1 Natural history

Hornbills have been held in zoos for more than a hundred years and have always been a great attraction. Their shape, flight and inquisitive behavior entice zoo visitors to slow their pace to watch these birds. Despite the evolution of zoos from "menageries" to present zoological institutions or conservation societies, successful breeding of many hornbill species remains a challenge.

The most striking physical similarity shared by the 54 recognized hornbill species is the presence of a casque. All hornbills are hole nesters, and the females of all but two species are usually “sealed-in” the hole throughout incubation and most of the chick rearing. The extent of their collective range is fairly restricted, being almost entirely between 30 °N and 30 °S of the equator. Hornbills do inhabit a variety of habitats, from dry savannas in Africa to rainforests of Asia and range from 100 g to 4 kg in mass.

Zoo managers not only need to take into account the ecological and behavioral traits common to all hornbills, but also important species-specific variations. The suggestions given in the following chapters are based on general hornbill natural history in general. These Hornbill Husbandry and Management Guidelines are meant to compliment Alan Kemp's book "The Hornbills *Bucerotiformes*" published in 1995, which contains detailed information on each species' natural history and biology. Furthermore the guidelines follow the nomenclature of Kemp’s book, as participants of the 2nd International Hornbill Workshop in 1997 agreed to use this nomenclature in future references. Traditional common names of *Buceros* species are used here however.

2 Captive population management

2.1 Identification

Conclusions on this topic were made during the International Hornbill Workshop 1997 in Malaga (Spain), and were originally summarized by Christine Sheppard.

Large hornbills are rarely individually-marked in zoos because they are dimorphic and usually kept in pairs. However, if future, more intensive, population management results in more hornbill exchanges between institutions, all individuals should be readily identifiable. Transponders are useful, but can migrate or fail, and are unreadable unless a bird is very near the transponder reader. There have been no reports of significant problems with any type of metal leg band. Therefore it is recommended that these two marking systems, bands and transponders, are used simultaneously.

Transponders should be implanted in a hornbill's right pectoral muscle. If possible, a second transponder should be implanted as a back up. The second transponder should be implanted in the left pectoral muscle as two transponders implanted in the same site can give hybrid readings. All hornbills should be ringed below the tarsometatarsal joint with metal bands engraved with identification numbers. Males should preferably be banded on the right, females on the left. While "closed" rings or bands, which cannot be removed without being destroyed, should ideally be used, other bands can be used when necessary. Young hornbills should be banded as soon as possible without disruption to management. Transponder and band numbers and site of placement on the body should be included in the bird's records.

A comprehensive list of ring sizes and appropriate age to fit closed rings should be compiled for a future edition of hornbill guidelines or as a supplement to the guidelines.

2.2 Morphology and sex determination

Males are equal to, or up to 17% heavier, than females in mass. Wing length of males is 1 to 21 % greater and bill length 8 to 30% greater than in females. Male casques are always larger than female casques. The bill and the casque probably have a role in communicating age, sex and status of an individual in conjunction with changes in eye, skin and plumage coloration (Kemp, 1995). Examination of the degree of dimorphism in various features through out the hornbills (Kemp 1995) suggests that species that are highly dimorphic in coloration are often not extremely dimorphic in casque volume, while many that are very dimorphic in casque volume are relatively monomorphic in coloration.

Most hornbill species are dimorphic as adults but age at which adult coloration is acquired is variable; generally it is relatively delayed in cooperatively breeding species. Coloration can be misleading, for example juveniles of both sexes in some species, e.g. most *Aceros*, resemble adult males while juveniles of *Ceratogymna* spp. resemble adult females (Kemp, 1995).

Sexual dimorphisms and ages at which they are acquired are noted in Kemp (1995) if known, however information on many taxa is still incomplete. Hornbill managers could note the age at which sexual dimorphisms develop, to check against available information of known species and to add to the knowledge of species for which no information is currently available.

Some species can be sexed correctly by appearance upon fledging or shortly thereafter, but the sex of most hornbills must be determined by other means if it is necessary to know the sex fairly quickly for management reasons.

The easiest sex determination method is DNA sexing using feathers or a very small amount of blood. It is also the quickest, as it can be done as soon as a hornbill acquires its first real feathers or is large enough to spare a drop of blood. There are several laboratories within Europe that are offering this service now, but permits to send feathers or blood may be necessary for managers wanting to send samples to another country, as many hornbill species are covered by CITES regulations. A comprehensive list of laboratories offering this service throughout European countries should be made; the laboratories currently known to us are listed in Appendix A. If DNA sexing is not possible, hornbills can be sexed by laparoscopy.

2.3 Maturation and longevity

The ages at which different hornbills become reproductively mature in the wild is presented in Table 5. Average life expectancy is not known for any hornbill species. The hornbill longevity record is currently held by Josephine, a great hornbill *Buceros bicornis* female held at London Zoo for 47 years (Brouwer and Derks, 2000). She was believed to be four years upon arrival at London Zoo and is estimated to have died at the age of 51. A great hornbill pair at Vogelpark Avifauna also bred successfully at a minimum age of 30 years of age in 2000 (R. Verkade, pers. comm.). Five species of hornbills reportedly still breed in their 30's at Audubon Park Zoo, and one pair of rhinoceros hornbills *Buceros rhinoceros* is estimated to be 36 years of age (S. Barrios *in* Birdkeepers listserv, 31 October 2001).

2.4 European hornbill collection plan taxa

There are currently three EEP and ten ESB taxa, of which three are African and ten are Asian, in the European collection plan.

a. **Great hornbill** (*Buceros bicornis*) **EEP**
EEP Coordinator: Koen Brouwer, NFRZG, Amsterdam
45.48 birds in 40 institutions as of 31 December 2000

b. **Sunda wrinkled hornbill** (*Aceros corrugatus*) **EEP**
EEP Coordinator: Jens Lilleor, Aalborg Zoo
13.24 birds in 21 institutions as of 31 December 2000

c. **Mindanao wrinkled hornbill** *Aceros leucocephalus* **EEP**
EEP Coordinator: Roger Wilkinson, Chester Zoo
5.5.2 birds in 2 institutions as of 31 December 2000

d. **Rhinoceros hornbill** *Buceros rhinoceros* **ESB**
European Studbook Keeper: Stephan Hübner, Frankfurt Zoo
17.20.1 birds in 18 institutions as of 31 December 1999

e. **Malay black hornbill** *Anthracoceros malayanus* **ESB**
European Studbook Keeper: John Ellis, London Zoo
15.17 birds in 11 institutions as of 31 December 1999

f. **Asian pied hornbill** *Anthracoceros albirostris albirostris* **ESB**
European Studbook Keeper: John Ellis, London Zoo
9.11.2 birds in 10 institutions as of 31 December 1999

g. **Sunda pied hornbill** *Anthracoceros albirostris convexus* **ESB**
European Studbook Keeper: John Ellis, London Zoo
9.14 birds in 10 institutions as of 31 December 1999

h. **Tarictic hornbill** *Penelopides* spp. **ESB**
European Studbook Keeper: Duncan Bolton, Bristol Zoo
7.8.1 birds in 10 institutions as of 31 December 1999

i. **Bar-pouched wreathed hornbill** *Aceros undulatus* **ESB**
European Studbook Keeper: Irena Pavlin, Ljubljana Zoo
15.17 birds in 12 institutions as of 31 December 1999

j. **Papuan wreathed hornbill** *Aceros plicatus* **ESB**
European Studbook Keeper: Irena Pavlin, Ljubljana Zoo
12.14 birds in 7 institutions as of 31 December 1999

k. **Southern ground hornbill** *Bucorvus leadbeateri* **ESB**
European Studbook Keeper: Stéphanie Bidaux, Zooparc Beauval
40.37.4 in 34 institutions as of 31 December 1999

l. **Northern ground hornbill** *Bucorvus abyssinicus* **ESB**
European Studbook Keeper: Stéphanie Bidaux, Zooparc Beauval
16.28.10 in 21 institutions as of 31 December 1999

m. **Von der Decken's hornbill** *Tockus deckeni* **ESB**
European Studbook Keeper: Catherine King, Rotterdam Zoo
21.15.21 birds in 12 institutions according to the 2001 EAZA Hornbill TAG Survey.

3 Veterinary care, handling and transport

3.1 Veterinary care

Reviewed and supplemented by W. Schaftenaar (Rotterdam Zoo), A. Kruszewicz (Warsaw Zoo), K. Gamble (Lincoln Park Zoo) and H. Cornelissen (Dierenkliniek Broerdijk).

3.1.1 Rodenticide poisoning

Several hornbill managers mentioned problems with secondary poisoning from rodenticides, although in some cases assurances had been made that these compounds were safe for birds. Rodenticides antagonize the action of vitamin K in the synthesis of the blood clotting factors. General clinical signs may be vomiting, depression, diarrhea and anorexia (Frazier, 2000). Sources of poisoning have been grain-based baits, food contamination or consumption of poisoned rodents. The only way to ensure that such poisoning does not occur is to refrain from using rodenticides anywhere in the vicinity of hornbills. It has been suggested that rodenticide programs could be carried out near hornbills if vitamin K is given to the hornbills on a prophylactic basis. Given that there is no information on effectiveness or side-effects of long term prophylactic vitamin K treatment it might be advisable to carry out such programs only during short periods of intensive rodent combat. Suitability of this treatment for different types of rodenticides should first be evaluated: Vitamin D analogue intoxication occurring with “anti-coagulant” rodenticides will not be helped by Vitamin K.

3.1.2 Bill hygiene

Hornbills in the wild perform many bill maintenance behaviors such as cleaning food residue from the bill and wearing down the bill tips. It is important that small forked branches are available to hornbills for bill-cleaning purposes. Many hornbills will use a short length of knotted rope to clean their bills. This is useful if the birds are held in temporary accommodation for any reason. The rope can be attached to the aviary roof above a favorite perch (J. Gregson, pers. comm.) Feeding watery food, e.g. tomatoes, in the afternoon may also help with bill sanitation.

3.1.3 Treatment of bill and casque injuries

Damaged casques or bills can be a problem, especially if the broken appendage becomes infected. Fowler (1986) recommended using fiberglass and epoxy to repair bills. Two people reported successful repair of bird bills using material developed for hoofstock hoof repair (L. Hudson *in litt*. to C. Rowsome, 13 July 2001; M.J. Willis *in litt.* to C. Rowsome, 20 July 2001).

Dental acrylic, pins, wires and elastics have successfully been used to repair avian bills, and techniques are described in Parsons and Wissman (1995). The authors report that these techniques are relatively inexpensive and easy to perform.

3.1.4 Pseudotuberculosis (Yersiniosis)

Hornbills are highly susceptible to pseudotuberculosis, a disease caused by the bacterium *Yersinia pseudotuberculosis*. This disease results in very rapid and usually fatal inflammation of the liver (peracute hepatitis). Birds often die without showing many signs of illness, and are in good physical condition upon death. Post-mortem examinations typically show a grossly swollen liver studded with small white or off-white spots. The spleen is often similarly affected. Contamination of food and water by infected droppings from rodents and wild birds as well as by avian carriers within the collection are likely sources of the bacterium. Good food and water hygiene are the best preventative measures: e.g. rodent control, storing food in rodent-proof containers and placing food trays in covered places where wild birds cannot defecate on them. Amoxicilline or another antibiotic can be used in treatment. Disease progression is extremely rapid once there are visible signs that the bird is ill, and waiting for a conclusive diagnosis before beginning treatment may critically delay treatment (Waine, 2001).

The formol killed vaccine “Pseudovac” to protect pseudotuberculosis-sensitive animals is available from the Department of Veterinary Pathology, section Zoo and Exotic Animals, Utrecht University, Yalelaan 1, 3584 CL Utrecht, The Netherlands (Telephone: +31 30 253 4602, fax: +31 30 253 313). A formal study of effectiveness of the vaccine needs to be carried out, but anecdotal information does indicate that the vaccine is effective. The first two vaccinations should be undertaken with a six week interval between them, and a booster given periodically thereafter. Vaccine protectiveness declines after nine months, however some Dutch zoos have chosen to vaccinate only once per year, before the winter, as pseudotuberculosis is not considered a problem in the Netherlands in the summer and fall months. This strategy can be risky though, as birds have been known to die of pseudotuberculosis when the interval between vaccination boosters barely exceeded one year, thus vaccination every six to nine months might be prudent.

Birds susceptible to pseudotuberculosis are often also susceptible to iron storage disease (see Section 3.1.6: Iron storage disease).

3.1.5 Other bacteria, parasites and fungal infections

Transmission of bacteria and/or parasites from adult to young (e.g. gape worm *Syngamus trachea)* may be one of the reasons that young routinely die in the nest.

The following parasites were reported for *Buceros bicornis* by EEP institutions in Galama (1996a):

- Nematodes, e.g. *Ascaris, Trichostrongylus, Strongyloides*. Preventive medical treatment: fenbendazole, (e.g. in Panacur®, producer: Hoechst, NL);
- Several blood sucking mites (Dermanyssidae);
- Feather louse (*Mallophaga*), e.g. *Paroncophagus forcipatus.* Permethrin (spray form) can be used to treat ectoparasites. Carbamates are a bit more toxic but can also be used. Bromocyclen is another agent sometimes used, but is even more toxic.

Fungal infections:

- *Aspergillosis:* the standard treatment for acute aspergillosis in the lungs is (oral) Itraconazole; therapy needs to be continued for three to six months. Air sac aspergillosis is sometimes treated with Amphoteracine-B and oral Itraconazole, but is not really successful. Some vets recommend concurrent treatment with Vitamin A while others advise against it.

- *Candida:* the standard treatment for infections in the alimentary canal is with Nystatin. Plaque debridement with topical Nolvasan (chlorhexidine solution at 1:40 dilution) can be used in mild cases (throat and oral cavity) and Itraconazole or Ketoconazole (Nizoral) in very severe (systematic) cases.

3.1.6 Iron storage disease

Iron storage disease (hemochromatosis), clearly a problem in hornbill management, occurs when too much iron accumulates within the hepatocytes and Kupffer's cells of the liver and then in the heart, lungs and other organs. The accumulation causes significant damage and eventually death. Common symptoms of iron storage disease are labored breathing, abdominal swelling and ascites, weight loss and depression. Enlargement of the liver, heart and spleen is often visible in radiographs, however, a liver biopsy is the only way to confirm accumulation of iron in cells. Hemosiderosis is a second, less malignant form of the disease in which excess iron (hemosiderin) accumulates in the tissues and circulates freely in the blood. While it does not damage major organs it has been shown in mammals that it can be a precursor to hemochromatosis (Johnston, undated).

There are many factors that may play a role in a bird’s susceptibility to iron storage disease, and in disease progression, however little has been unequivocally established. Obviously more study is needed on this matter. There is thought to be a genetic component as entire avian genera or even families are often susceptible, regardless the ecological difference between the species comprising the group. Birds are particularly susceptible if their livers have been damaged by toxins or infection. Heavy metals can also intoxicate birds and are known to cause deposition of iron pigment within hepatocytes (Lowenstine, 1986).

Fruits and vegetables used in captive hornbill diets are generally low in natural chelators (e.g. phytates, fiber and tannins) that may play an important role in mediating absorption of dietary iron in nature (E. Dierenfeld, Hornbill Digest Listserv 1998). Therefore, a paucity of natural cheleators in zoo diets could also play a role in the disease in captivity. Additionally, several studies in both mammals and birds have shown that ascorbic acid (Vitamin C) increases iron take up (Johnston, undated). Immunological or nutritional stress could furthermore predispose at least some birds to this disease.

A female Sunda wrinkled hornbill *Aceros corrugatus* at Fort Worth Zoo was successfully treated for hemosiderosis by offering a diet primarily consisting of low-iron pellets soaked in tea. The tannins in the tea bind the iron and prevent it from being stored in the liver. Her feather condition and activity level improved (C. Brown, Hornbill Digest Listserve, 1998). A study of the effect of feeding tea on avian iron levels is currently being studied at Riverbanks Zoo, U.S.A. (Johnston, undated). However, tannins can only bind a limited amount of iron, and are generally not viewed as the solution to iron storage problems (G. Dorrestein, pers. comm.).

Phlebotomy (blood letting) is often used as treatment, on the premises that birds making replacement blood will draw on iron in the liver. Practitioners usually start with removal of 1% of blood per week, while testing to ensure that the bird does not become anaemic. Bloodletting may be continued periodically for two or three years before complete remission of the disease is declared (Johnston, undated). A recent study using an oral chelator to bind iron in pigeons and chickens was inconclusive because of death of the study subjects. Daily injection of deferoxaminemesilate (Desferal) is currently the most reliable means to decrease the amount of stored iron. It is expected that in the future this treatment will be available orally. It is important that effectiveness of methods used be investigated by liver biopsies.

While there is much to be learned before this disease can be adequately prevented, there are some steps that can be taken to try to ensure that susceptible birds take up as little iron as possible:

- Use a low-iron (see also Section 5.1.7: Iron) and low-heavy metal diet. Sheppard and Dierenfeld (2000) recommend a diet that contains 50-100 mg/kg iron, on a dry matter basis. G. Dorrestein (pers. comm.) suggests that an effort should be made to stay below 50 mg/kg (see 5.3: Diet suggestions).

- Avoid feeding items high in Vitamin C

- Check the environment for other sources of iron. Although environmental iron oxides are poorly available (Dierenfeld and Sheppard, 2000), environmental iron can pose a risk (G. Dorrestein, pers. comm.). Sources of significant iron ingested by birds at some institutions have been:
  -- tap water;
  -- utensils (knives, cutting machines) used to chop fruit;
  -- substrate; and
  -- food of other animals in the enclosure that are not on a low-iron diet.

3.1.7 Plumage condition

Molt of hornbills is quite variable. Smaller species tend to molt seasonally (usually during the breeding season when food availability is highest) while larger species have a more prolonged or continuous molt. Females of many species (not *Bucorvus* or larger *Ceratogymna*) often simultaneously molt their flight and tail feathers during the period they are sealed in the nest cavity. Surprisingly, breeding males often molt while feeding their partner and young. Hornbills regulate their molt according to their nutritional status and other factors, and can molt feathers quite selectively. The hormonal and nutritional regulation of molt is not well understood in hornbills, and deserves further study (Kemp, 1995). A disturbed molt might indicate a hormonal, environmental or nutritional problem, or a combination of these.

3.1.8 Immobilization

Inhalant anaesthetics are the safest and easiest to use in the zoo setting. Isoflurane gas is currently the most commonly used inhalant, however another comparable drug will soon be on the market as well. Use of inhalant anaesthetics for a hornbill requires some creativity, as hornbill have relatively small nostrils, low breathing rate, and the bill will not fit into standard gas induction caps. A plastic bag into which the gas can be tubed can function as an induction cap. Large plastic bottles (e.g. approximately 1 gallon or 4 litre) that are padded around the rim have also been used as masks. As soon as anaesthetic depth is sufficient, the animal should be intubated.
Injection of ketamine hydrochloride (10 mg/kg, but possibly higher if the bird needs to be immobilized for a prolonged period) can also be used. Ketamine has the disadvantage of a longer recovery time during which the hornbill must be manually restrained to prevent injury through beating the bill, legs or feet during recovery, however in cases in which an inhalant cannot be used (e.g. field conditions, escapees) it could be the most suitable. Some vets mix ketamine with other drugs (e.g. Xylazine or the more specific Medetomidine) however the appropriateness of this practice with birds is controversial. Should a hornbill suffer dyspnea or other respiratory problems during recovery, an injection of an antidote might be used. Yohimbine (0.1 mg/kg bw; i.m.) has been used, but some vets consider Atipamezole, a newer drug, a better alternative.

3.1.9 Physiological references

Physiological reference ranges for a number of physiological data values are available to ISIS users (ISIS, 2002). Values available for great hornbills *Buceros bicornis* are illustrated in Appendix B. Physiological references are also available for: Northern ground hornbills *Bucorvus abyssinicus*, Southern ground hornbills *Bucorvus leadbeateri*, African crowned hornbills *Tockus alboterminatus*, African red-billed hornbills *Tockus erythrorynchus*, Von der Decken's hornbills *Tockus deckeni*, Oriental pied hornbill *Anthracoceros albirostris*, rhinoceros hornbills *Buceros rhinoceros*, white-crowned hornbills *Aceros comatus*, Sulawesi wrinkled hornbills *Aceros cassidix*, Sunda wrinkled hornbills *Aceros leucocephalus*, Papuan wreathed hornbills *Aceros plicatus*, bar-pouched wreathed hornbills *Aceros undulatus*, trumpeter hornbills *Ceratogymna bucinator*, and silvery-cheeked hornbills *Ceratogymna brevis*.

3.1.10 Pathology review

It was agreed at the Malaga conference in 1997 that general survey of the pathology data from the EEP and SSP collections should be undertaken, coordinated by Kathryn Gamble (Lincoln Park Zoo; kgamble@lpzoo.org), veterinary and pathology advisor for the AZA Hornbill SSP. Of particular interest is the incidence of iron disease. Liver samples should be collected for iron storage research during hornbill necropsies. The liver samples can be stored frozen or in formalin.

EAZA hornbill holders are requested to use the MEDARKS post mortem investigation form (Appendix C) when performing post mortem examination of hornbills, and to send a copy to Andrzej Kruszewicz (email: akruszew@zoowarszawa.pol.pl), the EAZA Hornbill TAG Veterinary Advisor. Additionally, institutions using MEDARKS should also enter post mortem data into this system.

3.2 Handling and transport

Hornbills are usually captured using a net. The bird is extracted from the net by grasping the bill first, maintaining control of the beak at all times to prevent serious injury to the face, eyes or fingers (Fowler, 1986). Stress to the birds (and keepers) and personnel time during loading of hornbills for transport, or even transfer to another enclosure, might be eased by target-training (see Section 3.3: Environmental enrichment and training).

IATA guidelines for crate specifications and transport procedures must usually be followed if commercial air carriers are used.

Plastic pet transportation crates can be ordered in all sizes suitable for hornbills. Plastic crates are easy to clean and disinfect and may be more resistant than wooden crates to bill "shaving" activities. Large slits or other openings should be covered with mesh so that the hornbills cannot manipulate the crate or bite.

Risk of damage to the casque may be avoided by taping the casque and padding it with cardboard (Anonymous, 1990, in Kemp, 1995). Taping of the long tail with gummed paper might also prevent feather abrasion and breakage (Kemp, 1995). A hornbill should have sufficient time to become used to the crate before shipment. If transport time will be longer than a couple of hours it should be ascertained that birds are drinking and eating in the crate before transportation.

3.3 Quarantine

Even if quarantine in an external station is required prior to arrival at the receiving facility, "in-house" quarantine for a period of minimally three weeks is recommended to assess a hornbill's general health and to repeatedly test for parasites.

Standard quarantine procedures (e.g. use of foot bath, care of animals by keepers not in contact with other birds in the collection, easily cleaned walls and floors) should be applied when working with hornbills. The quarantine period is inherently stressful to birds, yet there is a number of measures that can be taken to minimize stress:

An adequately sized enclosure, allowing the birds to exercise by flying to perches at the opposite end of the enclosure, should be provided. The enclosure should be large enough to allow the hornbill to comfortably extend its wings fully. Wing lengths of hornbills are provided in Table 2.4 of Kemp (1995).

Perches should preferably be mounted horizontally above human height. If enclosures are not large, perches for ground hornbills *Bucorvus* spp. should be closer to the ground. The circumference of quarantine perches should be approximately 1/3 larger than the hornbill's foot closed around the perch. Perches should not be hard or slippery.

Food and water should be offered 1.5 m off the ground or higher (with the exception of ground hornbills, which can be fed about 30 cm above the ground) and preferably accessed from outside the cage.

The diet provided at the hornbill's previous institution should initially be given; other items can be given in addition to these; diet changes should be gradually made (see Section 5.1.2: Palatability and Familiarity).

A short length of knotted rope attached to the aviary roof above a favorite perch can be used by the hornbills to clean the inside of their bills (J. Gregson, pers. comm.).

Hornbills should generally be held separately during quarantine. Possible exceptions might be family groups or pairs with a long-term pair bond. However, even these situations bear watching as the quarantine situation may evoke aggression.

Hornbills should not be held adjacent to other hornbills or individuals of other species with which aggression is observed unless a closed wall can used to separate the animals.

Enclosure boundaries should be able to withstand a hornbill's assaults, and should not promote bill damage. See Section 4.7.1: Boundary (roof and wall) materials.

3.4 Environmental enrichment and training

Environmental enrichment improves the welfare of animals. There are forms of environmental enrichment that can significantly increase foraging, locomotion and maintenance behaviors (Galama and Weber, 1996). Some possibilities are: offering food in difficult to obtain ways (e.g. in pine cones, on skewers, hidden in piles of straw, leaves or other organic matter), providing variety in foods (e.g. seasonal fruits, foods gelled in cubes), offering live food (on the ground or from dispensers). Sprinkling the enclosure with water or providing other bathing opportunities, such as in wet vegetation (see Section 4.8.2: Vegetation), and planting vegetation for the hornbills to destroy are possibilities. Many hornbills greatly enjoy sunbathing, often from a perch but sometimes also on the ground (see also Section 4.3: Light regime).

Other ideas gleaned from listservs include offering "large parrot toys, marbella beads and things that can be torn up". A cardboard box filled with shredded paper hung on a rope was a favorite of a pair of silvery-cheeked hornbills *Ceratogymna brevis*: "they beat the boxes to pieces and pull the paper out of it". A dog kong toy hung on a rope was also well used (C. Lewis *in* Birdkeepers listserv, 17 July 2001). R. Knight (Birdkeepers listserv, 24 October 2001) also noted that ground hornbills *Bucorvus* ssp. seem to enjoy pulling/tugging on objects, for example a tennis ball hung on a heavy duty rope, and on pieces of sissal rope or heavy-duty rubber hose hung with a carabiner. Novel objects that he recommended included kong toys, boomer balls, phone books, paper bags, browse and scrub brushes. J. Clark (Birdkeepers listserv, 24 October 2001) observed that a young ground hornbill actively attacked a frisbee and threw it around the cage.

Another idea for ground hornbills was live fish in a bowl: "they do not seem to be interested in eating them but love to watch them swim around in the bowl and 'play' with them" Food, e.g. mice or chicks, can also be offered frozen or in a water bowl. Organic material raked into a pile is another source of enrichment (Birdkeepers listserv, 24 October 2001).

Some hornbills enjoy chasing small gourds and destroying pumpkins and squash filled with treats (Birdkeepers listserv, 24 October 2001).

Short training exercises can form a welcome challenge for birds and can greatly facilitate medical examinations (e.g. bill check and blood draw training), weight measurements (scale training) and transportation (crate training). Obviously, any form of training that negatively affects a bird's social behavior towards its conspecifics should not be practised. L. Mochinski at the Philadelphia Zoo uses insects to reward 1.1 African red-billed hornbills *Tockus erythrorhynchus* during target training (Birdkeepers listserv 2000).

J. Mellen and M. Sevenich MacPhee at Disney's Animal Kingdom (USA) have developed a very helpful website with information on how to set up, implement and evaluate an enrichment program using a framework. The web page is www.csew.com/enrich/. A similar web page on training will be available in the near future.

4 Environmental conditions and housing

4.1 Disturbance

Disturbance should be minimized during the beginning of the nesting season, when nest-visiting and sealing in of the female occur. The female is particularly sensitive to disturbance prior to egg-laying once sealed in the nest (Kemp, 1995). The need to enter the cage as little as possible during the breeding season should be taken into consideration in cage design. For example, access to food trays, water faucets, light switches and other environmental controls should be placed outside the enclosure. Plants and perches should be positioned so that the need for enclosure cleaning can be minimized.

Vegetation around the indoor (part of the) enclosure, with only one side open for public viewing, is recommended as hornbills housed indoors often share facilities with many other birds that might disturb them. By their very shape and design, walls and floors of indoor aviaries often intensify noise levels, which can frighten the hornbills, particularly during the breeding season. Vegetation planted in and around the enclosure lowers the noise level and enhances the natural appearance of the aviary.

It was noted during nest checks of a great hornbill *Buceros bicornis* nest at Cotswold Wild Life Park (UK) that sounds made by visitors seemed to be amplified in the nest, possibly because of the nest was placed in an area walled on most sides. A hessian barrier was placed between the visitors and the nest (Golding and Williams, 1986), with the idea that this might muffle and/or redirect sounds that could be disturbing the hornbills. The hornbills did nest successfully for the first time thereafter, however it was not possible to determine whether the barrier played a role in this development (S. Blackwell, pers. comm.).

Conspecifics, other hornbills or even other avian taxa showing territorial behavior, especially during the breeding season, should not be housed in aviaries adjoining the hornbills and visual contact should be minimized. For example, fighting between a male toco toucan *Ramphastos toco* and a Papuan wreathed hornbill *Aceros plicatus* in adjacent enclosures at Rotterdam Zoo resulted in loss of the tip of the toucan's bill. A female great hornbill *Buceros bicornis* was injured when she launched herself at a small window through which she could see a female Papuan wreathed hornbill in winter quarters at the same institution. Another disturbance problem in addition to aggression can be mis-directed reproductive behaviors: the mate to this female great hornbill had been observed feeding the female Papuan wreathed hornbill *Aceros plicatus* through wire-mesh outdoors.

The effect of vocal/auditory contact is unclear. Bar-pouched wreathed hornbills *Aceros undulatus* have been observed to react strongly to play-backs of their own vocalizations and great hornbills *Buceros bicornis* to tape recording of rhinoceros hornbills (*Buceros rhinoceros* at Rotterdam Zoo.

While the birds seem to desensitize to these vocalizations, it is uncertain whether the vocalizations have a negative (or positive) impact on the birds. The bar-pouched wreathed hornbill vocalizations are only sporadically played and the pair breeds, but the great hornbills, which have regular exposure to the rhinoceros hornbill vocalizations, do not. As most great hornbills in captivity do not breed, this does not necessarily indicate a relationship however. Certainly formal studies of affect of conspecific or congeneric vocalizations on hornbill behavior would be useful.

4.1.1 Mixed species enclosures

Ground hornbills *Bucorvus* spp. are often held with large African mammal species, particularly hoofstock. While this provides the birds with much space it has several disadvantages. Possible injury from hoofstock poses a physical risk to the hornbills, and unless the birds are well trained the lack of control in an open enclosure can be deadly. Ground hornbills have been killed by antelope and in one savannah enclosure almost starved to death because they could not compete with indigenous grey herons *Ardea cinerea* and gulls *Larus* spp. that stole their food. Another disadvantage in temperate climates is that ground hornbills are usually moved to minimal “temporary” accommodations during the winter months when they often come into breeding condition.

Enclosures housing hornbills with other species have had variable success (see Appendix B for examples). Several factors can play a role, including the species and individuals involved, amount of vegetation and space, and perching possibilities. Reproductive condition was reported by several hornbill managers to be an important factor. For example, a pair of Sunda wrinkled hornbills *Aceros corrugatus* housed in the 150 X 90 X 20 m rainforest exhibit at Arnhem Zoo (Netherlands) was compatible with the some 100 other species with which it was housed until it began breeding. The parents developed a marked preference for feeding the offspring live food, taking a huge toll on smaller birds as well as reptiles and amphibians in the exhibit; resulting in the pair being moved elsewhere (Luttenberg and Bisselink, in press).

Examples in Appendix 11.D indicate that arboreal avian species can be considered at high risk to be killed by hornbills larger than they are. Hornbills have mixed more successfully with ground dwellers such as pheasants and plovers. However, while several hornbill managers did indeed report success mixing hornbills with pheasants others concluded that eventually the hornbills kill the pheasants. While the smaller species (e.g. *Tockus*) are more often held with other species, they are also known to kill smaller enclosure mates.

It should not be assumed that “arboreal” hornbills will remain out of range if held in an enclosure with potential ground predators, even relatively small ones such as slendertailed meerkats *Suricata suricatta*.

Most hornbills sometimes investigate the substrate, eat from the ground and use the ground for sun or dust bathing, exposing themselves to attack.

Hornbills are sometimes also held with other hornbill species. Hybridization is a potential problem, at least among congenerics. For example a male rhinoceros hornbill *Buceros rhinoceros* and female great hornbill *Buceros bicornis* at Neopark Okinawa formed a bond despite the presence of conspecifics of the opposite sex, and reared a hybrid offspring (Uehara, 1990 *in* Takaki, 1996). A Jackson's hornbill *Tockus deckeni jacksoni* and African red-billed hornbill *Tockus erythrorhynchus* hybridized in a free-flight aviary at San Antonio in the 1980's. Subspecies need to be identified and kept separately; e.g. Von der Decken's hornbill *Tockus d. deckeni* and Jackson's hornbill *Tockus d. jacksoni* have probably hybridized freely in North American zoos (K. Smith, pers. comm).

An important consideration in housing hornbills with other species is availability of unsuitable food items. It is highly likely that the hornbills will consume items higher in iron than recommended for them if such items are available (see Section 3.1.6: Iron storage disease).

4.2 Temperature

It is suggested for well-studied birds (e.g. chickens, pheasants, ducks and geese) that colder weather (< 15°C) lowers sexual activity. Low temperatures also make it difficult for the female to be able to maintain the appropriate temperature of the eggs during incubation (Anderson Brown and Robbins, 1994).

Although exact tolerable minimum and maximum temperatures are not known for any hornbill species, hornbills almost entirely range between 30° N to 30° S latitude, and experience warm and fairly stable temperatures in their natural environment. Hornbills in open, arid habitats experience greater daily temperature fluctuations than forest species, but nevertheless average temperatures in such habitats are warmer than average temperatures throughout most of Europe, and the air is drier. Like most tropical to sub-tropical species, hornbills will suffer from frost-bite if held in freezing temperatures, and their large casques and bills are particularly vulnerable. It is difficult to factor in the effect of wind, precipitation and humidity into temperature management, nevertheless these parameters certainly do influence how cold it is. The amount of shelter from wind and amount of sun are also important. Age and condition of the birds influence their temperature tolerance.

Managers should strive to duplicate temperature regimes that species are adapted to in their native habitats (see Table 1.A) rather than holding them at the far lower temperatures found throughout much of the northern hemisphere (Table 1.B). It can be seen that annual temperature variation in *in situ* ranges of hornbill genera (Table 1 A) is far smaller than annual variation in Russia and most of Europe as shown in Table 1.B.

If heat lamps are used to provide warmth each hornbill in the enclosure should have one to ensure equal access. Heat lamps should be placed near perches that the hornbills like to use, and checks should be made to ensure that the birds are actually using them. Some bird managers prefer the bulbs that only give heat rather than light, or to direct the radiation from the side of the perch rather than above it, as light, even infra-red light, may be disturbing. It should never be taken for granted that hornbills will use heat lamps or come inside during cold weather. When threateningly low temperatures occur the hornbills should be brought into controlled conditions.

J. Gregson (pers. comm.) pointed out that while it is not ideal to have tropical species outside in near freezing temperatures, there is a balance between keeping birds fit and active and keeping them at ideal temperatures. She proposed 12°C as a bottom temperature for hornbills to stay out for most of the day (but not for prolonged periods), and only allowing hornbills out for short periods between 1°C-12°C.

The hoofstock department at the Rotterdam Zoo developed the following temperature management scheme for tropical species. A similar approach to hornbill management may be useful:

Frost (under 5°C): animals remain inside or come outside for a short period (approximately an hour) if it is not windy or rainy.
Cold weather (10°C to 5°C): animals allowed outside for a couple of hours, or less if windy or rainy. Young animals or animals in compromised condition brought in after shorter periods.
Fair weather (10°C-16°C): outside between 11:00 to 15:00, dependent on other factors.
Good weather (above 16°C): outside the entire day.

Hornbills may be sprinkled with water as refreshment for short periods during the day in warm temperatures.

Table 1. Mean temperatures in January and July and yearly temperature variance for natural distribution ranges of hornbill genera (A), mean temperature ranges in January and July for European locations and yearly temperature variance (B). The temperatures are reduced to sea level. This information was compiled by using Kemp (1995) for hornbill ranges and an atlas (Wolters-Noordhoff, 2001) for temperature data.

Table 1.A

Hornbill genus	**Mean *in situ* temperature range (°C) in January**	**Mean *in situ* temperature range (°C) in July**	**Yearly *in situ* temperature variance (°C)**
Bucorvus	20 – 25	15 – 30	< 5 – 10
Anorrhinus	20 – 30	20 – 30	< 5 – 10
Tockus	25 – 35	15 – 30	< 5 – 15
Ocyceros	10 – 30	20 – 30	< 5 – 20
Anthracoceros	10 – 30	20 – 30	< 5 – 20
Buceros	10 – 30	20 – 30	< 5 – 20
Penelopides	20 – 30	20 – 30	< 5
Aceros	10 – 30	20 – 30	< 5 – 20
Ceratogymna	20 – 30	15 – 30	< 5 – 10

Table 1.B

1) Mean temperature range (°C) in January	Location zone in Europe – up to Moscow
-15 – -10	Zone east of Moscow
-10 – -5	Zone east of Sweden, Poland and Moldavia up to "-15 – -10" range
-5 – 0	Zone east of the Netherlands, France, Italy and north of Greece. Up to "-10 – -5" range. Also coastal parts of Norway and southern part of Sweden.
0 – 5	UK, Scotland, Ireland, Denmark, Benelux, France (except west coast). Inland of Spain, Italy and Turkey.
5 – 10	Coastal areas of Ireland, France, Spain and Italy. Greek Islands, Cyprus, Portugal, Sicily, Corsica.
>10	South of 45° northern latitude
2) Mean temperature range (°C) in July	**Location range in Europe - up to Moscow**
10 – 15	Zone north of mid Ireland and mid Sweden
15 - 17.5	Zone north of Paris, Copenhagen and Helsinki, up to "10 - 15" range.
17.5 – 20	North of 43° northern latitude, up to "17.5 - 20" range
20 – 25	Between 37° and 43° northern latitude
>25	South of 37° northern latitude
3) Yearly Temperature variance in °C	**Location range in Europe - up to Moscow**
10 – 15	UK, Ireland, Scotland, western part of France, Portugal, southern part of Spain
15 – 20	Zone east of Amsterdam and Madrid, up to "20 - 40" zone. Greece, Norway
20 – 40	Zone east of Norway-Berlin. And north and east of Greece

4.3 Light regime

Light regime is relatively constant in natural habitats of hornbills (mainly 30°N to 30° S latitude) compared to light regimes in most of Europe (Table 2). While there is no evidence that photoperiod influences hornbill breeding results, inappropriate light cycles could be a factor in the poor breeding results of captive hornbills in northern Europe. It is known that some tropical birds can respond to very small changes in the photoperiod (e.g. 17 minutes) with dramatic increases in reproductive activity as measured by gonadal growth (Hau *et al*., 1997). A helpful web-site for calculating the natural photoperiod cycle of any particular species is: http://www.saunalahti.fi/%7ejjlammi/sun.php3

Table 2. Minimum and maximum daylight hours at various latitudes. The information was compiled using http://www.saunalahti.fi/%7ejjlammi/sun.php3

Location: North (N) or South (S) latitude	**Minimum daylight hours**	**Maximum daylight hours**
60°	5:53	18:52
55°	7:11	17:23
50°	8:04	16:22
45°	8:46	15:38
40°	9:20	15:02
35°	9:48	14:31
30°	10:13	14:04
25°	10:35	13:42
20°	10:55	13:21
15°	11:14	13:01
10°	11:33	12:43
5°	11:50	12:25
0° (Equator)	12:07	12:07

Ultraviolet (UV) irradiation transforms provitamin D2 and D3 into active D3 and D2 which regulate calcium absorption and release for formation of bones and eggshells (Holsheimer, 1980). Hornbills should preferably have some exposure to natural light for health reasons and their welfare, as they are fond of sunbathing. In northern climates, where hornbills, especially tropical species, should be housed indoors, a sliding roof or sky light window can expose the birds to natural light. If this is not possible broad spectrum sun lamps should be offered so that the birds can bath in the "sun" on the floor and on the perches (Figure 1). Ultraviolet irradiation is only effective within short distances from lamps currently marketed. The lamps rapidly loose ultraviolet irradiation, most being considered ineffective within six months. A study of UV irradiation loss of lamps at Rotterdam Zoo indicated that the rate of loss was variable even between lamps manufactured by the same company. It is necessary to carefully read the instructions on proper use of the lamps, and to monitor how effective the lamps' radiation is over time.

Figure 1 Sunbathing (Kemp, 1995)

4.4 Sprinkling and humidity

Humidity should be similar to that experienced in the natural habitat. Many avian species breed in response to rains, especially arid country birds, therefore the use of showers might trigger reproduction. For example hornbills in Khao Yai National Park in northern Thailand start nest searching at the end of the monsoon (December-January; Tsuji, 1996). Keepers at Rotterdam Zoo and Vogelpark Avifauna (NL) are convinced that sprinkling is stimulating to breeding pairs of bar-pouched wreathed hornbills *Aceros undulatus* and Sunda wrinkled hornbills *Aceros corrugatus* respectively. Data from the EEP Great Hornbill questionnaire (Galama, 1996a) did not show a significant correlation between sprinkling frequency, duration and breeding success of this species. However, institutions with successful breeding pairs sprinkled their birds more frequently throughout the year. It would be useful for zoos with sprinkling-programs in indoor hornbill enclosures or rainy periods in outdoor enclosures to gather data on precipitation/sprinkling in relation to breeding activities.

The fluid stream and other characteristics of a living nesting tree may naturally control humidity and temperature within the nest. The humidity was constantly 90% inside nest cavities studied in Thai forests (P. Poonswad, pers. comm.). Humidity in the upper layer of Asian forests where great hornbills *Buceros bicornis* normally forage is approximately 85% (Ursen, pers. comm.). Maintaining humidity levels similar to those found in natural habitats might positively affect breeding success in captivity, particularly regarding incubation and chick rearing. African hornbill species that live in open, arid environments may not require as high a humidity level as forest hornbills.

Humidity levels can be influenced by frequency and duration of misting sessions. Sprinkling plants and substrate can help to increase humidity. Sprinkling as replacement for rain also gives hornbills (especially those housed indoors) the opportunity to clean their feathers, as "bathing" in rain is not uncommon in the wild.

Good ventilation of the enclosure and nest is very important, especially in humid conditions.

4.5 Indoor or outdoor?

The decision to house hornbills indoors and/or outdoors depends on the geographic location of the institution concerned. Relatively constant conditions, e.g. for light and humidity, are preferred. Hornbills in captivity may survive lower temperatures in northern zoos but as all species in the wild are found between 30° north and 30° south latitude, they are adapted to much warmer temperatures (see Section 4.2: Temperature). We suggest holding hornbills at 18° C or higher. Certainly access to fresh air is desirable when possible, and essentially indoor enclosures can be adapted to allow natural sunlight and ventilation. See also Sections 4.3: Light regime, 4.4: Sprinkling and humidity, and Section 4.7.1: Boundary (roof and wall) materials.

4.6 Dimensions of the enclosure

Elongated enclosures are recommended for large hornbill species, as they need to exercise their wings. The minimal width of the enclosure should be 4 times the wingspan of the species housed in it, enabling the birds to easily pass each other in flight, particularly when young are present. Wing length (of one wing) for most hornbills is provided in Table 2.4 of Kemp, 1995. Sufficient room for flight is necessary for health of the birds; it is believed that not having developed enough muscle and flight ability resulted in traumatic death of juvenile Sunda wrinkled hornbills *Aceros corrugatus* released in a very large enclosure (C. Sheppard, pers. comm).

A minimal enclosure height of 3.0 m is recommended to allow the hornbills to perch above the public and keepers. As forest hornbills in the wild are often found high in, or above, the canopy, it is assumed that the higher the enclosure (and its furnishings) the more suitable the enclosure is.

4.7 Boundary and floor materials

4.7.1 Boundary (roof and wall) materials

The public should be able to view the hornbills on only one or two sides of the enclosure to prevent disturbance. Wooden boarding can serve as boundary material on the non-public sides of the enclosure. Problems in cleaning wooden boarding if placed where the hornbills are likely to defecate needs to be considered. Most hornbill enclosures in Europe have wire-mesh boundaries on at least one side, i.e. the side open to public viewing. Several incidences of fledging chicks flying into the wire and damaging their still-soft bills have been reported. It is possible to make the wire-mesh more visible to the hornbills when the chicks are about to fledge, for example by tying horizontal and vertical wooden sticks to the wire mesh or placing wooden boards/planks outside the enclosure on the viewing side.

The size of the wire-mesh should be small enough that the hornbill's bill cannot pass through it. Some hornbills can alter the shape of the casque and beak, apparently through rubbing, and mesh size should preclude this possibility. It should also be suitable to exclude undesirable animals such as predators and vermin. Hornbills are often kept in enclosures in birdhouses with free-flying passerines outside of their enclosures. There have been many reports of smaller birds being caught by hornbills when the enclosure meshing is large enough to allow the smaller birds to fly into the enclosure.

Care must be taken to choose a suitably strong mesh. Trumpeter hornbills *Ceratogymna bucinator* housed in 14-gauge 0.5 inch (1.27 cm) wire-mesh tore it to shreds (K. Shelton, pers. comm.). Sunda wrinkled hornbills *Aceros corrugatus* systematically opened a 0.5 inch (1.27 cm) galvanized poultry mesh (W. Maynard, pers. comm.).

A vinyl coated-chicken wire proved inadequate to hold a Southern ground hornbill *Bucorvus leadbeateri* at Jacksonville Zoo (D. Bear Hull, pers. comm.).

Sunda wrinkled hornbills *Aceros corrugatus* and bar-pouched wreathed hornbills *Aceros undulatus* have been successfully held in 16-gauge 0.5 inch x 1 inch (1.27 cm x 2.54 cm) wire-mesh, and silvery-cheeked hornbills *Ceratogymna brevis* in 19-gauge 0.5 inch x 0.5 inch (1.27 cm x 1.27 cm) wire-mesh (J. Jennings, pers. comm).

Zoomesh, a knitted stainless steel cloth-like material manufactured in the U.S. is considered a suitable boundary material for birds with a high risk of bill damage that are not chewers (Siebels and Vince, 2001). It has been used with mixed success with hornbills. Zoomesh has been successfully used with Sunda wrinkled hornbills *Aceros corrugatus* at Audubon Park Zoo (M. Meyers, pers. comm.). There were no problems with use of Zoomesh with silvery-cheeked hornbills *Ceratogymna brevis* at Kansas City Zoo, but there were problems with the Zoomesh itself (D. Roberts, pers. comm.). J. Curton (pers. comm.) reported successful use of Zoomesh with silvery-cheeked hornbills and red-billed hornbills *Tockus erythrorhynchus*. A Southern ground hornbill *Bucorvus leadbeateri* systematically destroyed Zoomesh at Jacksonville Zoo (D. Bear Hull, pers. comm.). Zoomesh serves as a barrier between a rhinoceros hornbill *Buceros rhinoceros* enclosure and an adjacent bird enclosure at Riverbanks Zoo, however M. Vince (pers. comm) noted that this would probably not work if perching is available within bill-reach of the Zoomesh.

In general, **not** providing perching near vulnerable boundaries is recommended to prolong appearance and life of the materials Similar to Zoomesh, small mesh nylon netting has been used with mixed success with hornbills. Another possibility is a coiled 3-dimensional “Phantom mesh” which is soft and somewhat flexible. It has been used successfully with Sunda wrinkled hornbills *Aceros corrugatus* but has the disadvantage that the birds can pinch it and deform the structure (E. Kolwalczyk, pers. comm.). Again, providing no opportunities for hornbills to perch near the mesh could help prevent this problem.

Glass is sometimes used as a barrier; precautions need to be taken when young birds are fledging or when hornbills are introduced into the enclosure to ensure that the birds are aware of the glass. Piano wire is rarely a suitable boundary material for hornbills, as hornbills have been known to fly through it and/or to become trapped between the wires. However, piano wire has been used successfully as a partial barrier for a pair of rhinoceros hornbills *Buceros rhinoceros* at Riverbanks Zoo (M. Vince, pers.comm.). In this case the piano wire is in the lower 40% of the enclosure, where the birds seldom descend. Piano wire is used as the enclosure barrier on the public side of great hornbills *Buceros bicornis*, rhinoceros hornbills and Papuan wreathed hornbills *Aceros plicatus* inside the Saint Louis Zoo Bird House and has been used for trumpeter hornbills *Ceratogymna bucinator*. African red-billed hornbills *Tockus erythrorhynchus* easily fly through the wire while large hornbills tend to get the head caught in the wire. In most cases birds quickly learn to avoid the wire, although if upset may fly at or through it (M. Macek, E. Diebold, pers. comms).

It was found in a cross-institutional study of 36 pairs of great hornbills *Buceros bicornis* that "solidness" of the roof was the only environmental feature that correlated with breeding success: the more solid the roof, the more reproductive behaviors were performed by females, resulting in higher reproductive success. Entirely open-topped (thus outside) enclosures were least successful, partially transparent enclosures were more successful than enclosures with entirely transparent roofs (covered by sky lights), and solid roofed enclosures were the most successful of all (Carlstead and Sheppard, in prep.). Further investigation into this trend is certainly needed. Further discussion on lighting is found in Section 4.3: Light regime.

The roof of the outside part of the enclosure should be partially covered to provide weather protection from both sun and rain. Nest boxes and food trays in the outdoor areas should also be placed in covered areas (see also Section 3.1.4: Pseudotuberculosis). Perches should be placed both in covered and not covered areas of the enclosure.

4.7.2 Floor (substrate) materials

An absorbent layer of substrate, e.g. non-treated bark or cedar chips, should cover the enclosure floor, allowing the birds to land smoothly without sliding. Bark chips may also be used as nest lining material: *Ceratogymna* spp. and Indian grey hornbills *Ocyceros birostris* males in the wild have been observed offering sealed-in females pieces of bark. Leaves, stones, and grass are also sometimes offered (Kalina, 1989; Sant, 1995 in Brouwer and Hiddinga, 1996; Kemp, 1995).

Wood bark can become mouldy if damp and should therefore be replaced as necessary. Some plant materials (e.g. some types of bark and leaves) are said to have anti-fungal or antibacterial properties, and their suitability for hornbill enclosure substrates should be investigated. If the floor has a hard surface other sources for nest lining and dust bathing should be offered.

Iron content should be considered in substrate selection as hornbills may actively ingest the substrate or inadvertently ingest it when consuming pieces of food that have fallen to the ground.

Sand is often considered an appropriate substrate to place under food trays, as it is easier to clean then organic substrates. However, because post mortem examination of diverse avian species at Rotterdam Zoo has revealed sand in the stomach of the deceased, the veterinarian has requested that mats rather than sand be placed under food trays. Other zoos may have encountered similar problems.

4.8 Furnishing of the enclosure

4.8.1 Water source

Hornbills do not usually need a water pool for drinking but will drink water if the diet supplies insufficient water. Occasionally hornbills use shallow water pools for bathing. Pools, small streams and waterfalls can add aesthetic value to enclosures and may also be necessary because of public perception. They can also serve as vehicles for environmental enrichment. See also Section 3.4: Environmental enrichment and training.

4.8.2 Vegetation

Vegetation adds aesthetic value to enclosures, provides perching and can create sound and visual barriers (see also Section 4.1: Disturbance). Vegetation can allow hornbills to get out of each other's direct view, which may help reduce aggression. It has been noted at Rotterdam Zoo that both male *Buceros* and *Aceros* hornbills land on a flexible branch of a living tree, grasping the branch with their feet and shaking it. This activity may have a display function or may otherwise serve as an outlet for aggression. Rhinoceros hornbills *Buceros rhinoceros* at Paignton Zoo enjoy bathing in rainwater that collects on the leaves at the flat tops of shrubs in their aviary. For that reason the small leafed fly honeysuckle *Lonicera nitida* was planted (J. Gregson, pers. comm.). Vegetation is also important in humidity control (see also Section 4.4: Sprinkling and humidity).

The enclosure should contain plants of various heights, and outdoor enclosures should have a few taller living trees that serve as shelters. Suggested plants are: Gramineae (e.g. *Arundinaria*), Bougainvilleae, *Ficus, Polygonum, Yucca, Hibiscus, Hedera* and non-poisonous climbing plants, e.g. *Lonicera nitida*. If the vegetation is all planted at the same time (or the hornbills are introduced to a fully-planted enclosure) the hornbills should theoretically focus less on destroying any particular plant.

4.8.3 Perches

Perches should optimize hornbill use of vertical and horizontal enclosure space. Care should be taken to position perches so that the birds' flight path is not obstructed. Placing perches at different heights provides more perching options, and hornbills often jump back and forth between different levels. A stable perch should be placed where the male can extend his wings and has sufficient room above his head to mount the female during copulation. Perches should be fundamentally horizontal in inclination, and variable in size so that the feet and toes are well exercised. Perches that are too small in diameter can result in the foot being punctured by a toenail however. Some of the natural perches should have small, forked side-branches that hornbills can use to clean the inside of their bills.

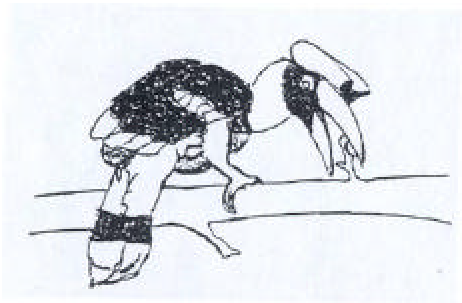


Figure 2 Hornbills need small branches to clean the inside of their bills.

A horizontal perch that reaches the nest entrance allowing the male to feed the female more easily is recommended, as most artificial nest materials are difficult for hornbills to cling to (Kemp, 1995). Perches should allow easy gripping and should by cushioned if the material is solid (pipe) or somewhat flexible to reduce the impact upon landing. Hornbills are quite proficient at removing bark from perches and often hammer perches with their beak. These activities are good sources of enrichment, and possibly help reduce aggressive tendencies but do take a toll on perching.

Thick ropes, attached to the ceiling or to the walls, can serve as additional perches for hornbills. Rope has advantages in that it is not hard or slick. As rope is more flexible hornbills must make an effort to keep their balance, particularly when landing, which is good exercise and serves as a form of environmental enrichment. Ropes need to be replaced on a regular basis, and rot more quickly in a humid environment.

Perches should be strategically placed to discourage hornbills from destroying boundaries and plants, and to minimize the amount of material defecated in food and water sources and on difficult to clean surfaces (some walls and plants).

4.8.4 Nests

Nests should be provided in both indoor and outdoor parts of the enclosure. Nests should be placed in a quiet corner with a visual barrier between the nest and the adjacent enclosure to prevent disturbance (see also Section 4.1: Disturbance).

A roof or screen above nests is recommended to protect the nest from direct sun, rain and misting, and may also encourage breeding (see Section 4.7.1: Boundary (roof and wall) materials).

The distance between the enclosure floor and nest bottom should preferably be more than 1.5 m, in order to give the birds a safe feeling. Generally, the higher the nest the more easily it is accepted by hornbills.

See Section 6.3 for more details on nest box requirements.

4.8.5 Food tray and feeding

Regular hand-feeding of hornbills may have a negative effect on pair-bonding between hornbills, as a hand-fed bird could eventually become more interested in the keeper than in his/her partner (see section 7.1: Human-hornbill interactions).

The food tray should be placed >1.5 m above the ground as foraging on the ground might give hornbills an insecure feeling. Food trays for ground hornbills *Bucorvus* spp. can be placed nearer the ground.

It is preferable for keepers to access food trays from outside a hornbill enclosure as hornbills can become extremely aggressive to keepers when in breeding condition. A perch close to the food tray allows the male and female to feed each other. If not in public view, a wide surface around the feed tray can be very useful in keeping food items from falling to the ground, thus reducing waste and/or inadvertent consumption of the substrate when dropped food items are picked up. Substrate suitability should indeed be considered in placement of food trays. Mats that can be easily replaced and cleaned are a possible option. If natural substrates are used beneath food trays these need to be low in iron in case of possible ingestion when the hornbills pick food up from the ground. Sand is not digestible and is not recommended as it can cause impaction. See also 4.7.2: Floor (substrate) materials.

Food trays that other birds (wild or captive) might defecate onto should be covered to avoid disease transmission. Rodent-proof feeders (free standing, mounted on a pole encircled by a metal “guard” can help prevent food theft and disease spread. See also Section 3.1.4: Pseudotuberculosis and Section 4.7.2: Floor (substrate) materials.

Ideally non-breeding hornbills should be provided with fresh food two times a day (early morning and mid-afternoon), and hornbills with chicks at least three times a day.

4.9 Maintenance

Feeding areas should be cleaned every day so that feces and old, fallen food are not eaten by the hornbills. The rest of the enclosure can be cleaned less frequently and cleaning procedures used should minimize disturbance. Strategic placement of food areas and perches (not close to walls or above plants) can greatly reduce the amount of cleaning time needed.

5 Diet requirements

5.1 Formulation of captive diets

Conclusions on this topic were made during the International Hornbill Workshop 1997 in Malaga (Spain), and were originally summarized by Christine Sheppard.

Development of an optimal diet for hornbills (and other animals) in captivity is hampered by several factors. First, it is virtually impossible to provide birds with diets identical to those they consume in the wild. Second, we rarely know exactly what wild diets are. Even when items consumed are well documented, relative proportions are often not known and may change according to season, year, local variation in abundance and individual preference. Third, it has been well demonstrated that, in addition to the variations just described, there is also significant variation in consumption patterns of different species, and that these reflect differences in levels of nutrients consumed. Information on species "feeding guilds", i.e. how carnivorous and frugivorous each species is, and whether they feed in trees or on the ground is provided in Table 3. "The Hornbills" by Kemp (1995) provides more detailed information on diets of hornbill species in the wild.

Table 3. Assignment of hornbill species to feeding guilds. Assignment of feeding guilds for lesser know hornbills is based on what is known of their diet and by comparison with well-studies species (marked by an asterisk). This table was taken from "The Hornbills (*Buceritiformes*)" by A. Kemp (1995).

Species	**Feeding guild**				
	Arboreal	**Terrestrial**	**Frugivorous**	**Carnivorous**	**Special attributes**
Bucorvus					
B. abyssinicus		+++++		+++++	
*B. leadbeateri **	+	+++++	+	+++++	Digging, grouping
Anorrhinus					
*A. austeni **	+++++	++	+++++	+++	Grouping
A. tickelli	+++++		+++++		Grouping
A. galeritus	+++++	+	++++	++	Grouping, peeling, husks/bark
Tockus					
*T. alboterminatus**	+++++	+	++	++++	Buoyant flight
T. bradfieldi	+++	+++	+	+++++	Digging, buoyant flight
T. fasciatus	++++	++	+++	++++	Buoyant flight
T. hemprichii	+++	+++	+	+++++	Buoyant f light
T. pallidirostris	++++	++	+	+++++	Buoyant flight
*T. nasutus **	++++	++	+	+++++	Buoyant flight
*T. monteiri **		+++++		+++++	Digging
*T. erythorhynchus**		+++++		+++++	Digging, running
*T. leucomelas **	+	+++++	+	+++++	Versatility, running
T. flavirostris	+	+++++	++	++++	Running
T. deckeni	+	+++++	++	++++	Running
T. hartlaubi	+++++	+	+	+++++	Ant -following

Species	Feeding guild				
	Arboreal	**Terrestrial**	**Frugivorous**	**Carnivorous**	**Special attributes**
T. albocristatus	+++++	+	+	+++++	Agile flight
Ocyceros					
O. griseus	+++++	+	++++	++	
O. gingalensis	+++++	+	++++	++	
O. birostris	++++	++	+++	+++	
Anthracoceros					
A. coronatus *	+++++	++	++++	++	Versatility
A. albirostris *	+++++	++	++++	+	Versatility
A. marchei	+++++	++	++++	+	
A. malayanus	+++++	+	++++	+	
A. montani	+++++	+	+++++	+	
Buceros					
B. bicornis *	+++++	+	+++++	++	Peeling off husks/bark
B. rhinoceros *	+++++	++	++++	++	Peeling off husks/bark
B. hydrocorax	+++++		+++++	++	Grouping
B. vigil	+++++		++++	++	Axe -like bill
Penelopides					
P. exarhatus	+++++		++++	++	Grouping
P. panini	+++++		++++	++	
P. manillae	+++++		++++	++	
P. affinis	+++++		++++	++	
P. mindorensis	+++++		++++	++	
Aceros					
A. comatus	++++	++	+++	+++	Grouping
A. nipalensis	+++++	+	+++++	+	
A. cassidix	+++++		+++++		Social, mobile
A. corrugatus	+++++		++++	++	Mobile
A. leucocephalus	+++++		+++++	+	
A. waldeni	+++++		+++++	+	
A. narcondami *	+++++		+++++		Social
A. plicatus	++++	+	+++++	+	Social, mobile
A. subruficollis	++++	+	+++++	+	Social, mobile
A. undulatus *	++++	++	+++++	+	Versatile, social, mobile
A. everetti	++++	+	++++	+	
Ceratogymna					
C. fistulator	+++++	+	+++++		Social, mobile
C. bucinator	+++++	+	+++++	+	Social, mobile
C. cylindricus	+++++	+	+++++	++	Mobile
C. subcylindricus *	+++++	+	+++++	++	Social, mobile
*C. brevis**	+++++	+	+++++	++	Social, mobile
C. atrata	+++++	+	+++++	+	Grouping
C. elata	+++++	+	+++++	+	Grouping

5.1.1 Fruits

While some hornbills, notably the ground hornbills, are mostly carnivorous, the single largest fraction of most hornbill diets is fruit. Fruits consumed by hornbills are significantly denser in nutrients than are domestic fruits available commercially. Hornbills are heavily reliant on figs *Ficus sp.* as a key food source, and figs have been found to be particularly high in calcium (see also Section 5.1.6) and in total nutrient value based on a Fruit Nutrient (FN) index derived using the ratio of pulp mass to overall fruit mass (French *et al.*, 1999).

The factor most important in selection of food items in the wild is local abundance (e.g. Poonswad *et al*. 1998). When formulating the artificial diet it is important to start with nutrient levels appropriate for the species in question. For any given set of nutrient levels, considerable variation in items should be offered.

Type of fruits in wild hornbill diets include:
- soft and fleshy with tiny seeds;
- dry fleshy with single stone;
- hard-shelled fruit which opens when ripe, generally lipid rich;
- fleshy and juicy.

Fruits can offer an additional source of protein in the form of insects that are also feeding on them, and this can be a factor in avian item selection: white-tailed back cockatoos *Calyptorhynchus funereus* feeding on fruits of *Banksia attenuata* have been observed selectively feeding on those *Banksia attenuata* fruits containing the seed-eating weevil *Alphitopsis nivea* (Scott and Black, 1981).

5.1.2 Palatability and familiarity

Palatability of food items offered, iron levels, availability and cost, ease of preparation and the difference between food presented and food consumed must be considered in diet formulation. Different regions differ considerably in the food products available, therefore it is impossible to formulate one diet that can be universally used by all zoos. The emphasis should be on developing affordable and palatable diets with appropriate absolute and relative levels of fat, protein, carbohydrate, vitamins and minerals rather than on trying to obtain particular ingredients. Potential studies on this topic can be found in Section 8.1.1: Dietary issues. Wild fruits relished by hornbills are often considered sour or bitter to humans. Hornbills also prefer smooth-skinned fruits to rough-skinned fruits, and do not peel fruits, they eat them whole. This should be considered when diets are formulated.

Familiarity with food items can greatly influence their acceptability to hornbills. For example, six great hornbills from the other zoos remaining six weeks at a “dating center” at Arnhem Zoo never lost their preference for items that they were fed in their resident zoos (M. Damen, pers. comm.). It is therefore important to give hornbills ample time to adapt to new dietary items.

5.1.3 Colors

P. Poonswad (pers. comm.) noted that Asian hornbills in the wild select fruits which are predominantly red, orange, dark purple/black. Sunda wrinkled hornbills *Aceros corrugatus* at Arnhem Zoo were noted to show a stronger preference for red items when feeding young (Luttenburg and Bisselink, in press). Reddish to blackish fruits may be high in cartenoids, flavenoids and other colored pigments that have been shown to affect plumage and skin color in many bird species. Potential studies on this topic can be found in Section 8.1.1: Dietary issues.

5.1.4 Fiber

Further investigation of wild fruits provides useful directions for possible diet improvement. Field researchers M. Kinnaird and P. Poonswad have noted that fiber content of Asian hornbill diets is far higher than in captive diets, and suggested that fiber in captive diets should be increased (Sheppard and Worth, 1997). A low amount of insoluble fiber may provoke a tendency towards watery feces. Increasing dietary fiber has proven beneficial in some cases with other birds. Addition of ground chitin or wheat bran improved feces of rollers and bee-eaters at the New York Bronx Zoo and allowed the bee-eaters to show normal casting behaviors when kept on a non-insect diet. A pheasant that consistently plucked its own feathers stopped the behavior when fiber was added to the diet.

P. Poonswad (pers. comm.) noted that many fruits eaten by hornbills contain large pits/seeds that the hornbills regurgitate, and that this behavior may be important for healthy functioning of the hornbill digestive system. Uncured olives might serve as replacement for wild seeds, however, the nutritional value of olives has to be evaluated.

5.1.5 Protein

A study on nitrogen requirements of captive *Aceros* (three species) and *Buceros* (two species) hornbills was carried out at the Wildlife Conservation Society. It was found that the hornbills could maintain body mass on a diet containing 10.8% crude protein (4 Kcal/g dry matter). The results also suggested that *Aceros* and *Buceros* hornbills have similar nitrogen requirements. More work needs to be done before these values can be verified (Foeken and de Vries, 2001).

Amount of animal matter increased in diets during chick rearing in the four species of hornbills studied by Poonswad *et al*. (1983; Figure 3) and in Malabar grey hornbills (Mudappa, in press). Managers often note that captive hornbills also consume large quantities of animal matter during chick rearing, presumably to fulfil protein dietary requirements of the chicks. Poonswad *et al*. (1998) observed that animal matter fed included many different vertebrates as well as invertebrates, however centipedes and cicadas were preferred. Invertebrates are recommended for sources of animal food, as even though they provide few minerals they are also generally lower in iron than vertebrate protein sources (insects: 30-100 mg/kg DM, vertebrate prey 50-250+ mg/kg DM, Dierenfeld and Sheppard, 2000). Necessary minerals can be supplemented.

5.1.6 Calcium

Calcium and magnesium are important constituents of bone, eggshells and muscle development. Calcium combined with phosphorus plays a role in fat and carbohydrate metabolism. Many hornbill species in the wild eat figs *Ficus* spp. that are available throughout the year and contain high levels of calcium, for example 427 mg per 100 g fruit (Poonswad *et al*., 1988), which suggests that a high calcium intake may be important for hornbills. Kinnaird and O'Brien (1997) found that figs eaten by Sulawesi wrinkled hornbills *Aceros cassidix* are a particularly good calcium source. An imbalance of the available calcium, vitamin D or the ratio of calcium to phosphorus can disturb calcium absorption into the serum from the gut and calcium resorption from the bones. If calcium or phosphorus is in surplus, the availability of the other decreases. Calcium deficiency can also be a result of primary diseases of kidney, liver and intestine or a protein deficiency (Fowler, 1986).

The calcium:phosphorus ratio should be between 1:1 and 2:1. Supplementation of Vitamin D should be in the form of Vitamin D3, and supplementation of calcium and phosphorous in the form of calcium phosphate (tribasic). If this is not available Calcium phosphate (dibasic) can be used (Fowler, 1986). Snail shells could also be offered as a natural calcium source. See also Section 5.3: Diet suggestions.

5.1.7 Iron

Iron storage problems are discussed in Section 3.1.6: Iron Storage Disease. The amount of dietary iron that birds receive is believed to play a role in iron storage disease, therefore it is important to keep the amount of dietary iron as low as possible. While it is has not been firmly established just how low iron should be in diets of iron storage disease-susceptible birds, most experts agree that lower than 100 mg/kg DM is advisable, and even below 50 mg/kg DM is recommended (G. Dorrestein, pers. comm.). Invertebrates, lower in iron than rather than vertebrate prey, can serve as a source of animal matter (see Section 5.5: Protein). Dietary items rich in Ascorbic acid (vitamin C), e.g. citrus, berries, tomatoes and greens, should be minimized as vitamin C enhances iron bioavailability.

Dierenfeld and Sheppard (2000) recommend a level of approximately100 mg/kg DM Ascorbic acid in the diet. Vitamin and mineral supplements should be low in iron. Iron interacts with some other minerals, however these interactions are not well understood at this time. As mentioned in Section 3.1.6, some zoos are now feeding tannins to irons to iron storage susceptible birds.

5.1.8 Enrichment of the standard diet

Some items in the standard diet can be offered in a variety of ways to increase foraging behavior. For example a bunch of grapes hanging in the enclosure in a difficult place to reach (Galama and Weber, 1996), or a mealworm dispenser hanging on a perch (Shepherdson *et al.*, 1989; Galama and Weber, 1996), will provide hornbills with some attractive challenges. Seasonal fruits can also be offered as food enrichment (see also Section 3.3: Environmental enrichment and training).

5.2 Diet changes during the breeding season

Nutrition may be a psychological or physiological trigger for reproduction. For some birds, e.g. many waterfowl, dietary protein levels often increase at the beginning of the breeding season. P. Poonswad (pers. comm.) noted that the rainy season in Thailand is followed by a short dry season or drought, which is then followed by hornbill breeding. The hornbills increase their intake of lipid-rich fruits when these fruits become more abundant just before the breeding season. For example, fruits from the family Lauraceae are eaten by great hornbills *Buceros bicornis* in India (Kannan and James, 1998). An increase in dietary lipids could also be important for females in marginal condition at the beginning of the breeding season. Intake of animal matter, including Diplopoda (millipedes), other invertebrates, reptiles, birds and mammals, increases when hornbills are feeding young (Poonswad *et al.*, 1983; Figure 3).

An increase in dietary lipids and/or protein may be stimulatory to captive hornbills. Diet changes should be introduced one month before the expected start of the breeding season, which is dependant on housing conditions and geographic location of the institution, to optimally prepare hornbills for breeding. Hornbills may not easily accept new food items (see Section 5.1.2: Palatability and Familiarity) and it is also helpful for pairs to acclimate to unfamiliar items that will become part of the chick-rearing diet, such as animal food and possibly the gelatin "cake" (see Section 5.3.3: Gelatin “cake”), before breeding starts.

Animals containing chitin (e.g. mealworms, crickets), hair or feathers (e.g. one-day-old chicks) should preferably not be offered to very young hornbills**,** as these food items can obstruct the gullet or the gut, resulting in death. Young hairless mice (“pinkies”) are more digestible. Boiled meat, e.g. fillet of chicken or turkey, can be offered as an ingredient in gelatin "cake" that is easier for chicks to swallow.

The total amount of food should be increased according to the demands of the male, and as observed by his food preferences when he is feeding the female and the chick(s). Changes in food consumption during the breeding cycle of great hornbills *Buceros bicornis* at a study site in Thailand are illustrated in Figure 3.

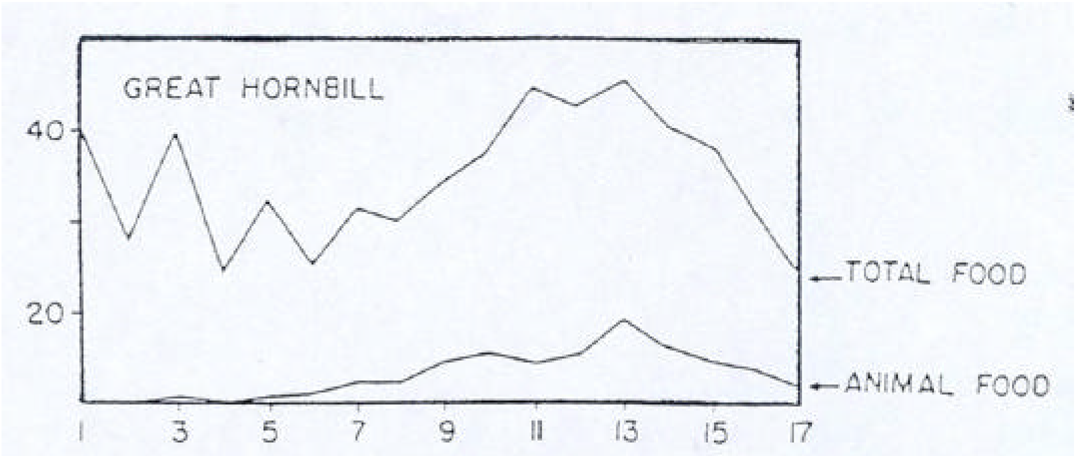


Figure 3 Average weekly food consumption rate during the breeding cycle of *Buceros bicornis* at Khao Yai Park (1981-1985). (Poonswad *et al*., 1987). X-axis: weeks, Y-axis: food items.

Week 1: The female is sealed in properly.
Week 7: The approximate hatching time.
Week 17: The chick leaves the nest.
The total food amount increases when the chick has hatched and declines again as the female leaves the nest to help the male feeding the chick.

5.3 Diet suggestions

Items that are frequently available to zoos are listed by food type in Section 5.3.1. These can be combined to provide a varied diet. It is important to have items in the diet that hornbills can pass back and forth to each other and that males can feed to the female, as these activities are important pair-bonding and bond-maintenance behaviors (Kemp, 1995).

5.3.1 Food items

As it is virtually impossible to provide hornbills in Europe with the same fruits and prey available in the wild we have compiled a list (Table 4) of food items that may be easier to obtain and are nutritionally similar. Also see Appendix 11.E for diets used in a number of zoos successful in parent-rearing hornbills.

Table 4. Food types and food item suggestions for captive diets

Food types	Items
Water rich fruits	Apples, pears, tomatoes, oranges, currants, cherries, grapes, pineapple, apricots, kiwi fruits, strawberries, plums, papayas
Lipid rich fruits	Soaked sultanas, avocado, juniper-berries, dates, rosehips, mountain-ash berries Or: sesame seed oil, palm oil, olive oil
Carbohydrate rich fruits and selenium	Bananas, passion-fruits
Germinated seeds/grain	Maize, lentil, beans
Vitamin and mineral supplements	The iron-, and heavy metals content should remain as low as possible. Calcium supplement: for example cuttle fish bone, high-calcium limestone, bone meal, egg shells
Animal food	Minced low fat beef, lean poultry, crushed boiled egg, mealworms, crickets and other insects, one-day-old mice, one-day-old chicks
Produced food	Whole grain bread

5.3.2 Manufactured diets

Manufactured diets, particularly in the form of pellets, are becoming increasingly popular in formulation of diets for captive birds. Particular attention is being given to the need for low-iron diets. Often a combination of fruits, vegetables and other items are mixed with the manufactured diet.

Seibels and Vince (2001) listed several larger pellets available from zoo diet manufacturers considered suitable for toucans (and presumably similarly suitable for hornbills): Red Apple Jungle Pellets (Marion Zoological), Exact Low Iron Pellets (Kaytee), Softbill Fare (Reliable Protein), Bird of Paradise Pellets (Zeigler Brothers) Bird of Paradise Pellets (Zeigler Brothers), Low Iron Maintenance Diet (Harrison), and a smaller pellet: Tropical Bits (Marion Zoological). Some caution needs to be applied when calculating total diet nutritional composition using the manufacturer's data, as it has been found that nutritional levels of manufactured diets are sometimes not the same as stated on the label. In constituents such as iron in which only small amounts should be used, this can be critical.

5.3.3 Gelatin "cake"

Some hornbills will not eat all items in their diet: for example the vitamin and mineral supplements could remain in the food tray. Hornbills often also waste much food by throwing it out of the tray. To avoid these problems some diet constituents (vitamin and mineral supplements, chopped food etc.) can be offered as ingredients in a gelatin "cake" (Bataille, 1996). Small blocks of this cake can be offered as a part of the standard diet.

During the beginning of the chick rearing period boiled chicken or turkey fillet can also be mixed into the cake, as the gelatin makes it easier for small chicks to swallow the meat. As mentioned previously, it is advisable to introduce the gelatin cake to the parents before chicks hatch to increase the parents' acceptance of the cake if it is not fed year-round.

Preparation of a gelatin "cake"

- Dissolve 8 spoons of gelatin powder in 1 liter boiling water.
- Remove pan from heating unit when all the gelatin is dissolved.
- Add the other* ingredients to the hot gelatin water and stir 5 minutes until the mixture becomes thick.
- Pour the mixture into a "Tefal" layer, 20 cm diameter spring cake pan
- Put the gelatin cake in the refrigerator to harden.
- After 1 day the cake can be cut up in blocks of 1.5x1.5x1.5 cm.

* other ingredients could be pieces of meat (for easier swallowing by chicks), fruit, vitamin and mineral supplements or other diet components that the hornbills for whatever reason do not consume otherwise.

6 Reproduction

6.1 Nesting cycle preparations

Some hornbill managers suggest that a lack of synchrony in the physiological and psychological reproductive condition of pair members may be a problem in reproduction of many pairs. While more data are needed to evaluate their success, some zoos are experimenting with management practices to synchronize hornbill pair members.

Some managers move hornbills to another enclosure during the non-breeding season, returning them to the breeding enclosure a couple of weeks before breeding is anticipated. There is some evidence that this can indeed be stimulating, for example for a pair of great hornbills *Buceros bicornis* at Vogelpark Avifauna in the Netherlands. However in other cases, such as for Papuan wreathed hornbills *Aceros plicatus* and great hornbills at Rotterdam Zoo, temporary housing in another enclosure made no difference in the first year that this technique was tried. Certainly though it is a technique worth further exploring, and is easily carried out if multiple hornbill pairs with similar enclosure requirements are housed at the same zoo, so that pairs can just be shifted.

Dietary lipids and protein are also increased and sprinklers regularly turned at some zoos approximately a month before the expected hornbill breeding season.

Some managers remove the nest during the non-breeding season and then put it back into the enclosure just prior to the anticipated breeding season, or make the nest inaccessible until reproductive activities such as increased vocalizations begin occurring (Ellis, in press; Scheres and Alba, 1997; H. Michi, pers. comm.). The nest is normally refurbished just prior to the expected breeding season.

A schedule of preparatory activities and some events relevant to hornbill reproductive management used at Audubon Park Zoo are provided in Appendix 11.F.

6.2 Breeding behavior

In addition to optimal climate, food resources and photoperiod, psychological factors such as courtship rituals, a firm pair bond and territorial display may be of great importance in stimulating the development of the ovary and testes at the beginning of the breeding season (Anderson Brown and Robbins, 1994). Frequency, duration and intensity of calls and displays of hornbill pairs increase prior to breeding. Some species also exhibit an intensification of facial soft-part coloration as the breeding season approaches. Rate of allopreening and allofeeding increases and become directed by the male towards the female (Kemp, 1995). The female selects and begins preparing the nest, with the male following her closely. The female begins entering the cavity and remains there for increasingly longer periods, while the male feeds her. A number of hornbill species at least sometimes have cooperative breeding systems in the wild in which helpers also feed the female and later the young (Kemp, 1995; see Chapter 7).

Heavy allopreening forces the female to crouch so that copulation can take place, generally close to the nest. Although hornbills may dabble at sealing the nest entrance for some time, serious sealing of the nest opening is normally accomplished in a few days. *Bucorvus* hornbills are the only hornbills that do not usually seal the nest entrance. Egg-laying is usually initiated 4-6 days after the female is sealed-in but a period of 24 days before laying of the first egg has been recorded. Females are quite sensitive to disturbance during the pre-laying period and may abandon the nest if disturbed. The female and later her chicks defecate through the nest opening and toss remains of food brought by the male out of the cavity. These behaviors help to keep the nest free of infectious materials. Females generally leave the nest to help their mates forage when the young are almost adult-sized, in order to supply the chicks with sufficient food. The chicks follow her or reseal the nest until they can fledge safely (Kemp, 1995).

Some reproductive data important in captive management of hornbills are presented per genus in Table 5. This information was extracted from Kemp (1995). Some of the time ranges seem quite broad, and in some cases no data are available. Incubation periods for several species of hornbills at Audubon Park Zoo are quite consistent (Appendix 11.F). Entire incubation time can be extensive in species that lay larger clutches: a inter-laying interval of 3 days was recorded between four eggs of Von der Decken's hornbills *Tockus deckeni* and hatching was asynchronous, with eggs hatching after 24 days incubation (Smith, 2002). There is a sixteen day age difference between the oldest and youngest of four Malay black hornbills *Anthracoceros malayanus* being parent-reared at London Zoo in 2002 (J. Ellis, pers. comm.). Hopefully more data from closely monitored nests in captivity can be compiled to calculate average time periods and standard deviations for these time ranges.

Table 5. Some reproductive parameters for different hornbill genera

Species	**Largest clutch size**	**Incubation period in days**	**Nestling period (from hatch to leaving nest)**	**Female in nest (days)**	**Age (years) ***
Bucorvus	2-3	37-41	80-90	70+	2-3/ 4-6
Buceros	2-3	37-46	72-96	86-134	4-5
Aceros	2	29-40	63-92	113-137	3
Ceratogymna	2-4	28-42	50-80	107-132	?
Anorrhinus	2-5	30	62	92	2
Anthracoceros	2-4	25-29	42-55	48+	2
Penelopides	2-5	?	95	?	?
Tockus	2-8	23-27	39-55	42-69	1-2
Ocyceros	3-5	29	?	?	?

*: Age of reproductive maturity (years)

Hornbill females will sometimes remain sealed in the nest for extremely long periods even if the eggs do not hatch, and this may be detrimental to their health. Attention should be paid to how long the female is in the nest and a decision made whether to open the nest seal if the female remains sealed in for a long time with no signs of young present.

Behavior of the male will often give some indication of whether chicks are present or not. Chicks are probably not present if the male continues to feed the female but does not show additional interest in the nest, does not increase feeding frequency and does not alter selection of food items, as more animal matter is usually fed when chicks are present. One month plus the incubation period is a time frame to consider using before intervening if the nest cannot be easily inspected, chicks are not heard and the male's behavior has not indicated presence of chicks. Interventions should always be cautiously undertaken.

It is in most cases desirable to open the nest-seal if the eggs are known to be infertile or broken, or chicks are no longer heard. Hornbills often recycle after approximately a month if either the eggs or chicks are lost from the first clutch (Primm, 1996). Some hornbills, such as *Penelopides* sp. at Raritatenzoo Ebbs (Meier, in press) may even rear two broods in one season. Often some reproductive activities will be performed for a time by the parents after the chicks fledge or a clutch is lost even if renesting does not occur. Frequently seen activities include copulation, nest plastering and nest lining.

6.3 Nest

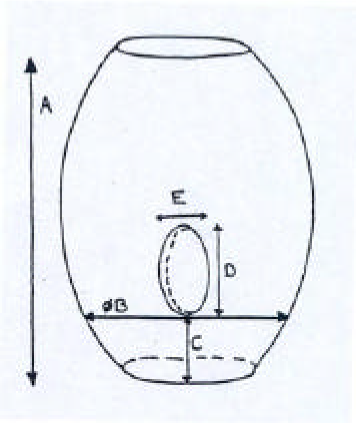
The nest and nest-related behaviors are considered extremely important in breeding success of hornbills, thus the nest receives considerable attention in these guidelines.

6.3.1 Type of nest and nest material

While recommendations regarding which type of nest is best vary, generally wooden nest logs and wooden nest barrels (round shaped) seemed to be more successful than rectangular wooden nest boxes in a survey of great hornbill *Buceros bicornis* reproductive success (Galama, unpubl. data). Nests that are outside should be protected from weather. A roof can be placed overhead (see also Section 4.7.1: Boundary (wall and roof) materials). A slanted roof on the nest itself allowing rainwater to run off was felt to be important in breeding successes at Jurong Bird Park (Khin *et. al*., 1997).

Managers should strive to incorporate natural nest characteristics that could be important in breeding success. For example, pieces of bark can be nailed to the outside and/or inside of the nest box so that the hornbills can scrape them off and use the shavings for plastering. Studies of nests in the wild indicate that characteristics of the nest, e.g. entrance and cavity shape and the (usual) presence of a funk hole are important in nest ventilation and probably also nest temperature and humidity regulation (A. Kemp, pers. comm.).

The thickness of the nest walls is important: thicker walls facilitate maintenance of stable humidity (and presumably temperature), and a thicker opening is easier to seal, a minimum of 3 cm is recommended by A. Kemp (pers. comm.).



A =	height
ØB =	diameter (log or barrel)
B1=	length (box)
B2 =	width (box)
C =	bottom box-lower side opening
D =	height opening
E =	width opening

Figure 4 Artificial nest with important features.

6.3.2 Inside measurements

Important nest features are illustrated in Figure 4 and suggested measurements are given in Table 6 for various hornbill taxa. The inside diameter (Figure 4: B) of an artificial nest box should be large enough for the female to turn around in but not so spacious that the female "looses track" of her eggs. There have been reports of hornbill females sitting next to, rather than on, eggs, particularly if the female throws the lining out of the nest so that there is no natural depression (see Section 6.3.8: Camera monitoring of nests for an example). Should there be an indication that this is occurring, a material that is not easily removed can be used to reduce the internal dimensions of the nest bottom and to give it a a concave form to help keep the eggs in the center.

The space in the nest above the entrance area functions as a hiding (escape) area for the female and allows air-circulation (Kemp, 1995; pers. obs.). The ultimate height of the nest box (Figure 4: A) depends on the size of the hornbill female (Kemp, 1995) and ideally should be approximately the same length as the female. For example, an average female great hornbill *Buceros bicornis* is 120 cm from the tip of the bill to the end of the tail feathers.

6.3.3 Dimensions of the nest entrance

Important nest entrance features are illustrated in Figure 4 and their measurements are given in Table 6 for various hornbill taxa. Hornbills are possibly best known for their habit of sealing the nest opening; only the *Bucorvus* species do not regularly practice this habit: they usually prefer a large savannah tree-stump from which the female can emerge to forage and defecate (Kemp, 1995). Kemp (1995) also provides a diagram of a artificial nest illustrating important points.

Dimensions of the nest entrance are of great importance for most hornbill species; they prefer an oval, elongated entrance (Poonswad *et al*., 1987). Shape of nest entrances used by four hornbill species in Thailand are shown in Appendix 11.G. A small entrance helps to keep intruders out and is easier to seal (see Section 6.3.4: Plastering the nest opening). The entrance does not have to be much wider than the width of the female from shoulder to shoulder when the wings are drawn in (Kemp, 1995). This is approximately 15 to 17 cm for the larger Asian hornbill species (Poonswad, 1994). The mean width of 32 great hornbill *Buceros bicornis* nest entrances in Thailand was 13.5 cm (range 7.4-25.5 cm.) and mean length of the entrance 40.5 cm (range 14.8-71.6 cm). The bottom of the nest entrance was 0- 7 cm from the nest floor (Poonswad *et al*., 1988).

The width of the opening (Figure 4: E) should be the width of the shoulders plus 10%. The floor depth (Figure 4: C) should be sufficient to allow the female to add lining material to the nest floor, e.g. wood shavings and leaves. The female and the chick(s) must be able to reach the opening to defecate through the entrance so that the nest remains clean. If the nest entrance is quite long (Figure 4: D), almost to the bottom of the nest box, the female can plaster the entrance to the height (from the bottom of the nest box) that she wants to close the nest entrance.

The thickness of the wall next to the opening should be 3 cm or more, otherwise the sealing material may fall out of the entrance (A. Kemp, pers. comm.).

Table 6. Suggested measurements for artificial hornbill nest features illustrated in Figure 4 for some hornbill taxa, based on mean taxon size (weight).

Species	**Weight (g)**	**Measurements (cm)**						
		A	**ØB**	**B1**	**B2**	**C**	**D**	**E**
Tockus spp.	80-160	30	20	20	20	5	15	5-10
Tockus spp., *Ocyceros* spp., *Ceratogymna f. fistulator*	161-320	50	20	20	20	5-10	15	5-10
Tockus spp., *Penelopides* spp., *Ceratogymna* spp.	321-640	70	30	30	30	10	20	10
Anorrhinus spp, *Aceros* spp., *Anthracoceros* spp., *Ceratogymna* spp., *Buceros hydrocorax*	641-1280	90	50	50	50	10	25	14
Buceros spp., *Aceros* spp.	1281-2560	130	60	60	60	15	>35	17

6.3.4 Plastering the nest opening

Hornbills, predominantly the female in some hornbill species, may occasionally plaster the nest entrance (or other crevices in the enclosure) throughout the year. However, when the female is determined to enter the nest for 3 to 4 months, the entrance will often be sealed in just a few days. Only a small slit of approximately 5 cm (possibly 2 cm in smaller hornbill species) will normally be left open.

Only the *Bucorvus* hornbills do not seal their nest opening in the wild (Kemp, 1995). Plastering the nest opening until only a small slit remains is thought to be very important to the chick's survival. Tsuji (1996) observed Tickell's brown hornbill *Anorrhinus tickelli* chicks being killed by a predator after they failed to re-seal the opening soon after their mother left their nest in Khao Yai National Park in Thailand. The female usually stays in the nest until the chicks fledge in three species nesting in Khao Yai: Tickell's brown hornbill, Papuan wreathed hornbill *Aceros plicatus* and Asian pied hornbill *Anthracoceros a. albirostris*. The great hornbill *Buceros bicornis* is the only one of the four hornbills nesting in the park in which the female leaves the nest prior to chick-fledging to help the male forage. Tsuji (1996) suggests that this may be why of the four species only great hornbill chicks seem to have the instinct to re-seal the nest.

Kalina (1989) studied nesting behavior of grey-cheeked hornbills *Ceratogymna subcylindricus* in Uganda, and concluded that sealing in of the female of this species primarily serves to deter conspecifics from usurping the nest cavity. Kalina also observed that male grey-cheeked hornbills usually performed a nest sealing display after defending the nest against conspecifics.

How much involvement the male has in nest preparation and sealing seems to be very individual- per pair, but also per breeding cycle- both in the wild and in captivity. A comical situation was created once when a male and female bar-pouched wreathed hornbill *Aceros undulatus* at Rotterdam Zoo sealed the entrance so zealously from inside the nest that the male was also trapped inside. The birds had to break the entrance open so that the male could provide sustenance for himself and his mate.

The defensive sealing behavior may not be as easily stimulated in captivity where there usually is a lack of predators and/or nest-site competitors, and/or where there are difficulties in sealing the nest. White-crowned hornbills *Aceros comatus* and Sulawesi wrinkled hornbills *Aceros cassidix* have been observed to be particularly 'poor' sealers in captivity. Successful breeding of hornbills in captivity has occurred when hornbills have not sealed the nest at all, or have sealed it incompletely, and when males entered the nest regularly. However, males entering the nest has been reported in several cases to be clearly disturbing, such as in the first breeding attempt of great hornbills *Buceros bicornis* in Arnhem Zoo in 2002 (W. Schoo, pers. comm.). We recommend that hornbills be encouraged to seal the nest by offering an appropriate nest opening and sealing materials.

M. Kinnaird (Sheppard and Worth, 1997) found that sealing material of great hornbills *Buceros bicornis* largely consisted of their high-fiber fecal material (see Section 5.1.4: Fiber), compared to captive hornbills, which frequently plaster the entrance with sticky, soft food items. Kinnaird and O'Brien (1997) noted that figs in the plastering matrix of Sulawesi wrinkled hornbills *Aceros cassidix* function as limestone gravel in concrete. Items such as bananas, figs, boiled (not too soft) potatoes, boiled yam, soaked Bird of Prey diet and minced meat are used in captivity. Mud, pottery clay, riverbank clay and the hornbills' own (relatively low fiber) feces have also been mentioned in breeding reports. Elephant and horse feces, soil, saw dust, straw, peat, insects (cockroaches and bumblebees) have been worked into sealing mixtures by hornbills, and do provide fiber. Materials placed in the nest can serve for plastering as well as lining materials (see Section 6.3.5: nest lining). Each pair may have its own preferences, and offering a variety of potential plastering materials could stimulate nesting activity. If the nest entrance is appropriate in form and thickness and sealing material falls out of the opening, other materials should be offered.

The shape and size of the nest entrance can greatly affect the hornbills' ability to seal the nest. The larger the opening the more difficult sealing it is. A square or rectangle nest opening is more difficult to seal then an essentially diamond or oval shaped opening. Shape of nest entrances used by four hornbill species in Thailand are shown in Appendix 11.G. A thin material is more difficult than a thick one (minimally 3 cm wall thickness is recommended). Straight edges are more difficult to seal than uneven edges and smooth edges more difficult than rough edges (A. Kemp, pers. comm.). Hemp rope has been attached to the inner edge of the nest opening at some zoos, including Audubon Park Zoo (Reilly, 1988; Uzee Sigler and Myers, 1992), to provide anchorage when plastering materials could not adhere to the nest opening. Attaching extra wood around the entrance to make it thicker has also worked in some cases.

6.3.5 Nest lining

Both males and females bring lining to the nest, and males may continue to do so after the entrance is sealed. Nest lining can help to control nest humidity, and provides a soft substrate and a means to sanitize the nest through removal of soiled material. Nest lining can be adjusted by the female and young to raise or lower the height of the cavity. Some species prefer a moist lining, such as green leaves and grass, while others prefer dryer materials, e.g. bark flakes and dry leaves. Some materials may have anti-parasitic and anti-pathogenic properties, but this must be tested (Kemp, 1995).

Hornbill managers at Audubon Park Zoo have a schedule for changing the nest substrate a couple of weeks before breeding of a given species is anticipated (Appendix 11.F). The substrate used at Audubon Park Zoo for all the hornbills is a combination of approximately equal portions of moist potting soil, wood (pine) shavings and sphagnum moss. Enough potting soil is added that the mixture holds together fairly well when compressed in the hand. The lining is thought to be quite important to general health survival of the chicks.

Problems with the lining becoming too soiled and damp have been observed in a rhinoceros hornbill *Buceros rhinoceros* nest at Audubon Park Zoo when the substrate level was too low and/or the fecal load very high (Meyers, in press; M. Meyers, pers. comm.). Wood shavings for lining and plastering materials are also used at some zoos.

It has been noted that some females throw all the nest material out of the nest. Other lining materials could be tried, and if these are not accepted it may be necessary in some cases to adapt the nest to enable the female to better incubate eggs (see Section 6.3.2: Inside measurements).

6.3.6 Nest humidity and temperature levels

Very low humidity levels may cause embryonic death or kidney failure in chicks. However, high humidity can result in chicks that appear oedematous and/or have an open umbilicus or exposed yolk sacs (Fowler, 1986). Most Asian hornbills nest in living trees in the upper layer of the forest where the average humidity level is 85%. The fluid stream and other characteristics of the nest tree may control the nest humidity level. Inside nest cavities studied in Thai forests the humidity is constantly 90% while the humidity fluctuates more outside the nest (Poonswad, pers. comm.). A similarly high humidity is recommended for tropical to semi-tropical hornbills in captivity but suitable humidity might be lower for species adapted to arid habitats.

Nest temperatures are also more stable than ambient temperatures in the wild (Kemp, 1995). A study of great hornbill *Buceros bicornis* artificial nest environments indicated that stability of internal nest temperature is also a characteristic of successful nests in captivity. Another study of this species found that the low-temperature of successful nests was higher than the low-temperature of unsuccessful nests in captive environments in the northern hemisphere (Sheppard and Worth, 1997).

Hornbills in captivity nest in dead tree logs and wooden boxes so that the inside humidity level is more heavily influenced by the outside humidity level, and temperature regulation is more difficult. The thicker the nest walls the more stable the nest temperature (Sheppard and Worth, 1997). Choice and amount of nest lining can influence nest humidity (see Section 6.3.5: Nest lining). Nest humidity is also influenced by enclosure humidity, which in turn is influenced by sprinkler or rain cycles, amount and type of vegetation and substrate. (See also Section 4.4: Sprinkling and humidity, and Section 4.7.2: Floor (substrate) materials). Great hornbills *Buceros bicornis* did not hatch at the Rostock Zoo if left with the mother throughout the incubation period, but only if removed for artificial incubation one week prior to hatching, until keepers began monitoring the moisture content of the nest material by feeling it. The keepers added warm water to the material every two or three days when it became dry, increasing the moisture content of the material markedly, and thereafter the eggs hatched naturally (H. Nehls *in litt*. to P. Robertson, 6 December 1985).

6.3.7 Inspection door and observation devices

While the editors of these guidelines believe that breeding hornbills should be left alone as much as possible, there are certainly times when nest inspections or some form of intervention are desirable. It is highly recommended that an inspection door be fashioned at the backside of the nest box so that the inspection door can be opened to clean the nest, to remove eggs or young and to observe the female and her brood as appropriate. The door should be positioned at the height of the nest entrance, assuming that the entrance is not too high (see section 6.3.3: Dimensions of the nest entrance). The door should be fairly large (approximately 15 cm X 20 cm) so that even older chicks can be removed if necessary. The door should shut perfectly to avoid droughts, incoming light and opening by the female. Cuts to make the door can be angled inward to ensure that light will not come through the opening. Females may pound on the door and unless very well fastened, the door may open (e.g. Meyers, in press). For this reason Khin *et al*. (1997) recommended using a sliding door.

Some hornbill managers (e.g. at Audubon Park Zoo and San Diego Zoo) that are quite successful with hornbills do routinely check hornbill nests (M. Mace and M. Meyers, pers. comms.). Nests at Audubon Park Zoo are checked every couple of days until egg laying is completed and then less frequently but regularly once hatching is expected. Nest inspections are made once or twice a week once chicks have hatched. One person distracts the female with a stick at the nest entrance while another person looks through the inspection door. The inspection door entrance is shrouded with a blanket, and a flashlight used to spot the eggs (M. Meyers, pers. comm).

Presence of chick(s) inside the nest box can be observed with an investigation tube with a 45° angle (Mace, pers. comm.), as described below in Figure 5, or by holding a stethoscope to the wall to hear chick sounds (Euing, 1995). A microphone mounted in the nest out of reach from the hornbills can enable hornbill managers and possibly visitors to monitor vocalizations and other sounds made within the nest. The speakers should be a good distance from the male so that he does not become confused.

A video surveillance system provides a non-invasive monitoring method that yields much information. If nest images are also viewable by visitors, the system also provides a wonderful educational tool. Lieras (1983) provided a description of the video arrangement used to monitor a Luzon tarictic hornbill *Penelopides manillae* nest at San Diego Zoo and of observations made. Smith (2002) found monitoring equipment surprising inexpensive: the entire surveillance system to monitor a pair of Von der Decken's hornbills *Tockus deckeni* at Oklahoma City Zoo, including two cameras, a monitor and all the necessary cables was US$ 90. See Section 6.3.8: Camera monitoring of nests for a description of video monitoring experiences at Chester Zoo.

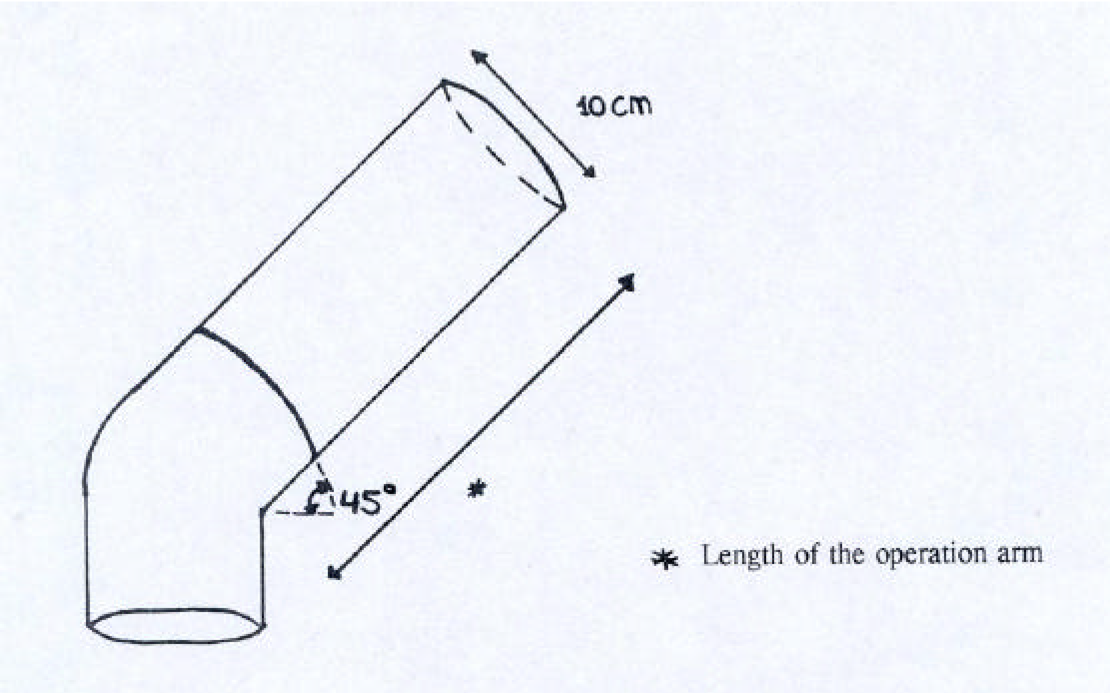


Figure 5 Nest Investigation Tube (San Diego Wild Animal Park)

Materials/measurements
PVC-tubing wide and long enough to accommodate the investigator's arm is used. The tube is bent to a 45° angle towards the far end.

How to use the Investigation Tube
Keep the observation opening dark by adequately covering the nest box with a black cloth before opening the observation door. Open the observation door and insert the tube so that the far end of the investigation tube rests on the bottom of the nest box. Look into the tube using a flashlight to see what has been "captured" by the investigation tube.

The tube allows the investigator to clearly see the nest contents without disturbing the female with presence of light. It also reduces the chance of the female accidentally breaking an egg or stepping on a small chick during inspection. The tube can also be used to remove eggs and/or chicks when necessary.

6.3.8 Camera monitoring of nests

By Roger Wilkinson, Chester Zoo

Small, commercially available nest cameras were fitted in four hornbill nest boxes in the *Tropical Realm* at Chester Zoo prior to the breeding season of 2001. To reduce costs the four nest box cameras were all connected to a single inexpensive portable television used as a monitor and based in the bird kitchen area. A control panel then allowed scheduled scanning of the four nests or selection of only one nest for a longer period. A camera was also fitted in the nest box of the great hornbill *Buceros bicornis* pair in the aviary inside the Asian Elephant house.

This had its own television monitor located in an off-exhibit keeper area adjacent to the aviary. Video recorders were connected to both televisions so that behavior sequences could be recorded for subsequent analysis. Our cameras were purchased from a company called Pro-cam Ltd based in Nelson, Lancashire, UK.

A hole for the camera was initially made at the side of each nest at a position judged to be on a level with the sitting bird, anticipating that this would enable observation of any eggs and determine laying dates, egg turning behavior, and subsequent clutch history. Once fitted it became apparent that the cameras emitted a low intensity light that elicited pecking from the hornbill in the nest chamber. Accordingly the cameras were relocated in the top of the box at a position more out of reach of the bird. The cameras also produce a small amount of heat but in our situations this did not appear to be sufficient to cause any difficulties.

A single season of use already repaid the costs of installing this relatively inexpensive equipment. We learned that the females of both pairs of great hornbills each laid a single egg. The female located in the Asian elephant area removed all the bark chips provided as nest material from her nest barrel and laid directly on the flat floor of the barrel only to sit with the egg to her side rather than cover it. As a result of this knowledge we modified the nest box to both reduce its internal dimensions and to include a concave bottom. The following year (2002) the female did indeed incubate well, and reared a chick. The female great hornbill in the *Tropical Realm* aviary behaved quite differently in that she did not remove the nest material and incubated her single egg. This failed to hatch, suggesting that we need to concentrate on problems associated with incubation rather than potential problems later in the nesting cycle, e.g. inadequate parental care.

The cameras in the Sunda wrinkled hornbill *Aceros corrugatus* nest also gave us important information that assured us that the recently received nesting female was not losing condition despite her overlong stay in the box. We also learned that this particular female laid eggs and showed appropriate incubation behavior but the eggs failed to hatch. Knowing that the male of this pair was fertile with his previous female this led us to ask further questions about reproductive synchronisation or whether the female was being mated before sealing herself in the nest box. In this case the observations inside the nest did not give us an answer but at least have prompted us to ask what we think are appropriate questions.

The Visayan tarictic hornbill *Penelopides panini* male was initially very shy of feeding the hen in the box when keepers were close to the aviary and we were concerned whether he was offering sufficient and appropriate food items. The nest camera monitor showed that he was behaving parentally and enabled us to follow chick development. We were also able to gather other information; for example sex of the chicks was determined in the nest by differences in plumage that became apparent soon after the chicks began to grow feathers.

Additional to the information that is of direct relevance to better husbandry and management of our captive birds is the presentation of the opportunity to collect significant scientific data on female molt, parental care and nestling development. We encourage students to take advantage of the research opportunities presented by these cameras and have included this as a project on the list of undergraduate research opportunities offered by Chester Zoo. Additionally the opportunity is available through the use of nest monitors to show zoo visitors the hornbill nesting cycle and add to this with appropriate educational interpretation. We are encouraging our Education Department at Chester to take advantage of this opportunity.

6.4 Chick development and care

Information was extracted from Kemp (1995), where more detailed information appears. Information on development of particular species can also often be gleaned from articles focussing on breeding or hand-rearing.

Newly hatched hornbill chicks are altricial, pink skinned, naked and with eyes closed. Chicks respond immediately to auditory and tactile stimuli. They have a strong neck and a well-developed swallowing reflex. The hind legs develop quickly, a necessity for moving around in the nest, taking food directly from the male and resealing the nest cavity if the female leaves the nest prior to fledging time. Unique to hornbills is the development of an air sac under the skin of the shoulder region within a day of hatching. It starts as two separate pockets, but spreads within days to cover the entire dorsal surface with extensions down the sides of the breast. The purpose of the chick being partly "inflated" is not yet known.

Feather growth starts within a few days after hatching. The feather quills emerge around the time the eyes begin to open (15-20 days). Feather sheaths enclosing each feather are not shed immediately, giving the chick a prickly appearance. The chick is extensively feathered when the sheaths fall off. The flight feathers develop and elongate later.

The chick's begging call develops from a weak cheeping into strident cries. Nearer to fledging the chick may begin to make the loud contact call. Larger chicks also make loud acceptance calls when they are directly fed by the male.

Length of the nestling period correlates with the adult body size, ranging from five weeks in the smallest hornbills to over three months in the largest species. Chicks are almost adult-sized at fledging, but the bill is smaller and the casque is not fully developed. After fledging chicks stay in the vicinity of the nest, improving flying skills and still being fed by its parents. When chicks are confident enough they join their parents on foraging trips.

The father is responsible for feeding the female and chicks until the female emerges from the nest and helps feed the young. Incidences in captivity have been observed in which the female emerges after the young, or that the young fledge but then return to the nest for a period.

While the motivation to feed at a nest hole is very strong, sometimes resulting in males offering food to empty nests (Kemp, 1995), some males need time to learn this behavior. A bar-pouched wreathed hornbill *Aceros undulatus* male at Gettorf Zoo did not initially feed the sealed-in female, thus the keepers fed her three times a day by offering a dish of food directly outside the nest opening. The male showed much interest in these feedings, and after approximately a month he started to bring food to the nest himself (de Ruiter, 1995).

Eggs or young chicks often vanish from hornbill nests for no apparent reason. In some cases it may be that the parents need to practice all aspects of parenting, and hope should not be lost if a pair is not successful the first few times. However management practices should be reviewed, and if possible the nest monitored non-invasively to determine where problems lie (see Section 6.3.7 Inspection door and Inspection devices and Section 6.3.8. Camera monitoring of nests).

Often hornbills rear fewer chicks than hatch, and some different techniques have been tried to increase survivorship of young. A human-parent "shared" rearing technique for Northern ground hornbills *Bucorvus abyssinicus* is described by Falzone (1989). The first chick is removed for hand-rearing when the second chick hatches, and after a week or two the chicks are exchanged. Thereafter the chicks are switched on a weekly basis, with the goal that the birds become tame but not imprinted. Schratter (1997) advocated hand-supplementation of Northern ground hornbill chick diets (supplemental feeding of chicks on the nest) over the shared technique because she felt it is less disturbing. Offering supplemental food, especially animal matter, directly to females or to males feeding the female and young is sometimes practised by hornbill managers during chick-rearing.

Males can sometimes become quite aggressive to the female or young once these emerge from the nest. Reilly (1997) described a situation in which an aggressive male Sunda wrinkled hornbill *Aceros corrugatus* was placed in an adjoining enclosure, from where he continued to feed the female and young through wire-mesh without being able to injure them. Females can also be very aggressive: a female *Penelopides* sp. killed young reared in previous breeding attempts when young from a current attempt fledged (Meier 2001, in press).

6.5 Artificial incubation

While parental incubation is often preferable, there are occasions when artificial incubation is desirable. Data on artificial incubation techniques used for hornbills contributed by hornbill managers or taken from the literature is included in Appendix H.

6.6 Hand-rearing

Hand-rearing can increase the reproductive output of hornbills by saving young that would otherwise be out-competed by siblings or by rescuing chicks abandoned by parents. Hand-rearing may be applied in future management of wild hornbill populations, especially in short-term rescue and population support projects. Hand-rearing of large hornbill species, for which collection space is relatively limited and inflexible, may result in over-representation of the few founders and in unbalanced age structures in captive populations. Many wild caught chicks were, and still are, taken from the nest (Tsuji, 1996) and hand-reared for export to purchasers.

Behavior of many hand-reared (and suspected hand-reared) hornbills suggest that hand-rearing may be one reasons for poor reproductive success of captive hornbills. There are some reports of hand-reared ho rnbills breeding quite successfully, for example a hand-reared female Sulawesi tarictic hornbill *Penelopides exarhatus sanfordi* paired with a wild caught male at San Diego Wild Animal Park has successfully raised 13 young since 1996 (D. Rimlinger, pers. comm.). Data are currently insufficient to adequately assess the impact of hand-rearing on the breeding potential of individual hornbills, or to assess the success of various techniques in avoiding abnormal imprinting. If hornbill managers do hand-rear birds or use other techniques to increase fledging success, such as the human-parent "shared" rearing described by Falzone (1989) or hand-supplementation of chick diets (Schratter, 1997), data should be gathered on later behavior so that well-founded conclusions can be drawn.

Participants at the second international workshop agreed that hand-rearing techniques for the different genera should be perfected. At the same time, captive population sizes for target species should be monitored and, especially once techniques are reliable, hand-rearing should be restricted to cases where rapid population growth is essential.

Hand-rearing data contributed by D. Rimlinger on hornbills hand-reared at San Diego Zoo is included in Appendix I. Much information on hand-rearing Northern ground hornbills *Bucorvus abyssinicus* and scattered information on other species is available, and can be found via a hornbill bibliography or via internet.

6.6.1 Abnormal imprinting

Hand-reared birds can become imprinted on humans (see also Section 7.1: Human-hornbill interactions). How firm this imprinting is depends on the species as well as various social and environmental factors. Imprinting can last into adulthood and be difficult to overcome; lack of contact with conspecifics in an early stage of life may result in no interest for the opposite sex later when the physiological full breeding potential is reached (Anderson Brown and Robbins, 1994). Hornbills have been seen displaying towards their keepers instead of their mates. Hand-reared great hornbills *Buceros bicornis* at the Rostock Zoo (Germany) have been difficult to pair with conspecifics; one female even killed a male she was housed with.

A study of great hornbills in captivity indicated that hand-reared birds were less likely to breed themselves, perhaps because they relate too strongly to their keepers (C. Sheppard *in* Hornbill Digest listserv, 14 February 1999).

If hand-rearing is undertaken some steps that can be taken to reduce the likelihood of abnormal imprinting are:

- puppet rear (minimizing direct contact with humans);
- play conspecific calls;
- keep at least two (preferably conspecific) chicks together;
- give visual and auditory access to adults as soon as possible; and
- hold juveniles in conspecific flocks, as hornbills join youngster groups or remain in family groups in the wild after fledging (Tsuji, 1996).

7 Social behavior and pair/group composition

Social behavior of most hornbills has not been extensively studied. However, we know that all hornbill species seem to be monogamous, and that some form cooperative groups. During the non-breeding season pairs join flocks for roosting and foraging.

Most of the social interactions are generally between mated pairs, parents and their off-spring and members of cooperative groups. Apart from the parent-young bond the pair-bond is the most clear affiliation, and both the female and the male have an essential role in rearing the offspring. Whether the pair-bond has to be re-established every year around the start of the breeding season or is maintained for several years is not known yet for many species although Kemp (1988) demonstrated long-term pair-bonds in the Southern ground hornbill *Bucorvus leadbeateri*. Pairs studied were monogamous and often bred cooperatively, with the alpha pair aided by helpers (probably family) to defend the territory and to raise the chicks. Cooperative breeding has been confirmed in eight hornbill species: *Bucorvus leadbeateri, Anorrhinus austeni, A. tickelli, A. galeritus, Buceros hydrocorax, Penelopides exarhatus, Aceros comatus* and *Ceratogymna bucinator* and possibly occurs in other species (Kemp, 1995). Kemp pointed out that this is the highest known proportion of cooperative breeding species among any order of birds. Cooperative breeding in hornbills seems to be primarily facultative, as pairs breed both with and without helpers.

Formation of flocks is especially frequent in hornbill species that rely on patchy food resources such as fruiting trees and travel from one patch to the other (Kemp, 1995). One fruiting tree can be visited by more than one hornbill species at the same time without any visible aggressive or territorial behavior (e.g. great hornbill *Buceros bicornis* and helmeted hornbill *Buceros vigil* in Malaysia; W. Galama, pers. obs.). Young birds may remain in a family group for an extended period or may join a flock of juveniles after leaving their parents. Flocking provides juveniles protection and an opportunity to find the right mate when they reach adulthood (Leighton, 1986; Kinnaird and O'Brien, 1993). Early morning vocalizations within roosting groups can precipitate departure of the entire group towards foraging areas. Hornbills within the group not only communicate with conspecifics but also with other hornbills throughout the day. Vocalizations that are similar throughout the order are territorial-, fright-, acceptance- and begging calls. Visual signals such as the facial and body colors are also used in communication. Changing of the skin color and the frequency in which it changes may provide the keepers with useful information about the psychological and physiological welfare of hornbills.

Aggressive behaviors i.e. raised bill, banging the bill on a perch and wing movements, are quite uniform throughout the order. Territorial behavior in the wild is more common in carnivorous species inhabiting the open savannah and includes a lifted or lowered head position and expanded/fanned tail and wing feathers. Mutual grooming and allopreening are common social activities to establish and reinforce social bonding and hierarchies of dominance. Cohesive movements of the flock, territorial defence and vocalizations may also reinforce relationships between individuals (Kemp, 1995).

7.1 Human-hornbill interactions

A cross-institutional study examining behavioral and environmental factors associated with breeding success of great hornbills *Buceros bicornis* found that high ratings of "approaches keeper spontaneously" and "interested in surroundings" for female hornbills are negatively associated with female reproductive success, and may indicate an excessive orientation to humans (Carlstead and Sheppard, in prep.). As discussed in Section 6.6.1, hornbills may imprint abnormally, and even many wild-caught birds have been hand-reared for a portion of the nesting period. Interactions that are likely to attract hornbills to humans, such as hand-feeding (by the public or caretakers) should generally be avoided. Supplemental feedings by hand directly to the female or via the male during chick rearing have not appeared to encourage hornbills to become more human oriented however.

Hornbills, particularly males in breeding condition, can become extremely aggressive to people. Wearing helmets when entering the cage and entering with two people, one armed with a broom or other such fairly harmless defence tool to fend off an attacking bird are precautions often taken. As mentioned in Section 4.8.5: Food tray, it is desirable to have food trays accessible to the keepers from outside the cage. The need to enter the cage as little as possible should be taken into consideration in cage design. For example, water faucets, light switches and other environmental controls should be placed outside the enclosure. Plants and perches should be positioned so that the need for enclosure cleaning can be minimized.

7.2 Introductions and pair formation

Incompatibility of pair-members could be one of the reasons for the generally poor breeding success of hornbills in captivity. Incompatibility may be due to personality differences, which in some cases could be aggravated by less than optimal introduction techniques and/or husbandry conditions. Taxonomic (and therefore ecological or genetic) differences may sometimes be a factor. Taxonomic questions for some hornbill groups remain problematic, and it is often not possible to determine where a wild-caught individual originated.

7.2.1 Pair compatibility assessment

A finding in the multi-institutional *Buceros* study was that breeding success is higher the longer a pair is together (Carlstead and Sheppard, in press). While some pairs may eventually breed after many years together, the *Buceros* captive population is ageing and much time could be wasted in hope that a pair will eventually breed if the male and female remain together. Repairing great hornbills *Buceros bicornis* that were with a conspecific of the opposite sex for years has several times resulted in fertile eggs and even chicks being produced within months (Macek, 1997; W. Schoo, pers. comm.). Placing a more difficult-to-pair hornbill with an experienced one may improve the difficult-to-pair bird's chance of breeding.

Hornbills may perform some reproductive behaviors such as feeding each other, allopreening and nest showing for years without proceeding further. While feeding a conspecific through wire-mesh during introductions is certainly a positive sign, it is no guarantee that a true pair bond will be formed, or even that aggression will not occur once the barrier is gone. Indeed Carlstead and Sheppard (in prep.) reported that male "Feeding of his Partner" was a poor predictor of reproductive success in *Buceros*, as it only separated very successful males from non-reproductive males. High frequencies of "Nudging Partner", i.e. poking or nudging the partner with the bill, was a good indicator of egg laying and chick production for both males and females. Studies to ascertain whether "Nudging Partner" is a good predictor of reproduction in other genera, and which other behaviors can also be used as predictors, would be very useful.

Hornbill courtship has some elements of aggression, and some pairs have higher levels than others. Frequent copulations by a successful pair of rhinoceros hornbills *Buceros rhinoceros* at Audubon Park Zoo were "always preceded by pursuit of the female [by the male] with intermediate bouts of bill-fencing" (Reilly, 1988). While male pursuit of the female may be a form of courtship in such cases, continual or intermittent pursuit otherwise, particularly if the female seems afraid or harassed, is reason for management actions such as at least temporarily separating the hornbills. More data are needed to determine whether pairs with this level of aggression other than during introductions are likely to breed.

A pair of hornbills in which at least one member has prior successful reproductive experience is probably more likely to breed, and to reproduce more quickly than an entirely inexperienced pair. However, even pairs in which both members were with other partners for years without reproductive activity have reproduced within months of introduction. If a pair of reproductive age has been in a good breeding situation for three years without producing eggs, or at least the female becoming sealed in, repairing the hornbills should be considered. Should a pair produce infertile eggs for several years despite management actions to synchronize the birds and optimize conditions, it may also be prudent to repair the birds.

7.2.2 Pair formation methods

Participants of the International Hornbill Workshop 1997 concluded that formation of juvenile flocks in captivity could contribute to better pair-bonding, and that non-reproductive adult birds should be given a choice of partners. There are not enough data at this time to confirm that finding a partner within a group (group pairing) is more effective than random pairings for adult birds, however there is some anecdotal evidence. For example two pairs of great hornbills *Buceros bicornis* formed with a group of two males and seven females at Tobe Zoo (Japan), and both pairs laid eggs within a short time (Takaki, 1996). A Sunda wrinkled hornbill *Aceros corrugatus* pair formed within a group at the Bronx Zoo also had strong pair-bond (P. Shannon, pers. comm.).

Any opportunity for a non-reproductive pair of hornbills to form a pair-bond with novel potential partners can only improve chance of reproducing. If it is not possible to provide opportunities for group pairing, small-scale pairing trials could also be attempted, for example placing a male between two females or a female between two males (depending on which sex is in surplus) in three adjoining cages. Even random reshuffling of genetically compatible individuals will increase overall success, as two birds may just "click". Some experiences obtained with two recently established "dating centers" yielded some interesting information.

7.2.2.1 Sunda wrinkled hornbill dating center at Heidelberg

A dating center for Sunda wrinkled hornbills *Aceros corrugatus* was established at Heidelberg Zoo (Germany) in 1999. The hornbills are slowly introduced by putting them in adjoining enclosures and then are released into a larger area. A shortage of males has been a problem, and one female may have been killed by conspecifics, although post mortem investigation revealed a pseudotuberculosis infection; trauma to the head may have been secondary. Enough experience has been gained that the following conclusions were drawn by the Sunda Wrinkled Hornbill EEP Coordinator J. Lilleor and Heidelberg Zoo representative S. Reichler (*in litt.*):

1. Only competitive females can be grouped together; it is possibly better to have a space for subadult birds and another for adult birds;
2. No more than one male should be placed in the group of females at the same time;
3. A pair should be separated as soon as pair formation is seen.

7.2.2.2 Great hornbill breeding center at Arnhem Zoo

A trial dating center in which eight (4.4) great hornbills *Buceros bicornis* from four Dutch and Belgian zoos was established for a period of six weeks at Arnhem Zoo in August and September 2001. Each bird received a pseudotuberculosis vaccination and a transponder, was tested for parasites and began receiving an extra Vitamin B treatment a week before transport.

The hornbills, held separately but with visual, auditory and sometimes limited physical contact, were given one week to adjust to the new surroundings before partner-choice trials began. One bird was released into a hallway for six hours in one day and interaction with the other birds was recorded by video. There were three series of trials, i.e. each bird was placed in the hall three times (days) throughout the experiment. Activity levels of all birds were highest in the first and third trials, it is thought that activity was lowest in the second trial because all birds molted feathers then. Some birds were more active than others were generally, and all males showed particular interest in one female that was more responsive to them than the other females were.

One pair (including the very popular female) that had been together for a year at the resident zoo before the experiment had the most positive interactions during the trials, and went home together. It had taken several years to bring this pair together because of aggression, and intermittent aggression has been observed in the year since the experiment with no breeding. The results were ambiguous for the remaining hornbills, but as all three pairs had been together for at least several years at their resident zoos without showing much interest in reproduction, the six birds were repaired at the end of the experiment. One repaired pair, including a hand-reared male from Rostock Zoo did not work well, and the birds are now separated (the last female with this male was also sometimes separated because she was afraid of him). A second repaired pair began sealing the nest within a period of months and the third pair produced fertile eggs but these did not hatch.

While the trials did not clearly indicate which birds were the most compatible, they did indicate that there was nothing to be lost by reshuffling the birds. High inactivity levels of some of some individuals suggested that these birds needed more time to adjust to the situation and each other. The trials preceded the normal breeding season (winter) for great hornbills in Europe, and took place while the birds were molting- or the experiment triggered molting. Better results might have been achieved if the trials occurred several months later, as hornbills in the wild seem to pair at the beginning of the breeding season. The duration of this experiment and time of year that it was carried out was constrained by a need to use the facilities for winter holding. Nevertheless the experiment was still a valuable learning experience and given that two of the three repaired pairs became reproductively active it can be considered successful (Schoo, 2001; W. Schoo, pers. comm.).

7.2.3 Introductions

Introduction of any two hornbills older than nestlings can be a risky business and introductions should be undertaken with the utmost care. The same precautions and introduction techniques that apply to birds generally apply to hornbills. The birds should first be held in adjacent cages separated by appropriate wire-meshing (see Section 4.7.1: Boundary (roof and wall) materials) so that they can familiarize with each other. Having a "continuous" perch in the two cages can offer an opportunity for a male and female to sit together and perform pair-bonding behaviors through the meshing. Waiting until such behaviors are observed before placing a male and female together is recommended. The bird(s) expected to be the most aggressive should be the one(s) introduced into the other's cage. Precautions such as cutting a few wing feathers to impede an aggressive bird's flight can also be made.

Presence of ample perching possibilities and multiple food trays can reduce conflict. Recently introduced birds should be carefully watched for signs of aggression and to ascertain that the birds are indeed eating well.

Data need to be compiled on the best time of year to introduce hornbills. Introduction of potential pairs may be most successful in the breeding season, when pair-bonds normally form. Introductions of one female great hornbill with (consecutive) males at St. Louis undertaken during the winter when courtship would normally occur proceeded smoothly and were followed by rapid reproduction (Macek, 1997). In some cases, e.g. holding hornbills in non-breeding situations, it may be better to introduce birds during the non-breeding period, when aggression levels are lower.

7.3 Conspecific groupings and aggression

Hornbills are long-lived birds and if we become more successful in managing these birds in zoos space demands will increase. While it seems that same-sex birds are sometimes held together there is little data on how successful that is, or whether some adult hornbills could be held in small (same-sex) groups. It is known that many hornbills live in cooperative (possibly family) groups in the wild but whether it will be possible to hold young with adults for extended periods in captivity is not usually known. Personnel at Audubon Park Zoo have noted ages of young at which time parental aggression was observed for three species (Appendix 11.F), and it would be very useful for other managers to also record this type if information so that we can refine future management practices.

There can be a strong, possibly sex-dependant, difference in response to offspring. A pair of rhinoceros hornbill *Buceros rhinoceros* at Audubon Park Zoo showed aggression towards female offspring 7 months of age (Appendix 11.F) but no aggression to male offspring. In fact a male offspring born in 1995 helped his father feed the female while she was sealed-in in 1997 (Meyers, in press). Some species are known to be unusually aggressive towards offspring. Sunda wrinkled hornbills *Aceros corrugatus* have to be removed as soon as possible after fledging because of, sometimes fatal, aggression from the male (Uzee Sigler and Meyers, 1992; Reilly, 1997). A female *Penelopides* sp. killed previously reared young when young from a current attempt fledged (Meier, in press).

Carlstead and Sheppard (in prep.) noted that male *Buceros* hornbills are generally more aggressive to their partners than females are, and that great hornbills *Buceros bicornis* are generally more aggressive than rhinoceros hornbills *Buceros rhinoceros*.

Juvenile hornbills in the wild often live in flocks, and it is recommended that juveniles in captivity also be held in flocks if they cannot remain with the parents. At this point it is not generally known whether juveniles that have been housed together would form pair bonds with birds within the group, or whether growing up together might inhibit pair-bonding. Certainly however holding juveniles in flocks gives the birds an opportunity to practice their social skills and individuals could be exchanged between flocks if pair formation is poor within flocks.

A juvenile group of Sunda wrinkled hornbills *Aceros corrugatus* was established at the Bronx Zoo in 1996, and there were plans to hold Papuan wreathed hornbills *Aceros plicatus* in a flock at Louisville Zoo (Reilly, 1997). The *Aceros corrugatus* group at the Bronx did well, however individuals needed to be removed from the group as soon as they formed a pair-bond (C. Sheppard, pers. comm.).

While introductions are considered the most dangerous period for conspecific injuries or killings, these events can occur at any time and hornbill managers must remain vigilant for problems. For example, a pair of Northern ground hornbills *Bucorvus abyssinicus* with a long breeding history at Dallas Zoo injured each other in a battle while rearing two 100 day old chicks (C. Brown, Hornbill digest listserv, 10 August 2001). Possibilities to at least temporarily remove hornbills should be available and such actions taken if serious aggression or continual low level aggression is observed.

8 Suggestions for research, public education and expanded guidelines.

8.1 Suggestions for research

8.1.1 Dietary issues

Diet composition: Items consumed may be very different in nutrient composition from the entire diet offered and it may be important to document this, as well as to look for species-specific intake differences in collections where the same diet is fed to several different species. A form for intake trials is available from K. Brouwer, and the European Zoo Nutrition Center based at the EAZA Office is willing to help anyone with questions regarding intake trial protocols. The email address for the nutrition center is: info@eznc.org.

Diet as a source of pigments: P. Poonswad notes that hornbills select fruits which are predominantly red, orange, dark purple and black. Such fruits may be high in cartenoids, flavenoids and other colored pigments that have been shown to effect color of plumage and skin in many bird species. Soft part colors often vary among sub-species and have not been well documented in some species. As color is often important in species recognition, courtship displays and other communication, the question of whether or not hornbills would benefit from feeding of pigments should be answered. As a first step, it would be useful to know whether, for a given species, there are differences in soft part coloration in zoos that feed diets including many red-pigments and zoos that do not. It should also be noted that feeding too many pigments may cause improper coloring.

Iron storage disease: Hornbill (and other susceptible bird) managers need to develop an experimental design to systematically answer questions about iron storage disease mentioned in Section 3.1.6.

8.1.2 Color change of the circumorbital skin

The pink skin around the eyes of female great hornbills *Buceros bicornis* can become reddish when faced with threats, food, inspecting the nest, engaging in courtship (Thormahlen and Healy, 1989), or while experiencing exciting new situations e.g. the presence of a mealworm dispenser and a bunch of grapes hung in the enclosure (*Buceros bicornis*; Galama and Weber, 1996). The change in skin color might be a visual signal providing useful information for the great hornbill male about the psychological and/or physiological state of the female. Keepers might also be able to use of this sign to distinguish the welfare of the female.

8.1.3 Reproductive physiology

Non-invasive monitoring of reproduction physiology can help in inventorying the reproductive status of the captive population. Various zoos in the U.S.A. are participating in a study to establish baseline sex hormone levels in a few Asian hornbill species using non-invasive collection techniques. Coordinator of this study is J. Azua at Denver Zoological Gardens (curbirds@denverzoo.org). W. Galama can be contacted for information regarding collection protocols and hormonal measurement techniques (wtgalama@hotmail.com).

8.1.4 Life history and other physiological data

There are still many mysteries in life history of hornbills: Kemp (1995) commented that our understanding of hormonal and nutritional regulation of molt is not well understood. Why is the molt so variable and what triggers it? Why do chicks have an extensive air sac? It is much easier to gather data that can answer these kinds of questions in zoos than in the field, and zoo managers can work with field researchers to answer them.

8.1.5 Social and reproductive behavioral studies

Data on timing of reproductive behavior and activities can be collected and compiled to improve hornbill management. Data should be compiled on introduction techniques tried and their success. More work should be done to establish which cues can be used to assess pair compatibility, and environmental features important in stimulating successful reproduction.

Pair formation:

- Length of time reproductively active pairs were housed together before breeding commenced to get some indication of how long pairs should be left together before attempts are made to find another partner.

- Presence or absence of behaviors described in the great hornbill *Buceros bicornis* ethogram based on Hutchins *et. al*. (undated) in Appendix J, and if behaviors are present note their approximate frequency.

Reproductive stimulation and synchronization, effect of:

- management strategies such as removing the nest, or making it inaccessible, or removing pairs from the breeding enclosure during the non-breeding season.
- seasonal (or artificial) changes in photoperiod, rainfall or sprinkling, playback vocalizations and diet in triggering breeding activity.
- roof type (covered, partially covered, sky lights).

Timing of reproductive events per zoo, region, and inter-regionally:

- nest inspection/nest showing (Appendix J), female entering nest box, sealing of opening, eggs laid (if known), chicks heard, female emergence, chick emergence.

Data should also be recorded on:

- number and sex of chicks and sex, female molt (if occurs and which feathers), fate of unhatched eggs (fertility, condition, i.e. cracked, broken, presence and age of dead embryos) if eggs found after the female leaves the nest. Type of nest material used and how much, materials used to close entrance.

8.1.6 Introductions and grouping strategies

At this time there is little information regarding optimal number of birds to place together, how enclosures should be configured for different group sizes and compositions, and best time of the year to introduce birds. Undertaking more experiments as the two mentioned in Section 7.2 (group pairing trials) would certainly be valuable in answering these questions. Housing juvenile hornbills in flocks is a promising management technique that deserves more effort.

Research could be done to determine whether the ethogram in Appendix 11.J is useful to evaluate social relationships in groups other than pairs.

Data on successful combinations of conspecific hornbill groupings (number of individuals, age, and sexes) and age at which aggression directed towards young by the parents would be useful.

8.1.7 Incubation and rearing

Nesting data can be more easily gathered using a video surveillance system. Hornbill managers are strongly urged to make use of this very valuable tool whenever possible. Accumulating more information on nest humidity and temperature throughout incubation (looking at fluctuations throughout the day and throughout the incubation cycle) in relation to breeding success would be very useful, and comparison of forest and open-habitat species could be made.

Anecdotal and published information on artificially incubation and hand-rearing for hornbills in particular is very scarce.

Type of incubator, temperature, humidity and egg weight over time are some artificial incubation parameters that should be documented and examined.

M. Meyers and others at the Audubon Park Zoo (USA) are collecting information on existing hand-rearing techniques for the AZA Hornbill TAG. EAZA zoo data will be added to create a master compilation. Information on hand-rearing diets and protocols should be collected, as well as data on growth rates and development. Data can also be gathered on parent-reared chicks as possible to compare results.

8.2 Public education

Hornbills can easily be used for educational purposes. Some of their remarkable breeding strategies, e.g. sealing- in of females and a high rate of cooperative breeding species, are topics that can be presented in interesting ways. Images of hornbills in the nest via a video surveillance system can be a very exciting educational tool.

Hornbills are masters in juggling food items with their bills. A hornbill's imposing bill is useful in illustrating how the shape of a bird's bill correlates with its purpose, and comparisons with toucans give opportunities to discuss analogous characteristics.

Text boards and/or a keeper can educate the public during short training sessions or enrichment events about unique breeding and feeding strategies employed by hornbills. However, direct interaction of the keeper/public with hornbills should be avoided as the birds easily become focused on humans. Therefore, remote methods to offer the enrichment or training devices are recommended.

8.3 Future guidelines

Topics in addition to the ones mentioned already in Chapter 8 that we would like to see included in a future edition of the husbandry guidelines when more data are available include:

- A catalogue of sexual dimorphisms, and ages at which they are acquired, per species (or other relevant taxon);

- A list of ring sizes per species (and sex?);

- A list of substrates and nest linings that have desirable properties (e.g. antibacterial, anti fungal).

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