Zoos as locations for scientific studies

Marcus Clauss

Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Switzerland
BIO354 Zoo Biology 2019
Why do research with zoo animals?

- interest in zoo-specific questions

- interest in an animal species that cannot be attained somewhere else
What kind of research is of interest?

Conservation of biodiversity is set as a main driver.

Developing the research potential of zoos and aquaria

The EAZA Research Strategy
When considering the ethics of acquiring animals which may be subject to research there are issues concerning purpose and value, i.e. what serves the ‘greater good’ in conservation and/or welfare terms?

Developing the research potential of zoos and aquaria

The EAZA Research Strategy
What kind of research is of interest?

The European Council Directive 1999/22/EC relating to the keeping of wild animals in zoos (the EU Zoos Directive)

The Member States guarantee that all zoos will implement the following conservation measures:

- participating in research from which conservation benefits accrue to the species, and/or training in relevant conservation skills, and/or the exchange of information relating to species conservation and/or, where appropriate, captive breeding, repopulation or reintroduction of species into the wild;

The EAZA Research Strategy
What kind of research is of interest?

Identify research priorities
The scope for research is huge, and time and resources are always limited, so it is important to identify research priorities. There are several bases for this. For example:

> degree of threat, where threatened species are high priorities (e.g. IUCN www.redlist.org);
> species that are endemic to biodiversity hotspots (e.g. www.unep-wcmc.org);
> problems identified by EAZA Taxon Advisory Groups, EEP Species Committees and other EAZA Groups;
> biological issues in individual collections;
> specialities and facilities of associated university departments;
> specialities and expertise of staff.
What kind of research is of interest?

To the zoo / zoo community:
- conservation-related issues
- issues related to animal welfare (i.e., captivity)

To many students / researchers:
- anything that allows work with zoo animals
- high 'adventure' factor
- pioneer situation
- easy way to expertise position
- perception of low failure risk
- automatic justification (at first)

reproduction, diseases (diagnostics and intervention), management, biological characteristics, enrichment, nutrition
To the zoo / zoo community

- conservation-related issues
- issues related to animal welfare (i.e., captivity)

To many students / researchers

- anything that allows work with zoo animals

**XYZ is a highly endangered species ...**

... more knowledge is essential for the management of this endangered species ...
Counting the books while the library burns: why conservation monitoring programs need a plan for action

David B Lindenmayer\textsuperscript{1a}, Maxine P Piggott\textsuperscript{1}, and Brendan A Wintle\textsuperscript{2}

Conservation monitoring programs are critical for identifying many elements of species ecology and for detecting changes in populations. However, without articulating how monitoring information will trigger relevant conservation actions, programs that monitor species until they become extinct are at odds with the primary goal of conservation: avoiding biodiversity loss. Here, we outline cases in which species were monitored until they suffered local, regional, or global extinction in the absence of a preplanned intervention program, and contend that conservation monitoring programs should be embedded within a management plan and characterized by vital attributes to ensure their effectiveness. These attributes include: (1) explicit articulation of how monitoring information will inform conservation actions, (2) transparent specification of trigger points within monitoring programs at which strategic interventions will be implemented, and (3) rigorous quantification of the ability to achieve early detection of change.

What kind of research is of interest?

Assessing the *effectiveness* (or not) of specific conservation measures is a vital and challenging area of research.

Developing the research potential of zoos and aquaria

The EAZA Research Strategy
Does conservation need science … or fences, guns & education?
but if the library burns, taking stock of what will be lost is interesting in its own right

...monitoring a species to extinction might be better than letting it go into extinction without any documentation
What kind of research is of interest?

<table>
<thead>
<tr>
<th>EAZA Research Project Example</th>
<th>Breeding biology and reintroduction of amphibians</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size and scale</strong></td>
<td>Collaborative working group for breeding amphibians</td>
</tr>
<tr>
<td><strong>Collaborators</strong></td>
<td>Moscow Zoo; various research institutes</td>
</tr>
<tr>
<td><strong>Disciplines</strong></td>
<td>Natural history; in situ wildlife management</td>
</tr>
<tr>
<td><strong>Summary</strong></td>
<td>A special Working Group for breeding of endangered, exotic and problem amphibian species was established in the 1980's by scientists from Moscow Zoo, the Koltsov Institute of Developmental Biology and the State Research Centre's Institute of Biophysics. As a consequence of studying breeding biology, methods for hormone stimulation of amphibian reproduction and husbandry guidelines for all life stages have been developed. These methods made it possible to establish new wild populations of the banded newt Triturus urialarius and Eastern spadefoot toad Pelobates syriacus within their natural habitats in the Caucasian Natural Reserve and Armenia respectively. These populations are still thriving and further reintroductions within the natural range of <em>P. syriacus</em> are underway. See also Amphibian Ark Project (Glossary).</td>
</tr>
</tbody>
</table>

**Publication**

Goncharov et al. (1989)

**Illustration**

[Image of a frog]
What kind of research is of interest?

**Wider needs and benefits**
As well as underpinning practical or applied science, zoo research can make a general, perhaps major contribution to fundamental or theoretical knowledge.

Developing the research potential of zoos and aquaria

The EAZA Research Strategy
AZA believes that contemporary animal management, husbandry, veterinary care and conservation practices should be based in science, and that a commitment to scientific research, both basic and applied, is a trademark of the modern zoological park and aquarium.

Types of Research

Research investigations, whether observational, behavioral, physiological, or genetically based, should have a clear scientific purpose with the reasonable expectation that they will increase our understanding of the species being investigated and may provide results which benefit the health or welfare of animals in wild populations.
Research efforts on these topics will, in turn, typically draw on combinations of major scientific disciplines such as anatomy, anthropology, biochemistry, biogeography, bioinformatics, biotechnology, ecology, education, endocrinology, ethnology, ethology, evolution, forensics, genetics, genomics, information technology, nutrition, parasitology, pharmacology, physiology, population biology, psychology, sociology, taxonomy and veterinary medicine.

The EAZA Research Strategy
What kind of research is of interest?

Appendix VIII. Zoo research: sample serial publications

This list provides examples of printed and online serial sources of research information and potential outlets for zoo-associated research papers. It has, with kind permission, been adapted and expanded from a list in the World Zoo and Aquarium Conservation Strategy (Chapter 3) but is by no means comprehensive. Please refer to the EAZA website (www.eaza.net) for updates.

Animal Behaviour
Animal Conservation
Animal Welfare
American Zoo and Aquarium Association Conference Proceedings (Annual and Regional)
Animal Keepers Forum
Applied Animal Behaviour Science
Aquarium Sciences and Conservation
Australian Regional Association of Zoological Parks and Aquaria (ARAZPA Newsletter, website)
Bongo (Journal of the Berlin Zoo, contains scientific articles on animal husbandry and conservation)
British and Irish Association of Zoos and Aquariums (BIAZA Research Newsletter, BIAZA Research Symposium Proceedings, BIAZA Research Guidelines)
Conservation Biology
Copena (American Society of Ichthyologists and Herpetologists)
Dodo (Journal of Durrell Wildlife Conservation Trust)
European Association of Zoos and Aquariums (EAZA Research Committee Newsletter, EAZA News, EAZA Conference Proceedings, EAZA website)
International Zoo News
International Zoo Yearbook
Journal of Applied Animal Welfare Sciences
Journal of Fish Biology
Journal of Herpetology
Journal of Mammalogy
Journal of Wildlife Management
Journal of Zoo and Wildlife Medicine
Oxyn: The International Journal of Conservation
Pan African Association of Zoological Gardens, Aquaria and Botanic Gardens (PAAZAB News, website)
Ratel (publication of the Association of British Wild Animal Keepers)
Reproduction
South East Asian Zoos Association (scientific papers from conferences available on SEAZA website)
Thylacine (Australasian Society of Zoo Keeping)
Turtle and Tortoise Newsletter (Chelonian Research Foundation)
Wildlife Information Network
World Association of Zoos and Aquariums (WAZA News, WAZA Conference Proceedings and website)
Zeitschrift des Kölner Zoo (Journal of Cologne Zoo)
Zoo Biology
Der Zoologische Garten (The Zoological Garden)
Zoo Vet News (American Association of Zoo Veterinarians)

Developing the research potential of zoos and aquaria

The EAZA Research Strategy
Bureaucracy

Know the zoo organisations:
- WAZA, EAZA, AZA etc., e.g. BIAZA
- EEP / SSP – incl. their TAGs

Many zoos want to see the statement of some organisation before they will consider participating in a research project.

Many (esp. British) zoos have a bureaucratic procedure for research that is time-consuming and must be factored into any research plan.

Health & Safety
observations
Typical zoo biology: observations

Resting postures in terrestrial mammalian herbivores

Endre Pucora, Christian Schiffmann, and Marcus Clauss*
Exceptional zoo biology: very insightful observations

When elephants fall asleep: A literature review on elephant rest with case studies on elephant falling bouts, and practical solutions for zoo elephants

*Zoo Biology*. 2018;37:133–145.

Christian Schiffmann¹,² | Stefan Hoby³ | Christian Wenker³ | Therese Hård⁴ | Robert Scholz⁵ | Marcus Clauss¹ | Jean-Michel Hatt¹

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(b) ![Graph and images of elephants]
leftovers
What methods are used in zoo research?

As well as observational data, a wide variety of materials and methods may – subject to risk assessments, biosecurity and health and safety precautions – be utilised in studies of living zoological collections and associated products (e.g. tissue and blood samples, faeces, urine, bones, eggs, nests and feathers). For example, some substances such as hormones contained in faeces and urine are important in non-invasive studies of stress. All animals die eventually, and post-mortem material can be usefully studied and be deposited in museums and universities for future reference; especially material from threatened species.

Equally important are the computerised records and archives that zoos and aquaria maintain on breeding, e.g. parentage, clutch/litter size, inter-birth interval, infant survival, group composition, behaviour, medical issues etc.
SHORT COMMUNICATION

An isthmus at the caecocolical junction is an anatomical feature of domestic and wild equids

Marcus Clauss · Jürgen Hummel · Angela Schwarm · Patrick Steuer · Julia Fritz · Olga Marián Jurado · Anja Tschudin · Jean-Michel Hatt

DOI 10.1007/s10344-007-0126-y

SHORT COMMUNICATION

The macroscopic intestinal anatomy of a lowland tapir (Tapirus terrestris)

Katharina Hagen · Dennis W. H. Müller · Gudrun Wibbelt · Andreas Oehs · Jean-Michel Hatt · Marcus Clauss

DOI 10.1007/s10344-014-0870-8
experiments
Practical problems related to these approaches

As well as observational data, a wide variety of materials and methods may be subject to risk assessments, biosecurity and health and safety precautions — be utilised in studies of living zoological collections and associated products (e.g., blood samples, tissues, feathers, eggs, eggs from ursate homing pigeons, and feathers).

For example, some substances such as hormones, contained in faeces and urine are important in non-invasive studies of stress. All animals die eventually, and post-mortem material can be usefully studied and be deposited in museums and unique literature reference; especially material from threatened species.

Equally important are the computerised records and archives that zoos and aquaria maintain on breeding, e.g. parentage, clutch/litter size, inter-birth interval, infant survival, group composition, behaviour, medical issues etc.

- sample size
- permits (CITES, internal and official animal welfare committees)
- logistics of physically attaining the sample
- logistics of sample storage and transport
As well as observational data, a wide variety of materials and methods may – subject to risk assessments, biosecurity and health and safety precautions – be utilised in studies of living zoological collections and associated products (e.g. tissue and blood samples, faeces, urine, horns, eggs, nests and feathers). For example, some substances such as hormones contained in faeces and urine are important in non-invasive indices of stress. If animals die eventually, and post-mortem material can be usefully studied and be deposited in museums and universities for future reference, especially material from threatened species.

Equally important are the computerised records and archives that zoos and aquaria maintain on breeding, e.g. parentage, clutch/litter size, inter-birth interval, infant survival, group composition, behaviour, medical issues etc.

Opportunistic sampling or experimental design?
Fundamental approach

Sodium metabolism in black rhinos across different dietary intakes?
Stress hormones in orangutans related to group size?

Opportunistic
- use inter-zoo variability (in diets, in group composition)

Experimental
- change diets/group size within a constant group of animals

you need a lot of zoos that only have to give you access to the samples you need

Sometimes taking the ‘normal zoo data’ requires methods that are in themselves ‘experimental’
Mineral absorption in the black rhinoceros (*Diceros bicornis*) as compared with the domestic horse

M. Clauss¹, J. C. Castell², E. Kienzle², P. Schramel³, E. S. Dierenfeld⁴, E. J. Flach⁵, O. Behlert⁶, W. J. Streich⁷, J. Hummel⁶,⁸ and J-M. Hatt¹


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Organic matter and macromineral digestibility in domestic rabbits (*Oryctolagus cuniculus*) as compared to other hindgut fermenters

K. B. Hagen¹, A. Tschudin¹, A. Liesegang², J.-M. Hatt¹ and M. Clauss¹

Species-specific patterns in fecal glucocorticoid and androgen levels in zoo-living orangutans (Pongo spp.)

Tony Weingrill\textsuperscript{a,}\textsuperscript{*}, Erik P. Willems\textsuperscript{a}, Nina Zimmermann\textsuperscript{b}, Hanspeter Steinmetz\textsuperscript{c}, Michael Heistermann\textsuperscript{d}

General and Comparative Endocrinology 172 (2011) 446–457
Prevalence of Regurgitation and Reingestion in Orangutans Housed in North American Zoos and an Examination of Factors Influencing its Occurrence in a Single Group of Bornean Orangutans

Christine M. Cassella, Alyssa Mills, and Kristen E. Lukas

Zoo Biology 31: 609–620 (2012)
surveys
Questionnaires!

If you want to do a survey, travel & interview people yourself and try to avoid questionnaires.
The myth of ‘hypothesis-driven research’: getting used to lying

Hypothesis-driven

“our hypothesis was confirmed”

Serendipity-driven

“we stumbled across a pattern and we think we can explain it”

Schiffmann et al. (2019)
Elephant body mass cyclicity suggests effect of molar progression on chewing efficiency

Christian Schiffmann\textsuperscript{a, b}, Jean-Michel Hatt\textsuperscript{a}, Stefan Hoby\textsuperscript{c, d}, Daryl Codron\textsuperscript{e, f}, Marcus Clauss\textsuperscript{a, *}

Mammalian Biology xxx (2018) xxx-xxx

mass data. These data revealed a pattern corresponding to the considerations on molar progression above (which we had collated after identifying the pattern; this study therefore did not test a hypothesis, but reports a serendipitous result). We consider this an outstanding ex-
example:
digestion studies
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?

from Lechner et al. (2010)
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?

from Tschuor & Clauss (2008)
Case example: digestion studies

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What are the minimum conditions you need to perform reasonable studies on digestive physiology?

Sampling frequency test

=> how much are you allowed and are you prepared to work?
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?

Rhinoceros faeces test: Crude ash content of sample

- sent in by zoo – 50 % dry matter
- taken by doctoral student – 18 % dry matter
- taken by postdoc supervisor – 9 % dry matter

=> how accurate do you work / how high do you rate personal comfort?
Case example: digestion studies

What are the minimum conditions you need to perform reasonable studies on digestive physiology?
The Effectiveness of Indigestible Markers for Identifying Individual Animal Feces and Their Prevalence of Use in North American Zoos

Grace Fuller,¹,²* Susan W. Margulis,³,⁴ and Rachel Santymire³

<table>
<thead>
<tr>
<th>Species</th>
<th>Marker type</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing cat, \textit{Prionailurus viverrinus}</td>
<td>Liquid food coloring (green)</td>
<td>0.5–1.0 ml daily</td>
</tr>
<tr>
<td></td>
<td>Sesame seeds</td>
<td>0.125 tsp</td>
</tr>
<tr>
<td></td>
<td>Wilton paste food dye (Christmas red and kelly green)</td>
<td>Enough to color feed well</td>
</tr>
<tr>
<td>Giant panda, \textit{Ailuropoda melanoleuca}</td>
<td>Corn, various colors</td>
<td>NR</td>
</tr>
<tr>
<td>Grey wolf, \textit{Canis lupus}</td>
<td>Rice</td>
<td>1 Tbsp</td>
</tr>
<tr>
<td></td>
<td>Finch seed</td>
<td>1 Tbsp</td>
</tr>
<tr>
<td></td>
<td>Kernal corn</td>
<td>1 Tbsp</td>
</tr>
<tr>
<td></td>
<td>Scratch</td>
<td>1 Tbsp</td>
</tr>
<tr>
<td></td>
<td>Foil glitter</td>
<td>1 Tbsp</td>
</tr>
<tr>
<td></td>
<td>Sweet potato</td>
<td>0.25 cup chunks</td>
</tr>
<tr>
<td></td>
<td>Carrot</td>
<td>0.25 cup diced</td>
</tr>
<tr>
<td></td>
<td>Fresh corn</td>
<td>1 ear</td>
</tr>
<tr>
<td></td>
<td>Beets, chopped</td>
<td>NR</td>
</tr>
</tbody>
</table>
Case example: digestion studies

- can you keep animals individually
  i.e. are there enough enclosures
  will they cope with being isolated
  will they fight when put together again
- how many can you keep individually at a time
- can you shift the animals to get at faeces regularly
- can you work ‘after-hours’
- can you weigh the animals
- can you process your samples on site / is there freezer space
- can you manipulate the diet
Effect of different feeding regimes on cecotrophy behavior and retention of solute and particle markers in the digestive tract of paca (*Cuniculus paca*)

Letícia Guerra Aldrigui\textsuperscript{a}, Sérgio Luiz Gama Nogueira-Filho\textsuperscript{a}, Alcester Mendes\textsuperscript{a}, Vanessa Souza Altino\textsuperscript{a}, Sylvia Ortmann\textsuperscript{b}, Selene Siqueira da Cunha Nogueira\textsuperscript{a}, Marcus Clauss\textsuperscript{c,*}

Comparative Biochemistry and Physiology, Part A 226 (2018) 57–65

Patterns: secondary marker peaks
Sorting of ingesta for caecotroph formation

**Mucus trap** mechanism
(Hystricomorph rodents)

**Wash back** mechanism
(Lagomorphs)

from Hagen et al. (2015), Sakaguchi & Hume (1991), Franz et al. (2011)
Ruminant vs. Nonruminant Foregut Fermentation

Schwarm et al. (2008, 2009)
Rumination I: convergence

Lechner et al. (2010), Dittmann et al. (2015)
Rumination II: no convergence
Fluid vs. particle retention

Schwarm et al. (2008, 2009)
Fluid vs. particle retention

from Müller et al. (2011)
An old question:

Do larger herbivores ingest lower-quality diets, and are they physiologically equipped for a ‘better’ digestion of such diets?
An old question:

**Does body mass convey a digestive advantage for large herbivores?**

Patrick Steuer\(^1\), Karl-Heinz Südekum\(^1\), Thomas Tütken\(^2,^\dagger\), Dennis W. H. Müller\(^3,^4\), Jacques Kaandorp\(^5\), Martin Bucher\(^6\), Marcus Clauss\(^3\) and Jürgen Hummel\(^*1,^7\)
... or larger animals eat lower quality diets

from Steuer et al. (2014)
Assessing the Jarman–Bell Principle: Scaling of intake, digestibility, retention time and gut fill with body mass in mammalian herbivores

Dennis W.H. Müller a,b, Daryl Codron a,c, Carlo Meloro d, Adam Munn e, Angela Schwarm f, Jürgen Hummel g,h, Marcus Clauss a,*
Vital skills I

- do an internship in a zoo to learn basic routines such as
  - handling brooms (use broom and shovel simultaneously)
  - handling & closing doors
  - understanding zoo logistics
- be able to communicate your topic and study goals
- know your animals (but rather listen than talk about what you know)
Vital skills II

- don’t come to work later than those who shall help you (e.g., keepers)
- ensure nobody has to wait for you
- if you need help, ensure everybody realizes that you are reciprocating by helping back
- never expect anyone to do extra work for you because you need it or find it interesting
- never act as if a certain task is below your level of dignity that is part of the work of someone who shall help you
- always wash your dishes immediately
- bring your own food, tea, sugar from day 1
zoo data
Mating system, feeding type and ex situ conservation effort determine life expectancy in captive ruminants

Dennis W. H. Müller¹,*, Laurie Bingaman Lackey², W. Jürgen Streich³, Jörns Fickel³, Jean-Michel Hatt¹ and Marcus Clauss¹
Demographic data

Reproductive seasonality in captive wild ruminants: implications for biogeographical adaptation, photoperiodic control, and life history

Philipp Zerbe¹,², Marcus Clauss¹,*, Daryl Codron¹,³,⁴,⁵, Laurie Bingaman Lackey⁶, Eberhard Rensch¹, Jürgen W. Streich⁷, Jean-Michel Hatt¹ and Dennis W. H. Müller¹,⁸
non-seasonal reproduction

highly seasonal reproduction
Daylength (h)

Day of the year

Equator
Tropic of Cancer
Temperate zone zoos
Polar circle

from Zerbe et al. (2012)
Daylength (h)

Day of the year

Equator
Tropic of Cancer
Temperate zone zoos
Polar circle

from Zerbe et al. (2012)
$y = 1.01x + 0.30$

$R^2 = 0.87$

Daylength at conception in the wild (h)

Daylength at conception in captivity (h)

from Zerbe et al. (2012)
how do you tell your story?
Compromised Survivorship in Zoo Elephants

Ros Clubb,1 Marcus Rowcliffe,2 Phyllis Lee,3,4 Rhyme U. Mar,2,5 Cynthia Moss,4 Georgia J. Mason2*

Wild animals can experience poor welfare when held captive (1), an effect with ethical and practical implications. In zoos, the welfare of African elephants (Loxodonta africana) and Asian elephants (Elephas maximus) has long caused concern. Infectious, Herpes, tuberculosis, lameness, infertility, and stereotypic behavior are prevalent (2), and zoo elephant populations are not self-sustaining without importation (3). We compiled data from over 4,500 individuals to compare survivorship in zoos with protected populations in range countries. Data representing about half the total zoo population (1960 to 2005) came from European “studbooks” and the European Elephant Group (4). We focused on females as relevant to population viability (N = 786, both wild-caught and captive-born; 302 African and 484 Asian). African elephants in Amboseli National Park, Kenya (N = 1089), and Asian elephants in the Burmese logging industry (Myanmaree Timber Enterprise, MTE, N = 2093, wild-caught and captive-born) acted as well-provisioned reference populations (for details, see (2) and (3)).

For African elephants, median life spans (excluding premature and still births) were 16.9 years (95% confidence interval CI) 16.4 to 17.4 known; upper estimate for median survival not reached) for zooborn females and 56.0 years (95% CI 51.5 to unknown) for Amboseli females undergoing natural mortality (35.9 years with human-induced deaths, 95% CI 33.8 to 40.3). Neither infant nor juvenile mortality differed between populations (Fig. 1A and tables S1 and S2), but adult females died earlier in zoos than in Amboseli (Fig. 1B and table S2). Zoo adult African survivorship has improved in recent years (z = -2.75, P = 0.006) and mortality risks in our data set’s final year (2005) decreased 2.8% higher (95% CI 1.2 to 6.5%) than that of Amboseli females undergoing natural mortality.

For Asian elephants, median life spans (excluding premature and still births) for captive-born females were 18.9 years in zoos (95% CI 17.7 to 20.0) and 41.7 years in the MTE population (95% CI 38.2 to 44.6). Zoo infant mortality rates were high (table S1). Rates have not significantly improved over time (eg., live births controlling for parity: z = 1.19, P = 0.10). For juveniles, captive-born survivorship did not significantly differ between populations, whereas wild-born survivorship was poorer in Burma (Fig. 1C and table S2) because of after-effects of capture (5). In adulthood, however, survivorship was lower in zoos (Fig. 1D and table S2), with no detectable improvement in recent years (z = -1.48, P = 0.006). Within zoos, captive-born Asain elephants have poorer adult survivorship than wild-born Asain (Fig. 1D and table S2) and wild-born, natural mortality.

Overall, bringing elephants into zoos profoundly impairs their viability.
Comparative analyses of longevity and senescence reveal variable survival benefits of living in zoos across mammals

Morgane Tidière¹, Jean-Michel Gaillard¹, Véranne Berger¹, Dennis W. H. Müller², Laurie Bingham Lackey³, Olivier Gimenez⁵, Marcus Clauss⁶ & Jean-François Lemaître⁷

While it is commonly believed that animals live longer in zoos than in the wild, this assumption has rarely been tested. We compared four survival metrics (longevity, baseline mortality, onset of senescence and rate of senescence) between both sexes of free-ranging and zoo populations of more than 50 mammal species. We found that mammals from zoo populations generally lived longer than their wild counterparts (84% of species). The effect was most notable in species with a faster pace of life (i.e. a short life span, high reproductive rate and high mortality in the wild) because zoos evidently offer protection against a number of relevant conditions like predation, intraspecific competition and diseases. Species with a slower pace of life (i.e., a longer life span, low reproduction rate and low mortality in the wild) benefit less from captivity in terms of longevity; in such species, there is probably less potential for a reduction in mortality. These findings provide a first general explanation about the different magnitude of zoo environment benefits among mammalian species, and thereby highlight the effort that is needed to improve captive conditions for slow-living species that are particularly susceptible to extinction in the wild.

Zoological gardens represent artificial environments in which animals are maintained, bred and displayed. By doing so, zoos achieve a diversity of goals beyond their visitors’ recreation: basic zoological and conservation education reaches 700 million visitors per year all over the world. Continuing research and expert building by many thousands of zoo staff worldwide continuously improves knowledge of animal, population and ecosystem management. Zoos also aim to maintain viable ex situ insurance populations of endangered species that can be used for re-introduction to the wild. Zoo staff manages and generates funding for in situ conservation projects. Finally, zoos facilitate opportunities for researchers to increase expertise in a large variety of areas, from basic zoology to applied husbandry and molecular biology.

When assessing the justification of holding nondomestic species in zoos, the welfare of the individual animals housed in captivity is a critical ethical issue that has to be weighed against those aims. There is no single proxy to measure the welfare of animals. Indicators typically employed include measures of survival (such as longevity, annual survival, or age at death), reproduction (such as fertility or litter size), physiology (such as stress hormones or the occurrence of specific diseases) and behavior (such as stereotypies). It is typically believed that zoo animals live longer than their free-ranging conspecifics due to the consistent provision of food, water, and shelter from harsh climates, the absence of predation and management to minimize violent intraspecific encounters and accidents, as well as veterinary prophylactic and therapeutic intervention. However, zoo animals may be subject to behavioral deficits. While an increasing number of comparative studies have demonstrated species-specific differences in the response to zoo conditions (8-10) and a few species-specific comparisons of survival metrics between free-ranging and captive specimens have been published (11, 12), large-scale inter-specific comparisons of captive and
<table>
<thead>
<tr>
<th>Age</th>
<th>Mortality rate</th>
<th>Age at sexual maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.03</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0.08</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>0.08</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>0.08</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>0.08</td>
<td>20</td>
</tr>
<tr>
<td>25</td>
<td>0.08</td>
<td>20</td>
</tr>
</tbody>
</table>

- Baseline mortality
- Onset of senescence
- Rate of senescence
- Longevity

Wild population vs. Zoo population
Longevity in free-ranging and zoo conditions for males $\triangle$ and females $\circ$ of each species of Artiodactyla, Carnivora, Primates and other orders. Species living longer in zoo are indicated with solid line while others are indicated with dotted line.

Wild Zoo

Environmental condition

Longevity according to environmental condition for Artiodactyla species (in years)

- S. caffer
- P. tajacu
- K. ellipsiprymnus
- C. canadensis
- B. gaurus, C. taurinus
- C. ibex, C. elaphus, C. eldi
- D. virginianus, S. scrotia
- C. nippon, R. rupicapra
- D. aries, D. korrigum
- K. leche, C. aegagrus
- A. aloeos, O. canadensis
- O. hemionus, D. dama
- K. kob, T. strepsiceros
- R. tanandus, A. melampus
- A. americana
- C. capreolus
- C. virginianus
- D. korrigum
- O. virginianus

Environmental condition

Longevity according to environmental condition for Carnivora species (in years)

- Z. californianus
- L. rufus, P. leo
- C. crocuta
- A. jubatus, M. meles
- L. lutra, H. parvula
- L. pictus
- V. vulpes
- N. procyonoides
- M. putorius
- M. erminiae
- M. mephitis
- M. vison
- M. cinereoargenteus
- A. pusillus

Environmental condition

Wild Zoo
These findings provide a first general explanation about the different magnitude of zoo environment benefits among mammalian species, and thereby highlight the effort that is needed to improve captive conditions for slow-living species that are particularly susceptible to extinction in the wild.