Captive Breeding

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INTRODUCTION

Birds of prey have been held in captivity for thousands of years by many cultures. However, it was not until the 20th century that they were bred in captivity and manipulated in the manner of domestic species. In his review of breeding records of aviculturists, zoos, and falconers, Cade (1986) found reports of 15 species that had bred in captivity by the 1950s, and 22 by 1965. None of these occurrences was part of an organized or sustained program.

It was the idea of saving a diminishing species that provided the catalyst to bring together the people and resources needed to overcome the challenges of consistently breeding these highly aggressive birds. Peregrine Falcons (*Falco peregrinus*) were disappearing from breeding sites in North America and Europe because of the contamination of their prey by DDT (Ratcliffe 1980). Western nations were committed to clean up the food chain, but would declining species such as Peregrine Falcons, Ospreys (*Pandion haliaetus*) and Bald Eagles (*Haliaeetus leucocephalus*) recover?

In the early 1960s, Willoughby and Cade (1964) demonstrated that it was feasible to breed American Kestrels (*F. sparverius*) in large numbers for scientific study. The Raptor Research Foundation was formed in 1966 by a group of falconers and biologists mainly focused on saving the Peregrine Falcon. Under its aegis, information and ideas were exchanged between private breeders and institutions. In North America, government and institutional programs were begun; the largest included The Peregrine Fund at Cornell University, the U.S. Fish and Wildlife Service's program at Patuxent, Maryland, the Canadian Wildlife Service's facility in Wainwright, Alberta, the Saskatchewan Co-operative Falcon Project at the University of Saskatchewan, and the Macdonald Raptor Research Centre at McGill University. At the same time Europe saw the creation of the Hawk Trust in the United Kingdom, and various falconry groups in Germany to promote breeding of large raptors for falconry and conservation.

Within 10 years significant progress had been made in understanding the behavior and management of breeding pairs as well as the art of incubation and the care of young. Survey articles by Cade (1986, 2000) documented that hundreds of large falcons were being produced each year and at least 83 raptor species had been bred by 1985.

The successes have continued. Captive breeding and the related manipulation of wild-produced eggs have proved critical in the re-establishment of at least 13 species. These include the California Condor (*Gymnogyps californianus*), Red Kite (*Milvus milvus*) in Britain, Bald Eagle, White-tailed Eagle *(H. albicilla*) in Scotland, Bearded Vulture (*Gypaetus barbatus*), Griffon Vulture (*Gyps fulvus*), Harris's Hawk (*Parabu-*

teo unicinctus), Mauritius Kestrel (*F. punctatus*), Aplomado Falcon (*F. femoralis*), Lanner Falcon (*F. biarmicus*), Peregrine Falcon on two continents, Barn Owl (*Tyto alba*) and Eurasian Eagle-Owl (*Bubo bubo*) in Europe. Another dozen species have been bred and released on a smaller scale (Cade 2000).

This chapter presents a summary of guidelines to the successful breeding of captive birds of prey. Raptors are a diverse group, one to which generalities do not always apply.

Artificial insemination and the use of imprints is one aspect of breeding that came about because of close association between trained raptors and their handlers. These birds, both male and females, accept humans as mates. They court, solicit copulation, and raise fostered young with humans. The mechanics of this specialized aspect of breeding is well presented in the literature (Weaver and Cade 1985, Fox 1995) and is not discussed here. The raptors presented in this chapter are divided into six major categories: large falcons, small falcons, eagles, hawks, owls, and vultures and condors. Since captive propagation of raptors began with the breeding of large falcons, we have placed an initial detailed emphasis on these raptors, followed by descriptions of the variations in breeding practices for the remaining groups of species. Within each raptor group, aspects of cage design, feeding methods, breeding behavior, and natural and artificial incubation and brooding methods are discussed. No matter what group of raptors the reader is interested in breeding, it is worthwhile to peruse the entire chapter for useful tips that are likely applicable across the board.

All birds of prey are protected by government agencies and the importation of exotic species is highly regulated (see Chapter 25). One should always verify which permits are necessary to set up a breeding facility and to acquire and raise raptors before beginning the project. Security to protect the birds from predators, thieves, and vandals also must be considered in the design and operation of a facility.

ORIGINS OF BREEDING STOCK

Acquiring the Birds

Raptors for captive breeding can be acquired from several sources; some are taken from the wild, particularly for species conservation programs (Cox et al. 1993). Special permits are required to remove birds from the wild or to import them from other countries. Birds can be collected as eggs or fledglings and then hand-raised or raised by existing captive pairs. These individuals grow up accustomed to their confinement and are generally well adjusted (Weaver and Cade 1985, Toone and Risser 1988, Jenny et al. 2004). Hand-rearing young to fledging age can cause significant socialization problems due to imprinting and should be avoided if natural pairing is intended. On the other hand, if nestlings are hand-reared in groups of two or more conspecifics, they also will imprint on one another. If these nestlings are placed in groups in flight pens at post-fledging, the human imprint phenomenon can be reversed, at least with American Kestrels (D. Bird, unpubl. obs.). Hand puppets can also be used (see Condors and Vultures section).

Some species will breed in captivity when caught as adults (e.g., California Condors [Wallace 1994, Harvey et al. 2003], American Kestrels [D. Bird, unpubl. obs.]), but this is less likely for larger falcons (Weaver and Cade 1985). Injured, unreleasable wild owls frequently have been used as natural breeders if not too severely compromised (McKeever 1979) and endangered raptors held in rehabilitation programs can be used as semen donors (Blanco et al. 2002). All newly acquired birds should be quarantined and tested for disease and parasites before being used in a breeding program (Toone and Risser 1988).

Female raptors usually are larger and more aggressive than males. To reduce the risk of injury or death to the male, the male should be placed in the breeding pen several days or weeks before the female (Heidenreich 1997). This may allow the territorial male to exert a certain degree of dominance over the newly introduced female. Even so, in some species such as Merlins, the female will suddenly and explicably kill her long-time mate (D. Bird, unpubl. obs.).

SEXING AND PEDIGREES

Many raptors are size- or plumage-dimorphic, and thus can be sexed easily (D'Aloria and Eastham 2000). A few, however, are size- or plumage-monomorphic. For the latter, breeders must resort to collecting blood or excreta in order to perform radioimmunoassays to test for the presence of testosterone or estrogen (Saint Jalme 1999). Birds also can be sexed using standard DNA blood analyses and karyotyping (Saint Jalme 1999, Leupin and Low 2001). Bald Eagles have been sexed

using laparoscopy (Mersmann et al. 1992, Parry-Jones 2000). Observing the behavior and vocalizations of interacting birds also can be an indication of their sex (McKeever 1979).

There always is a risk of inbreeding when working with a small population. Stock secured from other captive populations may already be inbred. Severely reduced wild populations also may be highly related. Careful records should be kept and genetic fingerprinting (microsatellite marking) can be used to ascertain the relationships between birds (Toone and Risser 1988). Programs such as KINSHIP have been used to test the pedigree of potential pairs to ensure that inbreeding is reduced (Gautschi et al. 2003).

LARGE FALCONS

In 1983, The Peregrine Fund, Inc. (now based at the World Center for Birds of Prey in Boise, Idaho) produced a publication: *Falcon propagation: a manual on captive breeding*, edited by Jim Weaver and Tom Cade (revised in 1985), that contains sections on "Artificial Incubation of Falcon Eggs" by William Burnham, and "Incubation and Rearing" by Willard Heck and Dan Konkel that are especially useful. These sections are summarized in the earlier version of this manual (Burnham et al. 1987). Both are among the best sources of general information available on the propagation of large falcons and other species of raptors. We draw heavily from these documents and refer the reader to them for greater detail.

Cage Design

The Peregrine Fund's breeding facilities formerly in Ithaca, New York and Fort Collins, Colorado and now in Boise, Idaho were among the most thoroughly researched for the reproduction of large falcons. These facilities serve as a model for those now belonging to a good number of private falcon breeders in many parts of the world (e.g., the Middle East, the United Kingdom, Europe, North America). The chambers are designed primarily for peregrine-sized falcons with other facilities for raptors ranging from kestrels to eagles. The chambers are grouped on either side of a two-story central hallway from which the chambers are viewed and serviced. The buildings are basically "pole barns." The floors of the chambers measure 3 × 6 m. The roof of each breeding barn is sloped, making the chambers 6 m high on the interior wall and 4.2 m high on the outside wall. The outer wall is open and covered with two layers of wire mesh on the outside and vertical bars of 1.3-cm thin walled electrical conduit placed at 6.2-cm centers on the inside. The PVC bars prevent the birds from coming in contact with the mesh, which is 15 cm beyond the bars. The roof is solid except for a 9 × 3-m panel of mesh and bars to allow light and air flow. The walls of the chambers are painted plywood, which provides a smooth washable surface. The floor and nest ledge are covered with pea-sized smooth gravel, which has smooth edges and does not compact, thus providing a "giving" surface for landing birds. The bottom meter of the outer wall is paneled with metal sheeting to keep out snow. Predator barriers are buried around the buildings to protect the birds from potential predators and rodents (Weaver and Cade 1985). The service corridor runs down the center of the barn on the first and second floor, allowing keepers access to each pen for maintenance and observation of the breeding pairs. The floors of these corridors are soundproofed with carpeting. Strategically placed one-way glass panels permit keepers to observe the birds (Weaver and Cade 1985, Jenny et al. 2004).

In two-story breeding facilities, the upper corridor should provide hatch-door access for removing eggs from the nest ledge without entering the pen. Similarly, each pen should have access ports for food to be slipped into the room and the bath to be removed and replaced without keepers entering the chamber. Raising the bath pan above the floor reduces the amount of feathers and debris in the water. Food should be provided using inclined chutes from the upper and lower corridors (Jenny et al. 2004). Microphones to detect copulatory behavior (J. Weaver, pers. comm.) or even better, closed-circuit television (K. McKeever, pers. comm.) greatly improve the ability to monitor a pair's behavior.

Facilities built after the ones in Ithaca employed several smaller barns offering identical types of pens in order to reduce the risk of spreading of disease (Weaver and Cade 1985). As mentioned earlier, The Peregrine Fund design has been modified by other breeders. In drier climates, most of the roof of each pen can be barred like the walls instead of being fully covered. Parts of the roof should still be covered to provide shelter and shade for the birds. In facilities where disturbance from traffic or people cannot be avoided, the walls can be solid metal or wood sheeting and the roofs meshed or barred. Vents can be added to sidewalls where extra air circulation is needed. Screening can be placed over the wire mesh to protect the birds against

mosquito-born diseases such as West Nile virus (Weaver and Cade 1985, K. McKeever, pers. comm.).

The Aplomado Falcon breeding facilities at the World Center for Birds of Prey consist of 3 × 6.1-m breeding pens with roofs sloped from 4.3 to 5.5 m. The structure is solid except for two roof skylights and one wall window with 4.3-cm bar spacing (Jenny et al. 2004). Circular cages also have been successful with large falcons, allowing them to fly in circles for exercise (Heidenreich 1997). Gyrfalcons (*F. rusticolus*) have been bred in circular pens of more than 20 m in diameter and up to 6 m high (Heidenreich 1997).

Nest ledges ranging from 0.75 × 1.25 m to 1.25 × 3 m have been successful for large falcons (Parry-Jones 2000). Nest ledges should be lined with clean aquarium sand or small gravel (Fig. 1). Aplomado Falcons are given a choice between two 0.6-m^2 nest boxes lined with cedar chips (*Thuja* spp.) on a nest ledge (Jenny et al. 2004). Perches in the pens should have at least 1 m of clearance above them, and some branch perches should be higher than the nest ledge to provide lookout posts. Coco fiber doormats or AstroTurf® (some carpet fibers can cause the bird's talons to become entangled) should be placed on flat shelf perches or on the lips of nest ledges to reduce the potential of bruising a bird's foot when landing (Weaver and Cade 1985, Jenny et al. 2004). Large smooth rocks also can serve as perches on the ground. Perches should be placed such that excreta do not foul other perches or the bath pan.

Figure 1. A female white Gyrfalcon (*Falco rusticolus*), arguably one of the more difficult large falcons to breed in captivity, solicits copulation on her gravel-lined nesting ledge.

Pen floors can be covered with coarse gravel overlaid with 10 cm of pea-sized gravel for rapid drying and good drainage. For cases where the photoperiods of the birds must be adjusted, or in case of emergency, light fixtures should be added to the pens in such a way that prevents the birds from perching on or shattering them (Weaver and Cade 1985). Birds also may require radiant heat panels near perches or heat tape on nest ledges if they are being kept at a facility with temperatures below their accustomed range (Jenny et al. 2004).

Food, Feeding, and Watering Procedures

Large falcons at the World Center for Birds of Prey facilities are fed quail, day-old chicks and 5-week-old chickens alternately. Large food items are cut in pieces. Feeding is once per day. During cold weather the daily ration may be offered in two half-portions to prevent it from becoming frozen before being consumed. Vitamin supplements (e.g., Avitron) are added to food in the breeding season. During the breeding season smaller food items are given more frequently to encourage males to begin food transfers with the female as part of the pair bonding process. Water baths consist of large, open, shallow pans and are changed once per week or as needed. Clean pans are used every time. It may be necessary to remove baths in colder months.

Capture of Falcons in the Chamber

To provide clean chambers at the World Center for Birds of Prey, the falcons are captured and moved immediately after the breeding season and in mid-winter. In some cases it is necessary to capture and briefly hold a female while her eggs are removed from the nest ledge. A defensive female can break an egg or the whole clutch; males are less of a problem. Birds are caught with a long-handled net. A slight noise made prior to entering the chamber reduces the chance of a panic flush resulting in injury.

After entering the chamber and netting the bird or birds, an assistant allows the bird to grip his gloved hands to prevent self-inflicted foot punctures. When punctures occur they may cause low-level foot infections (small scab and limited swelling). To minimize stress however, there is no attempt to treat such individuals, as they seldom, if ever, develop a serious chronic foot problem. Rarely, a sprained wing results during capture; it may last from a few hours to several weeks. Appropriate provisioning of food and perches to limit

flight should lead to recovery, but persistence of the condition warrants examination by a veterinarian.

Moving the birds to a clean chamber offers the chance to examine their health. Talons are clipped extremely short. The beak also is trimmed if overgrown. The whole operation takes only a few minutes, and the bird may be hooded if necessary (Burnham 1983).

Courtship Behavior

Courtship behavior of large falcons varies among species, but often involves flight displays, vocalizations, and food transfers between the pair. Courtship displays in Peregrine Falcons include fly-bys by the male near the female, scraping of the gravel on the nest ledge by both sexes, food transfers from male to female, and the female calling for food or chasing the male for food. Courtship can progress to displays and vocalizations on the nest ledge, including "hitch-winged" displays by the male, and solicitation by the female (see Fig. 1). For further information on courtship displays, see Weaver and Cade (1985) and Platt (1989).

Management for Production

Large falcons may take 2–3 years before reaching sexual maturity (Parry-Jones 2000). They usually lay 2–6 eggs, depending on the species. Incubation is typically 30–35 days. Chicks usually are fledged in about 6 weeks (Parry-Jones 2000). Ideally, young birds should be placed in communal pens to encourage natural socialization in order to make pairing more successful (Weaver and Cade 1985). The need to propagate certain genetically valuable individuals, especially with small populations of endangered species, may mean that some pairings are decided by keepers.

Birds may have to be paired together for several years before nesting successfully, and some individuals take longer to mature than others. Pairing a younger bird with an experienced breeder can increase the new bird's chance of having a successful first breeding season (Jenny et al. 2004). Pairs that continue to fail to produce young should be separated and offered new mates. Pairs should be monitored for aggression and be separated if necessary. The birds should be disturbed as little as possible, ideally using microphones or cameras in the pens, or one-way observation windows, or both to monitor them (Weaver and Cade 1985).

To increase egg production, pairs can be forced to double-clutch by removing the first clutch or by removing eggs sequentially and incubating them artificially (Weaver and Cade 1985, Jenny et al. 2004). This should be done only with more experienced pairs. First-time breeders should be given the chance to raise their own first clutch, unless the breeder suspects potential problems. Second clutches can be replaced by the hatched chicks of the first clutch for the adults to raise, whereas the second clutch is incubated artificially. Burnham (1983) and Weaver and Cade (1985) are good sources for information on this subject.

Incubation and Hatching Procedures

Unless otherwise indicated below, most of the details on the procedures of artificial incubation can be taken from this section, as there are similarities in the procedures for all raptors.

Eggs can be incubated naturally unless there is concern that the pair will damage the eggs, or if double-clutching is desired. Males and females often share the task of incubation (Weaver and Cade 1985). Before incubating eggs artificially, several factors must be considered. First, even if artificial incubation is to be used, ideally eggs should be incubated naturally for the first 7–10 days to increase their chance of hatching (Burnham 1983, Weaver and Cade 1985, Jenny et al. 2004). This natural incubation also can be achieved using chickens, but facilities must be built for the chickens and only specific-species and specific individuals can be used (Weaver and Cade 1985). Second, if breeders want artificially incubated eggs to hatch at approximately the same time, eggs can be stored temporarily before incubation at 14–15°C and at 60–80% humidity for up to 5 days while being turned four times per day (Weaver and Cade 1985, Parry-Jones 2000). In the wild, incubation of eggs usually does not begin until the last or second last egg is laid.

The room used for artificial incubation must remain as undisturbed as possible, and without direct sunlight or temperature fluctuations, which might affect the internal temperature of the incubators (Weaver and Cade 1985, Parry-Jones 2000).

The incubators, hatchers, and brooders should be cleaned and disinfected every 2 weeks when in use and every year before the start of the breeding season (Heck and Konkel 1985, Parry-Jones 2000). Eggs can be transferred to an alternative incubator during the process. The machines should be disassembled, cleaned with bactericidal and fungicidal disinfectants (e.g., Hibiscrub, Virkon) and all wiring should be cleared of dust

with pressurized air (Weaver and Cade 1985, Parry-Jones 1998). The re-assembled incubator should be fumigated with formaldehyde gas or a similar agent for about 20 minutes (Weaver and Cade 1985). The gas should be allowed to dissipate for several hours before the machine is considered safe to use.

A facility should have a minimum of three incubators, one to act as an incubator, a second to serve as a hatcher, and a third to act as a backup (Weaver and Cade 1985, Parry-Jones 2000). Many types of incubators exist ranging in cost from hundreds to thousands of dollars; The Peregrine Fund uses "Roll-X" counter-top incubators that take up minimum space and are easy to clean (Burnham 1983, Weaver and Cade 1985). All incubators should have a double-temperature control system, with a second thermostat acting as an override system should the primary thermostat fail to keep the temperature in a safe range.

The ideal incubating temperature for Peregrine Falcon eggs appears to be 37.5°C (Heck and Konkel 1985). Humidity, which determines the rate of water loss from within the egg, can be manipulated by placing Petri dishes of distilled water in the incubator, and varying their number to achieve the humidity desired (Weaver and Cade 1985). Artificial incubation usually is begun at approximately 30% humidity (Burnham 1983, Weaver and Cade 1985, Parry-Jones 2000). A dial hygrometer can be used to monitor humidity.

The number of times an egg must be turned may vary depending on the species, but eggs should be turned at regular intervals. Incubators can be programmed to turn eggs, eggs can be turned by hand, or both methods can be used (Burnham 1983, Weaver and Cade 1985, Parry-Jones 2000). Eggs should be rotated between 45° and 90°, and turns should be done in alternate directions. The turning grid that the eggs are placed on must be adjusted for egg size to reduce the risk of breaking the eggs.

Eggs should be tested for fertility even if they are being naturally incubated. Infertile eggs can be immediately removed to encourage pairs to re-lay if it is not too late in the season. Candling can be used to determine if the eggs are fertile (Burnham 1983). Thin-shelled or lightly pigmented eggs can be candled using incandescent lights, whereas thick-shelled or heavily pigmented eggs can be examined with ultra-violet candlers (Weaver and Cade 1985). A good-quality candler will avoid overheating the egg.

An egg must lose an appropriate amount of water to ensure proper hatching (see Burnham 1983, Weaver and Cade 1985). The weight of eggs must be monitored individually and the rate of loss regulated by manipulating the humidity to which it is exposed. On average, Peregrine Falcon eggs lose 18% of their weight before hatching; including 15% before pipping (the first crack in the shell) (Burnham 1983, Parry-Jones 2000). If the eggs are losing weight too rapidly or too slowly, the humidity in the incubator can be adjusted to slow or speed the process (Heck and Konkel 1985). Further information about candling and adjusting weight loss of problematic eggs can be obtained in Burnham (1983), Weaver and Cade (1985) or Parry-Jones (2000).

Forty-eight hours or less before pipping, the air cell in the egg will extend and move down one side of the egg (Burnham 1983, Weaver and Cade 1985). Eggs should not be turned after the expansion begins. When pipping occurs, the eggs should be placed in the hatcher with the pipped end up (Weaver and Cade 1985). Soft padding such as gauze should be placed under each egg and each egg should be surrounded by a ring of metal, a wire mesh corral or plexiglass to prevent other hatching chicks from bumping the egg. Containing the egg in this manner also facilitates keeping pedigree records, should two or more young hatch simultaneously overnight. The hatcher's humidity should range from 55% to 60% and the temperature should be similar to that in the incubator (Burnham 1983, Weaver and Cade 1985, Parry-Jones 2000).

The pip-to-hatch interval averages 50 hours and ranges from 24 to 72 hours (Burnham 1983, Heck and Konkel 1985). Patience is needed to prevent well-intended help from injuring the chick. The yolk sac is outside the body while the chick is in the egg and it must be absorbed before hatching. The chick also must turn within the egg, extending the pip into a line of breakage around the egg. Low humidity may dry the egg, causing the chick to become stuck within the egg. The calling of newly hatched chicks within the hatcher appears to stimulate the chick within the egg. The newly hatched chicks should have their navels swabbed with 1% iodine antibiotic ointment containing Bacitracin, and be placed in a brooder (see below) with a sterile corncob litter base when they have dried (Weaver and Cade 1985, Parry-Jones 2000). Burnham (1983) or Heck and Konkel (1985) should be consulted for problems with hatching such as unretracted yolk sacs or dried-egg membranes.

Brooding and Hand-Rearing

Two approaches to brooding are used. In still-air brooders, the temperature is constant throughout the chick's space and the breeder must modify it for the bird's comfort. K-pads and an infrared bulb suspended over the chick allow the hatchling to move between warmer and cooler portions of its environment. The chicks are kept in shallow aluminum cake pans filled with corncob covered with paper towel that is changed after every feeding (Weaver and Cade 1985). The corncob should be formed into a cup to prevent the chick's legs from splaying. A 25-cm diameter aluminum ring or corral surrounds the pan to catch the young's defecation and the whole fixture is placed on newspaper sheets. This system is easy to clean. Birds can be placed two to four per pan initially (fewer as they grow). Humidity and temperature (36°C) must be monitored and adjusted as needed. Chicks will huddle if they are cold or spread out and pant if they are hot (Weaver and Cade 1985). Chicks can be brooded under infrared lights hung overhead, though they should first be covered with a cloth to protect them from dehydration (Heidenreich 1997). A bottom heater also can be used to warm the chick's abdomens to enhance digestion (Heidenreich 1997).

The K-pad brooder consists of a pad filled with circulating heated water draped in a tent-like fashion over a prop in a pan filled with corncob. The temperature of the pan should be 38°C. Chicks should be placed in the brooder on patches of gauze under the pad and should be covered with towels. As the chicks age, the towels can be removed and the temperature reduced in the K-pad (Weaver and Cade 1985). The chicks in this brooder also should be encircled by a corral of plexiglass or aluminum to contain defecation. The corncob in the brooder should be changed as needed.

Temperature should be dropped daily by 1°C in the brooder until, after approximately 10–13 days, the chicks can be raised at room temperature in pairs in corncob-filled pans (30 cm in diameter) with aluminum corrals (33-cm diameter) around them (Weaver and Cade 1985, Parry-Jones 2000, Jenny et al. 2004). A cup should be formed in the corncob to prevent the legs from splaying out. Exposure to humans should be limited after two weeks of age to avoid imprinting (Jenny et al. 2004).

Chicks are not fed until they are at least 8 hours old. Nestlings younger than 10 days should be fed fresh, adult Coturnix Quail (*Coturnix coturnix japonica*) for the best growth (Heck and Konkel 1985). The quail is skinned, and the head, neck, digestive tract and limbs are removed. The meat is then finely ground and refrigerated until needed, although fresh food should be prepared daily. Young usually are fed every 3–5 hours except at night. Aplomado Falcons initially are fed five times daily and feeding is reduced to three times daily as they age (Jenny et al. 2004). Eventually feeding is reduced to once a day. Older chicks can be fed a mix of 50% ground six-week-old chicken and 50% ground horsemeat with a vitamin and mineral supplement (especially D3). A probiotic such as Avipro Paediatric (Vetark) can be added to the food every few days as an alternative (Parry-Jones 2000).

The meat should be warmed to room temperature before feeding or it should be freshly killed. The food should be wet with Ringer's solution or 0.9% saline before feeding to make swallowing easier (Weaver and Cade 1985, Heidenreich 1997). The chicks are fed with a pair of blunt forceps. Adult calls may have to be imitated to get the young to accept food. Older chicks should be encouraged to feed themselves directly from a bowl. The chick will continue to beg even if full and should not be overfed. Chicks with food still in their stomachs will have round, firm abdomens and should not be fed. Well-ground bone can be added after a few days. At 10 days the young can eat from a bowl, and the ground meat should include small body feathers to encourage casting. For problem chicks see Heck and Konkel (1985), Weaver and Cade (1985), or Parry-Jones (2000).

SMALL FALCONS

Cage Design

Breeding pens for American Kestrels range in size from 15.2 × 6.1 × 1.8 m to 1.5 × 1.2 × 1.2 m (Bird 1982, 1985, 1987; Parks and Hardaswick 1987). Much larger outdoor designs are used at the Patuxent Wildlife Research Center in Laurel, Maryland (Porter and Wiemeyer 1970, 1972). Aviaries can be built entirely out of wood frames and wire mesh, or with polyethylene or plywood walls with a wire mesh roof and floor that is elevated off the ground (Bird 1985). These small raptors will successfully breed in stove-sized cardboard boxes with a mesh roof and a nest box attached (Fernie et al. 2000).

Solid walls should be used when the facility is in a heavily disturbed area (Bird 1985). Mesh roofs should

be partly covered with plywood to provide shelter from sun and rain. Basic necessities include a food port, a nest box, one or two 2-cm rope perches and one 5-cm wide wooden perch for copulations, and a one-way glass window for observation. Nest boxes generally are 25 × 25 × 36 cm high and have an access port for checking on the eggs (Bird 1985). American Kestrels can be wintered in single sex flocks of 20–25 birds in indoor, unheated flight pens of 6.1 × 6.1 × 2.4 m (Bird 1985) with concrete floors equipped with drains. Wood shavings should be placed on the concrete floor to absorb feces.

Red-necked Falcons (*F. chicquera*) have been bred in rectangular pens 3.6 × 3.6 × 2.4 m high, as well as in polygon-shaped pens with a floor area of 17 m^2 and a height of 2.4 m (Olwagen and Olwagen 1984). The pens are constructed of treated wood frames and lined with plastic sheeting separating the pairs visually. The floor of the breeding pens consists of 0.5-cm concrete stone. The roofs of the pens are covered with metal roof sheeting, with one third of the roof covered with 25 × 50-mm mesh to allow for natural lighting. In this polygon cage design, only the corners are sheltered by metal sheeting. Shade cloth can be added just below the mesh (Olwagen and Olwagen 1984).

Red-necked Falcons use other birds' nests, therefore a selection of man-made and crows' nests are provided under the sheltered roof. The birds have a mesh feeding platform and plastic water trays for easy cleaning.

Food, Feeding, and Watering Procedures

Red-necked Falcons generally are fed 30–50 g of food per bird per day including day-old chicks, small passerines, doves, pigeons, mice and beef. Larger food items have to be defeathered and cut up. Vitamin-mineral supplements such as Beefee (Centaur Laboratories [Pty] Ltd.) can be added every 4 days (Olwagen and Olwagen 1984). Some small falcons also may require supplements of insects such as mealworms and crickets, and parents of some species should be provided with skinned food to feed their chicks, since down or fur can affect their digestive tracts (Parry-Jones 2000). Many breeders feed their small falcons day-old chicks (Heidenreich 1997). American Kestrels sometimes are fed only the latter (Bird and Ho 1976, Surai et al. 2001). In fact, American Kestrels have been maintained and bred in captivity at McGill University in Montreal for 34 years while fed a mono-diet of day-old cockerels without any apparent nutritional problems (D. Bird, unpubl. data). If desired though, small falcons can also be maintained on laboratory mice or commercial zoo diets (Porter and Wiemeyer 1970, 1972).

During the winter, food quantities may have to be doubled, and in freezing temperatures, birds should be fed twice daily (Bird 1987). While American Kestrels fed on moist day-old cockerels seldom drink, baths should be provided in temperatures above freezing. Alternatively, on a hot day, a garden hose perforated for watering lawns can be placed on the mesh roof of breeding pens to provide the birds with showers (Bird 1987).

Courtship Behavior

Food transfers are common in courtship behavior, as are nest inspections and vocalizations (Olwagen and Olwagen 1984). Pair-bonding can be encouraged in Red-necked Falcons by anchoring large food items to the feeding platform, encouraging the pair to eat together (Olwagen and Olwagen 1984). Generally, males feed females in courtship feeding, but in Red-necked Falcons, the female feeds the male. Successful courtship feeding often is followed by copulation. Feeding may continue even after the bond is formed in order to strengthen it (Olwagen and Olwagen 1984). Courtship behavior for American Kestrels has been documented by Willoughby and Cade (1964), Porter and Wiemeyer (1970, 1972) and others.

Management for Production

Small falcons often will breed in their first year and usually can lay between 2 and 6 eggs (Parry-Jones 2000). Birds can be double-clutched and can recycle in as little as 10–14 days (11 days for the American Kestrel [Bird 1987]). Some pairs of American Kestrels can produce up to 3 or 4 clutches per season (Bird 1987) or as many as 26 eggs if removed as laid (D. Bird, unpubl. obs.). Some pairs of falcon species, such as Merlins, should be separated after the breeding season to prevent injury from aggression (Heidenreich 1997). Antagonistic pairs should be separated and re-paired (Bird 1987).

Incubation and Hatching Procedures

American Kestrel eggs can be stored in a refrigerator safely for up to one week before beginning artificial incubation. Using Marsh Farms Roll-X incubators, eggs are kept at 37.5°C with 55% humidity (Bird 1987). Eggs can be turned hourly by the automatic turning device in the incubators or turned by hand at least 4

times daily. Once the eggs pip, they are placed in another Roll-X incubator serving as a hatcher set at 36.9°C and 55% humidity. The eggs are placed on a wire-mesh floor in a small wire-mesh corral, lined with masking tape to minimize sharp edges, to prevent the hatched chicks from moving around and for identification during hatching (Bird 1987). The eggs are kept in the hatcher for 2 days and then moved to a brooder.

Brooding and Hand-Rearing

Chicks can be kept in brooders separately in wire-mesh corrals or in groups in small bowls with cups formed from soft paper, which is changed after every feeding (Bird 1987). American Kestrels are brooded under heat lamps and can be reared in groups of up to five chicks. Temperature is adjusted in the brooder until 10–14 days, when the birds are comfortable at room temperature (Bird 1987).

Chicks are fed bits of neonatal mice within the first 24 hours after hatching and initially are fed 4 times daily (Bird 1987). Within a few days, they can be fed mashed day-old chicks that have been skinned with beak and legs removed (Bird 1987). Vitamin supplements can be added on occasion. Chicks can feed from bowls at 2 weeks of age and can be fed larger food items at this time.

When capable of flight, American Kestrels (but not Common Kestrels [*F. tinnunculus*]) can be housed and wintered in sex-segregated flocks of 20–30 birds in large flight pens measuring 6.6 × 6.6 × 1.3 m and equipped with rope perches (Fig. 2). A concrete floor with drains for cleaning and is otherwise covered in wood shavings to soak up feces, works well with these small falcons (D. Bird, unpubl. obs.).

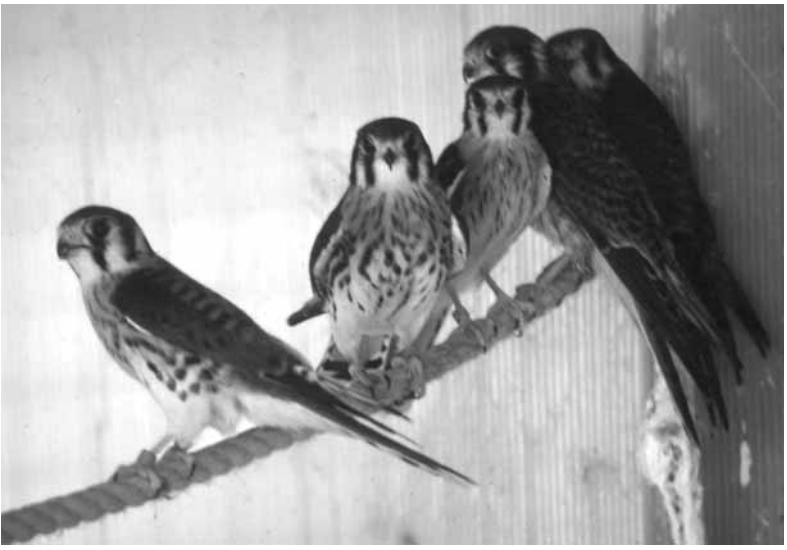

Figure 2. American Kestrels (*Falco sparverius*), which are extremely easy to breed in captivity, can be wintered in sex-segregated flocks of 25–30 individuals in large flight pens.

EAGLES

Cage Design

Eagles have been bred in pens ranging from 1.8 × 2.4 × 2.4 m to 48 × 30 × 33 m. They breed best in tall, elongated pens (Carpenter et al. 1987). Eagle pens generally range from 18 to 34 m^2 in floor space with heights ranging from 2.5–3 m (Heidenreich 1997). White-tailed Eagles have been bred in pens of 7 × 8 × 5 or 6 m high and pens of 9 × 13 × 5 to 6 m high (Carpenter et al. 1987). According to Parry-Jones (1991), minimum recommended sizes for eagle pens are 9 × 4.5 × 4.8 m or 6 × 3 × 3.6 m, depending on the size of the bird. Bald Eagles have been bred in pens of 22 × 11 × 5.5 m high at the Patuxent Wildlife Research Center (Carpenter et al. 1987). The pen frames are constructed from utility poles with wooden roof beams, and the walls and roof consist of 2.5 × 5-cm or 2.5 × 2.5-cm vinyl-coated mesh wire. Plywood sheets protect at least one corner of each pen from the weather. Aluminum roofing is used to cover the roof above the nest platform, which is 1.2 × 1.2 m in size, 3.7 m above the ground. The sides of the platform are 34 cm high, and the floor of the nest platform is 2.5 × 2.5-cm mesh covered with straw and sticks (Carpenter et al. 1987).

Nest ledges in eagle pens can be 2.4 m wide and 4.5 m long with a 23-cm high lip (Parry-Jones 1991). Nest ledges of 2.5 × 5 m are generally bolted to the back wall of the pens (Parry-Jones 2000).

Hardware cloth is buried underground to a depth of 1 m to keep out potential predators (Carpenter et al. 1987). Wooden stumps serve as feeding platforms serviced through feeding ports. Perches in eagle pens consist of tree-like structures using a vertical 30-cm diameter pine pole with branches attached (Parry-Jones 1991). Perches 6.6 to 10 cm in diameter that range in length from 1.2 to 5.5 m span the pens (Carpenter et al. 1987). Perches should have enough space around them to prevent damage to the birds' wings (Parry-Jones 2000). A shelter should be provided for the birds with a floor space of 4 m^2 and a height of 2 m (Heidenreich 1997).

Food, Feeding, and Watering Procedures

At Patuxent, eagles are fed 6 days per week in the nonbreeding season and 7 days per week in the breeding season (Carpenter et al. 1987). The pairs should be fed twice per day when they have chicks to raise. Food is supplied in quantities so that there always is some left over. Eagles are fed whole animals, including poultry, fish and laboratory mammals, depending on the species of bird (Carpenter et al. 1987). Day-old chicks should be supplemented with vitamins and minerals. If the food, especially fish, is stored frozen, its nutrient quality might be reduced, so vitamins should be added to the food (Carpenter et al. 1987). Eagles always should have access to fresh water for drinking and bathing.

Courtship Behavior

Courtship behavior in eagles includes territorial behavior, nest building, mutual preening, communal roosting and copulation. A breeder should understand the progression of behavioral development in order to ensure its sequence. For more information on eagle courtship behavior, the reader is advised to consult Carpenter et al. (1987), Heidenreich (1997) and Parry-Jones (2000).

Management for Production

Some species of eagles lay only one egg per clutch, while others will lay up to 5 (Parry-Jones 2000). Incubation time can range up to 61 days. Fledging can take up to 6 months in large species. Certain species will raise several chicks at a time, while others will raise only the first chick hatched and let any other young die. Such behavior can be avoided in some species by providing the adults with enough food to sustain several chicks. If the young are aggressive to one another, it is wise to raise one by hand until it is old enough to defend itself (Parry-Jones 2000).

Bald Eagles can be double-clutched if the first clutch is removed early enough (Wood and Collopy 1993), but eagles may take a long time to lay a replacement clutch. On average, it takes Bald Eagles 32 days to lay a second clutch (Heidenreich 1997).

The male should be placed in the pen days or weeks before the female to allow him to become familiar with the territory before the larger female is added, and pairs should be separated if they are incompatible. New breeders should have their eggs removed and replaced with dummy eggs to determine the parent's effectiveness as caregivers before allowing them to raise their own clutch. A new pair should not be double-clutched during their first breeding effort (Carpenter et al. 1987).

Incubation and Hatching Procedures

Eagles may be aggressive towards potential nest threats; therefore, anyone attempting to remove eggs from a nest should take caution (Heidenreich 1997). Generally, adults begin incubation with the first egg and share the task. Eggs can be incubated under bantam chickens to within 2–3 days of hatching, when they are transferred to artificial incubators (Carpenter et al. 1987). Artificial incubation is performed at temperatures of 37.4° to 37.6°C and eggs are turned every 2 hours. The eggs are placed blunt-end elevated in the incubator and laid out flat approximately 5 days before hatching, at which time turning should be stopped (Carpenter et al. 1987). Pipped eggs are kept in a humid hatcher at 36.9°C.

Brooding and Hand-Rearing

A major concern for some eagle species is siblicide (Heidenreich 1997). Often chicks will hatch several days apart, giving the oldest the advantage in size. The risk of fighting is reduced as the nestlings age. If the parents have been permitted to hatch their young, it is advised to remove the younger and weaker chicks, hand-rear them until they are strong enough to defend themselves and then move them to the nest (Heidenreich 1997). The birds should not be hand-reared after 3 weeks of age because of the risk of imprinting (Carpenter et al. 1987).

After artificially incubated eggs hatch, the young are allowed to dry in the hatcher and then they are shifted to a paper towel and straw-filled cardboard box in a humid brooder set at 35°C. Temperature is reduced until the chicks can tolerate room temperature, usually at approximately 3 weeks of age. They are fed minced fish and chicken or minced skinned mammals using blunt forceps. Vitamin supplements and digestive enzymes are added. The young are fed 6 times per day initially, and the feedings are reduced with age (Carpenter et al. 1987).

HAWKS AND HARRIERS

Cage Design

Pen sizes for hawks vary with the size of the birds, as

well as with their temperament. Very nervous, rapid fliers should not be placed in pens large enough to allow them to build up excessive speed and present a collision risk with the cage walls (Heidenreich 1997). Pens with 10–18 m^2 of floor space that are 2.5 m high have been successful (Heidenreich 1997). Minimum size for hawk pens ranges from 6 × 3 × 3.6 m to 4.5 × 2.4 × 2.4 m. The Falconry Centre has bred various hawk species in pens of 3 × 6 m, with sloped roofs 4 to 6.7 m high (Parry-Jones 1991). For other aviary design considerations for hawks, see Crawford (1987).

Some species of hawks cannot remain together year-round because of the risk of the larger female harming the male (Heidenreich 1997, Parry-Jones 2000). To resolve this, Northern Goshawk (*Accipiter gentilis*) breeding pens are designed as two adjacent pens separated by a sliding, barred window so that the birds can see each other. If the pair begins to show interest in each other (e.g., male offering female food through the bars and the female assuming copulatory postures and vocalizing), the door is opened to permit them to mate. The birds can be separated immediately thereafter if necessary (Heidenreich 1997). Harris's Hawks, on the other hand, are relatively social raptors, and placing several birds together can be beneficial for breeding (Heidenreich 1997). A male also may mate with multiple partners.

For most species, two nests should be provided. For accipiters and buteos, a freestanding metal basket on a pole and the other on a shelf in a pen corner should suffice (Crawford 1987). As an alternative, one could provide one long nest ledge (e.g., 1.2 m wide and 3 m long) with a lip of 23 cm, which serves to give the pair some choice on actual location (Parry-Jones 1991). Northern Harriers (*Circus cyaneus*) require two 1-m^2 platforms 15 cm off the ground and screened by long grass. All nests should be filled with sticks and, for harriers, grass. Extra twigs and conifer branches should be provided on the ground for the pair to adjust their nest (Crawford 1987). The substrate in the hawk pens at the World Bird Sanctuary in St. Louis, Missouri is composed of 2 cm of gravel covered with 8 cm of pea-sized gravel (Crawford 1987). Perches consist of branches set at various heights, partly covered with AstroTurf® to reduce the chance of bruising to the birds' feet (Parry-Jones 2000). If injured hawks and harriers are being bred, they may require walk-up ramps to reach the perches. Males may require perches out of sight from aggressive mates. Such perches require two exits so that a pursued male cannot become cornered (Crawford 1987). Shelters for the birds also can be added and can range in size from 2 to 4 m^2 with a height of 2 m (Heidenreich 1997).

Food, Feeding, and Watering Procedures

Hawks can be fed a variety of rats, mice, chickens, adult quail, and rabbits (Crawford 1987). They also can be given venison, day-old chicks, and guinea pigs at times. Normally fed daily, smaller portions of food are offered during the breeding season several times per day to encourage the male to make food transfers with the female (Crawford 1987).

Courtship Behavior

Courtship behavior includes food transfers, mutual preening and a variety of postures, nest construction, and vocalizations (Parry-Jones 2000). Readers should consult the general literature on species-specific behavior.

Management for Production

Accipiters are known to be nervous by nature and often are more vocal (Crawford 1987). If they are to be bred successfully, they should be kept isolated from human contact as much as possible (Parry-Jones 2000). When first introduced together, the pair should be observed for signs of severe aggression. If aggression does not lessen, they should be re-paired with other individuals.

Incubation and Hatching Procedures

If eggs are to be incubated artificially, they should be removed from the nest 7 days after the last egg is laid, and should be kept in incubators at 37.5°C at less than 50% humidity (Crawford 1987). Readers should consult the large-falcon section above for more information.

Brooding and Hand-Rearing

Accipiter chicks are fed ground quail, and buteos are fed ground rats or mice, but see Crawford (1987) for more details on the various diets used for different aged chicks. Vitamin and mineral supplements usually are added to these diets. Generally, for the first 10 days of life, chicks are fed 4 times daily, then 3 times daily, and after 21 days, twice daily.

Several hawk species such as Common Buzzard (*Buteo buteo*) and Red-tailed Hawk (*B. jamaicensis*) sometimes kill siblings in brooders (Heidenreich 1997),

so caution must be taken if they are to be hand-reared. Though most 2-week-old young raised in a brooder can be safely returned to their parents, Northern Goshawk young often are initially afraid of their natural parents, and may try to escape from the nest ledge, so strict observation of their behavior must be made when they are initially returned (Parry-Jones 1991).

OWLS

Cage Design

Most owls are relatively sedentary raptors and require less space in captivity than other birds of prey (McKeever 1979). Cage designs vary depending on the size and habits of the owls they are meant to house. The recommendations of Parry-Jones (1998) are as follows: for large owls such as Great Horned Owls (*B. virginianus*), 3 × 4.8 × 2.4 m high to 3.6 × 4.8 × 2.7 to 4.2 m high; for medium-sized owls, 3 × 3 × 2.4 m high to 3 × 3.6 × 2.7 to 4.2 m high; for smallish owls such as Tawny owls (*Strix aluco*) and Barn Owls, 1.8 × 3 × 1.8 m high to 2.4 × 3 × 2.4 to 3.6 m high, and for tiny owls (owlets, *Otus* spp.): 1.5 to 1.8 × 3 × 2.4 to 3.6 m high. Alternatively, the Owl Research Foundation in Ontario, Canada (McKeever 1979) offers the following minimum cage size requirements for large owls: 9.1 × 3.6 × 3 m high; for medium-sized owls such as Barred Owls (*S. varia*): 7.3 × 3 × 3 m high, and for small owls such as screech owls (*Megascops* spp.) and Northern Saw-whet Owls (*Aegolius acadicus*): 5.5 × 2.4 × 2.4 m high. Barn Owls also have been bred successfully in 5 × 4 × 2.5-m outdoor aviaries with a nest box provided (Durant et al. 2004). They have even been bred in 1.5 × 3 × 4-m pens with wooden nest boxes measuring 0.5 × 0.5 × 0.5 m (Rich and Carr 1999).

One style of owl pen used at the Falconry Centre in the U.K. consists of three solid walls and one mesh wall (Parry-Jones 1998). These pens have completely covered roofs made from Onduline or fiber and concrete and are equipped with ceiling lights to adjust photoperiods if necessary. The base of the walls consists of a low brick wall, and treated tongue and groove cladding is used to build the upper portion of the walls of the pens. The floors are constructed from sloped cement for better water drainage and perch holes can be built directly into the floor. All pens have an access door leading into a closed maintenance passageway large enough to permit passage of a wheelbarrow to facilitate cage cleaning and food delivery. One-way glass observation windows, food ports, and access ports to nest ledges or boxes are standard for each pen (Parry-Jones 1998).

The Owl Research Foundation has had great success with a cage design involving two breeding pens connected to each other by corridors that can be closed once a pair has been successfully established in each pen (McKeever 1979). This has worked well for breeding Northern Hawk-Owls (*Surnia ulula*) (McKeever 1995). The corridors, 1.5 to 6 m in length and fitted with removable gates, connect various breeding pens. The gates are opened in early spring, allowing the birds natural mate selection, and again in fall, allowing young to leave their "natal territory" (McKeever 1995).

Overall, this method leads to better pair formation. Each breeding pen is further divided into hunting and nesting sections. The pen frames are constructed of sealed spruce timber 5 × 10 cm thick and built up on steel stakes driven into the ground below the frost line. The roofs are sloped to shed rain and snow. The edges of the roofs are solid instead of meshed to provide shelter for the birds from the weather. For diurnal owls, transparent fiberglass or opaque Coroplast™ can be used (McKeever 1979). Additional wooden slats are strategically placed on the roof for shade. The rest of the roof consists of wire mesh ranging in size from welded mesh up to chain link depending on the bird's size. The walls of the cages are designed of the same material as the roofs, and the ratio of solid wall to mesh wall depends on the needs of the species in question and on the climate (e.g., more protection in regions with cold winters). A completely sheltered area should be available at all times in each pen. The lower section of the walls at ground level is lined with fiberglass to allow live mice to be inserted into the pens for the purposes of release training. Pens are placed out of line of sight of each other using vegetation to afford the pairs privacy. White and ultraviolet fluorescent lights fixed to the pen's roof can be used to adjust the bird's photoperiod to match that of its natural environment (McKeever 1979).

Burrowing Owls (*Athene cunicularia*) have been bred in 5 × 10-m buildings separated into private burrows for each pair, with outdoor flyways for each pair and a communal 3 × 33-m flyway surrounding the individual breeding areas for the non-breeding season (Leupin and Low 2001). An outdoor aviary of 18 × 18 m divided into three breeding pens also has been used successfully. Tunnels connect each of these pens to an individual underground nest chamber. These pens can be turned into a communal flyway by dropping partitions

after the breeding season. Tunnels are built using 15-cm diameter perforated flexible plastic pipes, and artificial burrows can be constructed using three 11- to 19-l plastic buckets joined together (Leupin and Low 2001).

Nests in the pens vary among species, and can range from a nest ledge to a nest box to an open-topped box on the ground (Parry-Jones 1998). Boxes and ledges can have 10 cm of peat over a base of pea-sized gravel or 15 cm of sand in them for the owls to dig a scrape in.

Perches vary in size depending on the species, and can consist of tree stumps, logs, branches, grapevine, rocks or rope (McKeever 1979, Parry-Jones 1998). Males must have a high roost in the nest area as a lookout station. If one or both of the pair are permanently injured birds, perches should be designed to allow them to travel to all the important features in their pen.

If training the young to hunt is necessary, at least two food boxes should be placed in the hunting area of each pen (McKeever 1979). All pens should have a built-in bath with an access port for cleaning (Parry-Jones 1998). Pools range from 30 to 90 cm in size and from 1 to 15 cm deep depending on the owl's size and can be made of cement or brick covered in concrete (McKeever 1979, Parry-Jones 1998).

Ground cover in the pens varies among species and can include small gravel and peat moss, wood chips, leaves and turf (McKeever 1979). Pens with concrete floors should be overlaid with gravel or 10 cm of sand (Parry-Jones 1998). In laboratory conditions, pen floors can be covered with cage bedding (recycled newspaper), which is changed every 2 weeks (Rich and Carr 1999). Rocky gravel also can be used to line the ground outside the pens to discourage potential burrowing predators (Parry-Jones 1998). Some species such as Snowy Owls (*B. scandiaca*) require large clear spaces in their pens for take-off, whereas others can be provided with trees and logs to provide a more forested setting (McKeever 1979).

Food, Feeding, and Watering Procedures

Most owls eat rodents; a few species eat birds, fish, amphibians, or insects. It is best to feed adult mice (20–50 g) to owls, and occasionally to offer rats and rabbits to large owls, which wears down their beaks and talons. Weanling rats and mice do not have the nutrient content of their adult counterparts, so vitamin and mineral supplements may have to be injected into the food several times per week (McKeever 1979). Burrowing Owls have been fed daily with laboratory mice, weanling rats, Common Starlings (*Sturnus vulgaris*) and House Sparrows (*Passer domesticus*) (Martell et al. 2001). Barn Owls in laboratory settings have been fed laboratory mice daily (Durant et al. 2004). Eagle owls have been successfully fed chicks, quail, rats, mice, parts of rabbits and guinea pigs (Parry-Jones 1998). Eurasian Scops Owls (*Otus scops*) and owlets can be supplemented with mealworms, crickets or locusts (Parry-Jones 1998). Day-old cockerels appear to offer poor nutritional supplements for owls, and their down can serve as an intestinal irritant (McKeever 1979). Two-week-old chickens are more suitable, but only for large owls.

The birds eat much more (sometimes more than twice as much) in winter and during the breeding season than in summer (McKeever 1979).

Courtship Behavior

Courtship behavior includes food transfers, vocalizations, and the digging of a nest scrape (Parry-Jones 1998). Females often will base mate choice on the male's territory or pen size (McKeever 1979).

Management for Production

Ideally, owls should be permitted to select their own mates to have a more successful pair bonding (McKeever 1979). Many owls have perennial pair bonding, and an individual taken from the wild or one whose mate has recently died may not show interest in another mate for several years (McKeever 1979, Parry-Jones 1998).

Incubation and Hatching Procedures

Eggs can be incubated by the adults or, where double clutching is desired, eggs can be incubated artificially. Eggs can be removed for artificial incubation or for surrogate incubation using chickens. Some owls will lay a second clutch approximately 2 weeks after the first is removed. Eggs can be candled after 8–10 days to test for fertility (Parry-Jones 1998). Apart from the differences presented below, details for artificial incubation and hatching are similar to those in the Large Falcon section. Readers are referred to Heck and Konkel (1985) or Parry-Jones (1998).

It is ideal to have several incubators set at a different temperature and humidity to transfer the eggs between as needed to insure proper weight loss (Parry-Jones 1998). Eggs should be cleaned with an egg disinfectant before being placed in the incubator. Incubators

for owl eggs are kept between 37.3°C and 37.4°C. The humidity should be adjusted to lose 15% egg weight by the pipping stage (Parry-Jones 1998).

Approximately 70% of Barn Owl eggs will hatch in incubator conditions, though they cannot be stored at low temperatures beforehand (Rich and Carr 1999). For good hatching results, Barn Owl eggs should be turned once every two hours (Rich and Carr 1999).

Brooding and Hand-Rearing

Owl nestlings can be hand-reared in small groups to insure proper socialization (Parry-Jones 1998). The brooder should be set up a week in advance to stabilize the temperature to 35°C or 37°C. Brooder temperatures can be adjusted to suit the chick's comfort. Once the young are dry, their navels should be disinfected and placed inside containers filled with sand and lined with paper towel forming a cup (Parry-Jones 1998). Containers should be cleaned at every feeding.

Hand-reared owls should be fed mashed, freshly killed mice that have been skinned, with teeth, tail, limbs and intestines removed (McKeever 1979). They also can be fed day-old chicks, rabbit and quail prepared the same way (Parry-Jones 1998). Vitamins such as Plex-Sol C (Vet-A-Mix Inc.) can be added to the food (Rich and Carr 1999). Vitamin and mineral supplements such as MVS 30 (Vydex) or Nutrobal (Vetark) and probiotics (e.g., Avipro by Vetark) can be mixed in their food as an alternative (Parry-Jones 1998). The young often have to be encouraged to eat by touching the food to the sides of their beaks and imitating the parents' calls (McKeever 1979, Parry-Jones 1998). The birds should be fed with round-ended forceps.

Owl nestlings should not be fed in the first 24–36 hours after hatching, thus allowing their yolk sacs to be fully absorbed (McKeever 1979). They can be given dextrose in water until that time. Young should not be overfed; this can be judged based on the feel of the stomach (it will be firm if the bird is full). Weight should be monitored. At 2–3 weeks of age, they generally can feed themselves from a bowl of minced food offered 3 times per day (Parry-Jones 1998). At this time they can be returned to the parents if desired; otherwise, imprinting can become a concern. According to McKeever (1979), owls imprint on a parental figure between their second and sixth week of life. Fostering young owls to an adult of their own species works so long as they are about the same age as that of the biological young of the foster parents.

CONDORS AND VULTURES

Cage Design

California Condors and Andean Condors (*Vultur gryphus*) breed in cliff cavities in the wild. Breeding pens should include a flight pen, a connecting catch pen to capture the birds as needed, and roosting and nesting areas (Toone and Risser 1988). Such facilities have been used at the San Diego Zoo, Los Angeles Zoo, and the Patuxent Wildlife Research Center. Pens for pairs of California Condors are 12.2 × 24.4 m in size and 6.1 to 7.3 m high (Toone and Risser 1988, Snyder and Snyder 2000, Harvey et al. 2003). Pens of this size in a breezy area can actually permit condors and vultures to soar briefly (Toone and Risser 1988). Pens are constructed of poles and cable covered by 5.1 × 10.2-cm welded mesh with visual barriers of corrugated metal sheeting on the sides of the pens adjacent to human activity to reduce disturbance (Toone and Risser 1988, Cox et al. 1993). Visual barriers of metal sheets also are placed at ground level between the pens, but birds are permitted to see each other from higher perches (Harvey et al. 2003). California Condor pens of 12.2 × 6.1 × 6.1 m also have been used (Snyder and Snyder 2000). Chain-link pens of 9.1 × 18.2 m in size and 3.6 to 9.1 m in height have been used to breed condors successfully (Cox et al. 1993). Andean Condors have been bred in pens that are 12 × 18 × 6 m high (Toone and Risser 1988), but also in pens of 5.5 × 11 × 5.3 m high (Ricklefs 1978). King Vultures (*Sarcoramphus papa*) have bred in pens one-third that size with a nest consisting of a raised wooden box.

The nesting area for California Condors at the San Diego Zoo consists of an open-fronted roost 1.5 × 1.5 m in size with a perch in it (Toone and Risser 1988). Near this roost is a 1.5 × 1.5 × 1.8-m high box with an entranceway that serves as the nesting area (Harvey et al. 2003). The floor of this box is covered with sand. Simulated rock caves also can be used (Toone and Risser 1988). The nest area should have a small, 30 × 35-cm access door for handlers to have access to eggs or young, and the roost area also should have a door for maintenance purposes (Toone and Risser 1988).

Vultures and condors require a great deal of space to land, as well as wide perch surfaces because their feet are not designed for gripping (Parry-Jones 2000). Perches for California Condors can be 5 × 15-cm thick wooden planks installed with the wide side as the perching surface. Some perches should be far enough from

the roost to allow for flight back and forth. For bathing purposes a pool of 1.8 × 2.4 m is suitable (Toone and Risser 1988).

Birds can be monitored with cameras placed inside the nest boxes, and adults can be observed from blinds outside of the pens (Cox et al. 1993). Heating lamps or perch heaters may be necessary if the birds are being bred outside of their normal climate (Parry-Jones 2000).

Food, Feeding, and Watering Procedures

The adult and juvenile California Condor diet at the San Diego Zoo consists of 0.5 kg of cat food (e.g., Nebraska Brand Feline Diet), mackerel, 2-day old chicks, and a rat or rabbit daily (Toone and Risser 1988). All food is fed fresh. The birds also have been fed Nebraska Brand Canine Diet, beef spleen and rainbow trout (Harvey et al. 2003). The birds are fasted twice a week on non-consecutive days.

Adult vultures of various species also have been fed a diet of cow's heads and whole rabbits twice per week (Mundy and Foggin 1981). Other facilities have been successful with fresh whole rabbits, chicken and horsemeat provided daily for the birds in the early morning (Dobado-Berrios et al. 1998). Water always is available for them. For problems with getting wild-caught birds accustomed to the captive diet, see Toone and Risser (1988).

Courtship Behavior

Pair bonds in Lappet-faced Vultures (*Torgos tracheliotus negevensis*) begin forming in their second year of age (Mendelssohn and Marder 1984). Bond formation includes the "head-stretch and turn" display, as well as the passing of nest material to each other. California Condors perform a "wings out and head down display" (Cox et al. 1993). Allopreening and approaching each other also are signs of interest in a potential mate (Ricklefs 1978, Cox et al. 1993). The birds may use the skin on their necks as a display to potential mates (e.g., puffing up their throats to show off colors or to create a drumming noise). They also perform courtship dances. Successful pairings often last until one of the mates dies (Parry-Jones 2000).

Management for Production

Condors and vultures require 5–8 years to reach sexual maturity depending on the species, and young require 3–6 months before fledging (Toone and Risser 1988, Cox et al. 1993, Parry-Jones 2000). They also have a low productivity rate; adults often breed only once every 2 years (Cox et al. 1993). Young California Condors were originally placed in pairs as early as possible to encourage bond formation. Current workers now raise fledglings in groups and place them in pairs at or after sexual maturity. Pair selection should be based on genetic considerations, although this does not always work as planned. Incompatible pairs should be separated and re-paired after 2 years of unsuccessful breeding. Extra birds are housed together in a group, which allows a chance for natural mate selection to occur (Cox et al. 1993). Bond formation can take a year or more to form and more time may be needed before a pair produces a successful fledging (Cox et al. 1993).

The pairs should be kept out of public view to reduce disturbance as much as possible (Cox et al. 1993). Condors and vultures normally lay a one-egg clutch on the ground, on ledges, in tree holes or in the undergrowth (Parry-Jones 2000). Andean and California condors have lain up to 3 eggs in a season after the first egg was removed. If recycling occurs, it is typically after about 30 days. Incubation can range from 40 to 55 days, depending on the species.

Incubation and Hatching Procedures

First-time breeders of an endangered species often are given a dummy egg, or the egg of a less vulnerable species, as a trial experience (Harvey et al. 2003). Both adults will incubate the egg. Breeders should watch for aggressive behavior between adults while exchanging positions in the nest as this can harm the egg (Harvey et al. 2003).

If artificial incubation is to be used, it is best to remove the eggs from the nest after a week of natural incubation (Mendelssohn and Marder 1984, Snyder and Snyder 2000). Lappet-faced Vulture eggs have been incubated successfully at 34.5°C and 40% humidity with 5 turns per day (Mendelssohn and Marder 1984). California Condor eggs have been successfully incubated at 36.3°C to 36.7°C with a humidity allowing for a 12–14% mass loss in the egg (Saint Jalme 1999, Snyder and Snyder 2000). Eggs are turned by machine every hour with an extra turn by hand every 12 hours. Young usually hatch approximately 48–68 hours after pipping (Mendelssohn and Marder 1984, Snyder and Snyder 2000).

Brooding and Hand-Rearing

Hand-rearing vultures and condors can raise imprinting concerns. When parents or surrogates cannot be used to raise the young, a successful alternative is to house young vultures and condors individually in protective cages (1.2 × 1 × 1 m) inside an aviary containing a pair of adults of the same species (Mendelssohn and Marder 1984). Initially the young can be hand-reared in a temperature-controlled room equipped with a mirror to give the hatchling a non-human image to focus on while keepers are feeding it. The use of hand puppets resembling the adults' heads to feed the young also has been successful in raising California Condors and Andean Condors (Mendelssohn and Marder 1984, Toone and Risser 1988, Cox et al. 1993, Wallace 1994). After releasing the puppet-raised young into the wild however, it was discovered that the birds were attracted to human habitations. Those tendencies appear to have lessened with age, and since survivorship is not significantly different, use of puppets to minimize imprinting continues to be one of the main methods of rearing for release.

Nestlings are first fed 24 hours after hatching and initially are fed 3 times per day (Mendelssohn and Marder 1984). Feedings are reduced from 3 times to 2 times to 1 time per day as the chick ages. Young raised by parents are fed a regurgitated diet. The recipes recommended by Heidenreich (1997) also have been successful. Lytren, an electrolyte solution, can be provided to the nestlings several hours after feeding if they are not digesting their food rapidly enough. For further problems with feeding young, consult Toone and Risser (1988).

After several days the young can be weaned onto small, skinned mice, and later on to mice with the fur peeled but still attached to the carcass (Toone and Risser 1988). The young also can be fed pieces of skinned, de-boned rats or small mice warmed in digestive enzymes using tweezers (Mendelssohn and Marder 1984). Nestlings also have been raised on lean meat, liver, lung, spleen, and guinea pigs (Mundy and Foggin 1981). After reaching a couple of weeks of age, supplements of vitamin D3 and bone fragments every few days also have been found to be useful (Mundy and Foggin 1981, Mendelssohn and Marder 1984). After several weeks, large pieces of skinned meat with bone can be fed to the young, and after a month, whole rats or large pieces of meat (Mendelssohn and Marder 1984). Young can feed themselves at approximately 3 months and can then be put on an adult diet.

GENERAL HEALTH CONCERNS

When holding and breeding birds in captivity, especially when those birds are rare or endangered, one must always be aware of the potential threats to their breeding stock. Burrowing Owl breeding facilities in British Columbia are geographically separated from one another to protect the birds from total population loss in the case of an infectious disease outbreak (Leupin and Low 2001). A footbath outside of incubation rooms and each pen also may be necessary to prevent the spread of disease (Giron Pendleton et al. 1987). Unexplained mortality of breeding adults, hatchlings or embryos should be tested for the presence of bacterial, viral, parasitical or fungal infections (Battisti et al. 1998). Blood samples, feces, pellets, unhatched eggs and cloacal swabs should be taken from each bird occasionally and tested as well. Cultures also should be taken periodically from the bird's food source (Battisti et al. 1998).

Illnesses in raptors can result in symptoms such as lethargy or a loss of appetite, and even in death (see Chapters 16, 17, and 23 for more specific information). Disease can result from infections of *Salmonella*, *Chlamydia* and *Mycoplasma* (Battisti et al. 1998). Food sources such as poultry, day-old chicks and mice are common sources of *Salmonella* infections (Battisti et al. 1998, Lany et al. 1999). *Salmonella* also can be transmitted to young or to eggs from contaminated meat deposited in the nest, from fecal contamination, or from direct ovarian transmission (Battisti et al. 1998).

Annual exams are recommended for all birds, if only to gather physiological data on the birds that may prove useful in the future (Ricklefs 1978, Toone and Risser 1988). The exams should be timed to provide the least stress on the birds (e.g., during cage cleaning). Video monitoring, observations via one-way glass, and a perch-weighing system can be used to gather continual information on the birds (Toone and Risser 1988). Minor injuries such as wing sprain can occur when birds are handled. Often the best and safest treatment for these injuries is to leave the birds alone and let them heal (Weaver and Cade 1985).

Diet always is a concern in captive breeding programs for raptors (Clum et al. 1997, Cooper 2002). Because of cost and facility location, breeders may not have access to the bird's natural food. Breeders often have to resort to commercial diets and domestic food sources such as quail, chickens or chicks, rats, mice or guinea pigs (Clum et al. 1997, Cooper 2002).

Studies of the domestic species used for food sug-

gest that nutritional content is variable depending on the food sources' diet, age and sex, as well as on the storage method (e.g., frozen or freshly killed; Clum et al. 1997). In general, lipid content of the food is sufficient because captive birds are generally less active, require less energy and are provided with excess food compared to their wild counterparts. We know little about the potential impacts (e.g., atherosclerosis) of long-term feeding of high-lipid foods such as day-old cockerels on raptor health. Vitamin and mineral content also are of concern to captive breeders (Clum et al. 1997). Diet must be optimum before and during egg laying for females to have a successful breeding season (Cooper 2002). Moreover, the eggs of certain species produced in captivity have different fatty acid profiles than those of wild birds of the same species, possibly due to diet (Surai et al. 2001). This may affect hatchability and the survival rate of chicks.

GENERAL FACILITY CARE

Overfeeding should be avoided so that uneaten food does not accumulate. Baths should be placed by a small hatch so that their regular removal for cleaning does not disrupt breeding birds. Nest platforms and boxes should be cleaned before and after the breeding season. Nest grass for harriers should be changed before each nesting season (Giron Pendleton et al. 1987).

Pens should be cleaned once or twice a year with a disinfectant wash and rinse (McKeever 1979, Olwagen and Olwagen 1984, Weaver and Cade 1985, Parry-Jones 1998) and usually at a time when minimum stress will be inflicted on the birds, such as in the autumn after the breeding season. Ideally, birds are captured, examined and moved to an already clean chamber. If the pair must be held until the original chamber is cleaned, they can be placed in individual boxes that are dark but well-ventilated and kept in a cool, quiet location. Nest ledges or boxes, perches and food platforms must be scrubbed well and rinsed. Mats, perches, nest ledges, or boxes should be replaced if needed. Gravel or sand substrate must be raked and replaced if necessary (Weaver and Cade 1985). If an outdoor pen has a grass, the grass and other vegetation should be mowed or pruned regularly (Giron Pendleton et al. 1987). Heavy paint on the walls can prevent insects from destroying wooden walls and facilitates washing.

SUMMARY

Captive breeding of raptors can be a useful tool in reintroduction, research, educational programs, zoos, and falconry. An important consideration to be made before breeding raptors is what will be done with surplus birds. Animals should not be bred in captivity unless the offspring are intended for release, research, or the enhancement of useful captive populations.

Captive breeding of raptors has come a long way. Advances in incubation, artificial insemination, and the hand-rearing of young have increased the success of captive breeding projects. Breeders now are more aware of health concerns, behavioral needs and dietary supplements that can enhance the quality of life of captive birds and thus improve their breeding. However, much has yet to be learned about the behavior and biology of captive and wild raptors, which could further improve captive breeding and conservation projects.

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