Captive breeding and conservation

Kristin Leus

Abstract. Captive breeding is one of a myriad of tools at the disposal of conservationists. It can fulfil specific tasks that should be an integral part of the overall conservation action plan for a species. Captive breeding and other types of intensive management of individuals and populations often become necessary when human caused threats (habitat destruction, exploitation etc.) have caused the population of a species to become so small and fragmented that even if the human caused threats could be magically reversed, the species would still have a high probability of extinction purely due to random demographic and genetic events, environmental variation and catastrophes; or when the continuing, unchecked decline in population size indicates that this will soon become the case. Provided sufficient knowledge on the biology and husbandry of the species exists, breeding individuals in the relative safety of captivity, under expert care and sound management may provide an insurance against extinction, and/or a stock for reintroduction or reinforcement efforts, and/or opportunities for education, raising of awareness, scientific and husbandry research and other contributions to conservation. Important challenges include recognising when "the time is right", identifying the precise role of the captive breeding efforts within the overall conservation action plan, setting realistic targets in terms of required time spans, population sizes, founder numbers, resources etc., ensuring sound management and cooperation and developing much needed new technical methods and tools. The above is illustrated with examples from the Arabian Peninsula.

Key words. Ex situ, population targets, genetic management.

Introduction

Captive breeding represents one of a myriad of tools conservation biologists have at their disposal to help prevent the extinction of a species, subspecies or population. The region of the Arabian Peninsula is home to a number of world famous captive breeding and reintroduction initiatives, e.g. the Arabian Oryx *Oryx leucoryx* (ABU JAFAR & HAYS-SHAHIN 1988, OSTROWSKI et al. 1998, SPALTON et al. 1999, AL QUARQAZ & KIWAN 2007). Furthermore, the annual Conservation Workshops hosted by Sharjah, UAE, between 2000 and 2009 (AL MIDFA et al. 2011) have been instrumental in the evaluation of potential current and future captive breeding needs in the region and in the implementation of new captive breeding initiatives. Using examples from the region, this paper will aim to illustrate a number of roles that captive breeding can fulfil in different stages of the extinction process, highlight a few important principles that are essential to success and point to a new challenge for the future.

The extinction process and captive breeding

The extinction process can roughly be divided in two phases (GILPIN & SOULÉ 1986). During the first phase, deterministic and often human caused threats such as habitat degradation and loss, direct exploitation of the species, competition from exotic and domestic species, killing

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due to human-animal conflicts etc, will cause the population(s) of a particular species or subspecies to decline. If these threats cannot be mitigated, this will eventually result in very small, fragmented and isolated remnant populations. The remnant populations are now so small that they become vulnerable to a number of other, non-human caused, threats and they enter phase 2 of the extinction process. These other threats are mainly stochastic (i.e. due to chance) genetic and demographic events (LACY 2000). In genetic terms, small populations will lose gene diversity very quickly due to genetic drift and inbreeding. This often affects the fitness of the population (REED & FRANKHAM 2003) and may cause it to become even smaller. In addition, very small populations are very vulnerable to normal environmental variation (for example normal variation in weather patterns), catastrophes (rare events that have extraordinary effects on reproduction and survival, for example, severe droughts) and random variation in reproduction and mortality (for example, if the average clutch size of a particular bird species is 3 eggs, then even if the environment would stay "magically" exactly the same in two consecutive years, a particular female can still have laid 3 eggs in one year and 4 in the other, purely due to chance). These types of "demographic stochasticity" can have very large effects on small populations, often already at larger sizes than one would expect (LACY 2000, TRAILL et al. 2010). Thus, small, fragmented, isolated populations can find themselves being dragged into an extinction vortex whereby genetic and demographic stochastic events can cause the species to go extinct, even if you could magically halt the human caused threats.

During this second phase of the extinction process, very intensive management of populations and individuals, in addition to the *in situ* activities to mitigate any ongoing human caused threats, is often necessary to prevent extinction. Intensive management of populations and individuals can come in many different forms, for example translocation, breeding in a fenced area of wild habitat, supplementary feeding, captive hand rearing of young so that wild parents double clutch or become pregnant again sooner, captive breeding etc. Particularly in phase 2 of the extinction process (although captive breeding can also play a role in phase 1 – see later in this paper), captive breeding can therefore be an important tool to help prevent extinction. It is however not the only tool and should also not be seen as a replacement for all other tools. It should rather been seen as one tool in a large tool box. Imagine you are about to carry out a technical job as part of your house renovations. Thousands of house renovations tools exist. Therefore, unless you first carefully consider what exactly the problems are and what you wish to achieve, it would be hard to select the right tools from the big selection available, and it is also unlikely that one tool will allow you to do all jobs you need to do to renovate your house. In terms of conservation strategies for a particular species, it is therefore important that the current conservation status and the exact nature of the problems is carefully analysed and that the goals and objectives are clearly stated. Only then will it be possible to "pick" the best suited and most efficient conservation tools. As part of this process it will become clear whether or not captive breeding should be one of those tools and what the precise role, goals and population targets of the captive breeding component should be.

A good example of such a process that is a direct result from the annual conservation workshops hosted by Sharjah over the last ten years is the "Strategy for the Conservation of the Leopard in the Arabian Peninsula" (BREITENMOSER et al. 2009). The current status and problems of the species were carefully analysed during several workshops, the vision and goal for the conservation of the species was clearly stated, the captive breeding component is an integrated part of all the objectives, targets and actions for the species and the goals and population targets of the captive programme are tailored to the species' and region's particular circumstances and needs.

Some important principles of captive breeding

Not only a numbers game

Captive breeding initiatives should not merely produce larger numbers of individuals of a threatened species, they should also aim to maintain a high proportion of the gene diversity that is present in the wild population.

The gene diversity of a population (variations in the DNA code within and between individuals) represents the evolutionary potential of the population. It is only because not all individuals are genetically unique (in other words that there is genetic variation) that natural selection can take place. Natural environments tend to be very variable and it is therefore important for the long term survival of the species that adaptation through natural selection can take place. Furthermore, higher levels of gene diversity tend to be correlated with higher fitness (REED & FRANKHAM 2003) and lower inbreeding levels. For naturally outbreeding species, high levels of inbreeding often have negative effects on life history traits related to reproduction and survival (FRANKHAM et al. 2002). Evidence is mounting that these genetic effects "should only be ignored at our peril" and it is therefore essential that captive breeding programmes for conservation purposes are managed in a way that ensures maximum retention of the gene diversity of the wild population in the captive population. Captive breeding programmes for conservation that are run by the regional or world zoo and aquarium organisations (e.g. www.eaza.net; www.aza.org; www.arazpa.org.au; www.waza.org) generally have as a genetic goal to have maintained at the end of the duration of the programme (usually taken to be 100 years for programmes currently without any reintroduction plans) at least 90% of the gene diversity that was present in the source population (SOULÉ et al. 1986, LACY 1994). A 90% gene diversity retained can be expected to correspond to an average level of inbreeding of 10% in the next generation if the current generation were to randomly breed and if no new founders are added (FRANKHAM et al. 2002). Although 75% of the wild population gene diversity retained may still sound like a high proportion, this can be expected to correspond to an average level of inbreeding in the next generation of 25%, which would be the equivalent of brother-sister matings. The more gene diversity one wishes to retain in the captive population, the larger the captive population required to be able to achieve this. The 90% target is therefore thought to be an acceptable compromise between losing a small amount of gene diversity (and as a consequence accepting a moderate level of inbreeding), but being able to achieve this with smaller captive population sizes (see also below: "Realistic population targets").

To be able to achieve a retention of 90% of the wild gene diversity at the end of the duration of the captive programme, three main issues need to be taken into account: 1) a sufficient number of founders should be at the basis of the captive population; 2) pair combinations should be carefully managed; and 3) the captive population must be large enough (see also below: "Realistic population targets").

Sufficient numbers of founders. When a typically small number of wild animals is extracted from the larger wild population, these founders contain only a sample of the gene diversity that is present in the wild population. The more founders are taken, the bigger the sample, the more gene diversity is represented in the captive population. Genetic theory teaches us that 20 founders would already represent 97.5% of the wild gene diversity (if we assume that these founders are not related to each other and are representative for the spread of gene diversity over the geographic range of the species) (CROW & KIMURA 1970). However, further gene diversity will be lost when these founders, and their descendants, start breeding in captivity. For example, some may never leave surviving offspring, some will have many descendants and yet others very few. In addition, the smaller the captive population stays, the faster gene diversity will be lost through genetic drift and inbreeding. A founder calculation tool can be found at www.amphibianark.org. The author's experience with analysis of captive breeding programmes run by member institutions of the European Association of Zoos and Aquariums (EAZA) has taught that in reality, often considerably more than 30 founders are needed to reach this genetic goal. This may pose problems if the wild population is already critically endangered when the captive breeding programme is started (see also below: "Do not wait until extinction is imminent").

Carefully managed pair combinations. By carefully managing which individual breeds with which other(s) and how often, the speed with which gene diversity is lost while breeding in captivity can be reduced. Captive breeding programmes run by zoos typically use the method of "minimising kinship" (MONTGOMERY et al. 1997) to determine pair combinations – this has been shown to be as good, or better, than other available methods for small captive populations for conservation (BALLOU 1991, BALLOU & LACY 1994).

Digital studbook databases (for example SPARKS - Single Population Animal Record Keeping System Software (ISIS 2004)) and corresponding analysis software (for example PM2000 (POLLAK et al. 2007)) allow the mean kinship value of each living individual to be calculated which reflects the degree to which this individual is related to the whole population. Animals with low mean kinship values are then given breeding priority, whereby males and females with similar mean kinship values are bred with each other. In second order, inbreeding is also minimized.

Several digital studbook databases are maintained for species from the region of the Arabian peninsula and are used to direct the breeding within their captive breeding programmes, for example: Arabian Leopard *Panthera pardus nimr* International Studbook (Breeding Centre for Endangered Arabian Wildlife (BCEAW)), South West Asian Caracal *Caracal caracal schmitzi* European Studbook (BCEAW), Gordon's wild cat *Felis silvestris gordoni* International studbook (Cologne Zoo), Northern Cheetah *Acinonyx jubatus soemmerringi* EAZA European Endangered species programme (EEP) and International studbook (H.E. Sheikh Butti Maktoum's Wildlife Center), Arabian Oryx *Oryx leucoryx* EEP (Zoological Society of London) and International studbook (Living Desert Palm Springs), Northern Bald Ibis *Geronticus eremita* EEP (Alpenzoo Innsbruck-Tirol), and several others.

Good coordination and cooperation are essential for the success of these methods of breeding programme management and the annual Sharjah conservation workshops have been and remain very important to foster this kind of cooperation.

Realistic population targets

Studbook and analysis software programmes also allow captive programme managers to calculate how large the captive population should eventually be to retain a certain amount of gene diversity for a certain amount of time, given a certain number of founders, a certain growth rate and certain degree of success in breeding management. Ideally, as is the case for the Arabian Leopard, the overall conservation strategy for the species informs these calculations and the results of the calculations in turn inform the overall strategy.

Although the target population size should, as described above, be determined for each programme separately, taking into account its specific captive population parameters and overall conservation goals and objectives, the author's experience with the analysis of captive breeding programmes of EAZA has taught that one should typically expect to need several hundred individuals to maintain a population that is not only demographically but also genetically a good safety net for the wild population. There are some exceptions to this, for example if reintroduction can start sooner and many founders are expected to be available (see for example LEUS & LACY 2009). However, reintroduction should not start sooner than the practical situations on the ground, or the status of the captive programme, allow (see below "when to start reintroduction"). Before starting a captive breeding programme it is essential that careful thought goes into the likely length of the programme, the likely number of founders available and the likely scale of target population size needed, as this will direct the level of space and resources that will be necessary to run the captive programme.

Regular meetings of the main partners in the conservation programme for a species, such as in the framework of the Sharjah conservation workshops, are important to be able to continuously adjust these targets in view of developing events in the field and in captivity.

Do not wait until extinction is imminent

Considering that likely at least 30 founders should be included in the programme to ensure that the captive population represents a large enough proportion of the gene diversity of the wild population, problems will arise when the captive programme is started when the species/subspecies is already critically endangered (which according to the IUCN criteria for this category of threat mean that there are less than 250 reproducing individuals (IUCN 2001)). Indeed both the Arabian Leopard and Arabian Tahr *Hemitragus jayakari* are in this situation. When the wild population is so small, actively removing individuals from the wild population to serve as founders for the captive population may compromise the survival of the wild population even further, so that one may be forced to try to make the best of those founders that are available. The Arabian Oryx captive breeding programme shows that captive programmes based on fewer founders are not necessarily doomed to fail, but the chance that they will experience problems due to low genetic variability and inbreeding can be high. One should furthermore take into account that the world captive population of Arabian Oryx was allowed to grow to a couple of thousand individuals, with just over 1,100 currently under tight breeding management, which helps to reduce the risks (BROWN 2009).

In addition, using captive breeding to help save a species from extinction will only work if sufficient knowledge exists about the biological and husbandry needs of the species, so that sufficient numbers of offspring can be reliably bred from the desired parent combinations. This may require research and a sufficient number of individuals for the studies. However, if one waits to start a captive breeding programme until the species is in imminent risk of extinction, and little is known about the species' biology and husbandry, one often no longer has the time to await the results of studies and every individual is so important to the population that one cannot afford to run risks with research (for example on reproductive biology and assisted reproduction techniques).

IUCN therefore recommends in its guidelines for the management of *ex situ* populations for conservation (IUCN 2002) that one should consider whether captive breeding can play a role in the conservation of taxa/populations which a) are prone to effects of human activities or stochastic events, or b) likely to become critically endangered in the very short-term. In terms of the phases of extinction mentioned above, this therefore means that ideally, the potential need for a captive breeding programme should be assessed for taxa in phase one, which look like they are heading for phase 2, but before they have actually entered phase 2. In this context it is be important to take note of the fact that evidence is growing suggesting that the number of individuals required for wild populations that are not only demographically but also genetically viable (i.e. can also maintain their evolutionary potential) is much higher than typically thought and can be expected to be several thousand adults (Traill et al. 2010).

The types of conservation workshops convened by Sharjah, which monitor and analyse the status of the most important taxa for biodiversity conservation in the region of the Arabian Peninsula, are very beneficial in order to be able to keep a continuous finger on the pulse. In this way, the alarm can be raised for species whose status directs that one should at least consider if *ex situ* populations should be started, even if in the starting phases only to gather necessary knowledge to ensure successful breeding once the situation becomes more severe.

Other reasons for captive breeding programmes for species which are not (yet) in imminent danger of extinction are to use the individuals for conservation education and the raising of awareness (in the hope to contribute to reducing the human caused threats), and/or to use them as fundraising tools for other conservation activities etc.

When to start re-introducing

The IUCN guidelines for reintroduction (IUCN 1995) provide direction for timing, planning and executing reintroductions and should be followed at all times. However, there are also some concerns from the point of view of the captive population that are worth highlighting in the context of this paper.

"The wild" is a very risky place compared to the relative safety of the captive environment. Reintroduction is also a relatively risky undertaking, especially in the beginning stages where many things have to be tried out for the first time and techniques and protocols have to be developed. If the captive population is the insurance population for the wild population, it would be unwise to extract individuals from this population before it has reached its target size and before the reproductive success is relatively predictable and fairly evenly spread over the population (i.e. one is confident that one can generally get most individuals to breed successfully and reproduction is not due to the chance reproduction of only a few individuals). Otherwise, one risks compromising the very population that is the insurance for survival of the species.

In addition, the individuals to be reintroduced must be carefully chosen according to their genetic value to the captive population and to the wild population and according to the stages of the reintroduction process. In the beginning stages when reintroduction success is uncertain, it would be wise to choose individuals that are least genetically important to both the captive and the wild population, because the risk to these individuals is high. Later, when reintroduction protocols have been developed and are successful, it is best to chose individuals whose genes are well represented in the captive population, but not yet in the wild, and the individuals being reintroduced into the same location should be as unrelated to each other as possible. In this way one ensures that the reintroduced population has a high gene diversity without compromising the genetic health of the captive population (which remains the "insurance policy"). More details can be found in Frankham et al. (2002).

New challenges

The methods for the genetic management of captive populations described above (pedigreed populations managed with the mean kinship method) are suited to species which can be individual recognized, have fairly certain parentage, have sexual reproduction whereby an offspring inherits 50% of the genetic material from each parent, and have fairly small litter or clutch sizes. However, this is not applicable to a whole range of species and taxa. For example, one of the areas of focus of the past conservation workshops in Sharjah has been the freshwater fauna (fish, amphibians, invertebrates etc). For the majority of these species the current methods are inconvenient at best, and inappropriate at worst. Yet, the need for captive breeding programmes for a number of these species has already been highlighted. For that reason several institutions and teams are currently developing new animal data and studbook registration software (e.g. ZIMS – Zoological Information Management System – www.isis.org), new studbook analysis software and new scientific theories and principles for the genetic and demographic management such species in captivity.

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Author's address: Dr Kristin Leus, Conservation Breeding Specialist Group, European Office, Copenhagen Zoo, p/a Annuntiatenstraat 6, 2170 Merksem, Belgium. – Email: kristin@cbsgeurope.eu.