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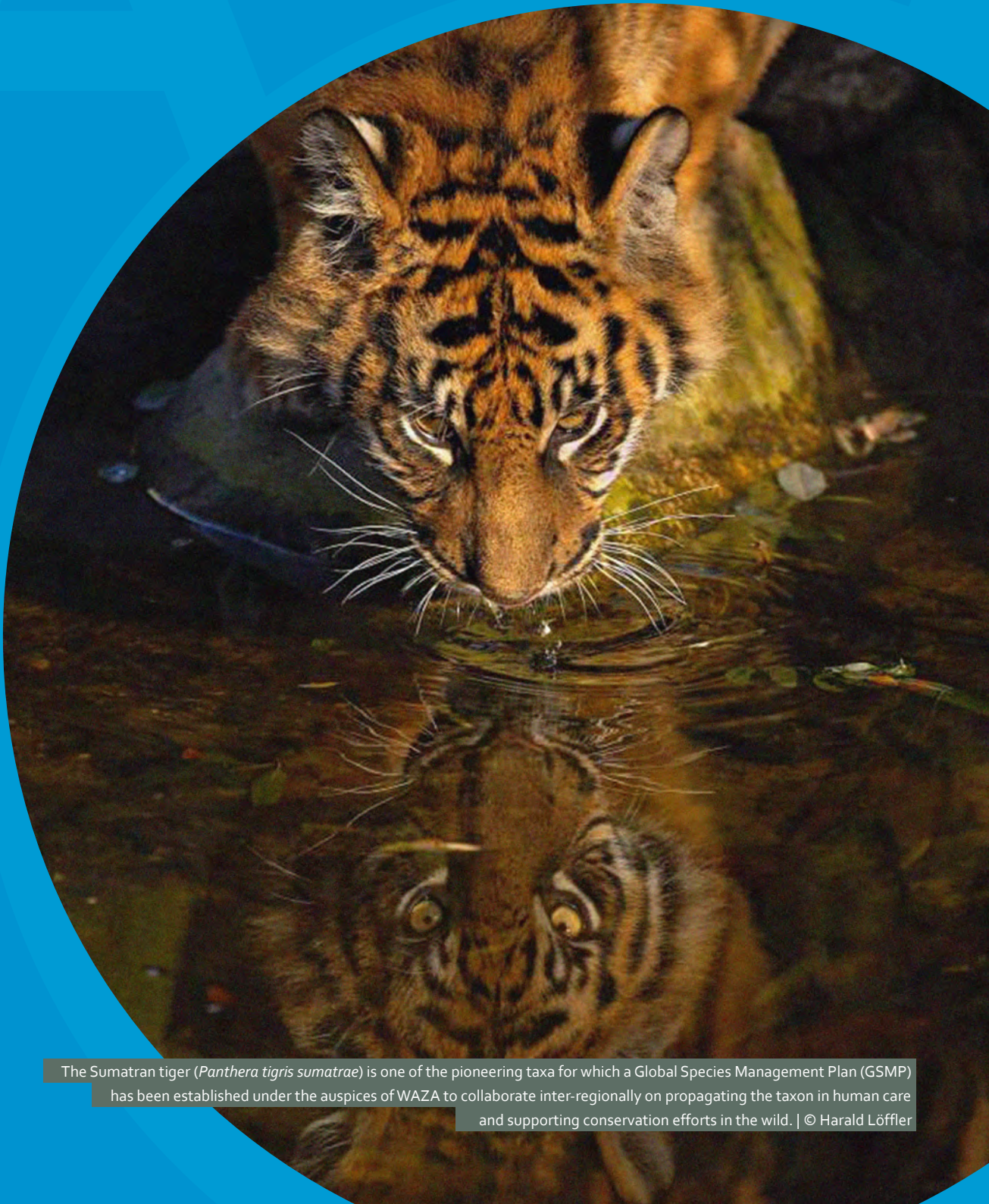
magazine

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World Association of
Zoos and Aquariums
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Towards Sustainable Population Management



The Sumatran tiger (*Panthera tigris sumatrae*) is one of the pioneering taxa for which a Global Species Management Plan (GSMP) has been established under the auspices of WAZA to collaborate inter-regionally on propagating the taxon in human care and supporting conservation efforts in the wild. | © Harald Löffler

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World Association of
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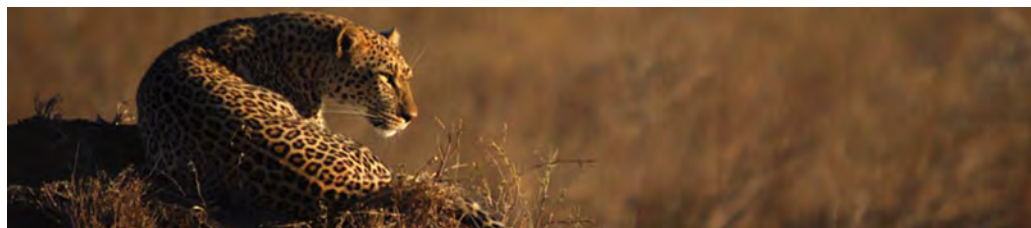
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Editorial

A recent evaluation of the status of the world's vertebrates (Hoffmann *et al.* 2010; *Science* 330: 1503–1509) showed that one-fifth of species are classified as threatened. On average, 52 species of mammals, birds and amphibians move closer to extinction each year. However, the rate of deterioration would have been at least one-fifth more in the absence of conservation measures. Therefore, while current conservation efforts remain insufficient to offset the main drivers of biodiversity loss, this overall pattern conceals the impact of conservation successes. Notably, conservation breeding in zoos and aquariums has played a role in the recovery of 28% of the 68 species whose threat status was reduced.

To fulfil the full suite of conservation roles required of animal populations in human care, they must be demographically robust, genetically representative of wild counterparts and able to sustain these characteristics for the foreseeable future. In light of growing concerns about the long-term sustainability of captive populations, WAZA organised a two-day workshop in April 2011 on the sustainable management of zoo animal populations. This workshop, which was an integral part of a series of workshops on related topics summarised in this edition of the WAZA Magazine, tackled the issue of studbook-based global population management, which lies at the heart of successful conservation breeding programmes aimed at preserving biodiversity.



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Lion (*Panthera leo*) in the Serengeti.

In this edition of the WAZA Magazine, the results of population sustainability assessments globally (Lees & Wilcken) and in three major regions (Australasia: Hibbard *et al.*; Europe: Leus *et al.*; North America: Long *et al.*) are presented. Two important biological factors impacting population sustainability are reviewed, namely genetics (Ballou & Traylor-Holzer) and mate choice (Asa *et al.*). Overviews of how biodiversity is represented in zoological institutions (Conde *et al.*), managed programmes (Traylor-Holzer) and studbooks (Oberwemmer *et al.*) are provided, including a study on studbook-driven husbandry success (Müller *et al.*). Finally, a vision for the future of population sustainability is outlined (Baker *et al.*).

We hope that this edition of the WAZA Magazine will make a substantial contribution to the challenge of how animal populations in human care can be managed sustainably in the long term, and thereby further increase the contribution of the world zoo and aquarium community to global biodiversity conservation.

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Global Programmes for Sustainability

Summary

Zoos and aquariums may support multiple conservation endeavours. They may be involved in the design and delivery of environmental education programmes, support wildlife research, provide funds, manpower and expertise in intensive management to support conservation efforts and, increasingly, are involved in the interactive management of captive and wild populations. These activities rely on the presence in zoos of living animal collections. To fulfil all of the roles required of them, these animal collections must be demographically robust, genetically representative of wild counterparts and able to sustain these characteristics for the foreseeable future. Here, we propose a definition of a "sustainable" population, describe the challenges in building one and explore the potential of global species management programmes to overcome some of these challenges.

Sustainable Populations

We define a sustainable population here as one that is able to persist, indefinitely, with the resources available to it. Under this definition, sustainable populations fall into two categories:

Category 1: Self-sustaining Populations. This includes populations with sufficient *internal* resources to persist without supplementation. That is, they are large enough to withstand or avoid the otherwise damaging effects of small population size (i.e. naturally fluctuating birth and death rates, sex ratio skews, inbreeding, low gene diversity) (Frankham *et al.* 2002). Populations in this category are necessarily very large.

Category 2: Supplemented Populations. This second category contains populations that, usually because of their smaller size, do not have sufficient internal resources for self-sustainability, but are supported by external supplementation. For the sustainability test to be satisfied, this supplementation must be from source populations able themselves to sustain the required harvest without depletion. A population of any size can be sustainable provided that the supplementing source population can accommodate the required harvest. The larger and better managed the population, the lower the rate of supplementation needed.

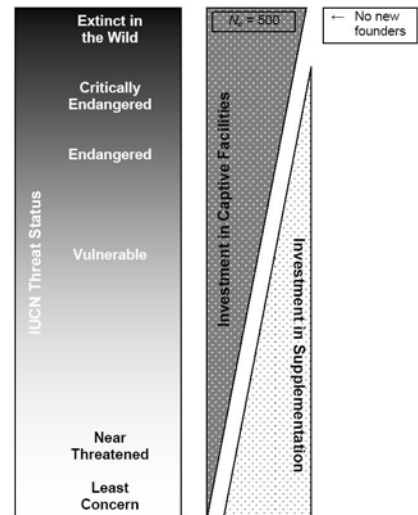


Fig. 1

Recommended allocation of captive resources based on IUCN categories of extinction risk (modified from Lees & Wilcken 2009).

It seems reasonable to suggest that all taxa for which the captive population constitutes a significant part of the species' genome, or for which further collection from the wild is considered impossible, should be managed as self-sustaining captive populations. Included would be all species categorised by the International Union for Conservation of Nature (IUCN) as Extinct in the Wild or Critically Endangered, and some of those categorised as Endangered or Vulnerable.

On the other hand, those species for which further collection from the wild is still considered a viable and responsible option may be more efficiently maintained through periodic, minimal and scientifically calculated rates of supplementation from the wild (Fig. 1). It is important that population size targets are calculated and periodically revised for each individual population, based on its characteristics and management. However, indicative ranges of population sizes can be suggested for each of these categories of sustainability.

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Targets for Self-sustainability

For self-sustainability, populations ought to encounter no net loss of genetic diversity. Genetic diversity is the raw material for evolution and as it declines so does a population's adaptive potential (Frankham *et al.* 2002). Genetic diversity is lost through non-random breeding and chance processes (drift), and is gained by mutation. The smallest population size for which drift is balanced by mutation is estimated to be about $N_e = 500$ (Frankham *et al.* 2002), where N_e is the effective population size and genetic diversity is measured through heterozygosity and additive genetic variance. N_e is a measure of that proportion of the census population that is contributing to the next generation.

The ratio of effective to actual population size (N_e/N) is greatest where the number of animals that reproduce is high, the sex ratio of breeding animals is equal and the life-time family sizes of reproducing animals are also equal, with the latter having most influence in zoo populations. Wild populations differ significantly from these ideal characteristics and may achieve N_e/N ratios of around 0.1 (Frankham *et al.* 2002). That is, they may require about 5,000 animals to achieve a sustainable effective population size of 500. Through management, captive populations can be brought closer to these ideal characteristics, regularly showing N_e/N ratios of 0.2–0.4, though ratios as high as 0.7 have been reported (Willis & Wiese 1993). Based on these reported ratios, for captive populations to be self-sustaining, they will need an N_e of at least 500, or an actual population size of 700–1,900 animals.

Targets for Supplemented Sustainability

Models suggest that it is possible to retain relatively high levels of gene diversity in population sizes smaller than $N_e = 500$ if coupled with periodic addition of new founders (Lacy 1987; Willis & Wiese 1993). At low population sizes (50–100), the supplementation rates required are too high to be contemplated (Willis & Wiese 1993) and demographic factors pose a real risk. However, at an N_e of 120, Lacy (1987) calculated that it is possible to retain 95% of wild gene diversity with the addition of five new founders each generation. In 2005, $N_e = 120$ could equate to somewhere between 170 and 460 animals, depending on the effectiveness of management.

It should be noted that the extent to which new wild founders may be responsibly available will depend on political and community sensitivities, and logistical and biological constraints. Any such initiatives should be based on an appropriate assessment of wild population viability.

Global Potential

In addition to sufficient size, populations need to be imbued with enough gene diversity in the form of founders, and they need to sustain the requisite growth rate to avoid large fluctuations in size. In recent years, a number of studies, including the one on which this article is based (Lees & Wilcken 2009), have shown that regional population management programmes are not achieving the conditions for sustainability. They are too small, are based on too few founders and are not achieving the required growth rates.

However, a review of potential across regions suggests that a move to global coordination would overcome some of the current within-region limitations. For example, of the populations registered in international studbooks (ISIS/WAZA 2005), 57.3% fall within the population size range required for supplemented sustainability, as it is described above.

In addition to species registered in international studbooks and again using data from the International Species Information System (ISIS), we estimate that by linking up regionally managed populations into global programmes, the average population size for vertebrate taxa can be increased from 120 to 170, placing many more taxa within the accessible range for supplemented sustainability.

Further, of the populations registered in international studbooks (ISIS/WAZA 2005), 9% fall within the population size range for self-sustainability, including scimitar-horned oryx (*Oryx dammah*) (Extinct in the Wild), Przewalski's horse (*Equus ferus przewalskii*) (Critically Endangered) and Amur tiger (*Panthera tigris altaica*) (Endangered) – all of which fall into risk categories where self-sustainability is either advisable or essential (Fig. 2).



Fig. 2

Przewalski's horses are potentially self-sustaining at a global level.

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Global *versus* Regional Management

Despite the obvious sustainability advantages of global management, it remains the exception and regional management the norm. The reasons for this are easily identified: within-region transfers are logistically simpler and often less expensive, permitting and quarantine requirements are less onerous and the necessary administrative structures and lines of communication are (usually) better established and more effective. Indeed, the zoo region is often the most sensible unit for cooperation, particularly for local species that are the focus of short-term breed-for-release initiatives. However, as described above, many regional populations are not reaching viable sizes. Populations tracked across multiple regions reach necessarily larger sizes. Inter-regional or global management, though difficult to implement successfully, offers not only the advantage of scale but also of strategic overview. For example:

- For *small, widely dispersed* populations, global management provides an opportunity to link up a number of isolated, unsustainable units, improving demographic stability and managing inbreeding and gene diversity more effectively.
- Research demonstrates that the genetic diversity of *large global populations* may benefit from strategic population subdivision and restricted but carefully managed migration between these subpopulations. Regional populations offer convenient subpopulations for use in this context.
- For *expanding populations* that are primarily held in one region but sought after in others, global management may be a useful mechanism for distributing important founder lines so that overall genetic diversity is maximised. In the ab-

sence of such management, over-represented lines are often continually exported from the source region to found new populations. This can reduce the genetic potential and therefore the conservation value of those populations and of overall global stocks.

In certain circumstances then, global management offers greater potential for extending the viability of zoo populations and improving their value to conservation. For this potential to be reached, global management needs to be a more accessible option. The new WAZA framework for Global Species Management Plans (GSMPs) provides this access and its use should be encouraged.

Recommendations

If zoo populations are not sustainable, neither are zoos themselves. Too few populations are currently satisfying the conditions for sustainability. There is scope for reversing this trend but it requires renewed commitment and new investment. The following five-point plan summarises steps that could be taken towards this end.

Step 1: Global Audit. A complete audit of WAZA populations to provide a useful snapshot of potential, for use in planning.

Step 2: Global Planning. An inclusive process, based on the audit, to identify a list of priority species for global management, based on population potential as well as wild status.

Step 3: Global Targets. Calculation of global target population sizes for each priority species, based on appropriate science and a rationale of sustainability:

- All taxa categorised by IUCN as Extinct in the Wild or Critically Endangered should be assigned a target N_e of 500 ($700 < N < 1,900$).
- All other taxa for which recruitment from the wild is considered inappropriate or impossible should also be assigned a target N_e of 500.
- For taxa where recruiting new founders is not considered inappropriate or impossible, an N_e of 120 ($170 < N < 460$) should be the target, in conjunction with the input of around five new founders each generation.
- Exceptions to this could be: taxa being deliberately phased out, taxa present for short-term research or breed-for-release programmes and taxa for which there are established gene banks that allow gene diversity targets to be met at lower numbers (noting that demographic considerations should dictate the minimum number in such cases).

Step 4: Global Investment. Appropriate investment in professional species managers, husbandry innovation and supporting technology. This will help ensure that science-based targets are set and that programmes are designed and managed to meet those targets at achievable population sizes.

Step 5: Global Commitment. Long-term programmes require long-term commitment. Mechanisms for securing this commitment from participating zoos should be factored into industry benchmarking and accreditation programmes.

Sustaining the viability and genetic value of zoo populations requires larger, better founded and more imaginatively managed populations than we often have at our disposal. A concerted move away from regional and towards global coordination of genetic and demographic management has the potential to dramatically improve the quality of captive resources available to support wild populations of many species. Fully mobilising that resource will be challenging, but must be a priority for the world's zoos over the coming decade.

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Maintaining the Status of Species Management in a Changing Operating Environment: Outcomes over Outputs

Summary

The Australasian region's Zoo and Aquarium Association (ZAA) is recognised internationally for its innovative approach to species management. A 2005 review of species management in the region highlighted an alarming proportion of species that were unlikely to be sustainable in the long term. In reaction to this, the Australasian Species Management Program (ASMP) developed a benchmarking tool, the ASMP Health Check Report, to measure fact-based criteria by breaking down species management into measurable components. The Health Check Report is structured into four portfolios: Administration, Science, Legislation and Overall Performance. The results of the Health Check Report allow ZAA to monitor the performance of ASMPs and better understand the

skills/expertise required to deliver the desired outcomes. Results are also incorporated into any annual report that is provided to directors of member organisations to provide succinct advice about the performance of ASMPs to which they contribute. The Health Check Report allows for an up-to-date assessment of managed programmes within their scope and activities, while providing assurance to the ZAA Board of Directors, and ultimately the membership, on the improvement, accountability and persistence of the region's priority programmes.

Introduction

The Australasian zoo and aquarium environment is geographically isolated, relatively small in population size and has a rigorous legislative environment. As a result, it has an established regional commitment to cooperative species management, a particular necessity with exotic species. As the conditions of geography, population and legislation are non-abating, it is vital that the region not only remains at the forefront of species management but recognises the importance of ongoing review and assessment of our species management performance. Small population biology in support of species management has been utilised by the zoo industry since the mid-1990s (reviewed in Ballou *et al.* 2010), and more recently the importance of sustainability relative to the challenges faced by zoos in maintaining viable populations has been discussed (Lees & Wilcken 2009). Of specific relevance to this article is the issue raised by Lees & Wilcken (2009) over implementing recommendations within institutions.

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In 2008, the Australasian Species Management Program (ASMP), the species management arm of ZAA, commissioned a review of the delivery of species management outcomes within the Australasian region. The initial discussion related largely to exotic taxa and was prefaced by a report prepared on the status of all exotic taxa under formal management within the Australasian region. The report suggested that an alarming proportion of exotic taxa were unlikely to be sustainable in the long term, including some which were facing imminent local extinctions in Australasian zoos (Barlow & Hibbard 2005). The scope of this discussion quickly expanded to include all Australasian programmes (both native and exotic) where a level of formal management had been applied.

The ASMP Committee, through the ZAA Board of Directors, launched a full review of species management services under the banner of the Future Directions Project. The ASMP Committee recognised the sound foundations already in place and focused on addressing issues that had arisen as a result of the programme maturing and operating environments evolving. In broad terms, the project was to examine resourcing, policies, processes and species to be managed. In order to apply specific and measured resolutions, the project was tasked with determining the specific causes for the shortfall in overall population “health” of species in managed programmes and establishing actions to resolve these.

The aim of the project was to improve the effectiveness of species management programmes through accountability, disciplined processes and inclusiveness, in order for the ASMP to remain current and relevant as a member service to the ZAA membership.

Methodology

The ASMP Future Directions Project commenced in 2008 and was earmarked for completion in 2010. There were various components to the project beginning with a rigorous review of the species selected for management and the level to which they could or should be managed. This article will not attempt to document the species review process, other than to recognise that many excellent models have been developed and that the Australasian model was not radically different from others in current use; that is, it addresses key goals identified in the World Zoo and Aquarium Conservation Strategy (WAZA 2005). For exotic taxa, the Australasian model rated highly the ongoing ability to acquire the species both in terms of import legislation and access to new genetic material (either by inter-regional or range state sources). This was of specific importance given the small size of our regional populations and the need to rely on periodic importation to sustain most populations.

The next step in the process was the development of a benchmarking tool with the current working title of the ASMP Health Check Report. The Health Check Report is by no means a completed piece of work and continues to evolve to reflect a changing zoo environment and respond to any issues that might be identified in the future. In the past, ZAA has used a compliance report to measure institutional adherence to specific recommendations on specimen transfers and breeding based on studbook analysis. The development of the Health Check Report has expanded the scope substantially and shifts the focus of assessment onto the delivery of a suite of measurable programme goals rather than the performance of individual contributors. The Health Check Report measures the overall health of the programme as well as giving insight into the “health” of specific areas.

It was acknowledged that in many cases sound scientific principles of small population biology had been applied; however, the results in programme performance were not all meeting expectations. A number of claims were put forward, many of which were consistent with those identified by Lees & Wilcken (2009), and included:

- A lack of spaces being offered for managed species, fuelled by a trend away from multiple, small, species-specific facilities to larger multi-taxa “experiences”, including a move away from extensive off-display holding facilities.
- Government legislation over the import of exotic taxa was having a negative impact on founder recruitment for populations.
- Species biology in some instances was not necessarily aligned with the mean kinship and genetic management employed.
- The concept that genetic management was better understood and more rigorously applied by species coordinators than demographic management and in some instances contributed to demographic instability.
- Species management expertise and innovation required further development.
- Implementation of specific programme recommendations although usually attempted often was not necessarily achieved, or resulted in the desired outcome.

The Health Check Report was developed to measure fact-based criteria, by breaking down species management practices into measurable components. This enables a programme’s performance to be quickly assessed and any remedial measures applied in a timely manner where programmes are seen to be falling short of expectation. In addition, it allows for the acknowledgement of positive progress and feedback to the many species coordinators hosted by member zoos.



The Health Check Report considers four broad portfolios with associated responsibilities and criteria for programme performance, as set out in Table 1. Each criterion has predetermined scoring parameters that is then translated into a traffic light system of green (performing well), orange (needs some specific attention) and red (needs immediate attention). The parameters for each criterion were set necessarily high to ensure the report represents a true level of current achievement. The scoring does not try to suggest a long-term level of sustainability, but attempts to isolate some issues around immediate need and priority for resource allocation.

Previously used species management criteria, such as purpose, role or threat status, were no longer considered, as these are assessed as part of the initial species selection process. The Health Check Report is designed to look specifically at the operational and sustainability performance of the species management programme after species selection and identification of what conservation contribution or purpose the population fulfils.

As an example of the benefits of the Health Check Report, only the results for the exotic fauna programmes are presented here for discussion. The data relate to 40 intensively managed exotic species programmes in the order Mammalia. No exotic bird programmes are managed by ZAA due to the significant restrictions on the importation of birds to the region since the 1950s, and the small numbers of exotic reptiles that are managed are grouped with the native reptile data.

Table 1.
ASMP Health Check Report: portfolios, responsibilities and scoring criteria.

Portfolio	Primary responsibility	Examples of scored criteria
Administration	ZAA ASMP staff	Species coordinator assigned, studbook currency and accuracy, annual report tendered (and currency), level of assistance provided to species coordinator, Captive Management Plan developed, etc.
Science	Species coordinators, Taxon Advisory Groups and participating institutions (with assistance from the ASMP for specific small population biology issues as required)	Retained genetic diversity, average inbreeding, success of recommended transfers and breeding, etc.
Legislation	ASMP Committee	Status of legislation in regard to the import from a variety of sources (including range states). Restrictions on the keeping of species within the region (based on pest potential, etc.). This set of criteria is individually tailored to exotic, Australian native and New Zealand native fauna.
Overall Performance	ZAA Board of Directors	The overall performance score is an amalgamated performance of all three criteria above. Specific attention is focused on any programme with an overall red score.

Results and Discussion

Administration. There is a demonstrated high compliance of the administration of the ASMPs (Fig. 1), with almost all programmes having a species coordinator assigned; the required reporting and interpretation of studbook data using PM2000 (Annual Report and Recommendation submitted) being tendered with relatively moderate coaching by the senior species management staff in the ZAA office (species coordinator assistance); and the facilities nominated score refers to adequate spaces dedicated to the programme (50 spaces), as set out in the ASMP Regional Census and Plan. The significant challenge for the region is the need to further develop a number of strategic planning documents in the form of Captive Management Plans (CMPs).

Science. The portfolio with the greatest proportion of factors in the red zone, and so requiring immediate attention, are those found in the Science portfolio (Fig. 1). It is thought that several factors may be cumulating within this area, where the transfer failure impacts on the planned breeding, which in turn may affect the scores for genetic diversity (scored as retained at 90% or higher), inbreeding (average for population is lower than 0.125) and mean kinship (average for population is lower than 0.125). Despite some obvious issues with breeding to plan in addition to transfer failure, population trends remain positive. Further investigation is required to determine which proportion of the population trend is as a result of importation over breeding.

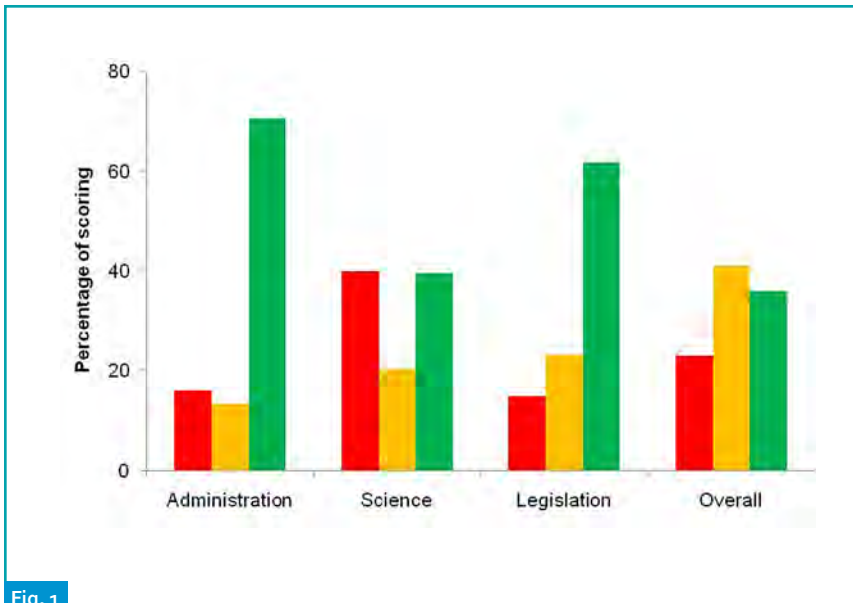


Fig. 1

ASMP Health Check Report: percentage of scoring in each of three major portfolios and overall across 40 intensively managed exotic mammals in ZAA membership, where green (performing well), orange (needs some specific attention) and red (needs immediate attention).

Legislation. The results of the Legislation portfolio have been useful in that legislative barriers have long been considered the significant cause for shortfall in programme performance (Fig. 1). It is clearly demonstrated that there is an ability to import a majority of the targeted exotic species into the region, and that interaction between New Zealand and Australia is also well supported by legislation (vital for effective Australasian-based programmes). There is a requirement from the Australian government for all species listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to have an approved Cooperative Conservation Plan in place prior to any international transaction and these are largely covered in regard to current need. As with other regions, the access to new founders is a challenge for a large number of programme species. The VPC threat category is

a rating applied by the Australian government on the pest potential of a species to the environment (including public safety), if it were to escape and establish. The results here assist in identifying the promotion of appropriate biosecurity measures in our member zoos, which in turn provides confidence in granting permits to hold such species.

Overall Performance. The overall performance scores (Fig. 1) show approximately 75% of all the exotic programmes within the sample either in good order (green) or with some specific issues (yellow).

Conclusions

The Health Check Report process has allowed ZAA to commence a measured approach to the assessment of its intensively managed species programme performance. It is by no means exhaustive but does represent an ongoing commitment to self-assessment and a structured approach to problem solving, communicating priorities and deployment of resources. This will provide tangible benefits to supporting programme goals and assurances and value to the membership of ZAA who jointly fund the association's activities.

The process has allowed us to mobilise resources into the areas of most need. Recently the results have been fed into the region's Taxon Advisory Group (TAG) structure, with each TAG charged with developing a specific action plan against any species with a red score. As a consequence, there has been support in aligning the actions of the TAGs, with a greater focus on animal husbandry and behaviour along with the identification of staff training and development. It is hoped that this will have a direct and positive impact in the areas of animal transfers and breeding.

The legislative assessment has proven to be very productive, as it has long been considered throughout the membership as a primary limitation to programme progress. Although hoofstock imports continue to provide biosecurity challenges for the region due to the existing commercial livestock industry in both New Zealand and Australia, a majority of the other taxa can be imported under current legislation.



Of significant interest were the findings of the Health Check Report that highlighted the challenges associated with achieving recommended animal transfers and breeding. There is a need for detailed assessment of contributing factors so that resolutions can be developed. These outcomes may also indicate a need for greater alignment of genetic management strategies with the biology of the species in order to support long-term sustainability outcomes.

In addition to providing direct feedback into the TAGs, the results of the Health Check Report now feature in every executive summary for all Annual Reports and Recommendations generated for intensively managed populations. The executive summary also includes graphical evidence of the five-year trends of both the genetic and demographic management of the programme, as well as reporting against the strategic goals of the CMP (where these have been developed), or against a set of generic managed programme goals. These executive summaries will be collated at the end of every year and published as a Director's Executive Summary, so programme performance is not only being reported to curators and keepers, but also to the chief executive officers and directors, allowing all those involved to gain an understanding of how the programme is tracking both in the short and long term.

As described, the Health Check Report is not a complete piece of work but rather an evolving one. Although there appears to be a good delivery on annual reporting by species coordinators, in the future ZAA will be devoting a concerted effort towards the development of a greater suite of CMPs that guide a more strategic approach over the longer term. To date ZAA has already completed the realignment of the CMP process to meet a range of operational, small population biology and business outcomes.

In conclusion, the Health Check Report:

- currently provides every TAG with an up-to-date assessment of the managed programmes within their scope and focuses activities on constant improvement;
- allows the ASMP Committee to ensure that all managed programmes are receiving the appropriate level of attention from the TAGs, participating institutions and ZAA species management staff;
- provides the membership of ZAA and its Board of Directors an assurance that a detailed level of scrutiny will ensure every effort is applied to continued improvement, accountability and persistence of the region's priority populations.

The Health Check Report provides a succinct graphic representation of the performance of our managed species programmes, clearly capturing the outcomes towards agreed goals achieved during the year.

Acknowledgements

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Sustainability of European Association of Zoos and Aquaria Bird and Mammal Populations



Introduction

A rapid assessment of the sustainability of bird and mammal populations managed by the European Association of Zoos and Aquaria (EAZA) as European Endangered Species Programmes (EEPs) and European Studbooks (ESBs) was initiated in 2008, in response to concerns arising from the European Union (EU) bird import ban triggered by avian influenza. There is as yet no such blanket ban for mammal populations, but we have already experienced transport restrictions for various groups of mammals in response to disease outbreaks, such as bluetongue, bovine spongiform encephalopathy (BSE) and foot-and-mouth. All of this begs the questions “are, or can, EAZA bird and mammal populations be sustainable” and “what do we mean by sustainable”?

Self-sustainability generally implies that a population can remain genetically and demographically healthy without further importation. For the time being, the “default” criterion for genetic self-sustainability of zoo populations is that the captive population be able to maintain 90% of the genetic diversity of the wild population for 100 years without further imports. The demographic factor is equally important and is a precondition for genetic sustainability. Genetic diversity comes “wrapped up” in living individuals. A population that is losing individuals is therefore always losing gene diversity – when the animals are gone, the genes are gone.

Are EAZA bird and mammal populations demographically self-sustainable? Demographic self-sustainability implies that, on average, the number of births and hatches is as high, or higher, than the number of deaths (and, where relevant, exports). If imports into the EU are becoming (more) restricted, then we will have to rely on births and hatches in EAZA collections or high quality private and/or non-EAZA collections in the

EU to counteract deaths and removals of individuals from the population for other reasons. This is easy to say but hard to track. Although it is encouraging that the number of EAZA institutions joining the International Species Information System (ISIS) has rapidly increased over the years, some zoos are not yet members; not all zoos have entered all their data; data are not always up to date; and the origin of individuals is not always clear. Analysing the EAZA data in ISIS will therefore be time-consuming and not always successful. We therefore decided to evaluate the EAZA EEP and ESB bird and mammal populations by utilising the SPARKS studbook databases. Furthermore, one would normally expect that more of the managed populations are self-sustainable than are non-managed populations.

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Methods

A total of 91 bird and 177 mammal populations were analysed. The datasets used for analysis were those submitted to ISIS that were no more than two years out of date. The “EAZA.fed” file in SPARKS was used as a filter to include only individuals in EAZA institutions in the analysis. This approach tells us what can be achieved with only the individuals in EAZA member institutions.

Those studbooks/programmes that manage their species at the subspecies level were analysed at subspecies level. Hybrids were eliminated from the analysis. Species or subspecies that we knew (e.g. from Regional Collection Plans [RCPs]) were no longer recommended to be kept in EAZA institutions were also omitted.

The degree of self-sustainability of the populations was assessed based on five criteria. For each population, a score card was completed showing how many of the self-sustainability criteria it failed (Fig. 1):

- Does the population have less than 50 total individuals? Populations with very low numbers of animals have a high probability of going extinct purely due to random demographic events and catastrophes. Therefore, even without taking genetics into account (which would obviously add to the threat), populations with less than 50 individuals have a high probability of extinction.
- Is the proportion of breeding individuals of the total population lower than 25%? The ratio of the effective population size (N_e) to the true population size (N) is an important indicator of the genetic and demographic health of a population. It indicates how “effective” the true population size can be in terms of preserving the population. For example, you might have 500 individuals right now, but if for some reason only five of those can breed,



Fig. 1

The Sumatran orangutan (*Pongo abelii*) was among the bird and mammal species that did not score on any of the five criteria, implicating that the population is self-sustainable according to the parameters set in this study.

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the effective size of the population would be much smaller and the situation would be much less secure than the total population size would lead you to believe. Important factors influencing the effective size of a population are the number of breeding animals, sex ratio, family sizes and fluctuations in population size. Because reliable calculations of N_e created problems for studbooks with a high proportion of the pedigree unknown (which was the case for a large proportion of pedigrees), we used the number of breeding animals in the population as a crude alternative for N_e .

- Is the PM2000 lambda smaller than 1? In other words, is the growth rate (i.e. lambda) lower than the replacement rate, or does the population have a declining projected growth rate based on the age-specific birth and mortality rates?
- Is less than 85% pedigree known? If less than 85% of the overall population's pedigree is known, the genetic calculations are unreliable and it is not possible to draw conclusions about the genetic status of the population. Even if the studbook keeper or EEP coordinator is somehow able to improve knowledge about the



pedigree, this would not necessarily result in a higher percentage of gene diversity retained. If the unknown portions of the pedigree turn out to be related to already well-represented founder lines, gene diversity might even decrease.

- Does the population contain less than 30 known founders? We stated above that the current “default” criterion of genetic self-sustainability for captive populations is the ability to maintain 90% of the gene diversity of the wild population in the captive population for 100 years without new founder imports. However, since many pedigrees are more than 15% unknown, a reliable number for gene diversity retained could not be calculated (see criterion 4). For that reason, we decided to use the number of founders in the known part of the pedigree as an alternative criterion for genetic sustainability.

Sampling and genetic theory indicates that 20 unrelated wild individuals are sufficient to capture 97.5% of the gene diversity of the wild population within the founder population (Crow & Kimura 1970; De Boer 1989; Lacy 1994; Frankham *et al.* 2002). In practice, however, contributions of founders to the living descendant population are uneven and many founders may have only marginally contributed to the genetics of the living descendant population. For that reason, quite a few more than 20 founders are often necessary. The cut-off point was set at 30 founders because most EEPs and ESBs that had more than 85% pedigree known and that could maintain 90% of gene diversity for 100 years had at least 30 founders (and many had more than that).

In order to calculate the score card criteria, an MS Excel spread sheet was created to hold various parameters for all the bird and mammal studbooks.

Table 1.
Sustainability summary score card for EAZA bird and mammal EEP and ESB populations.

Criterion	Birds	Mammals
(1) Population of less than 50 living individuals	36%	28%
(2) Proportion of individuals breeding lower than 25%	73%	25%
(3) PM2000 growth rate lower than 1 (i.e. decline)	37%	16%
(4) Less than 85% of pedigree known	78%	52%
(5) Less than 30 founders	94%	85%

Results

The average bird studbook has the following characteristics:

- 90 living individuals at 25 institutions in ten countries;
- 40 living females;
- less than 50% of the pedigree can be traced;
- 21% 30-day mortality, 32% first-year mortality;
- 20% of the population is breeding.

The average mammal studbook has the following characteristics:

- 128 living individuals at 27 institutions;
- 69 living females, 55 living males, four unknown sex individuals;
- 67% of the pedigree can be traced;
- 28% 30-day mortality, 36% first-year mortality;
- 31% of the population is breeding.

In Table 1, the scores for each of the five self-sustainability criteria are presented for the bird and mammal populations. From the table, it can, for example, be concluded that 36% of the EAZA bird EEP and ESB populations have less than 50 living individuals. Or that 52% of the EAZA mammal EEP and ESB populations have less than 85% known pedigrees. Overall, 75% of bird programmes and 30% of mammal programmes fail on three or more criteria.

Conclusions

Although the results of the mammal populations are overall somewhat better than those of the bird populations, there is still plenty of room and serious need for improvement. A high proportion of populations fail two or more criteria and many programmes that fail a certain criterion, fail it by a relatively large margin. In addition, we are uncertain of the status of the non-managed bird and mammal taxa, but it seems likely that the majority of these populations are in worse shape than the EEP and ESB populations.

Such a rapid standardised assessment of a large number of populations has of course some limitations. For example:

- Some species may in reality be managed at world level, whereby this larger population has to be self-sustainable, not the EAZA population by itself.
- Some species-specific characteristics cause some of the cut-off points used to be unsuitable for the species. For example, species with longer generation times may be able to be genetically self-sustainable with fewer founders, while species with shorter generation times might need more.



- The standardised time period analysed may miss important events in a certain population's history. For example, a population analysed from 1980 until the current date may show a high growth rate for most of that period, but then a rapid decrease. The PM2000 growth rate obtained from a life table based on that overall time span may reflect a positive or stable projected growth rate, whereas in reality the population is currently declining and *vice versa*.
- As with any kind of cut-off point employed, some species may just miss the cut-off, which may in reality not be significant in terms of sustainability.
- Taxon Advisory Groups (TAGs) may have decided that some populations do not need to be self-sustainable according to the criteria used for this analysis, for example because they are willing to accept the increased risk of extinction (the populations may in some ways be less important), because further imports from the wild are still possible (logistically, ethically, legally) or because the population represents the last individuals in the world and no additional genetic material exists.

Nevertheless, the scale of the problem suggests that the overall conclusions regarding the general level of self-sustainability of bird and mammal programmes will be little influenced by a few programmes shifting position on a few criteria.

Apart from the realisation that many of EAZA's managed programmes for birds and mammals are by and large not self-sustainable, this analysis has led to another important realisation. To be able to truly decide whether or not EAZA's breeding programmes are successful, we should not be measur-

ing whether each population is self-sustainable, but whether each population is achieving its specific goals as outlined by the TAG in the RCP. Only when it is clear what role each captive population should play, and what targets it needs to achieve to fulfil that role, can each programme be measured against those targets and can the level of management necessary to reach those targets be defined.

This then leads to the realisation that we lack a sufficiently sound basis for setting priorities and determining roles and targets in the RCPs. It is at present not clear:

- Which species would benefit from *ex situ* populations as part of their conservation strategy, and how to decide that in a standardised and transparent way.
- How this decision-making process may vary depending on whether or not the species is threatened (and to what extent), whether or not the species is already in captivity, how feasible success is and what resources it would take, etc.
- How the priorities for conservation and for other zoo roles (e.g. education, entertainment, research) should be balanced.

In collaboration with other regional zoo associations, WAZA, the Conservation Breeding Specialist Group (CBSG) of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN), other IUCN/SSC Specialist Groups, ISIS and other conservation organisations, EAZA is therefore playing an active role in the various initiatives that are currently underway to create the necessary methods, tools and paradigm shifts to ensure that we increase our contribution to conservation through the intensive management of populations, and achieve more secure long-term populations for our collections.

Acknowledgements

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Status of Association of Zoos and Aquariums Cooperatively Managed Populations

Introduction

The Association of Zoos and Aquariums (AZA) is one of the many zoo associations worldwide that is undergoing a renewed focus on the sustainability of its managed populations. Sustainability is generally characterised by population biologists as the ability of a population to maintain a stable size and healthy age structure through reproduction (if self-sustaining) or other means (importation from private facilities, other regions or the wild). Genetic diversity is often measured as a component of population viability, as genetically diverse populations are likely to be more resilient in adapting to environmental change and avoiding the negative effects of inbreeding depression (Frankham *et al.* 2002). Maintaining both demographic stability and gene diversity have long been part of cooperatively managed programmes in zoos and aquariums, including AZA's Species Survival Plan[®] (SSP) and Population Management Plan (PMP) programmes. Here, we present an examination of the current demographic and genetic status of AZA cooperatively managed Animal Programmes and an assessment of key indicators of the viability of these populations.

As in other regions, population management in AZA depends upon a network of volunteer studbook keepers and species coordinators to collect, compile and validate pedigrees and life histories (birth/hatch dates and locations, transfer events, death dates and locations) for each individual of a cooperatively managed population and to coordinate animal and institutional needs with population goals. AZA is unique among regional zoo associations in having a staff of full-time professional population biologists assisting its cooperatively managed programmes. The AZA Population Management Center (PMC) based at Lincoln Park Zoo in Chicago, IL provides a bridge between studbook data and the management plan by helping to improve data quality, conducting demographic and genetic analyses and integrating institutional needs and husbandry information into breeding and transfer recommendations. The transformation of studbook data into management plans is an essential step in population management, without which cooperative efforts towards population stability and genetic management are likely to falter. Since its inception in 2000, the PMC has provided scientific and logistical support to approximately 60% of AZA's Animal Programmes, producing more than 800 management plans for over 300 populations. Some of the remaining populations are assisted by a small number of volunteer advisors, but over 150 AZA Animal Programmes have yet to receive any formal population management advice because they are newly designated, awaiting assistance from a population biologist, or lack a studbook database or a species coordinator.

Despite all the organisational, institutional and scientific resources dedicated to these cooperatively managed programmes, AZA populations are facing challenges similar to zoo populations in other regions – limited space for expansion, loss of gene diversity, declining population sizes, incomplete data with which to manage the populations – all of which may threaten the ability of AZA-accredited zoos to meet their exhibit, education or conservation goals with these species. In an attempt to characterise the viability of AZA-managed populations, basic descriptive information was gathered from studbooks and management plans for 428 populations and results of demographic and genetic analyses conducted by the PMC have been summarised for 319 populations. Of particular interest are measures that provide insight into genetic and demographic health, such as founding population size, current population size, proportion of animals breeding and recent population growth rates.

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Genetic Status of AZA Populations

Genetic analyses provide estimates of a population's gene diversity, which is an indicator of its adaptive potential. Estimates of gene diversity require pedigrees of living animals tracing back to the wild founders, and therefore only reasonably complete pedigrees should be trusted for accurate genetic calculations. For some populations with incomplete pedigrees, the best efforts are made to develop, in coordination with species experts, reasonable assumptions regarding number of founders and likely relatedness among unknown pedigreed animals.

Of the populations with reasonably complete pedigrees for which genetic calculations could be conducted (264), the median number of founders is 15, below the minimum 20 founders generally recommended to provide a good foundation of gene diversity (Soulé *et al.* 1986). Gene diversity estimates indicate a median of approximately 92% for these populations as of the most recent analysis date, and falling to 67% in 100 years. Approximately 38% of AZA populations have a current gene diversity that falls below the 90% benchmark selected to represent the threshold between sufficient adaptive potential and increasing inbreeding risks (Soulé *et al.* 1986). While genetic diversity is often utilised to describe the health of a population, demographic factors are more often the cause of immediate and obvious struggles for population viability, and act synergistically to either improve or further decrease a population's genetic outlook.

Demographic Status of AZA Populations

The most basic demographic descriptor is population size. The median population size of the 428 AZA Animal Programmes with studbooks or published breeding and transfer plans is 66 individuals (Fig. 1). Across species, approximately 39% of populations are comprised of 50 or fewer individuals. Populations of this small size are more vulnerable to variations in birth/hatch rates, death rates and birth/hatch sex ratios (Lande 1988), and can more rapidly lose gene diversity and encounter effects of inbreeding depression (Frankham *et al.* 2002). In addition, non-biological constraints caused by logistical factors or lack of cooperation among participating zoos can easily further impede the success of populations as small as these.

The sustainability of closed populations (i.e. those without access to additional founders) is heavily dependent on reproduction. The proportion of animals breeding in a population reflects the husbandry expertise, breeding success and intensity of management focused on a species. While these factors are correlated with the demographic health of a population, the proportion of animals breeding is also indicative of the efficiency at which gene diversity is retained over time. As more individuals breed, their cumulative genetic contributions are passed on to the next generation, thereby allowing the population to better retain gene diversity over time. This genetic and demographic metric can be estimated by calculating the ratio of the number of males and females with living offspring in the population (N_e , effective population size) to the total population size (N). Ratios of N_e/N may be constrained by breeding sex ratios or family sizes (e.g. lower in populations with polygamous breeding systems or large groups with many non-breeding individuals).

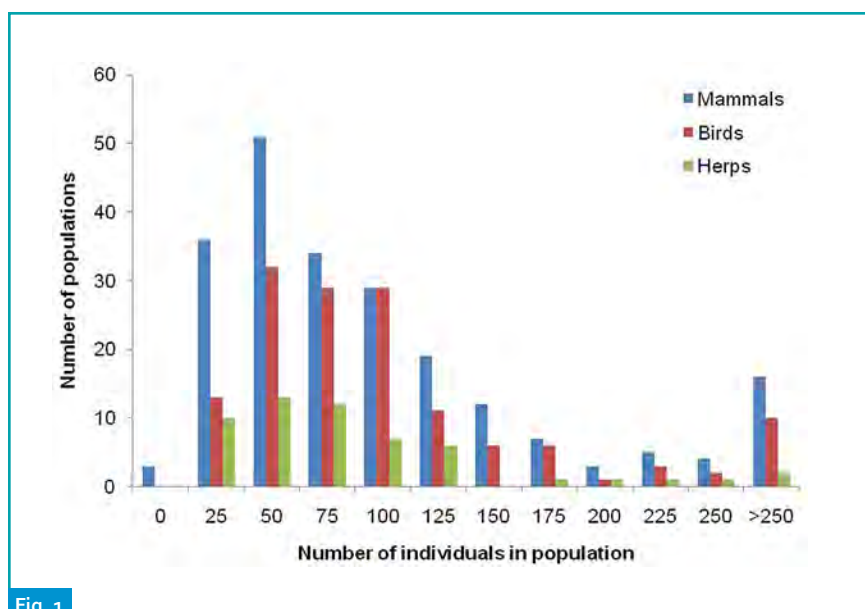


Fig. 1

Distribution of population sizes of mammal, bird and reptile/amphibian ("herp") programmes cooperatively managed by AZA ($N = 428$).



or be temporarily exaggerated in very small populations with large numbers of animals breeding. Species with longer reproductive spans, faster growth rates, monogamous breeding systems or fewer limitations on producing or holding offspring will be able to achieve higher effective sizes and therefore achieve better gene retention.

In 255 AZA populations for which effective population size ratios (N_e/N) could be calculated, values varied widely from 0.0 to 0.62 but exhibited a median of 0.25; in other words, successful breeders commonly comprise around 25% of AZA-managed populations. Trends among taxonomic groups appear to reflect the previously mentioned biological and management differences, with mammal populations exhibiting slightly higher effective population sizes (median $N_e/N = 0.28$, $N = 138$) and reptiles and amphibians exhibiting lower effective population sizes (median $N_e/N = 0.12$, $N = 34$); avian populations show intermediate effective population sizes (median $N_e/N = 0.24$, $N = 93$).

The population growth rate, or change in population size from one year to the next, is another important indicator of the demographic health of a population. Depending on population goals and available space, either a stable (approximately 0%) or an increasing growth rate is desirable for population viability. In closed populations, the population size is maintained or increased solely through reproduction. In open populations, animals may be brought in from private facilities, other regions or the wild to continue to maintain the population size and offset deaths. In an examination of recent growth rates (rates for the five years prior to the most recent PMC planning analyses) of 289 AZA cooperatively managed populations, approximately 40% were decreasing, 15% were stable and more than 44% were increasing in population size (Fig. 2). Among taxonomic groups, birds and reptiles/amphibians have slightly lower proportions of decreasing populations (34% and 35%, respectively) than mammals (45%).

Improving the Status of AZA Populations

Characterising the current demographic and genetic health of managed populations is a transparent and common way to assess whether cooperatively managed programmes are effective. However, there has been little examination of the process by which our populations are managed – through breeding and transfer recommendations. In the coming year, AZA will begin to use an Internet-based system developed at Lincoln Park Zoo called PMCTrack to measure the effectiveness of Animal Programmes by tracking and quantifying the outcomes of breeding and transfer recommendations distributed by SSP programmes. By tracking outcomes and surveying institutional representatives to determine the reasons surrounding why breeding and transfer recommendations were not fulfilled, this system may reveal factors correlated with successfully managed populations. Eventually, this information should provide insight into improving the process of managing populations and ultimately, improving the viability of zoo populations themselves.

While the management and husbandry issues that foster or hinder population viability may not be entirely clear, the basic demographic and genetic factors that contribute to healthy populations have been well studied and are strongly correlated with space. Assuming that populations with reasonable founder bases and effective sizes need to grow to least 150–200 individuals to remain healthy (Soulé *et al.* 1986), there is simply not enough space to keep *viable* populations of all species currently managed in zoos. Exhibits have become larger and provide space for fewer individuals, and interest in particular species varies over time. Multiple species within a taxonomic group (e.g. old world monkeys, bears, ungulates) and across taxonomic groups (e.g. canids, felids) often compete for the same space. While managers wait for

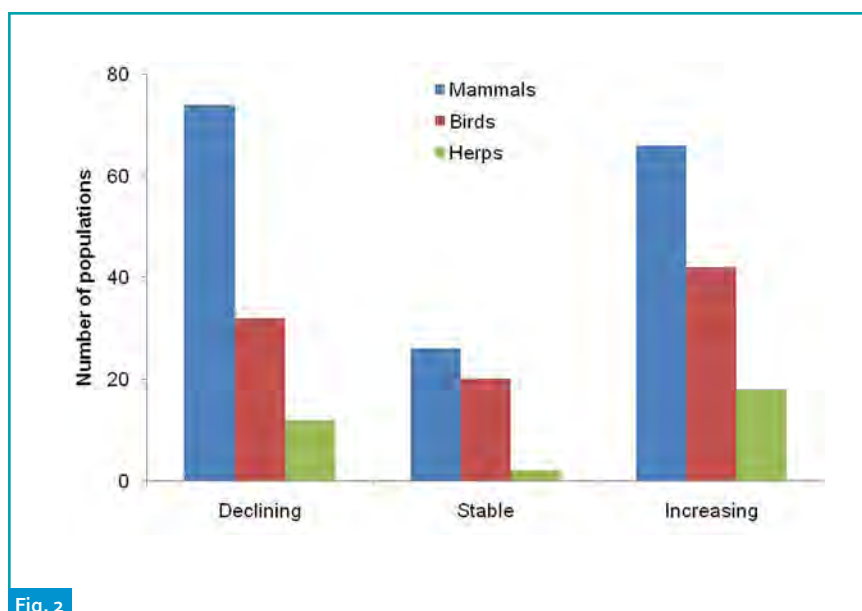


Fig. 2

Distribution of recent population growth rates (five years prior to analysis date) for mammal, bird and reptile/amphibian ("herp") programmes cooperatively managed by AZA and analysed by the PMC ($N = 289$).



additional facilities and resources, the age structures of these populations become destabilised as breeding is decreased and individuals age and become reproductively senescent.

Rather than being left to chance or whim, a prioritisation system is desperately needed to select the species that zoos find most important for achieving their missions (e.g. conservation efforts, education goals, exhibit needs) and to phase out the species that are not serving a role valued by the majority of zoos. The zoo community should critically examine cooperatively managed populations and other species held in zoos, clarify the roles of these populations, define specific goals and outline realistic objectives required for the populations to meet those goals. Regional Collection Plans (RCPs) have been used in multiple zoo regions to recommend and prioritise cooperatively managed species, typically organised at the level of taxonomic orders. However, it may be more useful to examine species outside of taxonomic groupings and with an eye towards functional categories (e.g. exhibit needs, behavioural requirements, education messaging), as space at modern zoos is often fluid with the same exhibit being capable of housing different species across multiple orders. Although quantifying the space available to hold species is notoriously difficult, space assessments and interest need to be part of any prioritisation scheme so that realistic goals can be set. RCPs and other such species prioritisation schemes may then consider many factors including, but not limited to, the number of holding institutions, exhibit and education value, conservation status, husbandry expertise and success, costs and a connection to *in situ* conservation programmes.

In addition to better management tools and metrics to assess and prioritise populations, greater attention to removing barriers to global cooperation is needed. In particular, as the scientific community recognises the vital role of zoos in protecting biodiversity (Conde *et al.* 2011), it is crucial that governments and regulators recognise the importance of moving animals and gametes for building sustainable zoological populations and respond with more favourable permitting processes if our potential is to be fully realised.

While this summary of the status of AZA Animal Programmes may highlight the demographic and genetic challenges that these populations face, it may also serve to illustrate the biases of human perception and the tendency to nostalgically view the past in an unrealistic positive light. For most of the demographic and genetic indicators discussed, there are as many populations doing well as there are doing poorly. It may be that what is currently being observed is a natural waxing and waning of species based on existing conditions (e.g. space, interest, availability). Species that were once common and familiar in zoos of a prior generation may no longer be suitable or sustainable in modern zoos that are facing increasing barriers to importing animals from other regions and are building larger, more naturalistic, mixed-species exhibits that provide space for fewer individuals. As exhibits increase in size to meet animal welfare and exhibit needs, the number of species that zoos can maintain at a sustainable population size decreases. If we try to come to terms with the realities of modern zoos and continue to examine the reasons for both successes and failures, we will find that many species thrive in these conditions. By shifting management priorities in response to these variables, we may find that we can tip the balance towards creating sustainable zoo populations for generations to come.

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Captive Populations and Genetic Sustainability

Introduction

Conservation biologists have long been interested in the questions of population viability and sustainability. The concept of Minimum Viable Population (MVP) size was first developed to answer the question of how large a population needs to be to survive. Quantitatively, MVP is usually expressed as: "How large does this population need to be to have 95% (or some similar percentage) chance of surviving for 100 years (or some moderately extended timeframe)?" Computer modelling (population viability analysis [PVA]) is typically used to answer this question, the reliability of which critically depends on the amount of detailed data available for the population. PVA has now become a standard tool for use in wildlife conservation.

Soon after the development of organised captive breeding programmes in the early 1980s (e.g. the European Endangered Species Programme [EEP] of the European Association of Zoos and Aquaria [EAZA] and the Species Survival Plan [SSP] of the Association of Zoos and Aquariums [AZA] in North America), zoo biologists also began wondering about MVPs for captive populations. How large should our captive populations be? We asked a number of prominent conservation, wildlife and zoo biologists to address this question at a workshop hosted by the Smithsonian National Zoo's Conservation and Research Center in 1986. Their recommendation was: large enough to maintain 90% of the source population's genetic diversity for 200 years (Soulé *et al.* 1986). The authors clearly recognised that these metrics were somewhat arbitrary, but nevertheless felt that they were in the right ballpark. *Ninety percent* because this represents "the zone between a potentially damaging and a tolerable loss of heterozygosity". *Potentially damaging* because a loss of 10% of the genetic diversity is roughly equivalent to an increase in the average inbreeding coefficient in the population of 10% and approaches the level at which individuals are as

related as half siblings, and we know that inbreeding decreases the health of populations (Frankham *et al.* 2010). *200 years* because it "is a reasonably conservative temporal horizon... A longer time ignores the exponential rate of progress in biological technology". The reference to biotechnology being the benefits of realised and expected future advances in the science of storing and regenerating embryonic cells, and hence a lesser need for living captive populations to act as genetic reservoirs for threatened species. The authors allowed for disagreement with these metrics and proposed them as a first step in the process of determining MVPs for captive populations. Additionally, while the metrics are genetic, it was assumed that genetic criteria for viability would be stricter than demographic criteria, and any population that satisfies the genetic goals would very likely satisfy any demographic goals as well (such as those above for MVPs).

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Size of Captive Populations

So, how large do populations need to be to meet the “90%/200 Year” goal? It turns out they need to be pretty large. The size depends on the generation length of the species (the shorter the generation length, the larger the size required), number of founders (fewer founders require a larger population size), how rapidly the population can grow (slow growth requires a larger size) and how well the population has been and will be managed (the less intensively, the larger the size required). For example, to meet this goal the golden lion tamarin (*Leontopithecus rosalia*) population (generation length of six years, population growth rate potentially 8% per year, 47 founders – which is an unusually large number of founders) would need to grow to and maintain over 850 individuals. A species with similar characteristics except with a generation length of three years would require over 1,800 individuals (Fig. 1). This is one of the rare cases in conservation where species with longer generation lengths have an advantage; since gene diversity is potentially lost during reproduction with each generation, species with longer generation times will experience fewer generations and therefore less genetic loss over the same time period. These required population sizes are quite large given the number of species that rely on conservation breeding as a core part of their conservation planning. Given the limited resources of zoos, managing larger populations means conserving fewer species, leading to hard decisions regarding which species to conserve and which to abandon.

It was for this reason that in the mid-1990s, AZA modified their recommended goals to retain 90% of the source population’s gene diversity for only 100 years. There simply was not enough space for enough species to meet the 200-year criterion, thus

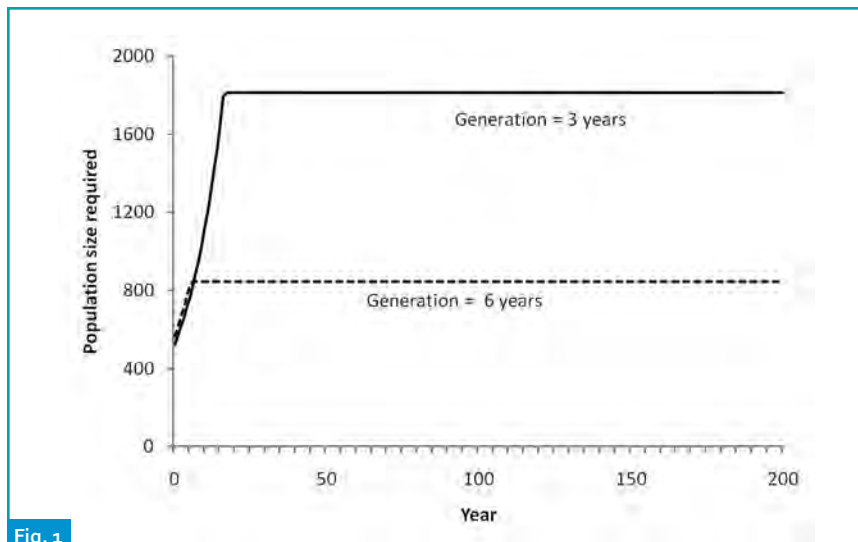


Fig. 1

Population size required to maintain 90% of genetic diversity for 200 years. Species like the golden lion tamarin (generation length of six years) requires about 850 individuals; a species with similar characteristics, but a three-year generation length, would require about 1,800 individuals.

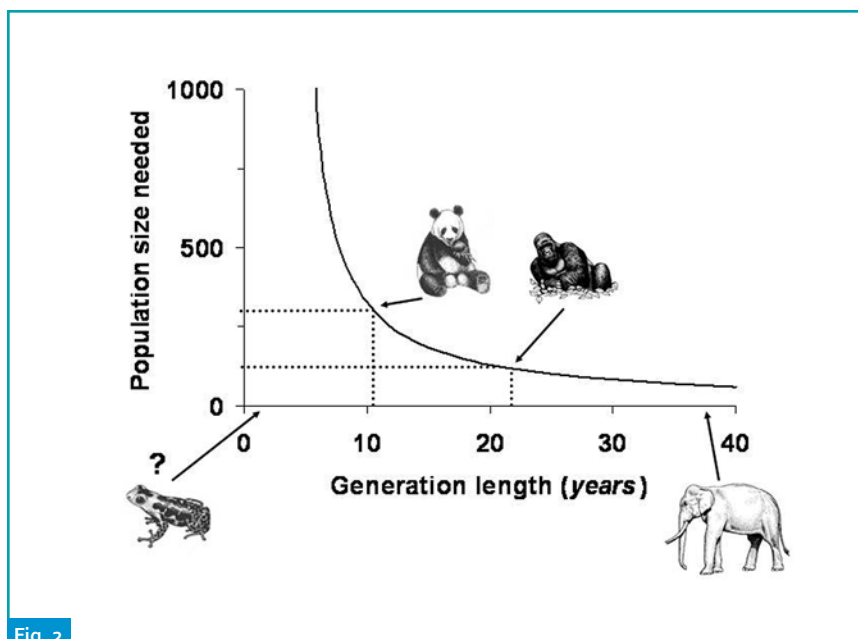


Fig. 2

Population size required to maintain 90% of genetic diversity for 100 years for different species (modified from Frankham *et al.* 2010). Population sizes for species with very short generation lengths (e.g. amphibians) may require extremely large population sizes to meet this goal.

sustainability goals were relaxed. This revision makes a substantial difference. In the golden lion tamarin example above, meeting the 100-year goal “only” requires a population of about 420 rather than 850 individuals. Fig. 2 shows the approximate popula-

tion sizes needed for species of different generation lengths (making some simplifying assumptions).



The revised “90%/100 Year” goal is now used regularly for population planning in conservation breeding programmes, although a majority of the officially recognised programmes do not have sufficient space to meet even this objective (Baker 2007; Lees & Wilcken 2009). Nevertheless, it is typically accepted as the standard towards which programmes strive. For example, AZA has even recently used it as a primary criterion upon which to base their new categorisation of their breeding programmes (e.g. “green” programmes are those that appear to be able to reach that goal). Thus, the goal of “90% for 100 Years” arguably seems to have become an operational definition of sustainability for captive populations.

Genetic Sustainability of Captive Populations

But is “90%/100 Year” really a sustainability goal? As Robert Lacy reminded us at a recent workshop on Intensively Managed Populations for Conservation in San Diego in December 2010, no, it is not. In fact, it is the opposite. Accepting a 10% loss and setting a timeframe of 100 years are both counter to the concept of sustainability. Depending on the source, sustainable is defined as being able to be maintained at a certain rate or level or by avoiding depletion of a resource. Tolerating a 10% loss in the gene pool per century is hardly sustainable. And what happens in the year 2111, 100 years from now? Can we count on the technology to which Soulé *et al.* (1986) referred to be in place? Advances have not been as rapid as had been predicted. Thus, the “90%/100 Year” goal is certainly not a sustainability goal, but rather a goal that specifically allows for loss, acknowledging depletion.

If the “90%/100 Year” goal is not a genetically sustainable goal, then what is? Conservation geneticists have debated this extensively (Frankham *et al.* 2010). With sustainability being

defined as maintaining a population large enough so that genetic diversity is not depleted, then the population has to be large enough so that the rate of loss of gene diversity due to genetic drift (i.e. the random process of passing genes from parents to offspring, causing changes in gene frequencies between generations) is offset by the rate of increase in genetic diversity, added via mutations (the ultimate source of all genetic variation). Since mutation rates are very low (e.g. 10^{-4} to 10^{-5} per locus per generation for microsatellite loci; Frankham *et al.* 2010), the rate of loss due to genetic drift has to be correspondingly very low. And since genetic drift is inversely proportional to population size, the population sizes have to be very large.

In genetics, population size is best expressed as an *effective population size* (N_e), defined as the number of individuals in an ideal population that loses genetic diversity at the same rate as the real population. An ideal population is a theoretical population that breeds randomly, and all animals can breed with each other and with themselves. It is a useful concept because we can accurately predict, using population genetics theory, how the genes in an ideal population will behave under varying conditions. To understand the genetics of real populations, we compare them to ideal populations. For example, if a population of 200 wombats loses genetic diversity at the same rate as an ideal population of size 52, then we say the *effective size* of the wombat population is 52. The wombat population is behaving like an ideal population of 52. So it is a population's effective size that determines how it behaves genetically, not its actual census size. How N_e is calculated is beyond the scope of this article, but N_e can be estimated for most captive populations. Of particular interest is the ratio of a population's effective size and its census size (N_e/N), which allows one to calculate a population's census size given its effective size, and *vice versa*.

To return to the question of how large populations need to be to be genetically sustainable (i.e. suffer no loss of genetic diversity), the answer appears to be between N_e of 500 and 5,000 (Frankham *et al.* 2010). This is regardless of whether the population is in the wild or captivity. What does depend on whether the population is wild or captive is how its effective size translates into its census size. Wild populations are typically not managed genetically, have uneven sex ratios, fluctuate in size and have some breeders that produce more offspring than others, all of which decrease a population's effective size. Estimates of effective sizes in wild populations are on the order of 10% of census size ($N_e/N = 0.11$; Frankham *et al.* 2010). Thus, genetically sustainable wild populations need to be about ten times the effective size, or 5,000 to 50,000 individuals. What about captive populations? Although no extensive surveys have been conducted, population management plans typically report N_e/N as being between 0.25 and 0.30 – much higher than wild populations, primarily because captive populations do not fluctuate in size as much as wild populations and, presumably, because of population management. Thus, to be genetically sustainable, captive populations need to be on the order of 1,700 to 20,000 animals. Clearly this is not an option for the vast majority of species under conservation breeding and may be only possible for invertebrates and small vertebrates that can be housed en masse in breeding centres. Our captive facilities simply do not have the capacity to maintain genetically self-sustaining populations. For that matter, neither do many if not most wildlife reserves.

Possible Ways Forward

How do we deal with this challenge? We need to recognise that conservation breeding alone cannot maintain genetically sustainable populations, and we should not claim that it can. This includes recognising that the goal of “90%/100 Years” is not a goal for sustainability, but a goal that explicitly recognises our lack of ability to maintain genetically sustainable populations. It means that we will be challenged with genetic deterioration in captive populations in the form of accumulating inbreeding depression and adaptation to captivity, the former impacting the health and welfare of our populations and the latter impacting the utility of these populations for future conservation rescue efforts. These are not new concerns, but they are concerns that will not dissipate even if we were to achieve the goal of “90%/100 Years”. Although these genetic threats will not necessarily lead to population extinction, accumulation of enough inbreeding significantly increases the chances of this (Frankham *et al.* 2010).

Given this, we need to do a better job at conservation breeding. If zoos, aquariums and related facilities are to be seen as legitimate contributors to species conservation, we need a more successful conservation breeding model or paradigm. We need to expand the size and scope of our populations by managing multiple, interacting populations. Conway (2011) calls for sharper focus of these efforts, including managing our captive populations mutually with wild populations. Captive populations should be managed globally when possible, not as isolated regional populations. Integrated management of multiple populations will increase census (and therefore effective)

population size and potentially provide increased genetic diversity, as compared to smaller, isolated populations. We also need to manage our populations more effectively for conservation – compliance with population management recommendations is not what it should be. The current paradigm of managing a fragmented captive population among multiple facilities, each one holding only a breeding pair, is not working (Baker 2007; Lees & Wilcken 2009; Conway 2011). We have it backwards. Rather than designing conservation breeding programmes to meet our public exhibit zoo-centric infrastructures, as we do now, we instead need to design the facilities to meet the goals of our conservation programmes. This was done for the black-footed ferret (*Mustela nigripes*) conservation breeding programme with the dedicated breeding centre at Sybille, WY, and there are plans to use similar breeding centres for cheetahs (*Acinonyx jubatus*) by the Conservation Centers for Species Survival (C2S2), a consortium of North American zoos with large land holdings.

Ultimately, we need a shift in thinking – a refocusing and recommitment by zoos to serve as effective conservation centres for the world’s threatened wildlife species. The past year has seen a series of workshops that have begun to raise these issues, and many are poised to begin tackling these challenges we face. Let’s hope the momentum continues.

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Mate Choice as a Potential Tool to Increase Population Sustainability

The Sustainability Problem

The sustainability of populations has become an important consideration for the zoo and aquarium community. In their analysis of 87 zoo mammal populations, Lees & Wilcken (2009) found that 52% were not breeding to replacement and that 67% fell below the threshold of 200 animals recommended by Baker (2007). Conway (2011) pointed out that new policies and practices in zoo collection management, including more specialisation and focused propagation efforts, are needed if zoos are to fulfil their conservation potential. Regional zoo associations are examining possible reasons for the unsustainability of their populations, but one clear factor is the failure of many assigned pairs to reproduce, often due to pair incompatibility. The typical reaction is to assign another breeding partner, often requiring the transfer of an animal to or from another location. This dating game may finally result in a successful match, but meanwhile valuable time and reproductive opportunities are lost.

Female Choice and Reproductive Success

In nature, many animals are able to choose their mates and the importance of female choice (females choosing their mates) has been documented in many different taxa (Asa *et al.* 2011). The factors affecting mate choice are not always apparent, but allowing animals to choose can increase pregnancy rates, litter sizes and offspring survival. There are many steps in the reproductive process, from courtship through rearing young to independence, and it appears that mate choice can affect most if not all of them. Most obviously, compatible pairs are more likely to copulate. A female that rejects mating attempts from a particular male will not conceive unless forced, but even when forced, females of at least some species can impede or prevent reproduction. Best studied in birds, females that mate with non-preferred males can eject sperm or even influence the ability of sperm to fertilise ova. Females of some species influence embryo survival and litter size by restricting nutrients or differentially allocating hormones. Females can also withhold parental care and affect survival of offspring that result from non-preferred matings.

Enhancing animal wellbeing and promotion of natural behaviours are goals of modern zoos. Allowing animals to select partners can contribute to the wellbeing of those individuals and better simulates their natural mating behaviour, contributing to something we sometimes refer to as the "happy factor". Happy females (i.e. happy with their partners) are more likely to mate, conceive, incubate or carry a pregnancy to term and more likely to be good parents, also improving offspring wellbeing as well as survival.

If mate choice is important to the reproductive success of most species, then preventing choice could be counterproductive to reaching programme objectives. The benefits from mate choice, for example higher birth or hatching rates and higher offspring survival plus enhanced animal wellbeing, are obvious. Higher reproductive success means higher probability of sustainability and faster growth to the population's target size, which helps to slow the loss of genetic diversity. Allowing animals to exhibit natural reproductive behaviours also reduces the unintentional selection for traits that are adaptive to certain captive environments, but not adaptive to more natural environments for the species.

Mate Choice and Population Genetics

However, allowing mate choice is not without risk and may undermine genetic goals if animals choose mates that are genetically over-represented in the population (Asa *et al.* 2011). Numerous studies have shown that females make good genetic mate choices in terms of their own individual fitness and under the conditions in which they are living. Such choices, however, may not result in maximum retention of genetic diversity in the population, balance founder representation or avoid loss of adaptations to wild environments, which are the primary goals of captive breeding programmes (Lacy 1994).

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As many population managers have found, the most genetically valuable animals in the population (i.e. the top priority animals for breeding) are not always the most successful breeders. Concentrating breeding efforts on such animals can reduce population growth and even lead to demographic instability and population decline. However, ignoring genetic factors and concentrating on good breeders only can reduce genetic variability and long-term population health and increase adaptation to captive conditions. Allowing mate choice by offering multiple genetically acceptable mates may be one tool to help balance demographic and genetic needs of a population and ultimately maintain higher levels of genetic diversity by increasing reproductive success while relaxing the necessity for imposing rigid genetic management.

Integrating Mate Choice and Genetic Management

The cues mediating mate preferences have not been determined for many species, but this need not prevent incorporating choice into breeding programmes. The simplest approach is to provide a female with access to several males and observe her reactions. Generally, females approach and spend more time with or near the preferred male; in addition, species-typical behaviours, such as sniffing or performing visual displays, may be apparent. The female can then be paired with that male for breeding. To minimise any negative impact on population genetics, the several males presented to the female could be limited to those considered to be genetically appropriate potential mates, with the hope that merely having a choice will be sufficient to influence her willingness to mate. It is important to note that sequential presentation of potential mates is not equivalent to allowing choice but is actually sequential mate rejection/



Fig. 1
Male cheetah scent marking on urine collector.
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Fig. 2
Female cheetah investigating male scent dispenser with male urine sample.
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acceptance. Studies have shown that females have highest reproductive success when they can assess their mate options simultaneously.

Housing and management constraints may limit the number of males that can be physically presented simultaneously; the feasibility and logistics of providing mate options also varies greatly among species. Assessing choice by substituting appropriate cues (proxies) for the potential mate himself (e.g. scent) is a possible alternative that has been successful in animal models ranging from mice to humans. For example, the preference of a female mouse is consistent whether she is presented with an assortment of males or their urine sample. Thus, rather than transfer a potential mate to a new location, his urine or other scent sample could

be sent first to assess the female's reaction before investing the resources, time and risk in transferring the male. As a first step in assessing the practicality of using urine as a proxy for the actual male, one of our graduate students confirmed that female cheetahs (*Acinonyx jubatus*) do investigate male urine samples and can use urine to distinguish between males of different genetic relatedness (Figs. 1 and 2; Mossotti 2010).

Managers might also be able to influence female choice by manipulating cues. Females of some species are more likely to mate with familiar males, so the scent of a partner that would fulfil programme goals could be presented before presenting the potential mate himself. In other species, high rates of scent marking stimulate a female, presumably by

representing male vigour and territory ownership, suggesting another approach to influencing choice. In some species, dominant males mark over scent marks of competitors and females prefer the male that marks on top. Managers could use this strategy to create a “winner” by adding scent samples sequentially so that scent from the male best for achieving population goals is added last. Females also can be influenced by the behaviour of other females and may prefer males that other females have chosen. Thus, appropriate social groups may facilitate mate acceptance, even acceptance of males that might not have been selected were the females housed individually.

Given the clear importance of mate choice in so many species, we believe the zoo community should consider incorporating choice in captive breeding programmes. This should be approached, however, in a careful and controlled manner. Not only is the phenomenon of mate choice very complex, but allowing mate choice could be challenging, both the logistics of offering choice and implementing choice so that it augments rather than hinders population management goals.

Recognising the complexity of this topic, a Mate Choice Symposium was held at Saint Louis Zoo in March 2010, where top scientists who study mate choice came together with zoo population managers, including studbook keepers, species coordinators and population management advisors. After a series of research presentations by the scientists summarising the mechanisms and consequences of mate choice across a wide variety of species, taxon-based working groups discussed the implications of mate choice, opportunities for incorporating mate choice in captive management and potential research projects to investigate these issues. Participants identified possible strategies for incorporating mate choice into our current breeding programmes, including: (1) using information on

mate choice to increase the reproductive success of genetically valuable animals; (2) providing multiple genetically acceptable mates rather than a single mate; (3) developing methods for assessing mate acceptability (via testing of odour or other cues) before actual animal transfer; and (4) considering alternate breeding strategies such as specialised breeding centres or inter-institutional management that optimises reproductive success combined with periodic exchange of individuals.

The results of this symposium along with two smaller, related workshops led to the identification of three proposed research projects that span a breadth of taxa, breeding systems and captive management to address issues related to incorporating mate choice into zoo-managed programmes. These studies are designed to evaluate the effects of allowing controlled mate choice within the following populations: a multi-zoo breeding programme for a high-profile species (cheetahs), a single-facility breeding centre (tanagers) and a controlled experimental population (mice). Funding is now being sought to support these proposed projects. It is hoped that such studies can serve as models to help guide the effective use of mate choice in zoo populations.

Allowing choice may improve reproductive success and, ultimately, programme effectiveness. A better understanding of mate choice can help population managers reach their goals for viable, genetically healthy populations, while potentially helping minimise selective changes to captivity and providing insight into developing a more effective breeding management strategy for captive animal populations.

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Zoos Can Lead the Way with *Ex Situ* Conservation

Summary

Zoos can play a key role in the management of threatened species that require the support of captive breeding for their survival. In this sense, it is important to have an accounting of how many at-risk species are already represented in zoos, which can inform future prioritisation efforts. We used data from ISIS and the IUCN Red List of Threatened Species to assess the conservation status and population size of terrestrial vertebrates in ISIS member institutions. Our results show that 15% of described species classified as threatened are represented in ISIS zoos. Zoos already hold important populations for certain threatened species, especially for mammals. However, the number of threatened birds and their population sizes are much lower, which is even more dramatic for amphibians, although almost one-quarter of their populations are above 250 individuals. The implementation of cooperative captive breeding programmes across large numbers of institutions is one of the more demanding actions where zoos as a global network could play a key role to support the conservation of some of the most threatened species.

Introduction

Zoos and aquariums face a major task if they are to be effective in preventing the extinction of some species. Habitat loss, overhunting and predation and competition from invasive species are some of the pressures that are driving species to extinction. Moreover, it is expected that these pressures will be exacerbated by future climate change. As a result, although the ultimate goal must be conservation in the species' natural habitat, captive breeding programmes may be the only short-term solution to avoid the extinction of those species whose populations are highly threatened. In fact, captive breeding played a major role in the recovery of 13 of the 68 species that had improved their conservation status in the last assessment (Hoffmann *et al.* 2010; Conde *et al.* 2011b). Thus, it is clear that while captive breeding is not a conservation goal in itself, it can be an important conservation tool.

Zoos can potentially lead the way with *ex situ* conservation efforts since they hold a large number of threatened species and employ staff with extensive experience of captive breeding techniques. However, without knowledge of which species, and how many individuals per species, zoos hold, it is difficult for the conservation community to appreciate the status of their "insurance populations". In this article, we outline the findings from our recent publication (Conde *et al.* 2011a), where we carried out a detailed accounting of zoo species using the freely available data from the International Species Information System (ISIS) and the Red List of Threatened Species published by the International Union for Conservation of Nature (IUCN).

ISIS is an organisation that holds the most extensive information on zoo animals, with more than 2.6 million individuals across more than 800 member institutions. Although ISIS does not represent all of the world's zoos, it has the best data available to estimate the representation of the planet's biodiversity in captivity. In Conde *et al.* (2011a), we matched the species-level data in ISIS zoos with the latest IUCN Red List data. The taxonomic matching was done at the species level for terrestrial vertebrates (i.e. mammals, birds, reptiles and amphibians). Where the ISIS and IUCN taxonomic names differed, we used the Catalogue of Life for taxonomic synonyms. The ISIS data were then mapped to obtain the distribution of threatened species across ISIS zoos.

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Terrestrial Vertebrates in ISIS Zoos

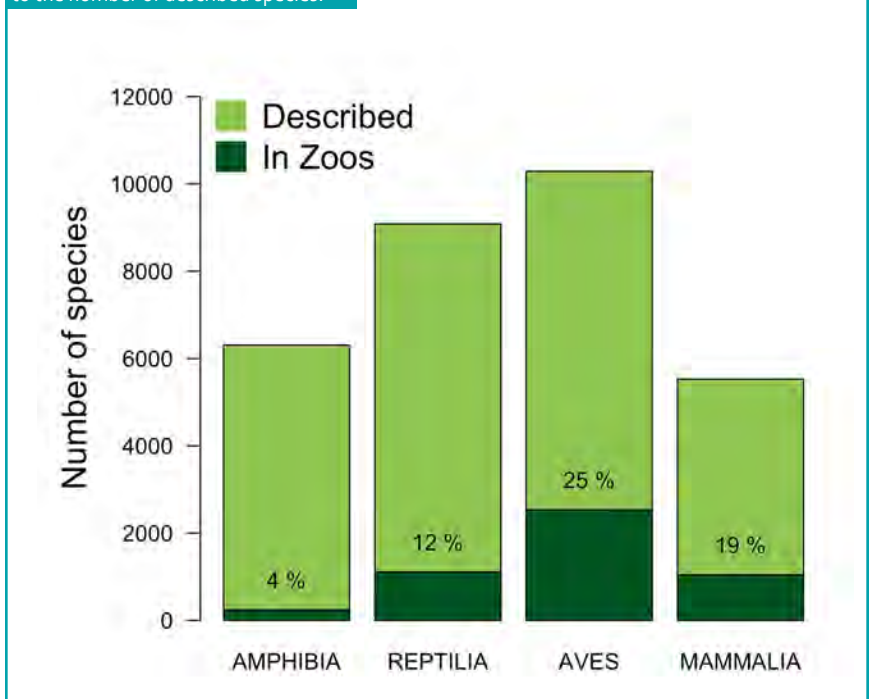
Conde *et al.* (2011a) found that one-quarter of the world's described bird species and almost 20% of its mammal species are represented in ISIS zoos. In contrast, the representation of reptiles and amphibians is considerably lower with just 12% and 4%, respectively (Fig. 1). The picture is slightly different when we focus solely on threatened species. Mammals have the highest representation, with 24%, 23% and 19% of species classified as Vulnerable, Endangered and Critically Endangered, respectively (Fig. 2). Although the bird collections account for one-quarter of all known species, the representation of threatened species is lower (Vulnerable = 17%, Endangered = 17%, Critically Endangered = 9%). However, the lowest representation of threatened species is for amphibians, with only 4%, 2% and 3% of species classified as Vulnerable, Endangered and Critically Endangered, respectively (41% of amphibian species are threatened and ISIS zoos hold only 4% of all described amphibian species). IUCN has so far only assessed the conservation status of 1,672 of the 9,205 described reptile species. From this incomplete survey, zoos hold 37%, 28% and 51% of species classified as Vulnerable, Endangered and Critically Endangered, respectively. As a whole, roughly one in seven threatened species of terrestrial vertebrates (15%) are represented in ISIS zoos.

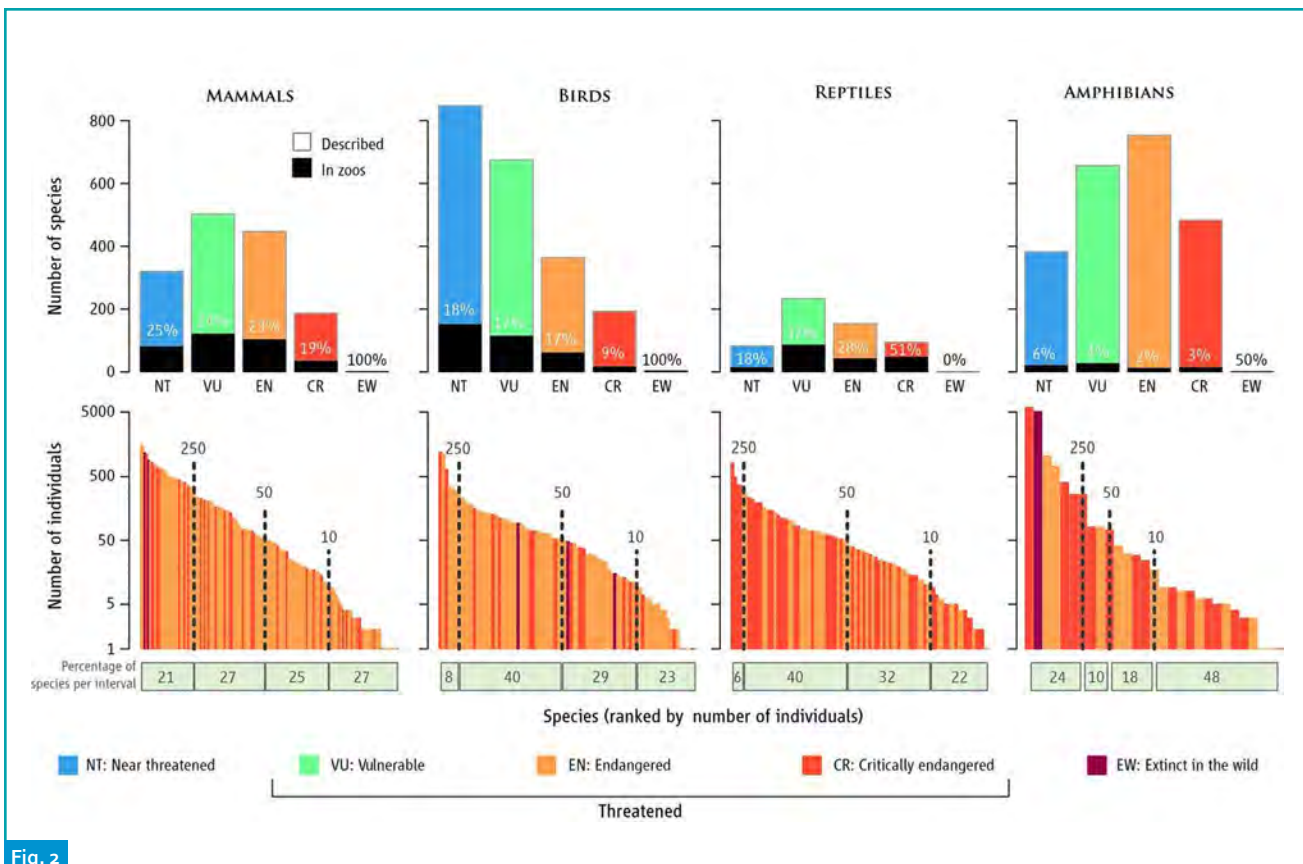
Although individual zoos usually do not hold large numbers of individuals of particular species of conservation concern, zoos as a global network hold important populations for some of the more highly threatened species. For example, almost one-quarter of the amphibian populations and 21% of the mammal populations include more than 250 individuals worldwide (Fig. 2). The figure is smaller for bird and reptile populations; only 8% and 6%, respectively, exceed 250 individuals.

The distribution of threatened species among the world's ISIS zoos does not coincide with the distribution of threatened species in the wild (Fig. 3). Zoos that hold most threatened species are concentrated in Europe and North America, while most of the wild populations of threatened species are concentrated in the tropics. However, it is important to emphasise that this map only shows species richness and does not account for the number of individuals per species. Consequently, zoos that hold a large number of species, albeit populations consisting of few individuals, would rank higher (brighter on this map) than zoos having small numbers of species with large population sizes. In this sense, Fig. 3 only shows the distribution of threatened species across zoos and it should not be seen as a measure of how zoos contribute to conservation.

Fig. 1

The number of terrestrial vertebrates in ISIS zoos compared to the number of described species.





Discussion

Zoos already hold important populations for certain threatened species; this is especially so for mammals. However, zoos are rethinking the way they should manage their collections if they want to maximise efforts for *ex situ* conservation. For birds, for example, the total number of threatened species is low and it is even lower considering the number of individuals in highly threatened categories, with only 8% of them above 250 individuals; the figure is similar for reptiles. Although zoos have significantly increased their collection holdings for amphibians, as a result of the amphibian crisis, they can focus on further increasing these collections. As well it may be advisable for particular zoos to specialise

their collections on a smaller number of at-risk taxa rather than aiming to increase diversity, since it has been shown that specialisation increases breeding success (Conway 2011).

Zoos' contribution to conservation is not limited to captive breeding, but as well is growing towards research, education and the financing of *in situ* conservation projects. For example, members of the WAZA network collectively are the third largest contributor to field conservation projects worldwide after The Nature Conservancy and the WWF global network. As a global network, WAZA zoos and aquariums contribute approximately US\$ 350 million per year (Gusset & Dick 2011). However, zoos' contribution towards conservation could extend further. The accumu-

lated knowledge and data that the zoo community has collected on the ISIS network could provide key data for species for which we lack such information from the wild, especially since adequate data from natural environments are often unavailable for threatened species. For example, demographic data such as average litter size, interval between successive litters and age at maturity could be used to fill knowledge gaps for the development of population viability analyses. Of course, if these data are used it should be with caution, since zoo conditions and the management of the populations do not mimic the conditions in the wild. Furthermore, the data accumulated by the zoo network in ISIS can be used to assess selection pressures on the species in captivity; this could inform which of these pressures may hamper the

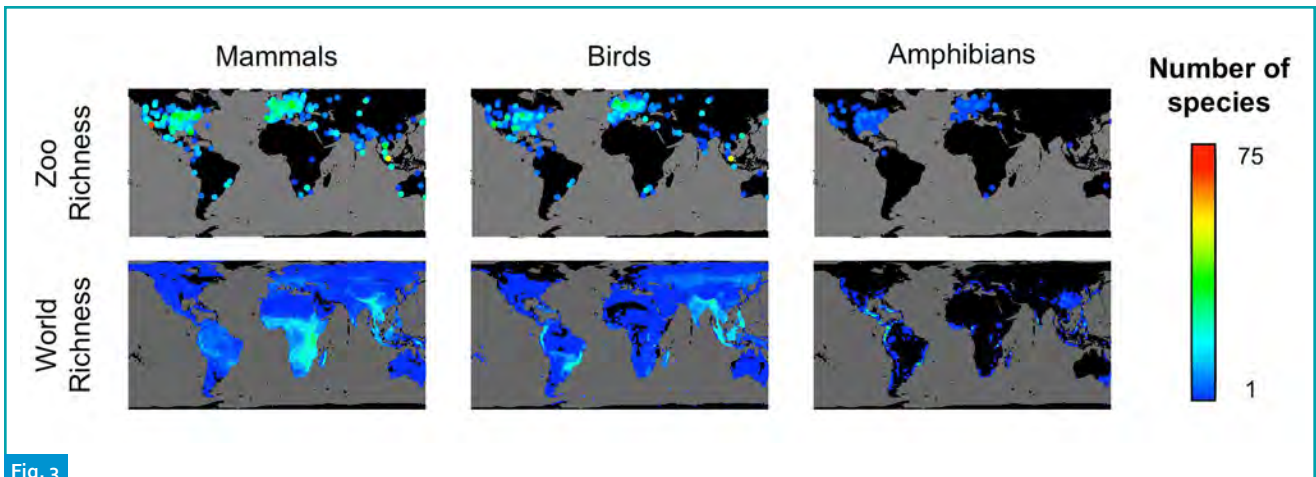


Fig. 3

Species richness map for threatened mammals, birds and amphibians within ISIS zoos (top) and in their natural ranges (bottom; modified from Grenyer *et al.* 2006).

Zoo species richness is represented by points coloured to indicate the number of species within individual zoos; global species richness corresponds to the number of species occurring within a 1° latitude by 1° longitude cell.

Reptiles are omitted because the IUCN Red List assessment is still incomplete (modified from Conde *et al.* 2011a).

success of their reintroductions into the wild (Pelletier *et al.* 2009). In this sense, studbook keepers have an important responsibility and a key role to play since the data they collect cannot only be helpful for the management of the species in their institutions but also for the development of conservation and management programmes, such as the reintroduction of threatened species into the wild.

The implementation of cooperative captive breeding programmes across large numbers of institutions, which are also referred as Intensively Managed Populations (IMPs), is one of the more demanding actions where zoos as a global network could play a key role. There are many challenges that must be overcome in order to further develop these programmes. For example, one of the first issues will be to identify which species will need the assistance of captive breeding before it is too late to successfully implement it. The Conservation Breeding Specialist Group (CBSG) of the IUCN Species Survival Commission (SSC) is currently working on guidelines to identifying those species. Another

challenge is to estimate the capacity of zoos, both in terms of space and monetary funds, to manage sustainable IMPs that could be reintroduced into the wild over the long term. For this reason, accurate data on at-risk species will be essential for the prioritisation and management of IMPs. In the future, organisations such as ISIS will certainly play an active role in providing critical information support for IMP programmes among member zoos across the world; therefore, there is a need for more institutions to become part of this global network, in particular for zoos in countries that are located in areas with high biodiversity and high threat, but which are under-represented in ISIS. Zoos are at the forefront of global conservation efforts and, with their combined efforts, their network has the potential to make a huge difference.

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Identifying Gaps and Opportunities for Inter-regional *Ex Situ* Species Management

Summary

A database of 942 studbook and managed *ex situ* animal taxa was compiled and assessed to better understand the characteristics of managed species and to be used as a tool for identifying management opportunities. Mammals and birds account for 76% of studbook/managed taxa, and 48% of managed taxa are considered to be threatened by IUCN. Most taxa are only managed in one region; only 10% of managed taxa are intensively managed in multiple regions. Regional differences exist in number of programmes, taxa and management intensity. There are 77 threatened taxa with multiple regional studbooks that are priority candidates for an international studbook; similarly, the database identified 69 threatened species that are intensively managed in multiple regions, and should be further assessed for the potential benefits and feasibility of inter-regional management. Cooperation and management among regional programmes may improve the viability of non-sustainable regional populations and encourage increased range country *ex situ* involvement.

Threatened Species in Zoos

One-fifth of the 33,468 vertebrate species assessed in the 2010 Red List of Threatened Species published by the International Union for Conservation of Nature (IUCN) are classified as threatened (i.e. Critically Endangered, Endangered or Vulnerable), and the projected future trend is not optimistic. The number of threatened vertebrate species has doubled from 1996 to 2010 – from 3,314 to 6,714 species. Each year about 52 species of mammals, birds and amphibians move one category of threat closer to extinction (Hoffmann *et al.* 2010), and 15–37% of species across sampled regions are predicted to be “committed to extinction” due to climate change (Thomas *et al.* 2004). Clearly, there is a great need for increased conservation efforts to prevent species extinctions, including the intensive management of animal populations both *in situ* and *ex situ*.

Intensive management of populations by zoos and aquariums can play a myriad of roles that can contribute to species conservation. Not all threatened species benefit from *ex situ* management, as outlined in the IUCN Technical Guidelines on the Management of *Ex Situ* Populations for Conservation (IUCN 2002), but for some it has played a critical conservation role (Hoffmann *et al.* 2010). Conde *et al.* (2011) estimate that 15% of threatened terrestrial vertebrate species are held in zoos (based on the holdings database of the International Species Information System [ISIS]), with the proportion being higher for mammals and birds. However, over one-half of these species are held in numbers totalling fewer than 50 individuals.

These *ex situ* populations vary greatly not only in size but in degree of active monitoring and cooperative management. Population-level management requires a population database (studbook), analysis of these data and application of the results into population planning to achieve demographic and genetic goals for the species. Only 9% of species registered at ISIS are monitored through an officially recognised studbook (Oberwemmer *et al.*, this issue); a smaller portion of these are managed actively at the population level. Population management also varies among geographic regions, as some regional zoo associations have well-established administrative and training resources to promote population management, while this capacity is still developing in other regions.

As evidenced by many of the articles in this issue, much concern has been expressed regarding the lack of sustainability of most zoo populations, including managed populations. Most management efforts, however, are conducted at the regional level. Inter-regional management through international studbooks and global management programmes has the potential to improve viability through careful metapopulation management (Leus *et al.* 2011). Cooperative programmes among regions also may help to expand involvement by range countries or developing zoo associations in species conservation.

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Zoos hold only a small fraction of the world's threatened species, maintain studbooks for only a portion of these and actively manage even fewer, often not effectively as sustainable populations. A database of species managed by the regional zoo associations was compiled to evaluate the scope of the situation, to assess the level of management across taxa and regions and to serve as a potential tool to identify gaps and opportunities for inter-regional management in existing zoo populations.

Managed Species Database

A database was developed comprised of 942 taxa monitored (via an active studbook) and/or actively managed by regional zoo associations or under the Amphibian Ark (AArk). Taxa were listed at the species level except in a few cases in which multiple regions manage by subspecies and/or the category of threat deviated by subspecies. *Partula* snails were considered as one taxon, although approximately 20 species are managed. For each taxon, the 2010 IUCN Red List status of threat was recorded along with the presence of any monitored or managed population in each of ten regional zoo associations – AZA (North America), EAZA (Europe), ZAA (Australasia), JAZA (Japan), CAZG (China), SEAZA (South East Asia), CZA (India), PAAZAB (Africa), ALPZA (Latin America) and AMACZOOA (Mesoamerica) – as well as AArk, and the level of management, using the following definitions:

- Monitored population: Regional or international studbook only; this category also includes ZAA MON1 and MON2 programmes. No population-level management.

- Managed population: Some population-level management (e.g. studbook data analysis, general recommendations for breeding and/or transfers); this category includes AZA Population Management Plans (PMPs), EAZA European Studbooks (ESBs) and low-intensity management programmes identified by other regional associations.
- Intensively managed population: Structured population-level management (e.g. species management committee, mandatory breeding and transfer plan); this category includes AZA Species Survival Plans (SSPs), EAZA European Endangered Species Programmes (EEPs), ZAA Conservation Programmes (CPs) and Population Management Programmes (PMPs), AArk programmes and other high-intensity management programmes identified by other regional associations.

Programme data were obtained either directly from the zoo associations, population managers working in the region and/or association websites, and are believed to be current as of early 2011. For analysis purposes, species listed as Extinct in the Wild were included among threatened taxa.

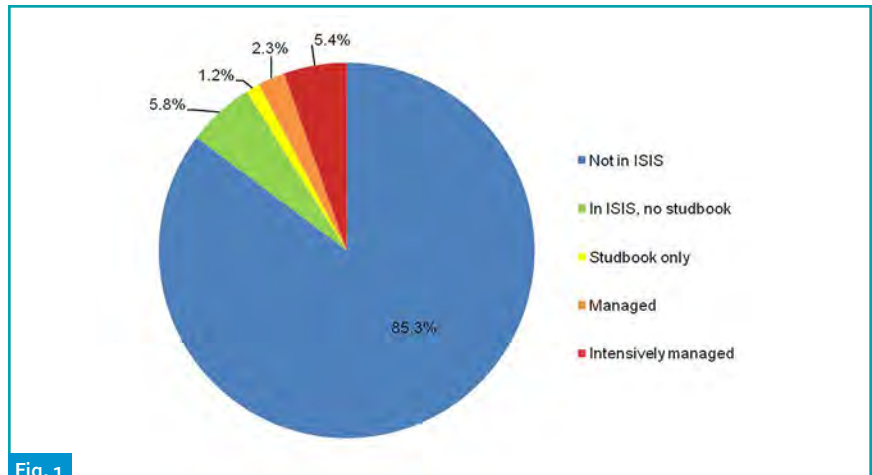


Fig. 1

Percentage of 4,733 IUCN-assessed threatened taxa that are held in ISIS member zoos (14.7%), have studbooks (8.9%), are managed (7.7%) and are intensively managed (5.4%).

Managed Species Characteristics

The majority of the 942 monitored taxa are mammals (44%) and birds (31%), with the rest divided among reptiles (10%), amphibians (7%), fishes (7%) and invertebrates (< 1%). Studbooks fall evenly between threatened (48%) and non-threatened (45%) taxa, with the remaining 7% of undetermined threat status (Data Deficient or not assessed by IUCN). Comparison of this database with data reported by Conde *et al.* (2011) indicate that while 15% of threatened vertebrate species (excluding fish) are held in zoos, only about one-third of these (5.4%) are intensively managed by zoos (Fig. 1).

Although species may be held in multiple regions, most management takes place within a single region (Table 1). Most (65%) of the 942 monitored taxa are monitored by a studbook in only one region, 20% have multiple regional studbooks and 15% have international studbooks. For those taxa that are actively managed, most are managed in only one region and only 50 are managed by more than two regions (mean number of management programmes = 1.3).

Rates for multiregional management are higher for threatened (29%) than for non-threatened (4%) taxa, and threatened taxa (60%) are managed more intensively than non-threatened taxa (27%). About 10% of the 942 monitored taxa are intensively managed by two or more regions, most of these being threatened taxa ($N=79$). This means that only 1.6% of the 4,733 IUCN-assessed threatened mammal, bird, reptile and amphibian species are intensively managed by more than one regional programme.

Regional Differences

Not surprisingly, AZA and EAZA account for the largest number of actively managed populations (550 and 358 taxa, respectively) – these are large regional zoo associations with long-standing histories of population management, established population management advisors and regular training courses for studbook keepers and species coordinators. With smaller capacity, ZAA manages a smaller number of taxa ($N=83$), but essentially all are managed intensively. Other regions are quickly developing studbook and population management expertise; most notably, JAZA has made a strong commitment to population management in recent years, now maintaining studbooks for 142 species and managing about half of these on some level. While AZA, EAZA and ZAA have the longest his-

Table 1.

Number of taxa in the database ($N=942$) that have studbooks, management programmes and intensive management programmes compared to the number of regional zoo associations coordinating those programmes (proportion for each column given in parentheses).

Number of regions	Studbook/database	Population-level management	Intensive management
0		111 (0.12)	549 (0.58)
1	664 (0.70)*	607 (0.64)	296 (0.31)
2	181 (0.19)	174 (0.18)	72 (0.08)
3	58 (0.06)	38 (0.04)	19 (0.02)
4	26 (0.03)	12 (0.01)	6 (0.01)
5	8 (0.01)	0	0
6	5 (0.01)	0	0

*An international studbook is the single database for 49 of these taxa.

torical capacity for population management, not all taxa are managed within these three regions. If AArk programmes are excluded, 110 taxa are monitored via studbooks outside of these three regions; of these, 29 taxa are managed and 12 are intensively managed by the other seven regional associations (Fig. 2).

Regions differ in other ways in terms of the taxa they monitor and manage. All regions hold studbooks or management programmes unique to their region – that is, they are the only region with a studbook or management programme for that taxon (although specimens might be present in other regions). While AZA ($N=309$) and EAZA ($N=144$) have the highest number of unique programmes, a high percentage of studbook or programme taxa in ZAA (53%) and CZA (63%) are exclusively managed in those regions. CAZG, CZA and SEAZA have the largest proportion of their studbook/managed taxa (82%, 67% and 85%, respectively) comprised of threatened taxa. JAZA (25%) and PAAZAB (24%) have a larger proportion of their studbook/managed taxa represented by reptiles, amphibians and fishes compared to other regions. Although AArk programmes are found worldwide, the majority of species are being managed in North, Central and South America. Each region offers unique contributions to *ex situ* population management and conservation.

Opportunities for Inter-regional Management

This database represents taxa that are already living in the world's zoos and for which some population-level data exist within one or more studbooks. Various criteria can be used to filter these 942 taxa to identify potential candidates for inter-regional management in a structured fashion. For example, among those 801 taxa for which there is currently no international studbook, there are 77 threatened taxa with two or more regional studbooks and/or managed populations, and an additional 11 non-threatened taxa with at least two intensively managed populations. These taxa can be easily identified and are potential priority candidates for an international studbook. Similarly, there are 79 threatened taxa with at least two intensively managed populations, only ten of which are currently being managed inter-regionally in some coordinated fashion – the remaining 69 are potential candidates for global management.

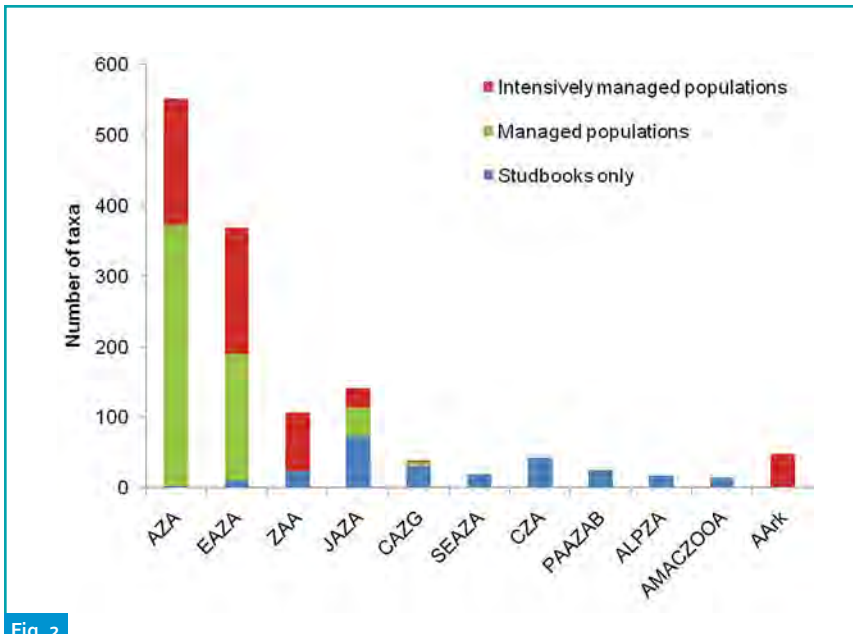


Fig. 2

Number of taxa for which there are studbooks, low intensity managed populations or intensively managed populations for each of ten regional zoo associations as well as the Amphibian Ark.

There are many additional factors that should be considered, such as the genetic and demographic status of the *ex situ* populations as well as feasibility issues; however, this tool can serve to produce a shorter list of potential candidates that can then be evaluated more thoroughly with additional criteria. Currently, this process is being undertaken by WAZA's Committee for Population Management (CPM). Another potential use of this database is to quickly identify the current management level of the *ex situ* population within the native geographic range of each taxon. This in turn can help to identify gaps where range country involvement and *ex situ* population management can be encouraged or supported. The expansion of the database to explicitly identify range country management will facilitate this.

Conclusions

Increasingly, intensively managed populations may be needed to reduce the risk of extinction for wildlife species. Only a fraction of currently threatened species are held by the world's zoos, only about half of these are actively managed and a small fraction of these are believed to be sustainable. There are many opportunities to increase the viability of regional *ex situ* populations through inter-regional databases and inter-regional population management. A database of managed species has been created as a tool to help identify opportunities for inter-regional cooperation and management of existing studbook species, including increased involvement of range country *ex situ* programmes.

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Which Species Have a Studbook and How Threatened Are They?

Summary

We sought to provide an understanding of the taxonomic representation and threat status of species with a studbook, using data on all studbooks registered in the ISIS/WAZA studbook library and data on threat status from the IUCN Red List of Threatened Species. Studbooks for 1,027 different species are actively updated. The majority of species with an active studbook are vertebrates (96.3%), mainly comprised of mammals (48.8%) and birds (31.8%). There are active studbooks for 1.6% of all 62,574 described vertebrates, including 9.1% of known mammals and 3.3% of known birds. Of those species with an active studbook, 41.5% are classified as threatened (i.e. Vulnerable, Endangered or Critically Endangered) on the IUCN Red List; 17 out of 34 animal species (50.0%) classified as Extinct in the Wild have an active studbook. Of the 989 vertebrates with an active studbook, 42.6% are classified as threatened; 8.6% of 25,780 assessed vertebrates classified as threatened have an active studbook. Without studbooks, it would be virtually impossible to scientifically manage animal populations in human care.

Background

With more than 700 million visitors worldwide annually and conservation expenditures in the range of US\$ 350 million each year (Gusset & Dick 2011), the world zoo and aquarium community has the potential to play an important role in both environmental education and wildlife conservation. Indeed, a recent evaluation of the impact of conservation on the status of the world's vertebrates (Hoffmann *et al.* 2010) showed that conservation breeding in zoos and aquariums has played a role in the recovery of 28% of the 68 species whose threat status was reduced according to the Red List of Threatened Species published by the International Union for Conservation of Nature (IUCN). Species previously classified as Extinct in the Wild that have improved in status thanks to the reintroduction of captive-bred animals include the Przewalski's horse (*Equus ferus przewalskii*), black-footed ferret (*Mustela nigripes*) and California condor (*Gymnogyps californianus*).

International and regional studbooks provide the data necessary for coordinating such conservation breeding efforts across zoological institutions. Studbooks are repositories of pedigree and demographic data on animals kept in human care internationally or regionally (Bingaman Lackey 2010). According to the International Species Information System (ISIS), as of July 2010 there were studbooks for 1,174 different species included on the international (kept under the auspices of WAZA) and/or one of the regional zoo associations' lists of species to have a studbook

(a number of species have multiple regional studbooks assigned). Of the 13,004 species registered at ISIS, 9% thus have a studbook. Of these, 1,027 are actively updated, while 147 are no longer being maintained (i.e. they were "archived") for various reasons (e.g. because there is no further need for the studbook, no captive animals are left to track or the studbook keeper could not be replaced).

Zoos and aquariums worldwide keep at least 15% of threatened terrestrial vertebrate species (Conde *et al.* 2011), but populations of wild animals in human care are often not viable in the long term (Lees & Wilcken 2009). Captive ruminants with an international studbook have a significantly higher relative life expectancy than those without (Müller *et al.* 2011), suggesting that the existence of a studbook may impact conservation breeding efforts. However, in terms of their conservation role, we lack an understanding of the taxonomic representation and threat status of species with a studbook. To this end, we initiated the present study, using data on all studbooks registered in the ISIS/WAZA studbook library and data on threat status from the IUCN Red List as of July 2010.

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Taxonomic Representation

The majority of species with an active studbook are vertebrates (96.3%), mainly comprised of mammals (48.8%) and birds (31.8%) (Fig. 1). Vertebrates constitute just over 3% of the ca. 1.8 million described species and include 5,498 mammals, 10,027 birds, 9,084 reptiles, 6,638 amphibians and 31,327 fishes (Hoffmann *et al.* 2010). There are thus active studbooks for 1.6% of all 62,574 described vertebrates, including 9.1% of known mammals and 3.3% of known birds. Studbooks for reptiles were significantly more often (chi-square analysis: $\chi^2 = 8.84$, $P = 0.003$), whereas studbooks for fishes tended to be less often ($\chi^2 = 3.61$, $P = 0.06$), archived than those for other taxonomic groups.

Threat Status

Of those species with an active studbook, 41.5% are classified as threatened (i.e. Vulnerable, Endangered or Critically Endangered) on the IUCN Red List (Fig. 2); 17 out of 34 animal species (50.0%) classified as Extinct in the Wild have an active studbook. Of the 989 vertebrates with an active studbook, 42.6% are classified as threatened. A recent survey of 25,780 vertebrates represented in the IUCN Red List (including all mammals, birds, amphibians, cartilaginous fishes and statistically representative samples of reptiles and bony fishes) revealed that 19% are classified as threatened (Hoffmann *et al.* 2010). Thus, 8.6% of all assessed vertebrates classified as threatened have an active studbook. Studbooks for Least Concern and Near Threatened species tended to be more often archived than those for threatened and Extinct in the Wild species ($\chi^2 = 3.32$, $P = 0.07$).

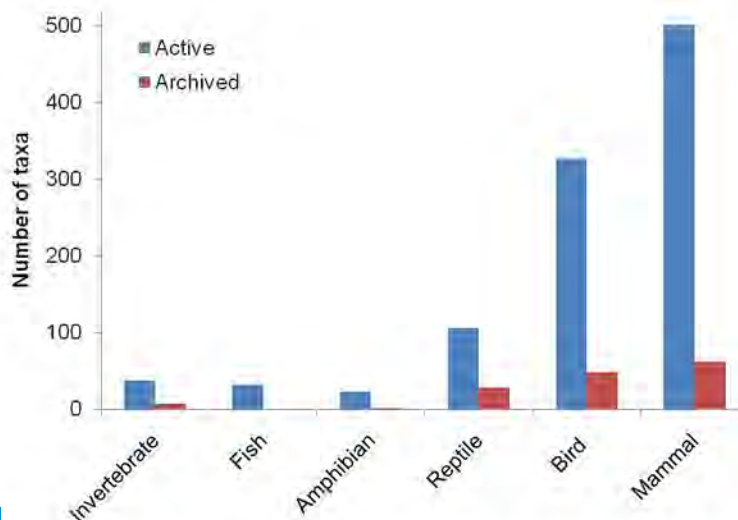


Fig. 1

Taxonomic representation of species with a studbook.

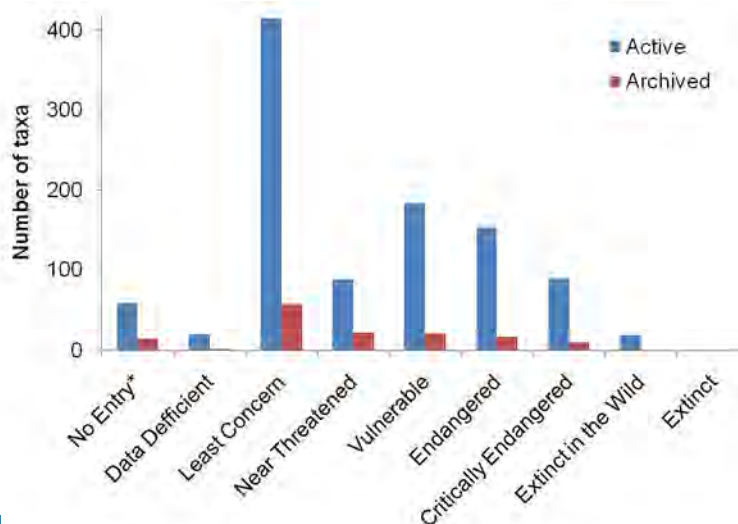


Fig. 2

Threat status of species with a studbook (*no entry = species not found on IUCN Red List).

Conservation Role

More than 1,000 different species have a studbook (cf. Conde *et al.* 2011). Species with a studbook are heavily biased towards (charismatic) vertebrates; around one out of ten known mammals has a studbook. While about one-fifth of all assessed vertebrates are classified as threatened on the IUCN Red List, about two-fifths of all studbooks cover threatened vertebrates; around one out of ten threatened vertebrates has a studbook. If species with a studbook fare better genetically and demographically (cf. Müller *et al.* 2011), there is potential for hundreds of threatened vertebrates to benefit from the conservation role that studbooks may play. However, some

taxa, especially amphibians as the most threatened taxonomic group of vertebrates (Hoffmann *et al.* 2010), are grossly under-represented in studbooks.

There are reasons other than a species' threat status that determine whether a studbook is established or not, including the following: (1) It might be considered as important to keep charismatic vertebrates (e.g. in order to attract visitors), and thus to manage these species in the long term based on a studbook. (2) Even if a species is common in its native range, there may be only a small number of specimens kept in human care (e.g. for educational or research



purposes), which may necessitate managing this stock collaboratively for genetic and demographic reasons. (3) Species not currently threatened may become so in the future, making a studbook-based assurance population potentially valuable. Therefore, given the limited space in zoos and aquariums, sound and adaptive collection planning to prioritise which species to keep, and for which species to establish a studbook, is more important than ever.

There are a number of factors that may compromise the conservation role of species with a studbook, including the following: (1) Not all of the institutions keeping a given species provide pedigree and demographic data for inclusion in the studbook, reducing the overall number of animals in a conservation breeding programme. (2) The system of maintaining studbooks is based mainly on voluntary commitment and few institutions have professional studbook keepers (or population managers), thus the value of studbook data is not fully explored. (3) Recommendations made by studbook keepers regarding animal transfers between institutions are not always followed or are constrained by legal restrictions, impairing the effectiveness of a conservation breeding programme. All these factors together may diminish a captive population's genetic and demographic viability.

Conclusions

The potential of zoos and aquariums to assume responsibility for conservation breeding programmes has been growing over the years. No other group of institutions has the scientific knowledge and practical experience to keep and breed thousands of animal species, thereby evidently contributing to wildlife conservation (Hoffmann *et al.* 2010). Nevertheless, these same institutions have not (yet) succeeded in managing their populations sustainably (Lees & Wilcken 2009). This is despite frequent calls to

action over the past 30 years, significant scientific input and much organisational effort. Although WAZA has mandated ISIS with the management of studbook data, not all institutions are required by their regional zoo associations to submit data for inclusion in the ISIS/WAZA studbook library. Lees & Wilcken (2009) calculated that the average population size for captive vertebrates would increase by 42% if regionally managed populations were linked up.

To fulfil the full suite of conservation roles required of animal populations in human care (Conde *et al.* 2011), they must be demographically robust, genetically representative of wild counterparts and able to sustain these characteristics for the foreseeable future. International and regional studbooks form the basis of such conservation breeding efforts. Studbook keepers thus provide an invaluable service to the world zoo and aquarium community; the single most important determinant of a sound studbook probably is having a dedicated keeper. However, it seems that studbook data are not being adequately translated into management recommendations and/or those recommendations are not being implemented within institutions. This implies that the system of maintaining studbooks needs to move from mere bookkeeping to proactive population management. Based on the above, for zoos and aquariums to be a recognised conservation force, more professionalism, compliance and inter-regional cooperation appear to be advisable.

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How to Measure Husbandry Success? The Life Expectancy of Zoo Ruminants



Summary

Relative life expectancy (i.e. the *average* life expectancy of a species expressed as a percentage of the *maximum* longevity ever reported for this species) may describe husbandry success in captive populations. By correlating the relative life expectancy with biological characteristics and husbandry factors for different species, reasons for variations in relative life expectancy can be detected. We analysed data for 166,901 ruminants of 78 species and demonstrated the presence of such a correlation between relative life expectancy and percentage grass in the species' natural diet (not necessarily the diet fed in zoos). This suggests that species adapted to grass (so-called grazers, such as bison and wildebeest) can be managed more easily when compared to species that feed on leaves and twigs (so-called browsers, such as giraffe and moose). Another finding of our analysis is a true success story of zoo animal management: the

relative life expectancy was higher in species that were managed by an international studbook than in species not managed this way. This highlights the positive effect of intensive studbook management on the overall husbandry success of the respective species. Translating these results into husbandry recommendations, our approach can help to improve zoo animal husbandry.

Background

Zoo animal husbandry is aimed at constantly improving husbandry conditions, provision of veterinary care, reproductive success and thus ultimately husbandry success. Important questions arise from these aims: how can husbandry success be measured objectively, and how can we improve it on the basis of scientific results? Although some zoological institutions make a great effort to study various aspects of wellbeing for certain species, comparative analyses needed to determine factors influencing the husbandry success of different species in captivity are rare (Mason 2010).

In 2003, WAZA proclaimed the goal "to exercise the highest standards of animal welfare", leading to the question of how husbandry success and animal welfare can be measured objectively. A comparison of life history parameters such as breeding success per year or life expectancy between a zoo population and a wild population is an option to find out whether a species fares better in captivity than in the wild. In comparing three

populations of wild but unhunted deer species with their respective zoo populations, we demonstrated that life expectancies of red deer (*Cervus elaphus*) and reindeer (*Rangifer tarandus*) were within the same range or even markedly higher in zoos, whereas captive roe deer (*Capreolus capreolus*) had a shorter life expectancy than their free-ranging conspecifics (Müller *et al.* 2010a).

We believe that the problems in providing adequate browse to captive roe deer (a typical browser that feeds on leaves and twigs) and problems associated with more crowded conditions in zoos (as roe deer live predominantly solitarily in the wild) may have led to nutritional deficiencies and increased stress, leading to shorter life expectancy in captivity. On the other hand, reindeer and red deer are naturally socially living and are both so-called mixed feeders, adapted to feed moderate amounts of grass. Thus, they cope well in zoos and achieve comparatively high life expectancies. Unfortunately, such analyses will be restricted to a few exemplary comparisons, as reliable data for free-ranging populations are missing for most species. To test our hypotheses that the social system and feeding behaviour of a species in the wild have an influence on husbandry success, we conducted an analysis of the life expectancy of ruminant species (deer, giraffes, cattle, antelopes, gazelles, etc.) in zoos.

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Comparison of Life Expectancy among Ruminants

A comparative analysis of different species' life expectancies in captivity can be used to detect factors that influence life expectancy in captivity. Such factors would consequently have an important impact on husbandry success and also on animal welfare. We used data from approximately 167,000 animals representing 78 ruminant species kept in about 850 zoos around the world (data from the International Species Information System [ISIS]) to calculate the life expectancy of a species' overall zoo population. Life expectancy of different species depends on the body mass of a species – species with a higher body mass such as bison (*Bison bison*) and giraffe (*Giraffa camelopardalis*) achieve higher life expectancies than do smaller species such as roe deer or gazelles (*Gazella* spp.). Comparative analyses of different species' life expectancies require a correction for this effect. This was done by calculating the relative life expectancy of a species in captivity.

The average life expectancy of a species was hereby expressed as a percentage of the maximum longevity ever reported for this species. Ranging from 0–100%, a relative life expectancy of 0% would denote the death of all individuals at birth, whereas a relative life expectancy of 100% would imply that all individuals reach the maximum longevity for that species. For example, assuming an average life expectancy of 80 years and a maximum longevity of 122 years for women in western Europe, women nowadays have a relative life expectancy of 66%. In zoo ruminants, the relative life expectancy ranged from 27% for moose

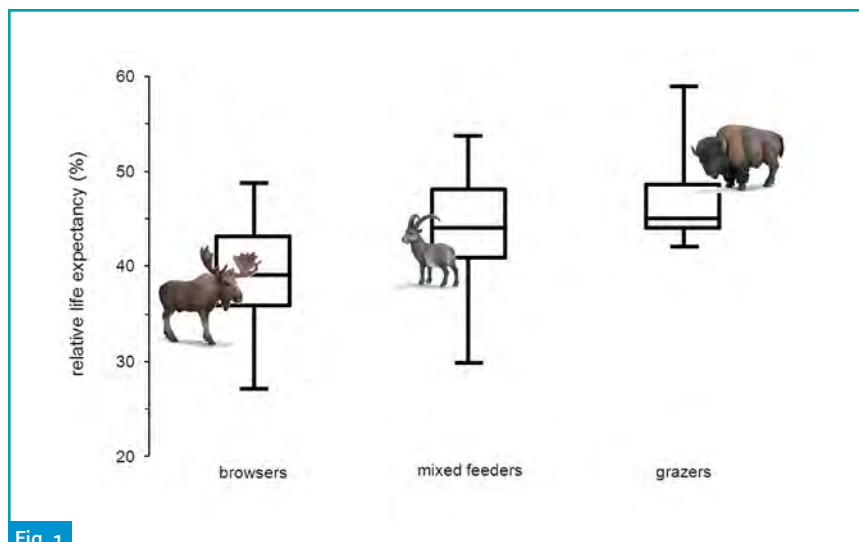


Fig. 1

A boxplot of the relative life expectancy of ruminant species with low amounts of dietary grass in the wild (browsers) in comparison with species that feed moderate proportions of grass in the wild (mixed feeders) and species that ingest high proportions of grass in the wild (grazers). Included are 20 browsers (e.g. moose), 32 mixed feeders (e.g. Alpine ibex [*Capra ibex*]) and 26 grazers (e.g. bison). From top to bottom, boxplots show the highest value, the value achieved by 75% of species, the value achieved by 50% of species, the value achieved by 25% of species and the lowest value of the relative life expectancy.

Note that the relative life expectancy was lowest in browsing species and highest in grazers.

(*Alces alces*) to 59% for Arabian oryx (*Oryx leucoryx*), with a mean relative life expectancy of 43% (Müller *et al.* 2011). We then tested the influence of several biological parameters (e.g. feeding behaviour, social system) and husbandry measures (e.g. keeping of an international studbook for a species) on the relative life expectancy.

The relative life expectancy correlates positively with the percentage of grass in a species' natural diet (not necessarily the diet fed in zoos) (Müller *et al.* 2010b, 2011). Browsing species with a lower percentage of grass in their natural diet (e.g. giraffe, moose) had, on average, a lower relative life expectancy compared with grazing species (e.g. bison, wildebeest [*Connochaetes taurinus*]) that have a high percentage of grass in their natural diet (Fig. 1). Thus, our results confirm the general experience of zoos where browsing species, evolutionarily adapted to eat leaves

and twigs, have more nutrition-related problems than mixed feeders (with a moderate proportion of grass in their diet) and grazers. Obviously, these nutrition-related health problems have a significant influence on life expectancy in captivity.

One of the major achievements of zoos in the last century was the conservation of species that had become extinct in the wild, including European bison (*Bison bonasus*), Przewalski's horse (*Equus ferus przewalskii*) and Père David's deer (*Elaphurus davidianus*). A major key to this success was the cooperation and breeding coordination of many zoos with international studbooks. Nowadays, conservation of endangered species by *ex situ* breeding programmes is one of the most important aims of zoological institutions (WAZA 2005), and international studbooks for more than 150 species have been established. Detailed husbandry recommenda-

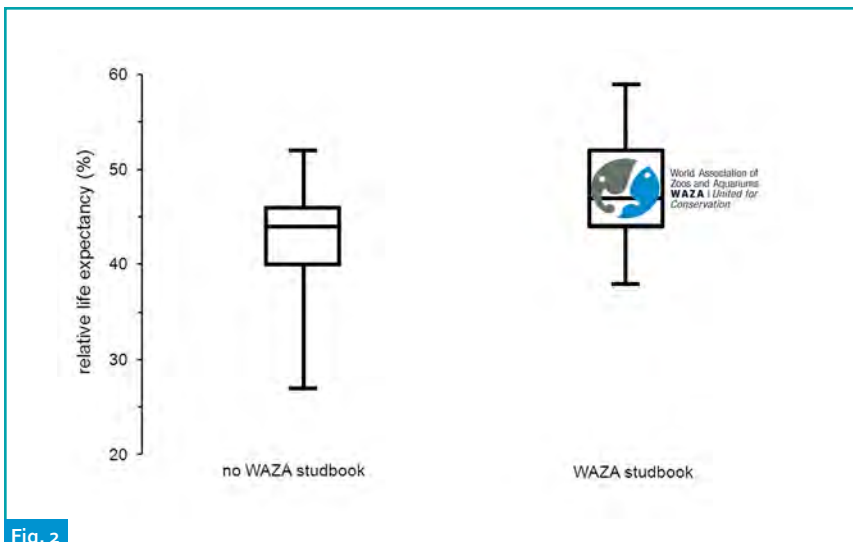


Fig. 2

A boxplot of the relative life expectancy of species that were not managed ($N=64$) and of species that were managed ($N=14$) with the help of an international studbook. In descending order, the boxplots show the highest value, the value achieved by 75% of species, the value achieved by 50% of species, the value achieved by 25% of species and the lowest value of the relative life expectancy. Note that species that were managed with an international studbook had a higher relative life expectancy compared with species without such management.

tions including spatial requirements, housing facilities, group size and composition and feeding regimes are often an integral part of these studbooks. The relative life expectancy was higher in species managed with the help of an international studbook kept under the auspices of WAZA (Fig. 2; Müller *et al.* 2010b, 2011). Consequently, the success of such intensive population management seems to be reflected in the higher life expectancy of studbook-managed species.

Although it is unknown whether efforts to reduce inbreeding in studbook-managed populations as compared to species without an international studbook, or the implementation of detailed husbandry guidelines, have also contributed to the higher relative life expectancies of the relevant species, this finding should encourage more intensive use of studbook coordination in additional species.

Conclusions

Our results identified species that live under suboptimal husbandry conditions (e.g. moose); additional efforts should be undertaken to improve these. Furthermore, we identified biological characteristics of species relevant to their life expectancy in captivity, such as natural diet, which should be considered in further improving husbandry success in zoos. Finally, we demonstrated that intensively managing a population with the help of an international studbook has a positive effect on the husbandry success of the respective species.

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Intensive Management of Populations for Conservation

What is an “Intensively Managed Population”?

As habitats are increasingly altered and wildlife populations impacted by human activities, more species are being actively managed to assure their persistence. This has led to a new term among conservationists – Intensively Managed Populations (IMPs). An IMP is one that is dependent on human care at the individual and population level for its persistence (Fig. 1). *Ex situ* populations that depend on managers for food, medical treatment, living space, protection from predation and access to mates are clearly intensively managed. Some wild populations are reliant on at least some of these kinds of individual care and would also fall within the scope of IMPs. Populations living without regular intervention for individuals but requiring management at the population level (e.g. protection from poaching) or habitats will often be “light managed” or “conservation dependent” (Cook 2010).

The Opportunity for Zoos

The opportunity for zoological institutions to contribute to species conservation through the long-term maintenance of populations is very large. The more than 800 zoos and aquariums that are members of the International Species Information System (ISIS) currently hold more than 600,000 living specimens of about 4,000 species of tetrapod vertebrates. Of these populations, 18% are currently for those species identified at some level of conservation risk in the wild. For mammals and birds, zoos hold about one-fifth to one-quarter of the species identified by the International Union for Conservation of Nature (IUCN) as threatened, while the numbers are much lower for reptiles and amphibians (Conde *et al.* 2011). However, for about half of these threatened species, the total number of individuals held in all ISIS zoos is fewer than 50 specimens, a size below which conservationists do not consider a population to be viable for even the short term.

Concerns regarding the sustainability and not fully realised conservation potential of these zoo populations led to a workshop on the use of intensively managed populations for species conservation held in December 2010 and hosted by San Diego Zoo. Facilitated by the Conservation Breeding Specialist Group (CBSG) of the IUCN Species Survival Commission (SSC), the workshop was attended by 45 zoo professionals from around the world. The purpose of the workshop was to address the challenge of insuring that intensive population management contributes to species living within healthy ecosystems in evolving communities.

This workshop involved focused discussions on those populations that are being intensively managed for the conservation of those species. Zoo populations serve also important educational, aesthetic and cultural values, but these roles do not necessarily involve the maintenance of threatened taxa. Efficient use of resources might require that zoo populations that are used for educational and display purposes also be breeding populations of species needing protection (Conway 2011), and in those cases the management of the populations must be adequate for achieving the species conservation goals as well as the exhibit goals.

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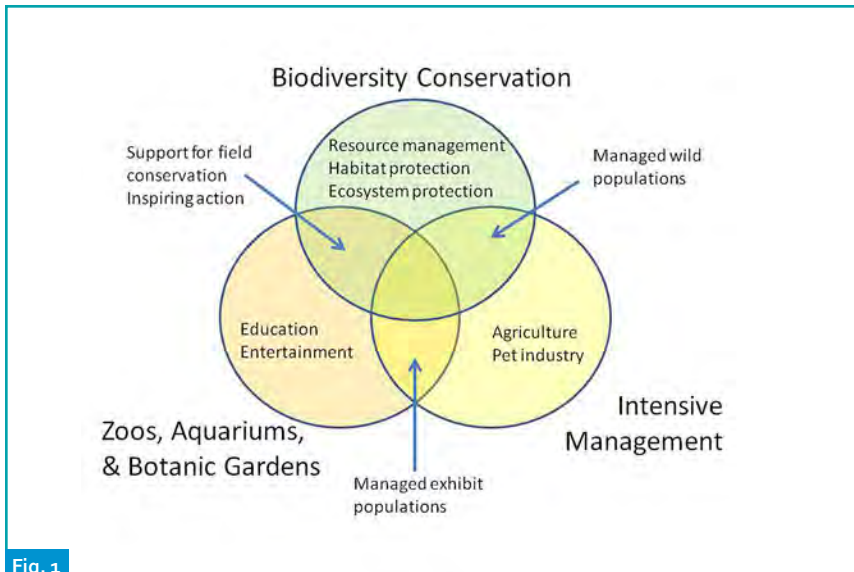


Fig. 1

Intersections of biodiversity conservation, *ex situ* zoological and botanical institutions and intensive management of populations, with examples of the activities that fall within each region. The centre of overlap between all three circles are those *ex situ* populations that are being managed intensively to help achieve their conservation. That region plus the intensively managed wild populations constitutes the focus of the discussions on the use of IMPs for conservation.

The Challenges

Regional zoo associations coordinate the collaborative management of about 800 species, in programmes such as the Species Survival Plan (SSP) of the Association of Zoos and Aquariums (AZA) in North America, the European Endangered Species Programme (EEP) of the European Association of Zoos and Aquaria (EAZA), the Australasian Species Management Program (ASMP) of the Zoo and Aquarium Association (ZAA) Australasia, and others. Often, however, these populations are managed in isolation and *ex situ* efforts often are not integrated with *in situ* conservation needs or activities, even for endangered species. Although we in the zoo community have convinced ourselves, our staff and our public that our managed programmes serve important conservation roles for those species, rarely can this be documented to be the case.

Working groups tackled aspects of intensive population management for species conservation, from identifying priority species for management to improving management effectiveness and increasing collaboration. The following goal encapsulates much of what participants believe zoos need to achieve: *The world zoo and aquarium communities are, and are acknowledged as, effective conservation partners in the context of integrated conservation strategies that include intensive population management.*

To work towards this goal, we must:

- Change the current paradigm of the ways zoos contribute to species conservation by committing to conservation missions and adopting appropriate business models to achieve this.
- Incorporate IMPs as potential effective conservation tools into holistic species conservation strategies, increase collaboration with conservation partners and improve understanding of the role of IMPs in conservation.
- Improve the viability and success of long-term IMP programmes, ensuring that each species has a precise and appropriate management plan and adequate resources to achieve its roles.
- Improve the success of species conservation programmes by optimally utilising populations along a management continuum, including exploration of alternative approaches to population management and expanding metapopulation strategies for managing multiple populations effectively.

Population goals for managed taxa are usually defined in terms of genetics and demographics, rather than in terms of supporting species conservation. Even given these limited goals, most managed zoo populations are not sustainable. Recent analyses (Baker 2007; Lees & Wilcken 2009) and data presented at the IMP workshop showed that most of these populations are not currently being managed at the numbers of individuals, reliability and predictability of reproduction and levels of genetic diversity that would be required to assure that they can contribute to species conservation. Rather than managing for conservation, the majority of programmes are managing for “acceptable” levels of decay and loss, instead of for truly sustainable, resilient and adaptable populations that will be available and suitable to serve conservation needs in the future. Not surprisingly, some colleagues within the conservation and scientific community do not see the conservation value of intensively managed *ex situ* populations.

Changing the Paradigms

Effecting this shift will not be easy and will require that zoos change a number of current practices and paradigms. At the outset they need to work more collaboratively with others in the conservation community, working together to assess species for their full range of conservation needs and developing holistic species management plans. There are a few shining examples of collaboration between Taxon Advisory Groups (TAGs) of regional zoo associations and the IUCN/SSC Specialist Groups; this type of interaction needs to be expanded. The networks of taxon conservation experts in the IUCN/SSC Specialist Groups should be best able to identify which taxa require intensive management as part of the species conservation strategies. However, they are unlikely to provide that guidance unless they view the zoo community as effective partners in conservation. Achieving that level of confidence in the role of zoos in species conservation will require changes in both the practices and the perception of zoos.

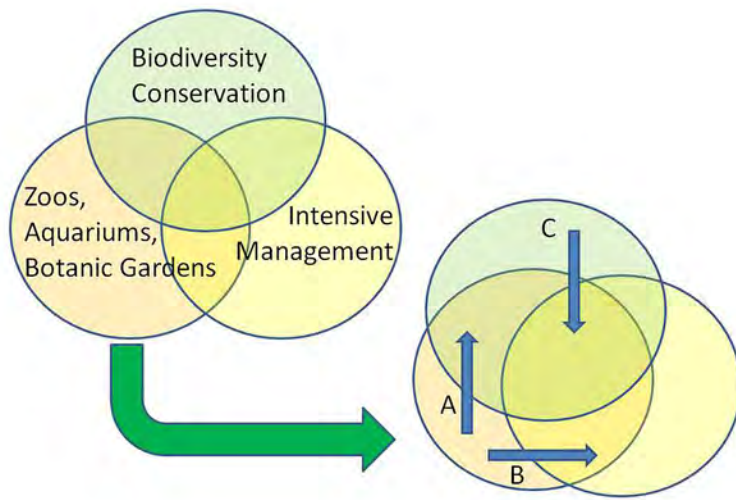
Fig. 2

The desired and expected shifts of emphasis among roles. *Ex situ* facilities have the capacity and responsibility to focus more of their resources on actions that directly lead to improved species conservation (arrow A). Moreover, to be able to sustain also exhibit populations for other purposes, increased management will be needed for those *ex situ* populations that will not be easily replaceable (arrow B). As wild environments continue to be degraded by increasing human activities, it is expected that more species conservation will require coordinated intensive management of both *ex situ* and *in situ* populations (arrow C).

Zoos can become and be seen as very powerful forces for species conservation, not only through the significant resources that they direct towards field conservation programmes (to which members of the WAZA network contribute more than US\$ 350 million per year; Gusset & Dick 2011), but also through the direct conservation roles of the populations managed within their collections. Reaching this goal will require strategic assessment, planning and action, and this will occur only if zoos shift their focus from managing facilities as places with animals that also do some conservation, to managing themselves as conservation organisations that support *ex situ* animal populations in order to

reach conservation goals (Fig. 2). The World Zoo and Aquarium Conservation Strategy (WAZA 2005) identifies conservation as the primary purpose for modern zoological institutions. However, most zoos are still managed in ways that demonstrate that they are focused first on exhibition; they attend to conservation only when resources permit or when the conservation serves the other goals of the institution.

Methods are needed to assess the need and value for intensive management and also for prioritising these taxa; factors to be taken into account include existing expertise, capabilities, resources and likelihood of success. This cannot be accomplished without reaching outside of the *ex situ* community to embrace other stakeholders, including field biologists, academics, regional and global conservation organisations and interdisciplinary specialists such as sociologists.



With clear goals defined by holistic species management plans, *ex situ* programmes will need to be refined and restructured to maximise success. The traditional approach of trying to sustain zoo populations only through breeding within exhibition programmes will be sufficient for only a relatively small number of species – those that are so popular that large exhibit populations will be maintained, that breed readily in exhibit facilities with little need for specialised facilities and that are easy to transport and amenable to periodic rearrangement of social groups. For the remaining species, a broader range of population management strategies needs to be considered along a management continuum (Conway 2011). For some species, this may mean Global Species Management Plans (GSMPs) administered by WAZA. For others, it may mean placing breeding individuals into specialised breeding facilities, while ensuring that exhibit needs can be met with non-breeding animals. For yet others, it may mean exploring the concept of extractive reserves, a strategy that the aquarium community has already made progress in developing.

Accomplishing the above will require additional resources and has implications for how *ex situ* institutions structure their financial plans. We will need to better understand our business models, questioning assumptions about what we believe may negatively impact our ability to manage species effectively. For example, zoos often assume that the public wants to see a huge variety of species and that if species collections are similar from zoo to zoo, then attendance will suffer. We assume that exhibits need to be large and elaborate to be successful. These assumptions need to be tested, as they impact our ability to develop business plans that expand our ability to adequately resource intensive population management in support of conservation goals.

There are a number of factors that have contributed to a lack of success for many IMPs. Common problems include lack of necessary husbandry expertise, regulatory obstacles, space limitations, inadequate founder base and lack of institutional commitment, exacerbated by poor communication among staff and lack of accountability for those responsible for implementation of recommendations. None of these obstacles is insurmountable, but overcoming them will require commitment to change. Discussion among IMP workshop participants led to the identification of specific actions needed in areas from species prioritisation to collection planning, exploration of new management approaches and integration with other conservation efforts and partners. Putting these recommendations into action to achieve success will require concerted efforts by zoo associations, zoos and individuals. Efforts are already underway to implement some of the necessary activities identified at the IMP workshop. The scope and urgency of the species conservation crisis obligates us to move ahead as quickly as possible.

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Greater flamingo (*Phoenicopterus roseus*) at Berne Animal Park.



experienced Zoo Animal Carrier

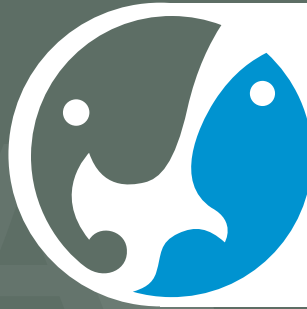


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