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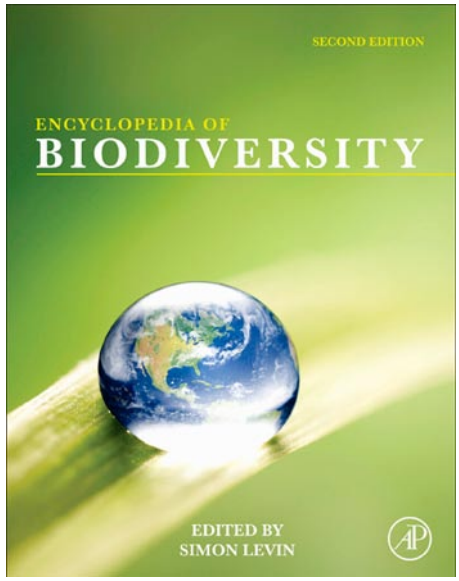

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Captive Breeding and Reintroduction

Katherine Ralls and Jonathan D Ballou, Smithsonian Conservation Biology Institute, Washington, DC, USA

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Glossary

Allele One of two or more alternative forms of a gene.
Founder Wild-caught individual that contributes genetically to the captive population.
Founder genome equivalent Number of equally contributing founders that would have produced the same genetic diversity found in an existing captive population if there had been no random loss of founder alleles.
Genetic drift Variation of allele frequency from one generation to the next that occurs due to chance. Genetic drift leads to the loss of genetic variation in small populations due to the random loss of founder alleles during reproduction.
Heterozygosity Average proportion of loci that are heterozygous (have two different alleles in an individual) in a population.
Mean kinship This value, calculated for every living member of a captive population, is the average kinship between that individual and all members of the population (including itself). Typically, living founders are excluded in the calculation of mean kinships. A population's average mean kinship is the average of the mean kinships of all the individuals in the population.
Reintroduction Releasing individuals of a species into an area where that species no longer occurs in an effort to reestablish a wild population. Reintroduced individuals may be captured from a healthy wild population in another area or may be derived from a captive population if there are no healthy wild populations remaining.
Studbook List of all the living and dead individuals in a captive population that contains information on the mother, father, date of birth, location, and other topics for each individual.

General Aspects of Captive Breeding and Reintroduction Programs

Captive breeding is the only choice for species that are extinct or nearly extinct in the wild. Nearly one-fourth of mammals, 12% of birds, and almost one-third of amphibians are threatened with extinction, according to the International Union for the Conservation of Nature (IUCN) Red list of threatened species. The need for captive breeding will undoubtedly increase as loss and degradation of wildlife habitat continue as a consequence of human population growth. However, captive breeding and reintroduction programs can play only a minor conservation role in comparison to protecting and improving habitat. Owing to limited space, staff, and funds, zoos will not be able to preserve populations of all animal species likely to become extinct in the wild.

The major goal of most captive breeding programs is to develop a selfsustaining captive population. Even if a species is never reintroduced, a successful captive breeding program will supply zoos with animals to exhibit, thereby minimizing the need to collect them from the wild. Captive breeding programs also have considerable educational value because they are used to inform zoo visitors of the value of conserving biodiversity and to increase public interest in conservation issues. Animals maintained in captive breeding programs also support a variety of research programs.

Several organizations provide help with captive breeding and reintroduction efforts. The International Species Information System (ISIS) has about 825 member institutions in almost 80 countries around the world and maintains a global database on over 10,000 species of captive animals dating back to 1829. ISIS also develops and provides software to maintain and analyze data on captive animals, such as Single Population Analysis and Record Keeping System (SPARKS) and ZIMS (Zoological Information Management System). The World Association of Zoos and Aquariums (WAZA) manages 118 international studbooks for rare or endangered species or subspecies. About 1150 other populations are cooperatively managed at the regional level. In the United States alone, the Association of Zoos and Aquariums (AZA) manages 115 populations through interzoo captive breeding programs known as Species Survival Plans (SSPs). More than 300 other

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populations are covered by less formal population management plans. Similar regional programs exist in Europe, Africa, Central America, Australia, and New Zealand. Some species may be maintained in captivity for long periods without the possibility of reintroduction. For example, Pére David's deer and the Mongolian wild horse survived in captivity many decades after their extinctions in the wild before reintroduction began.

The IUCN maintains two international committees that offer help with population management, and reintroduction: the Conservation Breeding Specialist Group and the Reintroduction Specialist Group. In the US, the AZA maintains two similar committees: the Small Population Management Advisory Group and the Reintroduction Advisory Group. Both groups provide guidelines for captive breeding and reintroduction programs and maintain other committees that focus on particular groups of species such as carnivores, primates, or parrots.

Difficulties with Captive Breeding and Reintroduction Programs

Not all species breed well in captivity. The species that are easiest to breed in captivity are those that have management requirements similar to those for domestic animals or for other species with which zoos have had considerable experience. For example, zoos suddenly faced with the challenge of breeding California condors experienced little difficulty because they had been breeding Andean condors for many years. However, species with which zoos have had little prior experience may breed very poorly at first until zoos develop appropriate husbandry techniques. Thus, because husbandry techniques tend to be species specific, new captive breeding programs often require substantial research programs on behavior, reproductive biology, nutrition, genetics, or disease. Research on closely related species is also often helpful.

Poor reproduction in captivity is often due to behavioral problems caused by inadequate husbandry techniques. Because different zoos often have different degrees of success in breeding a particular species, important insights can often be gained by comparing the behavior and reproductive success of individuals kept under different conditions at different zoos. More invasive research work can also make important contributions. For example, studies on black-footed ferret reproductive biology have improved captive breeding success for this species. Asa *et al.* (2011) have suggested that allowing individuals to mate with preferred partners might improve reproductive success. If true, it will be important to develop ways to allow mate choice without compromising genetic goals for captive populations.

A captive population's risk of extinction is increased by inbreeding and loss of genetic variation, and inbred animals with little genetic variation are less likely to survive when reintroduced to the wild than more outbred individuals. However, both inbreeding and loss of genetic variation are unavoidable in small, closed populations because all individuals in the population eventually become related to each other. Captive populations are routinely managed to minimize inbreeding and loss of genetic variation. Another threat to captive populations is that selective pressures in captive habitats are different than those in wild habitats; thus captive populations tend to adapt to captivity, which can make it more difficult to re-establish a population in the wild. Genetic management can reduce but not prevent adaptation to captivity. Thus, it is advisable to minimize the number of generations in captivity before animals are reintroduced when possible.

Learned behavioral traits can degenerate in captivity even more rapidly than genetic diversity. Traits that may degenerate in the captive environment include foraging skills, detection and avoidance of predators, and fear of humans. When captive-bred and wild-born individuals have been experimentally released in the same location, the captive-bred individuals have tended to survive for shorter periods due to lack of appropriate behaviors. Behavioral problems tend to be species-specific and research on how to minimize these problems and thus maximize survival of the reintroduced individuals is often needed when starting a reintroduction program.

Genetic and Demographic Management of Captive Populations

In contrast to husbandry of captive animals and reintroduction techniques, genetic and demographic management methods are similar for all captive populations (Ralls and Ballou, 1992; Ballou *et al.*, 2010; Frankham *et al.*, 2010). Genetic and demographic management of captive populations focuses on maintaining genetic diversity in order to minimize undesirable genetic changes due to selection in the captive environment, avoid deleterious effects of inbreeding depression, and maintain future options for genetic management.

Ideally, the first step in the development of a captive breeding is agreement among all concerned parties, such as agency personnel, nongovernmental conservation groups, and outside scientific advisers that such a program would benefit a particular species. Once in place, captive breeding programs have three phases. In the founding phase, the captive population is started. In the growth phase, the population rapidly increases to the final "target" population size specified by its managers. In the carrying capacity phase, the population is maintained at its target size and excess individuals may be reintroduced into the wild (**Figure 1**). Management concerns change as the captive population progresses through these phases.

The main management concerns during the founding phase are removing individuals for the captive population with minimal impact on the wild population, acquiring enough founders from the wild to achieve genetic goals, getting the species to breed reliably in captivity, and setting general goals and plans for the captive population. Ways to capture animals for the captive population with minimal impact on the wild population include removing eggs from nests, using orphaned or injured animals, and capturing dispersing juveniles. Many birds (e.g., condors) will usually lay another egg to replace an egg that has been removed, and dispersing juvenile mammals often have high mortality rates

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in the wild. If the species is one that zoos do not know how to breed reliably in captivity, it is best to solve husbandry problems with only a few wild individuals or even animals of a closely related species.

Genetic goals for a captive population are usually specified in terms of the proportion of genetic variation (measured as heterozygosity) to be maintained for a specified time. A common goal is to maintain 90% of the genetic diversity of the source population for 100 years. However, some programs use other time frames. For example, the Guam rail and black-footed ferret programs are using the goal of "90% for 50 years" because of the short generation times for these species (**Table 1**) and plans for the rapid establishment of several wild populations.

Once a genetic goal has been set, population genetics theory enables calculation of the number of founders needed for the captive population (the number of wild animals that must be captured and successfully bred) and the target population size (the number of individuals that the population needs to grow to achieve its genetic goals). Planning to retain a higher proportion of genetic variation usually increases the target population size. Increasing the number of founders reduces the size of the target population needed to reach a particular goal. Twenty to thirty unrelated individuals are generally a sufficient number of founders. Unfortunately, many existing captive breeding programs were begun after it was already too late to acquire this many founders. For example, the ferret population had only 10 founders. If it had been possible to obtain 25 founders, the target population size could have been reduced from 500 to 200 individuals. Although a small number of founders reduces the probability that a captive breeding program will be successful, it does not doom it to failure. Thus, the lack of an ideal number of founders does not justify abandoning or failing to initiate a captive breeding program.

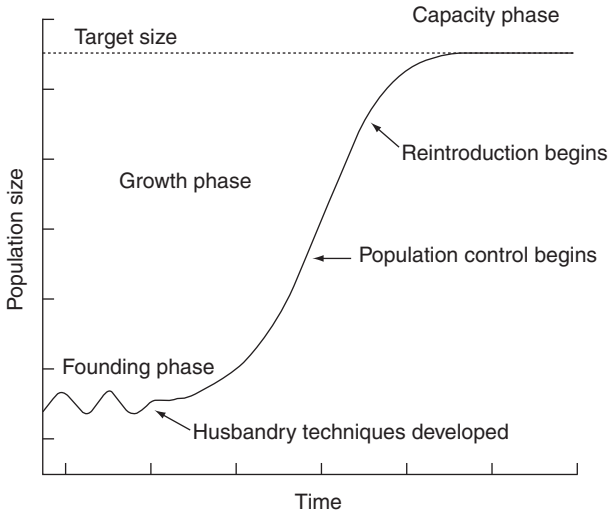

Figure 1 The development of a captive breeding and reintroduction program from the founding to the capacity phase.

The target population size also depends on the rate of species reproduction and generation length. A smaller target population will be required to reach the genetic goal if the species can grow more rapidly each generation or if it has a long generation time (because genetic variation is lost due to genetic drift each time individuals reproduce). The target population size may also be limited by practical considerations, such as the number of spaces available in zoos. Fewer zoos may be willing to participate in the program if the species is not attractive as an exhibit. Thus, the target population size may be a compromise between genetic and demographic factors and the limited resources available.

Once husbandry problems have been solved and the species is breeding well in captivity, the rest of the founders should be obtained as soon as possible. Unfortunately, the number of animals that must be captured from the wild is usually greater than the number of founders needed. Wild-caught animals may be related or fail to breed, or their descendants may fail to reproduce. For example, although 25 wild black-footed ferrets were captured, some died of distemper, some were known to be parents and offspring, and some failed to reproduce. Although ideally each founder would contribute an equal number of offspring to the captive

Table 1 The goals and number of founders of captive breeding programs with reintroduction components[a]

	Species			
	California condor[b]	*Black-footed ferret*	*Guam rail*	*Golden lion tamarin*
Heterozygosity goal (%)	90	90	90	90
Length of program (years)	200	50	50	200
Number of generations	10	20	22	33
Target population size	150	500	150	550
Number of wild-caught	14	18	21	69[e]
Number of contributing founders[c]	14	10	13	45
Founder genome equivalents[d]	8	5	5	12

[a]Species are listed in order of increasing number of generations in the program length (reproduced from Ralls and Ballou, 1992).
[b]Heterozygosity goal and program length have not been officially adopted by program managers; target population size is the minimum size of the captive population (which, with the two reintroduced populations in California and Arizona, should total no less than 450–500). Other data derived from Mace (2010).
[c]Founders with currently living descendants.
[d]The number of theoretically ideal founders taking into consideration loss of genetic diversity in the current captive population (Lacy, 1989).
[e]Includes the number of wild-caught tamarins acquired after the captive program was initiated in 1981 in addition to the number of founders and wild-caught individuals alive at the initiation of the program.

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population, those ferrets that did reproduce did so unequally, skewing their genetic contributions to the captive population. Ultimately, the ferret population was founded by the theoretical genetic equivalent of only five ferrets; that is, five founder genome equivalents.

Management efforts during the growth phase center on getting the population to increase as rapidly as possible. Rapid growth has two benefits: it increases the captive population's chances of survival and it retains as much of the founders' genetic diversity as possible. Small captive populations are at higher risk of extinction due to many factors, including random demographic events (such as a succession of male births), inbreeding depression, and unpredictable events that can kill numerous individuals such as diseases, fires, hurricanes, and other catastrophes.

The standard SSP breeding strategy used in the US is designed to maximize the retention of genetic diversity. This is accomplished by minimizing mean kinship among the members of the captive population. Breeding pairs are formed based on mean kinship, beginning with the individuals with lowest mean kinships, until the desired number of pairs is attained. Efforts are also made to avoid mating closely related individuals when forming new pairs. During the growth phase, this strategy is modified slightly to choose new pairs to minimize mean kinship as much as possible but breed all individuals in the population.

Species living in groups, where individuals cannot be individually managed (i.e., fish in tanks, flocks of birds, some antelope herds), need to be managed differently. Here genetic management focuses on maintaining multiple groups of individuals, periodically transferring individuals between groups, and for some species, restricting the number of offspring any one individual can have (e.g., limiting the tenure of herd sires in an antelope herd).

Although managers attempt to minimize mean kinship and inbreeding during the growth phase, rapid population growth takes priority over genetic concerns, particularly when the population is very small and the risk of extinction outweighs the risk of a few less-than-ideal matings. For instance, if a female rejects the genetically ideal mate, she may be allowed to mate with another male she prefers.

At some point during the growth phase, the captive population usually is divided into subpopulations housed in different breeding facilities. This reduces the risk that a catastrophe such as disease or fire will decimate the entire captive population. To ensure that each subpopulation is as genetically diverse as possible, each should have individuals descended from each of the founders.

Once the population has reached the target size, relatively few offspring may be needed each year to maintain it at that level. Thus, genetic concerns become more important as managers need to determine exactly which individuals to breed in the population.

The number of offspring needed to maintain the captive population can be calculated by standard demographic techniques. Any "extra" offspring can be used for reintroduction. If there are more offspring than are needed for reintroduction, managers can prevent some adults from breeding either by

Table 2 The elements of a successful captive breeding and reintroduction program

Captive population
Ongoing research in behavior, genetics, physiology, nutrition, reproduction, and pathology
Genetic and demographic management of the population
Selfsustaining viable captive population
Sufficient size to remove animals for reintroduction without impacting the viability of the captive population
Field studies
Regular censuses of the size, distribution, and genetics of the wild population
Behavioral ecology studies (home range size, movements, habitat preferences, social organizations, mating system, feeding, and antipredator adaptions)
Locating existing suitable habitat containing critical resources for reintroduction
Habitat preservation and management
Protection of habitat from degradation and exploitation
Restoration and management of degraded habitats
Increase in or maintenance of the number of preservation areas
Conservation education for long-term support
Professional training through academic studies, workshops, internships, courses, and fellowships
Determining the most appropriate public relations and educational strategies through surveys
Public relations educational efforts using appropriate mass media (e.g., television, radio, magazines, and newspapers)
Local community education, both formal and informal
Preparation and reintroductions of animals
Choice of candidates and assessment of their characters for retrospective correlation with postrelease survival
Training in survival techniques, including foraging and feeding, antipredator tactics, locomotion, and orientation
Adaption to local conditions at release site (food, climate and temperature, and disease)
Release and long-term monitoring to evaluate causes of death and basis for survival

Source: Reproduced from Kleiman DG (1989) Reintroduction of captive mammals for conservation: Guidelines for reintroducing endangered species into the wild. *Bioscience* 393: 152–161.

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using contraceptives or by housing them individually or in same sex groups.

There are two general strategies for producing the individuals to be reintroduced. If the date of a reintroduction effort can be scheduled well in advance and the species has a predictable breeding pattern (such as breeding once a year during the spring), males and females can be paired up for the specific purpose of producing excess young for that particular reintroduction. However, if the date of a reintroduction effort is difficult to predict in advance (this may occur due to difficulties with funding or permits), animals for reintroduction can be selected from the existing population and breeding pairs can be set up to replace the reintroduced individuals.

In the early stages of a reintroduction program, reintroduction techniques are still being refined and mortality may be high. Thus, initially the most genetically expendable individuals are usually released. Later, emphasis will gradually shift to choosing individuals that are not closely related to the individuals already present in the wild population. This maximizes the genetic diversity of the wild population. The final genetic goal is to make the wild population as genetically diverse as the captive population.

Reintroducing Captive-Bred Animals to the Wild

Ideally, the goals of all captive breeding plans would include reintroduction back to the wild. However, some species may be impossible to reintroduce due to lack of habitat or other problems. Furthermore, some species will be easier to reintroduce than others. The elements of a successful reintroduction program are shown in **Table 2**. These elements include research on both the captive and wild populations, habitat preservation and management, conservation education to ensure long-term support of the program, and careful management and monitoring of the reintroduced individuals (Serena, 1995; Seddon *et al.*, 2007; Griffiths and Pavajeau, 2008; Earnhardt, 2010). The IUCN and AZA have developed guidelines that discuss the biological, socioeconomic, and legal requirements for successful reintroduction.

Most important, reintroduction is a realistic goal only when habitat protection is an integral part of the species' overall conservation plan. A species should not be reintroduced unless the factors that led to its decline in the wild have been identified and eliminated – or at least greatly reduced – and suitable legally protected habitat exists. In addition, the release site should be within the species' historic range. Occasionally, however, a species must be "reintroduced" into areas of suitable habitat outside of its historic range. For example, the Guam rail was reintroduced to the nearby island of Rota because the non-native brown tree snake, which led to the bird's extinction in the wild, has invaded its entire historic range on Guam. Similarly, a variety of species, including birds, reptiles, and invertebrates, from New Zealand and Australia are being reintroduced to offshore islands that are free of the non-native predators that led to their extinction on the mainland.

There are many other factors to consider when reintroducing captive-bred individuals. For instance, the release of captive-bred animals can spread diseases to an existing wild

Table 3 Checklist for deciding whether or not appropriate conditions exist for beginning a reintroduction program applied to three species of lion tamarins

	Lion Tamarin Species		
	Golden	*Golden-headed*	*Black*
Condition of species			
1. Need to augment wild population	Yes	No	Yes(?)
2. Available stock	Yes	Yes	No
3. No jeopardy to wild population	?	?	?
Environmental conditions			
4. Causes of decline removed	?	No	No
5. Sufficient protected habitat	Yes(?)	No	Yes
6. Unsaturated habitat	Yes	Yes(?)	?
Biopolitical conditions			
7. No negative impact for locals	No	?	?
8. Community support exists	5	2	4
9. GOs/NGOs supportive/involved	Yes	Yes	Yes
10. Conformity with all laws/regulations	Yes	?	?
Biological and other resources			
11. Reintroduction technology known/in development	4	3	3
12. Knowledge of species' biology	5	1.5	3
13. Sufficient resources exist for program	Yes	No	No
Recommended reintroduction/translocation?	Yes	No	No

Some conditions were rated on a numerical scale from 0 = worst to 5 = best.

Source: Reproduced from Kleiman DG (1990) Decision-making about are introduction: Do appropriate conditions exist? *Endangered Species UPDATE* 8(1): 18–19.

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population or disrupt its social organization. Thus, it is advisable to screen captive-bred individuals for diseases prior to release and to release them in habitat that has no wild individuals.

When reintroduced to the wild, captive-bred individuals are likely to suffer high mortality rates due to inappropriate behavior. For example, they may have difficulty finding enough food or fail to avoid predators. It has proven very difficult to help orphaned sea otter pups raised in captivity develop appropriate foraging skills and teach them to avoid humans. Captive-bred condors develop appropriate foraging skills fairly easily but often fail to avoid humans and human structures. Substantial research programs are often needed to develop husbandry and reintroduction techniques that will promote behaviors needed for survival in the wild.

The conditions under which captive-bred individuals are raised can be critical. The development of appropriate survival skills may require a skilled parent or a particular stimulus at some critical period during development. For example, adult ferrets prefer eating whatever they were fed when they were 2 or 3 months old, which is when ferrets develop their permanent teeth. Therefore, at the age of 2 or 3 months, captive ferrets should be fed prairie dogs, their exclusive prey in the wild. Methods of reintroduction may also require research. For example, should the animals be released as social groups or as individuals? Should they be fed after they are released and, if so, for how long? The answers to such questions depend on the particular species being reintroduced. Reintroduction programs using captive-bred individuals are usually expensive, lengthy, complex, and difficult. Thus, the decision to begin such a program should not be made lightly. A short checklist of the major factors should be considered when deciding whether or not to reintroduce a species is illustrated in **Table 3** with respect to three species of lion tamarins. Answers to the questions in the checklist indicate that reintroduction is appropriate for golden lion tamarins but not the two other species because the causes of their decline have not been eliminated and funds to support a reintroduction program are not available.

There are no generally accepted guidelines for declaring the success of a reintroduction effort. Beck and colleagues suggested two possible criteria: if 500 wild individuals survive without human support or if a formal population viability analysis predicts that the population would be selfsustaining (Beck *et al.*, 1994). Successful captive breeding and reintroduction programs require sustained long-term, adequately funded efforts. Research can solve many problems involved in successfully breeding a species in captivity and reintroducing it to the wild. However, the ultimate success of many programs, such as that for the black-footed ferret, will depend on whether or not we are able to preserve enough suitable habitat to sustain viable wild populations of the species.

See also: Breeding of Animals. Biodiversity in Plant Breeding. Conservation Efforts, Contemporary. Endangered Amphibians. Endangered Mammals. Endangered Reptiles. Zoos and Zoological Parks

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