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Modern zoos' efforts on conservation, care and welfare of lemur species

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Summary

Modern zoos have assumed a crucial role in the conservation of endangered species, which has been possible through both in-situ and ex-situ projects and initiatives, with the aid of specific welfare guidelines, and through updated research on species-specific needs, such as nutritional requirements, behavior, and the implementation enrichment programs.

In addition to different conservation projects, zoological parks have involved zoo visitors and communities in educational projects aiming to sensibilize the importance of species conservation and habitat restoration.

This thesis will focus in particular on the management of lemur species in captive conditions, on how conservation projects dedicated to the preservation of these species have been committed to their protection, and on the husbandry techniques used in zoological parks aiming to provide the best care to the animals thanks to a deep knowledge on their biological needs: effective lemur management in captivity not only enhances their welfare but also supports broader conservation goals.

Lemurs are the most endangered group of primates; thus, their protection, welfare, and conservation are crucial.

1. INTRODUCTION – The role of modern zoos

Zoological institutions have become leaders of wildlife conservation, as they perform ex-situ activities to preserve natural resources, which are enabled by the housing of wild species. Zoo-managed animals facilitate new scientific knowledge, public education, and strategic breeding to maintain genetic diversity (Beer et al., 2023).

Today, zoos are critical players in global conservation efforts, research, education, and community engagement, reflecting their evolution into sophisticated institutions dedicated to preserving biodiversity and promoting sustainable practices.

Modern zoological parks have been dedicated to species conservation for decades, serving as sanctuaries for endangered species threatened by habitat loss, poaching, and climate change. Through carefully managed breeding programs, zoos strive to maintain genetically diverse populations of at-risk species.

In recent decades, zoos have grown in popularity, attracting over 700 million visitors annually worldwide. Zoos must continue publicly showcasing their conservation successes to their community stakeholders through social media campaigns and other media. Open and transparent communication about the role of zoos in species and habitat conservation and their dedication to animal welfare helps dispel misconceptions and garner support for preserving natural resources.
As the challenges facing wildlife continue to mount, the contributions of modern zoos will be increasingly essential in the global effort to protect and conserve the natural world.

1.1 Education

Raising awareness and fostering support for conservation among the public while educating it about species' biology and conservation are essential and core elements of the modern zoo's mission. Zoos need to be able to engage and empower visitors, serving as a meaningful platform to raise awareness about the challenges wildlife faces. By sparking inspiration and encouraging positive environmental action, zoos can equip people with a deeper understanding and the motivation to contribute to biodiversity conservation and environmental protection. Educators at zoos play a crucial role in sharing information about the species within their facilities highlighting threats in the wild and fostering proactive conservation efforts and initiatives.

Through diverse interactive exhibits, educational programs, and conservation-themed activities, zoos educate the public about the importance of biodiversity, the threats facing wildlife, and the actions needed to protect endangered species.

The effectiveness of zoo education initiatives remains unclear, and, likely, the most important educational aspect of zoo conservation is simply the caring values shown by zoos in their dealings with animals (Rabb and Saunders, 2005).

1.2 Animal Welfare

Professional zoos and aquariums are committed to promoting optimal animal welfare and providing environments where animals can thrive. This commitment is fundamental to supporting goals as modern conservation, education, engagement, advocacy, learning, and research organizations. Significant advances in knowledge about animals and animal welfare science have resulted in big changes in modern zoos and aquariums.

All zoos and aquariums can play a significant role in improving the lives of animals in their care by engaging with and responding to continued challenges of different attitudes, societal expectations, and varied jurisdictional frameworks and legislation in the global implementation of animal welfare standards.

1.2.1 What is animal welfare?

The official WOAH (the World Organization for Animal Health) website states that, according to the Terrestrial Code, animal welfare means 'the physical and mental state of an animal concerning the conditions in which it lives and dies.

A scientific, multi-disciplinary approach is essential to meet an animal's welfare needs. This includes providing veterinary care, meeting nutritional requirements, allowing for species-specific behaviors, and promoting positive emotional states. Understanding natural behaviors, physical needs, biochemistry, nutrition, and psychology is crucial for promoting animal welfare.

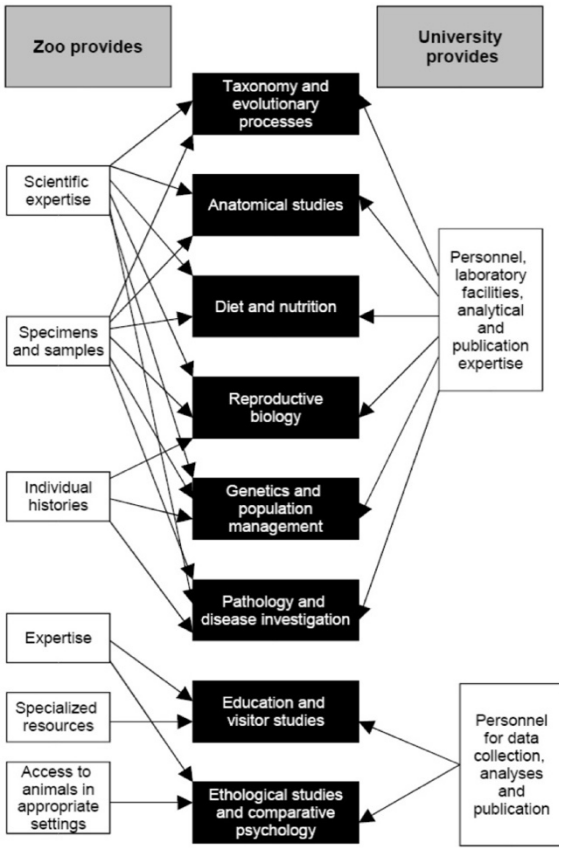
1.3 Research

Zoo research is indispensable to gain further knowledge on the needs of captive animals and the best ways to guarantee their welfare and health in such contexts. This can also be regarded as any activity that increases knowledge and understanding of animals and their environments, whether it being zoo or wild.

The function of zoo research is to help in furthering the operations of the zoo, to help other zoological parks achieve their mission and vision, and to increase knowledge and improve practice in things such as captive breeding, enclosure use, behavior, welfare, and conservation.

Zoos have been offering opportunities for research in many different scientific disciplines, such as reproductive biology, behavior, genetics, nutrition, and health.

Caretakers and other experts help identify research needs, and research findings contribute to the improvement of animal welfare within zoos. Scientific research on species-specific housing, dietary requirements, and



Different types of expertise, knowledge, and resources are involved in zoo research. Credit: WAZA 2005

the best individualized husbandry practices has manifested in more effective welfare management practices (WAZA, 2015).

Additionally, there are dedicated scientific journals concerning zoo research, Zoo Biology Journal being one of these, which is a diverse zoology journal devoted to the reproduction, demographics, genetics, behavior, medicine, husbandry, nutrition, conservation, and all empirical aspects of the exhibition and maintenance of wild animals in wildlife parks, zoos and aquariums (From Wiley Online Library). It is a landmark for those working with both zoo and wild animals, researchers, students, and veterinarians.

Research performed in zoos and the wild by zoo experts generates the scientific knowledge that makes educational programs possible, as it provides fundamental information for diverse learning topics like animal behavior, reproduction, health, nutrition, and ecology (Beer, H.N et al., 2023).

1.4 Species Conservation

Modern zoos in the 21st century aim to contribute effectively to species conservation through various projects, either in situ, meaning in the natural habitats in which animals and plant species live, or ex-situ, in facilities out of the species' natural habitats.

Stable population density and health status over time are primary indicators of successful conservation in wild animal populations and their habitats: robust genetic diversity is necessary to conserve healthy populations in the wild, as it increases fitness and adaptability to changing environments (WAZA).

Zoos are increasingly involved in conservation advocacy, using their platforms to influence public policy and garner support for wildlife protection measures. They work in partnership with international conservation organizations, such as the World Wildlife Fund (WWF) and the International Union for Conservation of Nature (IUCN), to amplify their impact. By leveraging their resources and expertise, zoos can drive significant local, national, and global conservation outcomes.

How zoos should be involved in conservation is elaborated in two strategy documents, the World Zoo and Aquarium Conservation Strategy (WZACS) (WAZA 2005) and its predecessor, the World Zoo Conservation Strategy (WZCS 19993). Both advocate an integrated approach to conservation both within and outside the zoo (Hosey et al., 2013).

Further information on conservation efforts by zoological institutions will be delved into in the next chapter.

2. CONSERVATION EFFORTS

Conservation projects and initiatives

Modern zoos have assumed a major role in ensuring the survival of endangered species through conservation, research, and public education (*Mellor et al., 2015*). They act as wildlife conservation organizations with projects around the world, working in partnership with local and national governments, civil society, and intergovernmental organizations (including the UN and its organizations), to design and implement conservation programs (Spiezio et al., 2022). Zoos must act both ex-situ, by delivering the highest standards of care and welfare for the animals, and in situ, by providing safety for those populations of species living in the wild (World Association of Zoos and Aquariums (WAZA); 2015).

With more than 700 million people annually visiting zoos and aquariums of the world, connected through regional associations of the World Association of Zoos and Aquariums (WAZA), zoological facilities have an unrivaled platform to engage the public in conservation.

In this way, it is possible to preserve and protect those lemur species that are currently facing extinction.

Lemurs are a highly endangered group of primates endemic to the island of Madagascar only. They are the most endangered group of mammals: there are over 100 known species of lemur, and 94% of these are considered threatened by the International Union for Conservation of Nature (IUCN), that is, they are currently classified as vulnerable, endangered or critically endangered (IUCN, 2021). Given such a large number of species at risk, and an increasing level of threats (habitat destruction, hunting, climate change), lemur conservation efforts have become multifaceted and employ a variety of strategies (Schwitzer et al., 2013). These strategies must focus on assuring the viability of wild populations in their natural habitats but given the rise of human-borne threats in Madagascar, it has also become increasingly important to maintain conservation-focused captive breeding ex-situ programs (Schwitzer et al., 2013). Ex-situ conservation through captive assurance colonies can have multiple advantages: complementing and supporting local conservation programs in Madagascar, maintaining genetic diversity, aiding population recovery and reintroductions, and raising awareness through educational and visibility activities (Zimmermann, 2010; Schwitzer et al.,

2013). Under the “One Plan” approach, populations of a lemur species within and outside of Madagascar, in the wild and in captivity, should all be managed as a meta-population, increasing the chances of success in an unpredictable future (Schwitzer et al., 2013).

2.1 Conservation status of lemur species

As mentioned in the introduction, most lemur species known are now facing many threats, which have been leading to their decline.

An update of the International Union for Conservation of Nature (IUCN) Red List of Threatened Species reveals that nearly a third, or 31% of all lemur species in Madagascar are now Critically Endangered.

On the IUCN website, a complete list of the status of all lemur families is available; in the Lemuridae family, out of 21 total species, 8 are endangered, including the red ruffed lemur and the black-and-white ruffed lemur, commonly found species in zoological parks.

The family *Indriidae* counts 11 critically endangered species. 9 species under the family of *lepilemuridae* are critically endangered, while the *cheirogaleidae*, the lemur family that includes dwarf and mouse lemurs, has a total of 5 critically endangered species (data from IUCN Red List Status of Lemurs, 2020).

The IUCN Red List thus states that, out of 107 species, the total of “Critically Endangered” is 33 (31%). Total “Endangered” species are 45 (42%), Total “Vulnerable” species are 25 (23%), Total “Least Concern” = 2 (2%) , Total “Data Deficient” = 2 (2%).

2.2 Threats

Lemurs have been facing many threats that have greatly impacted their populations, causing a decline in individuals and leading to many species being critically endangered.

These threats include:

1. Habitat change and loss: the shrinking and degradation of their habitats jeopardize the survival of lemur species and all other fauna of the Isle. The causes of habitat loss and change in Madagascar can be attributed to both commercial interests and locals' need for food and income. Major corporations clear land to produce goods for commercial purposes, leading to habitat loss, while local communities rely on the land for sustenance and earning a livelihood. All lemurs need intact forest ecosystems for food, with even the largely terrestrial

ring-tailed lemurs relying on intact forests for food resources and sleeping sites (Schwitzer et al., 2013).

The most pervasive form of habitat degradation has been selective logging, which consists of the removal of selected trees within a forest based on criteria such as diameter, height, or species.

Another massive driver of deforestation is the production of wood charcoal (Schwitzer et al*.,* 2013).

2. Climate change: this is a huge threat to both animals and the environment in which they live, as they're interconnected, they are affected simultaneously leading to a loss of both vegetation and species. Additionally, Madagascar is one of the top five countries most affected by human-induced climate change. Temperatures have been rising, leading to less rain and dried soils, which eventually resulted in a lack of food in affected areas.
3. Poaching, hunting, and illegal pet trade: direct poaching poses another concerning threat to wild lemur populations. In Madagascar, most of the wildlife harvest is driven by a need for food, although many wild lemurs are also captured for the domestic pet trade (Reuter KE et al., 2016*).* Overexploitation significantly threatens biodiversity with hunting and live capture. Effective conservation of Madagascar's mammals, therefore, requires a better understanding of the prevalence and breadth of the live capture of animals. The capture and sale of lemurs are illegal both domestically (Reuter KE et al., 2016) and internationally (UN, 1973), with punishments including confiscation.

   Because of low food security, high malnutrition, and insufficient animal-based foods, rural communities hunt many species of local wildlife, including endemic lemurs (Eppley, T. M. et al., 2024).
4. Invasive species: the presence of invasive species in Madagascar, introduced by humans and non-native to the local ecosystems, poses a serious threat to lemurs, plants, and other native species. Invasive species such as rats, stray dogs, and cats brought by humans could spread diseases and prey on natural wildlife, putting the native species at risk. Additionally, reforestation using non-native plant species can lead to habitat degradation and fragmentation as well.

Population declines and species extinctions not only reduce species diversity but also disrupt ecological interactions and functional diversity, leading to detrimental impacts on the bigger scheme of the ecosystems.

It is essential to advocate for conservation activities that help reduce threats and protect the environment. Different long-term solutions can be achieved, with the effort and commitment of many stakeholders. (Schwitzer et al., 2013).

The strategy for conserving Madagascar's biodiversity encompasses several comprehensive actions.

Community development and sustainable use are crucial. In combination with demographic growth, the increasing poverty of Madagascar continues to accelerate the conversion of natural habitats into arable and degraded land. Many of the island's impoverished communities live close to existing protected areas or other ecologically valuable sites, directly competing with lemurs for space and natural resources, leading to shrinking lemur habitats. The employment of local communities for conservation-minded research could also generate sustainable revenue (Schwitzer et al., 2013).

Empowering local conservation actors is essential, involving support and training for individuals and institutions.

Expanding reforestation and forest restoration projects are also vital for the recovery of native habitat. Efforts should focus on protected areas, peripheral zones, and corridors between forest fragments, adopting a landscape restoration perspective. Integrating native utilitarian trees and lemur food trees will benefit both biodiversity conservation and local communities, promoting wildlife dispersal.

Establishing and continuing long-term research and monitoring are crucial for informed conservation efforts. Addressing food insecurity, supporting environmental education, and promoting sustainable livelihoods are necessary to enhance community well-being and conservation outcomes.

Finally, developing community health initiatives is another critical component, as the healthcare needs of rural communities near protected areas are often unmet. Limited access to medical facilities poses significant challenges, and implementing community health programs can build trust, alleviate cycles of poverty and poor health, and support forest conservation efforts (Schwitzer et al., 2013).

Conservation education may be a tool to increase environmental awareness nationally and internationally, through zoo initiatives involving a big public with a very heterogeneous background. In Madagascar, as part of a lemur conservation strategy, effective conservation education is essential to raise awareness of lemur conservation on national and international scales. This will improve people's knowledge of lemurs and their habitat, promote pro-conservation behaviors, and involve more people in lemur conservation and sustainability initiatives (Schwitzer et al., 2013).

2.3 IUCN SOS Lemur initiative

IUCN, the International Union for Conservation of Nature, is a membership Union of government and civil society organizations. Founded in 1948, it works to advance sustainable development and create a world that values and conserves nature. IUCN regularly publishes the so-called Red List of Threatened Species, which has been established in 1964: this has evolved to become the world's most comprehensive information source on the global extinction risk status of animals, fungi, and plant species.

The IUCN Red List is a critical indicator of the health of the world's biodiversity; it is a powerful tool to inform and catalyze action for biodiversity, conservation, and policy change. IUCN Red List assesses the conservation status of species around the world, providing comprehensive information on the conservation status of plant and animal species worldwide, including population status, habitat range, ecological data, threats, and areas requiring further research.

The SOS Lemur Initiative, expected to run until 2029, is one of the major projects dedicated to lemur conservation in the world. The initiative is implemented in two phases. The first, which started in 2017 and ended in 2023, contributed to 49 projects which led to the protection of over 63 lemur species. Several of these projects reported notable increases in species populations, restored and improved forest habitats and strengthened food availability for local communities

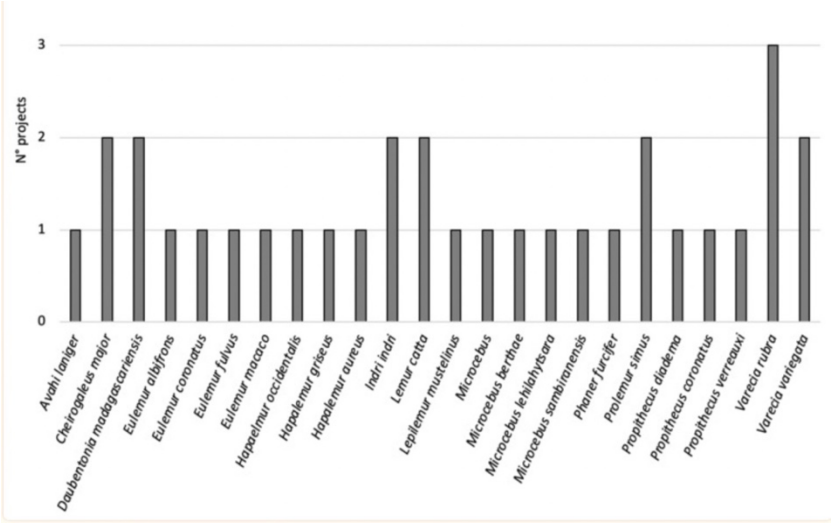
The ultimate goal of this initiative is to provide small to medium-sized grants to civil society organizations to ensure key lemur populations across key sites are secured, empower relevant communities with skills to help them coexist with lemurs, and help local conservation actors and NGOs develop their long-term development goals through knowledge sharing and financial support. This initiative is set to continue until 2029, working with local Madagascar communities and the local governments to support knowledge transfer among conservationists, influence national and international policies, and raise public awareness on the need to conserve lemurs, among other

species (From IUCN official website and SOS Lemur initiative website https://iucnsos.org/initiative/sos-lemurs/).

2.4 Zoo-led initiatives and ex-situ conservation programs

Modern zoos have assumed a major role in ensuring the survival of endangered species via conservation, research, public education, and outreach activities: Zoological institutions must create sustainable business plans to support field-conservation efforts while simultaneously facilitating pro-environmental behavior change. This balanced approach is the only way to address effectively human threats to wild populations (Barongi, R. et al., 2015).

Different projects led by zoos around the world are playing an important role in the conservation of these species, along with research centers and universities.



Lemur species involved in conservation projects. Credit: Spiezio et al., 2022

Ex situ lemur conservation programs are mostly managed by zoo associations in the developed world, such as the Association of Zoos and Aquariums (AZA) in North and Central America, and the European Association of Zoos and Aquaria (EAZA). Examples of coordinated captive breeding programs for lemurs include the AZA's Species Survival Plan Programs (SSPs) for black and Sclater's lemurs (*Eulemur macaco* and *E. flavifrons*), mongoose lemurs (*E. mongoz*), and ruffed lemurs (*Varecia* ssp.); EAZA's corresponding European Endangered Species Programs (EEPs) for the same taxa, as well as, for example, for red-bellied lemurs (*Eulemur rubriventer*), greater bamboo lemurs (*Prolemur simus*), crowned sifakas (*Propithecus coronatus*), (Schwitzer et al., 2013*).*

Captive lemur populations are maintained locally and outside of Madagascar in different zoological facilities and research centers, although the diversity of species is limited. Many of those priority species are still not yet held in captivity in EAZA institutions, including some that are currently critically endangered (Reimes et al., 2021).

The largest captive lemur population can be found at the Duke Lemur Center (DLC), in Durham, United States, whose mission includes non-invasive research, conservation, and public education. The center was founded in 1966 on the Duke University of Durham campus. The Center is committed to conservation breeding programs that seek to preserve endangered species such as the aye-aye and the blue-eyed black lemur.

The DLC also works within a network of other accredited institutions in North America and Madagascar to advance lemur care and welfare and to develop and adhere to Species Survival Plans (SSPs) that use carefully planned conservation breeding programs to create a "genetic safety net" for rare and endangered lemurs.

Today, the center houses more than 200 individuals across 13 species (Duke Lemur Centre website https://lemur.duke.edu/about/history-mission/).

Maintaining long-term viable, and genetically, demographically, and phenotypically healthy captive populations of priority lemur species already in captivity, are thus the most critical actions that need to be taken to ensure the integration of ex-situ and in-situ conservation, through the improvement of global population management. It is important also to facilitate the exchange and translocation of individuals within Madagascar and between Madagascar and member zoos of the major regional zoo associations, through close collaboration with the relevant Malagasy authorities.

Additionally, it would be beneficial to use captive or semi-wild managed breeding facilities to facilitate the management of existing captive lemur populations, both in Madagascar and in other countries (Schwitzer et al., 2013).

2.4.1 The Volohasy-Bamboo Project

The Volohasy-bamboo project is one of the many Conservation initiatives supported by zoological parks, aiming at species conservation and reforestation. The project has been promoted by the University of Turin and supported by UIZA, the Italian Union of Zoos and Aquariums, whose mission is that of favoring cooperation inside the Italian zoo and aquaria community, to promote their capacity of animal management and education, scientific research, and global biodiversity

conservation. The primary aim is to complement the extensive reforestation efforts in the degraded areas of the Maromizaha forest with a more specialized habitat restoration focused on plant species belonging to the bamboo family, a crucial resource for the species *Hapalemur griseus* and *Prolemur simus.*

The project was born to act towards the loss of forest ecosystems, due to agricultural practices such as slash and burn (tavy) and illegal wood cutting.

The main intent of the project is to combine extensive reforestation of degraded areas within the Maromizaha Forest with more specialized habitat restoration work focused on plant species belonging to the bamboo family, a key resource for the Lemur species living in those areas.

The Volohasy project aims to establish a pilot site where the criteria for sustainable forest resource management can be applied according to national and international standards. The participation of the local population is a key strength of this project.

Since the beginning of the project in 2021, it has been possible to reforest a two-hectare degraded area and monitoring of the bamboo lemur (Hapalemur griseus) has been conducted, which has confirmed its colonization in the area. After this success, the aim of the project is now to continue with the reforestation of degraded areas, adjacent to the regenerated one.

2.4.2 Madagascar Conservation Project – Parco Natura Viva

One of Italy's biggest and most important zoological parks, Parco Natura Viva in Bussolengo, Verona, has contributed to the conservation of lemur species through the Madagascar Conservation Project. This ex-situ project is a good example of how zoological parks actively contribute to protecting endangered species and the affected environments that they inhabit.

Since 2000 Parco Natura Viva has collaborated with the Department of Life Sciences and Systems Biology of the University of Turin in Madagascar carrying out initiatives dedicated to protecting Madagascar's biodiversity and improving the education of local communities. Education, as mentioned in Chapter 1, is indeed one of the main goals of zoological parks, involving both visitors and communities to sensibilize species conservation and habitat protection.

The plan for preserving Madagascar's endemic species through this project involves several key actions. These include participating in European ex-situ conservation programs to protect species outside their natural habitat and conducting in-situ activities within Madagascar to study endangered species and preserve forest biodiversity. Additionally, the plan focuses on educating and involving local communities in conservation efforts and collaborating with Parco Natura Viva

Zoo on research complementary to tropical studies. Another important aspect is promoting biodiversity conservation through public awareness campaigns, gaining support from qualified partners, and developing sustainable tourism that enhances understanding of the rainforest and local culture *(Source: Parco Natura Viva official website).*

2.5 A conservation paradox: The mismatch between current species representation and ex-situ conservation (Reimes et al., 2021).

Although Zoological Park's efforts in lemur care, welfare, and conservation, most of the time these facilities do not *fully* represent those species that are critically endangered, but rather those that are commonly found in other institutions and more 'known' by the public and visitors.

A recent study on the analysis of the current situation of lemur ex-situ population composition in Europe suggests that there is a bias in the lemur species that are currently represented in zoological parks.

Indeed, lemurs are popular zoo animals and are housed in hundreds of zoos outside of Madagascar. But are all captive lemur populations integrated into ex-situ conservation efforts? Are lemur species in zoos chosen because of their conservation value, or because of their popular appeal?

Results of a study by Reimes et al. show that some species (such as Lemur *catta* and *Varecia variegata*) are over-represented in zoos, while some species-rich genera are poorly represented (*Microcebus*) or not represented at all (*Lepilemur*).

A total of 15 species are currently bred under collaborative European ex-situ programs. The study shows that there is no link between the severity of IUCN status and species present in zoos, and endangered or critically endangered species are not more likely to be found in captivity. These results suggest that species in EAZA zoos have predominantly been chosen due to their appeal to the public and ease of husbandry.

Correcting the disparity between the species of lemurs currently housed by the EAZA and those that are conservation priorities would enhance the representation of endangered lemur biodiversity under ex-situ management.

The study found that the representation of lemur species in EAZA zoos is uneven with regards to taxonomy (genus), body mass and diet, with some categories being more widely represented than

others, and IUCN threat status does not play a role in which species are currently represented in zoos.

There are biological traits that influence current representation in zoos as well, these being the body mass and diet of the species: it has been shown by Reimes et al. that species with larger body mass are overrepresented in zoos.

In terms of diet, frugivorous lemur species are found in zoos at higher numbers than expected by chance. The diet is likely to affect the chances of sustaining an ex-situ population. Species with narrow dietary requirements are more difficult to keep in a captive environment.

Currently, many of the most threatened lemur species are not kept in captivity, neither in Madagascar nor in zoos belonging to any of the major zoo associations. There is an increasing number of highly endangered lemur species for which captive assurance colonies, with the potential for future population reinforcement or reintroduction, could play a role in their conservation. (Schwitzer et al., 2013*).*

A total of 87 species of lemurs are currently absent from EAZA zoos, including 40 endangered and 24 critically endangered species that are of high conservation priority (IUCN 2021).

There may be several reasons for this: threatened lemur species may be more difficult to breed and manage in captivity, possibly due to lack of knowledge of the species; captive programs are costly, and funding is often limited, or highly threatened species may possibly be less attractive to the zoo public.

As visible from the graph, the percentage of lemur species per genus currently held in captivity is unequal.

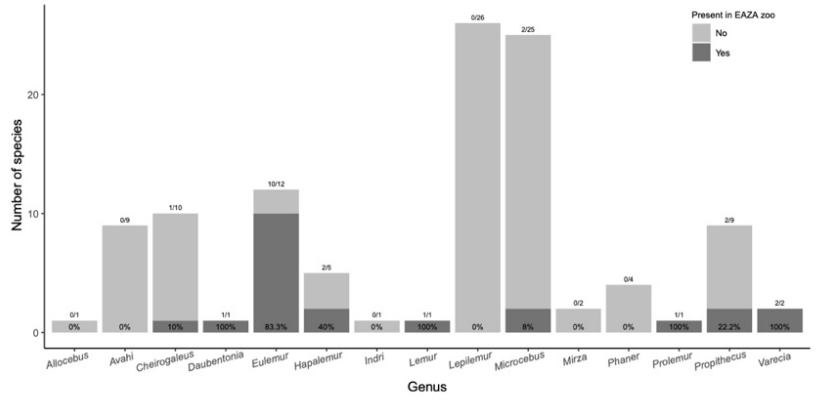


Fig. 1: Number and percentage of species of lemurs held in EAZA institutions as of July 2021. Numbers above the bars represent number of species in captivity/ total number of species in the genus. Percentage numbers shown on bars represent percentage of species present in EAZA zoos for each genus (July 2021).

Credit: Reimes et al., 2021

To conclude, although Zoological Parks have been committed to the protection and conservation of these species, some are still not part of any conservation project nor housed in any EAZA-accredited zoo, although critically endangered in the wild; this should be taken into consideration in future project and conservation initiatives focused on these primate species.

3. LEMUR BIOLOGY AND ECOLOGY

A comprehensive understanding of the biology of animals kept in captivity is essential. When working in zoological parks, sanctuaries, or similar facilities, it is important to provide the best care and meet all the needs of the animals, and this is possible only if the staff has deep knowledge of the biology of the animal, on its nutritional and behavioral needs, and how it would live in wild contexts. This knowledge is crucial for ensuring the animals' quality of life, appreciating their ecological importance, and addressing conservation challenges.

Lemurs are primates endemic to the Isle of Madagascar, where they have evolved in isolation. They are part of the primate suborder Strepsirrhini, which also includes lorises and galagos. This group diverged from other primates early in primate evolution, leading to distinctive biological and behavioral traits.

3.2 Taxonomy and lemur diversity

A basic knowledge of the taxonomy, diversity, and anatomy of lemur species is essential for their conservation and care.

The living primates of Madagascar comprise 5 families: *Cheirogaleidae, Lemuridae, Lepilemuridae, Indriidae,* and *Daubentoniidae*.

3.2.1 Family *Cheirogaleidae*; This family includes 5 genera: *Microcebus, Mirza, Allocebus, Cheirogaleus,* and *Phaner*. All move quadrupedally, and most have elongated bodies and short legs. They sleep during the day in small nests of dead leaves or holes in trees; some undergo prolonged periods of seasonal torpor (Mittermeier et al., 2008).

***3.2.1.1 Allocebus*:** hairy-eared dwarf lemur. *Allocebus* contains the single species *A. trichotis*, a tiny nocturnal dwarf lemur that closely resembles mouse lemurs (*Microcebus*) in size and color, but easily distinguished by the wavy hair on its ears (Mittermeier at al., 2008).

***3.2.1.2 Mirza*:** Dwarf lemur or giant mouse lemur. Dwarf lemurs of the genus *Mirza* are medium-sized, omnivorous, and nocturnal. This genus includes the *Mirza coquereli* and the *mirza zaza*.
The preferred mode of locomotion is rapid quadrupedal running.

***3.2.1.3* Microcebus**: Mouse lemurs. There is a total of sixteen species of *Microcebus*; The mouse lemurs are the smallest of the Malagasy prosimians. They are nocturnal omnivores and one of the most abundant and widespread genera of lemurs.

3.2.1.4 *Cheirogaleus*: Dwarf lemurs. The dwarf lemurs are small nocturnal primates that range from 150 to 600 g (Mittermeier et al. 1994, 2006). They employ quadrupedal locomotion along branches at all levels of the forest. As many as 7 species are now believed to occur throughout Madagascar, but the number will undoubtedly change as soon as the distributions are better defined. Indeed, at this time, it is fair to say that the taxonomy of the genus is by far the most confused of all 15 lemur genera.

3.2.1.5 *Phaner*: fork-marked lemurs**.** These nocturnal cheirogaleid lemurs are very vocal and display a characteristic locomotion, running rapidly along horizontal tree branches and jumping from one to the next without pausing.

3.2.2 Family Lepilemuridae

3.2.2.1 *Lepilemur.* Sportive or weasel lemurs. *Lepilemur* is a genus of medium-sized, nocturnal lemurs. They usually weigh less than 1 kg, with long lower limbs compared to their trunk and forelimbs.

3.2.3 Family Lemuridae

The *Lemuridae* family contains 5 living genera: *lemur*, *eulemur* (which comprehends most of the species that are more commonly found in zoological parks), *varecia, hapalemur* and *prolemur*.

3.2.3.1 *Hapalemur*: Bamboo or gentle lemurs. There are 5 species of *Hapalemur.* All are medium to small, have moderately long hind limbs. All have relatively blunt faces with short muzzles. Coloration is essentially gray (Mittermeier et al., 1994).

3.2.3.2 *Prolemur*: Greater bamboo lemur (*Prolemur simus*). *Prolemur simus* is much larger than any member of *Hapalemur*, although it is similarly colored.

3.2.3.3 *Lemur*: Ring-tailed lemur (*lemur catta*). *Lemur catta* is the only surviving semiterrestrial, diurnal lemur in Madagascar.

3.2.3.4 *Eulemur*: true lemurs. Eulemurs include the species *fulvus* (with 6-7 subspecies), *macaco* (with 2 subspecies), *coronatus, rubriventer*, and *mongoz*. All Eulemur species are medium-sized (body mass 1.2–2.5 kg), largely employ quadrupedal locomotion, and have cathemeral activity patterns. Except for *Eulemur fulvus*, all also exhibit sexual dichromatism (Mittermeier et al. 1994). *Eulemur* spp. occur in almost all forested areas of Madagascar except for the spiny forests of the extreme south.

3.2.3.5 *Varecia*: ruffed lemurs. *Varecia* includes the largest of the living quadrupedal lemurs. They are recognized by their striking coloration, luxuriant pelage, long faces, and raucous, loud calls. They inhabit the rainforests of eastern Madagascar.

3.2.4 Family *Indriidae*: *Indriidae* contains 3 subfamilies: *Archaeolemurinae*, *Palaeopropithecinae*, and *Indriinae*. The first 2 contain only extinct taxa, while the *Indriinae* contains 3 living genera: *Avahi*, *Indri*, and *Propithecus*.

3.2.4.1 Avhani: Avhani or Woolly lemur. Avhani contains the only nocturnal members of the family Indriidae. Avahis are small, with masses usually less than1 kg. Prominent white patches on the backs of the thighs contrast with the generally brown coloration and serve as distinguishing field marks.

3.2.4.2 *Propithecus*: Sifakas and Simponas

All the sifakas are diurnal, large and long-tailed, and have very long hind limbs

relative to the trunk and forelimbs. They move by leaping between vertical supports, propelled by their powerful hind limbs. On the ground, they bound along on their hind limbs in an upright position.

3.2.4.3 *Indri*: Indri (*indri indri*). There is only a single species of Indri, which is the largest of the living lemurs, with an adult body mass averaging 6–7 kg (reaching no more than 9 kg) and a head-body length of 60 cm or slightly more. In addition to their large size, diurnal Indri indris are distinguished from all other lemurs by having vestigial tails.

The extent and pattern of the black-and-white coloration may vary(Mittermeier et al. 1994, 2006).

3.2.4 Family Daubentoniidae. Daubentoniidae has only one living species, *Daubentonia madagascariensis,* the aye-aye. It is separated from all the other lemurs by its highly specialized dentition, including ever-growing incisors; they possess exceptionally large ears; and an elongated middle digit on both hands. *Daubentonia madagascariensis* is a medium-sized lemur, with a head-body length of ca. 40 cm, a slightly longer tail, and a mass of ca. 3 kg. It is covered in long, coarse, white-tipped black fur (Mittermeier et al., 2008).

3.3 Nutrition and Feeding Ecology

The great taxonomic, anatomic, and physiologic variety of lemur species suggests diverse diets and nutrition ecology. The latter encompasses their dietary habits, foraging strategies, and how these behaviors can impact on the ecosystems.

These primates are also capable of producing their own vitamin C, thus in the wild they will not consume any food that contains it (Jung et al., 2009).

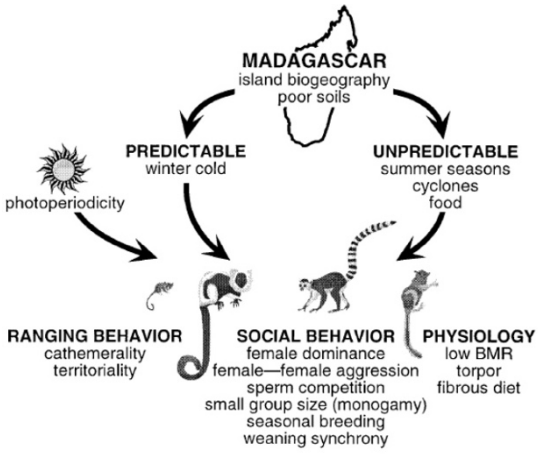
Lemurs exhibit a wide range of dietary preferences. Most species are frugivores and folivores, feeding mainly on fruits, which are high in sugar thus being an essential energy input, and leaves which provide fiber and protein. Examples of frugivore species are the black and white ruffed lemur, which has been observed feeding on fruits for 92% of feeding records (Briutt et al., 2000), and the red ruffed lemur. Being frugivore species, these animals also have an important ecological role: they act as seed dispersers, aiding in plant reproduction and forest regeneration.

some other species, such as the Mouse Lemurs (*Microcebus*) feed on insects and other small invertebrates.

Generally, some other lemur species exhibit a more variable and flexible diet, made by a combination of fruits, leaves, flowers, and small invertebrates, adapting to seasonal variations and food availability, making them versatile feeders.

3.4 BEHAVIOUR

An animal's behavior is a key indicator of welfare and a critical tool to inform husbandry decisions. Understanding the behavior of animals in captivity is crucial for identifying signs of potential discomfort, stress, or abnormal behavior, all of which are indicators of poor welfare. Behavior is widely acknowledged as a key indicator of an animal's overall health and well-being and has been effectively utilized for this purpose for many years. To understand whether behaviors exhibited by animals in captivity indicate health or stress, it's important to have a good understanding and knowledge of the behavior of these animals would exhibit in the wild.



How the environment influences lemur behavior; Credit: Wright, 1999

As lemur species exhibit significant morphological
variations, their behavior also varies depending on the species. However, some behavioral patterns are shared among these prosimians.

Distinctions in diet, social structures, activity patterns, movement, communication, predator avoidance strategies, reproductive patterns, and intelligence levels help to categorize different types of lemurs and differentiate individual species from one another.

3.4.1 Allogrooming

Lemurs engage in social grooming, *allogrooming*, to reduce tension and strengthen social bonds. Grooming occurs during greetings, upon waking up, before settling down for sleep, between mother and infant, in juvenile interactions, and response to sexual advances. All lemur species except Aye-ayes have a special "toothcomb" structure in their bottom teeth, which they use for grooming themselves and other individuals. Thus, grooming is an instinctive social behavior that is not just hygienic but also strengthens the social bonds within the group. (Duke Lemur Centre).

Lemurs, which have less manual dexterity compared to other primate species and apes, use an oral grooming technique based upon the use of the toothcomb and tongue (Barton et al., 1987).

3.4.2 Communication

Lemurs communicate through sound, sight, and smell. They use a variety of vocalizations, body language, and scent marking, as the ring-tailed lemur.

In mammals, olfactory communication plays an essential role in territorial and mating dynamics. Scent depositions in various species, including lemurs, can be placed via marking or overmarking (marking over previous depositions). (Miaretosa et al., 2022).

Scent marking is widely used among primates, and diurnal social lemurs have been showing different deployment modalities as part of their strategy to increase signal detection. Scent marking consists of the deposition of body odor in different substrates and objects within the home range (Miaretosa et al., 2022).

Lemurs are vocal animals: Indris *(indri indri*) are the best example of how vocalization is important for these animals, characterized by their ‘singing’ behavior. The function of an indri group’s song is complex and varies according to the location and identity of animals’ hearing (Pollock, J.I. et al., 1986).

Mongoose lemurs (*Eulemur mongoz*) are another great example of the vocal repertoire and phonation mechanism of these animals. Their repertoire includes four loud vocalizations likely to play a role in long-distance communication for regrouping or alerting the group to possible danger (B. Nadhurou, et al., 2015).

Additionally, some of the most common calls among lemurs are predator alarm calls. Lemurs not only respond to alarm calls of their species but also to alarm calls of other species and those of non-predatory birds. The ring-tailed lemur and a few other species have different calls and reactions to specific types of predators. Lemur calls can also be particularly loud and carry long distances. Ruffed lemur's vocal repertoire is extensive as part of and contains several loud calls audible at distances up to km when not dampened by wind or rain (Knapp et al., 2006).

3.4.3 Social organization and structure:

Most lemur species are social, living in groups of 15-20 individuals. Ring-tailed lemurs, for example, live in multi-female resident groups that usually contain 10 to 20 individuals.

In the wild, lemurs live in complex and diverse social groups, rely on olfactory communication, and have diverse vocal communication. They also sunbathe for thermoregulation and possess diverse diets and feeding strategies.

Most Malagasy lemur species organize their societies with adult females dominant over all males (Richard, 1987). Female lemurs are winners in aggressive interactions against males.

Lemur catta shows aggressive extremes in female dominance in multiple male-female groups (Jolly, 1966)

Nocturnal lemurs are mostly solitary, foraging alone at night but often nesting in groups during the day. An example of a nocturnal lemur species is the Gray mouse lemur (*Microcebus murinus*). They are solitary foragers, congregating at daytime sleeping sites. Aye-ayes (*Daubentonia madagascariensis*) are nocturnal species as well. (Fonte: Duke Lemur center)

Degrees of socialization vary by species, gender, location, and season. Diurnal lemurs display different social systems, similar to those found in other primates and apes, residing in relatively stable and tightly knit social groups. Black and white Ruffed lemurs have been shown to live in fission-fusion societies (Pereira M.E. et al., 1988.), and Indri live in small groups of two to six members; females are the dominant sex. These pairs live together with their offspring, maintaining exclusive territories.

Some lemurs exhibit female philopatry, where females stay within their natal range and the males migrate as they reach maturity, while in other species both sexes will eventually migrate.

Ring-tailed lemurs live in troops of up to 30 individuals. The social structure is matriarchal, with females generally dominating males. A single, top-ranking female appears to be the focal point for the rest of the troop. She often initiates the direction of group progressions (Sauther, Sussman, 1993).

A notable feature in many lemur species is female dominance, where females have priority access to food and other resources, a trait seen in species such as the ring-tailed lemur and the brown lemur (*Eulemur fulvus*).

3.4.4 Predator avoidance

The antipredator strategies of primates generally rely on the early detection and warning of approaching predators through specific vocalizations and calls. Lemur species, being either diurnal or nocturnal have been using specific strategies to better cope in different contexts.

Antipredator behaviors can be broadly classified as strategies that reduce the risk of detection by predators (precautions) and strategies that take effect when potential prey detects a predator. The first strategy includes avoiding places where predators are, and/or being vigilant against them. Once a predator has been detected, animals can respond in several ways.
They give alarm calls, flee, or seek confrontation with the predator.

Red-tailed sportive lemurs (*Lepilemur ruficaudatus*) are a nocturnal species that, as an example, in response to the calls of the Harrier hawk, remained stationary and scanned the sky. After hearing sportive lemur barks, individuals showed the strongest response. They fled or climbed up, scanned the ground, and
increased their scan rate, indicating that they associate a potential danger with these calls (Fichtel, C. 2007).

Another species of interest, regarding the anti-predator behavior, is the ring-tailed lemur (*lemur catta*). Ring-tailed lemurs are diurnal, social animals; they exhibit a large repertoire of anti-predator behaviors, which include both vocal signals and behavioral responses such as mobbing and vigilance. Ring-tailed lemurs engage in “representational signaling,” that is, they emit particular vocalizations

for particular kinds of predators. Predator vigilance occurs when a ring-tailed lemur ceases the activity in which it is engaged and starts to scan the environment surrounding them (Gould, L., Sauther, M.L.; 2007*).*

3.5 The ecological role of lemur

Lemur species play a very important ecological role in Madagascar's forests, serving a wide variety of ecological roles from seed dispersal and pollination to maintaining forest structure. Seed dispersal by lemurs might be an important contribution to the restoration of ecosystems; thus their decline has detrimental effects on the environment.

A study by Steffens et al. (2022) focused on the important ecological role of lemur species as pollinators and seed dispersers: this of course has an extremely important impact on the ecosystem in which they live, making them essential species for the dispersal of pollen and Seeds and contributing to the health and stability of Malagasy ecosystem.

Thus, apart from playing an important role in maintaining diverse forest ecosystems in Madagascar, seed dispersal by lemurs may diversify restoration plantings. Yet, when planting species to attract lemurs to restoration sites, negative effects like the spread of invasive and potentially harmful species must be considered as well (Steffens et al., 2022).

4. HUSBANDRY GUIDELINES FOR CAPTIVE LEMUR SPECIES

Caring for captive specimens by providing the best quality of life is a primary focus of zoological parks and similar establishments. This chapter will outline the essential considerations for the care and welfare of captive lemur species.

By meeting the animals' needs and providing exceptional care, it is possible to maintain a healthy captive population, conduct valuable research and behavioral studies, and establish breeding programs to conserve the species and preserve genetic diversity.

When considering the animals' housing and enclosures, ensuring that the environment is spacious enough to allow for freedom of movement, exploration, and exercise is crucial. The exhibit should also provide areas for the animals to retreat from visitors, rest undisturbed, and have access to an off-show area for direct interaction with keepers as needed, for veterinary visits and health checkups, as well as enrichment and training programs.

Care of these species should prioritize also their behavioral needs.

The ultimate objective is to provide the best care and ensure their welfare, rather than just meeting the basic standards and requirements.

4.1 Dietary management and nutrition

In Zoological Parks, one of the most important aspects to consider when taking care of the different species housed is to provide the right diet and ensure that all the nutritional requirements of the animals are met, by carefully formulating feed rations and by making nutritional analysis when possible. Captive diets should be palatable, practical, and economical to feed.

The formulation of a diet should address the animals' nutritional needs, feeding ecology, and individual and natural histories to stimulate species-specific feeding patterns and behaviors.

Implementing feeding enrichment and offering a natural diet can effectively promote natural behaviors, encourage a daily activity routine similar to those in the wild, and prevent boredom and physiological imbalances. An environment that provides natural foraging opportunities can also contribute to the welfare of animals.

By possessing adequate knowledge of the dietary requirements, lemur species have been successfully housed in zoos for many decades (Zoo and Aquarium Association Australasia).

Care should be taken when utilizing domestically harvested fruit products in lemur diets. domesticated fruits carry the potential to contribute to obesity and diabetes (Schwitzer et al., 2008), as obesity is a prevalent health issue among captive animals in zoological parks.

For what concerns lemur species, it is important to consider their feeding category: as mentioned in Chapter 3, lemurs are mainly frugivorous and florivorous.

In general, lemur species kept in zoological institutions select diets that are rich in leaves and fruits. Lemurs are generally folivores and frugivores, some also exhibit an omnivore diet consisting of small invertebrates as well, but their specific diets will naturally change among different species.

It is important to provide at least as many feeding sites as possible as there are group members, to reduce potential food competition and aggression.

Important is to consider all the medical issues linked to incorrect diets, these being obesity, diabetes, and hemosiderosis (this will be devolved into in the following paragraphs).

Feed should be provided early in the day in multiple locations within the enclosure, to promote foraging. When possible, the scattering of food may help to reduce or prevent dominant animals from monopolizing a particular feeding position.

The diet should be presented in such a way as to promote foraging activity and manipulation for weight management and behavioral enrichment: this can be done by varying the daily presentation of supplementary feed items, utilizing different feed locations, and the use of scatter feeding. Some species may also prefer arboreal feeding stations.
Enrichment items, browse and food chopped into different sizes are all techniques used to present food items.

4.1.1 An example of the Zoo Diet of Ring-tailed lemurs *(Lemur catta)*

Ring-tailed lemurs, one of the most common lemur species found in zoos, consume a wide variety of plants, although there is significant variation in dietary items depending on the seasonal availability and habitat. Some individuals have been observed feeding on ripe and unripe fruit, leaves, and flowers, invertebrates (Mowry et al., 2001). In an enclosure, there could be diverse feeding sites, or enrichment items such as puzzle feeders, and food in ice blocks, to encourage proactive foraging and feeding.
The ideal weight range, for ring-tailed lemurs, is between 2.2 – 2.7 kg (*Duke Lemur Centre*). The food offered to *Lemur catta* in captive contexts consists of fruit, starchy vegetables, leafy greens, and vegetables. These are in general offered daily. Year-round available fruits are most often offered. Starchy vegetables include sweet potatoes, turnips, potatoes, and corn; greens include kale, cabbage, and lettuce. Other vegetables include broccoli, celery, cucumbers, and green beans. Animals are fed either once or twice daily (Mowry, C.B. and J.L. Campbel; 2001).

4.2 Housing Requirements and General Husbandry

Housing and husbandry regimes must meet the needs of many stakeholders as the animals themselves, their keepers, and the visitors. Careful considerations should be given to exhibit design so that all areas meet the physical, social, behavioral, and psychological needs of the species.
Basic housing requirements include climate control, provision of food and water, and ensuring the safety of the animals housed and the staff working with them.

Many aspects need to be considered when designing an enclosure or introducing a new individual to it: the animals' needs, the age group, the size, and social organization, their behavior, and if there have been episodes of aggression between the individuals already housed.

For what concerns lemur species specifically, studies and even some guidelines have been published on housing requirements and needs.

Most lemur species are social animals; it is important to keep an adequately large group of individuals: appropriate social housing can be a good source of dynamic and social enrichment.

The enclosures must guarantee protection from the weather and any other adverse environmental conditions.

Lemurs housed in outdoor exhibits should be maintained in temperatures similar to those found in Madagascar: when below 18°C, heat sources should be provided. If temperatures fall below 9°C, the animals should be housed indoors only. Different artificial heat sources can be used, including brooders, heat lamps, heat mats, or additional bedding.

Drinking water and eventual pools and moats must be maintained so they remain free of contamination by feces, urine, food, and cleaning agents.

For keeper hygiene, it is recommended to wear gloves and boots when entering the lemur enclosures, as these species could carry bacteria and other pathogens that may be ingested by any person who touches fecal deposits, and these pathogens may be harmful to humans.

4.2.1 Exhibit design and spatial requirement

When designing an exhibit and selecting different enclosure types, it is essential to ensure ample space, create an enriching environment, and enable the animals to exhibit a wide variety of natural behaviors.

Lemurs are active animals, whose anatomy has been evolved and adapted to climbing, jumping, and grasping branches so the exhibit should have space allowing adequate locomotion. Across institutions that house lemur species, a variety of climbing structures and interlocking branches have been used to create environmental complexity (Hearn et al., 1993); hammocks, ropes, and swings can be used as climbing items as well as enrichments. The AZA *Eulemur* spp Care Manual recommends that the exhibit size for lemur species should be based on the size of the group, the complexity of the enclosure, the behavioral needs of the individuals, and the number of potential non-conspecific individuals that share the enclosure.

Common types of furniture to include in lemur enclosures are horizontal platforms, horizontal bars, tree branches, hanging tires, plastic chains, and nest boxes which create environmental complexity. Whenever possible, these perching structures and branches should be changed to create variation in the environment.

All enclosures should include multiple off-exhibit holding areas to allow for olfactory and visual contact during separations. All housing should be escape-proof, because most lemur species, especially young infants and juveniles, are very good at squeezing through small spaces.

All housing should be inspected daily for all potential escape routes, such as gaps in fencing or between gates, and repaired as necessary. Care should be taken to secure the perimeter of housing so that holes cannot provide escape routes.

Water features can include flowing streams, pools, and waterfalls.

Since lemur species typically do not swim, water or wet moats are sometimes used to contain island exhibits. Water depth should be deep enough to discourage animal entry, but also allow safe entry by animal care staff when necessary.

Outdoor exhibit substrates at most AZA institutions are usually natural materials such as dirt, soil, grass, mulch, gravel, and bark. Indoor exhibits and holding areas are generally constructed of concrete for ease of cleaning, with wood chips and shavings used as substrate or sand. Other substrates, including straw, wood chips, and shredded paper can be used as bedding material.

Species	Sizes	Additional Information	Reference
All *Eulemur*	Ranges from: 1.4 m x 2 m x 3.4 m–5.8 m x 3.5 m x 5.8 m (4.7 ft x 6.7 ft x 11.1 ft–19 ft x 11.6 ft x 19 ft)	Small enclosures hold individuals, geriatric animals, and non-breeding pairs. Breeding pairs are held in larger enclosures.	
E. mongoz	4–7.5 m^3 (140.6–265.8 ft^3)	Housed and reproduced	Hearn et al., 1996
E. macaco	25 x 18 m (82 x 59.1 ft)	Island exhibit with *L. catta*	Meyer, 1982
Eulemur	0.81–10.1 hectares (2–25 acres)	Large outdoor enclosures	Terranova, 1996
E. fulvus	6 m x 4 m x 2.6 m–8 m x 2.9 m x 2.6 m (19.7 ft x 13.1 ft x 8.5 ft–26.2 ft x 9.5 ft x 8.5 ft)	Inside/outside enclosures	Roeder et al., 2002
E. macaco	1 hectare (2.5 acres)	Wooded enclosure	Roeder et al., 2002
E. mongoz	7.5–22.5 m^3 (265.8–791.5 ft^3)	Pairs or small family units, outside runs	Perry et al., 1992
E. mongoz	36 m^3 (1270 ft^3)	Pairs or small family units, rooms that were inside	Perry et al., 1992

Table showing examples of exhibit sizes related to the species held. Credit: Eulemur spp. Care Manual (AZA)

Important is to provide, as mentioned, a 'rest' area, a calm and quiet environment where the animals can hide, rest or sleep. Usually, these areas can be accessed from elevated surfaces, out of the visitors' sight.

It is not uncommon to have mixed species exhibits. Ring-tailed lemurs, for example, have been housed with either brown lemurs, black and white lemurs, and red ruffed lemurs. Single-sex mixed exhibits appear generally more viable with less potential for territorial and resource disputes occurring (Taylor K., 2009).

4.3 Enrichment

Environmental enrichment refers to the practice of providing a variety of stimuli to the animals' environment or changing it to increase physical activity, stimulate cognition, and promote natural behaviors.

An enrichment can be considered a change in an animal's life or environment that confers benefits beyond those necessary to fulfill their basic needs and should consider the natural history of the individual, its needs, and potential facility constraints.

The enrichment programs should be integrated with veterinary care, nutrition, and animal training programs to maximize the effectiveness and quality of animal care provided (AZA Accreditation Standard 1.6.2).

There are different types of enrichment, each having its function**:**

1. Sensory enrichment will stimulate any of the five senses of the animals. In lemur species, examples of sensory enrichment can be olfactory, by using scents of other conspecifics or any biologically relevant scent.
2. Cognitive enrichment: this type of enrichment is described as cognitive and mental stimulation that requires problem-solving of different levels of complexity. These could be sorts of puzzle boxes, or cardboard tubes.
3. Physical enrichment encompasses an alteration of the physical elements of the enclosure, whose purpose is mainly to stimulate exploratory behaviors. It can be done through the placement of suspended platforms, branches,
4. Social enrichment consists in the social interaction with conspecifics, or with other species as in the case of mixed species exhibits.
5. Food-based enrichment aims at the stimulation of foraging and feeding behaviors that resemble their natural feeding behavior in a wild context.

Items should be chosen to stimulate the animal to engage in natural behaviors, such as locomotion through trees, and branches, scent marking exhibit items and enrichment pieces, and investigation and foraging behaviors.

The effect of enrichment may depend on the enclosure in which it was provided. Enclosure type

Enrichment initiative	Description
Boxes	String/tape removed
Bags	String/tape removed
Blocks	Colorful children's blocks, especially ones that rattle
Crates	Soft-sided dog crates- hang them up with bungee cords with the "door" open, may fill with shredded paper, hay, etc.
Hammocks	Carpet pieces, blankets, old nets, t-shirts
Logs	Put in with one troop for a day then move over to a second troop
Puzzle feeders	Can be as simple as holes drilled in a log for food to be stuffed in, hang log with an eye hook for increased difficulty, or fairly simple PVC ones with no more than one sliding piece to block a few holes
Ferret log	-
Sit 'n spin	This is a homemade device that spins when an animal jumps on it like a Ferris wheel, so they have to be pretty agile to get to the food item
Kongs® on a rope	-
Scents/spices	-
Grape vine balls	-
Formed "bird nests"	From craft stores as feeders
Swinging items	-
Milk crates	Hang several along a rope, they like to sit in them
Firehose triangle swings	-
Hay	-
Woodwool	-

Examples of enrichment; Credit: AZA Prosimian Taxon Advisory Group (2013)

may have a bigger impact on the behavior of the lemurs, where activity levels increased in the outdoor enclosure while self-directed behaviors decreased. Access to outdoor enclosures, and the accompanying environmental complexity, contributes to the welfare of ring-tailed lemurs (Laméris et al., 2021).

4.4 Common health issues of captive lemur species

Advances in the health care available to exotic animals in zoos and a better understanding of animals' nutritional requirements are largely responsible for the decline in mortality rates seen in zoos.

Husbandry plays a crucial role in maintaining the physical health of animals. Keeping the animals healthy requires regular monitoring by experienced staff members such as keepers and veterinarians who are familiar with the animals under their care.

Good preventive medicine, including pest control, hygiene, quarantine, and vaccination is an extremely important part of zoo animal health care.

In captive contexts, it is essential to consider any potential health issues that animals may face and follow the appropriate health guidelines, along with veterinary knowledge and the support of qualified veterinarians. Animal keepers working with lemur species should be trained to recognize specific welfare problems, such as abnormal behaviors or health concerns.

Health screening and preventive medicine of captive lemurs should consider regular fecal parasite screening, regular vaccination, regular physical examination, and regular tuberculosis screening

(Zoo Aquarium Association Australasia, ABN 71 836 556 156, 2014; 13.1 Guideline – Veterinary and health management of lemurs in captivity, 2014).

Common health concerns, on specie as the ring-tailed lemur (*lemur catta*) and the ruffed lemur (*varecia rubra*), include:

Gastrointestinal parasitism is quite common among captive lemurs. Bacteria isolated from fecal cultures from lemurs with evidence of gastrointestinal diseases included *Yersinia enterocolitica*, *Campylobacter fetus jejuni*, *Salmonella typhimurium*, *E. coli*, and *Klebsiella pneumoniae*. The presence of these is associated with symptoms such as diarrhea, thus attention must be given to the prevention of dehydration, electrolyte imbalances, and secondary systemic bacterial infections.

Additionally, dental diseases can occur as well. Common are plaque and tartar accumulation; tooth root and abscesses have been reported.

Regarding the respiratory system, bacterial pneumonia can occur, especially under stressful conditions or when exposed to drastic environmental changes. Clinical signs include fever, inappetence, and troubled breathing.

Hemosiderosis, which is an increase in iron storage in tissues, has historically been considered a common problem for zoo-housed lemur species; this condition is thought to be the result of the combination of excess dietary iron, easily absorbed forms of iron in the diet, and lack of tannins or other iron-binding ingredients in the managed diet. (Randall, Junge; 1997)

Recently, there have been reports on toxoplasmosis outbreaks in captive lemurs in Italian zoological parks. The first outbreak of diffuse and fatal toxoplasmosis in captive ring-tailed lemurs in Italy has been reported. The findings of a study by Rocchigiani et al., 2022, confirm the high susceptibility of this species to the protozoa and the importance of control measures in facilities housing captive animals.

For risk management in zoos, the application of appropriate distances between all sensitive primate species and possible sources of infection, such as felines, as well as disinfection of their food, is recommended (Dubey et al., 2021). In case of a toxoplasmosis outbreak, the lemur area must be separated from the park paths with fences, to prevent direct contact with the outside, especially with stray cats.

Obesity poses a persistent health concern for lemurs and many other captive species. This issue often arises from the selective consumption of preferred food items by dominant individuals within the group, from being fed cultivated fruits and vegetables that are high in sugar and low in fiber, or due to overfeeding and lack of exercise which can be due to small enclosure size or absence of enrichment.

A study by Goodchild et al. (2008) addresses the issue of obesity of captive lemurs, as it is quite common to see overweight or even obese individuals in captive contexts.

There are many health implications linked to obesity: it can lead to coronary heart disease and diabetes, and the animal can also become lethargic and inactive. Additionally, obesity can also cause problems when it comes to breeding: if the female is obese, she may not cycle properly and hence fail to breed.

It's important to note that the lifestyle of lemurs in their natural habitat differs significantly from those living in captivity, and this contrast extends to their diets. The fruits they consume in the wild generally have lower energy content compared to cultivated fruits and are typically seasonal rather than available year-round.

It is important to consider that lemurs have a relatively low basal metabolic rate, so it must be considered when re-assessing diets. Animals should be weighed regularly to monitor any weight gain or loss.

4.4.1 Body Condition Score

Body condition score, or BCS is a quantitative, yet subjective, method for evaluating body fat of animals. It is commonly used in zoological facilities to evaluate the physical health of the animal and its weight. Two BCS scales are utilized, one ranging from 1-5 and the other from 1-9, 1 being extremely underweight, and 5 or 9 being obese.

Fig. 2. Body condition scores for BMSR *L. catta*. 1.5 = Reduced body condition; 2 = moderate body condition; 2.5 = slightly high body condition; 3 = high body condition.

Credit: Millette et al., 2015

In lemurs, coat and body mass status provide a potential noninvasive way to assess the health status as well as the effects of seasonality, resource use, and reproductive state. (Millette et al., 2015).

4.5 Captive Breeding and Newborn Management

Captive breeding programs as a conservation strategy have been part of modern zoo missions, specifically concerning species conservation and captive population management.

Most conservation programs aim to establish self-sustaining populations; scientifically managed captive breeding programs can offer some protection against extinction for endangered species, such as most lemur species. Ideally, these programs should begin with enough founder members to maintain the existing genetic variation of the species. Genetic and demographic management can help maintain small but healthy populations over time, ensuring that individuals are available for reintroduction if the species becomes extinct in the wild.

The network of AZA (Association of Zoos and Aquaria)-accredited institutions work to develop and adhere to Species Survival Plans, which use carefully planned conservation breeding programs to create a genetic safety net for endangered species.

Infant survival in both in situ and ex-situ populations can be influenced by several infant-parent and environmental-related factors. Parental neglect, infection, and trauma are common causes of poor survival in both settings (Delaski et al., 2015). In the wild, *Eulemur* infant birth weights, dam milk quality and age at first birth, and interbirth interval may vary based on environmental and social conditions (Wright, 1999). Fortunately, some factors affecting wild populations, are less likely to affect *lemur* populations under human care; lemur dams under human care tend to begin breeding at a younger age, have shorter interbirth intervals, and produce heavier infants compared to their wild counterparts (Wright, 1999).

Newborn primates are altricial, meaning that they are unable to feed or move independently, and parental care in these species can also impact infant survival.

4.5.1 Medical management of neonates

Taking care of newborns is a delicate and challenging task. By following specific guidelines and through the right knowledge, it is possible to successfully raise them and ensure

The average size of newborn lemurs varies between species but generally ranges between 55 and 105 grams. If possible, infant weight should be taken 12-24 hours after birth using a gram scale (Brockman et al., 1987). Weaning is approximately after 3 to 5 months since birth.

Eulemur infant mortality is highest in the first 72 hours after birth. Careful observations of an infant's behavior and accurate daily weights are the best measure of health status. If possible, weigh the newborn on the day of birth, then twice weekly until the infant is 1 month old, then weekly until weaned.

Droopy eyelids, infrequent or weak vocalizations, hypothermia (body temperature less than 35.5 °C), and weak grip are all signs of health concerns (Gage, 2002).

A common problem in neonates is the failure to begin nursing after birth. Infants normally begin nursing within a few hours of birth and those that do not nurse during the first 8-12 hours lose strength rapidly. They may cling in abnormal positions such as to the mother's leg, arm, or back. Once the infant's strength wanes, its head begins to drop, and the grip becomes weak until it falls off the mother.

Infants may not nurse for several reasons, including neonatal weakness, which can be due to premature or traumatic birth; inability to initiate nursing because of irregular maternal anatomy (e.g., maternal obesity, or inverted or small nipples), inability to nurse often enough; agitated females move frequently thereby preventing infants from suckling for sufficient amounts of time and maternal neglect: maternal factors predisposing toward neglect include illness, first-time birth, increased agitation, and hypothermia or generalized weakness.

If hand-rearing or any other form of assisted rearing is required, it is recommended to house individual infants to prevent them from suckling on each other. The goal of hand rearing is to save vulnerable newborns and infants who cannot be taken care of by their mothers. The period of rearing may include late-night feeding activities done by dedicated caretakers (Mohapatra et al., 2019).

Additionally, a soft stuffed toy or rolled towel should be provided as a surrogate for the infant to cling to. It is critical to keep the neonate warm and an incubator is generally recommended. The ambient temperature for neonates should be around 35.5 – 36.7°C (Gage, 2002).

CONCLUSION

This study focused on assessing the contributions of zoological parks in the care, welfare, and conservation of lemur species, emphasizing husbandry techniques aimed at optimizing their well-being.

Continued research and collaboration among zoos, conservation organizations, and academic institutions are essential to refine these management practices and ensure lemur species' long-term survival in captivity and their natural habitats.

In conclusion, it is essential to effectively manage captive lemur species to ensure their conservation and the sustainability of their populations. By implementing comprehensive strategies that include diet, enrichment, social structure, and habitat simulation, it is achievable to improve the well-being of captive lemurs.

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