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Methods for the Effective Care and Rehabilitation of Captive Lumholtz's Tree-kangaroos

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Methods for the effective care and rehabilitation of captive Lumholtz's Tree-kangaroos (*Dendrolagus lumholtzi*)

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Abstract

Lumholtz's tree-kangaroo, *Dendrolagus lumholtzi*, is one of only two kangaroo species endemic to Australia's rainforests. However, studies concerning the species are limited, and public knowledge of the species is close to non-existent (Tisdell & Wilson, 2003). Lumholtz's tree-kangaroo is slowly making its way into Australia's zoos and into the public eye, but lack of formally presented information pertaining to its care has made maintenance of captive populations difficult. With an increasing number of Lumholtz's tree-kangaroos coming into care due to dog attacks and motor vehicle accidents, the need for formalized husbandry information is becoming ever greater (Tree-Kangaroo and Mammal Group, 2000). This study recorded the care methods used by the world's only tree-kangaroo rehabilitation organization, Tree Roo Rescue and Conservation Centre Ltd. Through daily observations of routine procedures and rehabilitation practices, this study was able to effectively describe current methods for housing, feeding, and management of Lumholtz's tree-kangaroos. In addition, comparisons against the most recent care manual highlight key differences in care between tree-kangaroo species. While more research is needed, especially pertaining to nutritional requirements, presentation of these methods is the first step in the creation of a husbandry manual tailored to the requirements of Lumholtz's tree-kangaroo.

Keywords: *Dendrolagus lumholtzi*; Lumholtz's Tree-kangaroo; Husbandry; Rehabilitation;

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1.0 Introduction

1.1 Context of Study

The Australian continent is renowned for its unique assemblage of flora and fauna. Visitors from around the world aim to catch a glimpse of kangaroos and koalas, but unfortunately, these endemics among many others are becoming increasingly threatened by invasive species, habitat loss, and urbanization. With Australia's signature species becoming more difficult to find in the bush, visitors must rely on those animals maintained in captivity. Koalas and several species of terrestrial kangaroos can be found in almost every Australian zoo, yet some of Australia's most remarkable animals are the least well advertised.

Take for example, the tree-kangaroo, featured in only nine of Australia's seventy-two zoos and sanctuaries (Oz Animals, 2014). Of these, only three zoos actually feature an Australian native, while the remaining six carry a species native instead to New Guinea (Oz Animals, 2014). This has resulted in a severe lack of knowledge and awareness within the Australian community concerning tree-kangaroos. In a survey conducted in 2003, only 36% of Brisbane residents had heard of tree-kangaroos, while only 16% knew that two species could be found in Australia (Tisdell & Wilson, 2003). Unfortunately, this lack of knowledge extends past the general public and into the scientific community. Research on the Australian tree-kangaroos did not truly take off until the late 1980s (*Dendrolagus lumholtzi,* Procter-Gray, 1985, Newell, 1998; Coombes, 2005*)* and early 1990's (*Dendrolagus bennettianus*, Martin, 1992) and has since progressed relatively slowly, leaving large gaps in information on population sizes and ecological requirements. In addition, dissemination of the current knowledge is extraordinarily limited. This has led to sub-optimal care of captive zoo animals, and difficulties in maintaining captive populations.

The first captive population of *D. lumholtzi* was established in 1974, and within ten years all of the animals had perished (Flannery et al., 1996). Today, *D. lumholtzi* individuals unsuitable for reintroduction into their native habitat are sent to zoos for breeding and education (Tree Roo Rescue and Conservation Centre Ltd., 2014). Unfortunately, the challenges of maintaining these animals in captivity still remain. Breeding programs are in their infancy, and while there have been some successes, there have been an equal number of unnecessary deaths (Coombes, pers. comm.). Thus, before the increasing demand for *D. lumholtzi* can be met, methods for their effective care must be made widely available.

1.2 Species Background

1.2.1 Distribution

Lumholtz's tree-kangaroo (*Dendrolagus lumholtzi*) is endemic to the Wet Tropics bioregion of Far North Queensland, Australia. *D. lumholtzi* is found south of the Daintree River to the southern edge of the Cardwell Range (Flannery et al., 1996). The core population of *D. lumholtzi*, however, is found in the tableland region between Ravenshoe and Atherton. *D. lumholtzi* appears restricted to high elevation rainforests on basaltic soils (Tree-Kangaroo and Mammal Group, 2000).

1.2.2 Social Environment

Individuals are solitary, with both males and females occupying exclusive home ranges of varying sizes (Procter-Gray, 1985; Newell, 1998; Coombes, 2005). Social interactions are limited to mating, the mother-young relationship, and fights between males (Procter-Gray, 1985).

D. lumholtzi is sympatric with several species of possum, including the coppery brush-tailed possum (*Trichosurus johnstonii*) and the green ringtail possum (*Pseudochirops archeri*). No aggressive interactions between *D. lumholtzi* and these species have been reported in the wild (Procter-Gray, 1985).

1.2.3 Feeding and Digestion

A complete understanding of the nutritional requirements of tree-kangaroos begins with an understanding of their gut morphology and digestive strategy. Tree-kangaroos are arboreal folivores, gaining the majority of their nutritional requirements from leaves (Procter-Gray, 1985). Mammalian herbivores and folivores rely on a community of microbial organisms to digest plant structural carbohydrates needed for energy (Landucci et al., 2007). In tree-kangaroos and other macropods, these microbes inhabit the foregut, and thus tree-kangaroos are classified as foregut fermenters (Landucci et al., 2007). Ingested plant material is processed by the gut microbes, and the products are absorbed and subsequently utilized by the host animal (Landucci et al., 2007).

To meet energy requirements on a high-fiber diet, folivores can either maximize intake, thereby processing as much food as quickly as possible, or maximize retention, slowing digestion to maximize extraction of nutrients (Cork, 1996). Examination of *D. lumholtzi* gut morphology confirms that unlike their grazing relatives, tree-kangaroos employ the retention maximizing strategy (Coombes, 2005). In fact, the gut morphology of tree-kangaroos is more similar to that of colobine monkeys and sloths than to other macropods (Coombes, 2005). Like tree-kangaroos, colobine monkeys and sloths are arboreal foregut fermenting folivores and evolved to fill analogous ecological niches (Landucci et al., 2007). Thus, in examining nutritional requirements of tree-kangaroos, it is beneficial to look to the research on these species rather than research on terrestrial macropods.

The majority of the *D. lumholtzi* diet consists of leaves, with only 1.3% of the diet made up of non-leaf material, such as flowers and stems (Procter-Gray, 1985). Over 140 plant species have been identified as food items for the species as a whole. However, individuals exhibit discrete food preferences, only using an average of 22% of the available plant species in their home range (Coombes, 2005).

1.2.4 Activity Patterns

D. lumholtzi is cathemeral, with bouts of activity throughout the day and night (Coombes, pers. comm.). *D. lumholtzi* spends about 61% of its time at rest, and when awake, is only feeding or changing location 10% of the time (Procter-Gray & Ganslosser, 1986) Feeding occurs in 2-30 minute bouts, followed by about 4 hours of rest. This general inactivity is likely an adaptation to divert energy expenditure to the digestion of plant material (Flannery et al., 1996).

Individuals are most commonly found in the mid to upper canopy, preferring larger, horizontal branches for feeding and rest (Martin, 2005). *D. lumholtzi* will come to the ground to move between trees or between patches of forest (Coombes, pers. comm.). *D. lumholtzi* does not den, instead preferring to sleep on open branches in a curled position with the head to the chest or feet (Martin, 2005).

1.2.5 Husbandry Resources

One husbandry manual has been put forth for the care of *Dendrolagus spp*. in captivity (Blessington & Steenberg, 2007b). The majority of information presented is based on experiences with *D. goodfellowi* and *D. matschiei* in North American zoos. While most of the information can be applied to *D. lumholtzi*, species differences and lack of research prevent this manual from being completely relevant. A second husbandry manual was compiled specifically for *D. goodfellowi* (Dominique, n.d.). Guides for the care of related and similar species are also available, including an extensive guide to the care of macropods by Staker (2006), and the husbandry manual for *Colobus spp*. (AZA Old World Monkey Taxon Advisory Group, 2012). While these sources have their limitations, valuable information can be pulled and adapted to the specific needs of *D. lumholtzi*.

1.3 Aims

Much of the available information on *D. lumholtzi* is not easily accessible by the general public. Currently, zoos must rely on the *D. lumholtzi* rescuer and rehabilitator for the valuable information needed to care for these animals. In the majority of cases, this rescuer is Tree Roo Rescue and Conservation Centre Ltd., a rescue organization committed to rehabilitating tree-kangaroos that have been injured, orphaned, or otherwise displaced (Tree Roo Rescue and Conservation Centre Ltd., 2014). Animals not suitable for return to the wild are provided with homes in zoos to become captive breeding animals and educational tools. Without a hard copy of the necessary information, many details of care are forgotten or ignored. With threats to the wild population increasing yearly, each animal is precious, and each loss is a blow to conservation efforts. Reducing these unnecessary deaths and effectively caring for the captive animals are the first steps towards education and conservation.

The overall aim of this study was to detail the methods employed by Tree Roo Rescue to care for and rehabilitate individual *Dendrolagus lumholtzi*, providing a framework from which a husbandry manual can be developed.

Specifically the aims of this study were to:

- Observe and record the existing methods for care and rehabilitation of *D. lumholtzi*
- Analyze gaps in current knowledge
- Suggest areas for future research critical to *D. lumholtzi* care and conservation

2.0 Methods

2.1 Location

This study was conducted at Tree Roo Rescue and Conservation Centre Ltd. in Malanda, Queensland. Tree Roo Rescue was established in 2012 by Dr. Karen Coombes and Neil McLaughlan, and is currently the only organization working to rescue and rehabilitate *D. lumholtzi*. All animals that come into care are rehabilitated with the intention of release back into the wild; however, when release is not an option, animals are prepared for life in a zoo to serve as breeding animals and educational tools.

2.2 Description of Animals

Eleven Lumholtz's tree-kangaroos were in care during the study period. Nine animals (six female, three male) were rescued within the past year, and suffer from varying degrees of vision loss and brain damage. Two animals, one female and one male, were hand-raised and suffer no medical abnormalities. The female was abandoned by her mother, and the male's mother died following rescue.

2.3 Data Collection

Husbandry methods were observed daily between April 7 and May 7, 2014 under the supervision of Dr. Karen Coombes. Protocols for routine procedures, such as feeding and cleaning of enclosures, were recorded in detail, noting any variations necessitated by particular animals. Additional observations concerning interactions with staff, and health and behavioral management were recorded as the opportunity arose.

3.0 Results

3.1 Housing Requirements

3.1.1 Ambient Environment

Nine of the eleven tree-kangaroos in care were housed in enclosures situated in type 1b complex mesophyll vine forest in Malanda, Queensland. The remaining two tree-kangaroos were housed indoors. Indoor temperature and humidity remained fairly consistent with outdoor conditions, with walls providing extra protection against wind. In the house, large windows provided adequate natural light during the day, with shade cloths and curtains offering protection from direct sunlight.

Tree Roo Rescue is situated away from main roads and areas of high noise pollution; therefore, sound levels remained low. The only exception was during mowing and other routine maintenance activities, during which animals were briefly exposed to increased sound and vibration. Animals were visually monitored during these activities for signs of panic and stress.

3.1.2 Enclosures

Four animals were housed in 4 x 2 x 2m cages, three in 6 x 3 x 3m cages, and three in 9 x 4 x 4m cages. Each cage was enclosed by aviary mesh (1” x 1” openings) on three sides, and corrugated steel on the fourth. Shade cloth was used to line the inside of the cage to prevent injury on the wire mesh. Roofing consisted of a combination between aviary mesh and corrugated steel to provide protection from the weather, especially rain, which is common in the area. A thick layer of washed, course-grained sand was used as a substrate.

3.1.3 Furnishings

Each cage was furnished with at least one platform, and a network of rough barked logs, placed at various angles and heights. Horizontal logs were placed at least 0.5m above the ground, while vertical or angled logs reached slightly below the roof of the cage. Nest boxes or bedding materials were not provided. The animal carrier used for rescue was placed in the corresponding animal's cage to provide security, and a place to hide if the animal became alarmed. These carriers were also used in the regular weighing process.

3.2 Social Environment

3.2.1 Positioning of Enclosures

Male tree-kangaroos were never housed directly next to each other. Three females were housed adjacent to males, and two were adjacent to other females. In general, animals were never housed together and interaction was restricted to "talking" through the mesh siding. The only exception to this was the two individuals housed indoors, who were kept together during the day. Both were constantly monitored for aggression, although none was observed. Grooming was observed, with the younger female licking and preening the older female, similar to grooming behavior that would be expected between related individuals.

3.2.2 Influence of Conspecifics

The male tree-kangaroos in particular showed increased levels of stress when housed in close proximity to other males. While never in direct contact with each other, the smell of other males induced a change in coloration from the typical yellowish-grey to an orange. In addition, one male displayed high levels of aggression and activity, presumably due to this proximity. There was no indication that housing females next to each other caused a similar increase in stress levels. Two of the male-female pairs "talked" through the mesh walls throughout the day, and one pair was observed to touch hands.

Wild *D. lumholtzi* were present within the surrounding rainforest, and on one occasion, came in close proximity to the enclosures. The tree-kangaroo was not spotted directly; however, there was clear evidence of his presence, including fresh scratch marks on surrounding trees and scats on the forest floor. All of the tree-kangaroos in care appeared agitated following this visit.

3.2.3 Influence of Other Animals

No other animals are housed with the tree-kangaroos at Tree Roo Rescue. Rats and mice did access the cages, evidenced by holes in the ground and small scats left near feeding areas. Other animals, most notably brush turkeys and pademelons, were present on the property, but were unable to enter the enclosures. These animals did not have a noteworthy effect on the behavior of the tree-kangaroos in care.

3.3 Nutrition

3.3.1 Feeding

Animals were fed a combination of browse (plant material) and commercial supplements. The weed species Small and Large-Leaved Privet (*Ligustrum sinense* and *Ligustrum lucidum)* were provided daily. The legume/pasture vine Glycine *(Neonotonia wightii*) was also provided on a regular basis. The animals received a variety of native trees previously determined to be a part of their natural diet. Some of the most common were *Schefflera actinophylla*, *Litsea leefeana*, *Neolitsea australiensis*, and *Euroschinus falcata*. Supplementary feedings occurred twice daily. Each animal was fed sweet potato, carrots, a slice of apple, several slices of banana, and chickpeas. Quantities of each item varied slightly with individual preference. Each animal was also provided with a bowl of local basaltic soil for consumption *ad libitum*.

3.3.2 Food Preparation

Sweet potato and carrots were peeled and cut into longitudinal strips, apple slices were cut in half, and bananas were peeled and cut into ½" slices. Chickpeas were soaked for approximately 7-8 hours, but were not cooked.

3.3.3 Placement in Enclosures

Browse was placed in upright tubes filled with water, which were attached to the mesh siding. Tubes were at least 1 meter above ground level and next to platforms or logs. Supplemental food items were placed in a shallow bowl on a platform, and food bowls were placed in the same location with each feeding. Fresh water and soil were provided at ground level in shallow bowls.

3.4 Health Management

3.4.1 Cleaning and Hygiene

Cages were raked daily to remove fallen debris and feces. In addition, old browse was removed and replaced. Animals were not removed from the cages during this procedure nor were they restrained. Water was replaced regularly, although not on a daily basis, and all food dishes were washed thoroughly following each use.

3.4.2 Preventative Medicine

Animals were not provided any preventative medicine, including vaccinations and deworming agents. One individual was occasionally given Zantac (1mL) to prevent stomach ulcers and to increase appetite. In the past, Zantac was given to each animal daily; however, it did not appear to make a noticeable difference in feeding habits, and the practice was stopped.

3.4.3 Routine Checks and Indications of Illness

Apart from regular weigh-ins, which occurred monthly, no routine veterinary procedures were performed. Animals were observed daily for any indications of illness, including a loose stool, and changes in behavior, feeding, and activity level. Animals were checked by a visiting veterinarian ophthalmologist to determine the extent of their sight and brain damage, and to determine if animals were suitable release.

3.4.4 Rehabilitation

One female was undergoing rehabilitation over the course of this study. This individual suffered a bone infection in her foot from a dog bite, and had been under treatment since her rescue in November 2013. Open wounds in the foot prevented her from being placed in an outdoor cage, thus she was housed inside and continuously monitored. Veterinary appointments were required weekly to administer medication and monitor progress.

3.5 Behavioral Management

3.5.1 Staff-Animal Interactions

The level of staff-animal interaction varied between individuals. Four animals were highly tolerant, and even invited, human interaction. For example, one individual waited by the door of his cage, expecting to be held prior to every feeding. In contrast, two animals became exceptionally stressed when staff entered their cages, evidenced by hyperactivity, increased vocalizations, and pacing.

3.5.2 Training and Enrichment

No training was undertaken over the course of this study. Enrichment was limited to a network of logs provided in each enclosure, and for one animal, a large rope suspended between several points of her cage. Two animals, both hand-raised, were also permitted to climb a large tree adjacent to the facility. Climbing occurred one animal at a time, and under staff supervision.

4.0 Discussion

4.1 Housing Requirements

4.1.1 Ambient Environment

According to Landucci, Vasey, and Watson-Jones (2007), enclosures should be kept between 18 and 27°C with a minimum temperature of 16°C. This is generally in line with average temperatures reported for the Atherton Tablelands although dry season lows for Malanda can reach 11.2°C (Digital Atlas Pty Limited, 2014). Because the animals at Tree Roo Rescue were housed outdoors within their natural range, temperature, humidity, and light conditions were all equal to what animals would be exposed to in the wild. Thus, *D. lumholtzi* will likely tolerate below 16°C in captivity for short periods of time. Pneumonia and over-heating are both concerns in *D. lumholtzi*, so animals should always be carefully monitored during periods of extreme temperatures.

The humidity suggestion for tree-kangaroos is between 50 and 55%, with anything over 60% considered high (Landucci et al., 2007). Humidity below this range may result in brittle coats and a condition known as scaly tail, caused by dry skin, while humidity above this range can result in over-heating (Landucci et al., 2007). Humidity in Malanda is unusually high, averaging over 70% for the majority of the year (Digital Atlas Pty Limited, 2014). It is possible that the combination of high humidity and cooler rainforest temperatures reduces the likelihood of heat stress in the animals at Tree Roo Rescue as well as in the wild.

One of the main stressors for *D. lumholtzi* is noise (Coombes, pers. comm.). Typically, loud or unusual noises are those that raise the most concern, but for some animals, specific noises, whether or not they are familiar, trigger a stress response (pers. obs.). For example, one female in care was consistently stressed by the sound of the rake used to clean her cage, despite hearing it everyday. Prolonged stress results in the suppression of the immune system, increasing the risk of disease and illness (Coombes, pers. comm.). Because *D. lumholtzi* stress easily, stress-related illness can often be life threatening, making management of stress a major priority (Coombes, pers. comm.). It is therefore essential that *D. lumholtzi* be exposed to as little extraneous noise as possible. It has been suggested that familiar noises may have a calming effect during times when loud noise cannot be avoided, such as during construction (AZA Old World Monkey Taxon Advisory Group, 2012). However, in light of the above example, this suggestion should be taken cautiously and with the individual animal in mind.

4.1.2 Enclosures

The minimum cage size suggested by Steenberg (1993) is 6 x 3 x 3m. Four cages at Tree Roo Rescue do not meet this requirement; however, each of the animals housed in the smaller cages was partially or fully blind. Smaller cages are more suitable for blind animals as it takes less time for the animals to settle and become accustomed to their enclosure. In addition, small cages prevent blind animals from achieving high speeds that may be dangerous if the animal runs into the side of the cage. This is common for blind animals when frightened (Coombes, pers. comm.).

Wire mesh cages are the most effective method of containment (Landucci et al., 2007). Tree-kangaroos will climb on the mesh, so openings should be large enough to prevent claws from getting caught and torn (Landucci et al., 2007). The 2007 Husbandry Manual also discusses the success of dry moats as a barrier in open exhibits (Landucci et al., 2007). While dry moats may be effective, open exhibits are strongly advised against, as other animals, particularly birds, can gain access to the exhibit. *D. lumholtzi* is susceptible to avian tuberculosis, and multiple captive tree-kangaroos have already been lost to the disease (Landucci et al., 2007). It is therefore crucial that enclosures are covered and designed to prevent access by birds. In addition, tree-kangaroos, even when blind, can and will climb out of enclosures, further supporting the need for a closed exhibit (Coombes, pers. comm.).

A layered substrate is suggested for tree-kangaroos, with soft material, such as woodchips, sand, or hay, on the upper layers (Landucci et al., 2007). Wild *D. lumholtzi* can jump to the ground from over 15 meters and land unharmed (Tree-Kangaroo and Mammal Group, 2014). Therefore, there is a strong possibility that captive animals will jump to the ground from the highest point in their enclosure. A soft substrate, such as that used at Tree Roo Rescue, is the best preventative measure against joint damage resulting from these leaps (Coombes, pers. comm.). In the case of joeys and blind animals, a soft substrate also serves as a protection against injury or death if the animal falls to the ground (Coombes, pers. comm.). Although Tree Roo Rescue does not employ a layered approach as suggested by Landucci et al. (2007), it may be beneficial for zoos to layer soft material over an easily cleanable substrate, such as concrete or artificial rock. Layers should be thick enough to prevent this hard layer from being rapidly exposed (Landucci et al., 2007).

4.1.3 Furnishings

Enclosures should be furnished to best meet the biological and behavioral needs of the species (AZA Old World Monkey Taxon Advisory Group, 2012). *D. lumholtzi* spends 99% of its time in trees; therefore, furnishings should be arranged to allow captive animals to spend the majority of their time off of the substrate (Procter-Gray, 1985). This is most effectively accomplished by creating a network using logs. A complete network was not generally possible at Tree Roo Rescue; instead, logs were arranged to create several smaller networks. In either case, this above ground network is crucial to 1) develop and maintain muscles necessary for climbing, 2) provide enrichment, and 3) encourage species-specific behaviors.

D. lumholtzi does not nest, instead sleeping in a curled position on a tree branch, or when in captivity, on a log or platform (Martin, 2005; pers. obs.). Therefore, it is not necessary to provide nesting materials. This is in contrast to *D. goodfellowi*, which will use provided nesting materials (Dominique, n.d.). While this may appear a minor detail, it is these species differences that prevent a general "tree-kangaroo" manual from being fully effective.

4.2 Social Environment

4.2.1 Positioning of Enclosures and Influence of Conspecifics

D. lumholtzi is not a social species, with both males and females occupying exclusive home ranges (Procter-Gray, 1985). Captured males are often heavily scarred in the face and ears, indicating that fighting is common in defense of these territories (Martin, 2005). It is unclear how females mark and defend their territory, but observations of captive females suggest that they too are aggressive, particularly towards other females (Coombes, pers. comm.). Although animals were not housed together, individuals were housed in close proximity to conspecifics, which is atypical in the wild. To decrease stress associated with this close proximity, males were distanced from other males as much as possible. The influence of other males could not be entirely avoided, and was most obvious in the color change previously described. Not much is known about this color change, but from the observations presented here, it appears to be a result of increased testosterone, and may be used to indicate dominance or physical fitness.

It is indicated in the Tree Kangaroo Husbandry Manual that female conspecifics are housed together, with the exception of pouch-gravid females (Landucci et al., 2007). This is not suggested for *D. lumholtzi*, with the exception of mother and joey, as both males and females are territorial, and display aggression to conspecifics (Coombes, 2005). The peaceful coexistence between the two females in this study was an exception, and was most likely facilitated by the large age difference between the two individuals, and the poor condition of their health. The young sub-adult would still be with her mother in the wild; thus, is may be that the two females acted as “mother” and joey (Coombes, pers. comm.).

4.2.2 Influence of Other Animals

The main concern when designing mixed-species exhibits is aggression between animals (Landucci et al., 2007). Tree-kangaroo deaths have been reported, but tree-kangaroos have also been known to stalk and harass animals within their enclosure (Landucci et al., 2007). For example, tree-kangaroos were reported to attack flying foxes, potoroos, goshawks, and lorikeets, to name a few (Landucci et al., 2007). In another captive study, dead frogs and brush turkeys were found within *D. lumholtzi* cages (Johnson et al., 2002). In addition, a male *D. lumholtzi* was observed eating a dead carpet python and a peaceful dove (Johnson et al., 2002). While the act of predation was not directly observed, it was fairly evident to the researchers that the tree-kangaroo was responsible for the deaths of the unfortunate trespassers (Johnson et al., 2002). Some animals have been reported as successful in mixed-species exhibits with tree-kangaroos, such as northern bettongs and echidnas, but the risk greatly outweighs any possible benefit (Coombes, pers. comm.). The reported attacks on birds is especially concerning as tree-kangaroos are at high risk of avian tuberculosis (Blessington & Steenberg, 2007a). Enclosures should be well protected from birds of any species to decrease the likelihood of transmission of this deadly disease (Coombes, pers. comm.).

4.3 Nutrition

4.3.1 Feeding

Currently, only limited information is available concerning the energy and nutritional requirements of *D. lumholtzi*. Two studies have examined diet composition in the wild, with only one study reporting on the chemical composition of chosen leaf species (Procter-Gray, 1985; Coombes, 2005). Over 140 plant species have been identified, mostly consisting of native rainforest trees and a small number of vine species (Coombes, 2005). Nutrient guidelines for *Dendrolagus spp.* have been put forth, but these suggestions are based on studies of similar and related mammal groups. While applicable, these guidelines should be used with caution until data on *D. lumholtzi* is available.

The primary requirement for tree-kangaroos is fiber, which is most often met using a high fiber biscuit, leafy greens, and vegetables (Edwards & Ward, 2007; Dominique, n.d.). Browse is not considered a primary component of the diet for the PNG species in captivity, and is instead typically fed in small quantities as a form of enrichment or a measure against loose stools (Edwards & Ward, 2007). In contrast, Tree Roo Rescue uses browse as the primary source of fiber and nutrients, with fruits and vegetables considered supplementary. It is highly recommended that large amounts and a variety of browse is supplied each day to provide fiber and nutrition, as well as for enrichment and security (Coombes, pers. comm.). In addition, some individuals like to hide amongst the browse, indicating that is also serves to reduce stress (Coombes, pers. comm.).

It is understood that feeding large amounts of browse is not feasible for most institutions, but keepers should bear in mind that the tree-kangaroo gut has evolved to process large quantities of plant material. Substituting a high quality diet in place of the natural "low quality" one is not beneficial if the animal cannot effectively utilize the added nutrients (Edwards & Ward, 2007). The microbial community of the gut, for example, is maintained in a fine balance. Feeding an improper diet can quickly upset this balance and harm the animal. One of the biggest concerns is the feeding of commercially available fruit, which are high in simple, readily fermentable sugars. As mentioned, *D. lumholtzi* employs the retention maximizing strategy of digestion, which means that fermentation is meant to occur slowly. Rapid fermentation results in a build of fermentation products, including carbon dioxide, methane, and volatile fatty acids (VFAs) (Edwards & Ward, 2007). When in excess, these products cause bloating and a drop in the gut pH, creating a toxic environment for the microbial community and a shift to sugar-loving bacterial species (Edwards & Ward, 2007). This reduces effective digestion and may lead to death of the animal. Some sick animals have been fed stomach contents from road-killed tree-kangaroos to replace the microbial community after upsets caused by illness or vaccination (Coombes, pers. comm.).

Despite this risk, commercial fruits are used in zoos and at Tree Roo Rescue as they provide necessary vitamins and minerals. Only bananas and apples are fed at Tree Roo Rescue, as these fruits are not particularly high in sugar. Despite being fed in large quantities, bananas have not caused any dietary complications (Coombes, pers. comm.). Melons and citrus fruits, which are high in sugar, are not recommended (Coombes, 2005). It is important to note that the microbial community does adapt over the course of the animals lifetime based on the diet the animal is fed. However, changes occur slowly, thus any alterations to the diet should be done incrementally (Coombes, pers. comm.).

4.3.2 Placement in Enclosures

Tree-kangaroos prefer food items to be placed high above the ground, consuming less than 75% of food when placed at ground level (Mullett et al., 1988). The tree-kangaroos at Tree Roo Rescue also would not eat any supplemental food items that had fallen to the ground, even after they had been washed and replaced in the food bowl. Consistently placing food bowls in a single location within the enclosure is necessary for the animals currently in care at Tree Roo Rescue due to their blindness (Coombes, pers. comm.). Research showed that *D. lumholtzi* relies primarily on olfaction to locate food items (Iwaniuk et al., 1998), but experience with blind animals has shown that vision is equally important. Tree Roo Rescue found that blind animals are not able to smell supplementary foods until in close proximity, possibly because sweet potatoes and chickpeas do not produce a strong odor (Coombes, pers. comm.). Individuals were observed sniffing and investigating food items before feeding, indicating that olfaction is instead more important in *choosing* food items rather than locating them.

4.4 Health Management

4.4.1 Cleaning and Hygiene

Cleaning recommendations for zoo enclosures are slightly more elaborate than methods employed by Tree Roo Rescue. These include washing and disinfecting all surfaces on a weekly basis, and regularly changing the substrate to prevent bacterial buildup (Reed & Collins, 2007; Dominique, n.d.). At Tree Roo Rescue, thorough scrubbing of cages and replacement of substrate occurs before a new animal is housed in an enclosure to prevent transmission of disease. There have been no incidents of sickness at Tree Roo Rescue attributed to cleanliness.

4.4.2 Preventative Medicine

North American and European zoos currently vaccinate tree-kangaroos against rabies, tetanus, and clostridial, a type of anaerobic bacteria (Reed & Collins, 2007). Rabies has not yet invaded Australia, thus the rabies vaccine is not necessary for Australian zoos. Before moving to zoos, *D. lumholtzi* individuals are vaccinated against bordetella, encephalomycocarditis (EMC), and clostridials (Tasvax 8-in-1 vaccine). Vaccines are then administered yearly. Shots should be separated by at least a week to prevent irritable bowel syndrome or any gut disturbances (Coombes, pers. comm.).

Tree-kangaroos are not preventatively dewormed, and are only treated if parasites are identified during fecal examination (Dominique, n.d.). A rich community of intestinal worms resides in the stomach of *D. lumholtzi*, and is thought to serve a beneficial function, possibly in the detoxification of ingested plant material (Coombes, pers. comm.). Therefore, *D. lumholtzi* should only be dewormed if absolutely necessary to avoid disrupting this symbiotic relationship.

4.4.3 Routine Checks and Indications of Illness

Routine physical examinations of *D. goodfellowi* involve an examination of body temperature, pulse, and respiratory rate (Dominique, n.d.). Normal ranges for these health indicators have not been recorded for *D. lumholtzi*, decreasing the usefulness of these values during initial examinations; however, with regular examination and detailed record keeping, any dramatic changes would become apparent. The normal ranges presented for *D. goodfellowi* may serve as a guide when examining *D. lumholtzi*, but should not be taken as absolute.

Changes in normal behavior are one of the earliest indicators of illness in tree-kangaroos (Reed & Collins, 2007). There are, unfortunately, many difficulties in relying on this method. First, these changes can be subtle. Second, what is normal for one individual may be abnormal for another. Finally, behaviors must be taken in context. Reed and Collins (2007) use the example of forearm licking, which is a cooling behavior and a response to stress in *D. goodfellowi*. It is essential for keepers to learn the idiosyncrasies of the individuals under their care in order to easily distinguish between what is normal and what is not. Other indications of illness include: decreased activity, changes in fecal or urine output or character, changes in the fur, and increased nasal discharge. Clear and continuous nasal discharge indicates stress, while colored discharge indicates illness (Reed & Collins, 2007).

4.4.4 Rehabilitation

At Tree Roo Rescue, rehabilitation is taken on a case-by-case basis, with the ultimate goal of releasing individuals back into the wild. Thus, animals undergoing rehabilitation are carefully monitored and cared for until they are able to survive without medical support. Nine of the tree-kangaroos rehabilitated at Tree Roo Rescue were unsuitable for release. Although otherwise healthy, these animals suffered brain damage and/or vision loss, and thus would not be successful in the wild. Seven of these animals will be relocated to zoos, while two will remain at Tree Roo Rescue for educational purposes.

4.5 Behavioral Management

4.5.1 Staff-Animal Interactions

Staff interactions with *D. lumholtzi* are encouraged to decrease stress during cleaning procedures, handling, and health examinations. However, staff should be mindful when entering enclosures with *D. lumholtzi*, even with non-aggressive individuals. The individual at Tree Roo Rescue who actively embraced interaction did not act aggressively towards carers, but regularly inflicted wounds with his claws and teeth. *D. lumholtzi* has extremely sharp claws, which they use to hold on to trees, and in captivity, their carers (Flannery et al., 1996; pers. obs.). In addition, *D. lumholtzi* will bite, with bite strength ranging in intensity depending on level of excitement (pers. obs.).

4.5.2 Training and Enrichment

Training tree-kangaroos has been successful using operant conditioning, a process that reinforces or discourages behaviors using a reward (typically food) as an incentive (Blessington & Steenberg, 2007a). Training is particularly beneficial when completing routine examinations or during transportation (Blessington & Steenberg, 2007a). For example, *D. goodfellowi* and *D. matschiei* have been trained to stand on scales, shift enclosures, and enter crates (Blessington & Steenberg, 2007a). Routine activities thus become less stressful for the animal, and more efficient for caretakers.

A myriad of items have been used for tree-kangaroo enrichment, including cardboard boxes and tubes, hammocks, "Boomer Balls", and perfumes (Blessington & Steenberg, 2007a). Individuals should be monitored following presentation of new enrichment items, and enrichment adjusted based on individual preference (Blessington & Steenberg, 2007a). Although a relatively inactive group, tree-kangaroos can benefit from enrichment. For example, enrichment has been shown to decrease aggressive behaviors in both *D. goodfellowi* and *D. matschiei* males (Blessington & Steenberg, 2007a).

Enrichment has also been shown to decrease or prevent the development of stereotypies (Swaisgood & Shepherdson, 2005). Stereotypies are repetitive or ritualistic movements with no apparent function or goal, and are often exhibited by captive animals (Philbin, n.d.). While the causes are unknown, stereotypies may be stress or boredom related. Several animals at Tree Roo Rescue expressed stereotypic behavior, all in the form of pacing or “running laps” around their cages. This activity appeared to increase in times of stress rather than a result of boredom; however, observations were limited to feeding periods and it was unclear if these activities occurred when staff was absent. In either case, enrichment may serve to decrease energy levels and subsequently reduce these behaviors (Swaisgood & Shepherdson, 2005).

4.6 Future Research Needs

The largest gaps in current knowledge relate to *D. lumholtzi* nutritional and health requirements. First and foremost, the nutritional requirements for *D. lumholtzi* are unknown. It is clear that in wild animals, these requirements are met by consuming a variety of leaf species (Procter-Gray, 1985). Unfortunately, institutions are reluctant to serve browse to captive animals, because the majority of leaf species contain anti-herbivore toxins (Edwards & Ward, 2007). While the microbial community of the gut likely plays a role in detoxification of ingested plant material, it has been suggested that over consumption of any one toxin would result in illness or death of the animal (Procter-Gray, 1985). Thus, for fear of accidently poisoning captive animals, browse is replaced with high-fiber biscuits and a variety of fruits and vegetables (Edwards & Ward, 2007). Browse is an essential part of the *D. lumholtzi* diet, thus chemical analysis of prospective food species is crucial to encourage institutions to include a large amount of it in daily feedings. In addition, further research into *D. lumholtzi* nutritional requirements is necessary to remove the guess work from planning meals, and decrease the requirement for dietary supplements, such as salt and mineral blocks (Edwards & Ward, 2007).

Further research is also needed into the role of soil in digestion. It is hypothesized that soil consumption may aid in removing toxins from ingested plant material, or may serve to populate the gut with symbiotic bacteria and worm species (Coombes, pers. comm.). A third hypothesis suggests that soil may provide needed minerals (Dominique, n.d.). Many institutions are unwilling to provide non-microwaved soil as it may harbor disease-causing bacteria (Coombes, pers. comm.). While microwaving does kill the majority of dangerous bacteria, it also kills beneficial microbes that the species may require. Research into the role of soil will provide insight into how to best manage its consumption by captive animals.

Finally, normal ranges for temperature, pulse, and respiratory rate are unknown for *D. lumholtzi*. Animals that come into care at Tree Roo Rescue are injured or otherwise stressed, thus recordings of these values would not accurately reflect what is normal for the species. Even in healthy and recovering animals, these examinations can cause stress, elevating pulse and respiration to abnormal levels. Techniques for obtaining these values without stressing the animal need to be developed to accurately monitor the health of individuals.

5.0 Conclusion

Tree Roo Rescue and Conservation Centre Ltd. has successfully cared for and rehabilitated numerous Lumholtz's tree-kangaroos since its establishment in 2012. The past year has been exceptional with eleven animals in care. While the methods presented here are not absolute, it is clear from the success of Tree Roo Rescue that they are effective. This study was inherently limited by the small amount of previous research, and it is likely that these methods will evolve as new information is presented and as more animals make their ways into care.

Regardless, the presented methods can be used to improve care of current captive *D. lumholtzi*, and to successfully maintain larger captive populations in the years to come.

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