Husbandry and Care of Hoofstock

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INTRODUCTION AND NATURAL HISTORY

Hoofed mammals, also known as ungulates, display an incredible diversity of forms, adaptations, and lifestyles—features which make them an enduring part of zoo collections around the world. More than 250 living ungulate species are currently recognized (although recent revisions suggest that there may actually be more than 450 distinct species), with representatives found in nearly every zoogeographic region and biome on earth. They range in size from rabbit- sized chevrotains (family Tragulidae) to the six-meter-tall giraffe *(Giraffa camelopardalis)* and 3,600-kilogram White rhinoceros (*Ceratotherium simum*), with social groupings ranging from solitary species like tapirs (Tapirus spp.) to immense herds of more than a million Serengeti wildebeest *(Connochaetes taurinus)*.

Although united by their common possession of enlarged, weight-bearing toenails (hooves), ungulates do not form a taxonomic group: the hooves have evolved several times independently. Modern hoofed mammals are classified either as "odd- toed ungulates" (order Perissodactyla) like horses, rhinoceroses, and tapirs, or as "even- toed ungulates" (artiodactyls) like pigs, peccaries, hippo-potamuses, camels, and the diverse ruminants (deer, cattle, antelopes, and giraffes, among others). Genetic evidence also includes whales and dolphins (formerly Cetacea) within the even-toed ungulate family tree (formerly Artiodactyla); combined

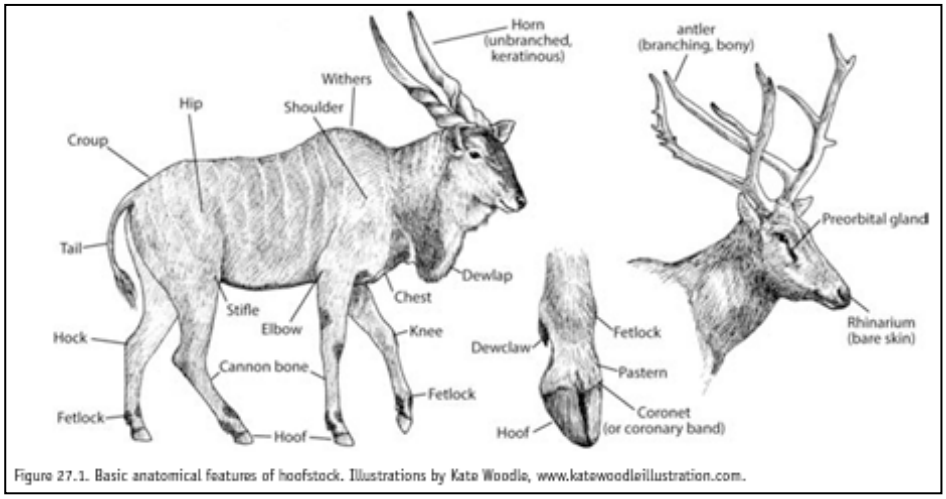

Figure 27.1. Basic anatomical features of hoofstock. Illustrations by Kate Woodle, www.katewoodleillustration.com.

together, they form the new order Cetartiodactyla.

Despite the disparate origins of hoofed animals, two common traits warrant their treatment as a group for husbandry purposes. First, all ungulates feed primarily on plants, using specialized strategies to deal with fibrous foods. Second, all ungulates have similar physical and behavioral adaptations for avoidance of predators. Although these common traits have been ecologically successful, they present challenges in the care of hoof stock (as ungulates are called in captivity).

Hoofed mammals have a long history of human care: evidence of captive sheep exists in the remains of 9,000 year old settlements (Herre and Röhrs 1990, 585). More than a dozen ungulates have since been domesticated, including the horse (*Equus caballus*), the pig (*Sus domesticus*), the goat (*Capra hircus*), four cattle species (Bos spp.), the water *buffalo* (*Bubalus bubalis*), camels (family Camelidae), and the reindeer (*Rangifer tarandus*). With 4.5 billion domestic ungulates (livestock) worldwide (FAO Database 2009, 2007 figures), the experience with their husbandry is extensive. This knowledge base is an important resource for those caring for exotic ungulates.

This chapter will elaborate on the challenges and techniques of working with ungulates in captivity.

After studying this chapter, the reader will understand:

- anatomical terms specific to ungulates impacts of species-specific biology on housing, nutrition, and social management
- effects of ungulate behavior and keeper demeanor on animal and keeper safety
- best practices for encouraging species-appropriate natural behaviors
- principal issues involved in the reproductive and medical management of ungulates.

BASIC EXTERNAL ANATOMY

The basic four-legged (quadrupedal) mammalian body plan has evolved for a running (cursorial) existence in ungulates: elongated legs provide speed when fleeing from predators. Because the limb joints of ungulates and humans are in different relative positions, the joints have specific names, detailed in Figure 27.1 along with other important ungulate anatomical features. The threat of predation has also molded keen threat-detecting senses; sensory emphasis varies between species, but all ungulates have eyes on the sides of their heads, providing an arc of vision approaching 360 degrees.

THE ZOO ENVIRONMENT

As a result of their cursorial tendencies and relatively large body size, zoos often exhibit hoof stock in large outdoor enclosures (paddocks).

Smaller yards and indoor housing are commonly provided to facilitate animal management. Enclosure requirements vary greatly between ungulate species and zoo locations, but several key considerations are universal.

SUBSTRATE

Local soil is the most common substrate in paddocks, since replacing large areas of ground is prohibitively expensive. However, rates of hoof growth are substrate-adapted: the coarser a species' native substrate, the faster its hoof growth must be to compensate for wear. Ungulates adapted to rough terrain, like wild goats, are therefore prone to overgrown hooves when kept on softer surfaces. Hoof wear can be increased by adding abrasive substrates like decomposed granite, limestone screenings, or roughened concrete to high-traffic exhibit areas, such as around feeders and along pathways. Holding yards are often covered exclusively with rough substrates, in part because of their relative stability in varying weather conditions. In all cases, the extent of this "hard- standing" should be determined on the basis of species' biology, as ungulates with sensitive feet (e.g., hippos and rhinos) may develop foot abrasions and injuries if confined on rough ground. Whatever the enclosure substrate, it should provide good traction and even footing. Proper drainage is necessary to prevent erosion ruts and areas of deep mud: these uneven surfaces can cause injuries to the long, slender legs of hoofstock. In cold climates, ice may form in poorly drained areas; similar slippery areas may form with compacted snow, and clearing
fresh snow from frequently-used areas should be a priority. Traction over slip hazards can be provided spreading sand, but rock salt and other potentially caustic or poisonous ice melters should be avoided. During spring thaws or after prolonged rain, even well-drained substrates may become waterlogged. If this occurs, hoof stock should be held in barns or yards until the ground is dry and firm. Soft terrain is readily mired by hooves, creating potentially dangerous uneven surfaces when dry; uneven ground can be smoothed with rakes or harrows, but prevention is preferable.

CONTAINMENT

Ungulates may jump over, crawl under, climb through, or dig beneath obstacles (Fitzwater 1972, 52), so it is vital to research physical adaptations and behavioral repertoires when choosing barriers. Visually solid barriers like walls and stockades are "understood" by hoof stock; even fabric walls can be effective short-term barriers. Enclosure boundaries that can be seen through carry the risk of collision-related trauma, so injury- reducing features should be employed whenever possible. Dry moats should slope gently downwards to solid walls; steep drops should be avoided, lest an ungulate run over the edge. A water moat requires an additional barrier on the public side to prevent escape should an animal choose to swim or panic and jump into the water, and a sloped area is essential to provide an easy route back to the enclosure. By far the most popular hoof stock barrier is wire fencing due to its availability, low cost, and ease of installation. Fences tend to "disappear" into land-scaping: a benefit for visitors, but a potential hazard for hoof stock. Flexible fencing, like chain link, can stretch to absorb impacts and thereby reduce the potential for injury; it is generally preferable to rigid or ungiving fence materials. Keepers should check for containment weaknesses daily, as these may cause injury, permit escape, or allow free- roaming predators and native species (which may bear disease) to enter the enclosure. Barriers may be the target of open sheds, or enclosed barns. Group- housed ungulates behaviors like sparring and ramming, so secondary barriers like bumper rails can be employed to minimize damage by keeping large, strong, or belligerent ungulates back from the primary containment. Electric fencing ("hot wire"), which delivers a shock on contact, is a common secondary barrier choice due to its effectiveness and unobtrusive appearance. The ease with which slender hot wires are broken makes them generally unsuitable for primary containment (especially for large ungulates), while the low visibility increases the chances of entanglement during panicked flight. The risk of collision with barriers is highest when hoofstock are introduced to unfamiliar enclosures. Burlap, shade cloth, and other materials are commonly attached to fences during initial introductions to give them a solid appearance and reduce visual distractions from beyond. Electric fences are usually "flagged" by tying strips of cloth or plastic (e.g., caution tape) at regular intervals; for naive animals, the stress of initially encountering hot wire in a new exhibit can be reduced by exposing them to sections of flagged fencing in a familiar environment. Further introductory precautions, such as reducing water depth in wet moats and pools, are covered in detail by Kranz (1996). As the new animals become established, hazard warnings can be gradually removed until the exhibit returns to its normal appearance.

REFUGE

Flight responses, as well as stress and conflct among group members, can be reduced by providing hoof stock with options for privacy. Refuges for smaller individuals (called creeps) can be created using secondary barriers that exclude larger animals. Visual barriers like plantings, exhibit furniture, and rolling terrain allow animals to retreat from their exhibit mates, keepers, and the public, thereby imparting a sense of security. Man-made visual barriers include wooden lean-tos, stacked straw bales, and sections of wall, but these may be inappropriate in naturalistic exhibits. Fallen trees (deadfall) provide natural, multipurpose furniture,

which—unlike live vegetation—does not need to contend with soil compaction and frequent browsing. Live plants often need to be protected by secondary barriers such as electric fence ("hot wire") or rings of boulders if they are to survive in hoof stock exhibits; trunks of established trees are commonly wrapped with chain-link fencing to prevent bark abrasion and browsing. Thorny or unpalatable (but nontoxic) plantings (e.g., Barberry [*Berberis* spp.] and Hawthorn [*Crataegus* spp.]; Hohn 1986, 10) are used with mixed success to create a natural look without protective barriers. However, grasses (including bamboos) tend to be the most resilient to damage from ungulates, even without protection: some grasses grow tall enough to provide cover, and even short species can enhance enclosure aesthetics. Wherever vegetation is present, regular checks for and removal of toxic plants should be performed; these may include nightshade (*Solanum* spp.) and alsike clover (*Trifolium hybridum*). Extensive toxic plant lists are available online.

SHELTER

Every enclosure should include protection from wind, precipitation, and sun, whether in the form of shade structures, should have numerous shelter locations; multiple entrances and visual barriers further ensure that dominant individuals cannot exclude others. If needed, supplemental heating (heaters, bedding) or cooling (misters, fans) can keep animals comfortable, while significant differences between local and native climates usually require temperature- controlled indoor holdings. Delicate species, such as gerenuk antelope (*Litocranius walleri*), may need indoor facilities regardless of the region. A typical hoof stock barn has a series of box stalls with sliding doors that connect pens and lead to outside yards. Floors must be slightly roughened to provide hooves with traction, and good drainage is needed to prevent water and urine from becoming slip hazards. Hard floors can be made more comfortable (cushioned and insulated) through the use of bedded areas. These are best located along walls or in pen corners — that impart a sense of security — and should be visible from keeper areas to permit observation. Wood shavings, straw, and (in some regions) grass hay are common bedding materials. Roughage - feeding species like camels and horses may consume forage-based bedding like hay or even coarse straw, and as a result can experience dietary upset, gain excess weight, or contract parasites or diseases. Where these issues occur, other bedding options exist, such as peat moss and mulch. Rubber mats, spray-on cushioned surfaces, and other novel livestock flooring products are also increasingly popular in zoo settings. Specifically developed for hoof stock, these synthetic materials increase animal comfort and reduce the need for disposable bedding. When extra cushioning and traction are needed—for a sore or unsteady animal, or in preparation for a birth or immobilization—a "deep bed" can be made. A dense, soft "mattress" is formed using a layer of cohesive materials like soil, mulch, or moistened shavings over an entire stall; this base is usually covered with regular bedding to facilitate cleaning. Similarly, "hot beds" have a base of bedding and manure which produces heat as it decomposes. Helpful for providing warmth in buildings without power, hot beds need proper ventilation to eliminate fumes and regular cleaning of the top bedding to maintain hygienic living conditions.

HUSBANDRY

Ungulate management practices vary depending on the local climate, facilities present, institutional goals, and species' natural histories. Regardless of whether hoof stock are loosely or tightly managed, the knowledge and skills of their keepers are universally important. The diversity of ungulates prevents a one-size-fits-all approach to their management, and one of the best investments a keeper can make is to research the species under their care.

OBSERVATIONS

Throughout the daily routine, keepers should be on the lookout for slight changes in their charges, remembering that ungulates hide signs of weakness that might attract predators. Slower reaction times, glassy eyes, or ears that fail to prick up all indicate that an individual may be feeling "off." Subtle changes in locomotion, such as a barely perceptible limp husbandry and care of hoofstock or a slight reluctance to rise, suggest a potential issue with hooves, feet, or joints. Minor gastrointestinal upsets may be evidenced by changes in fecal consistency, fecal volume, or appetite; visible bloating and awkward positioning may be seen in more advanced cases. In herd situations, aggression may be directed towards sickly individuals, causing them to withdraw and isolate themselves. In all cases, keepers must recognize changes—to do so, they must be familiar with what is "normal" with their animals. Documenting observations for coworkers is important, regardless of whether or not a problem is obvious; effective communication, such as identifying the individuals involved and using proper anatomical terms (figure 27.1), is essential. Early recognition of issues greatly improves the prognosis of ill individuals. Undertaking detailed visual checks and separating animals of concern is easily accomplished if hoof stock are brought into holdings on a routine basis; this practice also helps exhibits to recuperate from grazing and trampling. Daily separation of individuals permits keepers to monitor their food consumption and is also useful for delivering medications to specific animals. These shifting routines are best established if new animals are given time to associate holdings with food and shelter before being introduced to larger exhibits. In more loosely managed species that do not shift off - exhibit, keepers must be able to approach their animals close enough to identify and monitor

individuals. Doing so safely and effectively requires an understanding of ungulate behavior.

FLIGHT RESPONSES

Ungulates avoid predation by maintaining space between themselves and predators; their flight distances dictate how close a potential threat can approach before they retreat. Daily nonthreatening exposure to people habituates many zoo ungulates to humans, reducing their flight distances and allowing closer approaches than would normally be possible. Building (or rebuilding) this trust may take weeks upon the introduction of new keepers, enclosures, or routines, but such tolerance needs only a split second to be overridden by wild instincts in novel or stressful situations. Ungulates inherently recognize being cornered, being approached rapidly, and being separated from their herd as predatory scenarios, and they react with instinctive fight-or-flight responses. When there is space to flee, hoof stock may run desperately or unpredictably to reach security or rejoin herd-mates. In captivity, barriers are a common source of trauma for panicked ungulates, and collisions may result in facial trauma, broken limbs, or even death. With no option for escape, they may also show extreme aggression towards the threat as a last-chance survival strategy. Keepers should avoid creating these predatory scenarios for the safety of humans and animals alike. Predictability in environments, routines, and keeper movements allows hoof stock to anticipate future events and respond calmly. Wary hoof stock often allow closer approaches if keepers walk a zigzagging path perpendicular to the direction of actual movement. Surprise advances can be prevented by creating deliberate noises like jingling keys, pronounced to provide constant background noise in holdings, thereby reducing the impact of startling sounds. Desensitization to keepers is advisable in order to diminish flight responses during daily care; animals in smaller enclosures will generally habituate more readily than those that have extensive space to flee. However, there is a fine balance between desensitization and becoming overly friendly, and fearless ungulates can draw keepers into dangerous situations.

KEEPER SAFETY

Ungulates have the potential to harm humans in a variety of ways. Horns and antlers are efficient and effective weapons. Strong, hoofed limbs can deliver crushing blows: horses kick backwards, giraff's kick forward, deer may rear up and "punch" with their front feet, and camels can kick their legs in all directions. Several ungulates, including pigs, tapirs, camels, and tiny chevrotains, have sharp tusklike teeth. Body weight alone may pose a safety hazard, should part of a keeper's body be caught between the animal and a solid object. It is vital for keepers to understand the potential dangers involved with their animals, and to work wisely to avoid injury. Moving an animal to another enclosure before servicing is the best way to ensure keeper safety. Gates should be firmly latched and locked, since charging and butting may force unsecured doors open. When working close to barriers, keepers must remain aware that charging animals may cause fences to bulge outwards. Horns, antlers, mouths, and hooves can also be extended into keeper spaces; as an extreme example, the long horns of oryx antelope (*Oryx* spp.) can spear an object a meter away through a chain-link fence. If keepers must enter an enclosure with hoof stock, they should pay constant attention to animal behavior—starting before entering the enclosure and continuing until after servicing is complete and the enclosure is secured. The safety of both keepers and animals depends on recognizing changes in behavior, responding proactively, and knowing escape routes: keepers should immediately remove themselves from any potentially unsafe situation. If necessary, servicing can be delayed to allow the animals to calm down, or other keepers can be sought for backup. The presence of two or more keepers provides increased opportunities for observation and an immediate source of assistance in case of emergency; in many cases, ungulates will also keep a greater distance from multiple people than from one. A keeper should never hesitate to ask a colleague for assistance if uncomfortable in the presence of hoof stock. Ungulates normally tolerant of keeper presence may be more flight-prone during and after a traumatic event such as a severe storm, construction, or veterinary work. Their temperament may also be affected by changes in season, social structure, and hormonal activity; male ungulates, particularly deer, can be very aggressive during the breeding season (rut). Space and social considerations also play a role, and animals that are isolated or in confined spaces may behave differently than their counterparts in larger enclosures or more social settings. Habituated hoof stock are more likely to approach keepers when seeking food or attention, or when defending mates, infants, or territory. Although keepers may desire this close footsteps, or quiet talking. A softly-playing radio can be used connection, maintaining a healthy respect for—and distance from—all ungulates is prudent, since all animals have the potential to be unpredictable. The best practice is to reduce the motivation for approaching closely, such as by cleaning around feeders before bringing food into the enclosure. Bold keeper movements, which usually cause hoof stock to flee, can invite combat in unafraid ungulates. Brooms, rakes, and other tools can be used as passive barriers to keep animals back, but physical contact (striking an animal) may incite aggression and should be avoided as a method of defusing a potentially dangerous situation.

NUTRITION

Most hoof stock are exclusively herbivorous, although a few groups, like pigs (Suidae) and duiker antelope

(Cephalophinae), will consume animal matter opportunistically. Since mammals do not produce fiber-digesting enzymes, ungulates rely on symbiotic bacteria and protozoa (microbes) to digest (ferment) plant fibers, gaining the added benefit of microbe-produced vitamins and energy-rich fatty acids. These fermentation by-products are best absorbed in the upper intestines, so that species which accommodate microbes in their enlarged multichambered stomachs before the intestines (foreguts)—such as camels, hippos, and ruminants—are more efficient at extracting nutrients than those with expanded lower intestines (hindguts), like pigs, peccaries, and all odd- toed ungulates. The result is that foregut fermenters typically require much less food than similarly- sized hindgut fermenters (monogastrics). Plant-produced fiber comes in many different forms, which has led to a range of dietary specializations in ungulates. Roughage feeders like wild horses (*Equus* spp.) and wildebeests (*Connochaetes* spp.) have high-crowned teeth and muscular stomachs to cope with fibrous plants like grasses. A reasonable approximation of a grazer's diet can be achieved with fiber-rich grass hay like timothy or Bermuda grass. Conversely, browsers such as dik-dik antelope (*Madoqua* spp.) and musk deer (*Moschus* spp.) selectively forage on leaves, buds, and other high-protein, low-fiber plant parts. These concentrate selectors have low-crowned teeth and smaller stomachs, and therefore avoid fibrous stems and usually refuse grass hay. Legume hay like alfalfa is a better browser choice, but it is far from optimal due to the hay's large stem fraction and small, sparse leaves. Ungulates with intermediate feeding strategies, such as gazelles (*Gazella* spp.) and Père David's deer (*Elaphurus davidianus*), feed on a wide variety of vegetation in the wild and benefit from a mixture of the two hay types in captivity. When both hays are fed together, the amount of protein-rich (and therefore palatable) legume hay should be restricted to encourage consumption of grass hay; for grazing species, legume hay should be fed only in limited quantities to prevent digestive distress. Captive browsers frequently develop oral stereotypies and digestive issues because of the poor match with their natural diet: browse is their optimal fiber source. Formerly used strictly for enrichment, browse is slowly being integrated into nutritional plans thanks to production and preservation innovations. Keepers should consult a horticulturalist or browse reference (see further reading) before feeding any browse: toxic species may cause vomiting, inappetence, diarrhea, excessive or foamy salivation, paralysis, or even death (Rietschel 2002, 110– 12). Hay is the cornerstone of hoof stock diets, providing fiber and occupation in the form of chewing. However, local growing conditions often result in nutritional deficiencies. Supplementation with pelleted concentrates (which contain all major nutrients) helps to ensure that captive diets are nutritionally balanced. A variety of pelleted formulas are available commercially to meet species-specific requirements. For instance, Dall's sheep (*Ovis dalli)* do well on standard ruminant pellets, but European mouflon (*Ovis aries musimon*) require a low-copper version. New browser formulas are also being developed to address the common nutritional issues of the group. Balancing nutritional and occupational needs of hoof stock requires an appropriate ratio of hay and concentrate, typically 25 to 40 pellets by weight (Lintzenich and Ward 1997). Drinking water must be provided for proper digestion of these dry feeds: automatically filling reservoirs and manually filled water bowls are two popular options. Where freezing is a concern, heated water sources are needed to ensure constant availability; ungulates are also more likely to drink water that is not extremely cold. Nutritional demands may fluctuate between seasons and (for females) may increase dramatically during pregnancy and lactation, thus requiring keepers to adjust diets on the basis of their observations of food consumption and body condition. The amount of food offered can be easily increased or decreased, but changes to the diet's composition or to the relative proportion of feeds must be made gradually (over several weeks) to allow the gut microbes to adapt. Adding or removing components too quickly—including giving unaccustomed animals free access onto rich pasture—can lead to diarrhea or constipation. Some nutritional issues can be resolved with supplements like salt (sodium chloride) and coat conditioners; foregut fermenters can also benefit from trace minerals like cobalt, thanks to their symbiotic microbes (monogastrics cannot absorb mineral-based by-products). Fruits and vegetables (produce) are rarely used for nutritional purposes, due to their high sugar levels and low fiber content. However, their palatability can be used to encourage consumption of supplements or medication and to provide motivation during training and enrichment. Since produce ferments rapidly once ingested, only very limited amounts should be fed.

FEEDING

Feeding captive diets in an appropriate manner is important for encouraging consumption. Exposed locations may discourage feeding in inclement weather; sheltered locations have the added benefit of minimizing nutrient leeching and spoilage (pellets in particular disintegrate when wet). Feeding methods should cater to a species' foraging ecology: browsers like giraffes (*Giraffa camelopardalis*) may be reluctant to feed at low feeding stations, and grazers like white rhinos (*Ceratotherium simum*) may be unwilling or unable to feed from elevated feeders. Ground-level feeding can result in substrate ingestion, a risk that can be minimized by feeding pellets from troughs or bowls. Such feeders can also discourage freeloading pests (e.g., rodents and waterfowl) that might otherwise consume a large proportion of the rations. In group situations,

multiple feeding sites are often needed to ensure that dominant animals do not exclude subordinates from food or water. Creeps or exclusion feeders are another solution, using body size or the presence of horns or antlers to provide less competitive animals with access to food. By confining feeds, feeders allow good estimations of food intake. Left over food should be removed daily and the amounts offered should be adjusted to prevent excessive waste. Feeders are usually dry-cleaned (swept out) and sporadically washed, but wet cleaning may be needed daily with animals that salivate copiously, like giraffes. Feeders should be dry before being filled, since moisture accelerates spoilage of pelleted feeds. The variety of mouth sizes, feeding positions, and horn and antler morphologies in exotic hoof stock creates a number of species- specific challenges when selecting feeders and waterers. Horns, antlers, and tusks are prone to entanglement. Hay nets are unsuitable for hoof stock with these features, and hayrack bars should be spaced to accommodate only the muzzle (since horns and antlers can catch on wider bars, entrapping the head). Conversely, water bowls often need larger openings and should be located away from obstructions to ensure that horned individuals can freely access water. Pigs, which tend to root, should be fed and watered from weighted troughs to prevent overturning; a nipple- style waterer is another option successfully used with several wild pig species. Keepers should always pay close attention to food items. Pellets should be dry and firm; dustiness, clumpiness, and the presence of mold indicate spoilage. Flakes of hay should be pulled apart and examined using sight, smell, and touch: it should optimally be soft, green, leafy, and sweet-smelling, while inferior hay may be brittle or brown. Quality checks will also highlight hazards like wire, broken baling equipment, and baling twine, which may cause trauma to the mouth or gut, or carcasses, bird droppings, mold, and weeds, which may be sources of diseases or toxins. Problematic feeds should be discarded and reported; ingestion of inappropriate material can have severe health consequences.

CLEANING

The feeding ecology of ungulates makes cleaning an essential duty of hoof stock keepers. Parasites and diseases sustained by fecal-oral transmission are easily passed among confined ungulates feeding from fecally contaminated areas. Feces should always be removed daily from around feeders; regular removal from the entire enclosure is also important, particularly for grazing species. Most hoof stock produce hard, pelleted feces which can be raked or swept up easily, leaving minimal residue. Dry cleaning is often acceptable, conserving water, reducing potential slip hazards, and prolonging the life of bedding materials. Species with soft feces or messy toilet habits, such as hippos, are an exception: hosing and scrubbing may be needed daily.

HANDLING

Hoofstock instinctively avoid potential threats by maintaining their flight distance, and will typically move away if approached by a keeper. Used carefully, this innate avoidance behavior can be harnessed as a low- stress handling tool to move ungulates between enclosures and to recapture escaped individuals; Grandin (2005) provides an excellent perspective that all hoof stock keepers should read. Patience is necessary when working with ungulates. Walking at a slow pace behind hoof stock usually incites calm, directional movements, so long as keepers approach only as close as is needed to get the animals moving forward. Trying to hurry ungulates by making loud noises or by approaching too closely or too quickly is counterproductive: fear increases stress, and results in erratic fight- or-flight behavior.

RESTRAINT

Although hands-off handling is largely sufficient when managing hoof stock, physical handling is sometimes required, such as for medical purposes. To reduce the inherent stress of restraint, blindfolds and earplugs can be used on the animals to minimize sensory input and thereby induce calm and minimize struggling. Keepers should also work efficiently to prevent prolonged handling. Before any restraint procedure, the staff involved should review their individual roles, the intended movement of animals, and potential hazards (including horns, tusks, and hooves) to ensure everyone's safety. Understanding the risks to the animals is also vital. Capture myopathy, in which extreme stress and exertion cause muscle cells to die, is a serious and sometimes fatal risk in hoof stock restraint. Treatment is difficult once the condition begins, making preventative measures essential: high ambient temperatures, extended duration of chases and restraint, and excessive restraining force should all be avoided. Supplemental selenium and vitamin E may be administered during restraint procedures to prevent deficiencies that can exacerbate muscle issues (CAZWV 2009, 9.20– 9.23). Another principal concern is regurgitation and aspiration of stomach contents, which may cause fatal pneumonia in restrained hoof stock; ruminants are particularly at risk, due to their large foreguts. Veterinarians may suggest that ungulates be fasted to reduce their regurgitation, particularly before being chemically immobilized. A 12- to 24-hour fast is typical for monogastric ungulates, but recommendations vary for foregut fermenters because their stomach chambers always retain fluids. During restraint procedures, keepers should watch carefully for signs of regurgitation such as green froth in the nose or mouth, or heavy, wet breathing (CAZWV 2009, 9.15). Whenever possible, hoof stock should be restrained belly down (sternally); the head should be elevated, with the nose pointing downward to allow any fluids

to drain out of the mouth. Lateral positioning carries greater regurgitation risks for ruminants: when the animal's left side is on the ground, downward pressure from the body's weight can force stomach contents up into the esophagus, but when the animal is restrained on the right side, the force of gravity can draw fluids out.

PHYSICAL RESTRAINT

The capturing and handling of small ungulate species is often done by hand; this method is faster and poses fewer risks to delicate limbs than the use of nets. Bush (1996, 33) suggests a 15 kg maximum body size for manual restraint, although hoof stock weighing 45 kg can be successfully restrained by a coordinated team of keepers. Captures are quickest in small enclosures, which limit mobility; the natural tendencies of hoof stock to move as a group and run around the perimeter can be exploited to quickly catch individuals. Once the animals are in hand, their struggling can often be reduced by lifting at the groin, so that the rear hooves do not make contact with the ground; species or individuals that continually struggle are better suited to other restraint methods. Horns are convenient handles to hold during catch-ups, but forceful twisting should be avoided lest the outer sheath detach from the bony core beneath, particularly in young animals. Deer antlers, which are grown and shed annually, are unsuitable handles: while growing they are sensitive, vascularized, and easily injured, and when mature the gradual weakening of the connection to the skull may permit them to be broken off with minimal force. Mechanical restraint devices are commonly used for larger and tough-to-handle ungulates. Standing chutes, essentially narrow hallways, are easily created in existing corridors and work well with cooperative training programs. Physical restraint can be performed using drop-floor chutes and hydraulic tamers, which gently squeeze an animal with moveable floors and walls, and have access panels to reach various body parts. Restraint devices are typically associated with a series of pens and alley-ways to sort and separate animals. Walls in such facilities should be solid (with peepholes for monitoring) to eliminate external stimuli that may cause ungulates to balk; similarly, curved runways promote better forward movement than those with visible dead ends.

CHEMICAL RESTRAINT

For situations in which physical restraint is impossible or invasive procedures are involved, immobilizing drugs may be used. Anesthesia should be performed by a veterinarian, and keepers should be prepared to follow their directions throughout the procedure. By disrupting muscular function, immobilizations can hamper normal processes, leading to regurgitation or stalled breathing. On occasion, fermentation gases may build up in the stomachs of foregut fermenters and may further hamper breathing and stimulate regurgitation. This condition, observed as abdominal bloating, can usually be resolved by shifting the animal's body position to permit the gases to be burped up (eructed). After the immobilizing drugs are reversed, the ungulate should be kept in a dark, quiet stall as its poor post-procedure coordination increases the risk of self-injury. Depending on the drug, the recovery period may last for up to 72 hours, as signs of sedation may reappear after an animal has apparently recovered (this is called renarcotization or resedation).

BEHAVIOR TRAINING

While shifting can be accomplished using herding techniques, formal training programs can be used to reduce flight responses and facilitate cooperative medical treatment. Ungulates are adept learners and can be taught numerous behaviors such as voluntary blood draws, ultrasounds, semen collection, hoof care, and tusk trimming. A stumbling block in using positive reinforcement to train hoof stock is in finding effective reinforcers. Food may not be a strong motivator, especially for ungulates with constant access to forage. Common food rewards for ungulates include concentrates, browse, and produce. Other novel dietary items may also increase motivation: primate leaf-eater biscuits, for instance, tend to be popular with many browsers. Veterinarians and nutritionists can help adjust diets to accommodate training additions, and can also highlight concerns (onions, for instance, are toxic to most hoof stock). Other reinforcers can be found in training articles and husbandry manuals (see additional readings); tactile reinforcement has proven effective with several ungulates, including pigs, tapirs, and rhinos. The close proximity to animals during training can pose a danger to keepers. This risk can be reduced by minimizing opportunities for undesired contact (e.g., biting or crushing force), such as by using long-handled brushes to touch animals. When training without a protective barrier, a two-keeper policy is highly recommended. Training through a barrier is sometimes seen as a hindrance, but it can be a lifesaving precaution when keepers work with large or aggressive hoof stock. The training of timid species may even be accelerated with a barrier, as physical separation from keepers can give the animals a sense of security, reducing flight distance and nervousness.

BEHAVIORAL ENRICHMENT

Encouraging natural behavior is a principal goal of enrichment, and Burgess (2004) provides a wealth of enrichment ideas for hoof stock. Occupied animals are less likely to exhibit stereotypical behaviors as a result of their captivity. Severe problems such as self- mutilation are rarely seen in hoof stock, but captive ungulates spend far less time feeding than their wild counterparts, and may therefore develop oral stereotypies like object-licking and tongue-rolling. Multiple feedings per day and the use of

feeders (from simple hay racks to more complex puzzle toys) help eliminate these issues by promoting foraging. Providing additional hay or browse also helps by increasing chewing opportunities.

Many natural behaviors can be stimulated environmentally. A variety of substrates provides options for dust bathing, mud wallowing, and grazing; topographical diversity increases exercise while creating lookout points and sheltered refuges; and exhibit furniture like rubbing posts and deadfall encourages grooming and play. In addition to these choices, movement and exploration can be encouraged by thoughtfully positioning food, water, and shelter around the enclosure. Safety concerns must be addressed before enrichment is offered. Hanging items should be used with caution; lengths of rope, chain, and cable should be sheathed with pipe to prevent strangulation and entanglement. For the safety of the public, heavy enrichment and furniture for powerful species should be anchored to prevent them from being tossed wildly around.

The alertness and suspicion of ungulates can make providing them with novel stimuli a challenge. New objects may be viewed as a threat, and should not be placed near gates through which animals are expected to move. Nervous animals may derive enrichment from observing items placed outside of their enclosure; this is a good initial step before the objects are brought into the enclosure. As ungulates gain experience with novelty, their suspicion towards new things becomes less severe: enrichment makes change a part of their routine and helps reduce stress in unplanned unusual situations.

Group housing is arguably the best enrichment for herd- living ungulates, as it encourages social behavior like herding, hierarchical establishment, and breeding. Social interactions can also enrich typically solitary species, and need not be limited to the same species: mixed- species exhibits, in which hoof stock are housed with other animals, are common in modern zoos. Several databases (e.g., on the AZA Antelope TAG website) document experiences with mixed- species combinations. Mixing of ungulates should be attempted with an understanding of risk, as some groupings may be ill-advised due to behavioral incompatibility, enclosure setup, or even possibilities of hybridization.

HOOFSTOCK INTRODUCTIONS

Understanding a species' natural social tendencies and the demeanor of the animals involved is key to planning a successful introduction. For many species, females tend to be easier to maintain in groups; males, which must compete for access to mates in the wild, are usually more aggressive and may be intolerant of other males. Young ungulates are easier to integrate into established herds, on account of their sexual immaturity and the minimal threat they pose to existing hierarchies. In contrast, new adults are often harassed, especially by individuals of the same sex, in order to establish dominance.

Aggression in the initial introduction stages can be buffered by allowing restricted contact through a barrier. Even after ungulates have become accustomed to each other's presence, sparring matches and chases are common when they are introduced to the same space for the first time. Introduction locations should have sufficient space for the animals to get away from each other, with circular routes to prevent individuals from being cornered. Agonistic encounters help establish social order and should be allowed to occur; separating animals during a fight or chase can increase their aggression in later introduction attempts. However, excessive aggression between incompatible individuals may lead to injury or death. Keepers should therefore closely monitor introductions and keep records of behavior. Dominant or aggressive individuals can be preemptively impeded by blunting their tusks, sawing off their antlers, or sheathing their horn tips with rubber hose, tennis balls, or resin spheres. Tranquilizing drugs can be used to disrupt social patterns and permit new animals to integrate into a group, but timing introductions with the animals' reproductive cycles—when their sexual activity overrides other social factors—is often the most successful method.

REPRODUCTION

Captive environments do not always suit innate reproductive cycles: hoof stock infants born during freezing winters or scorching summers may experience high mortality. To maximize infant survival, it is common practice to time breeding introductions so that, based on the species' gestation period, births occur during the optimal birthing season (often in spring). Males are usually added to a group when females begin to enter their period of reproductive receptiveness (called estrus or "heat"). A variety of physical and behavioral signs can be used to detect estrus, including swelling and mucus discharge from the vulva, mounting by other females, and often increased vocalization. The behavior of males can also provide important clues: they are adapted to detect subtle reproductive signals, and often show increased agitation and competitiveness when near a receptive female.

PREGNANCY AND BIRTHING

After breeding introductions occur, recorded observations of mating are useful for determining when males can be separated, which females may be pregnant, and when births should be expected. Among pregnant ungulates, physical signs of impending birth (parturition) include a prominent udder, a swollen vulva, and a shift in how the fetus is carried. Hoofstock births usually occur at night or in the early morning, and as labor begins, expectant

mothers tend to seclude themselves and become restless. Females near parturition are sometimes kept in maternity stalls, which should be well bedded to provide cushioning to the newborn and to absorb fluids discharged during birth; these might otherwise cause infants to slip or splay, potentially causing life-threatening injuries. Single infants are typical of many ungulates, but twins, triplets, and (in the case of wild pigs) litters up to twelve may occur. Hoofstock infants are universally precocious, able to stand and nurse soon after birth. This is obvious in "follower" ungulates like wildebeests (Connochaetes spp.), in which infants closely accompany their mothers (dams) from the moment they gain their footing. In contrast, the monitoring of mother-infant interactions is more challenging with "hider" species like white- tailed deer (*Odocoileus virginianus*), in which the dam leaves the infant in a concealed spot and visits it two to four times per day for nursing; only after a period of days, weeks, or sometimes months is the infant consistently seen in its mother's presence. Knowing the species' biology is therefore essential in interpreting whether an isolated infant has been abandoned or is acting normally.

Identifying the dam (and the sire, if known) is important for management programs; in herd situations, new mothers can be identified by physical evidence, like fluid stains on the hind legs and afterbirth hanging from the vulva, and behaviorally, using cues such as nursing and defensiveness. Observations of nursing are important for assessing the infant's health, as the neonatal immune system depends on milk-borne antibodies during the first few days after birth (the antibody-rich milk is called colostrum). Proper positioning at the udder does not itself indicate nursing; milk acquisition is better inferred from an enthusiastically wagging tail during nursing or a milky muzzle afterward. Maternal behaviors to watch for include grooming, tolerance of nursing, and licking of the neonate's anogenital region to stimulate defecation. Keeper observations should be made from a respectful distance, since perceived threats can discourage normal mother-infant interactions. Remote video may be the best option for monitoring highly sensitive species.

INFANT CARE

Hoof stock neonates usually receive a veterinary exam 24 to 48 hours after birth. Performing the exam any sooner risks disrupting the mother-infant bonding process, and performing it any later can allow the cursorial skills of infants to outmatch those of keepers. Infants are almost always caught and restrained by hand; the capture should be done quickly, since neonates tire easily and can severely injure themselves while running on unsteady legs. Defensive mothers pose a risk to keepers during infant capture and examination, and even typically shy animals may be very bold in response to an infant's distress cries. For the safety of everyone involved, the dam and any other group members should first be separated into another enclosure. If this is not possible, the infant should be taken to a protected area for the examination.

Young infants usually require minimal restraint. Smaller hoof stock will often rest quietly when held in a keeper's arms, while larger individuals are usually held in a prone position. During the examination, veterinary staff will confirm the infant's gender, apply permanent identification (such as ear tags, ear notches, or microchips), and check for congenital problems like cleft palate or imperforate anus. A small blood sample is frequently drawn to test for glucose and antibody levels (to confirm nursing), and injections of antibiotics, vaccines, and other supplements may be given. The way an infant is returned to its mother after the examination depends on the species. Followers set down in view of their mothers will usually run directly back to them, while hiders should be returned to their caching spot. Keepers should then watch to ensure that the infants are successfully reunited with their mothers and that maternal care has not been disrupted.

Difficult decisions must occasionally be made during neonatal checkups. Untreatable conditions may warrant euthanasia; culling is also used by some institutions for population management, especially with surplus males. Treatable medical concerns or maternal neglect may require infants to be hand-raised. Some zoos also purposely hand-rear skittish species like duikers (*Cephalophus* spp.) and gazelles (*Gazella* spp.) to facilitate their habituation and reduce trauma-related mortality. Hand- raised infants can become imprinted on humans if reared in isolation, preventing successful integration with conspecifics. Socialization with other ungulates is important in promoting species-typical behaviors, and it reduces the likelihood that aggression or courtship will be directed towards humans in adulthood. To this end, keepers should avoid "roughhousing" with young ungulates, since it can encourage habits that are dangerous in adults. If hand-raising is needed for reasons besides desensitization to humans, it may be possible to maintain an infant in its natal group while providing it with supplementary feedings or treatment (Read and Meier 1996, 43); this strategy minimizes the potential for imprinting. Several resources are available for hand-rearing hoof stock (e.g., Greene and Stringfield 2002), providing guidance on milk formulas and amounts, feeding schedules, nipple sizes, and weaning times. As juveniles transition onto solid foods, they must acquire fiber-digesting microbes. Many of these and fecal consistency suggest that an infant is not digesting fiber properly, its gut can be inoculated by adding a sample of screened feces or stomach contents (for ruminants) from the natal group to the infant's food.

CONTRACEPTION

The limited space in zoos requires planning to avoid the production of surplus animals, but preventing reproduction can cause physical and behavioral issues. Indeed, female ungulates that do not breed for several years may become effectively sterile with the onset of physical and hormonal changes that prevents conception; this phenomenon nearly destroyed the American population of Przewalski's horses (*Equus ferus przewalskii*). Because each contraceptive option has different costs and benefits, a combination of methods is the best choice for sustainable population management. Breeding is most readily controlled by separating males and females. However, disrupting natural mixed-sex herd structures can lead to unstable hierarchies and increased aggression among females. Similarly, isolated males may lose normal social behaviors; if separated from the herd at a young age, they may become socially incompetent and unable to successfully court or breed females when eventually placed into a breeding situation. Bachelor groups comprised solely of males are one way to provide socialization, and short-term successes have been achieved with several ungulates, including Speke's gazelle (*Gazella spekei*) and Grevy's zebra (*Equus grevyi*). To circumvent natural aggressive tendencies among males, these groups are best created with similarly-aged, sexually immature animals, and should optimally be kept away from visual, auditory, and olfactory contact with females. Monitoring the behavior of these groups is important as males age and mature: bachelor herds are rarely stable over the long term. Surgical contraception of males (castration or vasectomy) eliminates the need to separate the sexes to prevent reproduction. Castrated males do not develop testosterone-induced characteristics; this reduces aggression but also reduces sexual markings, manes, and musculature. Vasectomised males, on the other hand, retain these physical and behavioral traits; their aggression can even be increased, since they often become competitive and aggressive to other individuals whenever a female comes into estrus (a frequent occurrence when pregnancy is prevented). Surgical contraception of females is significantly more invasive, and is usually done only for medical reasons. Chemical contraception is currently only effective for female hoof stock, where most options work by interrupting estrus cycles. This not only allows the sexes to remain together, but eliminates many of the behavioral consequences described above. However, while usually reversible in the short term, some contraceptives can cause sterility when used for extended periods, thus tempering their social benefits. The AZA's Contraception Center (listed in suggested websites) is a primary resource for chemical contraception.

TRANSPORTATION

Transportation options are limited for most exotic hoof stock. Crates are the most practical method for transporting powerful ungulates, and are usually necessary for moving animals by airplane. A crate should be sized appropriately to allow the animal to stand up and lie down, but too much space can allow a stressed individual to injure itself. Horns and antlers also need to be considered, as they may require significant additional height or width. When groups need to be relocated, livestock trailers provide an efficient way to move compatible individuals together. Bedding should always be provided to provide cushioning and traction in transportation. Most ungulates will not willingly enter a strange transportation container, but can be gradually desensitized to do so using dietary rations. Desensitization to the closing of crate doors is beneficial, but must be done slowly and well in advance of shipment; following a negative experience, hoof stock often balk at re-entering an enclosed environment. When training is not feasible, manual handling can be used to crate smaller species. Larger species may require mild sedation or closer approaches within their flight zone to get them to enter a confined transportation space. During transportation and after arrival at the destination, darkness and quiet can help calm hoof stock. Mild sedation of nervous individuals can further reduce stress. Excited individuals should be given time to calm down before being offloaded, to prevent them from rushing blindly into the new environment. Crated hoof stock should be released from the rear of the crate: backing them out minimizes the chances that a traumatic collision will occur. As further insurance, some arrival stalls have padded walls to reduce the risks of trauma; unpadded walls can be lined with straw bales if it is deemed necessary.

VETERINARY CARE

The veterinary care of exotic hoof stock draws heavily on the techniques developed for domestic livestock, although the similarities between these groups must be considered alongside significant and sometimes unexpected differences. Injuries are particularly challenging to treat, making the elimination of potential sources of trauma (e.g., uneven substrates and unsafe barriers) the better option. Proactive training is highly recommended to facilitate medical management.

GASTROINTESTINAL ISSUES

The most frequently encountered hoof stock health issues occur along the digestive tract. Colic is an umbrella term for symptoms such as bloating, abdominal discomfort, and diarrhea or constipation. Colic has many causes, including impactions of substrate, hair, and other foreign materials; insufficient water consumption; rapid dietary changes; excessive fermentation; or twisting of the

intestines. In mild cases, keepers can relieve the symptoms by withholding highly fermentable foods (e.g., produce and concentrated feeds), providing warm water to stimulate drinking, and encouraging exercise. Severe cases may require emergency surgery. Colic tends to be acute, while intestinal parasites are often a chronic problem. Many ungulates harbor parasites without showing ill effects, but high parasite numbers may cause loose stool, poor body condition, weight loss, or even sudden death, feces for eggs and parasites prior to treatment with medications like fenbendazole or ivermectin. Prophylactic treatment in temperate climates is often performed in spring and late summer when parasite egg counts typically rise. After medication, follow-up tests will confirm whether the treatment was effective and whether additional treatment is needed. Parasites are best controlled with good hygiene around feeding areas. In severe cases, parasite transmission can be hindered by restricting the animals' grazing opportunities, regularly mowing grass, providing rocky or sandy terrain, and bringing the ungulates off paddocks at night. Moving animals to different enclosures can also break the cycle. If an ungulate has trouble eating, salivates excessively, or chews more frequently than usual, there may be issues with its teeth. Older animals are more prone to overgrown teeth, which are corrected by rasping (or "floating") excess enamel ridges to realign the chewing surfaces. Other oral issues, like gum abscesses or trauma to the mouth, may develop into extensive swelling, known as "lumpy jaw." Because swelling is seen only in chronic cases, early diagnosis is challenging; treatment usually requires that teeth from the affected area be removed.

HOOF CARE

Activity levels, genetics, and injuries may make some animals prone to hoof problems even if they are housed on appropriate substrates. If left untreated, an overgrown hoof may crack or separate from the sole of the foot, thereby straining the underlying bone structures. Vascular issues, including high blood acidity levels from the rapid fermentation of rich feeds, may cause the hoof structures to become inflamed and to separate from each other. In severe cases, this laminitis can develop into a painful condition known as founder, in which the terminal bone of the foot rotates away from the hoof. Hoof problems can affect an animal's quality of life and its ability to breed, and may even result in death. Early detection and treatment is far easier than dealing with progressed hoof disease. Exotic ungulates can be trained to allow voluntary footwork, but usually this work is performed under anesthesia. The resulting unusual positions and species-specific morphologies can make trimming overgrown hooves a challenge even for experienced personnel (in some regions, all hoof work must be performed by licensed farriers). When a hoof is trimmed, its keratinous wall should be shaved down in numerous thin passes to prevent the sensitive living tissues within the hoof from being exposed.

DISEASES

Exotic ungulates are susceptible to many of the same diseases that affect domestic livestock, and the risk of transfer between these two groups (and to humans) has resulted in tight medical regulations for hoof stock. Zoos that house multiple ungulate species must also contend with the transfer of disease (e.g., malignant catarrhal fever) from asymptomatic carrier species to neighboring susceptible species. Important hoof stock diseases (Rovid-Spickler and Roth 2006, 113– 245; Junge 2007, 1– 2) include

- transmissible spongiform encephalopathies (prion diseases), like bovine spongiform encephalopathy (BSE or "mad cow disease"), scrapie, and chronic wasting disease (CWD)
- bacterial diseases, including anthrax, brucellosis, leptospirosis, bovine tuberculosis (TB), and Johne's disease (paratuberculosis)
-viral diseases, including foot and mouth disease (FMD), bluetongue, malignant catarrhal fever (MCF), rinderpest, equine encephalitis, and West Nile virus.

These diseases are rarely seen in healthy, well-managed zoo collections due to government-enforced quarantines, which maintain new animals in isolation for a period of testing lasting at least 30 days. Permanent quarantines, like Permanent Post-Entry Quarantine (PPEQ) in the United States, may be mandated for ungulates arriving from the wild or other high-risk areas. Quarantine regulations are in place to ensure the health and safety of human and animal populations, and they must be closely followed.

MEDICATING

When an illness or disease requires treatment, a principal challenge is delivering medications to hoof stock. Noninvasive oral medications are usually offered on favored foods like pellets or produce; consumption can be further encouraged by holding back other rations until the medication is consumed. Oral medications tend not to be used with foregut fermenters, as their stomach volume hampers timely absorption and the foregut microbes may neutralize drugs. Long-term oral antibiotics also risk destroying the microbial population, requiring gut inoculation after treatment. In contrast, injectable drugs ensure that therapeutic levels are achieved without harming the digestive microbe balance, but regular delivery can be nearly impossible unless animals have been trained for voluntary injections. Where nervous ungulates require extended treatment, long- lasting tranquilizing (antipsychotic) medications can make the procedures safer and less stressful.

CONSERVATION AND RESEARCH

Many wild ungulates are of conservation concern, as their relatively large size makes them vulnerable to habitat loss and hunting. Unfortunately, several recent ungulate species are already extinct: in 1883 the last quagga (*Equus quagga quagga*, a relative of the zebra) died at the Artis Zoo in Amsterdam, and in 1938 the last Schomburgk's deer (*Rucervus schomburgkii*) was killed in a temple zoo in Thailand. Despite these losses, several ungulates owe their continued existence to captive breeding, including the Przewalski's horse (*Equus ferus przewalskii*), the Père David's deer (*Elaphurus davidianus*), the Arabian oryx (*Oryx leucoryx*), and the European bison (*Bison bonasus*). These species were once extinct in the wild, but zoos have preserved them all and reintroduced them to their native ranges. Zoos are developing more partnerships with *in situ* projects, providing funding and expertise to help conserve ungulates in the wild. In captivity, research is being conducted on assisted reproductive technologies like artificial insemination been developed for several exotic ungulates including the bongo (*Tragelaphus eurycerus*), the banteng (*Bos javanicus*), and the gerenuk (*Litocranius walleri*). Their widespread use is limited by the species-specific nature of hormones, anatomy, and physiology, as well as by the expense involved. Once developed, however, these assisted reproductive techniques allow zoos to transfer gametes instead of animals and, through gamete preservation, involve deceased individuals in breeding programs. In the future, gamete transfer may permit gene flow between zoos and the wild, although tight quarantine regulations on biological samples (including semen) remain a major hurdle.

SUMMARY

The diversity of ungulates makes generalizing many aspects of their husbandry a challenge. Providing appropriate care in regard to housing, group size, and diet requires hoof stock keepers to research and understand the natural history of the species they care for. Keepers must work in a calm, predictable manner and develop keen observational skills to overcome the survival adaptations of ungulates. Although hoof stock is sometimes challenging to work with, the benefits of maintaining these species in zoos are immense, and captive conservation programs continue to directly enhance populations of ungulates in the wild.

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