Chapter 2
"Mayday Mayday Mayday", the Millennium Ark Is Sinking!

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Abstract Despite exceptional advances in ensuring the health and well-being of animals in human care, zoos of the twenty-first century are ill-prepared and overwhelmed by the sheer number of species requiring conservation support. Furthermore, small population management paradigms have failed to achieve the demographic and genetic targets required to sustain most endangered species in human care. Predictions made in the 1980s regarding the potential of a "millennium ark"—aided by the use of assisted reproductive technologies (ARTs)—for saving species have proven to be wildly over-optimistic. ARTs continue to be touted as a panacea for saving endangered species and even for resurrecting extinct ones. And yet, while the first successful interspecies embryo transfer in a wildlife species occurred 30 years ago, there still is not a single example of embryo-based technologies being used to consistently manage a conservation-reliant species. The limited contribution of ARTs to species conservation to date principally stems from the lack of knowledge of species biology, as well as inadequate facilities, space, expertise, and funding needed for their successful application. ARTs could and should be an important tool in our conservation toolbox, but we cannot fall into the trap of believing that we can "assist" or clone our way out of the present biodiversity crisis. Reproductive technologists overstate the potential of ARTs for saving endangered species, zoos overestimate their ability to sustain genetically and demographically viable captive populations with existing resources, and conservationists underestimate their need for zoos in the face of failing efforts to sustain species in nature. Unless all parties concerned—reproductive technologists, zoo biologists and conservationists—adopt parallel efforts to sustain wild populations and places, zoos risk becoming living museums exhibiting relic species that no longer exist in nature.

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1 Introduction

Zoos and aquariums have evolved over the past century from primitive menageries to modern zoological parks, with naturalistic exhibits and habitats designed to ensure the health and well-being of animals in human care (Wemmer 1995a; Hoage and Deiss 1996). London Zoo, founded in 1826, was the first zoo established to support scientific study (Wemmer and Thompson 1995), but it was not until the 1960s that stand-alone zoo-based research departments were established (e.g., London Zoo, Smithsonian's National Zoo, San Diego Zoo) with expanded research portfolios in disciplines we now know as "Zoo Biology"—reproductive biology, genetics, behavior and animal health and husbandry sciences (Benirschke 1984). Today, roughly 20 % of accredited European and American zoos have research departments, but a much smaller number employ full-time Ph.D.-level scientists and conservationists (Reid et al. 2008).

There is no question that modern zoos, working with diverse partners and stakeholders, have become champions for conservation. Zoos have pioneered the concepts of conservation breeding linked to species reintroduction and restoration of species like the golden-lion tamarin (Kleiman et al. 1986), California condor (Toone and Wallace 1994; Walters et al. 2010), black-footed ferret (Lockhart et al. 2005), and Wyoming toad (Dreitz 2006), among others. And the global zoo community currently invests more than $350 million per year in field conservation programs (WAZA 2005; Penning et al. 2009; Gusset and Dick 2010). But the challenge facing zoos in conserving species is daunting. The IUCN estimates that 25 % of mammals, 12 % of birds, 20 % of reptiles, 30 % of amphibians, 20 % of fishes, and 30 % and 68 % of invertebrate and plant species evaluated to date, respectively, are threatened with extinction (IUCN 2012). Faced with this accelerating global loss of species (Collen et al. 2008), zoos are forced to perform triage in determining which species to save, and which will be left to fend for themselves in nature (Conway 2003; Nijhuis 2012).

Despite exceptional advances, zoos of the twenty-first century have yet to achieve their potential as "conservation centers" or "environmental resource centers" focused on holistic conservation that emphasizes both species and the habitats they require for survival (Rabb 1994; Conway 1996, 2003; IUDZG/CBSG 1993). Furthermore, well-intentioned cooperative population management efforts designed to slow the inevitable loss of genetic diversity that occurs in small, closed populations, have largely failed due to insufficient numbers of founders, inadequate space, poor reproductive management, and inadequate knowledge of species biology (Lacy 2013). Numerous analyses have revealed that "most zoo populations are not being managed at adequate population sizes, reproductive rates, genetic diversity levels, and projected long-term viability that would allow them to contribute positively to species conservation." (CBSG 2011).

2 The Millennium Ark

In a landmark paper, Soulé et al. (1986) predicted that if environmental destruction rates continued unabated, virtually all primates, large carnivores, antelopes, rhinoceros, wild equids, and hundreds of species of birds, reptiles and amphibians would effectively disappear from the wild within 100 years. As a response to this impending biodiversity apocalypse, a group of scientists proposed the creation of "millennium arks" to buy time for the more than 2,000 wildlife species that would likely survive only under human care. The concept called for establishing zoo-maintained populations consisting of at least 20 founders per target species with a goal of sustaining 90 % of the genetic variation of the original founder population for a period of at least 200 years. While the authors recognized the limitations of the ark model, their great faith in unforeseen breakthroughs clearly was evident: "The captive breeding of so many species will saturate the available space and resources, but, hopefully, advances in cryogenics and similar technologies will obviate the need to maintain all of these at one time as living organisms." These authors went on to predict that, "…based on the recent successes in bovids, equids, and primates, we consider it likely that traditional captive breeding programs for many species in these groups will be obsolete in a few decades (given reliable refrigeration)." It is especially noteworthy that none of the authors of this paper were reproductive biologists.

Now, only 30 years later, some have concluded that the millennium ark is sinking (Lees and Wilcken 2009). Even relaxing the goal of sustaining 90 % genetic variation from 200 to 100 years does not alter the grim facts that: (1) less than 50 % of all of the worlds' zoo-managed animal populations are breeding to replacement levels; and (2) only 55 % are sustaining more than 90 % gene diversity. Presently, about 75 % of zoo-based programs for birds and 66 % of those for mammals are not achieving specified demographic and genetic targets (de Man 2011). Overall, 30 % of all zoo-maintained populations are declining and 30 % have fewer than 20 founders (Long 2011). Simply stated, zoos are overwhelmed and ill-equipped to manage more than 500 high-priority species programs due to lack of space, specialized facilities, technical expertise, and funding.

We possess an appalling lack of fundamental scientific knowledge of species biology. In a review of the roughly 250 wildlife species referenced in the reproductive sciences literature, 75 % of these species were represented by three or fewer references (Wildt et al. 2003). Additionally, only three species classified by IUCN as endangered (African elephants, Asian elephants, and cheetah) were considered relatively "well-studied", having more than ten peer-reviewed publications (Wildt et al. 2003). The routine application of research tools like noninvasive endocrine and genetic methods has increased the number of species studied over the past decade, but efforts are heavily skewed towards mammals and birds (Monfort 2003; Schwartz and Monfort 2008), and our knowledge of the reproductive biology of the vast majority of species in the animal kingdom remains rudimentary or non-existent.

3 The Application of ARTs for Conserving Endangered Species

Early breakthroughs in the application of ARTs to endangered species were stunning, including successful interspecies embryo transfers from eland (Dresser et al. 1982) and gaur (Stover and Evans 1984) to domestic cow, and bongo to eland (Dresser et al. 1985)—successes that soon raised great expectations that ARTs would revolutionize the management of endangered species. During these heady times, the concept of "Frozen Zoos"—biorepositories of frozen tissues—was introduced (Benirschke 1984; Clarke 2009), long before the benefits of such collections were fully understood, and before the name "Genome Resource Bank (GRB)" entered our lexicon (Wildt et al. 1997).

ARTs, including artificial insemination (AI), the use of sex-sorted sperm, embryo collection and transfer (ET), in vitro oocyte maturation (IVM) and fertilization (IVF), and cloning have been widely promoted as having tremendous potential for enhancing breeding management and the genetic and demographic sustainability of small populations of rare species (Pukazhenthi and Wildt 2004; Holt and Lloyd 2009). A wide range of ancillary methods and tools have been developed and applied, including hormonal and behavioral assessments for developing fundamental knowledge in diverse species (e.g., ovulatory mechanisms, seasonality, pregnancy, infertility), manipulating (e.g., superovulation, estrous synchronization), augmenting or overcoming blocks to reproduction (e.g., AI, ET, IVF), suppressing fertility (e.g., contraception, aggression control), and establishing biorepositories for capturing extant genomic diversity (e.g., cryoprotectant evaluations and cryopreservation methods).

Despite an early emphasis on embryo technologies in the 1980s, and recent interest in cloning and other genomic approaches for "rescuing" or even resurrecting extinct species (Zimmer 2013), major technical and ecological challenges remain for their application in conservation. This is reflected in the fact that 30 years after the first successful interspecies embryo transfer in a wildlife species, there is not a single example of embryo-based technologies having been used to consistently produce or manage a conservation-reliant species. The simple explanation for this is that reproductive mechanisms are incredibly diverse, and what works in one species likely will not be directly applicable to another species—even among closely related species in the same taxonomic group (Wildt et al. 2009). The problem has been summed up succinctly as follows: "Cow AI technology does not work in a cheetah or a gorilla. But, why should it? Each species is evolutionarily distinct, having developed highly specialized reproductive adaptations. It is the job of reproductive biologists to understand the diverse ways that animals reproduce, because reproduction is the essence of species survival." (Wildt and Wemmer 1999).

The time has come to stop and take stock in why we have generally underperformed in applying even the most basic ARTs such as AI for routinely producing offspring and managing the genetics and demography of wildlife species. We are in an age when genomes can be wholly reconstructed, and biodiversity genomics will soon be yet another tool to add to the ART toolbox. But what good are new or better tools to a mechanic when he or she has absolutely no idea of how the engine was designed to operate in the first place? The trap for the reproductive technologist—especially those with zero experience or knowledge of wildlife biology—is ignorance in believing that any ART can be successfully applied to any species. While history demonstrates that this is a specious notion, the latest technological applications continue to attract attention disproportionate to their potential for sustainably managing reproduction in endangered species, much less resurrecting extinct species (The Long Now Foundation 2013). Whether it is the successful application of AI or the use of cloning to sustain an endangered living species or resurrect an extinct one, success is dependent upon knowledge of a species' biology, ecology, social structure, reproductive cycle, seasonality, implantation, placentation, gestation, parturition, maternal behavior, neonatal care, nutrition, disease susceptibilities, and causes of endangerment. Failure to appreciate the need for this fundamental information is an epic miscalculation that dooms the application of ARTs to certain failure, at least in a practical sense.

4 Case Studies

While this chapter is not intended to provide a comprehensive overview of ART applications in endangered species, a few examples follow that demonstrate both the promise of these approaches, as well as the very real challenges to their practical application.

4.1 ARTs in Endangered Fish

One of the oldest applications of ARTs was invented in the mid-nineteenth century when Joseph Remy and Antoine Géhin harvested eggs and milt from trout and then artificially propagated them by the thousands in vitro (Halverson 2010). This is essentially the method that remains in use today for cultivating diverse species such as carp, salmon, trout, catfish, and tilapia, among others. For example, more than five billion hatchery-reared juvenile salmonids are released annually into the Pacific Ocean from North American hatcheries, alone (Flagg and Nash 1999). In addition, hormone-induced spawning at commercial levels has been practiced for decades (Mylonas 2010), and while fish embryo cryopreservation remains challenging (Hagedorn et al. 2002), sperm has been cryopreserved in more than 200 freshwater and 40 marine fish species worldwide, with routine offspring production using frozen-thawed sperm (Chew and Zulkafli 2012). As the numbers of threatened or endangered fish species increases, "conservation aquaculture," including the use of ARTs, has emerged as a strategy for conserving the genotypes, phenotypes and behaviors of locally-adapted fish populations in support of comprehensive recovery strategies (Anders 1998). However, new research suggests that this approach is not without risks, as the impacts of large-scale mixing of hatchery-produced fish with wild stocks have been shown to reduce overall fitness in species like salmon (Reisenbichler and Rubin 1999) and trout (Araki et al. 2007). Nonetheless, conservation hatcheries, augmented by ARTs, are likely to become increasingly important for recovering critically endangered fish populations—especially those of commercial value—to avoid reductions in population size and the loss of genetic diversity that could increase the risk of extinction (Drauch Schreier et al. 2012).

Zoos and aquariums are increasingly being called upon to help conserve endangered fish species using both ex situ and in situ approaches (Reid et al. 2013). After more than a century of management practice, it now appears that simply producing and releasing large numbers of hatchery-reared fish is not sufficient to sustain and/or recover fish populations. Conservation aquaculture is in its infancy, and its clear that more research is required to understand the impacts of diverse factors such as genetics (inbreeding, outbreeding), broodstock sourcing, maturation and development, growth rate modulation, environmental enrichment, anti-predator conditioning, as well as an improved understanding of anthropogenic impacts on aquatic environments, such as habitat loss/fragmentation, pollution, and climate change (Flagg and Nash 1999, Reid et al. 2013). To maximize their conservation impact, zoos and aquariums will need to make new capital investments in space, infrastructure and scientific expertise, as well as to leverage extant resources to create new and novel partnerships with governments, universities, fish hatcheries, aquaculturists and other technical experts, as required to achieve success.

4.2 ARTs in Endangered Birds

Intravaginal AI has been used in the domestic poultry industry for more than a half-century (Quinn and Burrows 1936), and today nearly 300 million turkeys are produced annually in the United States, alone (USDA Statistical Service 2012). AI has now been used to produce chicks in numerous species of raptors, cranes, waterfowl, psittacines, and passerines (Gee 1995), and this technology has played a key role in successful species recovery programs for the Peregrine falcon (Hoffman 1998), houbara bustard (Saint Jalme et al. 1994), and whooping crane (Ellis et al. 1996). The success of these excellent programs was underpinned by systematic research in diverse disciplines, including behavior, genetics, animal husbandry, veterinary medicine, and chick rearing (Ellis et al. 1996). While AI in wild or rare birds can be incredibly challenging, this approach has tremendous potential for augmenting reproduction in endangered birds for maintaining gene diversity in small populations, and especially when natural breeding is not possible due to behavioral incompatibility, reproductive asynchrony, physiological stress, poor libido, physical abnormalities, among other causes. For all bird species, successful application of AI requires pre-emptive research in semen collection and processing, access to sufficient numbers of birds for basic and applied research, baseline knowledge of species' biology, and appropriate facilities and expertise (Blanco et al. 2009).

An incredibly successful example of the application of ARTs to the conservation of an endangered bird species can be found with houbara bustards. Since the mid-1980s, scientists in Saudi Arabia (Saint Jalme et al. 1994; Seddon et al. 1995) and the United Arab Emirates (International Fund for Houbara Conservation 2012) have conducted extensive research on houbara bustards in the areas of behavior, genetics, reproductive biology, veterinary medicine, as well as the ecology, status, distribution and wild population trends. Since 1996, the Emirates-led program has released a total of more than 111,000 houbara in North Africa, with 20,310 released in 2013, alone; the long-term goal is to release 50,000 birds per year (International Fund for Houbara Conservation 2012). Success of this magnitude has required massive long-term financial investments in facilities infrastructure, scientific and husbandry expertise and logistical support motivated, in large part, by the desire to restore sustainable wild houbara bustard populations to support a strongly ingrained cultural interest in falconry. While conservation breeding programs of this magnitude are clearly out of reach of the zoological community, there are many valuable lessons to be learned from such programs that could be scaled appropriately to conserve zoo-maintained endangered bird species.

4.3 ARTs in Endangered Ungulates

It is not surprising that initial successes were achieved in the Bovidae, as many of the ARTs were developed and applied in domestic cattle in efforts to refine their reproductive management for economic benefit. The simplest of these techniques, AI, has now been successfully applied to produce live offspring in 14 species of non-domestic bovids and seven cervid species (Morrow et al. 2009). Yet, despite tremendous strides in developing this technology, AI is used to routinely manage the genetics of only a single zoo-maintained endangered ungulate, the Eld's deer (*Rucervus eldi*), and only in a very small number of individuals (Monfort et al. 1993).

The case studies of two endangered species—Eld's deer (critically endangered with fewer than 1,500 animals in the wild) and the scimitar-horned oryx (*Oryx dammah*, extinct in the wild)—illustrate some of the challenges in applying ARTs to the genetic management of small populations held in zoos. Both species were the subject of comprehensive research programs that successfully characterized ovarian cycles, developed estrous synchronization methods, semen collection and sperm cryopreservation protocols, and were found useful for routine offspring production (~50 % conception rate) following a single insemination with frozen-thawed sperm (Monfort et al. 1993; Morrow et al. 2000). Despite the clear potential for these methods for enhancing the genetics and demographics of ex situ populations, few zoos possessed the facilities or expertise to permit animals to be safely handled twice to permit insertion and removal of intra-vaginal progesterone-releasing devices during the prescribed 12- to 14-day estrous synchronization interval; followed by anesthesia and laparoscopic AI. In the early 1990s the author contacted a veterinarian at another zoo, which held the second largest Eld's deer population (of six AZA zoos managing this species), to inquire about the possibility of conducting AI to manage the genetics of their inbred Eld's deer population. The veterinarian conveyed that the risk of injury and/or mortality associated with simply darting (anesthetizing) the deer was too great, making this approach impractical. Thus, despite years of systematic research and proven success, ARTs could not be applied due to the limitations imposed by existing facilities and management schemes typical of most zoos. A decade later, AI is still only used to manage Eld's deer reproduction at the Smithsonian's National Zoological Park, which maintains a GRB for Eld's deer sperm, and has facilities that permit safe handling and manipulation of this species.

4.4 ARTs in Endangered Carnivores

The cheetah is a highly charismatic endangered species that has been maintained in human care for literally thousands of years, and yet cheetah populations are not sustainable in zoo-maintained collections worldwide. More than half of all captive cheetahs fail to ever reproduce, and despite more than 30 years of intensive research, the reasons for this remain elusive, although husbandry, management, behavior, health, and age-related infertility likely all contribute to poor reproductive success in zoos (Wielebnowski et al. 2002). While notable reproductive milestones have been achieved in the cheetah, including the birth of offspring following AI using both fresh (Howard et al. 1992) and frozen-thawed sperm imported from South Africa (Howard et al. 1997), these methods are not reliable for routinely producing offspring. A major insight into the reproductive biology of cheetah occurred when noninvasive fecal hormone assessments and behavioral observations revealed that females housed together often experience suppressed ovarian activity linked to agonistic behaviors (Wielebnowski et al. 2002). This fortuitous discovery led to a major shift in ex situ management practices to better mimic the social structure observed for this species in the wild, i.e., females are maintained alone or with their offspring, males are housed in small groups or coalitions, and social introductions are managed to permit natural mate choice and reproduction. The results have been impressive since implementing these changes. For example, at the Smithsonian's National Zoo, seven litters have been born during the last three years compared with only two litters being born over the Zoo's previous 125-year history. This is a case where fundamental reproductive knowledge (i.e., noninvasive endocrinology, animal husbandry, mate choice) has been far more significant in moving towards the goal of cheetah population sustainability than has heretofore been possible using ARTs.

A highly successful example of the practical use of ARTs for augmenting the conservation of an endangered carnivore species is the black-footed ferret. The species, which had declined to only 18 living individuals in the 1980s, has since been brought back from the brink of extinction as a result of cooperative management and breeding programs amongst zoos, state and federal government agencies (Howard et al. 2003; Lockhart et al. 2005). Basic research conducted at the Smithsonian's

National Zoo focused on understanding ferret reproduction and seasonality, semen collection and sperm cryopreservation methods, and laparoscopic AI of females that have not produced offspring via natural breeding (Howard and Wildt 2009). To date, more than 150 kits (60 % success with fresh sperm) have been produced by AI, including multiple litters of kits that have been produced from frozen founder sperm stored for as long as 20 years. Many of the individuals produced by AI have subsequently reproduced and some of their offspring have been reintroduced into the wild, representing a direct example of how ARTs have tangibly contributed to a successful species recovery program. Since 1987, more than 8,000 black-footed ferrets have been produced and more than 3,000 of these have been released into prairie dog colonies across North America.

5 Why Aren't There More Success Stories?

One thing is clear: we have grossly underestimated the complexity and diversity of reproduction in the animal kingdom, and we have certainly overestimated our ability to develop and apply ARTs that can be used to aid reproductive management and contribute to biodiversity conservation (Wildt et al. 2009; Holt and Lloyd 2009). In fact, the barrier to the successful application of ARTs is not a shortage of new techniques, but rather a fundamental lack of "conservation capital"—trained scientists, sufficient numbers of research subjects, funding, and appropriate facilities designed specifically to study and manage nondomestic species.

Scientists who work with rodent, primate, and dog or cat models appreciate the requirements for appropriate facilities, handling devices, trained staff, appropriate nutrition, adequate veterinary care, and standards of humane care. Farmers and ranchers similarly understand that excellent production and profits require appropriate investments in husbandry, care and management. And all animal scientists appreciate the decades of research and hundreds of millions of dollars invested in research, and the armies of scientists, lab managers, farmers and ranch hands that moved the state of the art to where it is today. With this solid history and understanding of the importance of methodically and systematically studying species' biology and management, we remain surprisingly ignorant about the biology of the hundreds of species of wildlife whose very survival is inextricably dependent upon human care.

The reproductive technologists are not the only ones underestimating the challenges they face in being relevant to ensuring species survival. The zoo community has been too slow to recognize that current management paradigms are insufficient for sustaining hundreds of species across diverse taxa. Zoos also lack sufficient knowledge of the biology of the majority of species under their care, and in many cases, maintain animals in facilities that suffer from limited space, an absence of handling/manipulation facilities, and insufficient flexibility to mimic and/or manipulate social groupings or to deal with multiple male aggression. Likewise, conservationists have often minimized the role of zoos and resisted biotechnology at a time when their own efforts to stem the loss of biodiversity and wild places have fallen short. Reproductive technologists, zoo professionals, and conservation biologists all want the same thing—to save species and the ecosystems they require for survival. Success will require collective efforts to identify extant limitations and fundamental gaps in knowledge, both intellectual and practical, and joint efforts to secure long-overdue improvements.

Conservation biologists are beginning to recognize the value of ex situ species management programs arguing that "minimal management" of wild species in their natural habitats is no longer realistic (Conde et al. 2011; Redford et al. 2012). Although the genetic, phenotypic and behavioral consequences of captivity support the notion that captive management should not be the first option for species recovery, the time to master a species' biology is when they are not rare (Snyder et al. 1996). Having extremely small founder populations (e.g., black-footed ferrets, 18; Przewalski's horses, 14; California condors, 14) severely restricts access to animals for most forms of research, hinders the design of experiments likely to yield statistically-valid results, and saddles the species with depauperate genetic diversity in perpetuity (Holt and Lloyd 2009). Fortunately, this scenario can be avoided because zoos have access to multiple planning (e.g., Population and Habitat Viability Assessment, Lacy 1993/1994), and database tools (e.g., Red Data List, IUCN 2012; computer modeling, ISIS 2013) that can be used to identify and prioritize species in need of basic and applied conservation science to aid in their survival and recovery. New concepts articulate the need to manage species along a conservation continuum with differing levels of intervention, from controlled captive breeding to metapopulation strategies that employ large spaces to managing extractive reserves to protected areas that require minimal intervention (CBSG 2011; Lacy 2013). Most conservationists agree that the list of conservation-reliant species will continue to grow unabated. These trends present a great challenge to the conservation community, but also a wealth of opportunities for reproductive technologies to contribute to species conservation.

Conservation Centers for Species Survival (C2S2 2013) is a new model that provides space, specialized facilities and expertise for the sustainable management of select endangered species (Sawyer et al. 2010). Established in 2005, C2S2 is a group of five Association of Zoos and Aquariums [AZA]-accredited institutions that collectively manage more than 25,000 acres of land that constitutes more than 60 percent of all land holdings of the entire AZA membership, which includes roughly 225 accredited zoos in North America. C2S2's mission is to "conduct science to understand biology and conservation complexities of species. Breeding to ensure availability of sustainable source populations—for recovery, reintroduction and managed populations." This is an innovative and welcome approach to addressing the need for increased knowledge and new models for sustaining species. This model recognizes that reproduction is fundamental to species survival, and that there are no shortcuts to developing a comprehensive understanding of the diverse factors that impact reproductive fitness, including endocrinology, genetics, developmental biology, animal behavior, health, nutrition, and the social factors needed to maximize natural breeding or to develop or apply ARTs. Additionally, the success of this model is dependent on providing appropriate environmental and social milieu, supported by highly trained, competent professionals. There is no doubt that the zoo and conservation communities need more such facilities, and not just in North America, but also in lesser-developed countries that are being challenged to respond to increasing numbers of endangered species emergencies. New and nimble alliances are needed to facilitate effective peer-based species survival programs deployed across a conservation continuum (Conway 2010). The success of the C2S2 program and other similar programs and alliances (e.g., Amphibian Ark, National Elephant Center, Turtle Survival Alliance) benefit from novel business models and cost sharing within and among the zoo and conservation community. It is worth noting that for species like amphibians, where space and facilities are less of a barrier to implementing effective conservation breeding and research programs, organizations like the Amphibian Ark (Amphibian Ark 2013) and the Panama Amphibian Rescue and Conservation Project (PARC 2013) have made tremendous progress in demonstrating zoo-based conservation leadership, including utilizing ARTs (Browne et al. 2006; Kouba and Vance 2009). Likewise, basic research and the application of ARTs in a zoo context shows great promise for breeding coral and collecting and raising coral larvae that may one day be used to out-plant sexually-derived coral for restoring reefs (Hagedorn et al. 2006). In summary, because the task facing zoos is immense, solutions must realistically rely on (1) forming new alliances among conservationists, scientists, and animal managers; (2) securing the space and specialized facilities needed to facilitate and manage reproduction; and (3) conducting the scientific research required to achieve sustainability targets across the continuum of extensively managed populations for conservation.

With some notable exceptions (e.g., amphibians), traditional zoos are currently not designed or equipped to utilize ARTs for routine animal management, nor even to support hypothesis-driven research that utilizes appropriate numbers of research subjects. New facilities and programs, perhaps supported through consortia and cost-sharing agreements, should be developed to specifically meet the strategic conservation needs of the zoo and conservation communities. And because of the unique and vital role that zoos can play, more effort should focus on engaging governments, bilateral agencies and civil society organizations to join with zoos to make the investments in infrastructure and human capital needed for zoos to affect greater global leadership—including outside of North America and Europe—in sustaining the biodiversity that benefits current and future human societies.

6 Good Science and Effective Conservation Practice Are Good for Zoo Business

Managing and sustaining species in human care is the mandate of the modern zoo. And the zoo community often speaks of educating and inspiring the public to care—to develop empathy for species and their conservation, and to inspire people to take actions in their own personal lives that will lead to tangible conservation outcomes (Rabb and Saunders 2005). There is no doubt that this is a noble and worthwhile goal, but there is another "social contract" that is implicit between modern zoos and their publics—that zoos will be champions in taking direct actions designed to save species from extinction. In essence, the general public may or may not take direct conservation actions to save species or ecosystems themselves, but increasingly, they will not excuse zoos for failing to do so. As former Wildlife Conservation Society Director, Bill Conway, wrote more than a decade ago, "If zoos do not act to help save nature now, much wildlife will be lost that might have been saved. The zoo's moment will have passed. It's relevance will disappear." (Conway 1996).

Zoos have made much progress in recognizing the importance of pursuing a conservation mission, but strategies employed to date have failed to achieve the goal of sustaining genetically diverse, demographically stable assurance populations. It seems clear that zoos, working in partnership with donors, governments and the wider conservation community, must vastly increase their investments in space, facilities, technical and scientific expertise, as well as their investments in supporting field conservation.

In fundamental ways, the zoo business is no different than any other business in that it relies on a "product pipeline" (animals) to generate the revenues required to sustain capital (e.g., exhibits, infrastructure) and operational (e.g., staff, maintenance) expenditures. In the zoo business, losing control of the supply and quality of the "animal pipeline" that zoos depend upon for the success of their business models would be catastrophic, potentially leading to an industry-wide contraction driven by the law of supply and demand. Many of the most sought after zoo exhibit animals, including okapi, elephants, cheetah, to name a few, are declining in nature, and zoo-based breeding programs cannot keep up with extant demand (Lees and Wilcken 2009; Lacy 2013). Combined with moral, ethical and legal restrictions associated with harvesting animals from nature, or even importing them from other zoos, sustaining animal populations has become an existential challenge for the zoo community that must be addressed urgently.

The choice for zoos is really quite clear: increase the supply of animals by alternate, sustainable means, or watch animal availability plummet and the price of doing business skyrocket. With this in mind, investments in conservation, just like investments in new exhibits and infrastructure, would appear to make good business sense for zoos. And while this process will undoubtedly increase costs in the near term, these actions will likely stabilize the cost of doing business in the future, and secure long-term institutional viability. While new animal and conservation costs are unwelcome, arguments against creating "pay to play" systems for acquiring animals are rather unsophisticated given that there already are real costs of producing and providing animals, the burden of animal importation and production is disproportionately borne by a relatively small number of large zoological institutions, and some species already come with great costs of acquisition (e.g., giant pandas, okapi, Asian elephants, golden monkeys). The inconvenient truth facing zoos today is that they must make a choice between paying now or paying more later, and ceasing to be relevant or even ceasing to exist at all. In summary, investments to ensure sustainability of wildlife populations provide at least two essential long-term benefits for zoos: (1) providing a steady supply of diverse animal species to fill exhibits so that zoos can continue to provide their customers with up-close-and-personal encounters with inspiring wildlife, while generating the revenues needed to meet expenditures; and (2) ensuring that genetically-diverse, demographically-stable, and behaviorally-competent populations of animals are available to support conservation-oriented goals including restoring, exchanging or bolstering wild populations of species of critical conservation importance. These goals are fully within the grasp of zoos, but success will first require an unflinching recognition that the problem exists, matched by outstanding leadership, a tenacious commitment to developing long-term solutions, and increased financial investments in conservation capital—animal management facilities, science and husbandry, including the factors that influence the reproductive fitness of conservation-reliant species.

And so what does “zoo business” have to do with the application of ARTs in wildlife species? Quite simply, improvements in zoo management schemes, and an increased emphasis on gaining new fundamental knowledge of species biology will make it increasingly possible to successfully utilize ARTs—some of which have been available for nearly a century. To a very large extent ARTs have outstripped the capacity of zoos to implement them. Aligning technological capability with good animal management and sound conservation principles will make it increasingly possible to apply ARTs to increase reproductive efficiency; to readily transport gametes (sperm, eggs, embryos), raw DNA or genomes to overcome increasingly onerous international animal importation restrictions; to facilitate zoo-to-zoo animal exchanges (e.g., elephant AI already serves this purpose, Brown et al. 2004); and eventually to permit the routine exchange of genetic material between zoo and wild populations (Holt and Lloyd 2009). The justification for a return to building basic knowledge boils down to this: what is the ultimate value of using ARTs to produce endangered animals, or even resurrect extinct species, if we lack the capacity to manage and sustain these species in the first place? If we cannot now sustainably manage an oryx, Eld’s deer or cheetah with or without ARTs, then what chance do we have of sustaining resurrected woolly mammoth, guagga or dodo in the future? Our strategy and focus must change or the true potential of ARTs for managing endangered species will never be fully realized.

7 Can We Rescue the Millennium Ark from Sinking?

Many zoo biologists and managers adopted an unquestioned belief in the philosophies so eloquently articulated by zoo directors Bill Conway, George Rabb, and others in the 1980s when they spoke of the on-going evolution of zoos into conservation organizations. Their clarion calls to action are as relevant today as they were nearly three decades ago. It may be too late for some species, but by pursuing progressive animal management strategies, and investing in new conservation capital and human resources, as well as embracing zoo and conservation biology more broadly, the zoo community still has the potential to match the rhetoric of conservation with measurable conservation outcomes. The millennium ark may yet be salvageable, although it may be smaller than originally envisioned. But ignorance and arrogance remain our worst enemies, and it is not especially visionary to predict that ignoring this advice for another 30 years will jeopardize the very survival of zoos themselves—or at least those that fail to evolve—and severely diminish their value as relevant cultural, scientific and conservation organizations.

There can be no disputing that wildlife will ultimately be managed across a conservation continuum whereby animals—in zoos and in nature—will increasingly be managed under human care. Nor should there be any doubt that our publics expect zoos to demonstrate a direct link between the animals under their care and the role they play in sustaining their counterparts in nature. The role and relevance of ARTs for contributing to species conservation is inextricably linked to whether or not zoos invest in developing an improved understanding of overall species' biology, and reproduction, in particular. But while reproductive biology is a vital piece of the conservation puzzle, we should not fool ourselves with the ignorant notion that we can "assist" or clone our way out of the biodiversity crisis. Technology combined with sound husbandry and management, appropriate facilities, and parallel efforts to sustain wild populations and places, offers the best chance for conservation success. Zoos must adopt such holistic conservation strategies or they risk becoming living museums exhibiting relic species that no longer exist in nature, and the resurrection biologists will have more work than they ever bargained for.

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