Estimating Mountain Lion Survival and Abundance in Arizona 2004-2014

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INTRODUCTION

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). The need for reliable and affordable techniques to monitor population trends for large scale species management plans, especially for those with hunted populations, has been identified by a variety of authors (e.g., Anderson and Lindzey 2005). A variety of population estimators have been used to estimate abundance in harvested populations, e.g., track counts, monitoring of radio-collared animals, and population estimators (Skalski et al 2005).

Statewide mountain lion management objectives in Arizona include maintaining an annual harvest of ≥ 250 animals/year and providing recreational opportunities for ≥ 6,000 hunters per year (AGFD Mountain Lion and Bear Conservation Strategies Report 2009). Arizona also maintains management zones with target female harvest not to exceed 35% above age 3 years. Should female exceed 35%, management objectives allow for implementing female harvest limits or restricting the season.

Open hunting is currently used to manage mountain lions in Arizona. Open hunting allows the harvest of 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). Multiple bag limits are also used manage mountain lion populations.

Even with these management objectives, 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 for a heavily exploited population of radio-collared mountain lion adults for southeastern Arizona at 0.62 and found it was one of the lowest in the country. McKinney et al (2009) compared estimated rates of survival also in radio-collared mountain lions for 2006 and 2006 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. Rates of survival in 2007 were 0.67 and 0.55 for Payson and Prescott respectively. Combining the two years, rates of survival were estimated at 0.44 for Payson and 0.55 for Prescott.

Mountain lion abundance estimates are lacking for Arizona making management limits difficult to assess or monitor. In this paper, I report on statewide estimated annual survival rates in mountain lion by applying catch-curve analyses and then estimate total minimum abundance for mountain lions statewide using virtual population analysis of Fry (1949) as reported by Skalski (2005*a* & *b*) using cementum annulations tooth age data for years 2004-2014.

Catch-curve analysis of Chapman and Robson (1960) was originally developed to estimate annual survival probabilities by using age-at-catch data from fisheries hauls (Skalski 2005*a*). The purpose of the analysis is to estimate a common or constant survival probability across adult age classes. The catch-curve survival estimate is based on the probability of observing a sample of animal ages from the population. The ages of the animals are the random variables for the Chapman and Robson (1960) estimator and the numbers of animals in each age class are the random variables. The result of the catch-curve analysis is a unique, minimum variance, unbiased estimator of survival.

Virtual population analysis (VPA) is an age-structured population reconstruction method based upon age-at-harvest (Skalski 2005*b*). VPA was first used in fisheries management where catch data are accessible but other traditional methods of abundance estimation are difficult to apply.

METHODS

The following survival rates and abundance estimates are based on Arizona mountain lion harvest and cementum annulations tooth age data from 2004-2014. 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 annulations tooth age data from premolar teeth removed during the physical inspection (Matson's Lab, Milltown, Montana). Harvest records where tooth age data were absent or unreliable were removed from the cumulative age and harvest calculations.

Analysis was restricted to years 2004-2014. Tooth age data is unreliable prior to 2004 when hunters were required to submit a premolar tooth during the physical inspection and check-out process.

Survival Estimates

Survival estimates were determined using Chapman and Robson (1960) catch-curve estimator as reported in Skalski et al (2005). Annual Survival is estimated to be

$$\hat{S} = \frac{T}{l. + T - 1}$$

where:

$\hat{S}$ = the survival estimate;
T = the cumulative age of harvested bears;
$l.$ = number of bears harvested.

The associated variance and standard error are estimated as:

$$\widehat{\text{Var}}(\hat{S}) = \hat{S}\left(\hat{S} - \left(\frac{T - 1}{l. + T - 2}\right)\right)$$

$$\widehat{\text{SE}}(\hat{S}) = \sqrt{\text{Var}(\hat{S})}$$

Assumptions of the Chapman and Robison (1960) catch-curve estimator include:

1. A stable age structure
2. A stationary population
3. All animals have an equal probability of selection
4. The sample is representative of the population of interest

5. Fates of all animals are independent
6. All ages are recorded accurately
7. Annual survival probability if constant across all age classes

Since harvest effort is used to collect the data, the assumption of a constant harvest probability across all age classes is also needed for the age structure to be representative of the population.

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.

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.

Results

Annual Survival Probability Estimates

Harvest rates for male mountain lions ranged from 204 lions in 2004 (124 male and 122 females) and 234 in 2014 (112 males and 120 females) with a low of 103 lions in 2005 and a high of 164 in 2013. Mean annual harvest was 253: 137 for males and 115 for females.

Results of the annual survival probability analysis for male and female mountain lions in Arizona are found in Table 1. Mean annual survival estimates were 0.77 for males and 0.76 for females. Survival estimates ranged from 0.78 in 2007 to 0.76 is 2014 for male mountain lions with a low of 0.74 in 2006 to a high of 0.81 in 2010 (SE = 0.063 for both years). Annual survival estimates for females were generally lower and ranged from 0.72 in 2004 to 0.76 in 2014 with a low of 0.71 in 2005 and a high of 0.79 in 2007 (SE = 0 and 0.044, respectively).

Year	Male $\hat{S}$	M var	M SE($\hat{S}$)	Female $\hat{S}$	F var	F SE($\hat{S}$)	M Harv	F Harv	Unk Harv	Total Harv	M Cum Age	F Cum Age
2004	0.78	0.009	0.094	0.72	0	0	124	122	2	248	120	152
2005	0.76	0.002	0.044	0.71	0	0	103	101		204	238	183
2006	0.74	0.004	0.063	0.76	0.0008	0.028	112	114		226	229	257
2007	0.78	0	0	0.79	0.002	0.044	149	111	1	261	438	347
2008	0.78	0	0	0.78	0	0	146	121	2	269	463	375
2009	0.77	0	0	0.78	0	0	151	102	1	254	432	279
2010	0.81	0.004	0.063	0.77	0	0	150	103	1	254	537	299
2011	0.77	0	0	0.76	0.003	0.054	161	127	3	291	497	310
2012	0.78	0.003	0.054	0.75	0	0	131	107	1	239	411	278
2013	0.78	0	0	0.76	0.004	0.063	164	137	3	304	490	353
2014	0.76	0.002	0.044	0.76	0	0	112	120	2	234	227	289

Table 1 – Annual survival probability estimates, harvest, and cumulative age for male and female mountain lions in Arizona from 2004-2014.

Virtual Population Analysis

Minimum abundance was calculated for mountain lions statewide using age-specific mortalities and cementum annulations 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 & 3 shaded in gray) for years 2004-2014. Age classes greater than 10 years were excluded from the calculation because of the few mountain lions that were harvested past age 10.

Minimum abundance values for mountain lions were estimated at 321 females and 396 males. Using the annual survival probability estimate from the catch-curve analysis for 2004 of 0.72 for females and 0.78 for males found in Table 1, we estimate the minimum abundance to be 1150 females and 1800 males.

Female	Age Class										
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Cohort total**
2004	3	17	14	11	3	7	2	1	1	0	0	3
2005	6	24	19	6	7	6	1	3	1	0	1	41
2006	2	24	16	11	10	7	6	1	2	0	0	49
2007	1	17	27	10	10	14	2	3	1	3	2	38
2008	4	15	16	22	15	13	9	4	2	2	1	45
2009	1	17	12	21	8	6	5	3	1	2	0	53
2010		19	22	18	5	7	8	2	3	2	0	33
2011	4	18	28	19	12	7	5	2	3	2	1	19
2012	4	22	26	8	14	5	8	1	3	0	2	17
2013	8	26	25	17	11	12	3	5	2	1	3	12
2014	2	22	24	14	10	6	2	3	4	2	1	11
												321

Table 2 – Cohort table for calculating minimum total abundance in statewide female mountain lion populations 2004-2014.

Male	Age Class											
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Cohort total**
2004	0	9	7	6	6	5	2	1	0	0	0	0
2005	2	16	19	17	6	8	3	1	2	2	1	25
2006	1	14	28	20	9	4	6	1	0	0	0	54
2007	1	9	30	32	19	14	6	5	2	2	1	75
2008	5	19	21	30	20	15	6	6	1	3	3	60
2009	7	14	20	36	24	4	13	7	1	1	1	50
2010	3	15	24	18	22	19	9	6	6	3	4	45
2011	1	28	33	27	22	14	7	8	6	2	0	35
2012	2	24	27	18	17	12	3	8	3	1	3	21
2013	2	28	34	24	20	15	5	8	2	2	2	16
2014	3	16	17	16	6	5	1	3	3	2	0	15
												396

Table 3 – Cohort table for calculating minimum total abundance in statewide male mountain lion populations 2004-2014.

Discussion

Annual survival estimates and minimum abundance were calculated for mountain lions statewide from 2004-2014. Annual survival estimates were similar for males and females and are within range of those reported by other states within the literature (Cunningham et al 2001). Annual survival estimates were found to be higher than those of 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.

Mountain lions killed due to depredation (per Department policy) are not factored into these survival probabilities or minimum abundance estimates because teeth age data are not captured on lions taken as part of a depredation event nor are these lions checked in or physically inspected. In 2004, 31 lions were removed per the Department's depredation policy (Table 5). This amounts to 11% of the total lions harvested in 2004 and 12% overall. Tooth age data from depredated lions would provide an even more comprehensive picture of survival and abundance of statewide mountain lion populations.

Year	F	M	U	Total
2004	17	10	4	31
2005	17	24		41
2006	15	18	3	36
2007	9	19		28
2008	21	19	2	42
2009	15	14		29
2010	6	25		31
2011	15	17	6	38
2012	20	17		37
2013	14	22	4	40
2014	10	24		34
Total	159	209	19	387

Table 5 - Mountain lions taken per Department depredation policy

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 survival. 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 will tend to underestimate abundance so these estimates are thought to be conservative and represent minimum estimates. The value of these estimates lies in providing a baseline for monitoring trend and utility for management of the hunts and populations.

Charts 1 & 2 show the survival estimates for male and female mountain lion with potential upper and lower sustainable survival rate limits based upon review of the literature. 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 upon age and sex of lions removed. Harvest of males and subadult females will have less of an impact on the population because males are replaced by immigration and females are replaced by female young produced in the population.

Using the low survival rate reported by McKinney et al (2009) and Cunningham et al (2001) of 0.55 for Arizona as the lower limit, 0.85 is then used as the upper limit. Cunningham et al (2001) reported a range of 0.55 for

Arizona to 0.73-1.0 for Wyoming for sport hunted mountain lions. Unhunted populations in New Mexico reported annual survival rates of 0.86.

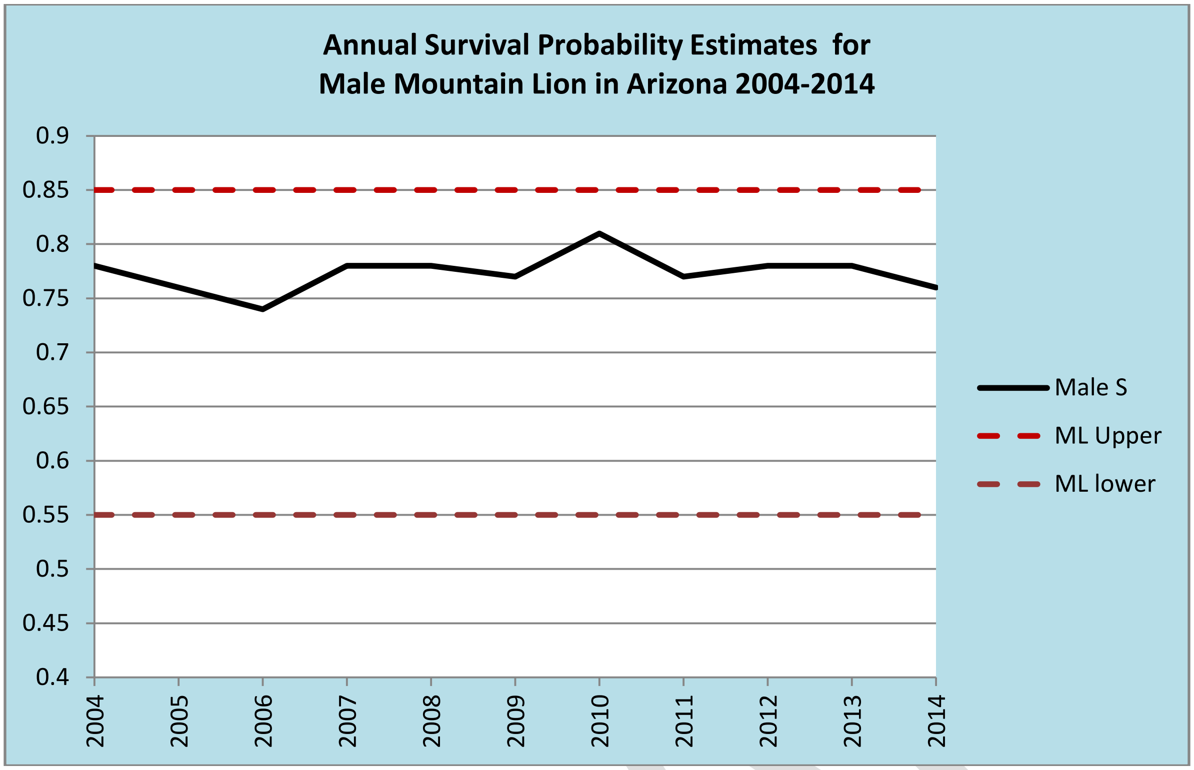

Chart 1 – Annual survival probability estimates for male mountain lion in Arizona with recommended upper and lower management objectives (based upon review of the literature).

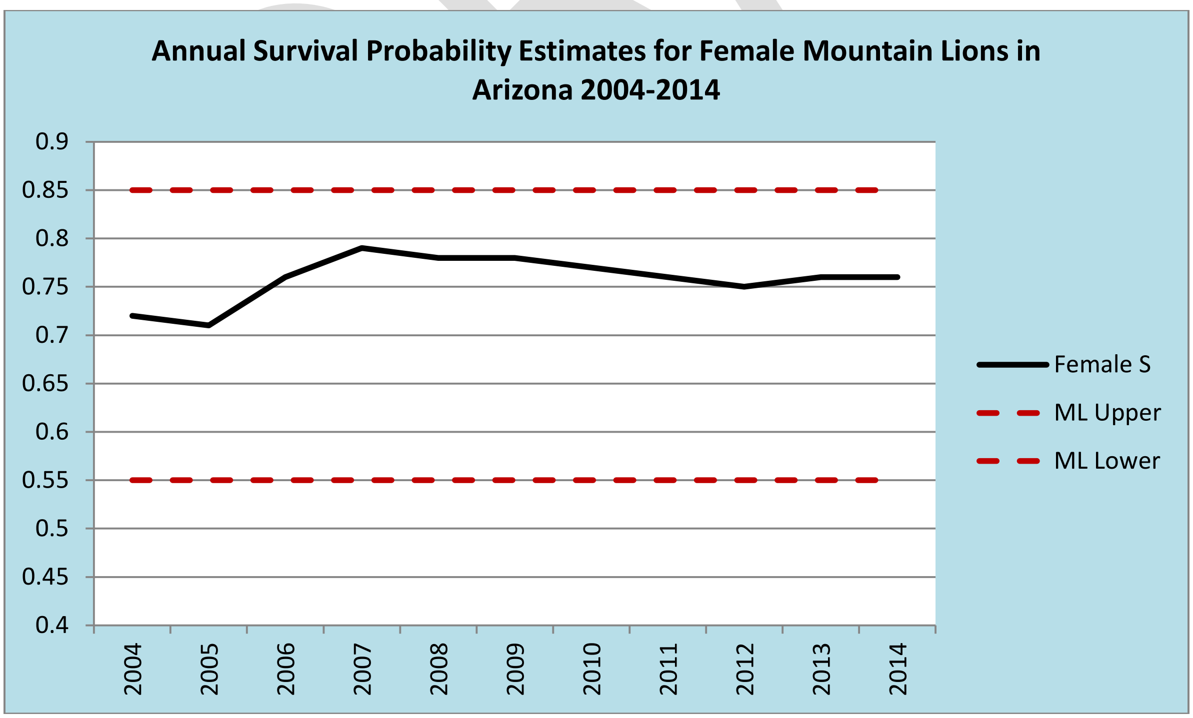

Chart 2 - Annual survival probability estimates for female mountain lion in Arizona with recommended upper and lower management objectives (based upon review of the literature).
Next steps would include analysis of mortality type as a function of survival to also include depredation. Reviewing 2004-2014 nonsport harvest (Department removals and illegal kills) and vehicle mortalities, nonsport harvest and mortalities due to vehicle collisions accounted for less that 1% each of total mountain lion mortality (Table 6).

Year	Hunter Harvest					Nonsport				Vehicle					Total
	F	M	U	Total		F	M	Total		F	M	U	Total		
2004	122	123	2	247			1	1							248
2005	101	103		204											204
2006	113	107		220		1	4	5			1		1		226
2007	109	146	1	256			2	2		2	1		3		261
2008	120	142	2	264			1	1		1	3		4		269
2009	96	150		246		5		5		1	1	1	3		254
2010	99	147	1	247		2	1	3		2	2		4		254
2011	125	159	2	286			1	1		2	1		3		290
2012	107	128		235			2	2			1	1	2		239
2013	136	163	1	300			1	1		1			1		302
2014	117	110		227		2	1	3		1	1		2		232
Total	1245	1478	7	2732		10	14	24		10	11	2	23		2779

Table 6 – Hunter Harvest, nonsport, and vehicle mortality for mountain lions in Arizona from 2004-2014

Analysis at the Game Management Unit (GMU) 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. 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.

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