lion mortality data from hunted populations in the Southwest USA (Table 1). These published estimates of non-harvest mortality rates ranged between 9.0% and 18.0% (Table 1). We used these values to generate additional estimates of abundance

(Figure 1). The 16 mountain lions reported in McKinney et al. (2009) represent a subset of our telemetry dataset.

DISCUSSION

The availability of age-at-harvest data makes age-structured population reconstruction methods appealing where traditional population estimation techniques are impractical. When considering only data from harvested animals, our analyses indicated that during 2004 – 2016 the average population of mountain lions was 1,299 animals with a slightly increasing population trend. However, this number is known to underestimate the population because it does not account for mountain lions that died of non-harvest causes (Skalski et al. 2005). We therefore incorporated information on non-harvest mortality to improve our estimates (Gulland 1965, Skalski et al. 2005). Using mortality data from collared mountain lions, the average estimated population size during this same period is 2,683 mountain lions. Our results suggest a slowly increasing trend with the estimated population reaching 3,006 animals in the most recent year. Additional abundance estimates generated with published mortality data from prior studies in Arizona and other parts of the Southwest USA fell between these two values (Figure 1).

Data from collared animals and published mortality data came from various geographic areas from studies implemented for other purposes. Patterns of mortality likely differ among populations of mountain lions, based on hunter access and other risk factors; however, using the range of documented non-harvest mortality rates from the GPS collared mountain lions in Arizona and the four previous studies, we estimate that the mountain lion population in Arizona has averaged between 1,728 and 2,683 during the past 13 years. Importantly, our analyses suggest that the population has been stable, and likely increasing slightly, indicating that the population, at a state-wide scale, has been harvested at sustainable levels.

Recent advances in population reconstruction modeling (Clawson et al. 2015, 2016) will allow us to further refine our population estimates over time while continuing to make use of harvest data collected on an annual basis. The incorporation of current data on natural (non-harvest) mortality rates has been shown to increase the precision of abundance rates (Clawson et al. 2013, Clawson 2015), while additional years of harvest data will also improve population estimates for this long-lived species (Skalski et al. 2005). Future estimates would also be improved by the incorporation of auxiliary survival data collected at the same spatial extent as our intended area of inference. Our current statewide estimate is based on a range of survival estimates from studies conducted in smaller geographies within and outside of Arizona, but future estimates including those for specific management units, would best be generated using survival data representing the same geographic area (Gove et al. 2002).

MANAGEMENT IMPLICATIONS

Hunter harvest data are easy to collect, relatively low cost, and frequently collected by wildlife managers (Skalski et al. 2005). However, there are some limitations to applying VPA to age-at-harvest data. For a longer lived species such as mountain lions, more recent cohorts will not have entirely passed through the population so final cohort abundance must be estimated. Therefore, the earlier years of cohort data will be more complete than more recent years, making estimates generated from earlier years of harvest data more accurate than those generated with recent (less complete) years of data.

Population reconstruction models provide a convenient and flexible framework for estimating abundance at large spatial scales such as in our study, where other traditional approaches such as mark-recapture methods may not be practical. Our analyses produced a statewide estimate that will be useful in monitoring statewide trends in population abundance but may not be appropriate for making inferences at a smaller scale. However, mountain lion management generally occurs at smaller geographic scales, such as zones or game management units. It may therefore be useful to estimate abundance based on more spatially refined harvest units in which informed management decisions can be made. In Arizona, the use of VPA will be further investigated to estimate abundance of mountain lions within smaller geographic areas, such as mountain lion management zones, to inform management decisions at the most appropriate scale.

Acknowledgements

Data were kindly provided by Dave Conrad, Brian Jansen, Andrew Jones, and Dan Sturla from AZGFD, Kirsten Ironside from U.S. Geological Survey, and Kerrie Nicholson from University of Arizona. This project was funded by a grant to the Arizona Game and Fish Department through the Federal Aid in Wildlife Restoration Act. XX, AZGFD, provided helpful comments on an earlier draft of this paper.

Literature Cited

Anderson, C.R. and F.G. Lindzey. 2005. Experimental evaluation of population trend and harvest composition in a Wyoming cougar population. Wildlife Society Bulletin 33(1):179-188.

Beausoleil, R. A., Clark, J. D., and Maletzke, B. T. 2016. A long-term evaluation of biopsy darts and DNA to estimate cougar density: an agency-citizen science collaboration. Wildlife Society Bulletin 40(3):583-592.

Broms, K. 2007. Small game population reconstruction: model development and applications. Thesis. University of Washington, Seattle, Washington.

Broms, K., J. R. Skalski, J. J. Millspaugh, C. A Hagen, and J. H. Schultz. 2010. Using statistical population reconstruction to estimate demographic trends in small game populations. The Journal of Wildlife Management 74(2):310-317.

Clawson, M. V. 2015. Management application of statistical population reconstruction to wild game populations. Doctoral thesis. University of Washington, Seattle, Washington.

Clawson, M. V., J. R. Skalski, J. L. Isabelle, and J. J. Millspaugh. 2015. Trends in male turkey abundance and harvest following restoration efforts in the southwest region of Missouri, 1960-2010. The Wildlife Society Bulletin 39(1):116-128.

Clawson, M. V., J. R. Skalski, and J. L. Isabelle. 2016. Statistical population reconstruction, a tool to improve how states monitor wildlife trends. The Wildlife Professional 10(2):34-37.

Clawson, M. V., J. R. Skalski, and J. J. Millspaugh. 2013. The utility of auxiliary data in statistical population reconstruction. Wildlife Biology 19(2):147-155.

Cunningham, S.C., W.B. Ballard, and H.W. Whitlaw. 2001. Age structure, survival, and mortality of mountain lions in southeastern Arizona. Southwestern Naturalist 46(1):76-80.

Davidson, G. A., D. A. Clark, B. K. Johnson, L. P. Waits, and J. R. Adams. 2014. Estimating cougar densities in northeast Oregon using conservation detection dogs. The Journal of Wildlife Management 78(6):1104-1114.

Fry, F.E. 1949. Statistics of a lake trout fishery. Biometrics 5:26-67.

Germaine, S. S., K. D. Bristow, and L. A. Haynes. 2000. Distribution and population status of mountain lions in southwestern Arizona. The Southwestern Naturalist 45(3):333-338.

Gilad, O., J. E. Janečka, F. Armstrong, M. E. Tewes, and R. L. Honeycutt. 2011. Cougars in Guadalupe Mountains National Park, Texas: estimates of occurrence and distribution using analysis of DNA. The Southwestern Naturalist 56(3):297-304.

Gove, N. E., J. R. Skalski, P. Zager, and R. L. Townsend. 2002. Statistical models for population reconstruction using age-at-harvest data. The Journal of Wildlife Management 66(2):310-320.

Gulland, J. A. 1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report, document no. 3. International Council for the Exploration of Sea, Copenhagen, Denmark.

Kelly, M. J., A. J. Noss, M. S. Di Bitetti, L. Maffei, R. L. Arispe, A. Paviolo, C. D. De Angelo, and Y. E. Di Blanco. 2008. Estimating Puma Densities from Camera Trapping across Three Study Sites: Bolivia, Argentina, and Belize. Journal of Mammalogy, 89(2):408-418.

Lambert, C. M. S., R. B. Wielgus, H. S. Robinson, D. D. Katnik, H. S. Cruickshank, R. Clarke, and J. Almack. 2006. Cougar population dynamics and viability in the Pacific Northwest. Journal of Wildlife Management, 70(1):246-254.

Laundré, J. W., L. Hernández, and S. G. Clark. 2007. Numerical and Demographic Responses of Pumas to Changes in Prey Abundance: Testing Current Predictions. The Journal of Wildlife Management, 71(2):345-355.

McKinney, T. T.W. Smith, and R.B. Waddell. 2009. Rates of survival and sources of mortality of cougars in hunted populations in north-central Arizona. Southwestern Naturalist 54(2):151-155.

Naidu, A., L. A. Smythe, R. W. Thompson, and M. Culver. 2011. Genetic analysis of scats reveals minimum number and sex of recently documented mountain lions. Journal of Fish and Wildlife Management 2(1):106–111.

Negrões, N., P. Sarmento, J. Cruz, C. Eira, E. Revilla, C. Fonseca, R. Sollmann, N. M. Tôrres, M. M. Furtado, A. T. A. Jácomo, and L. Silveira. 2010. Use of Camera-Trapping to Estimate Puma Density and Influencing Factors in Central Brazil. The Journal of Wildlife Management, 74(6):1195-1203.

Rosas-Rosas, O. C. and L. C. Bender. 2012. Population status of jaguars (*Panthera onca*) and pumas (*Puma concolor*) in northeastern Sonora, Mexico. Acta Zoológica Mexicana, 28(1):86-101.

Russell, R. E., J. A. Royle, R. Desimone, M. K. Schwartz, V. L. Edwards, K. P. Pilgrim, and K. S. McKelvey. 2012. Estimating abundance of mountain lions from unstructured spatial sampling. The Journal of Wildlife Management, 76(8):1551-1561.

Sawaya, M. A., T, K. Ruth, S. Creel, J. J. Rotella, J. B. Stetz, H. B. Quigley, and S. T. Kalinowskie. 2011. Evaluation of noninvasive genetic sampling methods for cougars in Yellowstone National Park. The Journal of Wildlife Management, 75(3):612-622.

Skalski, J.R., K.E. Ryding, and J.J. Millspaugh. 2005. Wildlife Demography. Pp 1-636. Elsevier Academic Press. Burlington, MA.

Skalski, J. R., J. J. Millspaugh, M. V. Clawson, J. L. Belant, D. R. Etter, B. J. Frawley, and P. D. Friedrich. 2011. Abundance trends of American martens in Michigan based on statistical population reconstruction. The Journal of Wildlife Management 75(8):1767-1773.

Smythe, L. 2008. Recent records of pumas (Puma concolor) on the Kofa National Wildlife Refuge, Arizona. Journal of the Arizona-Nevada Academy of Science 40(2):155-156.

Stoner, D. C., M. L. Wolfe, and D. M. Choate. 2006. Cougar exploitation levels in Utah: implications for demographic structure, population recovery, and metapopulation dynamics. Journal of Wildlife Management, 70(6):1588-1600.

Young, J. H., M. E. Tewes, A. M. Haines, G. Guzman, and S. J. DeMaso. 2010. Survival and mortality of cougars in the Trans-Pecos region. The Southwestern Naturalist, 55(3):411-418.

Table 1: Sources of estimates of non-harvest mortality rates.

Source	Location	No. of mountain lions	Non-harvest mortality rate	Notes
Cunningham et al. 2001	SE Arizona	24	12.9%	
Stoner et al. 2006	S-Central Utah	110	12.6%	We combined estimates from two study sites.
McKinney et al. 2009	N-Central Arizona	16	18.0%	We combined estimates from two study sites.
Young et al. 2010	W Texas and SE New Mexico	60	9.0%	We combined estimates from three study sites.

Figure 1: Estimated abundance of mountain lions in Arizona, 2004-2016, using a range of non-harvest mortality rates.

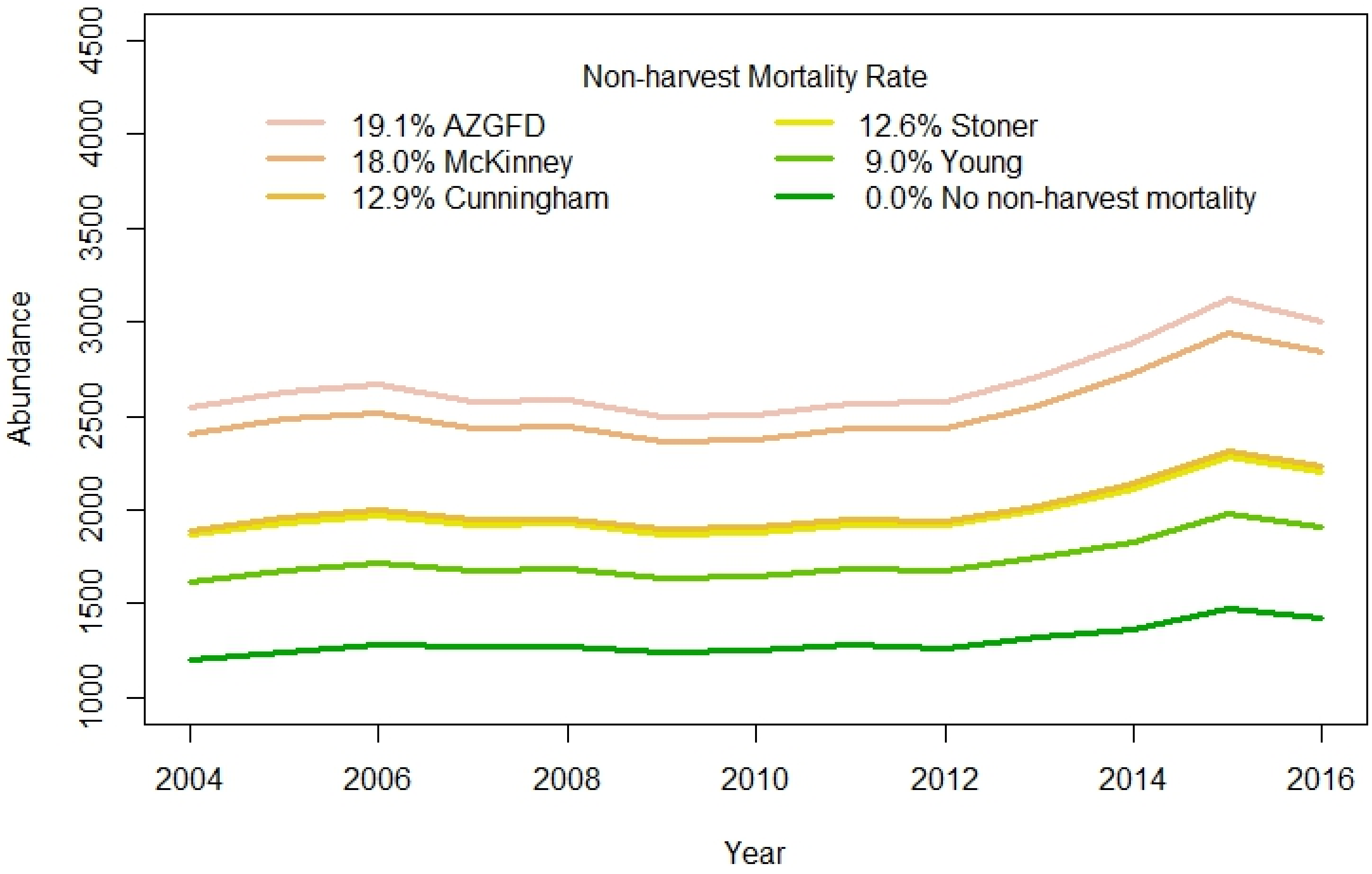

Figure 1: Estimated abundance of mountain lions in Arizona, 2004-2016, using a range of non-harvest mortality rates.