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COMMENTARY

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Collection planning for the next 100 years: What will we commit to save in zoos and aquariums?

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The "sustainability crisis" in zoos and aquariums has been a sobering reminder of how limited our resources are for maintaining viable populations of species threatened with extinction. This, combined with increasing concern among the public about the value of zoos and aquariums, suggests that the zoological profession should engage in a thorough re-examination of our guiding principles, philosophies, and practices with regard to collection planning at global, regional, and institutional scales. An analysis of AZA cooperative breeding programs reveals that in order to make these populations viable, many more founders and tens of thousands more spaces for animals, either in existing facilities or new ones, are necessary if we want to maintain all of the species that are covered by cooperative breeding programs currently. Regional zoological associations and their associated cooperative breeding programs must be more strategic and make more scientifically defensible decisions about which species to try and safeguard in zoos and aquariums. This would enable the zoological profession to give society a "Promise List" of species that we will commit to save from total extinction. Developing such a list will require a collaborative, inclusive process that transcends zoological regions. Regional association leaders, zoo & aquarium directors, and curators must make commitments to safeguard the species on the Promise List regardless of other interests. As our profession re-examines its philosophies and practices and finds ways to increase its capacity to provide refuge for species facing extinction in the wild, it may be possible to expand the Promise List.

KEYWORDS
conservation, cooperative breeding programs, sustainability, viability, zoos

1 | INTRODUCTION

Since Lees and Wilcken (2009) called attention to the sustainability crisis occurring in zoo animal populations, regional zoo & aquarium associations have devoted significant effort and resources to assessing and improving sustainability of animal programs (see WAZA magazine v. 12, 2011). While the sustainability crisis has brought about new tools, allowed zoos and aquariums (hereafter collectively referred to as zoos or zoological facilities) to obtain new resources, driven animal care staff to push the boundaries of husbandry, and stimulated important science, I believe that much more dramatic change as part of profession-wide, agreed upon initiatives will be necessary to create a significant number of truly sustainable populations (Lacy, 2013) of animals in zoos. In this commentary, I argue for immediate changes in our approach to collection management that involve decisions at multiple levels that will enable us to make a promise to society that we will be able to save a "Promise List" of species from outright extinction by maintaining genetically healthy, truly sustainable populations in zoos for the long term. A Promise List of species that we will be able to preserve, at least in human care, is still compatible with the notion of using zoo populations to support field conservation in various ways (e.g., education, fund raising, research, assurance colonies; IUCN, 2014) but differs in that it is a guarantee that at least some of the earth's biodiversity will be preserved in living form, even if habitats disappear.

Why does a Promise List need to be profession-wide and agreed upon? Because for many species, only by uniting our populations within and across regions—and likely outside of our profession—can we provide a sufficient hedge against extinction of animal populations in managed care. I say these initiatives are dramatic not only because of scale, but also because I think we must develop a more refined, agreed upon set of values and goals for animal populations in zoos and aquariums that transcends the needs of individual curators, program leaders, institutions, and directors.

Why should the Promise List be social contract? First, zoos are cultural institutions supported directly or indirectly by the visiting public, and we must provide experiences for visitors that they value to maintain their support. Second, given heightened concern about the legitimacy of zoos and aquariums at least among the public in the United States (e.g., https://www.theatlantic.com/news/archive/2016/06/harambe-zoo/485084/; http://nymag.com/daily/intelligencer/2014/07/case-for-the-end-of-the-modern-zoo.html), I feel zoos and aquariums must commit to a social contract with the public for preserving a suite of species in managed care. I believe we must show the public what species are actually "safe" in our care. While zoos can continue to support field conservation, the only way they can absolutely assure a species does not go extinct is to develop a sustainable and viable ex-situ population of the species. The zoological profession needs to collectively examine its resources, expertise, and the status of its animal populations across major zoological regions and decide what limited number of species it can ENSURE it can manage for the long term, even if the wild populations vanish. Making the Promise List as long as possible requires a great deal of re-examination.

2 | WHY RE-EXAMINE?

We know that the populations of species we already maintain in zoos & aquaria need to be larger, more genetically diverse, and breed at higher rates to ensure their viability over the next one hundred years (Lees & Wilcken, 2009 and references therein), meaning we need more institutional space and resources. Our existing resources are very limited, and we do not have any assurance they will increase dramatically in the future. For example, while some zoos are acquiring additional off-site property to use for propagation, we do not expect the creation of many more zoos and aquaria. We also do not have reason to believe that local, state, or federal governments would make significant resources available to bolster our populations unless the status of many of the species we manage nears collapse in the wild. Thus, the prospect for maintaining all of the species diversity we are trying manage currently is slim.

It is not just an issue of the number of species we are managing but also which species we are managing. In 2015, I accessed the IUCN Conservation Planning Specialist Group's list of animals for which captive breeding had been recommended as part of their conservation and recovery strategy. There were 737 species of higher vertebrates (mammals, birds, amphibians, and reptiles) on the list. Of these, only 106 species (or 14%) were in Species360 institutions, which does not include 62 AZA institutions, in populations of greater than 100 individuals (Table 1). We do not have the other species in collections yet. I'm not arguing to have these in our collections, but the point is that as threats to species survival in the wild continue to grow, the call for captive breeding is likely to increase. The recent attempt to establish a captive population of vaquita (*Phocoena sinus*) is a prime example.

Zoos have been criticized for maintaining collections of animals that are not of the highest conservation value in terms of the IUCN threat status to the species (Conde, Flesness, Colchero, Jones, & Scheuerlein, 2011; Gray, Flesness, Conde, & Gussett, 2014; Martin, Lurbiecki, Joy, & Mooers, 2014, but see Bowkett, 2014), but in these high-level analyses, many mitigating factors and realities are almost universally ignored (McCann & Powell, submitted). However, the zoo & aquarium profession has historically defined itself as delivering on four goals that may not completely overlap: conservation, education, recreation, and research. When a new exhibit is designed, opportunities are sought to maximize the chances to use those exhibits for all of the goals. For example, the proliferation of African savanna exhibits was underpinned by the desire to exhibit charismatic species like zebra and giraffe that the public wanted to see while also providing the opportunity to teach about grazing ecology and the need to protect entire ecosystems (i.e., the Serengeti). What has happened is that many zoos have all arrived at similar solutions to delivering on their goals with some non-intuitive consequences. The widespread desire to have an African savanna exhibit led to a dramatic decrease in space allocated to ungulates (Penfold et al., 2014) because zoos have tended to all choose the same, small subset of African ungulates to exhibit that mix well with one another in a single exhibit. Also, once a zoo established its African savanna, space occupied by other African ungulates was

TABLE 1 Population sizes according to Species360 of 737 species that had captive breeding recommended as of 2015 by IUCN as part of their conservation strategy

Population size	# of species	% of total species (*n* = 737)
500+	25	3
100–499	81	11
50–99	57	8
1–49	145	20
0	271	37
Unclear due to taxonomy	158	21

allocated to other uses in the zoo, decreasing the number of exhibit spaces available. This example suggests that discussion at a level above the institution is warranted so that as a profession, our resources are best allocated to deliver on our four broad goals. Later, I will touch on other examples where greater coordination and possibly division of labor might allow us to better protect the sustainability of our collections.

2.1 | Re-examining regional collection planning

Though Species Survival Plans (SSPs) first emerged in 1981, calls for regional collection planning really only surfaced in 1993 with the publication of the first edition of the World Zoo Conservation Strategy (IUDZG and IUCN/SSC CBSG, 1993) which called for regional and global coordination of animal collections to support conservation goals. Regional collection planning processes in the United States were first described by Hutchins, Willis, and Wiese (1995) and specific processes and requirements for regional collection planning were created by the AZA's Wildlife Conservation & Management Committee (WCMC) in 1998 and published in 2000 (AZA WCMC, 2000).

Despite a relatively short history in the zoological profession, Regional Collection Plans (RCPs) have existed long enough to go through several iterations in most AZA Taxon Advisory Groups (TAGs). A detailed analysis of how RCPs have changed within and across TAGs over the years in terms of species recommended (or not) for management, and why, would seem like a useful exercise. Regardless, it is fair to say that AZA TAGs have a history of attempting to manage populations of animals at the regional level given a set of constraints (e.g., space, institutional participation, husbandry proficiency, genetic diversity, population health). A possible problem is that goals may change as TAG chairs and steering committees change, making progress toward goals sometimes difficult to parse. A look at various RCPs available today reveals a variety of regional management philosophies from trying to hold onto as many species as possible to intentionally attempting management of a very small number of species in larger populations. Still, previous analyses of sequential RCPs or comparisons of populations sizes to RCP recommendations at certain points in time suggest that regional collection planning is effective in moving populations toward goals established by TAGs but also that there is large room for improvement. For example, in their analysis, Allard, Willis, Lees, Smith, and Hiddinga (2010) found that only 60% of the AZA species populations analyzed moved in the direction recommended by TAGs; they found similar results in a sample of Australasian TAGs. Other analyses also point to a "success rate" in the neighborhood of only 54–60% in moving animal populations in recommended directions (Searles, 2004; Smith and Allard, 1999). The reasons for success and failure are many and range from being squarely within the control of zoos and aquariums to squarely outside it (i.e., when government regulations make transports of animals between regions exceedingly difficult). Still, throughout the time course of these analyses, our processes and efforts as well as the space for housing animals have possibly not varied greatly. There has been a slow growth in the number of accredited zoos and aquariums in AZA from 174 in 1995 to 230 in 2017, about 2.5 institutions/year, which suggests that more space has become available. However, not all institutions have the same collection scope (e.g., some may be local nature centers that are accredited), and not all institutions have the same amount of space available for maintaining animal populations so it is unclear how much additional space has become available for AZA animal programs. Our knowledge of population biology continues to grow, but since SSPs, TAGs, and RCPs appeared, they have been led by passionate people who do their best to manage single species or groups of species for sustainability. A recent analysis by McCann & Powell (submitted) of a sample of 36 AZA zoos found that for four mammalian TAGs or parts thereof, institutions are also doing their part by populating their spaces most of the time with recommended species, though again there is room for improvement that could recapture a sizable number of spaces.

But I would argue that what we have today is TAGs presenting a "wish list" of species for population management in North America, which to be fair, is the TAG's job. We know however that at least for some taxa, thousands of additional spaces are needed now to bring small populations recommended for management up to somewhat reasonable sizes that we might consider as assurance populations (See Section 2.2 and McCann & Powell, submitted), even while ignoring genetic constraints on these populations. We also probably often fail to appreciate that capture of new space by one SSP or TAG must often mean that another SSP or TAG has lost that space.

If zoos and aquariums are going to make a promise to society to maintain some number of animal species in large, viable populations in perpetuity, then the wish lists of TAGs will have to be balanced against one another. I am not aware of any efforts to do this previously, though there have been discussions among the felid, canid, and small carnivore TAGs to produce a tool that gives institutions some guidance on swapping out carnivore species across these TAGs when exhibits change. There has also been discussion of coordinating space surveys between the canid and felid TAGs (K. Bauman, pers. comm.). It is probably worth thinking about what our zoos would look like if there were only one "Primate TAG," one "Ungulate TAG," or one "Carnivore TAG." Given that there are broad similarities in housing approaches for many Old World monkeys, New World monkeys, and Prosimians, what are the advantages or disadvantages of allocating space among them in a single exercise rather than creating three separate wish lists based on somewhat artificially subdivided resources (spaces)? A similar argument would apply to ungulates and probably many other taxa. There is no doubt that individual curator, keeper, program leader, and institutional affinities for different species would be impacted, but AZA zoos are not for those of us who work in them, despite our own passion and dedication to animals and the zoological profession. They are cultural institutions, and the American public at least has a mindset that we should protect animals by keeping them healthy and safe in zoos and make efforts to conserve them in the wild (Association of Zoos and Aquariums. Surveys of U.S. Americans. Quarterly 2015–2018). The public expects us to make a promise to them that we can keep at least some species safe from total extinction.

2.2 | Analysis of AZA SSP programs

Using the Sustainability Designations for AZA Animal Programs document on the AZA website at the end of 2017, I tallied the space needed for each SSP program that was below 100 individuals to reach that population size. SSPs may be created when the animal population size is at least 20 individuals cared for among at least three AZA-accredited organizations, unless the species is extinct in the wild, critically endangered, or endangered, in which case these population size and institutional requirements do not apply. Green SSPs are those that can maintain at least 90% of their current genetic diversity for at least 100 years. Yellow SSPs cannot maintain this level of genetic diversity for 100 years but number at least 50 individuals. Red SSPs also cannot meet the genetic criterion but have between 20 and 49 individuals in the population. Certain TAGs/SSPs were excluded from this analysis if breeding of the animals is prohibited by a government or by the TAG/SSP (e.g., puma [*Puma concolor*], Northern [*Enhydra lutris kenyoni*] and Southern sea otter [*E.l. nereis*], and generic tiger [*Panthera tigris*]). I also excluded all fish and invertebrates because space for these kinds of animals is possibly not best measured in terms of numbers of individuals. Giant pandas (*Ailuropoda melanoleuca*) were excluded because the U.S. population does not have a goal of being sustainable on its own; island foxes (*Urocyon littoralis*) were excluded because the Canid TAG has recently disbanded that SSP. Variegated/brown spider monkeys (*Ateles hybridus*) were excluded because the population is recommended as a phase out and was down to six individuals at the time of analysis. This left 472 SSPs in my analysis. A population size of one hundred individuals was chosen as an arbitrary goal, a starting point for building a sustainable population. With 100 individuals, I reasoned that there would be sufficient animals of breeding age, and if you can reach 100 individuals through propagation rather than sourcing from the wild or external sources and the species does not produce large litters/clutches, then husbandry is probably sufficiently established to allow for somewhat reliable propagation.

Most population biologists and animal managers are not likely to agree that 100 individuals is a sustainable population, given what we know about population genetics and demography. Larger population sizes are correlated with increased demographic stability, reduced risk of extinction, and higher gene diversity (Ballou et al., 2010). It is true that there are some AZA Green SSP populations that number less than 100 individuals (e.g., Andean condor [*Vultur gryphus*], jaguar [*Panthera onca*], Mariana fruit dove [*Ptilinopus roseicapilla*]). These populations are characterized by factors that allow them to be sustainable at a smaller population size, including long life (i.e., many founders are still alive), long reproductive life span, large numbers of founders, and/or regular infusion of new founders. I obtained founder numbers in AZA SSP Breeding and Transfer Plans, which were entered into PMCTrack (Faust, Theis, Long, & Shell, 2011) with the assistance of the AZA Population Management Center. Founder numbers are critically important and vary significantly across AZA programs ($F_{2,414} = 56.4$, $p < 0.001$; Figure 1). All three SSP types differ from one another significantly in average number of founders. Candidate programs (programs that the TAG wishes to grow to an SSP) were not included in this analysis, but when founder numbers are known in these programs,

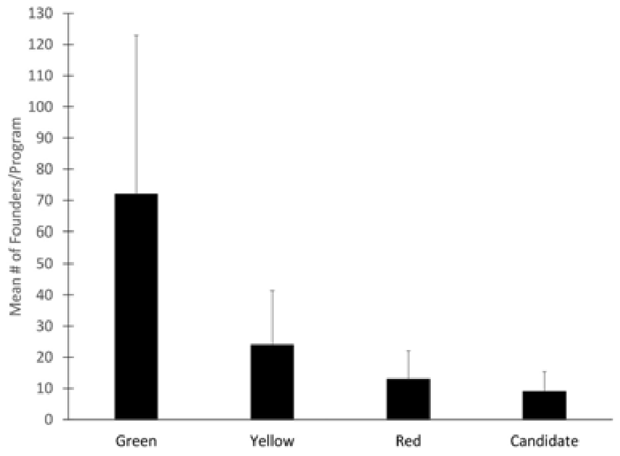

FIGURE 1 Mean (±SD) number of founders in AZA SSPs according to PMCTrack in December 2017. All means are significantly different from one another ($p < 0.0001$)

they have even fewer founders on average. Population genetics tells us that a founder base of 20–50 individuals is a reasonable starting point for long-term management (Foose & Ballou, 1998; Frankham et al., 2002). Currently, only 201 of approximately 500 SSPs have 20 or more founders; only 70 SSPs have 40 or more founders. Aside from genetics, large population size is also a characteristic of sustainable programs, and there is significant variation in population size across SSP types ($F_{2,463} = 157.3$, $p < 0.001$; Figure 2). The highly fecund amphibians are removed from the analysis. All three SSP types differ from one another significantly in average population size. Green SSPs average 341 individuals. Removing flamingo (*Phoenicopterus*) species and the African penguin (*Spheniscus demersus*), which are kept in large numbers, lowers the average to 229 individuals. All of this is to say that 100 individuals should not be an end-goal population size as it is very likely that a population that small will not be sustainable unless a number of other factors enhance the population's ability to retain genetic diversity.

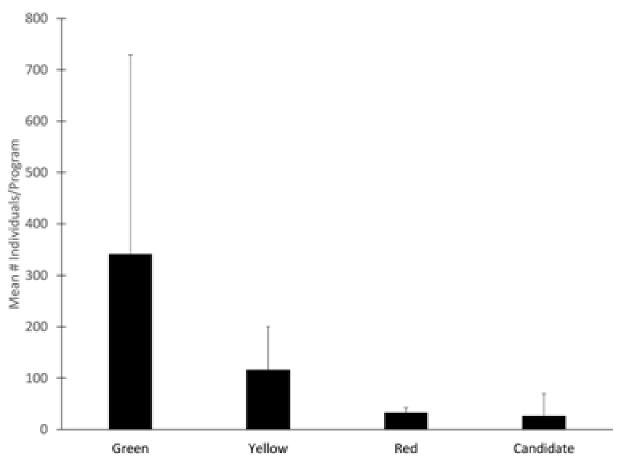

FIGURE 2 Mean (±SD) population size in AZA SSPs in December 2017. Amphibians have been removed from this analysis due to high fecundity. All means are significantly different from one another ($p < 0.0004$)

Regardless, how much space is needed to get all SSPs up to 100 individuals? We need 12,997 additional spaces or space for this number of additional individuals. Only 167 SSPs (35%) exceed 100 individuals. Looking across TAGs included in this analysis, on average 68% (range: 14–100%) of the SSP populations within a TAG are below 100 individuals. If we want to also bring Candidate programs up to 100 individuals, we need 19,671 spaces. This means every currently AZA-accredited institution and certified related facility (*n* = 242 at the time of my calculations) needs to create 54 spaces for SSP programs or 81 spaces for SSP and Candidate programs to improve the outlook for these populations.

These per-institution space numbers may not seem daunting if you consider small-bodied species. Yet the Amphibian TAG can find only enough space in AZA-accredited institutions to maintain just seven SSP programs out of 353 critically endangered species of amphibians found in the Americas and Caribbean recommended for management as assurance colonies (Barber & Poole, 2014). If we wanted all SSP populations to number 230 individuals, the average population size of Green SSPs excluding highly fecund and highly colonial species, we need 62,297 more spaces than we have now. What if we wanted to get populations up to the sizes that Lees and Wilcken (2009) argue are necessary to be truly self-sustainable (*n* = ~700)? We would need over 100,000 additional spaces.

AZA institutions are currently housing 58,438 animals in Red, Yellow, and Green SSP programs in my sample of SSPs. So if we take that as a measure of how much space we have within the AZA membership for SSP species and make a simplifying assumption that all populations should at least number 500 individuals (and have a good founder base), we have space to manage about 117 species currently. Dropping needed population size to 230 makes room for 254 species. Currently there are approximately 500 SSPs. As mentioned previously, there is a sizable amount of space occupied by non-SSP species in AZA institutions, and the solution is probably not to convert those populations to SSPs.

3 | HOW CAN WE MAXIMIZE THE PROMISE LIST?

3.1 | Institution-level actions

We must find space within our institutions. All existing spaces should assessed critically with regard to what they can hold. Peer-review of facilities with regard to how these spaces can be used would reduce the idiosyncratic nature of space assessments across numerous curators, even within the same institution. Zoos and aquariums must build more facilities for propagation. It should be a requirement that every new exhibit for a species be built to accommodate breeding, possibly multiple breeding groups, and at least one if not two successive generations of offspring until they can be placed. Zoos should critically analyze themselves species by species and determine whether they are consumers or producers with the goal of maximizing production ability (see Lynch, accepted). It is possible that enlarging the size of existing animal groups would give a significant boost to current population sizes. We can scavenge space by committing to more multi-species exhibitry. Institutions must do the work and take the risks involved to make these exhibits successful. Some accredited institutions are acquiring additional property; small amounts of acreage could make a difference for small-bodied species. Zoos and aquariums can better abide by RCPs and exhibit recommended species (McCann & Powell, submitted). We should also continue to advance husbandry and reproductive science such that more individuals are recruited into the breeding population despite logistical, health, behavioral, compatibility, regulatory, and other challenges. This would improve our effective population sizes in managed populations and promote better retention of genetic diversity.

We should re-examine management practices for the species we are going to commit to manage to improve their sustainability. Population management euthanasia is such a practice. If culling would allow zoos to use resources more wisely to promote sustainability, could it be justified, given there is mounting evidence that interrupting breeding of animals has negative consequences for future breeding potential in some taxa (Asa et al., 2014; Daigle et al., 2015; Hermes et al., 2006; Hermes, Hildebrand, & Göritz, 2004; Lockyear, Waddell, Goodrowe, & MacDonald, 2009; Penfold et al., 2014; Saunders, Harris, Traylor-Holzer, & Beck, 2014)? The potential benefits of culling can be modeled as proof of concept.

In 2015, Sarah Long, Jess Ray, and I modeled the effects of reallocating space from a downsized plains zebra (*Equus quagga*) population to other more endangered African equids being managed by the TAG. We used demographic and genetic data from studbooks and population modeling software ZooRisk (Earnhardt et al., 2008) to model the future genetic impacts of giving Grevy's zebra (GZ, *Equus grevyi*), Hartmann's zebras (HZ, *Equus zebra hartmannae*), and Somali wild ass (SW, *Equus africanus somaliensis*) each an additional 50 spaces. We modeled the impact of adding that space slowly versus quickly, for example if space became available through culling and/or transfer of large number of plains zebra to the private sector. Growth rates were based on the minimum (gradual) and maximum (rapid) lambdas from historical life table data, 5-year census averages, or stochastic projections for each species. Model projections showed that in terms of demographic benefits, all equid populations in the comparisons could grow to a larger population size and fill the available space. In terms of genetic diversity (GD) at 100 years, the GZ population, a relatively large population with a very high starting gene diversity, showed only a marginal (~2%, Table 2) genetic benefit from additional space, regardless of how quickly that space was provided, but additional space did extend the time to a 10% loss of GD by 43 years. SW benefited in terms of genetic diversity (~10% increase in GD at 100 years and a near doubling of the time to a 10% loss of GD), though there was not a large difference in benefits of obtaining the space slowly or quickly. HZ benefited from additional space (~11% increase in GD at 100 years) and would benefit more if the space appeared quickly (~24% increase in GD), though the space did not greatly affect how many years it would take for this small population to lose 10% of its genetic diversity (Table 2). Simulations of a barrier island horse population and free ranging bison have demonstrated that selective

TABLE 2 Genetic diversity retained (%) in 100 years and years it would take to lose 10% of existing genetic diversity in endangered African equid populations in AZA when given 50 additional spaces to grow into gradually or rapidly

	Genetic diversity			Years to 10% loss of genetic diversity		
Species	No space/no growth	Gradual growth	Rapid growth	No space/no growth	Gradual growth	Rapid growth
Equus grevyi	89.9	91.4	91.6	135	176	178
Equus africanus somalicus	55.8	64.7	65.1	38	64	68
Equus zebra	21.8	33.1	45.4	7	8	9

culling can improve genetic health (Eggert et al., 2010; Giglio, Ivy, Jones, & Latch, 2018). Use of population models can clarify relative benefits to populations competing for the same resources (i.e., space) and help managers better allocate these resources.

Exhibition of species in zoogeographic arrangement should be reconsidered (McCann & Powell, submitted). We may replicate the animals' natural habitat within their exhibit, but it does not follow that the next exhibit along the path also be from the same biome, or even the same continent. Zoos that do not arrange their animals in zoogeographic exhibit areas see comparable visitor numbers and can conduct just as impressive education programs (J. Sailer, personal communication).

Some in our profession fear that zoos will all look the same if we pay close attention to genetic and demographic requirements for healthy populations and focus on a smaller number of species, and yet zoo after zoo has built an African savannah for lions (*Panthera leo*), zebra, and giraffe (*Giraffa spp*.) and chosen ring-tailed lemurs (*Lemur catta*) first as their representative of Madagascar. Coordinated planning of exhibits across institutions would also reduce the need for each zoo to have an African savannah. If another zoo in the region has a spectacular African savannah, why not focus on a different theme for presenting ungulates or at least a different geographical region and provide space for other programs?

3.2 | SSP and curator-level actions

We must find more founders. There might still be captive founders available inside and outside of other established zoological associations (e.g., EAZA). These may be found in private collections (domestic and abroad), rescue and rehabilitation centers, commercial breeders, the pet trade, non-accredited zoos, on hunting ranches, or in laboratories. We know that the private sector in the United States also imports animals, and overseas zoos in developing nations are as well. Working with some of these parties as sources for some species could very well involve a re-examination of our ethics and comfort zones, with acknowledgment of the costs and benefits. Hard work, but possibly worth it if we want to preserve certain species. The alternative may be to drop some of these species from the Promise List.

Our decisions about which species to manage must be based on the most complete data obtainable and informed professional judgement. Program leaders must fully understand the history of the populations they have volunteered to manage and how those were and are managed in zoos and in the private sector, where relevant. They must understand not just how the population has performed in AZA but also have a sense of how it could perform. For example, a recent population viability analysis of the pink-neck fruit dove (*Ptilinopus porphyreus*) used a historical hatch rate for the population (2.5 hatches/year) in the model and projected population extinction within 30 years (Johnson, Sincage, Plasse, & Michael, 2016). Knowledge of the species' reproductive biology in the wild from literature review and personal experience suggested that consolidating the remaining birds of this species at a single institution might enable a higher hatch rate to be realized. The birds were relocated to the Toledo Zoo and the population now realizes up to 20 hatches per year, which PVA models project will allow the population to persist and eventually achieve >90% genetic diversity (Long, unpublished data).

Management of subspecies is another practice to be examined. Taxonomists do not agree on a species concept (see, de Queiroz, 2007; Groves et al., 2017; Zachos, 2014, 2018 and references therein), much less a subspecies concept (Patten 2010). Population geneticists argue that the benefits of supplementing small, inbred populations with genetic material from other populations (or possible subspecies) far outweigh the risks of outbreeding depression or loss of local adaptations in most cases (Ralls et al., 2018). In some cases subspecies management presents challenges to long-term sustainability. Desert bighorn sheep (*Ovis canadensis nelsoni*) were historically managed in AZA in three different subspecies groups. After the U.S. Fish & Wildlife Service decided to merge these into one subspecies, the population could experience a higher breeding rate, which helps the population to persist and maintain genetic diversity (Johnson, McCarty, Holland, & Powell, 2015; McCarty, 2017). Thus subspecies management needs to be critically analyzed and supported with population modeling to justify its use, rather than a philosophical desire to maintain "purity" that may not be biologically or practically relevant. Subspecies management only makes population management units smaller and threatens sustainability.

3.3 | Zoological association and TAG-level actions

Allard et al. (2010) argued for more global planning which is occurring in a group of World Association of Zoos & Aquariums Global Species Management Plans (GSMPs) now. TAGs are being connected across regions through joint TAG meetings. But Allard et al.'s suggestion for global planning also encompassed important decisions like which regions should manage which species. Each major zoological region need not have its own sustainable population of every species considered important for management. For species that can be sustainably managed indefinitely in a single region, other regions may serve as sinks for that population when possible or may not participate at all. The very high profile flagship species that are in great demand and effective at inspiring conservation action should be managed in multiple regions for zoos and aquariums to continue to deliver on their missions. But there are many lower profile species that could be managed in a single region. The Amphibian Ark has taken this regional approach by recommending which species be managed in which region. Global species management will likely be feasible for only a subset of species that are easily moved between regions with regard to permits, financial resources, safety, and veterinary regulations. For many other species, we must further critically analyze our population management protocols to support sustainability within our regions or consider removing them from the Promise List.

Within regions, we need to think differently about what to manage and why. Many authors (e.g., Colléony, Clayton, Couvet, Saint Jalme, & Prevot, 2016; Hutchins et al., 1995; Macdonald et al., 2015) have argued the value of flagship species. We need to identify effective flagships among lesser-known taxa and ensure that we can preserve those species indefinitely in zoos, while generating support for related or similar species. Species do not have to be endangered to serve as flagships (Colléony et al., 2016; McCann & Powell, submitted). We need to determine whether focusing on a small number or even single species of attractive pheasant, regardless of its conservation status, is sufficient for generating conservation dollars for a wider range of pheasants, for example. Do we get the best net conservation support effect from focusing on non-charismatic but more endangered species or from exhibiting non-endangered, attractive species that are easier to manage, breed, and exhibit well, and thus are better teachers and more inspirational to the public? In the relatively rare instances where a species is endangered, truly charismatic, demonstrably effective at inspiring conservation sentiment and relatively easy to care for, we should identify it as a Promise List species. We can use rescued North American or Asian bears as flagships to generate concern for endangered bear species on other continents without trying to maintain a self-sustaining population since there is currently a steady influx of these animals from the wild. This would allow us to dedicate more space in our facilities to a Promise List species where a sustainable ex-situ population is necessary.

We must consider eliminating redundancy within speciose taxa. How many different chelonians do we need to manage to effectively tell the story of the catastrophic decline of this taxon? We want to save as many as we can but there is a space shortfall for chelonians in the most recent RCP (Chelonian Taxon Advisory Group, 2016), because so many species recommended for management. How many small chelonian populations can actually serve as assurance colonies? As evidenced by my analysis, TAGs are recommending too many species for management among AZA institutions.

We should consider whether to maintain our own AZA populations rather than sustainably obtain them either from the wild or from responsible ex-situ sources. In past decades, zoos made conscious efforts to move away from sourcing many kinds of animals from the wild, but most of our managed populations today do not have enough founders. If we want these species on the Promise List, we must obtain more founders. Program leaders and interested curators must find them. We need to consider sourcing animals from the wild for a wider range of taxa, perhaps only to accomplish a one-time top up of founders. Where this is legal, logistically possible and responsible, it should be considered. It can be expensive, but setting up a population for long-term persistence is more than worth the initial cost, isn't it? What are the costs of long-term management of small populations without good founder bases? What is the cost to better founded populations that need space to grow? Reproductive technology may offer us some ability to obtain gametes from founders in the wild to incorporate into our ex-situ populations, but at present, this technology is only robust enough for implementation in very few species (Mastromonaco & Comizzoli, in press; Pukazhenthi & Wildt, 2004). For high profile species, removing animals from the wild may be too distasteful to the public, but survey research that asks people to decide how important it is to indefinitely preserve a captive population should tell us this. We may find a tolerance threshold among the public for this kind of endeavor and use that in making decisions about which species populations to try and bolster with animals from the wild.

We also need to think about which captive populations we actually need to manage versus letting their management lie outside of zoos and aquariums. At the AZA Annual Conference in Atlanta Colleen McCann and Anne Baker discussed the model of managing assurance populations of endangered amphibians in specialized breeding centers in their native range and sourcing from these colonies to populate zoo exhibits. We know there are thousands more non-native ungulates ranging on private and public lands in the United States than there are in accredited zoos. Why would we not obtain animals from these larger source populations to fill zoos rather than trying to manage small, feeble populations on our own (McCann & Powell, submitted)? The argument that these populations are genetic black boxes that cannot effectively contribute to genetic management and thus serve as assurance populations is often presented and is valid. But why not export our population management expertise to these populations when possible so that better genetic management can be done there? Molecular techniques to assess genetic diversity and uniqueness are decreasing in cost, and AZA has created a new Molecular Data for Population Management Scientific Advisory Group to address this new technology and help our community figure out how to harness it. Relationships are forming with exotic ungulate ranchers (e.g., the Source Population Alliance, www.sourcepopulation.org) that can create mutual genetic and demographic benefits to herds. If we can fortify larger, existing populations outside of AZA—which hold genetic diversity longer than smaller populations—with some of our genetic material and expertise, why not do that so we have a supply of addax (*Addax nasomasculatus*) to fill a relatively small number of zoo exhibits? This would allow zoos to use our limited space for ungulates that are not in the private sector.

Most of us who have worked in zoos for probably ten years or more have witnessed the disappearance of at least one species from zoological collections. An often-heard mantra regarding species availability is "once they're gone, they're hard (or impossible) to get back," referring to the difficulty of re-acquiring species that have disappeared from zoos. Often this thinking has led to attempts to hold onto as many species as possible, until it is nearly or definitely impossible to keep their populations viable. The notion of a Promise List is compatible with continual management of some small populations that probably would not last 100 years. However, taxa that are left solely to institutional discretion, persist despite recommendations to phase out, are chronically small for whatever reason, or have little chance for genetic enrichment impair other programs by using valuable space (Shoemaker, 1997). We could manage any number of smaller, less sustainable programs if we decided to manage fewer truly sustainable programs. I'm concerned that this is what we are doing, albeit unconsciously. Earnhardt, Thompson, and Marhevsky (2001) said it clearly "With smaller target population size comes the penalty of lower viability. Spreading this elevated risk among many species, rather than concentrating on few species with lower risk per species, sacrifices long-term conservation and education goals for short-term gains in variety on display." Rather than setting SSP by SSP population targets, they argue for an assessment of space that considers the needs of multiple species simultaneously. I would argue that analysis needs to occur across TAGs for species with similar husbandry and housing needs.

The IUCN Guidelines on the Use of Ex-situ Management for Species Conservation (2014) and the Integrated Collection Assessment and Planning process (ICAP, Traylor-Holzer, Leus, & Bauman, submitted) developed by the Conservation Planning Specialist Group can be of use in making some of these decisions. These processes help to identify conservation-related goals and roles for ex-situ populations that have direct and indirect impact on the survival of the species as part of an integrated conservation strategy. As Traylor-Holzer, Leus, & Bauman (submitted) say, many aspects of this process are not new. For example, AZA TAGs have already been tasked with identifying roles for animal populations and the goals for managing them. These new tools provide for more rigorous and structured deliberation and allow for potential planning across regions as an ICAP can be global or regional in scope. Distinctions between global perspectives on the role(s) of captive populations as generated in an ICAP process must also be reconciled with regional considerations and priorities. To date, only one global ICAP has been completed (Canids & Hyaenids; Traylor-Holzer, Leus, & Bauman, 2018). These processes are very labor intensive and place primary emphasis on conservation as the goal, whereas zoos may have other important goals that must be taken into consideration (i.e., visitor experience, affinity for different taxa) as well. Thus these tools still must be adapted or married with existing thought processes to meet very relevant non-conservation related goals for animal populations in zoos and aquariums open to the public. The European Association of Zoos and Aquariums is experimenting with this new approach currently in the re-design of its managed animal programs and has incorporated the non-conservation roles. It remains to be seen how these processes facilitate the management of sustainable animal populations in zoos and how efficient they are for highly speciose groups.

I assert that society is asking us to make a guarantee of what we can save in zoos and aquariums and in the wild, and as professionals we should be making strategic decisions to maximize the amount of biodiversity we can preserve indefinitely across the in-situ ex-situ spectrum. As a profession, we already partly establish our credibility for species preservation based on our past successes, as we often highlight in the media how zoos have saved species like the Przewalski's horse (*Equus ferus)* from extinction. It is time to make a promise about what we can save in the future and be transparent about what we are not sure we can preserve and why. Explaining this promise to the public will require significant effort from public relations professionals.

I argue that the scope of the Promise List should cover the major zoological regions of the world where capacity for excellent husbandry, population management and animal welfare currently exist. As other regions come online to meet these high standards, they may be added to the pool of participants hoping to grow the size of the Promise List. As discussed, the Promise List can also be grown by working outside of the zoological profession with partners who abide by the same high standards.

4 | CONCLUSIONS

Zoos and aquariums must critically analyze all of their thought processes, values, goals, missions, and protocols for managing our collections—and we need to do so in the most collaborative and cohesive way possible if we are to have any chance of maintaining even a reduced percentage of our current species diversity. In fact, we may be called upon in the future to work with more species as they face unstoppable threats in the wild. As part of the process of developing the Promise List, we will also have to decide how to use current and projected resources to address the future needs of species in the wild whose conservation status may worsen. The IUCN guidelines on the use of ex-situ management for species conservation (2014) should be consulted in those cases. Changes in direction with regard to captive populations will take time as we cannot bring more species onto the ark without divesting ourselves of others in a responsible way. Lees and Wilcken's (2009) analyses were a wake-up call to our profession, and we have made progress. One of their most important recommendations though is one that is likely the most difficult to implement. It is time for a global assessment of our capabilities for managing species sustainably. Only by going through an exercise like this, can we develop a rigorous Promise List to society. People will be the key factor in the success of this endeavor. Current and future zoological leaders and professionals will need to come to agreement on a number of difficult philosophical, ethical and practical questions and adhere to the plans laid out to move forward.

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CONFLICT OF INTEREST

The author has no conflict of interest to declare.

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