Estimating Mountain Lion ~~Survival and~~ Abundance and Survival in Arizona, 200~~3~~4-2016~~5~~

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INTRODUCTION

One of the most challenging aspects of mountain lion (*Puma concolor*) management is that abundance and density are difficult to estimate because of their elusive behavior, solitary nature and propensity for nocturnal movements. In Arizona, their distribution in rugged terrain and wide dispersal across the state make them a difficult population to study at large spatial scales. The high cost of field-intensive, long-term research projects is another limitation, making efforts to count every mountain lion logistically impractical or economically prohibitive. As an alternative to direct counts, indices and noninvasive sampling are widely used as alternative methods to survey mountain lion populations. Track counts, remote cameras, and genetic analysis of scats have been used to estimate local abundance in Arizona (Germaine et al. 2000, Smythe 2008, Naidu et al. 2011), but there are limitations to extrapolating these estimates to the statewide population (Long et al. 2003, CMGWG 2005, Choate et al. 2006). Consequently, wildlife managers may use expert opinion, numbers of mountain lion sightings, depredation incidents, and harvest as proxies for population size and trend (Martorello et al. 2006). However, these are not ideal methods for evaluating mountain lion populations because sighting reports can be unreliable and harvest information generally are not sensitive to small-to-moderate population changes over a short period of time.

In Arizona, statewide mountain lion abundance and survival is poorly understood and studies of survival and abundance have been limited in scope and sample size. Cunningham et al (2001) estimated low rates of survival (0.62) for a heavily exploited population of radio-collared mountain lion adults for southeastern Arizona and found it was one of the lowest in the country. McKinney et al (2009) compared estimated rates of survival in radio-collared mountain lions in 2 different study sites in north-central Arizona for 2006 and 2007. Survival rates ranged from 0.50 to 1.0 during that time period with combined rates of survival for the two years estimated at 0.40 for the Payson site and 0.55 for the Prescott site (McKinney et al 2009).

Given the shortcomings of indices and the increased public scrutiny of wildlife management, there is a need for reliable and affordable techniques to monitor population trends for mountain lions, especially for those in hunted populations (e.g., Anderson and Lindzey 2005). Currently, in Arizona, sex and age structure derived from harvested mountain lions is used to monitor trends in age and sex ratios but modern analytical developments offer additional opportunities for assessment (Gove et al. 2002, Skalski et al. 2005b). In this paper, we use statistical population reconstruction models of Fry (1949) and Gulland (1965) as reported by Skalski (2005a & b) using age-at-harvest data from 2004 through 2015 to estimate a range of total abundance for mountain lions statewide.

Statistical population reconstruction (SPR), also known as cohort analysis, is an age-structured population reconstruction method that uses age-at-harvest data to reconstruct cohort abundance over time and sums across cohorts to estimate animal abundance (Skalski 2005b). SPR was first used in fisheries management where catch data are accessible but other traditional methods of abundance estimation are difficult to apply. More recently, SPR has been applied to a variety of mammals including mountain lions (Clawson), black bear (Skalski 2005b), martens, (Skalski 2011), elk (Gove et al. 2002), moose (Ueno et al 2009), and black-tailed deer (Skalski et al 2005c).

Hunting harvest of mountain lions (Puma concolor) in Arizona is the primary mechanism for population level management (AGFD Mountain Lion and Bear Conservation Strategies Report 2009). There is a need for reliable and affordable techniques to monitor population trends for large scale species management plans, especially for those with hunted populations (e.g., Anderson and Lindzey 2005). Population survey techniques, such as track counts and monitoring of radio-collared animals have been used to estimate local abundance in populations in Arizona, but there are limitations to extrapolating these estimates to the statewide population. In this paper, we use cementum annuli tooth age data from premolar teeth removed during physical inspection between 2004 and 2015 to calculate age at harvest. Then by applying virtual population analysis models, we estimate the minimum abundance of mountain lions in the state.

Arizona offers a liberal hunting season for mountain lions. A tag is required to harvest a mountain lion in Arizona, and tags are available in unlimited number sold over-the-counter each year. Thus, individuals can hunt mountain lions anywhere in the state during the calendar year. The annual bag limit for mountain lions is one per calendar year except in areas designated as multiple bag limit areas. This liberal season structure allows for the harvest of an unlimited numbers of mountain lions of either sex in areas delimited only by hunter choice during a legal hunting season. Intense harvest under an open hunting strategy has been correlated with reduced short-term survival rates or local reductions in abundance (Anderson and Lindzey 2005).

Arizona's mountain lion management objective is to maintain a statewide population at levels that provide diverse recreational opportunities, while minimizing negative impacts to the mountain lion population due to hunting or to big game prey species due to predation by mountain lions. Specific objectives include maintaining an annual harvest of ≥ 250 animals per year and providing recreational opportunities for ≥ 6,000 hunters per year (AGFD Mountain Lion and Bear Conservation Strategies Report 2009). Within established mountain lion management zones, Arizona manages for adult (≥ 3 years of age) female harvest to be < 35% of the total take in that zone. Should female take exceed 35% of the total take, management objectives allow for implementing female harvest limits or restricting the season length.

One of the major difficulties with mountain lion management is that direct survey counts of mountain lions are not feasible, due to their secretive behavior, propensity for nocturnal movements, low abundance, and distribution in rugged terrain with abundant cover (AGFD Mountain Lion and Bear Conservation Strategies Report 2009). As an alternative to direct survey, indices have been proposed as alternative methods to survey lion populations. Indexing sign surveys, such as track counts, scent stations, and capture-mark recapture methods, have limited applicability for broad scale management programs that encompass diverse environmental conditions (Long et al. 2003, CMGWG 2005, Choate et al. 2006). Another indirect method, mark-recapture genetic data collection, has potential for cost effective, statistically-valid population estimates if restricted to defined geographic management areas for initial sampling efforts, but then can be applied to similar habitats and acreages (DeSimone et al. 2008).

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McKinney et al (2009) compared estimated rates of survival also in radio-collared mountain lions for 2006 and 2007 for Payson and Prescott in north-central Arizona. The rates of survival were estimated at 0.50 in 2006 for Payson and 1.0 for Prescott. In 2007, the rates of survival were 0.67 and 0.55 for Payson and Prescott respectively with combined rates of survival for the two years estimated at 0.40 for Payson and 0.55 for Prescott (McKinney et al 2009).

In this paper, we estimate total minimum abundance for mountain lions statewide using virtual population analysis of Fry (1949) and Gulland (1965) as reported by Skalski (2005*a* & *b*) using cementum annuli tooth age data for years 2003-2015.

Virtual population analysis (VPA), also known as cohort analysis, is an age structured population reconstruction method based upon age at harvest (Skalski 2005*b*). VPA was also first used in fisheries management where catch data are accessible but other traditional methods of abundance estimation are difficult to apply. VPA has been applied to a variety of mammals including moose (Ueno et al 2009) and black-tailed deer (Skalski et al 2005*c*).

In an age-structured population model, the population is monitored according to age class rather than in its totality and estimates minimum population size by summing harvest numbers over the lifetime of the cohort.

METHODS

We used age-at-harvest data collected from premolar teeth which were removed from hunter harvested mountain lions in Arizona during mandatory physical inspections from 2004-2016. Successful hunters were required to register harvested mountain lions within 10 days of harvest at which time the tooth was pulled and reported sex was verified. Tooth submission was initially voluntary, but made mandatory in 2006. Age at harvest was determined using cementum annuli analysis (Matson's Laboratory, Manhattan, Montana). Usable teeth averaged 84% of the annual harvest. We assumed that the distribution of ages from submitted teeth represented the overall harvest and inflated age-at-harvest records accordingly for those with unknown ages.

Only mountain lions that were hunter harvest or depredation removals were included in the cohort analysis. Mountain lions killed illegally or from vehicle collisions were removed from the cohort analysis but included in the natural mortality analysis described in more detail below.

Comment [AH1]: We need to double check with Matt on this. Need to make sure the natural mortalities from the database were included in his natural mortality analysis. If not, we need to talk about this some more. They need to be included in the analysis somehow since they are known lions that we had in hand.

The mountain lion hunting season was yearlong from 2004-2007. In 2007, the mountain lion hunting season was shortened to 9-months with a closure from June through August. In 2012, the hunt season was again extended to yearlong and remained that way through the study period. Because of the lengthy hunting season, it was presumed that harvest and natural mortality were occurring concurrently.

Population reconstruction does not rely on harvest numbers alone but requires the integration of auxiliary data, such as survival rates, harvest probabilities, and reporting rates, to relax assumptions and reduce confidence intervals making the estimated abundance more reliable (Fieberg et al. 2010). In this paper, we used reported natural and harvest mortality rates from studies of hunted mountain lion populations conducted in the southwest after the year 2000 to develop a probable range of total abundance. We then calculated a statewide natural mortality rate based on mountain lion survival data collected from independent studies around the state.

Description of Matt's natural mortality rate analysis

The following survival rates and abundance estimates are based on Arizona mountain lion harvest and cementum annuli tooth age data from 2003- 2015. Data presented were taken from reports generated through the mandatory reporting system instituted in 1989, which requires successful mountain lion hunters to report their kill within 10 days of harvest (Arizona Game and Fish Commission). Age at harvest was determined using

~~cementum annuli tooth age data (Matson's Laboratory, Milltown, Montana) from premolar teeth removed during the physical inspection. Harvest records where tooth age data were absent or unreliable were removed from the cumulative age and harvest calculations.~~

Minimum Total Abundance

Virtual population analysis method of Fry (1949) estimates minimum population size by summing harvest numbers over the lifetime of the cohort. The estimate of abundance, N_{ij}, of the *j*th age class in the *i*th year, is the sum

$$N_{ij} = \sum_{k=0}^{\min(A,Y)} h_{i+k,\, j+k},$$

where

h_{ij} = number of animals harvested in year *i* of age class *j*;
A = maximum age class;
Y = maximum number of years of data collection.
k = cohort at year 0

Total abundance in any year would then be estimated by the sum:

$$N_i = \sum_{j=1}^{A} N_{ij}$$

Assumptions for the Fry (1949) virtual population analysis (VPA) abundance estimates include

1. Age classification is accurate
2. Harvest numbers are reported accurately
3. Harvest mortality is the primary source of mortality in the population
4. Natural mortality is low and constant over time.

Skalski (2005) reports that the virtual population analysis of Fry (1949) provides a minimum population size for years with complete information. Skalski (2005) further reports that as harvest mortality approaches total annual mortality, the Fry estimate will approach actual abundance.

Virtual population analysis (VPA): methods developed by Gulland (1965)

After evaluating the method of Fry, we further applied the methods of Gulland. This method is more realistic than Fry's method because it adjusts cohort abundance for both natural and harvest mortality. Assumptions of this method are:

- Age classification is accurate
- Harvest numbers are reported accurately
- The instantaneous natural mortality rate is constant and known
- The harvest mortality rate of the oldest age class is known

Essentially, the number of harvested animals is adjusted upward to account for natural mortality, and then the adjusted numbers are added up, as before. The Gulland method allows us to incorporate natural mortality rates (if known), and relax the Fry assumption that natural mortality is low. We don't have statewide estimates of these numbers, and we know that these mortality rates and the contribution of natural and harvest mortality to these rates varies across the state, depending on harvest pressure (e.g., influenced by access, proximity to urban areas) and lion densities. We therefore used low and high range of these estimates, to generate low and high population estimates. We used published information, with an emphasis on Arizona and the southwest.

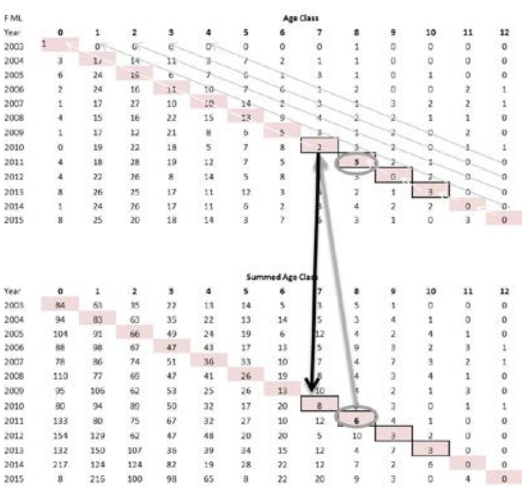

Figure 1 – VPA method of estimating abundance using cohort

RESULTS

Estimated Range of Annual ~~Survival Probability~~Total Abundance ~~Estimates~~

Between 200~~3~~4 and 201~~5~~6, 3,806 lions were harvested, including 2,069 males and 1,737 females. Age was estimated for 2,437 lions (64% of total harvested). Age was not estimated for some due to lack of tooth collection. Some mountain lions lack premolar teeth. We found 6 estimates of natural mortality rates that we thought were relevant to conditions in Arizona. Our analyses suggest an estimated range of ~~minimum~~ total ~~population of~~ abundance at approximately 1500-2000 but the population could be as large as 3500- 4000, dependent on the overall and natural mortality rates used in the analysis.

Annual Survival Probability Estimates

Table 1. Design of Cohort Table for Male Mountain Lion

Comment [AH2]: Update with correct numbers from 2004-2016

Comment [AH3]: Update with current numbers once we receive from Matt

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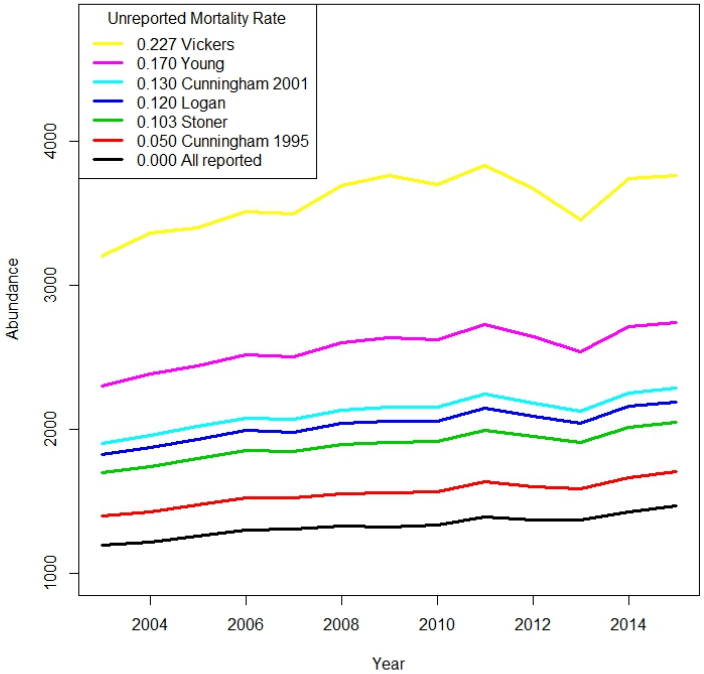
Harvest Data	Number of male mountain lions																			
Age class	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total		No Age	Depred	Total
2003				2												2		107	36	145
2004		9	7	6	6	5	2	1				1				37		87	15	139
2005	2	16	19	17	6	8	3	1	2	2	1					77		26	24	127
2006	1	14	28	20	9	4	6	1								83		29	19	131
2007	1	9	30	32	19	14	6	5	2	2	1		1			122		27	21	170
2008	5	19	21	30	20	15	6	6	1	3	3				1	130		16	19	165
2009	7	14	20	36	24	4	13	7	1	1	1					128		23	15	166
2010	3	15	24	18	22	19	9	6	6	3	4		1		1	131		19	25	175
2011	1	28	33	27	22	14	7	8	6	2						148		13	21	182
2012	2	24	27	18	17	12	3	8	3	1	3				1	119		12	21	152
2013	2	28	34	25	20	15	5	8	2	2	2	1		1		145		20	25	190
2014	6	17	19	20	7	10	2	3	4	2		1				91		22	24	137
2015	9	17	21	18	20	16	10	9	2	3	1		1			127		46	17	190
Total	39	210	283	269	192	136	72	63	29	21	16	3	3	1	3	1340				

Virtual Population Analysis

Minimum abundance was calculated for mountain lions statewide using age-specific mortality and cementum annuli tooth age data in Table 2 and 3. For any age class, abundance was estimated by summing harvest numbers over the lifetime of the cohort.

The estimate of minimum abundance is summed for cohort age class 0 through age class 10 (the area in Tables 2 and 3 shaded in gray) for years 2003–2015.



Figure

Table 3. Cohort table for calculating minimum total abundance in statewide male mountain lion populations

~~**Mountain Lion Zones**~~

DISCUSSION

Annual survival estimates in the current study were found to be higher than those reported for Arizona by either Cunningham et al (2001) or McKinney et al (2009). The sample size in the current study represents the statewide harvest of mountain lions for 2004–201~~4~~6 of 204-304 mountain lions with a mean annual harvest of 253 mountain lions compared to 24 lions reported by Cunningham et al (2001) and 16 lions in the McKinney et al (2009) study. As reported above, Cunningham et al (2001) studied a small radio-collared population in southeastern Arizona.

Comment [AH4]: Update with 2004-2016 numbers

Annual survival estimates and ~~minimum~~ a range of total abundance were calculated for mountain lions statewide from 2004–2016~~4~~. Annual survival estimates were similar for males and females and are within range of those reported for other states by Cunningham et al (2001). The range of annual survival rates reported by Cunningham et al (2001) is found in Table 4.

Table 4 – Annual survival rates of mountain lions in the United States (Cunningham et al 2001)

Location	Conditions	Surivival Rate	Reference
Arizona	Sport hunt/depredation control	0.55	Cunningham 2001
Utah	Sport hunt	0.68	Robinette et al 1997
Nevada	Sport hunt	0.73	Ashman et al unpubl rep 1983
Wyoming	Sport hunt	0.73-1.00	Logan et al 1986
Utah	Unhunted	0.72	Lindzey et al 1988
California	Unhunted	0.75	P. Beier and R . Barrett In litt.
Colorado	Unhunted	0.88	Anderson et al 1992
New Mexico	Unhunted	0.86	Ruth et al 1988

~~Annual survival estimates in the current study were found to be higher than those reported for Arizona by either Cunningham et al (2001) or McKinney et al (2009). The sample size in the current study represents the statewide harvest of mountain lions for 2004–2014 of 204-304 lions with a mean annual harvest of 253 lions compared to 24 lions reported by Cunningham et al (2001) and 16 lions in the McKinney et al (2009) study. As reported above, Cunningham et al (2001) studied a small radio-collared population in southeastern Arizona.~~

~~Mountain lions killed under the Department's livestock depredation policy are not factored into the survival probabilities or minimum abundance estimates since tooth age data is not collected from them. Having tooth age data from this subset of mountain lions would provide a more comprehensive picture of survival and abundance of statewide mountain lion populations.~~

While there are some limitations with using harvest only data, these estimations currently provide previous unknown statewide estimates of ~~minimum~~ abundance and survival and will be useful in monitoring population trend ~~and survivals~~. The availability of age-at-harvest data makes population reconstruction methods appealing where mark and recapture and visual count surveys are difficult, impractical, or impossible.

The abundance estimates from the Fry VPA analysis tend to underestimate abundance so these estimates are thought to be conservative and represent minimum numbers. The value of these estimates lies in providing a baseline for monitoring trend and informing management.

Comment [AH5]: We'll need to change this since we used Gulland.

Anderson and Lindzey (2005) reported that while research suggests that mountain lion populations can sustain harvest rates of up to 20-30%, harvest effects will differ depending on the age and sex of mountain lions removed. Harvest of males and sub-adult females will have less of an impact on the population because males are replaced by immigration while females are replaced by female young produced in the population.

Comment [AH6]: How does this fit in?

In this analysis, only hunter harvest mortality is reviewed. Reviewing 2003–2015 for mountain lion mortalities other than hunter kills (i.e., Department nuisance removals, reported natural mortality, vehicle mortalities, and illegal kills), these other mortalities accounted for less than 1% of total mountain lion mortality (Table 6). Mortality type as a function of survival may provide additional information on which to make informed mountain lion population management decisions.

Limitations

Incomplete cohorts = decreased abundance

Inability to differentiate between male and female individuals; one survival rate for both sexes and all age classes

Assumes no immigration or emigration

Additional inputs such as harvest probabilities, reporting rates, hunter effort, etc… Gove et al 2002 Although we assume reporting rates are high because mandatory reporting requirements and physical inspections have been in place for over a decade, we currently lack these data. Follow-up surveys could be conducted with mountain lion tag holders to further evaluate reporting rates. Different survival rates for ages or age classes.

Table 6. Hunter Harvest and Other Mortality for mountain lions in Arizona from 2003–2015.

Analysis at the Mountain Lion Management Zone level is currently underway to look for spatial as well as temporal survival rates and abundance. Population reconstruction methods and survival estimates provide tools for estimating and monitoring mountain lion populations temporally and spatially where survey or mark and recapture methods are unavailable. Hunter harvest data are easy to collect, relatively low cost to collect, and can provide crucial information on survival, productivity, age composition, and abundance (Skalski et al 2005). Population reconstructions methods can be used in conjunction with tagging or radio-telemetry studies to refine the accuracy of the abundance estimates.

MANAGEMENT IMPLICATIONS

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Population reconstruction models provide a flexible framework for estimating abundance at large spatial scales, where traditional surveys or long-term, expensive mark-recapture methods may not be practical. It also allows wildlife managers to monitor changes in abundance over time and predict population trajectory by estimating both past and present population abundance (Clawson et al. 2016). Hunter harvest data are easy to collect, relatively low cost, and can provide crucial information on survival, recruitment, age composition, and abundance (Skalski et al 2005). Population reconstructions methods can be used in conjunction with indices or radio-telemetry studies to refine the accuracy of abundance estimates.

SPR models can be tailored to the specific harvest and auxiliary data that wildlife management agencies have available. demographic data collected from both radio-collared and harvested mountain lions are often used to inform statistical models, which can then be used to monitor population growth rates and trajectory (CMGWG 2005, Whittaker and Wolfe 2011). The resulting model can be used to estimate annual population abundance, as well as investigate the effects of management actions. Predict harvest probability

Population reconstruction can be conducted annually, or any other desired length of time, incorporating current harvest data to update total abundance estimates. It can be used as an additional tool to monitor changes in mountain lion populations from year-to-year and to refine management approaches. In Arizona, SPR is currently underway to estimate abundance and survival rates for newly proposed Mountain Lion Management Zones in which harvest thresholds will be set for each management zone based on zone population estimates.

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