Lion
(*Panthera leo*)
AZA Animal Program Population Viability Analysis Report

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Population Viability Analyses (PVAs) for AZA Animal Programs

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Population Viability Analysis (PVA) model scenarios were developed with members of the Lion Animal Program during a meeting at the 2012 Felid TAG meeting in Salt Lake City, UT. In 2011, Lincoln Park Zoo researchers received a two-year grant from the Institute of Museum and Library Services (IMLS) to analyze AZA population's long-term viability. The project team is using ZooRisk 3.80 (Earnhardt et al., 2008), a PVA modeling software, to examine what would happen to AZA populations if current conditions remained the same (the baseline scenario), and then assess the impact of changes of increasing reproduction, managing the generic population via attrition, removing contracepted females, and not utilizing genetic management (alternative scenarios). The current AZA lion population size is **324 animals (139 males, 185 females) at 99 AZA institutions**

MODEL RESULTS

The AZA lion population is very strong demographically and genetically, and has a high likelihood of remaining so over the next 100 years. Model results indicate that if the AZA lion population continues on its current trajectory it will experience a small demographic decline in the next 15 to 20 years as the generic population declines due to natural attrition. Even with this decline, the population is able to increase to its potential spaces (356) in 32 years and maintain this level for 100 years, and to maintain high levels of gene diversity (93%). Increasing the population's reproduction rates allows the population to prevent the initial decline in the population and maintain slightly higher levels of gene diversity in 100 years.

Currently, the AZA Felid TAG does not recommend unpedigreed lions (generics) breed or be imported to the population. If there were no additional breeding or importations in the generic population, the Animal Program could expect no generic lions in the population in approximately 17 years. Currently, there are many female lions on contraceptives due to space limitations. If the females that are currently or have previously been on contraceptive do not breed in the future (removed from the breeding population), the population would face a much steeper demographic decline. With the removal of these females from the breeding population, the population will only have a 71% chance of reaching its potential spaces and will retain less gene diversity over 100 years.

MANAGEMENT ACTIONS

The AZA Lion Animal Program is currently on a positive trajectory in AZA institutions. There are several management strategies which could be applied to the population that may help it maintain or increase its current demographic and genetic health. **These management actions will be most effective when applied in combination with one another.**

- **Sustain current reproductive rates/Increase reproduction:** The program should focus on breeding reproductively viable females to **maintain or begin increasing** the number of offspring produced per year. Under current breeding rates, the population could reach its potential spaces in 32 years, and will sustain a slight decline in population size in the short-term. If reproduction is increased (29 – 33 births/year) the population has the capability of slowing or preventing the slight demographic decline that will occur as the generic population ages out of the population.
    - All breeding recommendations received are important to the long-term future of this population; institutions should work hard to get recommended pairs into appropriate breeding situations quickly and work on husbandry to improve breeding success.

- **Carefully weigh whether contraceptives are needed or warranted:** Currently, there is not enough information to determine the long-term effects of contraception on female lions. However, model results indicate that if the females currently on contraceptive do not breed again, the population will experience a much more severe decline than the baseline scenario. As the effects of contraceptives could be costly, it is important to carefully weigh whether contraception is justified for wide use across the lion population. Institutions should contact the SSP Coordinator prior to placing female lions on contraceptives.

- **Manage the generic population via attrition:** There are currently 115 (43.72) generic lions in the AZA population. The AZA Felid TAG does not recommend that lions with unknown pedigree (generics) breed or be imported to the AZA population. In the future, space occupied by generic lions will be converted to space for pedigreed lions. Institutions holding generic lions should discuss their plans for lions with the AZA Lion SSP Coordinator.

FULL REPORT
Lion AZA Animal Program Population Viability Analysis

POPULATION VIABILITY ANALYSIS (PVA) MODEL DESCRIPTION

A Population Viability Analysis (PVA) is a computer model that projects the likely future status of a population. PVAs are used for evaluating long-term sustainability, setting population goals, and comparing alternative management strategies. PVAs are tools that can be used to determine the extinction risk of a population, forecast the population's future trajectory, and identify key factors impacting the population's future.

ZooRisk is a PVA software package that can be used to model the dynamics of an individual population (Earnhardt et al., 2008). Full documentation on ZooRisk can be found in the software's manual (Faust et al., 2008). In this analysis, we use it to integrate the complex factors impacting a population – its age and sex structure, demographic rates, stochasticity (random chance due to variation in mortality, fecundity, and sex ratios among individuals), genetic management, and potential management actions. ZooRisk is an individual-based, stochastic model.

Since stochastic models have inherent variation, each model run (or iteration) will produce a slightly different population trajectory, and the model is run 1000 times to reflect the full potential variation a population could experience. For example, there may be a wide range in population trajectories (Fig. 1). For clarity, most figures in this report show the mean population size (Fig. 1). Model results such as mean population sizes, levels of gene diversity (GD), and inbreeding (F) are averaged across 1000 model iterations. Where relevant, results are reported on medium-term (25 year), and long-term (100 year) time frames. Results such as the probability of reaching the potential space or extinction (0 individuals) are based on the percentage of iterations that hit that target at least once over the 100 years. Where applicable, ± 1 standard deviation is included; large values represent wider variability in model results.

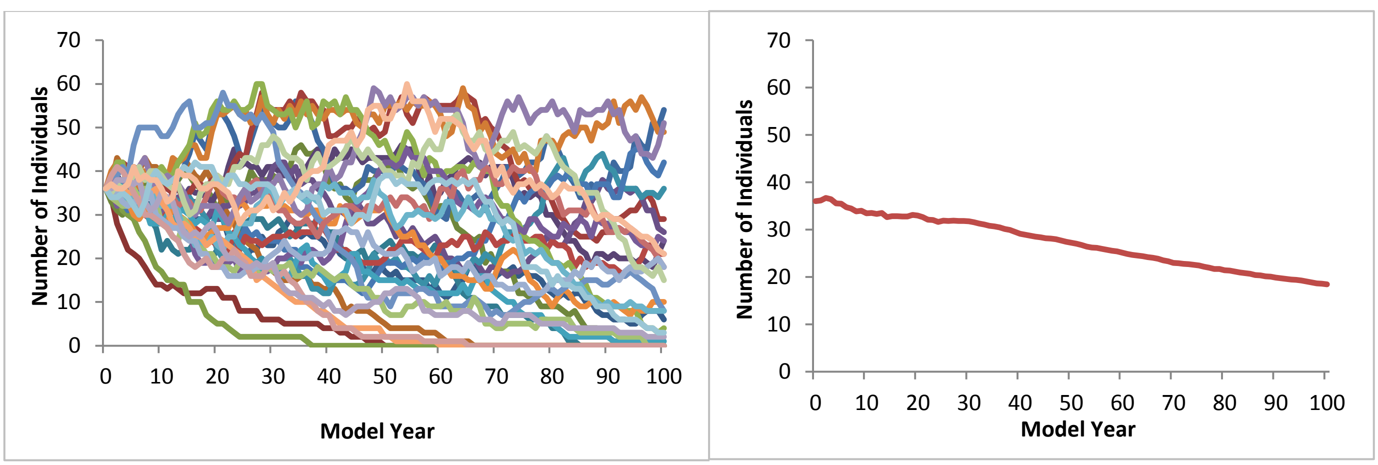

Figure 1. An example of 30 iterations of a stochastic model (left) and what the mean population size averaged across 500 iterations of the same model would look like (right).

The most powerful use of PVAs is to compare a baseline scenario, reflecting the population's future trajectory if no management changes are made, to alternate scenarios reflecting potential changes. These comparisons can help evaluate the relative costs and benefits of possible management changes. Note that for easy comparison, model results across all scenarios are included in Appendix G.

The future can be uncertain and difficult to predict. Model results are most appropriately used to compare between scenarios (e.g. relative to each other) rather than as absolute predictions of what will happen.

POPULATION'S DEMOGRAPHIC BACKGROUND

Demography: Based on the AZA Lion Studbook, the first record of lions in zoos was in 1890 at the National Zoo and the first zoo birth occurred as early as 1894. Low numbers of lions were held in zoos until the 1960s when the population began increasing from increased breeding and importations. The population reached a peak of 374 animals in 1974 and since this time the population has declined slightly though has maintained a relatively stable size (Fig 2). Space has become the limiting factor for this species.

Over the last 10 years, the lion population's yearly growth rate has ranged from 0.958 – 1.048 and has been on average slightly increasing at a rate of 0.6% or λ =1.006 (23 average births/year over this period). Over the past 5 years the population has been increasing at a slightly higher rate of 2% or λ =1.02.

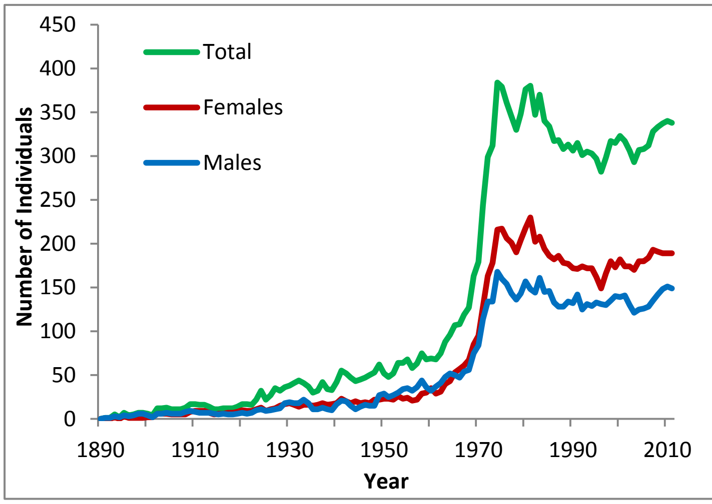

Figure 2. Number of lions in AZA institutions.

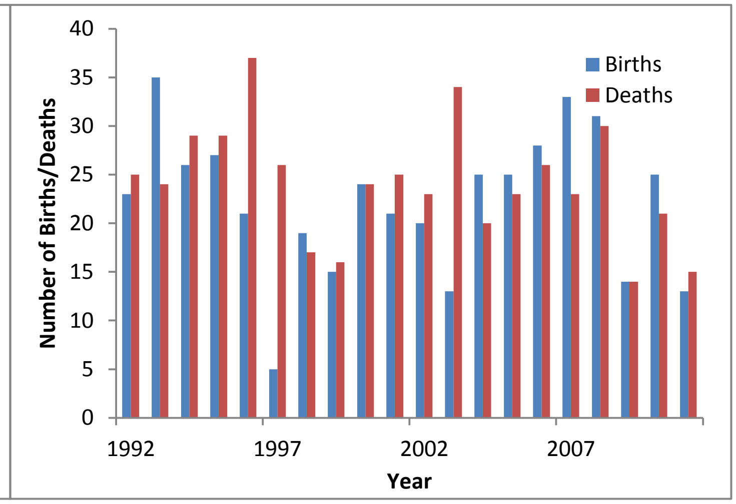

Figure 3. Number of births and deaths in the AZA lion population over the last 20 years.

PVA MODEL SETUP

Starting Population:

ZooRisk uses a starting population to initiate each model scenario, and it incorporates data on each individual's pedigree, age, sex, and reproductive status. Any animals unable to breed due to age, medical issues, or sterilizations can be designated as non-reproductive in the model, which removes them from the potentially breeding population. The model assumes that any new animals (either births or imports) are potentially reproductively viable; this may be an optimistic assumption.

At the time of analyses the AZA population consisted of **324 animals (139 males, 185 females) at 99 AZA institutions** (Fig. 4). The lion population has been divided into two groups, the "pedigreed" lions with known ancestry and the "generic" lions with unknown pedigree. The generic population consists of 115 (43.72) individuals. Generic lions are not recommended for breeding by the TAG and all generic individuals have been considered as non-reproductive and removed from the potential breeding population. In addition, 32 pedigreed lions (14 males, 18 females) were designated as non-reproductive, based on being outside of the reproductive age classes, sterilized, or medical issues that prevent them from breeding. Non-reproductive animals hold space in the model projections for the remainder of their lives but are not eligible to breed. With these exclusions, this leaves a **potentially breeding population of 177 (83.94) individuals.**

See Appendix E for a complete list of the individuals included in the model and their reproductive status.

Age Structure:

The total age structure illustrates a relatively robust population with many animals in the reproductive age classes (Fig. 4a). The potentially breeding population is still healthy, however the population size is reduced significantly (to 177 individuals) with the removal of generic lions and other individuals unable to breed (Fig. 4b). In addition, there is a female bias in the lion population, though this bias is not as evident in the potentially breeding age structure (Fig. 4b), as many females have been permanently sterilized or contracepted.

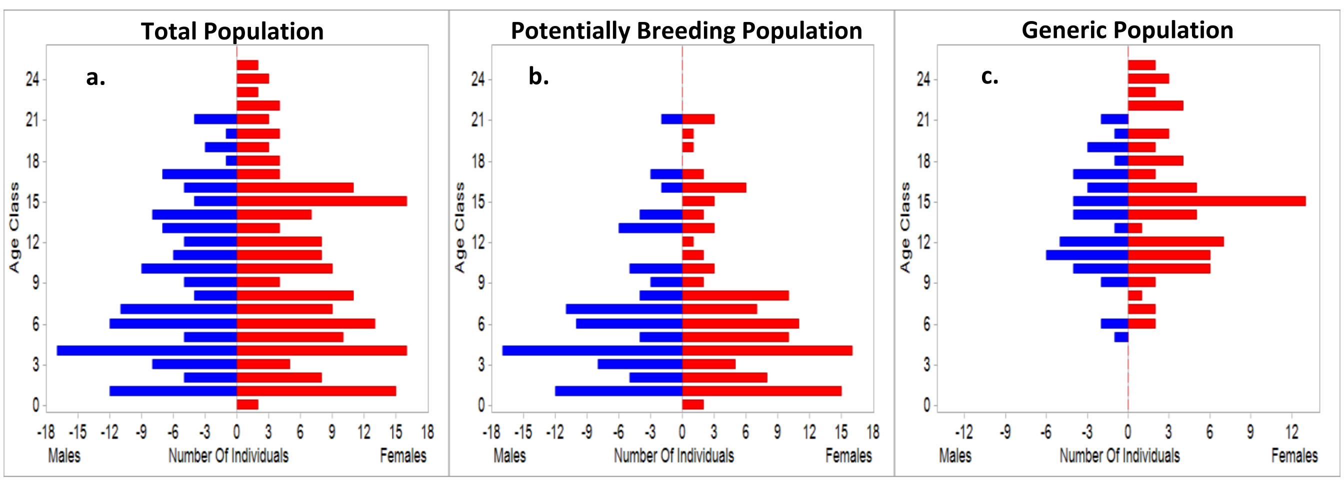

Figure 4. Lion age distribution within AZA institutions, divided into (a) total lion population 324 (139 males, 185 females), (b) Potentially breeding population 177 (83.94), and (c) the generic lion population 115 (43.72).

Current Demographics and Genetics: All ZooRisk scenarios started with the population's current demographics and genetics (Table 1). The population's current genetics are based on historical pedigree assumptions made by SPMAG members, the Population Management Center, and the Species Coordinator; these assumptions have been used in breeding and transfer plans in 2012 and for several years prior. See Appendix D for complete list of assumptions used in analysis. These assumptions were based on the most current knowledge of the population and its history at the time of analysis, but may be re-evaluated in the future. Genetic results should be interpreted with care, although the absolute predictions may shift, patterns comparing between scenarios should remain fairly consistent.

Table 1. Starting demographic and genetic statistics for the lion population.

Starting population size (Males.Females.Unknown Sex)	324 (139.185.0)
Potentially breeding population size	177 (83.94.0)
Percentage of pedigree known (after exclusions and assumptions)	100%
Gene diversity (GD)	97.52%
Population mean kinship (MK)	0.0248
Mean inbreeding (F)	0.0058
Mean generation time (T) (years)	6.71
Number of generations in 100 model years	14.9

Reproduction: ZooRisk uses the following parameters to determine how offspring are produced in each model year:

- **Female Reproductive Age Classes:** Ages 1 – 16. The oldest female to produce offspring was 19 years old (SB# 155, who was wild caught in the mid-1940s). There have been nine females which have reproduced between 17 and 19. However, the modeling team felt that realistically, lions in zoos are only reproductively viable until 16 years of age; hence the maximum age for reproduction was set at 16.

- **Male Reproductive Age Classes:** Ages 1 – 20, based on data from the studbook. According to the studbook, the oldest male lion without an age estimate to reproduce was 20 years old.

- **Female Probability of Breeding [p(B)]:** Female p(B) is the age-specific probability that a female will have at least one offspring or one litter in a given year. Since it is difficult to determine from the studbook what a population could do if all individuals were in breeding situations, model scenarios utilize simplified hypothetical levels of p(B) to illustrate the impact of potential changes in hatch rates. All female p(B) were set at a constant value across all the reproductively viable age classes. This constant p(B) can be thought of as an interbirth interval (e.g. p(B) = 25% = each female has an offspring/litter every 4 years on average) or as the percentage of reproductive-aged females reproducing (e.g. 25% of eligible females breed in any given year). Using a constant value means that all reproductively viable females have the same chance of reproduction regardless of age. This probability of breeding is used in the model to stochastically determine whether a paired female produces offspring in any given model year. The model p(B) varies depending on the model scenario. To determine the p(B) used in the baseline scenario, we extracted the average number of births/year over the past decade from the studbook (23 births/year), and then identified a p(B) level in the model that would produce an equivalent average number of projected births annually over the first 10 years of the model. Alternate scenarios used higher or lower p(B) levels.

- **Annual Number of Offspring (ANO):** Based on studbook data, lions can have between 1 – 7 offspring per litter. Typically lions are most likely to have 1 – 3 offspring, litter sizes of 4 – 7 occur at lower frequencies. See Appendix C for specific annual frequencies. When a female within the model is selected to reproduce in a given model year, ZooRisk uses these frequencies to stochastically determine the number of offspring she produces.

- **Birth Sex Ratio (BSR):** Based on studbook data, the historic birth sex ratio is not significantly different than the expected equal BSR (50 males: 50 females, df = 1, p > 0.05). For this population, all model scenarios were given a BSR of 0.5 (no bias).

Mortality:

- **Male and Female Age-Specific Mortality Rates (Qx):** Mortality rates for age classes 0 – 26 for males and females were based on studbook data from individuals living within North America from 01 January 1980 to 27 August 2012. See Appendix F for the male and female mortality rates used in the model.

- **Infant Mortality Rates (Qx):** Male = 26%, female = 23%, based on studbook data. Infant mortality for all scenarios was modeled at these levels.

- **Maximum Longevity:** Male and female longevity is 26 years old. These maximums were based on studbook records for animals in AZA institutions.

Space: There is limited space available in AZA institutions and in many cases populations can compete for similar spaces. Viability of some species may be limited if too little space is allocated, while others may exceed the space needed to maintain sustainable populations. PVAs can identify the number of spaces needed to attain a population's long-term sustainability. ZooRisk has the option of including a space limitation on population growth. This limitation reduces breeding in the model population as it approaches the potential space limit, mimicking zoo management. For example, a Program Leader may begin to recommend fewer breeding pairs if available spaces for a population become limited.

To determine an appropriate space limitation for the models, the PVA team, in consultation with the AZA Wildlife Conservation and Management Committee (WCMC), developed the approach of using the number of projected spaces in 5 years based on a Taxon Advisory Group's (TAG) Regional Collection Plan (RCP). If that number is unavailable or unsuitable, the team will use the current population size + 10% or 10 individuals, whichever is greater.

The 2009 Felid TAG RCP set the lion target population size (TPS) at 320 individuals. This number of spaces was deemed too small for the current size and goals of the lion population so, we used the current population size + 10% or 356 as the potential space in the model. All scenarios were set with potential spaces of 356.

Genetic Management: ZooRisk can model genetic management by mean kinship pairings and other genetic criteria, mimicking the way that AZA populations are managed to maintain gene diversity (GD) (Ballou & Lacy, 1995). Therefore, ZooRisk can more accurately project the amount of gene diversity retained through genetic management. Unless otherwise noted, we used mean kinship genetic management in all scenarios. We also modeled alternate scenarios with no genetic management.

Inbreeding Depression: One of the largest genetic threats to small populations is the potential detrimental effects of inbreeding, where breeding between close relatives results in decreased short-term and long-term fitness via reductions in fecundity or litter size, increases in infant mortality, and other detrimental effects (DeRose & Roff, 1999; Koeninger Ryan et al., 2002; Ballou & Foose, 1996; Reed & Frankham, 2003). This phenomenon, called inbreeding depression, has been observed in several ex situ species (Ralls & Ballou, 1982; Olech, 1987; Laikre & Ryman, 1991; Lacy et al., 1993), although effects vary between species (Lacy et al., 1993; Kalinowski et al., 1999). However, inbreeding depression is a concern in the zoo community as many populations have a limited number of founders, small population sizes, and a low chance of receiving additional founders in the future (i.e. they are closed populations) (Lacy, 1997). In other words, inbreeding depression could put this population at higher risk of extinction, particularly if the population size decreases further (Gilpin & Soulé, 1986; Lacy, 1997).

At this time inbreeding depression is not known to be affecting this population. There are several strategies that can delay the effects or lower the probability of inbreeding depression including pairing based on mean kinship and importing and breeding unrelated individuals (Ballou & Lacy, 1995). These strategies were modeled for all scenarios except those without genetic management.

Inbreeding depression can be challenging to incorporate into PVA models because of uncertainty about which populations and life history traits will be affected, and at what inbreeding level they will become affected. Due to this uncertainty and since modeling inbreeding depression adds an additional layer of complexity to interpretation of results we have not included a “standard” inbreeding depression effect in the PVA models. Readers should consider that model results may be optimistic if this species would be susceptible to inbreeding depression now or in the future.

MODEL SCENARIOS

Model scenarios for AZA Lion Program were created to reflect what would happen if current approaches continued (baseline) and to address potential alternate management strategies (Table 2); scenarios are described in more detail in their results sections below.

Table 2. ZooRisk Model Scenarios

Scenario Name	Scenario Description	p(B)	TPS
Baseline Scenario			
A. p(B) = 8% (Baseline)	Reproduction to match past 10 years (2002 - 2011). All lions included in total population size, however only pedigreed lions are allowed to breed.	8%	356
Alternate Scenario: Generic Population – No Breeding			
B. Generic Lions Only	Included only generic lions in the analysis. No breeding or imports were allowed in the model.	0%	0
Alternate Scenarios: Varying Female Probability of Breeding [p(B)]			
C. p(B) = 10%	Increase p(B) to 10% (1 litter every 10 years for each female)	10%	356
D. p(B) = 15%	Increase p(B) to 15% (1 litter every 7-8 years for each female)	15%	356
Alternate Scenarios: Excluding Contracepted Females			
E. Exclude contracepted females, p(B) = 8%	Remove all females that were previously or currently on contraceptives. Remove 43 additional females from the potentially breeding population. Potentially breeding population = 134 (83.51). Baseline p(B).	8%	356
F. Exclude contracepted females, p(B) = 15%	Remove all females that were previously or currently on contraceptives. Remove 43 additional females from the potentially breeding population. Potentially breeding population = 134 (83.51). Increase p(B) to 15%	15%	356
Alternate Scenarios: No Genetic Management			
G. No Genetic Management; p(B) =8%	Turned genetic management off (mean kinship pairing) for baseline model	8%	356
H. No Genetic Management; p(B) =15%	Turned genetic management off (mean kinship pairing) for scenario with increased reproduction p(B) = 15%	15%	356

BASELINE MODEL

If Conditions Remain the Same

The lion baseline scenario, p(B) = 8%, describes what might happen to the population if conditions remain the same, specifically if the population experiences the mortality patterns observed in the studbook and maintains a birth rate equivalent to that observed over the last decade (from 2002 – 2011, the population produced an average of **23 births/year**).

If no changes are made over the next 20 years, the population is projected to slightly decline over the next 15 – 20 years, while the generic animals age out of the population and that portion of the population declines. Once this initial decline occurs, the population is then able to increase to its potential size of 356 and maintain this size for 100 years (Fig. 5).

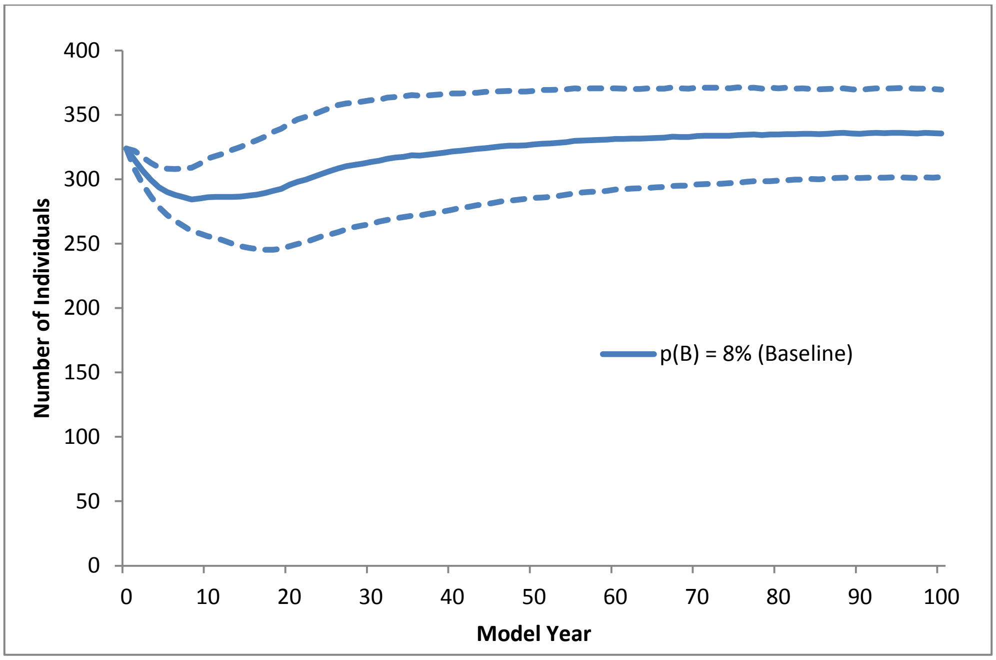

Figure 5. Projected Total Population Size for the baseline model scenario (p(B) = 8%). Solid lines are mean results across the 1000 iterations, and dashed lines are ± 1 standard deviation.

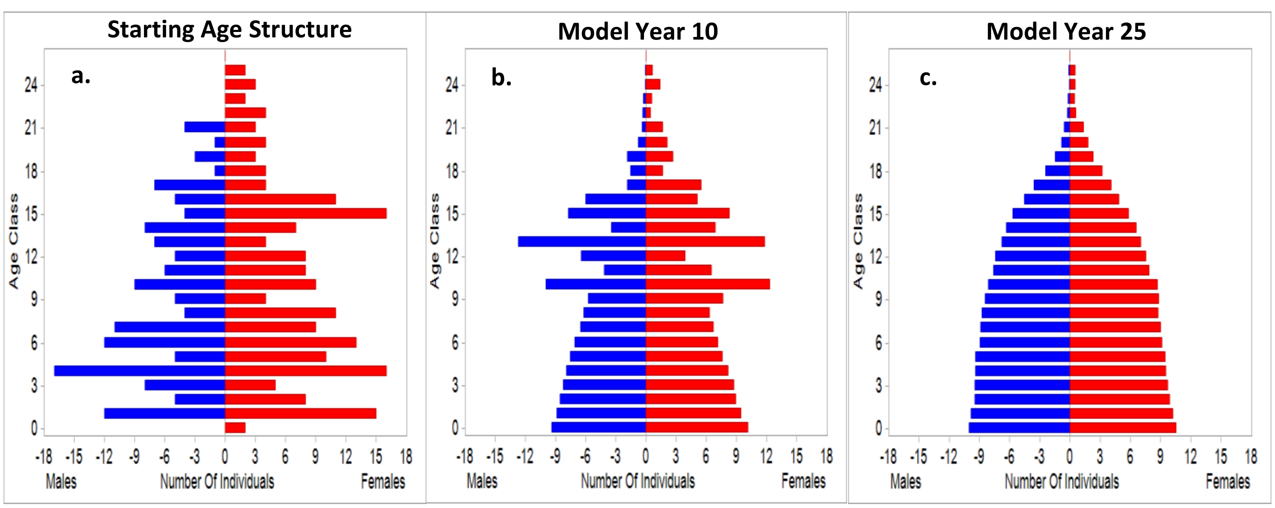

Figure 6. Lion population age structures under baseline scenario, p(B) = 8%: (a) starting age structure; (b) average age structure at model year 10; (c) average age structure at model year 25. Results are averaged across 1000 iterations. Starting population = 324 (139 males and 185 females).

Table 3. Baseline Model Results. Starting population = 324 (139 males and 185 females). Starting GD = 97.52%, starting F = 0.0058.

SCENARIO	Mean Population Size[1] in Year 25 ± 1 SD[2]	Mean Population Size[1] in Year 100 ± 1 SD[2]	Probability of Reaching 356 individuals	Median Time to 356 individuals (years)	Probability of Reaching Extinction	Median Time to Extinction (years)[3]	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Mean F Retained[1] in Year 100 ± 1 SD[2]
A. p(B) = 8% (Baseline)	306 ± 49	356 ± 34	97%	32	0%	-	93% ± 1%	0.09 ± 0.02

[1] *All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.*

[2] *One standard deviation.*

[3] *A dash (-) indicates that extinction will never be reached*

Results for Baseline Scenario:

1. If no management changes are made, the population will slightly decline over the next 15 to 20 years as the generic lions age out of the population. The population will then begin increasing towards its potential space of 356 animals.
    a) The population reached its projected space in 32 years (the median time to reach this size).
    b) Once the population has reached its projected space, it will be able to maintain this size at least until year 100.

2. At the end of 100 years, the population is able to retain on average 93% gene diversity and will on average have an inbreeding level between half-siblings and first cousins.

3. With this current, stable level of reproduction the population is able to maintain a healthy age structure with a larger base of young individuals to begin breeding in the future.

ALTERNATE MODEL SCENARIOS

Generic Lions Only

The AZA Felid TAG does not recommend that lions with unknown pedigree (generics) breed or be imported and all generic lions are currently being managed to decline via natural attrition. The TAG recommends all space occupied by generic lions be converted or utilized by pedigreed lions in the future. There are currently 115 (43.72) generic lions in the AZA population. We modeled the generic lion population with no breeding or importations to illustrate the time it may take for there to no longer be generic lions in AZA zoos.

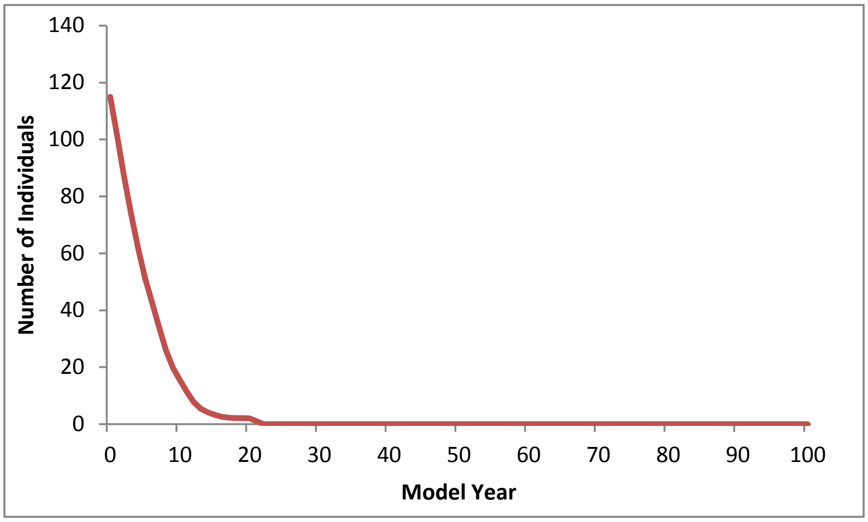

Figure 7. Projected Total Population Size for the baseline model scenario (p(B) = 8%). Solid lines are mean results across the 1000 iterations, and dashed lines are ± 1 standard deviation.

Table 4. Model results for generic lions only scenario. Starting population = 115 (43.72).

SCENARIO	Mean Population Size[1] in Year 25 ± 1 SD[2]	Mean Population Size[1] in Year 100 ± 1 SD[2]	Probability of Reaching 356 individuals	Median Time to 356 individuals (years)	Probability of Reaching Extinction	Median Time to Extinction (years)[3]	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Mean F Retained[1] in Year 100 ± 1 SD[2]
B. Generic Lions Only	0 ± 0	0 ± 0	0%	0	100%	17	0% ± 0%	0 ± 0

[1] *All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.*

[2] *One standard deviation.*

[3] *A dash (-) indicates that extinction will never be reached*

Results for Generic Lions Only Scenario:

1. If no additional reproduction or importations of generic lions occur, the median time to extinction (the point where there will be no generic lions in AZA zoos, freeing up space for pedigreed lions) is 17 years.

2. In ten years, there will on average be only 15 ± 3 generic lions in the AZA population.

ALTERNATE MODEL SCENARIOS

Varying Female Probability of Breeding [p(B)]

One way to increase a population's size more quickly is to improve reproduction, which we modeled by increasing the probability of breeding [p(B)] for reproductive-aged females (ages 1 to 16). We modeled the impact of varying levels of p(B) for the AZA population between the baseline (p(B) = 10%) and up to a maximum of p(B) = 15% which is equivalent to each reproductive-aged female producing a litter approximately every 6 -7 years. For detailed model results, see Table 5, Figure 8 and 9, below.

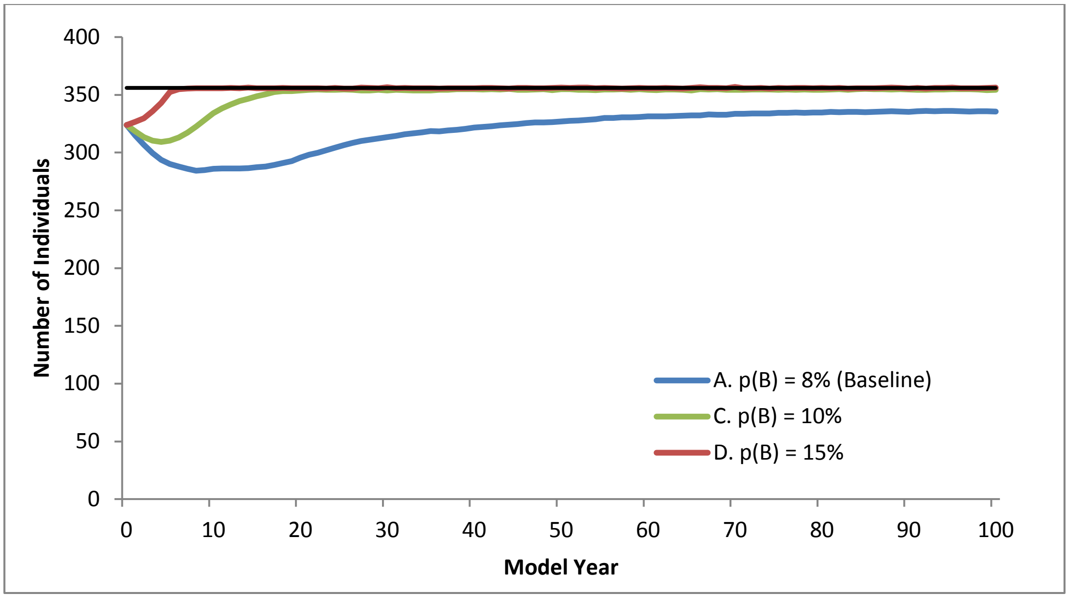

Figure 8. Projected mean total population size under varying female probability of breeding (p(B)) levels. The black line represents the Target Population Size of 356 individuals.

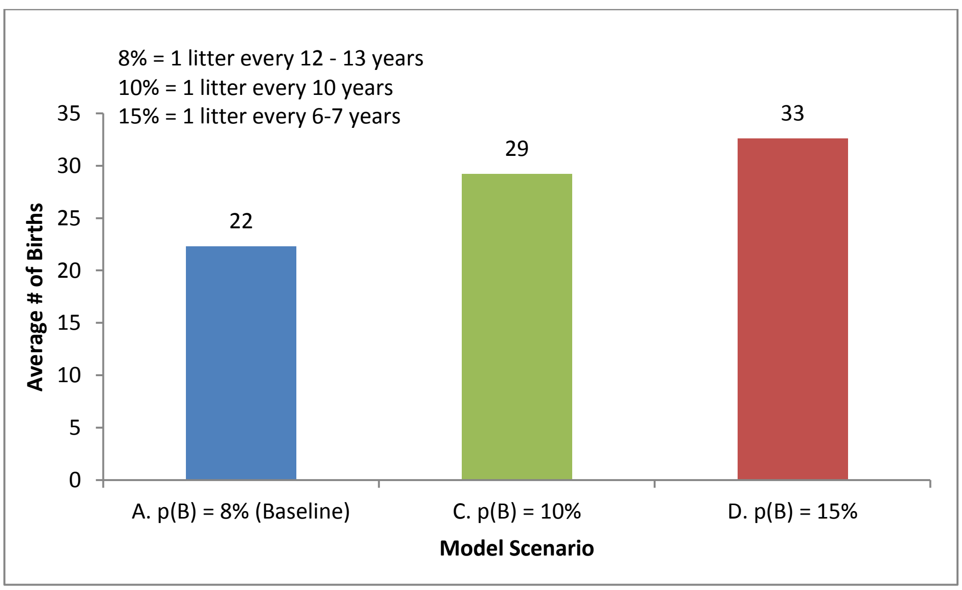

Figure 9. Projected mean total number of offspring per year over the first 10 years of the model based on varying levels of female probability of breeding (p(B)). Note that this is the total number of offspring produced before any infant mortality occurs – these would not have to be surviving births.

Table 5. Model results for varying female probability of breeding. Starting population = 324 (139 males and 185 females). Starting GD = 97.52%, starting F = 0.0058.

SCENARIO	Mean Population Size[1] in Year 25 ± 1 SD[2]	Mean Population Size[1] in Year 100 ± 1 SD[2]	Probability of Reaching 356 individuals	Median Time to 356 individuals	Probability of Reaching Extinction	Median Time to Extinction (years)[3]	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Mean F Retained[1] in Year 100 ± 1 SD[2]
A. p(B) = 8% (Baseline)	306 ± 49	356 ± 34	97%	32	0%	-	93% ± 1%	0.09 ± 0.02
C. p(B) = 10%	355 ± 11	354 ± 9	100%	12	0%	-	94% ± 0.3%	0.07 ± 0.01
D. p(B) = 15%	356 ± 9	356 ± 9	100%	5	0%	-	95% ± 0.2%	0.05 ± 0.01

[1] All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.

[2] One standard deviation.

[3] A dash (-) indicates that extinction will never be reached

Results for Scenarios Varying Female Probability of Breeding [p(B)]:

1. Increasing the female p(B) to just 10% or about 29 births per year (7 more cubs a year than the current rate) allows the population to increase to 356 individuals in about 12 years. Increasing the female p(B) to 15% (33 births per year) allows the population to reach its potential spaces in 5 years. Both increased reproduction scenarios maintain slightly more gene diversity than the baseline scenario, but not significantly more so.
    a. Note that reproduction is slowed once the population reaches the allotted potential space. For the increased reproduction scenarios p(B) decreases once the population grows to reach 356 individuals to prevent the population going over the allocated space.

ALTERNATE MODEL SCENARIOS

Excluding Females Previously Contracepted

Due to the group management strategy and space limitations for this population, many females have been placed on contraception to prevent surplus births. A few female lions on contraceptives have bred again once the contraceptive was removed, however many females whose contraception has been removed have yet to breed again. Managers are uncertain about the long-term effects of contraceptives on female lions. We excluded 43 females who were previously (taken off contraceptives but have yet to breed) or currently on contraceptives to explore the impact on the population should these females never breed again. For a complete list of females excluded in this scenario see Appendix E. With the removal of these females, the potentially breeding female population dropped from 94 to 72 females. Scenarios were modeled under baseline p(B) =8% and p(B) = 15%. Model results are presented in Table 6 and Figure 9.

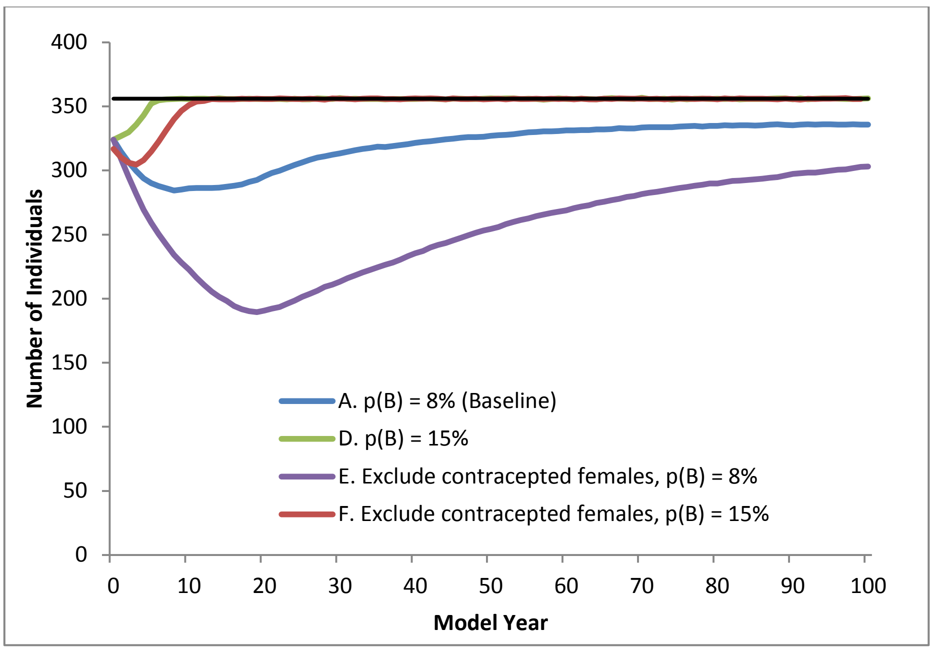

Figure 10. Projected mean total population size under varying female probability of breeding (p(B)) levels. The black line represents the Target Population Size of 356 individuals.

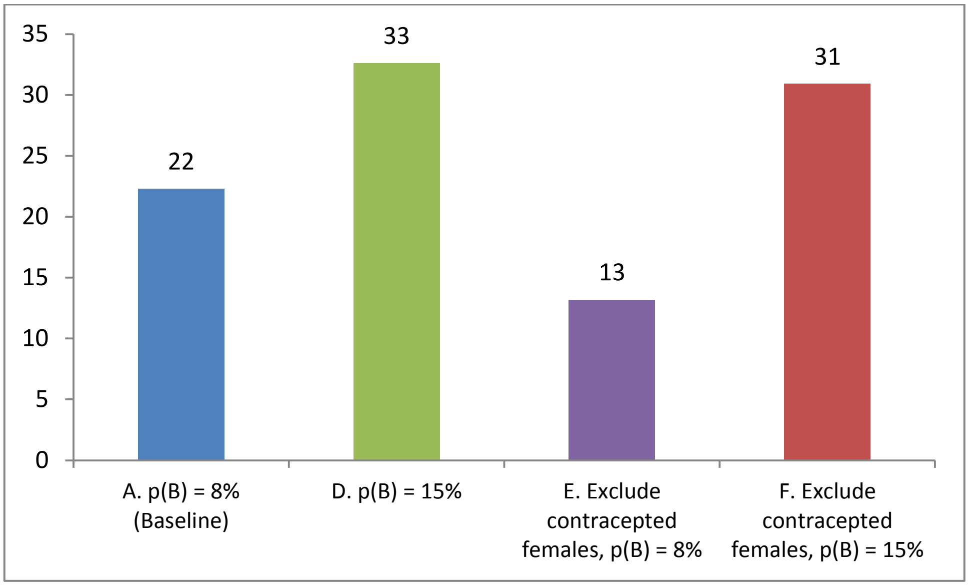

Figure 11. Projected mean total number of offspring per year over the first 10 years of the model based on varying levels of female probability of breeding (p(B)). Note that this is the total number of offspring produced before any infant mortality occurs – these would not have to be surviving births.

Table 6. Model results for excluding contracepted females scenarios. Starting population = 324 (139 males and 185 females). Starting GD = 97.52%, starting F = 0.0058.

SCENARIO	Mean Population Size[1] in Year 25 ± 1 SD[2]	Mean Population Size[1] in Year 100 ± 1 SD[2]	Probability of Reaching 356 individuals	Median Time to 356 individuals	Probability of Reaching Extinction	Median Time to Extinction (years)[3]	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Mean F Retained[1] in Year 100 ± 1 SD[2]
A. p(B) = 8% (Baseline)	306 ± 49	356 ± 34	97%	32	0%	-	93% ± 1%	0.09 ± 0.02
E. Excluding contracepted females, p(B) = 8%	201 ± 58	303 ± 81	71%	60	0.2%	88	90% ± 4%	0.12± 0.04
D. p(B) = 15%	356 ± 9	356 ± 9	100%	5	0%	-	95% ± 0.2%	0.05 ± 0.01
F. Excluding contracepted females, p(B) = 15%	356 ± 9	356± 9	100%	10	0%	-	95% ± 0.2%	0.05 ± 0.01

[1] *All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.*

[2] *One standard deviation.*

[3] *A dash (-) indicates that extinction will never be reached*

Results for Scenarios with Excluding Contracepted Females:

1. Excluding the currently contracepted females from the breeding population but maintaining similar p(B) levels (e.g. scenario A vs. E) results in a decreases the population size in projections, because fewer females are breeding and thus birth rates are lower (Fig 11). **If these females truly are incapable of reproducing in the future it will likely take much longer for the population to reach its potential space, or managers will have to compensate by increasing the birth rate (e.g. scenarios D, F).**

   a. The decrease in the population is extremely evident when contracepted females are removed and the breeding remains at baseline level (8%). In this scenario (E), the population will only have on average 201 individuals compared to the 306 animals at year 25 in the baseline scenario (A). In addition, it will take on average 60 years for the population to rebound and increase to the potential spaces compared to the 32 years under the baseline scenario.

   b. When increasing the probability of breeding to 15% and removing contracepted females, there is a briefer population decline due having fewer eligible females to produce births. However, it will take double the time (5 verses 10 years) for the population to reach its potential space.

   It is important to note that the females removed from the breeding population are only females that are currently or previously been on contraceptives. New females in the model are all considered reproductively viable, so any future contraception practices and contraceptive problems are not reflected in future projections.

2. Since there is still uncertainty on the long-term effects that contraceptives have on female lions, as a few have bred after being taken off contraceptives, all other model scenarios included these females as potential breeders.

3. Under all scenarios genetic goals of 90% gene diversity in 100 years can still be reached, however there will be far fewer lions in the AZA population than needed to meet institutional needs.

ALTERNATE MODEL SCENARIOS

No Genetic Management

The majority of scenarios were run simulating genetic management by creating pairs using ranked mean kinship, the typical strategy used to manage zoo populations. We created alternate scenarios without any genetic management for comparison, to illustrate the impact of genetic management. For these comparison scenarios, animals in the model were randomly paired for the 100 years of the model as opposed to all other scenarios where animals were paired by mean kinship. The results from these scenarios are presented in Table 6.

Table 7. Model results for excluding contracepted females scenarios. Starting population = 324 (139 males and 185 females). Starting GD = 97.52%, starting F = 0.0058.

SCENARIO	Mean Population Size[1] in Year 100 ± 1 SD[2]	Starting Gene Diversity	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Starting Inbreeding Coefficient[3]	Mean Inbreeding Coefficient[3] in Year 100[1] ± 1 SD[2]
A. p(B) = 8% (Baseline)	356 ± 34	97.52	93% ± 1%	0.01	0.09 ± 0.02
G. No Genetic Management; p(B) =8%	335 ± 37	97.52	91% ± 1%	0.01	0.12 ± 0.02
D. p(B) = 15%	356± 9	97.52	95% ± 0.2%	0.01	0.05 ± 0.01
H. No Genetic Management; p(B) =15%	356± 9	97.52	93% ± 0.4%	0.01	0.07 ± 0.01

[1] *All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.*

[2] *One standard deviation.*

[3] *Inbreeding levels: parent/offspring or siblings: 0.25, half-siblings: 0.125, first cousins: 0.0625*

Results for Scenarios with No Genetic Management:

1. The scenarios above illustrate that the population retains slightly more gene diversity in 100 years by managing with mean kinship pairing.

2. Inbreeding levels remain roughly the same at the end of 100 years; relatedness is slightly below half-siblings.

3. These results illustrate the implications of maintaining a population at a specific population size – if populations grow more quickly to that ceiling (scenarios D vs. A), they retain more GD; once they are at that ceiling they will gradually lose GD without new founders, but will lose it more slowly if genetic management occurs.

GENETIC RESULTS ACROSS SCENARIOS

Some of the risks inherent to small populations are related to the potential impacts of inbreeding depression. Inbreeding depression can result in higher mortality or lower reproduction rates throughout a population and can increase over time as inbreeding in the population increases. Although explicit effects of inbreeding depression were not included in model scenarios, if this population ***is*** susceptible to inbreeding depression, it would mean that the model scenarios presented are likely optimistic (i.e. if we included inbreeding depression, the model's demographic projections over time would be worse).

Genetic results are based on our current and historical knowledge of the AZA lion population. These assumptions are currently under review by the AZA Population Management Center in Chicago, IL (see Appendix D for more information regarding assumptions). According to current assumptions the lion population is descended from 58 potential founders that were assumed to be unrelated, and the living population is estimated to have retained approximately 98% of the gene diversity of this source population and the inbreeding level is very low (0.006). If no additional importations occur and the population remains closed in the future, gene diversity will slowly decrease and inbreeding levels will increase through genetic drift. However, scenarios under current baseline (p(B) = 8%) only reach an inbreeding level (F) approximately less related than half-siblings (0.09) and retain 93% GD in 100 years (Fig. 10b). This indicated that even with no additional importations to the population, the AZA lion population could retain high levels of gene diversity for 100 years. Increased reproduction will delay random genetic processes and assist the population in retaining even higher levels of gene diversity for a longer period of time as well as staving off inbreeding (Fig. 10a). Removing potential female breeders from the population increases inbreeding and decreases retention of genetic diversity over the long-term as fewer individuals are available to pass their genes on to the next generation.

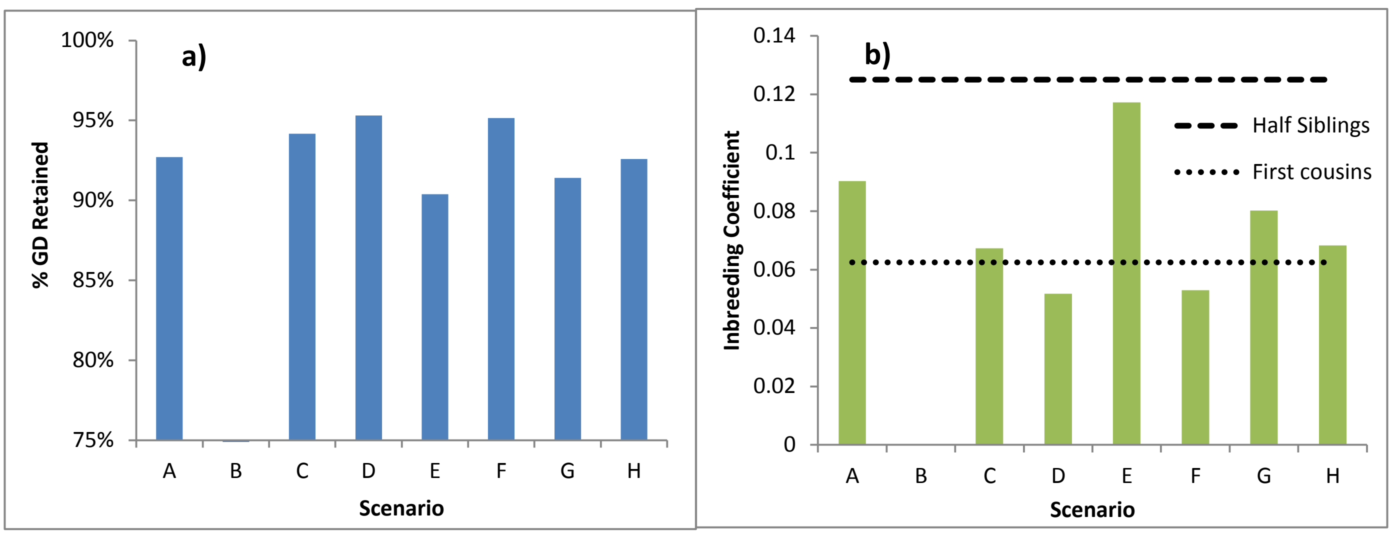

Figure 12. The mean genetic statistics at year 100 across 1000 iterations for each model scenario in Table 13, including a) gene diversity (GD) retained and b) inbreeding coefficient (F). The black horizontal lines indicate the levels of F equivalent to first cousins (0.0625) and half siblings (0.125). Starting GD = 97.52%, starting F = 0.0058.

Table 8: Scenarios in figures 12a and 12b above.

A. p(B) = 8% (Baseline)
B. Generic Lions Only
C. p(B) = 10%
D. p(B) = 15%
E. Excluding contracepted females, p(B) = 8%
F. Excluding contracepted females, p(B) = 15%
G. No Genetic Management; p(B) =8%
H. No Genetic Management; p(B) =15%

RISK RESULTS

ZooRisk also uses a standardized set of five risk tests which evaluate different aspects of a population's demography, genetics, and management that might put the population at risk, and summarizes them into a single Risk Score for each model scenario. A population under a given model scenario can be: Low Risk in captivity, Vulnerable in captivity, Critical in captivity, or Endangered in captivity (for a detailed description of risk categories see ZooRisk manual: Faust & Earnhardt, 2005). This approach standardizes assessments across species and allows managers to compare species programs using the same framework. For more details on what makes a scenario fall into a particular category, see Appendix G.

For the lion scenarios, the risk levels varied from Low Risk to Critical in zoos and aquariums depending on the model scenario (Table 12). However, the risk level was only categorized as Critical for the scenario No Generic Lions Breeding. This scenario was intended to reach zero individuals and the risk categorization should not be viewed as unsecure. These results indicate that based on the current population goals, the lion population will have a low risk of facing demographic or genetic issues over the next 100 years under all the explored scenarios.

Table 9: Overall risk results for each lion scenario (Low Risk is the most secure category, Critical the least secure).

Baseline Scenario	**Scenario's Risk Category (highlighted category = score)**			
A. p(B) = 8% (Baseline)	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
Alternate Scenario: Generic Population - No Breeding				
B. Generic Lions Only	LOW RISK	VULNERABLE	ENDANGERED	**CRITICAL**
Alternate Scenarios: Varying Female Probability of Breeding (p(B))				
C. p(B) = 10%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
D. p(B) = 15%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
Alternate Scenarios: Excluding Contracepted Females				
E. Excluding contracepted females, p(B) = 8%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
F. Excluding contracepted females, p(B) = 15%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
Alternate Scenarios: No Genetic Management				
G. No Genetic Management; p(B) =8%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL
H. No Genetic Management; p(B) =15%	**LOW RISK**	VULNERABLE	ENDANGERED	CRITICAL

MANAGEMENT ACTIONS

The AZA Lion Animal Program is currently on a positive trajectory in AZA institutions. There are several management strategies which could be applied to the population that may help it maintain or increase its current demographic and genetic health. **These management actions will be most effective when applied in combination with one another.**

- **Sustain current reproductive rates/Increase reproduction:** The program should focus on breeding reproductively viable females to **maintain or begin increasing** the number of offspring produced per year. Under current breeding rates, the population could reach its potential spaces in 32 years, and will sustain a slight decline in population size in the short-term. If reproduction is increased (29 – 33 births/year) the population has the capability of slowing or preventing the slight demographic decline that will occur as the generic population ages out of the population.
    - All breeding recommendations received are important to the long-term future of this population; institutions should work hard to get recommended pairs into appropriate breeding situations quickly and work on husbandry to improve breeding success.

- **Carefully weigh whether contraceptives are needed or warranted:** Currently, there is not enough information to determine the long-term effects of contraception on female lions. However, model results indicate that if the females currently on contraceptive do not breed again, the population will experience a much more severe decline than the baseline scenario. As the effects of contraceptives could be costly, it is important to carefully weigh whether contraception is justified for wide use across the lion population. Institutions should contact the SSP Coordinator prior to placing female lions on contraceptives.

- **Manage the generic population via attrition:** There are currently 115 (43.72) generic lions in the AZA population. The AZA Felid TAG does not recommend that lions with unknown pedigree (generics) breed or be imported to the AZA population. In the future, space occupied by generic lions will be converted to space for pedigreed lions. Institutions holding generic lions should discuss their plans for lions with the AZA Lion SSP Coordinator.

CONCLUSIONS

This model is a scientifically-sound comprehensive tool to be used by population managers for assessing future directions for the animal program. This PVA report is provided to the AZA community and others to integrate into management of the important species within our care. The PVA model results are intended to provide the necessary data to make science-based decisions.

These model results illustrate that if the AZA lion population continues on its current trajectory it will face a slight decline in population size over the next 15 – 20 years as the generic population is declines via natural attrition. However, after this decline the population (under current breeding rates) will be able to increase to its potential space and maintain at that population level for 100 years. Increasing the rate of reproduction will allow the population to reduce or avoid the demographic decline and grow towards the potential space more quickly in addition to retaining slightly more gene diversity. The removal of currently and previously contracepted females from the population shows that the population will face a much larger demographic decline if these females are no longer able to produce offspring in the future.

ACKNOWLEDGEMENTS

On July 18, 2012, the following attendees met at the Lion SSP meeting during the Annual Felid TAG meeting in Salt Lake City, Utah to discuss the Lion AZA Animal Program Population Viability Analysis:

- **Hollie Colahan,** Lion SSP Species Coordinator and Studbook Keeper
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- **Katelyn Marti,** Population Biologist
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This report was also reviewed by:

- **Melissa Theis,** Population Biologist
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- **Lisa Faust,** Vice President of Conservation and Science
    - Lincoln Park Zoo, lfaust@lpzoo.org
- **Nicole Clausen**, Lincoln Park Zoo

If you have any questions about the report, please contact Lisa Faust at lfaust@lpzoo.org.

Analyses in this report utilized the North American Regional Lion Studbook current to 17 March 2012 (citation) and were performed using PopLink 2.3 and ZooRisk 3.8.

Funding provided by Institute of Museum and Library Services (IMLS) LG-25-11-0185

Citation:
Marti, K, Colahan, H. 2012. Lion (*Panthera leo*) AZA Animal Program Population Viability Analysis Report. Lincoln Park Zoo, Chicago, IL.

APPENDIX A. LITERATURE CITED

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APPENDIX B. STUDBOOK DATA EXPORTS

Studbook Information	
Studbook Currentness Date	17 March 2012
Studbook Keeper	Hollie Colahan

Studbook Extractions:	Start Date	End Date	Institution Filter
Fecundity Window	01 January 1980	27 August 2012	AZA
Mortality Window	01 January 1980	27 August 2012	AZA
Living Population	27 August 2012	-	AZA

APPENDIX C. ZOORISK PVA MODEL SETUP

Name of ZooRisk Project = Lion 2012B

Model Parameter	Parameter Value	Additional Setup Notes
Species Biology		
Number of Males per Breeding Group	1	
Number of Females per Breeding Group	1	
Number of Years Between Pairing	5	
Model Settings		
Number of Years	100	
Number of Iterations	1000	
Extinction Threshold	0	
Gene Diversity Threshold	0.90	
Target Population Size	356	Reach TPS over 5 years
Genetic Management	Mean kinship pairing	Used in all scenarios except “No Genetic Management”
Annual Number of Offspring	**Model Frequency**	
1 offspring	0.2085	
2 offspring	0.2476	
3 offspring	0.2508	
4 offspring	0.1857	
5 offspring	0.0749	
6 offspring	0.0261	
7 offspring	0.0065	
Birth Sex Ratio		
Birth Sex Ratio	0.5153	Is not significantly different from 0.5 (chi-square value = 0.5153, p>0.05)

APPENDIX D. PEDIGREE ASSUMPTIONS

The following information was added to the studbook in the form of an overlay. These pedigree assumptions are based on the knowledge of the population as of July 2012. Currently the pedigree assumptions are under review by the Population Management Center (PMC).

HYPOTHETICAL SPECIMENS

Studbook ID	Sire	Dam	Sex	First Location
HYP17	WILD	WILD3	Female	S.AFRICA
HYP2	WILD24	WILD1	Male	S.AFRICA
HYP23	WILD26	WILD	Female	S.AFRICA
HYP30	WILD24	WILD21	Male	S.AFRICA
HYP32	WILD28	WILD1	Male	S.AFRICA

ANALYTICAL DATA FOR TRUE SPECIMENS

Studbook ID	Field	True	Overlay	Notes
105	Dam	UNK	WILD	
	Sire	UNK	WILD29	
106	Dam	UNK	WILD	
	Sire	UNK	WILD22	
145	Dam	359	WILD	
	Sire	358	WILD	
15	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
16	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
17	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
173	Dam	UNK	357	Master Analytical Notes: Lincoln Park records indicate 173 had the same mother (357) as 124. Could also be related to 103 so he shares the same sire (100).
	Sire	UNK	100	
18	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
19	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
20	Dam	WILD	WILD7	Master Analytical Notes: 15, 16, 17, 18, 19, 20 all captured on same date and location so assumed to be full siblings
	Sire	WILD	WILD6	
221	Dam	UNK	WILD	
	Sire	UNK	WILD	
224	Dam	UNK	WILD	
	Sire	UNK	WILD	
232	Dam	UNK	WILD	
	Sire	UNK	WILD	
233	Dam	WILD	WILD	Master Analytical Notes: 233 and 235 were captured at same location but about 1 month apart, assumed to be half sibs and share sire HYP12
	Sire	WILD	WILD12	
234	Dam	361	WILD	
	Sire	360	WILD	
235	Dam	WILD	WILD	Master Analytical Notes: 233 and 235 were captured at same location but about 1 month apart, assumed to be half sibs and share sire HYP12
	Sire	WILD	WILD12	

Studbook ID	Field	True	Overlay	Notes
252	Dam	UNK	361	
	Sire	UNK	360	
253	Dam	WILD	361	
	Sire	WILD	360	
254	Dam	WILD	361	
	Sire	WILD	360	
255	Dam	WILD	WILD15	
	Sire	WILD	WILD16	
256	Dam	WILD	WILD15	
	Sire	WILD	WILD16	
257	Dam	WILD	WILD15	
	Sire	WILD	WILD16	
360	Dam	WILD	WILD15	
41	Dam	WILD	WILD11	Master Analytical Notes: 41 and 42 were captured in the same location on the same date, assumed to be full siblings.
	Sire	WILD	WILD10	
42	Dam	WILD	WILD11	Master Analytical Notes: 41 and 42 were captured in the same location on the same date, assumed to be full siblings.
	Sire	WILD	WILD10	
441	Sire	446	456	
442	Dam	UNK	WILD	
	Sire	UNK	WILD	
443	Dam	UNK	WILD	
	Sire	UNK	WILD	
444	Dam	UNK	WILD	
	Sire	UNK	WILD	
445	Dam	UNK	WILD	
	Sire	UNK	WILD	
446	Dam	UNK	WILD	
	Sire	UNK	WILD	
447	Dam	UNK	WILD	
	Sire	UNK	WILD	
454	Dam	UNK	WILD	
	Sire	UNK	WILD	
47	Dam	WILD	WILD9	Master Analytical Notes: 47 and 48 were captured in the same location on the same date, assumed to be full siblings
	Sire	WILD	WILD8	
48	Dam	WILD	WILD9	Master Analytical Notes: 47 and 48 were captured in the same location on the same date, assumed to be full siblings
	Sire	WILD	WILD8	
83	Dam	WILD	WILD	
	Sire	WILD	HYP2	
84	Dam	UNK	WILD	
	Sire	UNK	WILD	
95	Dam	UNK	HYP23	
	Sire	UNK	HYP30	
97	Dam	UNK	HYP17	
	Sire	UNK	HYP32	
98	Dam	UNK	WILD	
	Sire	UNK	WILD	

APPENDIX E. INCLUDED INDIVIDUALS

These individuals were included as the starting population in all scenarios in the ZooRisk model except for the "exclude contraceptive females scenarios where 43 females were designated as non-breeders (see list below) and the no generic lions breeding scenario where all pedigrees lions were excluded from the population. Those animals with Allow Breed = NO hold space but are never eligible for reproduction. All animals with "T" in their studbook number are unpedigreed, generic lions that are not recommended for breeding.

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
48	YES	Male	100	21	ATLANTA	
49	NO	Female	87.5	21	PHILADELP	Sterile
50	NO	Male	87.5	21	PHILADELP	Sterile
51	NO	Female	87.5	21	PHILADELP	Sterile
52	NO	Female	68.75	21	PHILADELP	Sterile
59	NO	Female	100	20	SANDIEGOZ	Age
76	NO	Female	100	19	INDIANAPL	Age
90	NO	Male	100	16	KANSASCTY	Sterile
91	YES	Female	100	16	KNOXVILLE	
93	YES	Male	100	17	JACKSONVL	
98	YES	Male	100	17	SEDGWICK	
104	YES	Female	100	16	KNOXVILLE	
105	YES	Female	100	15	SAN FRAN	
108	YES	Male	100	17	FORTWORTH	
109	NO	Female	100	17	COLO SPRG	Age
110	YES	Female	100	17	SEDGWICK	
114	NO	Female	87.5	16	BALTIMORE	Sterile
121	YES	Male	100	13	AUDUBON	
122	YES	Male	100	13	OMAHA	
125	NO	Female	100	14	S BARBARA	Medical
128	YES	Male	100	13	S BARBARA	
132	NO	Female	100	16	KANSASCTY	Sterile
135	NO	Female	100	16	KANSASCTY	Sterile
136	NO	Male	100	14	DENVER	Non-reproductive
137	NO	Male	100	14	DENVER	Non-reproductive
139	NO	Female	100	13	WACO	Health
145	NO	Female	100	16	CHICAGOLP	Sterile
146	YES	Male	100	13	SEATTLE	
148	YES	Male	100	13	ASHEBORO	
152	YES	Male	100	13	TULSA	
153	YES	Female	100	13	SEATTLE	
170	YES	Female	100	11	COLUMBIA	
172	NO	Female	100	11	COLUMBIA	Sterile
175	NO	Male	100	10	KANSASCTY	Sterile
176	NO	Male	100	10	KANSASCTY	Sterile
177	NO	Female	100	10	KANSASCTY	Sterile
187	YES	Female	100	12	OKLAHOMA	
190	YES	Male	100	10	PUEBLO	
196	YES	Male	100	9	NORFOLK	
197	YES	Female	100	9	MILWAUKEE	
198	YES	Male	100	9	SAN FRAN	
200	YES	Female	100	9	TAUTPHAUS	
203	YES	Male	100	10	ABILENE	
204	YES	Male	100	10	NY BRONX	
205	NO	Female	100	10	TULSA	Sterile
206	YES	Female	100	10	SAN FRAN	
211	YES	Female	100	7	GREENBAY	
212	YES	Female	100	13	OKLAHOMA	
214	YES	Female	100	8	NORFOLK	
215	YES	Male	100	8	COLUMBIA	
218	YES	Female	100	8	ATLANTA	
221	YES	Male	100	16	MADISON	
222	YES	Female	100	8	LANSING	
223	YES	Female	100	8	LANSING	

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
225	YES	Male	100	9	MILWAUKEE	
226	YES	Male	100	7	TAUTPHAUS	
227	YES	Male	100	7	TOPEKA	
228	NO	Male	100	7	JOHN BALL	Health
229	YES	Female	100	5	GLEN OAK	
230	YES	Female	100	5	FT WAYNE	
231	YES	Male	100	5	LANSING	
232	YES	Female	100	15	DENVER	
233	YES	Female	100	15	DENVER	
234	YES	Male	100	14	DENVER	
235	NO	Female	100	14	DENVER	Non-reproductive
236	YES	Male	100	7	ATLANTA	
237	YES	Female	100	7	ABILENE	
238	YES	Female	100	7	NY BRONX	
239	YES	Female	100	6	COLUMBUS	
243	YES	Male	100	6	GARDENCTY	
244	YES	Female	100	6	INDIANAPL	
245	YES	Female	100	5	COLUMBUS	
246	YES	Female	100	8	NZP-WASH	
247	YES	Female	100	7	NZP-WASH	
248	YES	Male	100	6	NZP-WASH	
250	YES	Male	100	7	AKRON	
251	YES	Female	100	7	BIRMINGHM	
252	YES	Male	100	8	COLUMBUS	
253	YES	Male	100	8	SD-WAP	
254	NO	Female	100	8	SANDIEGOZ	Sterile
255	YES	Female	100	8	SD-WAP	
256	YES	Female	100	8	SD-WAP	
257	YES	Male	100	8	SANDIEGOZ	
260	YES	Female	100	6	JOHN BALL	
261	YES	Female	100	6	JOHN BALL	
262	YES	Male	100	6	SACRAMNTO	
263	YES	Male	100	6	CHICAGOBR	
265	YES	Male	100	14	WACO	
266	YES	Female	100	6	KNOXVILLE	
268	YES	Male	100	6	FT WAYNE	
269	YES	Female	100	6	KNOXVILLE	
271	YES	Male	100	6	KNOXVILLE	
273	YES	Male	100	6	DICKERSON	
274	YES	Male	100	6	LUFKIN	
275	YES	Male	100	7	BIRMINGHM	
276	YES	Female	100	8	TOPEKA	
277	YES	Female	100	8	TOPEKA	
280	YES	Male	100	6	GLEN OAK	
281	YES	Female	100	6	AKRON	
282	YES	Female	100	6	SACRAMNTO	
283	YES	Female	100	6	CHICAGOBR	
286	YES	Male	100	7	GREENBAY	
287	YES	Female	100	7	GARDENCTY	
292	YES	Female	100	6	PUEBLO	
294	NO	Male	100	7	KANSASCTY	Sterile
295	NO	Male	100	7	KANSASCTY	Sterile
296	NO	Male	100	7	KANSASCTY	Sterile
297	NO	Female	100	7	KANSASCTY	Sterile
298	YES	Male	100	5	LITTLEROC	
300	YES	Female	100	5	DICKERSON	
301	YES	Male	100	5	BALTIMORE	
302	NO	Female	100	5	COLO SPRG	Health
303	YES	Female	100	5	COLO SPRG	
304	YES	Female	100	5	COLO SPRG	
308	YES	Female	100	4	EL PASO	
309	YES	Female	100	4	EL PASO	
310	YES	Male	100	4	EL PASO	
311	YES	Female	100	4	EL PASO	
312	YES	Male	100	4	PORTLAND	

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
313	YES	Male	100	4	HONOLULU	
314	YES	Female	100	4	JACKSONVL	
315	YES	Female	100	4	JACKSONVL	
316	YES	Male	100	4	ST LOUIS	
317	YES	Female	100	4	WINSTON	
318	YES	Female	100	4	TUCSON	
319	YES	Male	100	4	INDIANAPL	
325	YES	Male	100	7	RACINE	
326	YES	Male	100	4	METROZOO	
327	YES	Male	100	4	METROZOO	
328	YES	Male	100	4	PUEBLA	
329	YES	Female	100	4	PORTLAND	
330	YES	Female	100	4	DALLAS	
331	YES	Male	100	4	GREENVISC	
332	YES	Female	100	4	DALLAS	
333	YES	Female	100	4	DALLAS	
334	YES	Male	100	4	GREENVISC	
336	YES	Male	100	4	PUEBLA	
337	YES	Male	100	4	PUEBLA	
338	YES	Male	100	4	PUEBLA	
341	YES	Female	100	5	PORTLAND	
342	YES	Male	100	5	WINSTON	
345	YES	Male	100	6	JACKSONVL	
346	YES	Female	100	6	ST LOUIS	
347	YES	Female	100	5	OMAHA	
349	YES	Female	100	5	LUFKIN	
352	YES	Female	100	4	HOUSTON	
353	YES	Female	100	4	HOUSTON	
354	YES	Male	100	4	TUCSON	
355	YES	Female	100	4	HOUSTON	
366	YES	Male	100	4	SEDGWICK	
367	YES	Male	100	4	BROWNSVIL	
369	YES	Male	100	4	JNGLARY F	
370	YES	Female	100	4	JNGLARY F	
373	YES	Female	100	3	HONOLULU	
375	YES	Male	100	3	BUFFALO	
376	YES	Female	100	3	MEMPHIS	
377	YES	Female	100	3	MEMPHIS	
378	YES	Female	100	4	OMAHA	
379	YES	Male	100	3	PHILADELP	
380	YES	Male	100	3	MEMPHIS	
381	YES	Male	100	3	DALLAS	
382	YES	Male	100	3	DALLAS	
383	YES	Female	100	3	SEDGWICK	
386	YES	Male	100	3	PITTSBURG	
387	YES	Male	100	3	PITTSBURG	
388	YES	Male	100	3	DISNEY AK	
389	YES	Female	100	3	KNOXVILLE	
390	YES	Male	100	2	PHOENIX	
391	YES	Female	100	2	SEATTLE	
392	YES	Female	100	2	ASHEBORO	
393	YES	Male	100	2	CHICAGOLP	
394	YES	Female	100	2	METROZOO	
395	YES	Female	100	2	METROZOO	
399	NO	Male	100	2	ABILENE	Transferring to non-AZA institution
400	YES	Female	100	2	DISNEY AK	
401	NO	Male	100	2	ABILENE	Transferring to non-AZA institution
402	YES	Female	100	2	DISNEY AK	
403	NO	Male	100	2	ABILENE	Transferring to non-AZA institution
404	YES	Female	100	2	RACINE	
405	YES	Female	100	2	PHILADELP	
407	YES	Female	100	1	NZP-WASH	
408	YES	Female	100	1	NZP-WASH	
409	YES	Male	100	1	NZP-WASH	
410	YES	Female	100	1	NZP-WASH	

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
411	YES	Male	100	1	NZP-WASH	
412	YES	Male	100	1	NZP-WASH	
413	YES	Female	100	1	NZP-WASH	
415	YES	Male	100	1	MADISON	
417	YES	Female	100	1	SEDGWICK	
420	YES	Male	100	1	BIRMINGHM	
421	YES	Male	100	1	BIRMINGHM	
422	YES	Female	100	1	BIRMINGHM	
423	YES	Female	100	1	BIRMINGHM	
424	YES	Female	100	1	BIRMINGHM	
425	YES	Male	100	1	MILWAUKEE	
426	YES	Male	100	1	MILWAUKEE	
427	YES	Female	100	1	MILWAUKEE	
428	YES	Male	100	1	TUCSON	
429	YES	Male	100	1	TUCSON	
430	YES	Female	100	1	TUCSON	
432	YES	Female	100	1	ST LOUIS	
435	YES	Female	100	0	ST LOUIS	
436	YES	Female	100	0	ST LOUIS	
439	YES	Male	100	1	FORTWORTH	
440	YES	Female	100	1	FORTWORTH	
441	YES	Female	100	1	FORTWORTH	
448	YES	Male	100	1	ROCHESTER	
449	YES	Female	100	1	ROCHESTER	
450	YES	Female	100	1	ROCHESTER	
T4149	NO	Female	0	23	LOSANGELE	Generic
T4151	NO	Female	0	23	SAN ANTON	Generic
T4223	NO	Female	0	22	PITTSBURG	Generic
T4230	NO	Female	50	22	CALDWELL	Generic
T4245	NO	Female	0	22	WINSTON	Generic
T4255	NO	Female	0	22	HOUSTON	Generic
T4320	NO	Male	0	21	MONTGOMRY	Generic
T4335	NO	Male	0	20	AUDUB SSC	Generic
T4342	NO	Female	0	20	DETROIT	Generic
T4349	NO	Female	0	20	REDWOOD	Generic
T4367	NO	Male	0	19	DETROIT	Generic
T4368	NO	Female	0	19	ST PAUL	Generic
T4392	NO	Male	25	19	CALDWELL	Generic
T4403	NO	Male	0	19	FRANKLINP	Generic
T4429	NO	Female	0	18	LITTLEROC	Generic
T4437	NO	Female	0	18	OMAHA	Generic
T4449	NO	Female	0	18	MEMPHIS	Generic
T4451	NO	Female	0	18	EVANSVLLE	Generic
T4454	NO	Male	0	18	COAL VAL	Generic
T4463	NO	Male	0	17	ALEXANDRI	Generic
T4471	NO	Female	0	17	LITTLEROC	Generic
T4481	NO	Female	0	17	ALEXANDRI	Generic
T4501	NO	Male	0	17	MONTGOMRY	Generic
T4502	NO	Male	0	17	GRANBY	Generic
T4514	NO	Female	0	16	CALGARY	Generic
T4522	NO	Female	0	16	CALGARY	Generic
T4556	NO	Male	0	16	DISNEY AK	Generic
T4557	NO	Female	0	16	DISNEY AK	Generic
T4568	NO	Male	0	15	RIO GRAND	Generic
T4570	NO	Female	0	15	DES MOINE	Generic
T4571	NO	Female	0	15	DES MOINE	Generic
T4573	NO	Female	0	15	WACO	Generic
T4576	NO	Male	0	15	ROLLING H	Generic
T4577	NO	Male	0	15	ROLLING H	Generic
T4583	NO	Female	0	15	GRANBY	Generic
T4584	NO	Female	0	15	JNGLARY F	Generic
T4585	NO	Male	0	15	JNGLARY F	Generic
T4600	NO	Male	43.75	14	CINCINNAT	Generic
T4601	NO	Male	12.5	14	CLEVELAND	Generic
T4605	NO	Male	0	14	CAPE MAY	Generic

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
T4607	NO	Male	39.0625	14	CINCINNAT	Generic
T4612	NO	Female	0	14	CINCINNAT	Generic
T4614	NO	Female	0	14	LOUISVILL	Generic
T4615	NO	Female	0	14	LOUISVILL	Generic
T4624	NO	Female	0	14	AUDUBON	Generic
T4634	NO	Female	0	14	ERIE	Generic
T4645	NO	Female	0	13	PHOENIX	Generic
T4648	NO	Female	0	15	BROWNSVIL	Generic
T4682	NO	Male	0	12	LOUISVILL	Generic
T4683	NO	Female	0	12	ST PAUL	Generic
T4684	NO	Female	0	12	OAKLAND	Generic
T4685	NO	Male	0	12	OAKLAND	Generic
T4692	NO	Male	0	12	SYRACUSE	Generic
T4693	NO	Female	0	12	SYRACUSE	Generic
T4694	NO	Female	0	12	SYRACUSE	Generic
T4695	NO	Female	0	12	W PALM BE	Generic
T4696	NO	Male	0	12	W PALM BE	Generic
T4706	NO	Female	0	12	PITTSBURG	Generic
T4707	NO	Female	0	12	PITTSBURG	Generic
T4708	NO	Male	0	11	SCOTTSBLU	Generic
T4709	NO	Male	0	11	SCOTTSBLU	Generic
T4710	NO	Female	0	11	ERIE	Generic
T4722	NO	Male	21.875	11	TOLEDO	Generic
T4723	NO	Male	21.875	11	TOLEDO	Generic
T4724	NO	Male	21.875	11	TOLEDO	Generic
T4725	NO	Female	21.875	11	CINCINNAT	Generic
T4727	NO	Male	0	11	W PALM BE	Generic
T4728	NO	Female	0	11	W PALM BE	Generic
T4735	NO	Male	0	10	ST PAUL	Generic
T4739	NO	Male	0	10	SOUTHBEND	Generic
T4740	NO	Male	0	10	SOUTHBEND	Generic
T4744	NO	Male	0	10	BUFFALO	Generic
T4745	NO	Female	0	10	BUFFALO	Generic
T4746	NO	Female	0	10	BUFFALO	Generic
T4747	NO	Female	0	10	GRANBY	Generic
T4748	NO	Female	0	10	COAL VAL	Generic
T4758	NO	Female	0	10	REDWOOD	Generic
T4759	NO	Female	0	9	REDWOOD	Generic
T4773	NO	Male	0	9	REDWOOD	Generic
T4780	NO	Female	0	9	COAL VAL	Generic
T4793	NO	Female	0	16	RIO GRAND	Generic
T4823	NO	Female	0	15	W PALM BE	Generic
T4824	NO	Female	0	15	W PALM BE	Generic
T4825	NO	Female	0	15	W PALM BE	Generic
T4829	NO	Male	0	12	W PALM BE	Generic
T4830	NO	Female	0	11	W PALM BE	Generic
T4831	NO	Female	0	15	W PALM BE	Generic
T4832	NO	Female	0	15	W PALM BE	Generic
T4833	NO	Female	0	15	W PALM BE	Generic
T4834	NO	Female	0	15	W PALM BE	Generic
T4862	NO	Female	0	7	ATTLEBORO	Generic
T4863	NO	Female	0	7	ATTLEBORO	Generic
T4895	NO	Male	0	13	HOUSTON	Generic
T5000	NO	Male	0	6	ATTLEBORO	Generic
T5001	NO	Female	0	11	BOISE	Generic
T5002	NO	Female	0	10	BOISE	Generic
T5003	NO	Male	0	9	BOISE	Generic
T5005	NO	Male	0	6	BUSCH TAM	Generic
T5006	NO	Female	0	6	BUSCH TAM	Generic
T5007	NO	Female	0	6	BUSCH TAM	Generic
T5011	NO	Female	0	20	IEFS	Generic
T5012	NO	Male	0	16	IEFS	Generic
T5013	NO	Male	0	16	IEFS	Generic
T5014	NO	Female	0	16	IEFS	Generic
T5015	NO	Male	0	17	IEFS	Generic

ID	Allow Breed	Sex	% Known	Age	Institution	Reason For Exclusion
T5016	NO	Male	0	21	IEFS	Generic
T5017	NO	Female	0	19	IEFS	Generic
T5027	NO	Female	0	11	DETROIT	Generic
T5036	NO	Female	0	24	PUEBLA	Generic
T5037	NO	Female	0	25	PUEBLA	Generic
T5038	NO	Female	0	25	PUEBLA	Generic
T5039	NO	Female	0	24	PUEBLA	Generic
T5040	NO	Female	0	24	PUEBLA	Generic
T5041	NO	Male	0	5	PUEBLA	Generic
T5042	NO	Female	0	8	PUEBLA	Generic

Females Removed from Breeding Population for Scenarios E and F:

List of 43 females currently or previously on contraceptive that have not reproduced once on medication. All of these females were not allowed to breed in the model for the scenarios "exclude contracepted females".

SB ID	Location	Age
170	COLUMBIA	11
200	TAUTPHAUS	9
206	SAN FRAN	10
211	GREENBAY	7
214	NORFOLK	8
222	LANSING	8
223	LANSING	8
229	GLEN OAK	5
230	FT WAYNE	5
237	ABILENE	7
239	COLUMBUS	6
244	INDIANAPL	6
245	COLUMBUS	5
255	SD-WAP	8
256	SD-WAP	8
276	TOPEKA	8
277	TOPEKA	8
281	AKRON	6
282	SACRAMNTO	6
283	CHICAGOBR	6
287	GARDENCTY	7
292	LANSING	6
300	DICKERSON	5
303	COLO SPRG	5
304	COLO SPRG	5
308	EL PASO	4
309	EL PASO	4
311	EL PASO	4
314	JACKSONVL	4
315	JACKSONVL	4
317	WINSTON	4
329	PORTLAND	4
341	PORTLAND	5
347	OMAHA	5
349	LUFKIN	5
352	HOUSTON	4
353	HOUSTON	4
355	HOUSTON	4
370	JUNGLARY F	4
376	MEMPHIS	3
377	MEMPHIS	3
378	OMAHA	4
389	KNOXVILLE	3

APPENDIX F. MALE AND FEMALE MORTALITY RATES (QX)

Male and female mortality rates used in all scenarios of the ZooRisk model are listed below. Each year, the model determines whether each individual lives or dies stochastically based on that individual's age- and sex-specific mortality rate.

Male

Age(x)	Qx	Number at Risk
0	0.262	567
1	0.029	343.5
2	0.029	313
3	0.003	305.5
4	0.003	302.5
5	0.007	295.5
6	0.027	298.5
7	0.025	275.5
8	0.004	257
9	0.023	258
10	0.040	249
11	0.034	236
12	0.049	225
13	0.073	206
14	0.087	185
15	0.067	164
16	0.170	147
17	0.193	119
18	0.308	91
19	0.365	63
20	0.384	36.5
21	0.342	20.5
22	0.500	8
23	0.250	4
24	0.667	3
25	0.000	1
26	1.000	1

Female

Age(x)	Qx	Number at Risk
0	0.228	585
1	0.033	397.5
2	0.016	373
3	0.011	367.5
4	0.021	376.5
5	0.026	379.5
6	0.016	371.5
7	0.019	360.5
8	0.017	358
9	0.009	354
10	0.026	350
11	0.050	337
12	0.054	313
13	0.066	290
14	0.076	265
15	0.109	239
16	0.116	198
17	0.137	161
18	0.206	136
19	0.279	104
20	0.144	69.5
21	0.243	53.5
22	0.514	37
23	0.286	14
24	0.000	8
25	0.400	5
26	1.000	1

APPENDIX G. OVERALL RESULTS TABLE

Table 15. Model results across all lion scenarios. Starting population = 324 (139 males and 185 females). Starting GD = 97.52%, starting F = 0.0058.

SCENARIO	Mean Population Size[1] in Year 25 ± 1 SD[2]	Mean Population Size[1] in Year 100 ± 1 SD[2]	Mean # of Offspring in the first 10 model years	Probability of reaching TPS	Median time to TPS (years)[3]	Probability of reaching Extinction	Median time to Extinction (years)	Mean GD Retained[1] in Year 100 ± 1 SD[2]	Mean F Retained[1] in Year 100 ± 1 SD[2]
Baseline Scenario:									
A. p(B) = 8% (Baseline)	306 ± 49	356 ± 34	22.3	97%	32	0%	-	93% ± 1%	0.09 ± 0.02
Alternate Scenario: Generic Population - No Breeding									
B. Generic Lions Only	0 ± 0	0 ± 0	0	0%	0	100%	17	0% ± 0%	0 ± 0
Alternate Scenario: Varying Female Probability of Breeding [p(B)]									
C. p(B) = 10%	355 ± 11	354 ± 9	29.2	100%	12	0%	-	94% ± 0.3%	0.07 ± 0.01
D. p(B) = 15%	356 ± 9	356 ± 9	32.6	100%	5	0%	-	95% ± 0.2%	0.05 ± 0.01
Alternate Scenarios: Excluding Contracepted Females									
E. Exclude contracepted females, p(B) = 8%	201 ± 58	303 ± 81	13.2	71%	60	0.20%	88	90% ± 4%	0.12± 0.04
F. Exclude contracepted females, p(B) = 15%	356 ± 9	356± 9	30.9	100%	10	0%	-	95% ± 0.2%	0.05 ± 0.01
Alternate Scenarios: No Genetic Management									
G. No Genetic Management; p(B) =8%	308 ± 49	335 ± 37	22.2	96%	31	0%	-	91% ± 1%	0.08 ± 0.01
H. No Genetic Management; p(B) =15%	356 ± 9	356± 9	32.7	100%	5	0%	-	93% ± 0.4%	0.07 ± 0.01

[1] All population sizes, gene diversity, and inbreeding are the mean values across 1000 iterations.

[2] One standard deviation.

[3] A dash (-) indicates that extinction will never be reached

APPENDIX H. RISK CATEGORIES AND RESULTS

ZooRisk uses five, standardized tests to determine a scenario's risk level. The ZooRisk development team and members of the AZA Small Population Management Advisory Group (SPMAG) worked to develop the cutoffs for each category level during the development of ZooRisk.

The 5 tests and the cutoffs for each level are:

#	Risk Tests	Low Risk	Vulnerable	Endangered	Critical
1	**Probability of extinction (P(E)) in 100 years, based on ZooRisk model**	0-9% P(E) within 100 years	10-19% P(E) within 100 years	20-49% P(E) within 100 years	50-100% P(E) within 100 years
2	**Distribution of breeding-aged, mixed-sex groups, based on current population**	>3 Zoos	3 Zoos	2 Zoos	1 Zoo
3	**Current number of breeding-aged animals (m.f), based on current population**	More than 10.10	7.7 to 10.10	4.4 to 6.6	0.0 to 3.3
4	**Reproduction in the last generation, based on historic studbook data**	Consistent success: >9 pairs reproducing	Inconsistent success: 6-9 pairs reproducing	Sporadic success: 3-5 pairs reproducing	Little success: 0-2 pairs reproducing
5	**Gene diversity of starting population or modeled population in 100 years, based on current population and ZooRisk model**	Starting GD >0.9 and modeled GD >0.9at 100 years	Starting GD <0.9 or modeled GD <0.9at 100 years	Starting GD <0.8 or modeled GD <0.75at 100 years	Starting GD <0.75 or modeled GD <0.5at 100 years

For a given scenario, the overall risk level is based on the most severe score it achieved for any of the five tests. Tests 2-4 are based on the population's history, and are the same across all model scenarios:

	Overall	Test 1 - Probability of extinction (P(E)) in 100 years	Test 2 - Distribution of breeding-aged, mixed-sex groups	Test 3 - Current number of breeding-aged animals (m.f)	Test 4 - Reproduction in the last generation	Test 5 - GD of starting population or modeled population in 100 years
Baseline Scenario						
A. p(B) = 8% (Baseline)	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
Alternate Scenario: Generic Population - No Breeding						
B. Generic Lions Only	CRITICAL	CRITICAL	LOW RISK	LOW RISK	LOW RISK	CRITICAL
Alternate Scenarios: Scenarios Varying Female Probability of Breeding (p(B))						
C. p(B) = 10%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
D. p(B) = 15%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
Alternate Scenarios: Excluding Contracepted Females						
E. Excluding contracepted females, p(B) = 8%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
F. Excluding contracepted females, p(B) = 15%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
Alternate Scenarios: No Genetic Management						
G. No Genetic Management; p(B) =8%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK
H. No Genetic Management; p(B) =15%	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK

APPENDIX I. DEFINITIONS

Age Structure: A two-way classification showing the numbers or percentages of individuals in various age and sex classes.

Current Gene Diversity (GD): The proportional gene diversity (as a proportion of the source population) is the probability that two alleles from the same locus sampled at random from the population will not be identical by descent. Gene diversity is calculated from allele frequencies, and is the heterozygosity expected in progeny produced by random mating, and if the population were in Hardy-Weinberg equilibrium.

Founder: An individual obtained from a source population (often the wild) that has no known relationship to any individuals in the derived population (except for its own descendants).

Inbreeding Coefficient (F): Probability that the two alleles at a genetic locus are identical by descent from an ancestor common to both parents. The mean inbreeding coefficient of a population will be the proportional decrease in observed heterozygosity relative to the expected heterozygosity of the founder population.

Mean Kinship (MK): The mean kinship coefficient between an animal and all animals (including itself) in the living, zoo born population. The mean kinship of a population is equal to the proportional loss of gene diversity of the descendant (zoo born) population relative to the founders and is also the mean inbreeding coefficient of progeny produced by random mating. Mean kinship is also the reciprocal of two times the founder genome equivalents: MK = 1 / (2 * FGE). MK = 1 - GD.

Mean Generation Time (T): The average time elapsing from reproduction in one generation to the time the next generation reproduces. Also, the average age at which a female (or male) produces offspring. It is not the age of first reproduction. Males and females often have different generation times.

Percent Known: Percent of an animal's genome that is traceable to known Founders. Thus, if an animal has an UNK sire, the % Known = 50. If it has an UNK grandparent, % Known = 75%

Population Viability Analysis (PVA): A PVA is a computer model that projects the likely future status of a population. PVAs are used for evaluating long-term sustainability, setting population goals, and comparing alternative management strategies. Several quantitative parameters are used in a PVA to calculate the extinction risk of a population, forecast the population's future trajectory, and identify key factors impacting the population's future.

Probability of Breeding [p(B)]: Female p(B) is the age-specific probability that a female will have at least one offspring in a year. For example, p(B) = 25% is equivalent to females producing an offspring once every 4 years. Within the reproductively viable age classes, all p(B) were set at a hypothetical constant value corresponding with an interbirth interval, which varied depending on the model scenario. Using a constant value means that all reproductively viable females would have the same chance of reproduction regardless of age.

Qx, Mortality: Probability that an individual of age x dies during time period.

Regional Collection Plan (RCP): document developed by Taxon Advisory Group (TAG) to describe species managed under their TAG, level of management with explanations, and evaluation of Target Population Sizes for each managed species.

Risk (Qx or Mx): The number of individuals that have lived during an age class. The number at risk is used to calculate Mx and Qx by dividing the number of births and deaths that occurred during an age class by the number of animals at risk of dying and reproducing during that age class. The proportion of individuals that die during an age class is calculated from the number of animals that die during an age class divided by the number of animals that were alive at the beginning of the age class (i.e.-"at risk").

Stochastic Model: A model that includes random chance and variation in model parameters (e.g. randomly select if an individual will breed). Stochastic models will produce many different outcomes each time the model is run due to this variation. Models are typically run for many iterations to fully explore the trajectory a population might take. ZooRisk is a stochastic model.

Target Population Size (TPS): In the context of a Regional Collection Plan, the 'target' size selected for each Program within the RCP, which may be based on available spaces for that species, desired spaces the TAG wishes to allocate, the size needed to maintain a viable population, or some combination of those factors. In the context of the ZooRisk modeling work, the TPS is a model parameter that can be set at any level, including the size listed in the RCP or a higher or lower size based on other criteria.

Taxon Advisory Group (TAG): There are several different TAGs and each oversees a broad group of animals (e.g. Antelope TAG, Small Carnivore TAG). Each TAG consists of several programs. The TAG contains experts including studbook keepers, program leaders, the TAG chair, and other advisors. TAGs evaluate the present conditions surrounding a broad group of animals (e.g., marine mammals) and then prioritize the different species in the group for possible captive programs.