ORANG-UTAN GLOBAL POPULATION MANAGEMENT WORKSHOP REPORT

Edinburgh, Scotland, UK
10-12 May 2024

Acknowledgements

Workshop organized by:

IUCN SSC Conservation Planning Specialist Group (CPSG)
The Orang-utan Conservation Genetics Project, Inc.

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Table of Contents

Executive Summary

On 10-12 May 2024, 25 population managers and biologists from around the globe met at the National Museum of Scotland, Edinburgh, to discuss issues related to the global and regional zoo populations of orang-utans. Participants represented all major regional and national zoo associations managing orang-utans (from North America, Europe, Australasia, Southeast Asia and East Asia), as well as other relevant experts and advisors.

Workshop objectives were to provide a forum to explore inter-regional collaborations related to orang-utan ex-situ population management and conservation, and to share and discuss the results of recent DNA testing, including any potential implications for population management. This workshop was made possible in part by the Institute of Museum and Library Services through a National Leadership Grant for Museums award to the University of Wisconsin-Madison, and subsequently to The Orang-utan Conservation Genetics Project, Inc., as part of a larger effort to improve the understanding of genetic issues that impact the management of orang-utan populations.

Wild populations of all three orang-utan species are recognized as Critically Endangered by the IUCN Red List. Current global populations of Sumatran and Bornean orang-utans are demographically and genetically healthy, although regional populations have several challenges. After reviewing species-specific population status, genetic results, and regional zoo program goals, participants identified challenges to effective population management and important gaps in knowledge or expertise. Concurrently, opportunities to address these issues were also identified. Participants also considered potential conservation roles that zoos, rescue/rehabilitation centers, and biobanks might play in supporting orang-utan conservation. Orang-utans are popular, charismatic animals for zoo exhibition, which provides an opportunity for conservation-related roles such as securing an insurance population against species decline or extinction and for conservation-targeted education and research.

Significant discussion centered around the importance of working with orang-utan range country governments to determine their goals for the species and to identify if and how zoos might be able to provide help or support. This might help lead to a One Plan Approach to orang-utan conservation, which would include involvement from both in-situ and ex-situ partners to develop a comprehensive approach.

Workshop participants recognized the important roles that ex-situ orang-utan populations play, including those managed by regional zoo associations. After reviewing and discussing the status of and challenges faced by these regional zoo orang-utan populations, the participants concluded that collaboration among themselves, and with other orang-utan conservation stakeholders, would be beneficial. This led to the consensus to form a collaborative group, tentatively called the International Collaboration for Orang-utans in Zoos (ICOZ), with the following draft vision and mission statement:

> *VISION: Healthy, viable populations of orang-utans, both ex-situ and in-situ, are preserved through collaboration among range country and external stakeholders. These populations are demographically, genetically and behaviorally healthy, and consist of thriving individuals with good well-being.*

MISSION: ICOZ promotes the development of a healthy, viable global zoo population of orang-utans through collaboration among its regional partners, and offers support to the range countries as an ex-situ resource to contribute to the conservation of wild orang-utan populations.

ICOZ strives to minimize redundancy with other orang-utan organizations and agencies, and instead to promote collaboration and provide complementary support and assistance to these stakeholders, as appropriate. In line with this perspective, ICOZ identified a two-path strategy. The short-term focus is to promote the development of a healthy, viable global zoo population of orang-utans. As the group becomes more established, it will develop a more long-term focus on working with rescue/rehabilitation centers and other range country partners to offer support, as appropriate.

ICOZ identified six primary challenges to address to support efforts to work toward its mission. This led to the formation of the following six goals designed to address these challenges:

1) Conduct consistent genetic testing of all zoo orang-utans and provide genetic results to regional zoo programs to better inform population management decisions.

2) Develop consistent, quality care for orang-utans to support thriving orang-utans across all regional zoo populations by sharing expertise, guidelines, protocols, and solutions to challenges, and by collaborating to address existing challenges.

3) Genetic material from prioritized (i.e., underrepresented) zoo orang-utans is collected and preserved in biobanks.

4) Trusted relationships are developed between ICOZ and range country stakeholders, including government wildlife authorities, rescue/rehabilitation centers, and national zoo associations.

5) ICOZ serves as an ex-situ resource and collaborator to other orang-utan organizations to better integrate effective in-situ and ex-situ orang-utan conservation efforts.

6) Public awareness of orang-utans, their conservation story, and the conservation roles of orang-utans in zoos is raised across regions.

The workshop participants identified initial action steps under each of these goals to help address these challenges. Steering Committee members will meet virtually in late 2024 to review status updates and further develop the work of the ICOZ.

Status of Global and Regional Orang-utan Populations

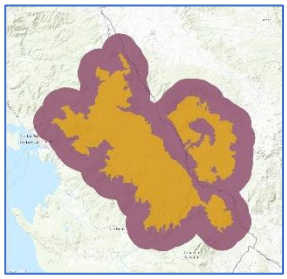
Kathy Traylor-Holzer, IUCN SSC Conservation Planning Specialist Group

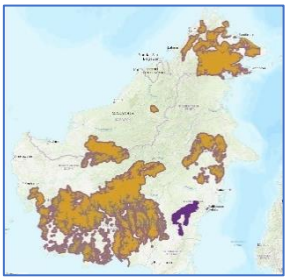
Status of Wild Orang-utan Populations

The IUCN SSC Red List assessment recognizes three orang-utan species, all of which are categorized as Critically Endangered. All three wild populations are in decline due to habitat conversion and fragmentation as well as the illegal killing or removal of individuals. Long generation time and slow life history make it difficult for orang-utan populations to withstand such losses.

The Sumatran orang-utan (*Pongo abelii*) is restricted to northern Sumatra (Aceh) with an estimated ~13,600 individuals (in 2016), plus two reintroduced populations established from confiscated illegal pets near Bukit Tigapuluh National Park and Jantho Pine Forest Nature Reserve. Logging, mining concessions, agricultural plantations and illegal settlement continue to cause high levels of habitat conversion and fragmentation, which, along with illegal killing, has led to a significant reduction in the wild population.
Taken from the Red List assessment by Singleton et al. (2023).

The Tapanuli orang-utan (*Pongo tapanuliensis*) is the least numerous of all great ape species, with an estimated population of fewer than 800 individuals living in the uplands of the Batang Toru Ecosystem in central Sumatra. The Tapanuli orang-utan was proposed as a separate species in 2017. Threats to this species include habitat conversion and fragmentation, killing related to crop conflict, losses due to illegal trade, and genetic impacts of isolation and small population size.
Taken from the Red List assessment by Nowak et al. (2023).





The Bornean orang-utan (*Pongo pygmaeus*) is the most numerous of the three orang-utan species, with perhaps ~58,000 individuals across Borneo. Three subspecies are recognized: *P.p. pygmaeus* (Sarawak, West Kalimantan); *P.p. wurmbii* (West and Central Kalimantan); and *P.p. morio* (Sabah, North and East Kalimantan). Habitat loss and fragmentation from human activities are compounded by fires and climate change impacts. Illegal killing is a major cause of decline such that habitat protection alone is insufficient to ensure the survival of wild populations.
Taken from the Red List assessment by Ancrenaz et al. (2023).

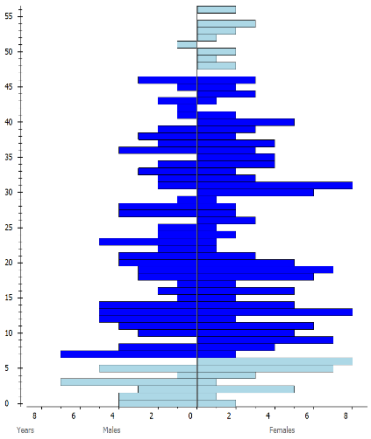
Status of Orang-utan Populations in Zoos

The following information is based on analysis of data exported from the Orangutan International Studbook database, maintained in ZIMS for Studbooks and provided by Megan Elder, International Studbook Keeper (Como Park Zoo & Conservatory, St. Paul, MN, US). Data were current as of export date of 13 March 2024 and included 'pure' species individuals, species hybrids, and individuals of unknown taxonomy. These data incorporate many of the results of previous genetic analyses by The Orang-utan Conservation Genetics Project that were reported to the ISB Keeper over the last decade and incorporated into the studbook prior to the date of data export. Note that these data represent zoo populations reported to ZIMS and/or the ISB Keeper and underrepresent orang-utans held in zoos in some regions. For the most part, data for individuals in rescue and rehabilitation centers are not included.

Global Sumatran orang-utan zoo population

Demography: The current global zoo population is 298 individuals (123 males, 175 females) with a relatively healthy age structure (Fig. 1). While population size (as recorded in the ISB) has been relatively stable for the past 50 years, the proportion of captive-born individuals has steadily increased (Fig. 2). Generation time (T) is 20.7 years, and represents the *average* age of reproduction. Population size is projected to remain around 300 individuals (Fig. 3, red line) based on stochastic projections that apply historical life-table rates (annual growth λ = 1.02) to the current age structure.

Figure 1. Age-sex pyramid for global Sumatran orang-utan population.



Genetics: This population is based on 109 founders that represent 98.7% gene diversity (GD). The Ne/N ratio is 0.444. If this population size is maintained with the same level of breeding management and could be managed as a panmictic (interbreeding) population, it is projected to retain 97% GD for 100 years and could maintain 90% GD for over 500 years without additional founders. Realistically, zoo populations are not globally panmictic and are managed on the national or regional level; however, periodic strategic animal exchanges using a meta-population management strategy could maintain high levels of gene diversity on a regional level.

Figure 2. Historical census of Sumatran orang-utans in zoos Sumatran from 1974 to 2024. Purple line = total population.

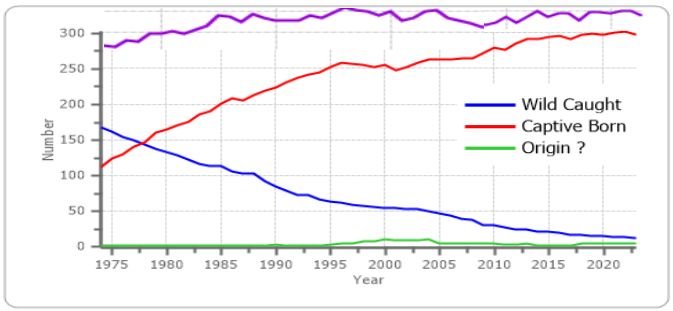
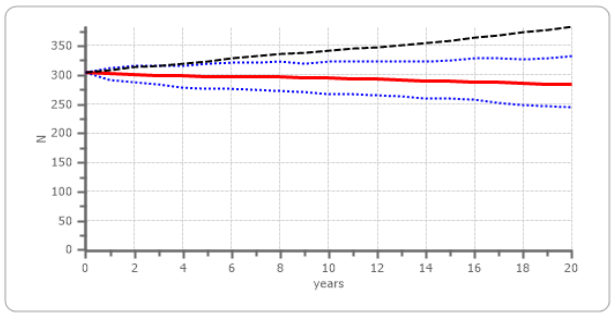


Figure 3. Stochastic 20-year projection for orang-utans in zoos (red line).



Regional Sumatran orang-utan zoo populations

Sumatran orang-utans are managed by several regional zoo associations. These include AZA (North America), EAZA (Europe), ZAA (Australasia), and SEAZA (Southeast Asia). National zoo associations include JAZA (Japan), CAZG (mainland China), Malaysia (MAZPA), and the range country of Indonesia (PKBSI) – see abbreviation list for full association names. A small number of Sumatran orang-utans are maintained in zoos outside of these zoo associations.

Several zoo associations (AZA, EAZA, ZAA, JAZA) have well-established ex-situ management programs and contribute data effectively to the ISB, which allows a good assessment of their population status. Both AZA and EAZA manage relatively large populations with high levels of gene diversity, low inbreeding and high management efficiency (Ne/N), and are projected to maintain at least 90% GD for 100 years (Table 1). ZAA and JAZA have small populations that likely cannot avoid future inbreeding and loss of gene diversity without significant expansion of population size and/or periodic animal exchanges.

Table 1. Population summary of the primary regional and national Sumatran orang-utan zoo populations. Excluded = individuals that are sterilized or females > 47 years (post-reproductive).

Association	Census	Life-table λ	Excluded	Managed	Gene diversity	Mean F	Ne/N	GD in 100 years at current N (λ=1)
AZA	92	0.994	11	81	0.976	0.0046	0.489	0.928
EAZA	145	1.006	14	131	0.975	0.0086	0.472	0.942
ZAA	14	0.992	4	10	0.894	0	0.480	0.643
JAZA	9	0.982	2	7	0.858	0	--	--
SEAZA	32	0.997	0	32	*0.923**	*0.0188**	0.149	0.562
TOTAL	292	1.020	31	261	0.987	0.0076	0.444	0.969

** based on 91% known pedigree*

Not all Southeast Asian zoos are members of SEAZA, and not all zoos report their holdings to the ISB. Table 2 shows detailed holdings of Sumatran orang-utans in Southeast Asian zoos as reported to the ISB. This is likely to be an underestimate of the actual number of Sumatran orang-utans held in zoos in this region, which includes the range country of Indonesia. In addition, there are several orang-utans listed in zoos in mainland China in the ISB; while these individuals have been genetically tested, these genetic results are not yet fully incorporated into the ISB.

Table 2. Number of Sumatran orang-utans held in Southeast Asian zoos as reported in the ISB.

Country	Census	Institutions	Zoo associations	Wild distribution
Indonesia	20	16 at BOGOR 1 at JAKARTA 3 at SURABAYA	PKBSI, SEAZA PKBSI, SEAZA PKBSI, SEAZA	Range country
Malaysia	5	5 at KUALALUM	MAZPA, SEAZA	--
Singapore	7	7 at SINGAPORE	SEAZA (+EAZA)	--
Vietnam	2	2 at VINPEARL	--	--

Global Tapanuli orang-utan zoo population

Genetic analysis by Banes *et al*. (2022) identified wild-caught female ISB# 695 ("Bubbles") to be *Pongo tapanuliensis*. This female lived most of her life in North American zoos, mated with a Sumatran male (ISB# 721), and produced five hybrid offspring before she died in 1995. Two female offspring are dead, leaving two male (ISB# 1703, 1773) and one female (ISB# 1980) living offspring in AZA zoos (Fig. 4). This female is reported to be a permanent non-breeder due to "apparent sterility". Both male offspring have successfully reproduced with females that are either Sumatran or of unknown/hybrid origin, resulting in three living F2 descendants of female Tapanuli ISB# 695. Thus, there are six living orang-utans in AZA zoos that can be identified as partly Tapanuli; four of these are currently considered to be part of the managed population of potential breeders (Table 3).

Table 4 provides the genetic status of the AZA Sumatran Orangutan SSP population before and after the five living individuals of Tapanuli lineage are excluded. Current and projected future genetic measures are not significantly affected by the removal of these individuals from the managed (breeding) population.

Figure 4. Pedigree for female Tapanuli 695 and descendants. Circle = female; square = male. Red = *P. tapanuliensis*; yellow = *P. abelii*; orange = hybrid; light gray = unknown species.

Heavy border indicates living individuals in SSP with Tapanuli lineage; solid border = managed, dashed border = excluded prior to genetic analysis.

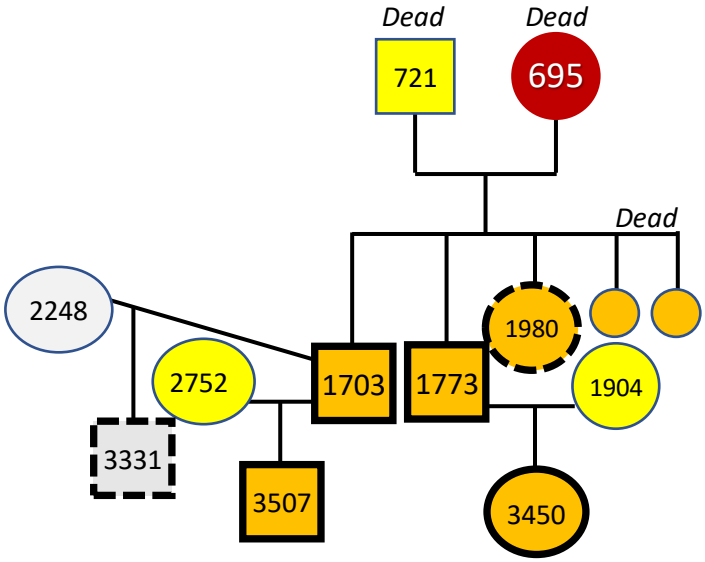


Table 3. Living descendants of ISB# 695 in AZA zoos, and identified as partly Tapanuli based on pedigree.

Generation	ISB	Sex	Age	Location	SSP status
1	1703	Male	45	Atlanta	Managed
1	1773	Male	43	Birmingham	Managed
1	1980	Female	39	Louisville	Excluded (sterility)
2	3331	Male	19	Indianapolis	Excluded (hybrid)
2	3507	Male	11	Atlanta	Managed
2	3450	Female	12	Birmingham	Managed

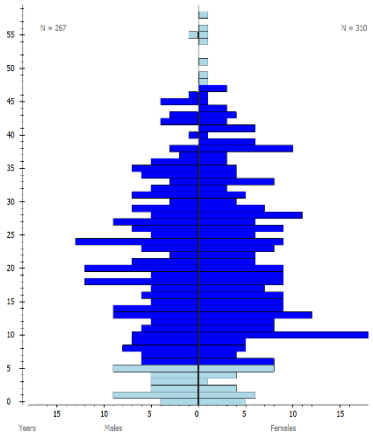
Table 4. Summary for the AZA SSP Sumatran orang-utan zoo population before and after excluding five individuals of Tapanuli lineage.

Association	Census	Excluded	Managed	Gene diversity	Mean F	Ne/N	GD in 100 years at current N (λ=1)
AZA	92	11	81	0.976	0.0046	0.489	0.928
AZA	87	10	77	0.975	0.0049	0.481	0.926

Global Bornean orang-utan zoo population

Demography: The current global zoo population is 577 individuals (267 males, 310 females). The age structure has proportionately fewer Individuals in the early age classes, but there is a high proportion of breeding age individuals that can be bred to sustain growth (Fig. 5). Population size (as recorded in the ISB) has been relatively stable for the past 10 years following decades of growth resulting from captive breeding (Fig. 6), although the number of wild-caught individuals remains high in comparison to Sumatran orang-utans. Generation time (T) is 20.1 years, and represents the *average* age of reproduction. Historical life-table rates and the current age structure project 2.5% annual population growth (λ = 1.025), subject to space availability and other management decisions (Fig. 7).

Figure 5. Age-sex pyramid for global Bornean orang-utan population.



Genetics: This population is based on 199 founders that represent 99.3% gene diversity (GD), based on 85.7% known pedigree. The Ne/N ratio is 0.406. If this population size is maintained with the same level of breeding management and could be managed as a panmictic (interbreeding) population, it is projected to retain 98.2% GD for 100 years and coud maintain 90% GD for over 900 years without additional founders. Realistically, zoo populations are not globally panmictic and are managed on the national or regional level; however, periodic strategic animal exchanges using a meta-population management strategy could maintain high levels of gene diversity.

Figure 6. Historical census of Bornean orang-utans in zoos from 1974 to 2024. Purple line = total population.

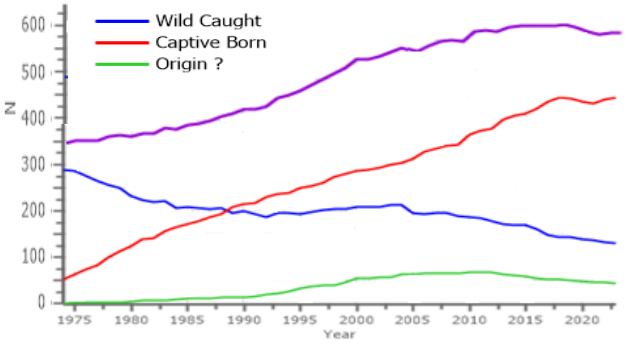
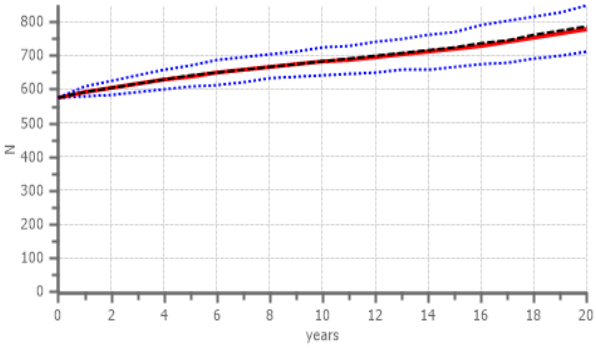


Figure 7. Stochastic 20-year projection for Bornean orang-utans in zoos (red line).



Regional Bornean orang-utan zoo populations

Bornean orang-utans are managed by several regional zoo associations. These include AZA (North America), EAZA (Europe), ZAA (Australasia), and SEAZA (Southeast Asia). National zoo associations include JAZA (Japan), CAZG (mainland China), and ZPO (Thailand) as well as the two range countries of Indonesia (PKBSI) and Malaysia (MAZPA) – see abbreviation list for full association names. A small number of Bornean orang-utans are maintained in zoos outside of these zoo associations.

Several zoo associations (AZA, EAZA, ZAA, JAZA) have well-established ex-situ management programs and contribute data effectively to the ISB, which allows a good assessment of their population status.

Both AZA and EAZA manage relatively large populations with high levels of gene diversity, low inbreeding and high management efficiency (Ne/N), and are projected to maintain at least 90% GD for 100 years (Table 5). ZAA currently houses only a few individuals, which are managed as part of the EAZA EEP. JAZA has a small population that likely cannot avoid future inbreeding and loss of gene diversity without significant expansion of population size and/or periodic animal exchanges.

Table 5. Population summary of the primary regional and national Bornean orang-utan zoo populations. Excluded = individiuals that are sterilized or females > 47 years (post-reproductive).

Association	Census	Excluded	Managed	Gene diversity	Mean F	Ne/N	GD in 100 years at current N (λ=1)
AZA	96	7	89	0.972	0.0035	0.516	0.924
EAZA	141	8	133	0.979	0.0029	0.485	0.944
ZAA	4	0	4	0.811	0	--	0.193
JAZA	28	2	26	0.936	0	0.286	0.678
SEAZA	176	1	175	*0.984**	*0.0039**	0.251	*0.929**
TOTAL	445	18	427	*0.992#*	*0.0030#*	0.478	*0.979#*

**78% known pedigree; #91% known pedigree*

Not all Southeast Asian zoos are members of SEAZA, and not all zoos report their holdings to the ISB. Table 6 shows detailed holdings of Bornean orang-utans in Southeast Asian zoos as reported to the ISB. This is likely to be an underestimate of the actual number of Bornean orang-utans held in zoos in this region, which includes the range countries of Indonesia and Malaysia. There is a particularly large number of Bornean orang-utans held in Indonesian zoos that hold potential for both PKBSI and SEAZA management programs.

Table 6. Number of Bornean orang-utans held in Southeast Asian zoos as reported in the ISB. # Unk ped = number of individuals with some unknown pedigree.

Region	Census	# Unk pedigree	Zoo associations	Wild distribution
Indonesia	107	19	PKBSI, SEAZA	Range country
	34	1	PKBSI only	
	4	--	--	
Malaysia	20	11	MAZPA, SEAZA	Range country
	18	4	MAZPA only	
Thailand	8	1	ZPO, SEAZA	
	5	3	ZPO only	
Singapore	10	--	SEAZA (+EAZA)	--
Philippines	12	12	SEAZA	--
Vietnam	1	1	SEAZA	
Hong Kong	5	--	SEAZA	--
Taiwan	12	--	TAZA, SEAZA	--
	5	--	TAZA only	

The ISB lists 34 Bornean orang-utans in 12 zoos in mainland China. Only four individuals have fully known pedigrees, and the population's pedigree is only 19% known in the ISB. This makes it impossible to accurately calculate gene diversity, kinships or inbreeding levels without additional data or molecular DNA analysis. However, genetic testing of orang-utans in Chinese zoos has been completed by The Orang-utan Conservation Genetics Project, with support of the National Natural Sciences Foundation of

China, the Chinese Academy of Sciences and Max Planck Society Partner Institute for Computational Biology, and by CAZG, and thus the requisite data could be integrated.

An additional ~60 Bornean orang-utans are maintained in zoos outside of these regional and national programs.

Orang-utan RSMP

In 2013, the Orang-utan Regional Species Management Plan (RSMP) was established among select Asian zoos to promote more effective management and collaboration in the region, with the following vision:

> "Orangutans (*Pongo pygmaeus*) now live only in the forests of the South-eastern Asian islands of Sumatra and Borneo, and their habitat is being destroyed like other rainforests worldwide. The goal of Asian zoos collaboration is to insure a sustainable and genetically healthy population in captivity through contributions of each zoo in the region."

The RSMP identified the following objectives:

- Improve studbook data (including taxonomy, missing animals, accuracy, currentness, pedigree issues);
- Determine taxonomy for individuals of unknown origin;
- Stop production of species hybrids;
- Improve retention of gene diversity and reduce inbreeding through effective husbandry and population management; and
- Use orang-utan as a model species for SEAZA

The RSMP is not administered under SEAZA but is a more informal collaboration among zoos that are very diverse. Progress on these objectives is enabling zoos to learn how each zoo or country works, and how to work together. This is setting the stage for more effective population management of orang-utans within SEAZA and in Asian zoos.

Summary

Overall, many regional zoo programs maintain populations of Sumatran and Bornean orang-utans that are demographically and genetically healthy and have the potential for long-term viability. Historically, the AZA SSP and EAZA EEP populations have been intensively managed for decades. Orang-utan populations in Asian zoos (Southeast Asia and East Asia) have the potential for long-term viability provided unresolved taxonomy and kinships are addressed, for example, through molecular DNA analysis; effective cooperative population management is maintained; small national/regional populations are expanded; and/or strategic and periodic international animal exchanges are used to support an effective metapopulation management strategy. In contrast to Sumatran and Bornean zoo populations, molecular DNA analysis to date has identified few orang-utans of Tapanuli lineage, which do not support a potential zoo population for this species at this time. However, the results of genetic testing in regions other than AZA are yet to be fully considered (see Genetics section).

The next steps to improve effective management and viability of Sumatran and Bornean orang-utan zoo populations are to improve the accuracy and completeness of information reported to and incorporated in the ISB, improve husbandry and reduce health risks, and support a framework for effective cooperative population management especially for orang-utans in Southeast Asian zoos.

Genetic Analysis of Zoo Orang-utan Populations

Graham L Banes, The Orang-utan Conservation Genetics Project

Overview

Since 2007, *The Orang-utan Conservation Genetics Project* has facilitated a range of genetic studies of orang-utans worldwide, culminating in the development of standardized methods that can be applied to both in-situ and ex-situ populations for consistent, comparative studies. Because the Project is an independent not-for-profit organization (initially incorporated as a UK registered charity in 2010, and later as a US 501(c)(3) charitable organization), the Project has been able to move through various host institutions, including the University of Aberdeen (2008-2009), the University of Cambridge (2009-2012), the Max Planck Institute for Evolutionary Anthropology (2012-2014), the Chinese Academy of Sciences and Max Planck Society Partner Institute for Computational Biology (2012-2016), and the University of Wisconsin-Madison (2013-2022). Biological samples and data are licensed, loaned or donated to the not-for-profit entity, which now operates independently in Madison, WI, USA and collaborates directly with zoos, NGOs, governments, law enforcement and academic institutions.

As of August 2024, the Project maintains *c.* 4,300 DNA samples collected between 2007 and 2024. These samples derive from specimens of *c.* 1,000 individuals, including wild, wild-caught, captive-bred and reintroduced orang-utans. To date, samples deriving from zoo orang-utans have been collected throughout North America, Europe, Asia and Australia, with the support of each national/regional zoo association and participating institutions.

Application of standardized laboratory methods

A principal goal of the Project is to standardize the generation and analysis of DNA profiles from every orang-utan sampled, to facilitate comparative study. As technology has advanced, so has the standardized method:

- **2007-2013: Microsatellites**
  Samples were initially genotyped at *c.* 30 autosomal tetranucleotide microsatellite markers. This approach is similar to the FBI's CODIS database: though very few positions in the genome are used, they are collectively sufficiently variable to differentiate unique individuals.
- **2013-2017: Microarrays**
  Samples were later genotyped using Illumina iScan microarrays designed for humans. This capitalized on the similarity of the human and orang-utan genomes, and enabled generation of DNA profiles using "off-the-shelf" chips in commercial laboratories.
- **2016-Present: Targeted sequencing**
  Samples are now target-enriched and sequenced for *c.* 185,000 unique positions in the genome that are known to be diverse in orang-utans, plus *c.* 109 medically relevant genes that may provide insight into chronic respiratory, cardiovascular and other health conditions.
- **2017-Present: High- and low-coverage whole-genome sequencing**
  Samples from wild-caught founders are now sequenced at high coverage (30x), while non-founders/captive-born individuals may be genome 'skimmed' at low coverage.

The application of any particular protocol is dependent on conditions set by the owners, licensors or donors of each sample. Consequently, though most samples have now been target-sequenced at minimum, a minority have not. Considering the potential for misuse and abuse of whole-genome data by human biomedical researchers, the Project's general policy is to minimally sequence only what is needed for particular studies or research questions.

Application of standardized computational methods

Since 2011, Susie – an orang-utan who lived at Gladys Porter Zoo in Brownsville, TX – has provided "the" reference sequence for orang-utans. This meant that all analyses of other orang-utans were comparative to Susie's genome. This was problematic for several reasons: Susie was a Sumatran orang-utan, and so Bornean and Tapanuli orang-utan diversity was not represented in her genome; Susie was female, and thus had no Y chromosome against which to compare male orang-utans sampled; Susie was a single individual, versus a spectrum of diverse orang-utans; and Susie's genome was incomplete.

Susie's genome was updated several times over the years, becoming more complete as new technologies were applied. Very recently, however, Susie's genome has been replaced by new reference genomes derived from male Bornean and Sumatran orang-utans, and produced by The National Human Genome Research Institute and the Telomere-to-Telomere Consortium. Moreover, new computational methods have enabled 'pangenomics', wherein samples are compared to a panel of diverse reference genomes versus a single reference. The Project now uses a pangenomic approach to variant calling and data analysis, capitalizing on the new reference genomes, on the Project's unpublished whole-genome assemblies of wild/wild-caught orang-utans, and on the Project's extensive reference panel derived from all samples analyzed to date.

Disposition of results and data

Results and data produced with federal funds are/will be published in accordance with data-sharing policies, though personally identifiable information will be redacted. The Project's policy is otherwise to share results and data only with the licensing/sampling institution and/or the relevant zoological association or management program. A core tenet of the Project is to facilitate ex-situ and guide in-situ conservation by providing stakeholders with the data they need to succeed in sustaining their populations. The publication of research findings for academic advancement is secondary to this goal.

Regional Program Goals, Challenges and Opportunities

Orang-utan Regional Program Goals

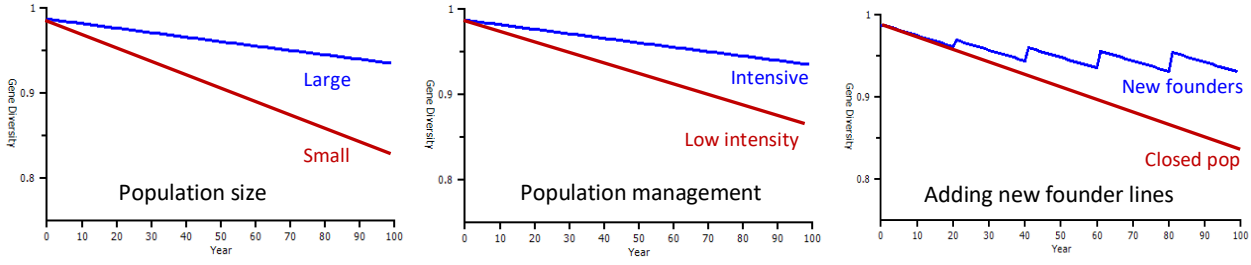
Each of the five regional zoo and aquarium associations that manage orang-utan populations were asked to provide their target population size (Target N) and genetic goals. These goals vary among regions and are species specific. Most programs aim to maintain at least 90% gene diversity for at least 100 years (Table 7).

Table 7. Demographic and genetic regional goals for Bornean and Sumatran orang-utans.

	SUMATRAN		BORNEAN	
Region	Target N	GD	Target N	GD
AZA	93	≥90% for 100yrs	97	≥90% for 100yrs
EAZA	152	≥90% for 100yrs	175	≥90% for 100yrs
JAZA	19 in 20yrs	>90% for 100yrs	46 in 20yrs	>80% for 100yrs
ZAA	≥30	≥90% for 100yrs	--	--
SEAZA	>35	≥90% for 100yrs	>260	≥90% for 100yrs

Factors affecting the retention of gene diversity (GD) were briefly reviewed. Current gene diversity is dependent upon the number of wild-caught individuals that successfully reproduce (founders), as well as how many surviving offspring they have. Gene diversity generally declines over time in small populations due to the stochastic (random) process of genetic drift. The rate of genetic loss is impacted by population size as well as population management. The larger the population, the more slowly it will lose GD. Similarly, the loss of GD can be slowed through effective genetic management using pedigree and/or molecular data to preferentially breed underrepresented founder lines. An additional strategy for meeting genetic goals is the periodic addition of new genetic founder lines. This can be achieved through breeding of potential founders (wild-caught individuals with no living descendants) and/or inter-regional transfers of animals (or their genetic material) (see Fig. 8).

Figure 8. General illustration of the effects of population size, population management intensity, and periodic addition of new founders on the retention of gene diversity in small populations.



Several factors can limit population size, population management, and inter-regional transfers, including biological factors (e.g., health, behavior) and logistical considerations (e.g., space, permits). Population managers may need to address all of these aspects of population management, as feasible, in order to meet their population goals.

Regional Challenges and Opportunities

Challenges

Workshop participants brainstormed their regional needs, challenges and opportunities in managing their orang-utan populations. The following areas were identified as challenges or knowledge gaps for one or more regions:

Logistical

- space limitations (especially for males): number of holders, welfare needs, etc.
- hybrids that are not part of a managed breeding program
- issues with compliance in breeding and transfer recommendations
- veterinary restrictions and other requirements for transfers
- growing public concern regarding great apes in zoos or other types of human care
- lack of legal/feasible ways to acquire orang-utans (popular exhibits)
- lack of standardized genetic testing protocols and laboratories
- reluctance to share some types of data (e.g., heritable diseases)

Biological

- low breeding success for priority breeders or pairs
- behavioral issues affecting reproductive success (e.g., aggression, material care, compatibility)
- potentially long acclimation following transfers, and other welfare issues related to transfers
- pervasive diseases that are challenging to manage
- some regional populations are in a dire situation without international transfers

Inter-regional

- permitting and other restrictions for international transfers (especially exports from range countries)
- different taxonomic management strategies across regions (e.g., species vs subspecies level)
- potential restrictions in collaboration outside certain regional associations
- lack of common guidelines across regions for husbandry and transfers (and ensuring implementation)
- lack of common terminology across regions (e.g., captive *vs* ex-situ *vs* in human care)
- lack of communication between in-situ and ex-situ stakeholders
- lack of communication and trust between zoos and range country governments

Knowledge gaps

- data inconsistency
- better understanding of founder kinships
- species identification and degree of hybridization (particularly Tapanuli)
- pedigree gaps
- information and guidance on heritable diseases
- heritable health and welfare
- identifying role(s) of regional and global ex-situ populations
- some countries do not have access to genetic testing, labs, procedures
- some zoos do not want their data shared (e.g., carriers of predisposition to genetic disease)
- lack of understanding of what range states want and need for the species (and how zoos can help)
- lack of understanding of the conservation needs of the species (and how zoos can help)

Consistent themes included factors that limit population size (e.g., holders, welfare), effective population management (e.g., taxonomic and genetic data gaps; husbandry and veterinary challenges); and the additional of new founder lines (e.g., international transfers). These limitations work together to make it more difficult to meet demographic and genetic program goals.

Working in and with range countries can be especially challenging. Transferring individuals (or biosamples) even within Indonesia requires government approval, and participants acknowledged the challenges of existing protocols and permitting to do research in Malaysia.

The group acknowledged that clearer guidance is needed in terms of what the range countries want and need for orang-utans. Participants emphasized the importance of formulating the right message when communicating with range countries – the message should convey that zoos are offering to help them with their goals, rather than suggesting what zoos want. Building trust with range countries will be an important first step to developing a collaborative relationship and may take time.

Opportunities

Workshop participants also identified some opportunities to help address some of these challenges and knowledge gaps. These opportunities primarily target improved population management through increased knowledge, technology, tools and collaboration, thereby helping regions to meet program goals. Others acknowledge the opportunity to expand strategies and partnerships to better address the needs of the species and the range country governments. Identified opportunities include:

<u>Population management</u>
- new strategies for social management and housing of orang-utan groups
- artificial insemination and other assisted reproductive techniques
- molecular-based population management
- capacity building across regions (provide expertise; mentoring; exchange advice on nutrition, veterinary care, husbandry, etc., including sharing manuals and protocols)
- surplus animals available from some regions
- zoos outside of formal regional or national programs
- possible global coordination (WAZA GSMP is one model, but there are other options as well)

<u>Collaboration</u>
- provide support to the range countries
- research that collaborates with range country (i.e., ties to existing work, includes in-country collaborators, etc.)
- parties to Nagoya Protocol, Convention on Biological Diversity (CBD), etc.
- open communication among the zoo regions to learn from each other in how to develop a relationship with range governments
- Orang-utan RSMP already established among select SE Asia institutions across several countries
- follow a One Plan Approach program (include all stakeholders and consider all options)

Participants noted that we have a demographically and genetically healthy global ex-situ population now, which is a great opportunity for future success.

Potential Ex-Situ Roles for Orang-utans

The regional and national zoo program goals in Table 7 outline goals consistent with maintaining a long-term breeding program as an insurance population against severe decline of the wild Sumatran and Bornean orang-utan populations, as well as a self-sustaining, healthy population to meet zoo exhibition needs. Ex-situ populations, however, can serve a variety of conservation (and non-conservation) roles (Traylor-Holzer *et al.* 2019). In addition, ex-situ populations include not only managed zoo populations but also orang-utans held in non-zoo facilities such as rescue or rehabilitation centers. Biosamples held in biobanks also follow the definition for ex-situ collections.

An overview of the IUCN SSC Guidelines on the Use of Ex Situ Management for Species Conservation (IUCN/SSC 2014) was given to familiarize the workshop participants with the diversity of potential ex-situ conservation roles and the recommended process for evaluating whether or not additional roles might be recommended based on benefits, costs, risks and feasibility. A full Ex Situ Conservation Assessment (ECA) for orang-utans was beyond the scope of this workshop. As an initial and useful step, however, each participant was asked to indicate which potential roles might be considered for zoos, rescue/rehabilitation centers, and biobanks (Table 8). This served to acknowledge the potential strengths and contributions of each of these three types of ex-situ situations, and allowed participants to focus subsequent discussions around potential roles best served by zoos. A full ECA for orang-utans in the future would be of value, which should include involvement by the range countries and in-situ stakeholders and would include feasibility issues such as ownership and costs.

Orang-utans are a popular, charismatic species for exhibition, providing a resource that can also benefit conservation efforts. Workshop participants recognized the potential for regional and national zoo populations to serve as insurance populations for Sumatran and Bornean orang-utans, and that zoos may be able to serve additional conservation-related roles such as targeted education, research and training. Collaboration among regional zoo programs can increase the feasibility and effectiveness of these roles, as well as support a healthy, sustainable ex-situ population for exhibition. These efforts will be more effective in supporting orang-utan conservation by working with range country governments to match their goals and needs.

These discussions on regional goals, range country interests, and potential conservation roles led to the realization that there are several, potentially competing interests in terms of orang-utan populations and their management (Fig. 9). All of these interests are supported by the workshop participants. The challenge is to balance management strategies and goals in ways to best support these interests.

Figure 9. Different interests that may impact orang-utan management strategies and actions.

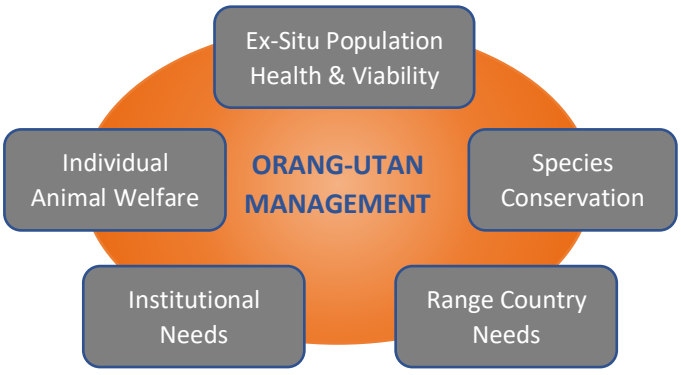


Table 8. Initial input on potential roles that might be addressed by different types of orang-utan ex-situ populations.

Zoos	Rescue/Rehab Centers	Biobanks
INSURANCE: Preserves future options against species extinction or severe genetic loss; provides additional level of insurance to range country conservation efforts		
SEAZA, EAZA, AZA all have potential to contribute to a global insurance population	Not likely to be feasible at this time; issues include unknown origin of animals, little breeding, lack of population management	Possible (as a genetic insurance population); could include cell lines, gamete rescue, embryo cryopreservation
REINTRODUCTION / DEMOGRAPHIC REINFORCEMENT: Releases of individuals into orang-utan habitat that is either empty (to re-establish a population) or has a resident population (to increase population viability).		
Maybe, but much lower potential than R/R centers, especially for reintroduction; case study by Australian zoo (to Sumatra)	Appropriate role to consider for range country centers, particularly for reintroduction into empty areas	Not applicable
GENETIC REINFORCEMENT: Transfer of genetic material from ex-situ to wild populations to increase their viability by increasing or restoring genetic variation and/or reducing inbreeding.		
Maybe; lower potential than biobanks	Maybe; lower potential than biobanks	Potential role in the future, dependent upon technology development and need
TARGETED CONSERVATION EDUCATION: Educational activities using ex-situ collection to target behavior changes in the audience that will benefit the conservation of wild orang-utan populations.		
Good potential for zoos to serve this role; in-range vs non-range zoos would focus on different messages (different audiences)	Possible role, but less so than zoos	Maybe, but much lower than facilities with living animals
TARGETED RESEARCH: Uses ex-situ individuals or biosamples to address knowledge gaps that impact conservation roles or actions.		
Potential for zoos to contribute to this role, depending upon the research question	Possible roll, but much less so than zoos	Good potential for biobanks to contribute, including knowledge gaps in health, disease, genetics and taxonomy
TARGETED TRAINING: Uses ex-situ individuals or biosamples to provide training that will support conservation roles or actions.		
Potential role; topics may include health assessment and immobilization, especially in range countries (need may be low)	Potential role as zoos, and may be more suitable than zoos (need may be low)	Some potential, for training in collection and banking techniques, analysis/DNA testing
NON-CONSERVATION ROLES: Additional potential roles that do not directly support orang-utan conservation.		
-Popular species for exhibition -Legal source for zoos wanting orang-utans for exhibition -Science education -Show animal diversity -Zoo Social License (demonstrate high quality care) -Improve staff skills -Fundraising (for the zoo and/or for conservation)	-Local awareness raising -Fundraising	-Biological data on phylogeny, phylo-geography, etc.

Global Orang-utan Zoo Management: Vision and Recommendations

The workshop participants recognize the important roles that ex-situ orang-utan populations play, including those managed by regional zoo associations. After reviewing and discussing the status of and challenges faced by these regional zoo orang-utan populations, the participants concluded that collaboration among themselves, and with other orang-utan conservation stakeholders, would be beneficial. This led to the consensus that they form a collaborative group, tentatively to be called the **International Collaboration for Orang-utans in Zoos (ICOZ)**, with the following draft vision and mission statement:

VISION

Healthy, viable populations of orang-utans, both ex-situ and in-situ, are preserved through collaboration among range country and external stakeholders. These populations are demographically, genetically and behaviorally healthy, and consist of thriving individuals with good well-being.

Mission statement

ICOZ promotes the development of a healthy, viable global zoo population of orang-utans through collaboration among its regional partners, and offers support to the range countries as an ex-situ resource to contribute to the conservation of wild orang-utan populations.

ICOZ strives to minimize redundancy with other orang-utan organizations and agencies, and instead to promote collaboration and provide complementary support and assistance to these stakeholders, as appropriate. In line with this perspective, ICOZ identified a two-path strategy. The short-term focus is to promote the development of a healthy, viable global zoo population of orang-utans. As the group becomes more established, it will develop a more long-term focus on working with rescue and rehabilitation centers and other range country partners to offer support, as appropriate.

ICOZ Steering Committee

The following regional program representatives were identified to form the initial ICOZ Steering Committee, along with two advisors:

Members:

- SEAZA: Wendy Chua
- SEAZA: Jim Kao
- PKBSI/Indonesia: TBD
- MAZPA/Malaysia: TBD
- AZA: Beth Schaefer
- CAZG: Bai Yali
- EAZA: Simone Schehka
- JAZA: Yusaku Eguchi
- ZAA: Lou Grossfeldt

Advisors:

- Graham L Banes, Genetics Technical Advisor
- James Burton, Indonesian Partnership Advisor

Key Challenges

After reviewing all of the workshop material and discussions, ICOZ identified six primary challenges to address to support efforts to work toward its mission:

1) Effective population management of orang-utans in zoos is hindered by uncertainties in taxonomy and kinships among individual animals, incomplete data, and genetic aspects affecting orang-utan health.

2) Effective population management of orang-utans in zoos is impacted by the lack of a consistent level of quality care and management, and by gaps in knowledge and expertise.

3) Genetic material from zoo orang-utans is being lost due to lack of production of sufficient surviving offspring. This reduces the quality of the genetic insurance reservoir for these species and reduces value as a source of material for assisted reproductive techniques.

4) There is a lack of understanding regarding the aims and priorities of the range countries for orang-utans, and a corresponding lack of clarity on if and how ICOZ can provide support. In some cases, there may be a lack of trust of zoos that hampers communication and collaboration.

5) Multiple entities are involved with various aspects of orang-utan management and conservation but are not working together under a One Plan Approach strategy and may not have adequate input/representation from the orang-utan zoo community.

6) There is insufficient awareness by the general public across all regions with respect to orang-utans, their conservation status in the wild, the role of orang-utans in zoos, and how people and their actions can impact orang-utans.

The workshop participants identified action steps under each of these problem areas to help address these challenges.

Recommended Actions

PROBLEM: Effective population management of orang-utans in zoos is hindered by uncertainties in taxonomy and kinships among individual animals, incomplete data, and genetic aspects affecting orang-utan health.

GOAL: Conduct consistent genetic testing of all zoo orang-utans and provide genetic results to regional zoo programs to better inform population management decisions. It is recommended that high coverage genome sequencing is done for all founders and potential founders (i.e., orang-utans of wild origin).

Action	Responsible party	Timeline
INDONESIA Explore both options of: a) exporting samples from Indonesia to the USA using the GSMP MoU template, and/or: b) securing a service lab in Bogor to perform the requisite Illumina sequencing.	Yohana Tri Hastuti	By 30 June 2024 (to confirm lab)
Inform all PKBSI member zoos on sampling and for members to send samples to service lab. a) Share protocol and SEAZA letter with PKBSI. b) Communicate with PKBSI member zoos and distribute sampling kits and protocols. c) Collect samples and send to service lab.	Achmad Muchsinin Juwari	By Nov 2024 (for step a)
MALAYSIA Provide Melaka, A'Famosa, Bukit Merah and Kemanan with oral swab kits and guide MAZPA members on sampling.	Mazwin Marjan, after receiving kits and SEAZA letter/ protocol	By Oct 2024
PERHILITAN will lead the Illumina sequencing work for Malaysia, including finding university student, proposal, student funding. *Update: Initial discussion held 29 July with Prof. Badrul Munir Md Zain and Ms. Millawati Gani; proposal in discussion w/GL Banes before Prof. Badrul can proceed with research permit application.*	Kayal Vizi Karuppannan	By Oct 2024 to set in place
Confirm the number of library preparation kits needed. *Update: Prof. Badrul to finalize with GL Banes*.	Kayal Vizi Karuppannan	By Aug 2024
Acquire library preparation kits.	Graham L Banes	By Aug 2024
THAILAND Conduct genetic analysis in Thailand through collaboration with local university and lab.	Sudarath Baicharoen (Mint) and Saowaphang Sanannu (Yai)	By Aug 2024
Acquire library preparation kits.	Graham L Banes	By July 2024
Explore holding a genetics workshop in Thailand in 2025 to provide training.	Graham L Banes, Sudarath Baicharoen (Mint), and Saowaphang Sanannu (Yai)	Discuss by July to initiate process
SEAZA Provide a letter of endorsement to those above.	Wendy Chua	By June 2024
Share protocols.	Graham L Banes and Wendy Chua	By June 2024

Table 9 provides an initial tally of the number of orang-utans sampled and testing per region, along with the researcher and method used. This information may be useful in working toward this Goal.

Table 9. Status of genetic sampling and testing across regions as of August 2024. BOR=Bornean; SUM=Sumatra; TAP=Tapanuli; UNC=uncertain taxonomy; HYB=known taxonomic hybrid.

		Total	BOR	SUM	TAP	UNC	HYB	Researcher and method	Status
AZA	# tested (includes historic)	316	119	114	1	-	82	TOCGP/Banes. Targeted sequencing; microarrays; high- and low-coverage whole-genome sequencing.	All findings reported to then-SSP Chair and ISBK; Tapanuli findings published in 2022.
	# tested	?						Tomas Marques-Bonet; method uncertain	Uncertain
EAZA	# tested (includes historic)	246						TOCGP/Banes. Targeted sequencing; high- and low-coverage whole-genome sequencing.	Additional testing (and continued sample collection) is underway for some individuals; disposition of results will be discussed at EAZA EEP meeting in October 2024.
JAZA	# tested (includes historic)	0	0	0	0	0	0	TOCGP/Banes. Targeted sequencing; high- and low-coverage whole-genome sequencing.	Awaiting Japanese export permit
ZAA	# tested (includes historic)	24	5	16	0	-	3	TOCGP/Banes. Targeted sequencing; high- and low-coverage whole-genome sequencing.	All findings reported to the ISBK; results did not differ from the ISB at the time.
SEAZA	# tested (includes historic)	77	29	1		45	2	TOCGP/Banes with University of the Philippines-Diliman, Chinese Academy of Sciences, Singapore Zoo and Taipei Zoo. Microsatellites; targeted sequencing; microarrays; high- and low-coverage whole-genome sequencing.	Remaining samples from SEAZA countries are currently being collected. Awaiting Taiwan export permit. 45 orang-utans are presently being re-analyzed using newer molecular methods.
CAZG	# tested (includes historic)	42						TOCGP/Banes with Chinese Academy of Sciences and CAZG. Microsatellites; targeted sequencing; microarrays; high- and low-coverage whole-genome sequencing.	Additional testing is underway for some individuals; disposition of results to be determined once complete.

See these following citations in References for TOCGP/Banes methods: Banes *et al*. (2020); Banes *et al.* (2022); Fountain *et al.* (2021)

PROBLEM: Effective population management of orang-utans in zoos is impacted by the lack of a consistent level of quality care and management, and by gaps in knowledge and expertise.

GOAL: Develop consistent, quality care for orang-utans to support thriving orang-utans across all regional zoo populations by sharing expertise, guidelines, protocols, and solutions to challenges, and by collaborating to address existing challenges. Areas of collaboration may include: husbandry, veterinary care and nutrition, reproduction and contraception, welfare and behavioral enrichment, and population management.

Action	Responsible party	Timeline
Establish one or more working groups, define scope of work, expand group members, and consult with SEAZA and other regions regarding priority needs and timelines.	Steering Committee	??
Use SEAZA orang-utan cross-committee workshop to determine priorities. Report back to ICOZ working group(s).	Jim Kao and Wendy Chua	Nov 2024
Initiate compilation and comparison of materials as potential resources.	James Biggs	By July 2024
Develop method to establish baseline and evaluate progress.	??	??

PROBLEM: Genetic variation from zoo orang-utans is being lost due to lack of production of sufficient surviving offspring. This reduces the quality of the genetic insurance reservoir for these species and reduces value as a source of material for assisted reproductive techniques.

GOAL: Genetic material from prioritized (i.e., underrepresented) zoo orang-utans is collected and preserved in biobanks.

Action	Responsible party	Timeline
Initiate discussion at the SEAZA Orang-utan CC workshop.	Jim Kao, Wendy Chua and Yai	Oct 2024
Feasibility study for each country	??	??
Prioritize individuals for banking for each country using studbook and/or genetic data.	??	??

PROBLEM: There is a lack of understanding regarding the aims and priorities of the range countries for orang-utans, and a corresponding lack of clarity on if and how ICOZ can provide support. In some cases, there may be a lack of trust of zoos that hampers communication and collaboration.

GOAL: Trusted relationships are developed between ICOZ and range country stakeholders, including government wildlife authorities, rescue/rehabilitation centers, and national zoo associations.

Action	Responsible party	Timeline
INDONESIA Initiate discussion between ICOZ and Action Indonesia/GSMPs regarding aims and overlap (virtually).	James Burton	By June 2024
MALAYSIA Initiate discussion with three government agencies (PERHILITAN, Sabah, Sarawak) and MAZPA.	Kayal Vizi Karuppannan	By Aug 2024

PROBLEM: Multiple entities are involved with various aspects of orang-utan management and conservation but are not working together under a One Plan Approach strategy and may not have adequate input/representation from the orang-utan zoo community.

GOAL: ICOZ serves as an ex-situ resource and collaborator to other orang-utan organizations to better integrate effective in-situ and ex-situ orang-utan conservation efforts. Potential collaborators include IUCN SSC Great Ape Specialist Group, UN-GRASP, Asian Species Action Partnership (ASAP), CITES and other permitting authorities, and CBD national focal points.

Action	Responsible party	Timeline
Initiate contact with these groups after ICOZ is formally established.	James Biggs	By Dec 2024

PROBLEM: There is insufficient awareness by the general public across all regions with respect to orang-utans, their conservation status in the wild, the role of orang-utans in zoos, and how people and their actions can impact orang-utans.

GOAL: Public awareness of orang-utans, their conservation story, and the conservation roles of orang-utans in zoos is raised across regions. This would include establishing a baseline and conducting awareness-raising activities, using an approach that accounts for cultural and regional differences. Specific messaging to target positive behavior change is developed for those audiences whose behavior may be impacting orang-utans.

Sub-goal: Define ex-situ conservation roles (possibly through an Ex-situ Conservation Assessment).
Sub-goal: Use orang-utans to develop supportive attitudes toward orang-utans in zoos by general public (social license).
Sub-goal: Enable behavior change to positively impact orang-utans (e.g., palm oil consumptions).

All sub-goals/steps may vary by country or region, and so it will be important to share ideas, materials, messages, etc.

Action	Responsible party	Timeline
Initiate discussion at the SEAZA Orang-utan CC workshop (e.g., survey).	Jim Kao	By Oct 2024

PROBLEM: Implementation of recommendations will require communication and follow-up.

GOAL: Maintain communication and provide status updates among the ICOZ.

Action	Responsible party	Timeline
Conduct a virtual meeting to update on work of ICOZ (time zone: maybe early AM in SE Asia?)	Wendy Chua	Nov 2024

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Abbreviations

AZA	[American] Association of Zoos and Aquariums
CAZG	Chinese Association of Zoological Gardens
CPSG	Conservation Planning Specialist Group
EAZA	European Association of Zoos and Aquaria
EEP	Ex-situ Programme
ISB	International Studbook
GD	Gene diversity (expected heterozygosity)
GSMP	Global Species Management Plan (administered by WAZA)
ICOZ	International Collaboration for Orang-utans in Zoos
IUCN	International Union for the Conservation of Nature
JAZA	Japanese Association of Zoos and Aquariums
MAZPA	Malaysian Assoc. of Zoological Parks and Aquaria
PERHILITAN	Dept. of Wildlife and National Parks Peninsular Malaysia
PKBSI	Indonesian Zoo Association
SEAZA	Southeast Asian Zoos and Aquariums Association
SSC	Species Survival Commission
SSP	Species Survival Plan
TAG	Taxon Advisory Group
TOCGP	The Orang-utan Conservation Genetics Project, Inc.
WAZA	World Association of Zoos and Aquariums
ZAA	Zoo and Aquarium Association [Australasia]
ZIMS	Zoological Information Management System (by Species360)

Note: Regional and national zoo and aquarium associations may be referred to in the report text as "zoo associations" for brevity; however, we recognize that these associations include aquariums as full members as well as zoos.

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