River Hippopotamus (*Hippopotamus amphibius*) AZA Animal Program Population Viability Analysis Report

Population Biologist
Brent Johnson, bjohnson@lpzoo.org

AZA Animal Program Leader & Regional Studbook Keeper
John Davis, jdavis@riverbanks.org

AZA Wild Pig, Peccary, Hippo TAG Chair
Martin Ramirez,
martin.ramirez@zoo.org

AZA Wild Pig, Peccary, Hippo TAG Vice-Chair
Jeff Holland, jeff.holland@lacity.org

May 13, 2016

Population Viability Analyses (PVAs) for AZA Animal Programs

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2

POPULATION VIABILITY ANALYSIS (PVA) APPROACH 3

POPULATION HISTORY AND CURRENT STATUS 4

MODEL SCENARIOS 7

POPULATION VIABILITY UNDER CURRENT MANAGEMENT 8

ALTERNATE MODEL SCENARIOS 9

MANAGEMENT ACTIONS 13

CONCLUSIONS 13

ACKNOWLEDGEMENTS 14

LITERATURE CITED 15

DEFINITIONS 16

APPENDICES 17

EXECUTIVE SUMMARY

Population Viability Analyses (PVA) are being conducted by Lincoln Park Zoo and Population Management Center researchers through funding from the Institute of Museum and Library Services (IMLS). The project team uses ZooRisk 3.80 (Earnhardt et al. 2008), a PVA modeling software, to examine what would happen to AZA populations if current conditions remain the same (the baseline scenario), and then assess the impact of changes in reproductive rates, space availability, imports/exports, and other potential management actions (alternate scenarios). Model scenarios for this population were developed with members of the Association of Zoos and Aquarium (AZA) Wild Pig, Peccary, and Hippo Taxon Advisory Group (TAG) in 2015 and 2016.

POPULATION HISTORY/CURRENT STATUS

River hippos (*Hippopotamus amphibius*) have been consistently held in North American zoos since 1883. Through a combination of zoo births and importation from other populations, the managed North American population (at AZA and one closely participating non-AZA institution) grew to a peak of 114 individuals in 1975. Over the past decade, the population had several years of purposefully low breeding to accommodate reduced institutional interest, and averaged 0.9 births per year. The population currently includes 80 individuals, which retain 94.9% of founding gene diversity and have low inbreeding (average inbreeding coefficient [F] of 0.018). Genetic values are based on a pedigree knownness of 61.9%.

PROGRAM CHALLENGES

Many currently participating institutions have space for only two adult river hippos. Consequently, many institutions choose to hold two adult females given the challenges associated with holding a potential breeding pair. Because of this practice, managers often have difficulty in placing adult male river hippos, which must be held singly, in spite of the female bias in the current potentially breeding population (1.9 females per male). Additionally, breeding is constrained by the limited number of breeding pairs that are formed. Ideally, more institutions would be able to hold larger breeding groups that could better accommodate the population's current sex ratio.

PVA RESULTS

Model results indicate that, under its average breeding rate from the past 10 years (~1 birth/year), the river hippopotamus population would decline over the next century. However, **maintaining consistently higher breeding is predicted to allow the river hippopotamus population to stabilize over the next 100 years**. If river hippos consistently produce 3 to 4 births/year (corresponding to a 13% probability of breeding for each female), the population could remain near its current size with the known-pedigree portion of the population retaining 89.7% gene diversity and inbreeding (F = 0.093) above that of offspring produced by mating between first cousins (F = 0.063) in 100 years. Additionally, pedigree knownness for the population is predicted to increase from 61.9% to 71.9% in 100 years due to prioritization of known-pedigree individuals for breeding. Without careful genetic management, the population could potentially maintain similar gene diversity (87.8%) and inbreeding (F = 0.102) over the next 100 years, but pedigree knownness may not increase above 61.9%. Alternatively, excluding all 20 individuals with 0% known pedigrees from breeding could help knownness increase to 81.6% over the next 100 years. However, doing so would cause the population to decline to 63 individuals during the next three decades unless breeding can be further increased among the remaining potentially breeding population. If the program can recruit new facilities capable of holding larger breeding groups, with two females per male rather than one, a greater number of females would have potential breeding opportunities. As a result, the population could grow to fill 90 spaces by producing 4 to 5 births/year under the same female probability of breeding required otherwise (p[B] = 13%). With routine importation, the river hippopotamus population could remain demographically stable and potentially maintain more than 90% gene diversity among known-pedigree individuals over the next 100 years. Conversely, routine exportation without any imports and an average of 3 to 4 births/year (p[B] = 13%) would cause the population to decline during the next century.

MANAGEMENT ACTIONS

Given the current challenges for the river hippopotamus population, PVA results indicate that the following changes in management should be considered in an effort to improve this population's sustainability. Note that the PVA allows us to compare between hypothetical changes, but cannot evaluate whether achieving these changes is feasible, practical, or desirable given the program's constraints.

- **To remain demographically stable, increase breeding:** If breeding can be increased from an average of ~1 birth per year to 3 to 4 births each year, the river hippopotamus population could remain near its current size and maintain nearly 90% gene diversity among known-pedigree individuals over the next century. This breeding rate would be difficult to achieve unless facilities capable of housing breeding groups and bachelor groups are constructed. Program managers recommend that new breeding facilities be capable of holding at least two adult females per adult male and allow for separation of adult males from females and their offspring. If the river hippo population produces fewer than 3 to 4 births per year, it could be expected to decline during the next 100 years.

FULL REPORT

POPULATION VIABILITY ANALYSIS (PVA) APPROACH

A Population Viability Analysis (PVA) is a model that projects the likely future status of a population. PVAs are used to evaluate long-term demographic and genetic sustainability and extinction risk, identify key factors impacting a population's dynamics, and compare alternative management strategies.

This PVA utilizes ZooRisk, a computer software package that models the future dynamics of a cooperatively-bred population using that population's age and sex structure, mortality and reproductive rates, and genetic structure (Earnhardt et al., 2008). ZooRisk is individual-based, meaning it tracks every animal (current and future) in the population over time. It also includes stochasticity, the randomness in mortality, fecundity, and birth sex ratios among individuals, which is especially important for small populations. Because of this stochasticity, we run each model many times, allowing us to determine the range of potential outcomes a population could experience under a given set of conditions.

The most powerful use of PVAs is to compare a baseline scenario, reflecting the population's likely future trajectory if no management changes are made, to alternate scenarios reflecting potential management changes. For zoo and aquarium populations, these alternate scenarios typically involve varying breeding rates (probability of breeding), potential space for the population, importation or exportation rates, mortality rates, or genetic management strategies. These comparisons can help evaluate the relative costs and benefits of possible management actions. Because 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.

Full documentation on ZooRisk can be found in the software's manual (Faust et al., 2008); complete details on the modeling approach for this PVA, including data sources, parameter values, and model setup, can be found in Appendix A.

POPULATION HISTORY AND CURRENT STATUS

Data presented in this section pertain to a starting population of river hippos housed among 31 AZA institutions (holding 79 individuals) and one non-AZA partner institutions (holding one individual) in North America. Information about the status of river hippos strictly within AZA can be found in Appendix B.

Demographics

Based on the Regional River Hippopotamus Studbook (Davis, 2014), river hippos have been consistently held in North American zoos since 1883, and the first zoo birth occurred in 1916. However, the population included fewer than 30 individuals per year until the 1950s, when large importations events and increased birth rates caused the population size to increase rapidly (Figs. 1 and 2a). (Note that throughout this report, "imports" are animals entering the managed population which may be coming from outside sources such as the private sector, zoos in other regions, or the wild, and conversely "exports" are animals exiting the managed population and going into outside populations, such as other zoo regions). High birth rates caused the population to reach a peak size of approximately 114 individuals in the mid-1970s, and exportation increased with the growing population size (Fig. 1 and 2). Annual birth numbers began to decrease in the 1980s, and the population declined to approximately 90 individuals in 1988. Although births continued to trend downward, the importation of 10 individuals from Europe in 1998 and a resulting spike in breeding caused the population to achieve a second peak size of 111 individuals in 2003.

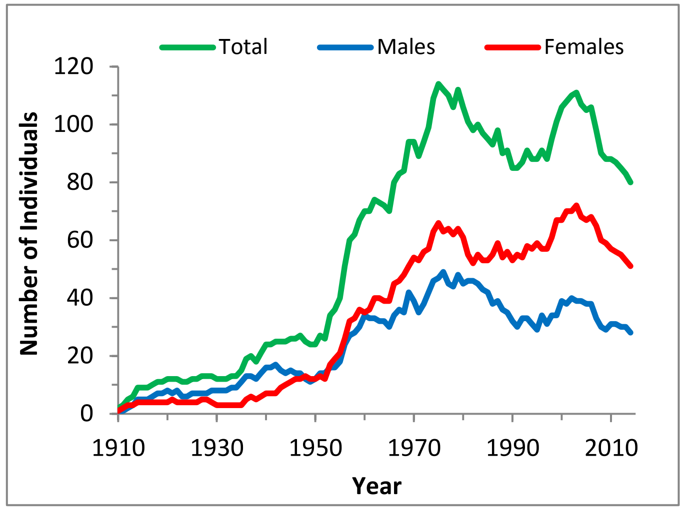

Figure 1. Number of river hippos in AZA and partner institutions since 1910.

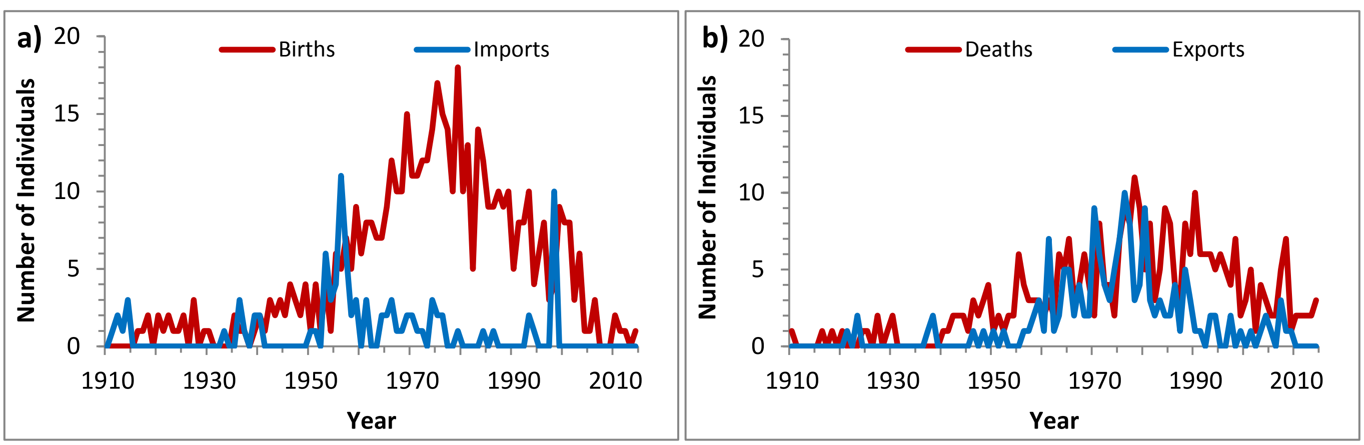

Figure 2. Number of a) births and imports and b) deaths and exports in the population since 1910. Imported animals entering the population may be coming from the private sector, other zoo regions, or the wild; exported animals may be going to other institutions outside of the population in North America or other zoo regions.

Over the last 10 full years (2005-2014, based on the studbook currentness date, July 20th, 2015), the river hippopotamus population decreased from 105 to 80 individuals at an average rate of -2.7%, although specific annual growth rates ranged from -8.2% to +1.0% (Table 1). Within the past five years, the population declined less rapidly at an average rate of -1.6% per year. In these years, managers purposefully reduced the population's size in order to accommodate recent changes in institutional interest. Over the past decade, the population averaged 0.9 births per year (which corresponds to each female having a 3.7% probability of breeding in a given year; see Appendix A) as well as 0.6 exports to outside holders in North America each year.

As of July 20th, 2015 (the studbook currentness date), our starting river hippopotamus population consisted of **80 individuals (28 males, 52 females)**. Seven animals (5 males, 2 females) are excluded from the potentially breeding population based on being beyond the reproductive age window (3-46 for males, 4-42 for females; see Appendix A) or otherwise unable to breed. In the model, these animals hold space until their death but do not produce offspring. This leaves **a potentially breeding population of 73 individuals (26 males, 47 females)**. See Appendix C for a complete list of the individuals included in the model and their reproductive status.

Table 1. Summary of demographic statistics for the population.

Population Sizes	**Total (male.female.unknown)**
Current population	80 (28.52.0)
Potentially breeding population	73 (26.47.0)
Annual rates over the last decade	**Mean (min-max)**
Population Growth (Lambda, λ)	0.973 (0.918-1.010)
Births	0.9 (0-3)
Deaths	2.8 (1-7)
Imports	0
Exports	0.6 (0-3)

The river hippopotamus population has a roughly columnar age structure with many empty younger age classes due to low reproduction in the past decade (Fig. 3a). Higher importation and slightly lower exportation of female hippos over the past several decades has resulted in an increasingly female-biased sex ratio (Fig. 1), and the potentially breeding population currently includes 1.9 females per male (Fig. 3b). Many participating institutions have space for only two adult hippos, and a large number of these institutions house female pairs. Others hold potential breeding pairs. Because most institutions house at least one female, program managers are concerned about their ability to place unpaired adult males among zoos. Managers are also concerned about the timely placement of offspring as many facilities cannot hold offspring for more than a few years.

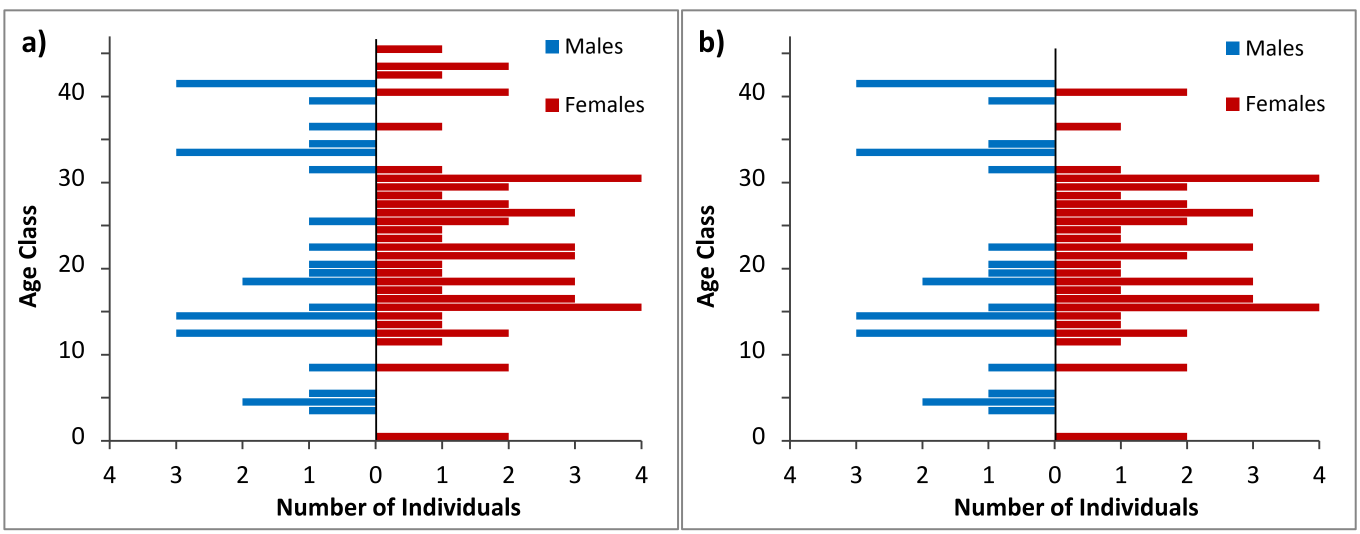

Figure 3. The age distribution of the river hippopotamus population divided into a) the total population, 80 (28.52), and b) the potentially breeding population, 73 (26.47).

Genetics

After breeding exclusions (see Appendix C) and analytical assumptions (see Appendix D), the pedigree of the river hippopotamus population is 61.94% known (Table 2). Before assumptions and exclusions, the pedigree is approximately 55% known. Much of the pedigree unknownness is due to a lack of historical records for the founding population. Approximately 53% (39 out of 73) of

Table 2. Summary of starting genetic statistics for the population.

Percentage of pedigree known[1]	61.94%
Gene diversity (GD)	94.86%
Population mean kinship (MK)	0.0514
Mean inbreeding (F)	0.0181
Mean generation time (T) (years)	16.2
Number of generations in 100 model years	6.2

[1]after breeding exclusions (Appendix C) and assumptions (Appendix D).

individuals in the current potentially breeding population have some amount of pedigree unknownness. Because reported genetic metrics are only representative of the known portion of the population, they may not accurately reflect actual gene diversity or inbreeding of the entire population. Consequently**, actual inbreeding or gene diversity may be higher or lower than the reported values and should only be considered as reliable as the percent of the pedigree known**. The known portion of the managed population is descended from 33 founders and no additional potential founders remain. Current gene diversity of the known-pedigree individuals is estimated to be 94.86%. As gene diversity falls, reproduction may become increasingly compromised by lower birth weights, greater neonatal mortality, and other negative factors.

The known-pedigree population is currently estimated to have a mean inbreeding level of 0.0181 (a mean inbreeding coefficient of 0.0625 is equivalent to mating between first cousins with no prior inbreeding). One of the largest genetic threats to small populations is the potential for inbreeding depression, in which breeding between close relatives results in reductions in fecundity or litter size, increases in infant mortality, and other detrimental effects (DeRose and Roff, 1999; Koeninger Ryan, et al., 2002; Ballou and Foose, 1996; Reed and Frankham, 2003). Given the high amount of pedigree unknownness for the river hippopotamus population, it is not appropriate to test for possible effects of inbreeding on infant mortality. Although we cannot determine if inbreeding is impacting the population at this time, inbreeding may be currently affecting the population or may become a threat in the future and should therefore be avoided (as prescribed by the SSP's population advisor) as much as possible. Because modeling inbreeding depression adds an additional layer of complexity to interpretation of results, we do not include a "standard" inbreeding depression effect in the PVA models. 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 and Lacy, 1995). Genetic management was incorporated into our model setup unless otherwise specified. **Because inbreeding depression is not included in our modeled scenarios, readers should consider that model results may be optimistic if inbreeding depression begins to impact the population.**

Management and Challenges

The river hippopotamus population is currently designated as a Yellow Species Survival Plan® (SSP). The starting population in our PVA is housed among 31 AZA institutions and one non-AZA partner institution, Louisiana Purchase Gardens & Zoo. Among these 32 institutions, five hold potential breeding groups with three or more adult hippos, and seven hold potential breeding pairs. Thirteen institutions hold only one or two adult females, six hold only one or two adult males, and one holds a breeding-age male with a post-reproductive female. The majority of current institutions do not have space to hold more than two adult hippos. Because male and female river hippos tend to breed readily when housed together, additional space is usually required to separate the pair for extended periods of time and limit breeding. Consequently, many institutions choose to hold two adult females instead of a potential breeding pair. Because of this practice, **managers often have difficulty in placing adult male river hippos, which must be held singly, in spite of the population's female-biased sex ratio**. Additionally, **breeding is constrained by the limited number of breeding pairs that are formed**. Ideally, more institutions would be able to hold larger breeding groups that better accommodate the sex bias of 1.9 females per male in the potentially breeding population and facilitate higher breeding rates.

River hippos are currently listed as Vulnerable in the wild by the IUCN (Lewison and Oliver, 2008) and as a CITES Appendix II species (limited trade; UNEP-WCMC, 2015). Managed populations are held by zoos in Australia and Europe, and unmanaged populations are held in Africa, Asia, and South America (ZIMS-ISIS, 2014). River hippos also exist at institutions outside of the managed population in North America, including several zoos in Mexico. Despite these potential sources of imports, the **AZA River Hippopotamus Animal Program did not import within the past decade, and it has no formal plan to import animals at this time**. However, the program could potentially attempt to exchange individuals with European or Mexican institutions to increase gene diversity in the future. Although a couple participating institutions have exported hippos within the past decade and may continue to based on their individual needs, **the program does not have formal plans to continue exportation in the future.**

ZooRisk can include a space limitation on population growth, reducing breeding as the population approaches the potential space limit. This mimics the way a population manager would recommend fewer pairs when at capacity. To accurately model the “potential space” for a population, we use either a) the projected spaces in 5 years based on a TAG’s Regional Collection Plan (RCP) or, if that value is unavailable or inappropriate, b) the current population size + 10% or 10 individuals, whichever is greater. These values are also placed in context of current institutional interest by the Program Leader. The most recent Wild Pig, Peccary, and Hippo TAG RCP was conducted in 2008 and included space estimates are now out of date because of population changes since that time. Therefore, based on current institutional interest, **we allowed 90 potential spaces (the current population size + 10 individuals) to become available over the next 10 years in our modeled scenarios**.

MODEL SCENARIOS

Model scenarios were created to reflect what would happen if current management approaches continued (baseline) and to address potential alternate management strategies (Table 3). Model setup is described more fully in Appendix A. Scenarios are described in more detail in the following sections.

Table 3. ZooRisk Model Scenarios.

Scenario Name	Scenario Description	p(B)	Spaces
Baseline Scenario			
A. Baseline; p(B) = 3.7%	Reproduction to match past 10 years (0.9 births/year)	3.7%	90
Alternate Scenario: Breeding			
B. p(B) = 13%	Reproduction required to sustain current population size	13%	90
C. p(B) = 13%; group size = 1.2	Reproduction required to sustain current population size, breeding group sizes of 1 male and 2 females	13%	90
Alternate Scenarios: Genetic Management			
D. p(B) = 13%; GM = off	Reproduction required to sustain current population size, genetic management turned off (random pairing of potential breeders)	13%	90
E. p(B) = 13%; exclude = 0% known	Reproduction required to sustain current population size, exclude 0%-known pedigree individuals from breeding	13%	90
Alternate Scenarios: Importation / Exportation			
F. p(B) = 13%; imports	Reproduction required to sustain current population size, import 4 individuals (2 males, 2 females) once per decade	13%	90
G. p(B) = 13%; exports	Reproduction required to sustain current population size, export 4 individuals (2 males, 2 females) once per decade	13%	90

p(B) = Probability of Breeding

POPULATION VIABILITY UNDER CURRENT MANAGEMENT

BASELINE MODEL PVA RESULTS

Following our standard approach, we first examined the viability of the river hippopotamus population (at AZA and two non-AZA partner institutions) under its average breeding rate from the past 10 years – 3.7% female probability of breeding (corresponding to an average of 0.9 births/year) – and 90 potential spaces within the next 10 years (Scenario A; See Appendix A for more details on all model parameters). In this scenario, the river hippopotamus population is predicted to decline during the next century, with a 69% chance of extinction within zoos or approximately 3 individuals remaining in 100 years if it does not go extinct (Fig. 4, Table 4). However, note that managers purposefully reduced breeding within the most recent years because of changing institutional interest, and they intend to increase breeding rates in future years.

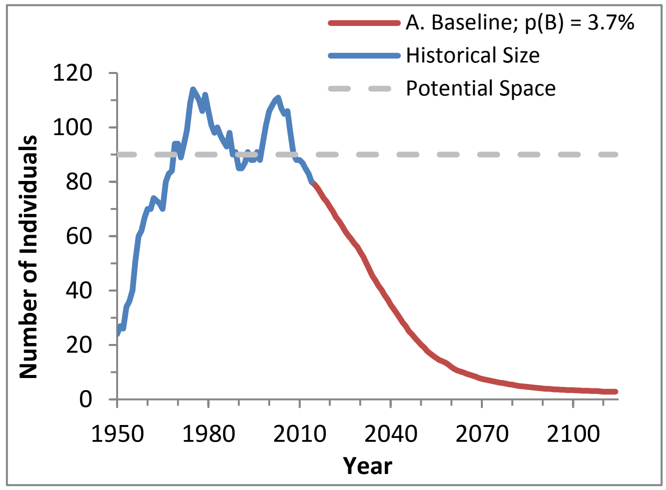

Figure 4. Historical and projected mean population size under the baseline model scenario. Projected results are averaged across 1000 model iterations.

ZooRisk uses five standardized risk tests to evaluate different aspects of a population's demography, genetics, and management that might put the population at risk (see Appendix E, Table E1). The ZooRisk development team and members of the AZA Small Population Management Advisory Group worked to develop the cutoff for each test. This approach standardizes assessments across species and allows managers to compare species programs using the same framework. Based on these tests, a declining river hippopotamus population is predicted to have a Critical risk status within zoos because of its high extinction risk.

Table 4. Baseline model results.

SCENARIO		DEMOGRAPHICS					GENETICS					OVERALL POPULATION STATUS[2]
		Initial Population Size	Size in Year 25[1]	Size in Year 100[1]	Probability of Reaching Space (%)	Probability of Extinction (%)	Initial GD (%)	GD Retained in Year 100[1]	Initial F	F in Year 100[1]	Final % Pedigree Known	
A	Baseline; p(B) = 3.7%	80	37 ± 6	3 ± 2	0	69	94.9	60.0 ± 23.5	0.018	0.112 ± 0.127	69.4 ± 13.5	Critical

GD = gene diversity, F = inbreeding coefficient

[1] Mean value ± 1 Standard Deviation, taken across 1000 iterations. If an iteration goes extinct that value is not included in the calculation. Some results may only reflect a few iterations in scenarios with a high probability of extinction.

[2]ZooRisk uses five standardized tests to give a summary risk score for each scenario, from Low Risk (most secure), Vulnerable, Endangered, to Critical (least secure). For more details on this score, see Appendix E.

ALTERNATE MODEL SCENARIOS

Increased breeding could allow the population to maintain its current size

Although the river hippopotamus population is predicted to decline under its average breeding rate from the past 10 years (0.9 births/year), the population could remain near its current size by increasing breeding to produce 3 to 4 births/year (p(B) = 13%, Scenario B; Figs. 5 and 6, Table 5). This result is consistent with the most recent Breeding and Transfer Plan for river hippos (Davis and Lynch, 2014), which recommended producing 3 or 4 births in the next year to maintain the population at its current size. However, such a breeding rate could potentially be difficult to maintain depending on how many potential breeding pairs are held among institutions. The river hippopotamus population produced 3 births in only one of the past 10 years (2006). The population is also predicted to develop a nearly even sex ratio (of only ~3 fewer males than females) within the next four decades. If many institutions continue to hold only females, a more even sex ratio could result in a greater number of unpaired males, which could further limit the possible number of potential breeding pairs.

Table 5. All model results.

SCENARIO		DEMOGRAPHICS					GENETICS					OVERALL POPULATION STATUS[2]
		Initial Population Size	Size in Year 25[1]	Size in Year 100[1]	Probability of Reaching Space (%)	Probability of Extinction (%)	Initial GD (%)	GD Retained in Year 100[1]	Initial F	F in Year 100[1]	Final % Pedigree Known	
A	Baseline; p(B) = 3.7%	80	37 ± 6	3 ± 2	0	69	94.9	60.0 ± 23.5	0.018	0.112 ± 0.127	69.4 ± 13.5	Critical
Alternate Scenarios: Breeding												
B	p(B) = 13%	80	77 ± 10	84 ± 10	93	0	94.9	89.7 ± 1.2	0.018	0.093 ± 0.017	71.9 ± 5.0	Vulnerable
C	p(B) = 13%; group size = 1.2	80	88 ± 4	87 ± 6	100	0	94.9	90.4 ± 0.8	0.018	0.080 ± 0.013	68.8 ± 5.9	Low Risk
Alternate Scenarios: Genetic Management												
D	p(B) = 13%; GM = off	80	77 ± 10	84 ± 11	90	0	94.9	87.8 ± 2.2	0.018	0.102 ± 0.020	60.4 ± 6.8	Vulnerable
E	p(B) = 13%; exclude = 0% known	80	65 ± 11	78 ± 18	68	0	94.9	89.1 ± 2.4	0.018	0.094 ± 0.019	81.6 ± 4.2	Vulnerable
Alternate Scenarios: Importation / Exportation												
F	p(B) = 13%; imports*	80	87 ± 7	88 ± 4	100	0	94.9	95.6 ± 0.7*	0.018	0.036 ± 0.012*	87.2 ± 3.4*	Low Risk
G	p(B) = 13%; exports	80	63 ± 12	51 ± 30	29	7	94.9	84.8 ± 9.5	0.018	0.099 ± 0.034	72.3 ± 6.8	Vulnerable

GD = gene diversity, F = inbreeding coefficient

[1] *Mean value ± 1 Standard Deviation, taken across 1000 iterations. If an iteration goes extinct that value is not included in the calculation. Some results may only reflect a few iterations in scenarios with a high probability of extinction.*

[2] *ZooRisk uses five standardized tests to give a summary risk score for each scenario, from Low Risk (most secure), Vulnerable, Endangered, to Critical (least secure). For more details on this score, see Appendix E.*

***Genetic results are likely optimistic as ZooRisk counts all imports as genetically unique potential founders (i.e., they are unrelated to each other and the current population). In reality, it is likely that final GD would be lower and inbreeding higher than the results displayed in the table.*

If new exhibits capable of holding larger breeding groups were to be constructed, managers could potentially increase the average breeding group size for river hippos to 1 male and 2 females. This breeding group size would be more ideal than breeding pairs as it would help to better accommodate the population's current female bias. Because more females would be placed in potential breeding situations, the population is projected to produce an average of 4 to 5 births/year over the next 10 years (and ~4 births/year thereafter) under the same probability of breeding as in the previous scenario (p(B) = 13%, Scenario C; Figs. 5 and 6). This higher birth rate would cause the population to grow to fill 90 potential spaces within approximately 11 years. Under either breeding group size, pedigree knownness in 100 years (71.9% in Scenario B vs. 68.8% in Scenario C) is predicted to be higher than that of the current population (61.9%) due to prioritization of known-pedigree individuals for breeding. Whether breeding groups include 1 female or 2 females, the population would maintain similar gene diversity (89.7% in Scenario B vs. 90.4% in Scenario C) in the known-pedigree portion of the population and inbreeding (average inbreeding coefficient [F] = 0.093 vs. 0.080) over the next 100 years (Table 5). For reference, a mating between first cousins generates an inbreeding coefficient [F] = 0.063 and a mating between half siblings produces an F = 0.125. Depending on remaining gene diversity, the population would have either a Low Risk status (>90%) or Vulnerable status (<90%) within zoos in 100 years (Appendix E).

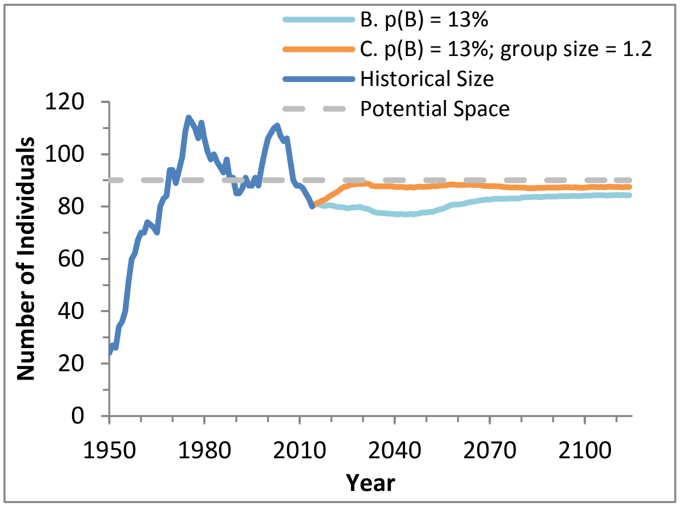

Figure 5. Historical and projected mean population size under alternate model scenarios B and C. Projected results are averaged across 1000 model iterations.

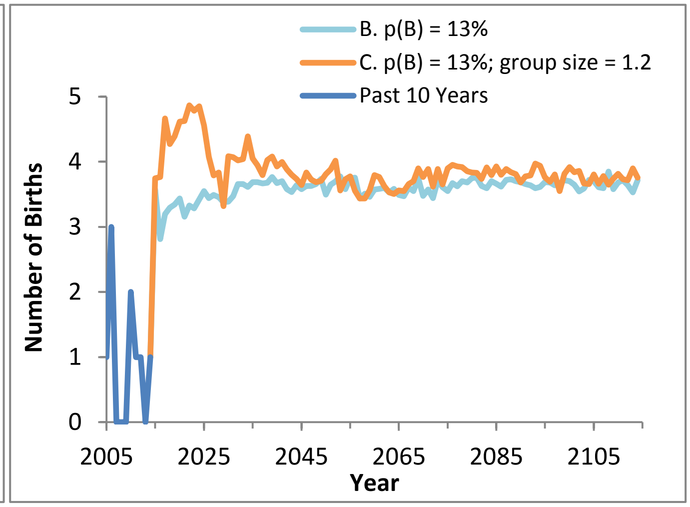

Figure 6. Number of total births in the population in the past decade and projected mean number of births under alternate model scenarios B and C. Projected results are averaged across 1000 model iterations.

The river hippopotamus program should continue careful genetic management of the population

The AZA River Hippopotamus Animal Program should strive to continue management of this population based on recommendations from the AZA Population Management Center in order to maintain genetic health of the population in future years. However, high pedigree unknownness, and persistence of this unknownness in long-lived individuals, makes genetic management of river hippos especially challenging. Although ZooRisk cannot specifically simulate genetic management as it occurs for this population, we modeled a scenario in which any individual could be paired with any individual, rather than pairing based on mean-kinship ranking (Scenario D, "genetic management = off"), to explore the potential effects of imperfect genetic management. As in all of our model scenarios, we set the re-pairing interval at 50 years, such that all pairings were randomly re-selected in years 0 and 50 of the model projection (see 'Number of Years Between Pairing' in Appendix A, Table A1). Compared to maintaining both higher reproduction and mean-kinship based pairing (Scenario B), higher reproduction and random pairing of individuals (Scenario D) results in lower pedigree knownness in 100 years (60.4% vs. 71.9%), or the genetic status of nearly ~40% of individuals remaining unknown. With random pairing, the population would retain only slightly lower gene diversity (87.8% in Scenario D vs. 89.7% in Scenario B) and slightly higher inbreeding (F = 0.102 vs. 0.093) in 100 years (Table 5). However, actual future gene diversity and inbreeding values could be either higher or lower than the reported values, as these values are based only on the portion of the population with a known pedigree. Continual breeding of the same pairs could be expected to result in lower gene diversity and higher inbreeding than in the "genetic management = off" scenario.

If managers were to exclude individuals with 0% pedigree knownness from breeding (removing 7 males and 13 females from the potentially breeding population) without increasing the probability of breeding for individual females from 13%, the river hippopotamus population would undergo a demographic decline (Scenario E; Fig. 7). More specifically, the population would decrease to roughly 63 individuals over the next three decades and then slowly grow back to ~80 individuals during the rest of the next 100 years. Although this management scenario would not be desirable for maintaining the population demographically, the population could be expected to have higher pedigree knownness in 100 years if 0%-known individuals are excluded from breeding (81.6% in Scenario E vs. 71.6% in Scenario B; Table 5). Among the portion of the population with a known pedigree, similar gene diversity (89.1% vs. 89.7%) and inbreeding (F = 0.094 vs. 0.093) would be maintained. Therefore, continuing to prioritize known-pedigree animals for breeding when possible could help to increase overall pedigree knownness in the long term, but continuing to breed some unknown-pedigree animals may be important for maintaining the population near its current size.

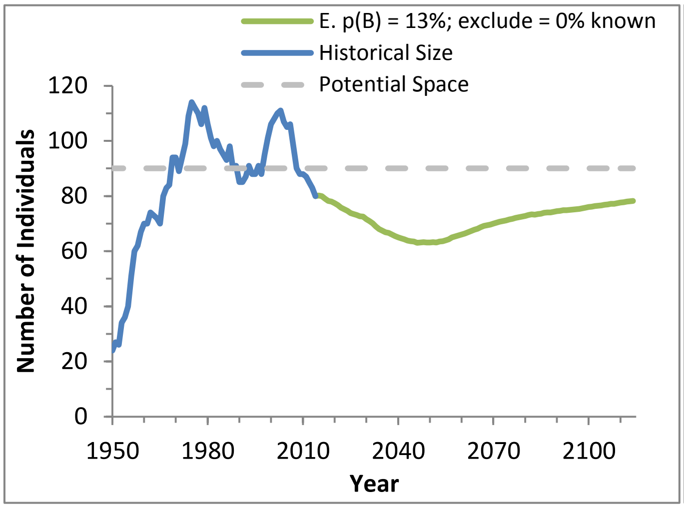

Figure 7. Historical and projected mean population size under alternate model scenario E. Projected results are averaged across 1000 model iterations.

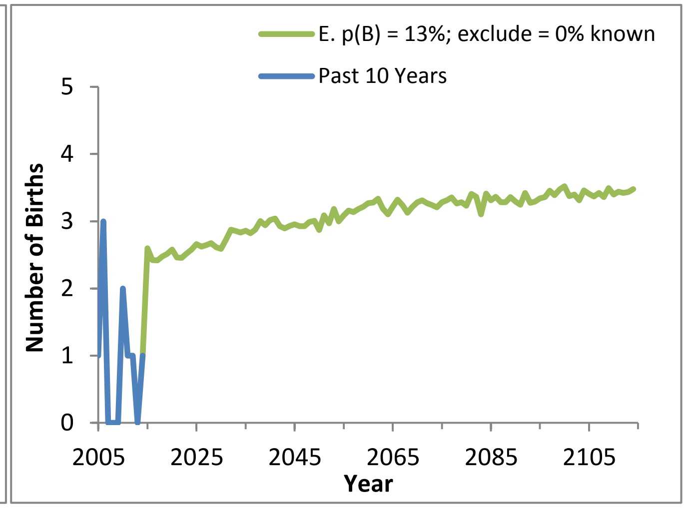

Figure 8. Number of total births in the population in the past decade and projected mean number of births under alternate model scenario E. Projected results are averaged across 1000 model iterations.

Imports may benefit the population while exports could potentially cause a demographic decline

Although the AZA River Hippopotamus Animal Program has not exchanged individuals with institutions in either Europe or Mexico within its recent history, the program may attempt to do so in the future. Therefore, to evaluate the potential impact of receiving new, unrelated individuals, we include a model scenario with routine importation into the population over the next 100 years (2 males and 2 females per decade; Scenario F). With these imports and a 13% female probability of breeding, the population would produce 3 to 4 births/year and grow to fill 90 potential spaces within approximately 16 years (Figs. 9 and 10). Although our model assumes that imported individuals would be fully unrelated to each other and to the managed population and have known pedigrees, imports from zoos in other countries are not all likely to fit these assumptions. Therefore, we can interpret the genetic results of Scenarios F and B to indicate that routine importation could help maintain between 89.7% and 95.6% gene diversity in the river hippopotamus population over the next 100 years (Table 5). Importation would also result in low inbreeding (F = 0.036 – 0.093) and pedigree knownness between 71.9% and 87.2% in 100 years. The population could maintain a Low Risk status within zoos if it retains greater than 90% gene diversity (Appendix E).

The river hippopotamus program does not have formal plans to export individuals in future years; however, some institutions may continue sending animals to outside institutions in North America based on their individual needs. If routine exportation were to occur at a rate of 2 male and 2 female exports per decade, without increasing the female probability of breeding above 13%, the population could be expected to decline during the next 100 years (Scenario G; Fig. 9). The population would have a 7% chance of extinction within zoos or approximately 51 individuals remaining in 100 years if it does not go extinct (Table 5). Pedigree knownness among these individuals would be approximately 72.3%. Compared to having no future exportation, the known-pedigree portion of the population would have lower gene diversity (84.8% in Scenario G vs. 89.7% in Scenario B) but similar inbreeding (F = 0.099 vs. 0.093) in 100 years with regular exportation.

In all alternate scenarios without imports (B-E and G), the river hippopotamus population is predicted to have a Vulnerable risk status within zoos because of the projected decline in gene diversity (Appendix E).

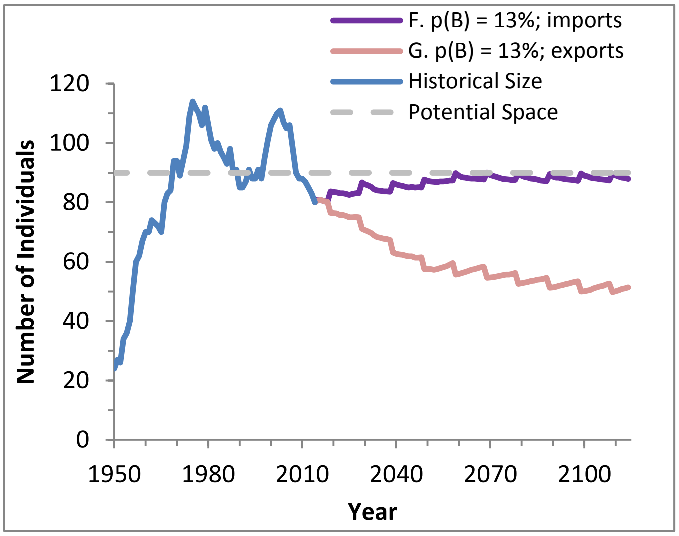

Figure 9. Historical and projected mean population size under alternate model scenarios F and G. Projected results are averaged across 1000 model iterations.

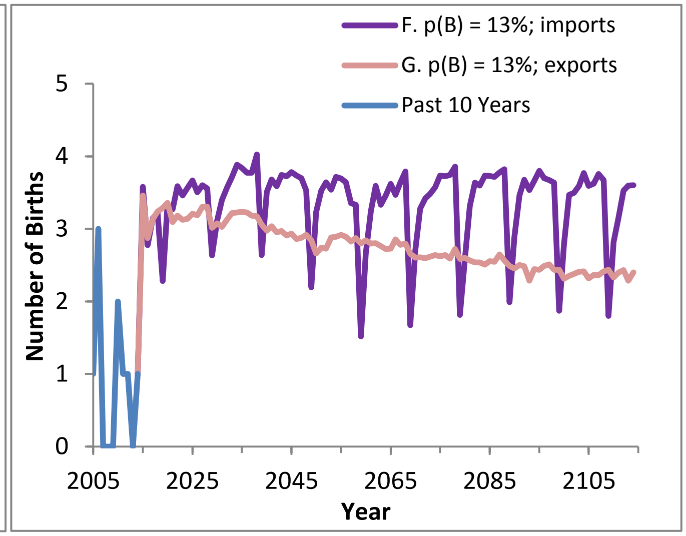

Figure 10. Number of total births in the population in the past decade and projected mean number of births under alternate model scenarios F and G. Projected results are averaged across 1000 model iterations.

MANAGEMENT ACTIONS

Given the current challenges for the river hippopotamus population, PVA results indicate that the following changes in management should be considered in an effort to improve this population's sustainability. Note that the PVA allows us to compare between hypothetical changes, but cannot evaluate whether achieving these changes is feasible, practical, or desirable given the program's constraints.

- **To remain demographically stable, increase breeding:** If breeding can be increased from an average of ~1 birth per year to 3 to 4 births each year, the river hippopotamus population could remain near its current size and maintain nearly 90% gene diversity among known-pedigree individuals over the next century. This breeding rate would be difficult to achieve unless facilities capable of housing breeding groups and bachelor groups are constructed. Program managers recommend that new breeding facilities be capable of holding at least two adult females per adult male and allow for separation of adult males from females and their offspring. If the river hippo population produces fewer than 3 to 4 births per year, it could be expected to decline during the next 100 years.

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.

Our model results illustrate that under recent management practices, the river hippopotamus population could be expected to decline during the next century. Increasing breeding to consistently produce 3 to 4 births per year, however, could help the population remain near its current size. This breeding rate will likely be difficult to achieve given current exhibit spaces. Therefore, the program recommends that more institutions commit to designing facilities capable of managing breeding groups with at least two adult females per adult male. These facilities should allow for separation of adult males from females and their offspring, and be able to hold calves for up to three years. More facilities may also be needed to hold bachelor males as the population develops a less female-biased sex ratio in future years. Continuing to incorporate unknown-pedigree individuals into the breeding population may help to achieve an increased breeding rate, but would perpetuate uncertainty in future genetic metrics. Because of the difficulty in moving and introducing river hippos to different institutions, precise genetic management of this population is unlikely, but managers should continue to follow breeding recommendations as they are issued by the program in Breeding and Transfer Plans. Increasing breeding to 3 to 4 births per year could potentially allow the population to retain nearly 90% gene diversity among known-pedigree individuals for 100 years, but importing unrelated individuals from outside institutions could help managers to more easily fill potential spaces and possibly retain higher gene diversity over the next century. Conversely, exporting individuals without imports or further increased breeding could be expected to result in a population decline. The AZA River Hippopotamus Animal Program should consider implementing the recommended management actions in order to keep the population on the path towards long-term sustainability within AZA and partner institutions.

ACKNOWLEDGEMENTS

A meeting was conducted on August 13th, 2015 to discuss the river hippopotamus population and was attended by the following:

- **Brent Johnson**, Population Biologist , Lincoln Park Zoo, bjohnson@lpzoo.org
- **Kayla Melton,** Research Assistant, Lincoln Park Zoo, kmelton@lpzoo.org
- **John Davis**, AZA River Hippopotamus Animal Program SSP Coordinator and Studbook Keeper**,** Riverbanks Zoo & Garden**,** jdavis@riverbanks.org
- **Katelyn Mucha,** AZA Population Advisor, Lincoln Park Zoo, kmucha@lpzoo.org
- **Martin Ramirez**, Wild Pig, Peccary, Hippo TAG Chair, Woodland Park Zoo, martin.ramirez@zoo.org
- **Jeff Holland,** Wild Pig, Peccary, Hippo TAG Vice Chair, Los Angeles Zoo and Botanical Gardens, jeff.holland@lacity.org

This report was also reviewed by:

- **Candice Dorsey**, Vice-President of Animal Programs, Association of Zoos and Aquariums, cdorsey@aza.org
- **Kayla Melton,** Research Assistant, Lincoln Park Zoo, kmelton@lpzoo.org
- **John Davis**, AZA River Hippopotamus Animal Program SSP Coordinator and Studbook Keeper**,** Riverbanks Zoo & Garden**,** jdavis@riverbanks.org
- **Colleen Lynch,** AZA Population Advisor, Riverbanks Zoo and Garden, clynch@riverbanks.org
- **Martin Ramirez**, Wild Pig, Peccary, Hippo TAG Chair, Woodland Park Zoo, martin.ramirez@zoo.org
- **Jeff Holland,** Wild Pig, Peccary, Hippo TAG Vice Chair, Los Angeles Zoo and Botanical Gardens, jeff.holland@lacity.org
- **Lisa Faust,** Vice President of Conservation and Science, Lincoln Park Zoo, lfaust@lpzoo.org

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 River Hippopotamus (*Hippopotamus amphibius*) Studbook current to 20 July 2015 (Davis, 2015) and was performed using Poplink 2.4 and ZooRisk 3.8.

Funding provided by Institute of Museum and Library Services (IMLS) LG-25-11-018 and MG-30-13-0065-13 to the Association of Zoos and Aquariums.

Cover photo: courtesy of Richard W. Rokes (Davis and Lynch, 2014).

Citation:

Johnson, B., Davis, J., Ramirez, M., and Holland, J. 2015. River Hippopotamus (*Hippopotamus amphibius*) AZA Animal Program Population Viability Analysis Report. Lincoln Park Zoo, Chicago, IL.

The contents of this report including opinions and interpretation of results are based on discussions between the project team and do not necessarily reflect the opinion or position of Lincoln Park Zoo, Association of Zoos and Aquariums, and other collaborating institutions. The population model and results are based on the project team's best understanding of the current biology and management of this population. They should not be regarded as absolute predictions of the population's future, as many factors may impact its future status.

LITERATURE CITED

Association of Zoos and Aquariums. Zoological Information Management System – International Species Information System, Version 1.7 Updated: 27 Jan. 2014. Accessed: 10 Aug. 2015. <https://zims.isis.org>

AZA Wild Pig, Peccary, and Hippo Taxon Advisory Group (TAG). 2008. Wild Pig, Peccary, and Hippo Taxon Advisory Group Regional Collection Plan (RCP) – 2nd Edition.

Ballou, J. D. and R. C. Lacy. 1995. Identifying genetically important individuals for management of genetic variation in pedigreed populations. Pages 76-111 in J. D. Ballou, M. Gilpin, and T. J. Foose, eds. Population Management for Survival and Recovery: Analytical Methods and Strategies in Small Population Conservation. Columbia University Press, New York.

Ballou, J. D. and T. J. Foose. 1996. Demographic and genetic management of captive populations. Pages 263-283 in S. Lumpkin, ed. Wild Mammals in Captivity. University of Chicago Press, Chicago.

Davis, J. 2015. River Hippopotamus (*Hippopotamus amphibius*) AZA Studbook. Riverbanks Zoo and Garden.

Davis, J. and Lynch, C. 2014. River Hippopotamus (*Hippopotamus amphibius*) AZA Species Survival Plan® Yellow Program Population Analysis and Breeding & Transfer Plan. Riverbanks Zoo and Garden, Columbia, SC.

DeRose, M. A. and D. A. Roff. 1999. A comparison of inbreeding depression in life-history and morphological traits in animals. Evolution 53: 1288-1292.

Earnhardt, J. M., Bergstrom, Y. M., Lin, A., Faust, L. J., Schloss, C. A., and S. D. Thompson. 2008. ZooRisk: A Risk Assessment Tool. Version 3.8. Lincoln Park Zoo. Chicago, IL.

Faust, L.J., Earnhardt, J. M., Schloss, C. A., and Y. M. Bergstrom. 2008. ZooRisk: A Risk Assessment Tool. Version 3.8 User's Manual. Lincoln Park Zoo. Chicago, IL.

Koeninger Ryan, K., Lacy, R. C., and S. W. Margulis. 2002. Impacts of kinship and inbreeding on components of fitness. Pages 82- 96 in V.W. Holt. Reproduction and Integrated Conservation Science. Cambridge University Press. Cambridge, U.K.

Lewison, R. and W. Oliver. 2008. *Hippopotamus amphibius*. The IUCN Red List of Threatened Species, Version 2015.2. Accessed: 10 Aug. 2015. <www.iucnredlist.org>

Reed, D. H. and R. Frankham. 2003. Correlation between fitness and genetic diversity. Conservation Biology 17: 230-237.

UNEP-WCMC (Comps.). 2015. The Checklist of CITES Species Website. CITES Secretariat, Geneva, Switzerland. Accessed 10 AUg. 2015. < http://checklist.cites.org>

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.

Potential Space: In the context of a Regional Collection Plan, the 'potential space' 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 potential space 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.

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.

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.

APPENDICES

APPENDIX A. MODEL SETUP AND METHODS

Analyses in this report were performed using PopLink 2.4, ZooRisk 3.8, and R statistical package. Complete documentation on ZooRisk's modeling approach and setup can be found in the software manual (Faust et al., 2008). These tables document the basic file information (Table A1), key model variables, give some context for how ZooRisk utilizes them in the model and how the PVA modeling team applies them, give values used in model scenarios, and describe data sources (Table A2). Additionally, age and sex specific mortality rates are documented in table A3.

For clarity, most figures in this report show the mean population size across multiple iterations. Model results such as mean population sizes, levels of gene diversity (GD), and inbreeding (F) are averaged across 1000 model iterations; if some model iterations go extinct, these values are only averaged over extant, surviving 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 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.

Table A1. Information regarding studbook utilization in PopLink 2.4 and ZooRisk 3.8.

File Information	
Studbook Currentness Date	20 July 2015
Studbook Name	hippo2014_20Jul15 + OverlayforPVA
Studbook Keeper	John Davis
ZooRisk Project Name	RiverHippo_2015

Table A2. Variable used in ZooRisk 3.8 scenarios, including a description of each variable, the value, and the source.

Demographic Settings			
Model Variable	**Description/Details of How Variable is Used in Model**	**Value in Model Scenarios**	**Source**
Living Population	ZooRisk uses a starting population to initiate each model scenario, incorporating 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.	See included individuals in Appendix C	Studbook data; animals in AZA + MONROE + TORONTO (FED file: RIVERHIPPO.FED) as of 21 Jul 2015
Male and Female Age-Specific Mortality Rates (Qx)	Probability that an individual of age x dies during time period. Each year, the model stochastically determines whether each individual lives or dies based on that individual's age- and sex-specific Qx.	See Table A3. No modifications were made from extracted Qx values.	Studbook data, filters = NAMERICA + MEXICO, 1 Jan 1980 – 21 Jul 2015
Infant Mortality Rates (Qx)	Mortality rate for infants 0-1 used in the model (as described above). Infant mortality is a vital rate that is sensitive to changes in husbandry and also may be a life stage that is vulnerable to inbreeding depression.	Male = 30.84% Female = 28.35%	Studbook data, filters = NAMERICA + MEXICO, 1 Jan 1980 – 21 Jul 2015
Maximum Longevity	The maximum age individuals are allowed to live to in the model (if they haven't died before that age). The model values were based on males = SB #99 and 124 and female = #83, all of which are deceased.	Male = 59 Female = 61	Modeling team consulted the following sources: Studbook data, Program Leader, TAG Chair and Vice-Chair
Reproductive Age Classes	Age classes in which females or males could potentially be paired for breeding in the model	Male = 3 – 46 Female = 4 – 42	Modeling team consulted the following sources: Studbook data, Program Leader, TAG Chair and Vice-Chair

Model Variable	Description/Details of How Variable is Used in Model	Value in Model Scenarios	Source
Annual Number of Offspring	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. Note that this distribution will be different than a litter size distribution if a species can have multiple clutches/litters within a year.	1 offspring = 95.73% 2 = 4.27%	Studbook data, filters = NAMERICA + MEXICO, 1 Jan 1980 – 21 Jul 2015
Birth Sex Ratio (BSR)	The model stochastically assigns a sex for any offspring created in the model. We extract historic studbook data and test for bias towards males or females in the sex ratio using a $\chi2$ test. This evaluates whether the population is significantly different than 50% males, 50% females. For this population, the extracted birth sex ratio was not significantly biased. The extracted value was 0.4587 (χ^2 = 1.4862, df = 1, $p > 0.05$).	0.5	Studbook data, filters = NAMERICA + MEXICO, 1 Jan 1980 – 21 Jul 2015
Female Probability of Breeding [p(B)]	P(B) is the age-specific probability that a female will have at least one offspring in a year. For example, p(B) = 0.25 is equivalent to females producing an offspring on average once every 4 years, or 25% of reproductively available females breeding in any given year. Historical studbook data include many females who never had access to a male and were non-reproductive for management rather than biological reasons. It is difficult to use extracted p(B) data to determine what a population could do if all individuals were in breeding situations or the population was truly trying to increase reproduction. Because of this, model scenarios use simplified hypothetical levels of p(B) to evaluate the impact of changes in reproduction. To set the baseline p(B), we extracted the average number of births/year over the past decade from the studbook and identified a p(B) level in the model that would produce, on average, an equivalent number of projected births over the first 10 model years. Alternate scenarios used higher or lower p(B) levels. In the model, all p(B) were set at the same value within all female reproductive age classes. Using a constant value means that all reproductively viable females would have the same chance of reproduction regardless of age. This population produced 0.9 births/year on average over the past decade, which was used to calibrate the baseline p(B).	Baseline Scenarios A: 0.037 Scenarios B - G: 0.013	Studbook data, filters = RIVERHIPPO.FED, 1 Jan 2005 – 31 Dec 2014
Genetic Settings			
Genetic Management	ZooRisk can model a randomly breeding population or 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). This allows ZooRisk to more accurately project the amount of gene diversity retained through genetic management.	GM by mean kinship = ON (Scenario D: GM =OFF)	Modeling team decision

Model Variable	Description/Details of How Variable is Used in Model	Value in Model Scenarios	Source
Inbreeding Depression	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. The PVA includes management by mean kinship and measurements of final mean inbreeding levels to help users understand the potential future levels of inbreeding even with careful management. **Readers should consider that model results may be optimistic if this species would be susceptible to inbreeding depression now or in the future.**	OFF	Modeling team decision
Breeding group ratio	ZooRisk can simulate breeding groups of 1 male: multiple females. If a population has few reproductive-aged animals and/or very few breeding age males, this can impact demographic results by limiting the number of pairs/groups that can be formed. It can also impact genetic results, as it influences how pairings by mean kinship are made (see manual for more details).	1 male: 1 female	Modeling team consulted the following sources: Program Leader, TAG Chair and Vice-Chair
Number of Years Between Pairing	ZooRisk reshuffles the pairings with this frequency; a breeding group is left together for this number of years unless an individual group member dies, in which case another individual is shuffled in. A group is left together even if they may no longer be optimally paired by MK because of subsequent births.	50	Modeling team decision Modeling team consulted the following sources: Program Leader, TAG Chair and Vice-Chair
Other Model Settings			
Potential Space	ZooRisk has the option of including a space limitation on population growth. This limitation reduces breeding in the model population as it approaches the 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 (i.e. if the population is already close to or larger than that space), the team will use the current population size + 10% or 10 individuals, whichever is greater. In some instances when more information is available, i.e. a more recent survey by the Species Coordinator, we will use this value. The most recent Wild Pig, Peccary, and Hippo RCP (2008) is out of date because of population changes since that time. We allowed for 90 potential spaces (the current population size + 10 individuals) in the modeled baseline scenario.	90	Modeling team consulted the following sources: 2008 Wild Pig, Peccary, and Hippo TAG RCP, Program Leader, TAG Chair and Vice-Chair
Approach to space limit	The model can allow the population to grow/decline immediately to its space limit (if birth rates will allow it), but it is more likely that increases/decreases in space will occur gradually as new institutions join or leave a program.	Approach space limit gradually over 10 years	Modeling team consulted the following sources: Program Leader, TAG Chair and Vice-Chair
Number of Years	How far into the future the model projects.	100	Modeling team decision
Number of Iterations	Since stochastic models have inherent variation, each model run (or iteration) will produce a slightly different population trajectory, and the model is run many times to reflect the full potential variation a population could experience.	1000	Modeling team decision

Model Variable	Description/Details of How Variable is Used in Model	Value in Model Scenarios	Source
Extinction Threshold	Size at which the population will be considered extinct.	0	Modeling team decision
Importations/ Exportations	ZooRisk can model removal or addition of individuals into the population. An importation event will bring a specific number of individuals (of a specified sex and age) that are completely unrelated to the current population (potential founders) into the population in a specified year. These might be individuals coming from the wild or from non-AZA institutions in other regions or in North America. Exportations can be used to model reintroductions into the wild or transfer of individuals outside of the AZA population. ZooRisk can model two types – a simple export that selects a specific number of individuals of the designated sex and age classes in the specified year, or a threshold export that will select the 'extra' individuals above some threshold to export in the specified year.	Scenarios A-E: 0 imports and 0 exports Scenarios F and G: 2 male and 2 female imports or genetically random exports, ages 2-20, in the 5th year of every future decade	Modeling team consulted the following sources: Program Leader, TAG Chair & Vice-Chair, Studbook data, filters = RIVERHIPPO.FED, 1 Jan 2005 – 31 Dec 2014

Table A3. 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 individuals age- and sex- specific mortality rate.

Male			**Female**		
Age(x)	Qx	Number at Risk	Age(x)	Qx	Number at Risk
0	0.3084	113.5	0	0.2835	130.5
1	0.0336	59.5	1	0.0276	72.5
2	0.0204	49	2	0.0156	64
3	0	48	3	0	61
4	0.0204	49	4	0	62
5	0.0208	48	5	0	65
6	0.0213	47	6	0.0435	69
7	0.0227	44	7	0.0145	69
8	0.0233	43	8	0.0143	70
9	0	43	9	0	72
10	0.0476	42	10	0	70
11	0.025	40	11	0	70
12	0	39	12	0.0143	70
13	0	35	13	0.0147	68
14	0	36	14	0	67
15	0.0303	33	15	0.0149	67
16	0	32	16	0	64
17	0	32	17	0.0794	63
18	0	32	18	0.0328	61
19	0	32	19	0.0179	56
20	0	31	20	0	54
21	0.0323	31	21	0.0185	54
22	0.0323	31	22	0	52
23	0	33	23	0.0189	53
24	0.0286	35	24	0.0566	53
25	0	37	25	0	52
26	0.027	37	26	0	52
27	0.0278	36	27	0.02	50
28	0.0294	34	28	0	47
29	0.0303	33	29	0.0217	46
30	0	33	30	0	43
31	0.0606	33	31	0.0513	39
32	0.0667	30	32	0	36
33	0.0714	28	33	0.0833	36
34	0	23	34	0.0588	34
35	0.0455	22	35	0.0909	33

Age(x)	Qx	Number at Risk	Age(x)	Qx	Number at Risk
36	0.0476	21	36	0.0625	32
37	0	19	37	0.0345	29
38	0.0526	19	38	0	28
39	0.0556	18	39	0.0357	28
40	0.125	16	40	0	27
41	0.0667	15	41	0.0833	24
42	0	11	42	0	23
43	0.1667	12	43	0.0435	23
44	0.1	10	44	0.1	20
45	0	9	45	0.2222	18
46	0.1111	9	46	0.2308	13
47	0	8	47	0.1	10
48	0.125	8	48	0	9
49	0.1429	7	49	0.1111	9
50	0	6	50	0.125	8
51	0.1667	6	51	0.1429	7
52	0.2	5	52	0.3333	6
53	0.25	4	53	0.5	4
54	0	3	54	0	2
55	0	3	55	0	2
56	0	2	56	0	2
57	0	2	57	0	2
58	0.5	2	58	0.5	2
59	1	1	59	0	0
			60	0	0
			61	1	0

APPENDIX B. ADDITIONAL SCENARIOS RESULTS

An additional scenario was run to supplement the PVA team's interpretation of model results:

- **AZA-only population (Scenario H):** Although one non-AZA partner institution (holding 1 female hippo) is expected to continue participating in the managed river hippopotamus population, if this partners was to discontinue its participation for any reason an AZA-only population is projected to follow a similar future trajectory over the next century. In the past decade, the AZA population has produced 0.9 births/year (corresponding to a 3.7% female probability of breeding). The AZA population, which currently includes 79 individuals, is projected to have a 67% chance of going extinct in the next 100 years (versus 69% in Scenario A) or 3 individuals remaining if it does not go extinct (versus 3 individuals in Scenario A; Table H). Because of its high extinction risk, the population would have a Critical risk status within zoos in 100 years (Appendix E).

Table B1. Additional model results.

SCENARIO		DEMOGRAPHICS					GENETICS					OVERALL POPULATION STATUS[2]
		Initial Population Size	Size in Year 25[1]	Size in Year 100[1]	Probability of Reaching Space (%)	Probability of Extinction (%)	Initial GD (%)	GD Retained in Year 100[1]	Initial F	F in Year 100[1]	Final % Pedigree Known	
A	Baseline; p(B) = 3.7%	80	37 ± 6	3 ± 2	0	69	94.9	60.0 ± 23.5	0.018	0.112 ± 0.127	69.4 ± 13.5	Critical
H	AZA Baseline; p(B) = 3.7%	76	36 ± 6	3 ± 2	0	67	94.8	58.8 ± 24.9	0.018	0.115 ± 0.133	69.7 ± 13.3	Critical

GD = gene diversity, F = inbreeding coefficient

[1] Mean value ± 1 Standard Deviation, taken across 1000 iterations. If an iteration goes extinct that value is not included in the calculation. Some results may only reflect a few iterations in scenarios with a high probability of extinction.

[2]ZooRisk uses five standardized tests to give a summary risk score for each scenario, from Low Risk (most secure), Vulnerable, Endangered, to Critical (least secure). For more details on this score, see Appendix E.

APPENDIX C. INCLUDED INDIVIDUALS

As of July 20th, 2015 (the studbook currentness date), the SSP population consisted of 80 individuals (28 males, 52 females) (Table C1). Seven individuals are excluded from the breeding population. Those animals with “Allowed to Breed = NO” hold space but are never eligible for reproduction. This leaves a potentially breeding population of 73 (26.47) individuals.

Table C1. Individuals included in the starting population.

Studbook ID	Sex	% Known	Age	Institution	Allowed to Breed	Reason For Exclusion
247	Female	0	45	MILWAUKEE	NO	Age
263	Female	100	43	SEDGWICK	NO	Age
268	Female	100	43	DISNEY AK	NO	Age
274	Female	100	42	SEDGWICK	NO	Age
276	Male	100	41	RIO GRAND	YES	
281	Male	0	41	TORONTO	YES	
292	Male	100	41	SAN ANTON	YES	
296	Female	100	40	SAN ANTON	YES	
324	Male	100	39	SANDIEGOZ	YES	
355	Female	100	36	SEATTLE	YES	
357	Male	100	36	BIRMINGHM	NO	Age†
390	Male	100	34	MILWAUKEE	YES	
397	Male	100	33	DICKERSON	YES	
401	Male	50	33	WINSTON	YES	
403	Male	0	33	LEON	YES	
415	Female	100	31	KANSASCTY	YES	
421	Male	0	31	PUEBLA	YES	
427	Female	100	30	SANDIEGOZ	YES	
428	Female	100	30	FORTWORTH	YES	
430	Female	100	30	FORTWORTH	YES	
439	Female	0	30	LEON	YES	
449	Female	0	29	TORONTO	YES	
450	Female	100	29	KANSASCTY	YES	
455	Female	50	28	CALGARY	YES	
462	Female	0	27	PUEBLA	YES	
468	Female	100	27	MONROE	YES	
474	Female	100	26	MEMPHIS	YES	
477	Female	0	26	PHILADELP	YES	
478	Female	0	26	LEON	YES	
481	Female	100	25	PHILADELP	YES	
490	Female	0	24	TORONTO	YES	
494	Female	100	23	HONOLULU	YES	
498	Male	75	22	GRANBY	YES	
500	Female	100	22	COLO SPRG	YES	
504	Female	100	22	PORTLAND	YES	
505	Female	100	22	PORTLAND	YES	
507	Female	0	21	DISNEY AK	NO	Reproductive
510	Female	0	21	DISNEY AK	YES	
514	Female	0	20	LEON	YES	
516	Female	100	19	TOLEDO	YES	
518	Male	0	19	LEON	YES	
520	Male	100	18	BUSCH TAM	YES	
522	Male	0	18	LEON	YES	
531	Female	100	40	DISNEY AK	YES	
533	Male	75	20	DISNEY AK	YES	
534	Female	100	18	DISNEY AK	YES	
537	Female	0	18	ADVENTURE	YES	
539	Male	0	25	DISNEY AK	NO	Sterile
540	Female	0	25	DISNEY AK	YES	
541	Female	0	21	DISNEY AK	YES	

Studbook ID	Sex	% Known	Age	Institution	Allowed to Breed	Reason For Exclusion
542	Female	0	18	GRANBY	YES	
543	Female	87.5	16	ST LOUIS	YES	
544	Female	100	16	ST LOUIS	YES	
545	Female	50	16	LUFKIN	YES	
583	Female	75	15	ST LOUIS	YES	
589	Male	100	15	DISNEY AK	YES	
590	Female	50	15	ADVENTURE	YES	
592	Male	50	14	WINSTON	YES	
594	Female	100	17	MEMPHIS	YES	
595	Female	37.5	15	SEATTLE	YES	
596	Male	100	14	TOLEDO	YES	
597	Female	100	15	COLO SPRG	YES	
607	Male	87.5	14	DISNEY AK	YES	
613	Female	25	11	LOSANGELE	YES	
614	Female	75	12	LUFKIN	YES	
615	Male	100	12	DISNEY AK	YES	
616	Male	50	12	SAN FRAN	YES	
619	Female	100	13	RIO GRAND	YES	
621	Male	100	12	DENVER	YES	
629	Female	75	14	ST LOUIS	YES	
630	Female	100	8	RIO GRAND	YES	
631	Female	71.875	8	BUSCH TAM	YES	
636	Female	0	12	PUEBLA	YES	
637	Male	37.5	8	CALGARY	YES	
653	Male	100	4	LOSANGELE	YES	
654	Male	37.5	4	TOPEKA	YES	
656	Male	0	5	PUEBLA	YES	
660	Male	0	3	PUEBLA	YES	
670	Female	62.5	0	LOSANGELE	YES	
671	Female	100	0	SANDIEGOZ	YES	

[†]Excluded due to age in most recent Breeding and Transfer Plan (Davis and Lynch, 2014)

APPENDIX D. ANALYTICAL ASSUMPTIONS

The following information was added to the studbook in the form of an overlay (Table D1). These pedigree assumptions were used by the Population Management Center (PMC) for the October 2014 River Hippopotamus Master plan.

Table D1. Analytical data for true individuals.

Studbook ID	Field	True	Overlay	Notes
58	Dam	UNK	WILD	Given wild/wild parents as a baseline assumption to root the pedigree.
	Sire	UNK	WILD	
59	Dam	UNK	WILD	
	Sire	UNK	WILD	
72	Dam	UNK	WILD	Assumed wild born because of early date and per 2006 assumptions.
	Sire	UNK	WILD	
117	Dam	UNK	WILD	Came to NZP c. 1956, assumed wild born or at least unrelated to N. American animals.
	Sire	UNK	WILD	
137	Dam	UNK	79	Only potential parents at Kansas City at the time of birth were 72 and 77.
	Sire	UNK	72	
236	Dam	UNK	101	66 and 101 selected as parents of 236, 252, and 247 because they were the only potential parents at Dallas at time of birth.
	Sire	UNK	66	
247	Dam	UNK	101	
	Sire	UNK	66	
252	Dam	UNK	101	
	Sire	UNK	66	
529	Dam	UNK	WILD	Came out of PRETORIA, assumed wild born or at least unrelated to N. American animals.
	Sire	UNK	WILD	
650	Dam	UNK	WILD	Given wild/wild parents as a baseline assumption to root the pedigree.
	Sire	UNK	WILD	

APPENDIX E. RISK CATEGORIES AND RESULTS

ZooRisk uses five standardized risk tests to evaluate different aspects of a population's demography, genetics, and management that might put the population at risk (Table E1). The ZooRisk development team and members of the AZA small Population Management Advisory Group (SPMAG) worked to develop the cutoff for each test. This approach standardizes assessments across species and allows managers to compare species programs using the same framework.

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. For the AZA River Hippopotamus Animal Program, the risk levels showed variation between scenarios (Table E2). The goal for managers should be to move the population from a Critical status towards a Low Risk status, utilizing some of the management tactics highlighted in the model results.

Table E1. Standardized Risk Test, reflecting the population's status in zoos and aquariums.

Tests	Low Risk (LR)	Vulnerable (V)	Endangered (E)	Critical (C)
Probability of extinction in 100 years, based on PVA	0 - 9%	10 - 19%	20 - 49%	50 - 100%
Number of zoos with breeding-aged mixed-sex groups in current population	>3 Zoos	3 Zoos	2 Zoos	1 Zoo
Number of breeding-aged animals (m.f); based on current population	>10.10	7.7 to 10.10	4.4 to 6.6	0.0 to 3.3
Reproduction in the last generation, based on historic studbook data	>9 pairs reproducing	6-9 pairs reproducing	3-5 pairs reproducing	0-2 pairs reproducing
GD of starting population and/or population in 100 years based on PVA	Starting: > 0.9 100 yrs: > 0.9	Starting: 0.8 – 0.9 100 yrs: 0.75 – 0.9	Starting: 0.75 – 0.8 100 yrs: 0.5 – 0.75	Starting: < 0.75 100 yrs: < 0.5

Table E2. Detailed risk results for the population model scenarios.

Scenario		Individual Risk Score for Each Test					OVERALL RISK SCORE FOR EACH SCENARIO (HIGHLIGHTED)			
		Probability of extinction	**Number of zoos**	**Breeding Groups**	**Breeding in Last Gen.**	**GD**				
A	Baseline; p(B) = 3.7%	C	LR	LR	LR	E	LR	V	E	**C**
B	p(B) = 13%	LR	LR	LR	LR	V	LR	**V**	E	C
C	p(B) = 13%; group size = 1.2	LR	LR	LR	LR	LR	**LR**	V	E	C
D	p(B) = 13%; GM = random pairing	LR	LR	LR	LR	V	LR	**V**	E	C
E	p(B) = 13%; exclude = 0% known	LR	LR	LR	LR	V	LR	**V**	E	C
F	p(B) = 13%; imports	LR	LR	LR	LR	LR	**LR**	V	E	C
G	p(B) = 13%; exports	LR	LR	LR	LR	V	LR	**V**	E	C
H	AZA Baseline; p(B) = 3.7%	C	LR	LR	LR	E	LR	V	E	**C**