TREE KANGAROO

(Dendrolagus spp.)

Nutrition Husbandry Manual

revised 2001

Tree Kangaroo Species Survival Plan ©

Edited by

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NUTRITION, FOOD PREPARATION, AND FEEDING

Mark S. Edwards, Ph.D., Ann Ward, M.S.

INTRODUCTION

The tree kangaroo (*Dendrolagus* spp.) is a popular and charismatic animal, which is currently represented by three species (*D. matschiei, D. goodfellowi, D. inustus*) in North American zoos. As with other folivorous/herbivorous species, the dietary husbandry of captive animals has not always duplicated or, sometimes, even been approximated with the food items for which the animal has co-evolved to utilize as principle sources of nutrition.

Information on tree kangaroos regarding the distribution of feeding in the wild, plant species selected, or nutrient composition of those selected feeds, is limited (Proctor-Gray 1985; Martin 1992). Additionally, the specific nutrient requirements of *Dendrolagus* species have not been determined under controlled conditions. Therefore, much of the information presented here is based upon species with similar gastrointestinal tract adaptations and/or feeding habits as well as on domestic animal models.

Dabek and Betz (1998) have collected over 90 species of food plants consumed by Matschie's tree kangaroos. Based on the interviews with local Papua New Guinea hunters, wild Matschie's tree kangaroos are thought to like young ferns, mosses and wild ginger (Dabek and Betz 1998).

The guidelines presented here indicate the appropriate amounts thought to sustain normal health. The numerical data presented are based upon the authors' experience in applying this information in a captive setting.

When at all possible, tree kangaroos should be fed as individuals, or individuals within a breeding pair (i.e., separate food containers). A joey should be fed in a separate food pan, near its dam, well before actual weaning or separation occurs. In applying these recommendations, the following factors should be considered:

- health status of the animal
- variable concentrations and availability of nutrients in feeds
- interrelationships among nutrients
- climatic and environmental conditions
- presence of pouch young
- individual metabolic and digestive differences between animals which result in the need for appropriate adjustments in offered quantities of food.

NATURAL FEEDING HABITS/DIET COMPOSITION

Tree kangaroos are described as browsing herbivores native to the tropical rainforests of Australia and New Guinea (George 1982). The diet of free-ranging tree kangaroos consists primarily of tree foliage (Drake 1984). In addition to a variety of leaves, tree kangaroos feed on ferns, fruits, bark, moss, flowers and creepers (vines) (Husson and Rappard 1958; Troughton 1965; Archer 1985; Flannery 1990; Laurance 1990, Dabek and Betz 1998).

Free-ranging *D. lumholtzi* are described as almost exclusively folivorous, selecting the leaf material of 33 plant species (Procter-Gray 1984). As much as 90% for *D. lumholtzi* consisting of mature leaves (Procter-Gray 1984). The fiber content of foods selected by *D. lumholtzi* was much higher when compared with those foods consumed by sympatric species of possums (Procter-Gray 1984). This suggests that tree kangaroos have evolved to occupy an ecological niche utilizing a relatively indigestible food source, similar to that of colobines or howler monkeys.

There are no observations of carnivory in free-ranging tree kangaroos (Archer 1985; Flannery 1990). There are, however, reports of captive animals opportunistically catching and eating several species of birds (Steenberg and Harke 1989, Mullett et al. 1989).

The arboreal nature of this genus is a secondary adaptation. In fact, some species of tree kangaroo will spend a significant amount of their daily period on the ground. As a result, plant materials of both arboreal and terrestrial origin are consumed (Nowak 1991).

When evaluating food items to include in the diet of captive tree kangaroos, it is important to consider the significant differences in nutrient composition of "wild" versus cultivated, or commercially available plant materials. For example, the botanical term "fruit" refers to the female reproductive portion of a plant. However, the characteristics of these cultivated fruits, including physical and chemical traits, can be dramatically different. For example, when the nutrient composition of commercially available fruits is compared to the fruits of plants consumed by free-ranging wildlife, commercial fruits are higher in moisture and simple sugars, and lower in structural carbohydrates. Therefore, commercially available fruits may not be appropriate analogs for the fruits harvested by free-ranging tree kangaroos.

GASTROINTESTINAL ANATOMY/BODY MASS

The similarities of gastrointestinal anatomy between macropod marsupials, including tree kangaroos, and ruminant ungulates have been previously described (Moir et al. 1955; Moir 1968). The presence of a large, complex stomach, which, when full, can weigh up to 15 percent of the total body weight (Bauchop 1978), as well as an esophageal groove indicate that these animals possess anatomical adaptations that support fermentation of fibrous plant material by symbiotic microorganisms (Hume 1982). Just as in ruminants, the presence of an esophageal groove probably suggests a similar function as in ruminants where this structure serves to shunt milk past the fermentative portions of the foregut to the enzymatic compartments of the gastrointestinal tract (GIT) (Hume 1982).

While there are some minor variations seen in the foreguts of *Dendrolagus* (Beddard 1923), the general characteristics are similar to that of other macropods. However, these differences would not affect fermentation in the foregut of the tree kangaroo (Bauchop 1978).

The symbiotic relationship with microbial organisms in the GIT allows the "host" animal to utilize plant polysaccharides, including cellulose and hemicellulose, as principle sources of energy; tree kangaroos lack the enzymes necessary to degrade these compounds. As a result, the tree kangaroo is in effect collecting food items to "feed" the microbial population inhabiting the gastrointestinal tract, and obtains its nutrition from the end-products of the fermentation process. The balance of organisms within the forestomach of a foregut fermenter is carefully regulated through a combination of intake of appropriate substrates, pH, and removal of end-products by absorption or movement through the GIT.

Consumption of foods which contain significant quantities of readily fermentable carbohydrates (e.g., starch, sugars) could lead to a rapid rate of fermentation, excessive production of fermentation end products (i.e., CO_2, CH_4), a lower than normal pH in the foregut, and a state of disbiosis (an inappropriate balance of gut microbial organisms). For this reason, **the use of commercially available fruits and other high sugar items, should be strictly regulated and limited**.

As with ruminants, pseudoruminants or camelids, and other macropod marsupials, tree kangaroos have been observed to regurgitate the contents of the foregut in order to reduce the food particle size by further mastication (Whitehead, 1986). The process is called merycism, and is a normal behavior in many non-ruminant species (e.g., tree kangaroos) with foregut fermentation

Variations in body mass were observed between species and individuals (Table 3.1). However, collection of routine body weights at an institution will permit identification of these differences, as well as demonstrate any seasonal weight changes or weight change trends.

ESTIMATED NUTRIENT GUIDELINES

Estimated nutrient guidelines are based on actual studies with tree kangaroos, requirements of closely related species (i.e., other macropod marsupials), species with similar gastrointestinal anatomy and feeding habits (i.e., folivorous primates), and domestic animal models. A summary of recommended nutrient concentrations for diets fed to captive tree kangaroos is listed in Table 3.2.

A. Energy requirements for adult maintenance

Maintenance energy expenditure is defined as the necessary chemical energy ingested to maintain basic body functioning or basal metabolism, to support activity costs, and to thermoregulate by balancing heat loss with heat production (Robbins 1983). Animals derive their caloric energy from carbohydrates, fats and proteins.

Age, body size, growth, pregnancy and lactation affect energy requirements. Additionally, temperature, humidity, activity level and stress of any kind will impact the energy requirements of an individual animal. An energy deficit may develop from inadequate food intake and/or from low energy of diet (NRC 1981). A more likely situation in the captive setting may be a factor of feeding an excessive quantity of high moisture food items (i.e., commercial produce, browse). These foods, which are often preferred over nutritionally complete foods, provide large quantities of "bulk" in the gastrointestinal tract. If presented in quantities which allow the animal to consume them to satiation, foods which provide the majority of nutrients and caloric energy (i.e., nutritionally complete foods) could be consumed in sub-optimal quantities.

Metabolic measurements were taken between 27^{o} and 37^{o}C on animals with a mean mass of 6.96 kg (McNab 1988). The rate of metabolism measure in two adult tree kangaroos (*Dendrolagus matschiei*) was 55% of the standard rate expected for a eutherian mammal based on Kleiber's (1932) calculations and 84% of the rate expected for a marsupial based on formulas established by Dawson and Hulbert (1970). Based on this work, neither equation appears appropriate for estimating the energy requirements of tree kangaroos.

The energy requirements of tree kangaroos at stages of the life cycle other than maintenance (i.e., pregnancy, lactation, growth) have not been defined. Until these requirements are determined, many institutions offer 50% more of the nutritionally complete feeds in the daily ration (See below) when the presence of pouch young is determined. This feeding strategy is continued until the joey is weaned. It is important to monitor the dam's weight during this lactation to prevent an inappropriate weight gain or loss.

Carbohydrates

Plant structural polysaccharides, cellulose and hemicellulose, are the principle sources of energy for herbivores. The symbiotic relationship of animals with microorganisms present in the gastrointestinal tract, which possess the required enzymatic capabilities, allows them to utilize these foods. Tree kangaroos possess the required enzymatic capabilities.

The micro-environment present in the foregut of these herbivores is a finely balanced system. The fermentation process of the microbes produces short-chain volatile fatty acids (VFA's), along with various concentrations of gaseous products, including carbon dioxide, methane, and hydrogen. The production of VFA's causes a reduction in the pH of the contents of the foregut. Foregut pH is maintained through a combination of VFA absorption into the blood, buffering from saliva, and removal of contents to more distal portions of the GIT.

C. Protein

Proteins are the principal constituents of the animal body and are continuously needed for cell repair and synthetic processes (NRC 1981). There are two primary sources of protein for species with foregut fermentation, dietary sources which "by-pass" microbial degradation and the microbial organisms themselves which pass through to the gastric portion of the GIT.

The ability of macropods to reabsorb filtered urea is correlated with the relative medullary thickness (RMT) of the kidneys (Dawson and Denny, 1969). For example, the euro, which has a RMT of 7.2, is able to reabsorb more filtered urea than the red kangaroo, with a RMT of 5.8. *Dendrolagus matschiei* has the lowest RMT 3.9 (Yadav, 1979) described in a macropod marsupial. This suggests that the tree kangaroo has a lower capacity to recycle urea, as a source of nitrogen for the microbes. These non-protein sources of nitrogen are utilized by gut microorganisms in the synthesis of peptides and amino acids within their bodies. **Regardless of these findings, the use of feed-grade urea, or other sources of non-protein nitrogen (NPN) in the diets of tree kangaroos is not recommended.**

D. Minerals

There are seven macro and nine trace minerals that are considered dietary essential for tree kangaroos. The macro minerals include calcium, phosphorus, sodium, chlorine, magnesium, potassium, and sulfur. Trace elements, which are required in relatively smaller amounts are iron, iodine, copper, molybdenum, zinc, manganese, cobalt, selenium and fluorine.

Some institutions provide a trace mineral salt block for tree kangaroos to consume ad libitum. Although these trace mineral blocks provide primarily salt (NaCl), they do contain a variety of other trace elements in different concentrations depending on manufacturer and intended use.

When offered free-choice access to salt, many species will consume it in excess of their requirement, with no apparent ill effects as long as an ample amount of water is available (NRC 1981). However, if the salt block is used excessively, access must be restricted and the reason for the excessive use determined. Many trace minerals can be consumed in toxic amounts. Therefore, if a salt block is to be offered to tree kangaroos, a plain block (NaCl) is preferred. The block should be firmly secured in a clean, dry location and clean, fresh water should be available at all times.

E. Vitamins

Vitamins are a group of organic compounds that are essential for health, maintenance, and reproduction. Vitamins are typically divided into two catagories, those which are fat-soluble (A,D,E,K) and water-soluble (C, B complex). Dietary sources provide vitamins which can not be synthesized or synthesized in adequate quantities by the animal. Bacterial synthesis of some vitamins, including the B-complex and vitamin K, in the gastrointestinal tract can reduce the dietary requirement (Robbins 1983).

Vitamin E is a generic description of those compounds, both natural and synthetic, which are qualitatively equivalent in biological activity to α-tocopherol (NRC 1989). Vitamin E and the mineral selenium are closely related in maintaining glutathione peroxidase as part of a multi-component antioxidant defense system. It is important to remember that both vitamin E and selenium are required in the diet of animals and that one nutrient can not completely assume the function of the other.

The occurrence of white muscle disease (WMD) has been described in *Dendrolagus*

(Goss 1940; MacKenzie and Fletcher 1980). This disease was presented as a "wasting" syndrome including a stiff gait, muscle atrophy, weakness, and anorexia. Upon necropsy, myopathies were described as pale in color and fibrous with caseous streaks were observed. The muscles may also possess a gritty consistency when cut. The diets fed to the animals described by MacKenzie and Fletcher (1980) appear to provide adequate quantities of vitamin E and selenium. However, no indication is given to the concentration of either vitamin E or selenium in the consumed diet. The authors do describe that there was considerable waste, with only a portion of the vitamin E supplement being consumed.

As a result of these case reports, there have been suggestions for the need to supplement tree kangaroo diets with vitamin E and selenium (Mullett et al. 1990; Whitehead, 1986). Due to the potential for vitamin/mineral toxicosis, especially in regard to the addition of selenium, it is more important to ensure that the animals eat the appropriate amount of the nutritionally balanced feed (e.g., herbivore pellet, leafeater diet) in the daily ration. This eliminates the need for, or the risk of additional supplementation.

The B-complex vitamins are normally synthesized by microorganisms in the foregut and hindgut of species possessing this type of anatomy. Although the production of B-complex vitamins in the foregut of tree kangaroos has not been quantified, the synthesis in domestic livestock meets the requirement of the animal without a diet source. Regardless of this bacterial source, estimated dietary requirements for the B-complex vitamins are provided in Table 3.2. If the diet provides these concentrations, this ensures that minimal quantity can be met. The water soluble vitamins have a relatively wide margin of safety when compared to the fat soluble vitamins.

Only vitamin B_{12} (cobalamin) is likely to be deficient in animals with functional foregut fermentation (NRC 1981). This vitamin requires cobalt to function. If cobalt is absent or at extremely low concentrations, a vitamin B_{12} deficiency can develop. A deficiency in domestic ruminants is an inability to utilize the VFA produced by microbes for energy.

There is no indication that tree kangaroos would have a dietary requirement for vitamin C (ascorbic acid); however, it is physiologically essential for them. Most mammals are able to synthesize ascorbic acid in the liver *de novo* from d-glucose.

WATER

The importance of water for tree kangaroos is obvious. The amount of water required by an individual will vary with the stage of the animal's life (e.g., maintenance, lactation, environment). An animal's water requirement can be satisfied by free water consumption, as well as by preformed water present in consumed feeds and metabolic water which is produced metabolically from the oxidation of energy sources in the diet. Water is lost from the body via urine, feces, lactation, evaporation, and perspiration.

Clean, fresh water should be available *ad libitum* for all captive tree kangaroos, but especially for lactating females or animals with higher water requirements.

CAPTIVE DIETS FOR ADULT TREE KANGAROOS

Diets offered to tree kangaroos are quite variable. This is particularly true when one examines dietary husbandry of the genus in European, North American, and Australian zoos. It is important for the reader to understand that animals require nutrients delivered by the ingredients of the diet, but do not have a requirement for specific ingredients in the diet. For example, tree kangaroos have a dietary requirement for vitamin A, which may be delivered in part as β-carotene found in sweet potatoes. However, the tree kangaroo does not have a dietary requirement for sweet potatoes.

Historically, European zoos typically have not emphasized the use of nutritionally complete feeds in diets of captive wildlife. Captive tree kangaroos at the Twycross Zoo and Cologne Zoo are offered mixtures of hay, mixed vegetables, mixed grains, tree leaves, fruits and bread (Collins 1973; Whitehead 1986).

Early reports of diets offered in the United States suggest that tree kangaroos were fed in a similar manner to strictly terrestrial macropods. These diets included, but were not limited to, "hay, rolled oats, pelleted feed, and any available vegetables and greens" (Crandall 1964). Diets offered to captive animals in Australia were similar, with some institutions offering large trees in enclosures for opportunistic browsing (Crook and Skipper 1987).

A myriad of supplements are offered among the various institutions, including salt licks and vitamin mixes, but little quantitative information is available as to the nutrient content of the consumed diet. These diets provide the opportunity to select favorite foods over those which, although they may be more nutritionally appropriate, are less palatable to the individual. Allowing an individual to self-select a diet from a variety of offered foods relies on a principle known as "nutritional wisdom" (Ullrey 1989). Although tree kangaroos select plant materials which provide them proper nutrition in the wild, these plant and animal species have co-evolved. It has been demonstrated that animals, when presented with a selection of novel foods, including plant materials, do not select those foods based upon appropriate nutrient content. Many of the diet items historically offered to tree kangaroos fall into a category of "non-nutritive" supplements. These items offer no known nutritional value, but are added based upon opportunistic observations in the absence of empirical data. Some such items, which have been offered for non-nutritive purposes, include fresh corn, tea leaves, and maize (Heath et al. 1990; Mullet et al. 1988). Both items have been implicated as important for maintaining pelage coloration. However, these items are not found in the diet of many animals which have normal coat color.

We are continuing to add to our knowledge of captive folivorous animals, a wide group of very sensitive species. Nutrition and digestion research with species such as red pandas and leaf-eating primates has trickled down to species with similar feeding habits and/or gastrointestinal anatomies, such as tree kangaroos.

The importance of plant fiber, or as described by some authors as "bulk", for arboreal folivores is increasingly apparent. The gastrointestinal tract of *Dendrolagus* species is adapted to process and utilize large quantities of relatively indigestible plant material. Although plant fiber has historically been considered a "negative feed factor," the evolutionary adaptations of the species cannot be circumvented by feeding higher quality foods available for use with captive specimens. In fact, the consumption of readily fermentable foods, such as commercially available fruits, may lead to digestive disorders like foregut acidosis that plagues some ruminant animals.

The negative effects of excessive fermentation are not only limited to types of foods, but also quantities of certain foods. For example, vegetables from Brassicaceae (e.g., cabbage, broccoli) may be included in a tree kangaroo diet to elevate the fiber content of the ration. However, these foods, known for their methanogenic properties, could also lead to inappropriate fermentation in the foregut if fed in excess quantities. The proportions presented in this manual should serve as a guide.

The use of browse in tree kangaroo diets varies from institution to institution. Although plant materials are not considered a primary source of nutrition for captive animals, their behavioral enrichment value and link to the prevention of loose stools make browse a desirable dietary supplement. The users should keep in mind that plants have many mechanisms (e.g., toxins) by which they protect themselves from consumption by herbivores. These mechanisms may not be apparent to the keeper or tree kangaroo. Only those species which have been demonstrated with domestic animals as non-toxic should be considered for use as browse (Appendix A). Additionally, the plant materials should be properly secured in a holder which limits the animals' access to the bark of the plant. Plant bark is relatively high in lignin, an indigestible fraction of the plant cell wall. Although no tree kangaroos have been known to be affected, several captive primates have died due to impactions of highly lignified plant materials which were offered as browse.

As previously mentioned, loose stools have been linked to a lack of fibrous plant material in a tree kangaroos' diet. Indeed, the condition of the fecal material is indicative of the animals' overall health, signaling possible underlying stress disorders or nutrition deficits when feces are not pelleted (pers. comm. Steenberg 1996).

Coprophagy (consumption of fecal material) has been reported in captive adult tree kangaroos, as well as both a female and her joey (Steenberg 1995). Although coprophagy is a behavior typically demonstrated by those species with hindgut fermentation (e.g., koalas, equids, rabbits) as a method of recovering nutrients lost in feces, the significance of this behavior in *Dendrolagus* species is thought to be similar. It is theorized that tree kangaroo joeys are being inoculated with gut flora through coprophagy.

Diets were reviewed from the National Zoological Park's Conservation and Research Center and the Zoological Society of San Diego for *D. matschiei* and *D. goodfellowi* tree kangaroos, respectively. Both of these facilities have sizeable collections and have had long-term success with the species. Additionally, both institutions have had their diets reviewed and revised by staff nutritionists.

National Zoological Park/Conservation and Research Center (NZP/CRC)

The diet offered to *D. matschiei* tree kangaroos at the National Zoo's Conservation and Research Center was revised in 1988 (Warnell and Oftedal, 1988). Their revised diet (Table 3.3:Diet B: Warnell and Oftedal 1988) is higher in crude protein concentrations and lower in starches and other readily fermentable carbohydrates than their previous diet (Table 3.6:Diet A).

The revised diet incorporated a higher fiber primate biscuit (Appendix B), which was formulated for leaf-eating primates, but has been demonstrated to have a wider species application following quantitative feeding trials with red pandas (*Ailurus fulgens*). The use of this palatable feed increased the total crude protein concentrations, eliminated the need for vitamin/mineral supplementation, and provided a more appropriate fiber substrate for a foregut fermenter. Additionally, the physical characteristics of the biscuits provides a feed which could promote improved oral health and minimize tartar build-up on the animals' teeth.

Zoological Society of San Diego (ZSSD)

Food intake of five, individually housed adult male *D. goodfellowi* was measured over 5-6 days. All food items were individually weighed prior to presentation. Orts (left-over foods) were removed and weighed the following day. A container of representative food items were weighed, placed adjacent to the area where the animals were housed, and the re-weighed the following day. These food items served as controls for the orts in order to correct for moisture loss over the 24 hour period. The results of these trials are presented in Table 3.4.

The diet offered *D. goodfellowi* at the ZSSD are based upon two complete feeds, a higher fiber primate biscuit (Marion Zoological Inc.) and an alfalfa-based lower fiber (ADF-16) herbivore pellet (Appendix B). To complement these feeds, a rotation of vegetable materials are presented daily. These vegetables include, each day, a type of leafy green vegetable, a root vegetable, and a third vegetable. Only a small, controlled portion of fruit is offered daily to facilitate close observation of individual animals. Finally, the animals are offered a one meter section of browse material daily. The amount of edible material on each section varies with browse species, maturity of plant material, and seasonal effects. The browse is considered a supplement to the diet, and is not relied upon to deliver any specific nutrients.

The diet offered to a single, adult tree kangaroo is presented in Table 3.5. Quantities provided to individual animals are based upon actual dry matter intake (Table 3.4). The nutrient composition of this diet as offered, along with those diets offered at the NZP/CRC, is provided in Table 3.6. Cultivated and harvested browse materials are provided in addition to the "core" diet presented in Table 3.5. The quantity of browse is limited to no more than three one meter sections per animal daily; however, the amount of edible material available is widely variable. The differences in dry matter offered and actual dry matter intake are considered to be filled with browse consumption.

Based on the information presented here, both diets (NZP/CRC Diet B and ZSSD) are appropriate for feeding captive tree kangaroos. The total quantities and relative proportions of food categories should be used as guidelines, in conjunction with the dietary husbandry information provided, for review of existing diets.

FOOD PREPARATION/PRESENTATION

A feeding protocol is important in the management of tree kangaroos. It can help identify problems, aid in exhibitry and bring tree kangaroos close to the keeper for close observations and/or capture. Such a protocol should include specific times when an animal should be fed. For example, at Woodland Park Zoological Gardens the keepers adopted a feeding regimen based on reports that *D. lumholtzi* feed for about 15 minutes every four hours (Procter-Gray 1985). Detailed diet cards are also valuable keeper reference materials (Steenberg 1996).

The importance of food preparation, specifically in regard to cutting-up of commercial produce, varies by institution. Some institutions designate specific sizes and shapes that the vegetables should be cut. Other institutions have found that animals show no preference for those vegetables which are cut in cross section versus longitudinally. While the vegetable materials should be large enough to allow the individual animal to manipulate the particle, they should also vary enough in size to provide occupation for the animal. (Steenberg 1996).

Food pans should be placed in high pan holders (approximately 4-5 feet off the ground) or secured to a horizontal platform. Feeding stations should be up off the ground. Tree kangaroos will often toss specific items aside to obtain preferred foods, pushing pans onto the ground in the process. Pans should be secured to reduce the amount of food lost to overturned pans. However, the pan must be removable for cleaning. Fallen foods are rarely consumed by captive animals. If the feeder is outside it should be covered. Also, be aware of how much transient birds eat if they have access to the food.

Browse materials should be presented in an upright fashion. The manner of presentation was shown to have a significant impact on consumption levels by captive animals (Mullett et al. 1990). When browse was placed in perching or branch materials, between 90-100% of the edible portion was consumed. When the same types of plant materials were "planted" in sand at ground level, consumption decreased to 65-75%. Only 50% of the browse was consumed when the portions were broadcast on the ground.

Browse may be placed in upright canisters, such as PVC pipe fitted with a cap on one end, which is secured to a branch or perch in the enclosure. This canister may be filled with water to prolong the "freshness" of the leaves. To ensure that the animals do not prematurely drop the browse, or that they may consume large amounts of the highly lignified bark previously mentioned the browse plants may be secured in the canister by large bungee cords or the equivalent.

HAND-REARING NEONATAL TREE KANGAROOS

Due to the specialized reproductive biology of marsupials, hand-rearing tree kangaroos presents multiple obstacles which are not considered by those who regularly rear placental mammals. As marsupials, the neonatal tree kangaroo is relatively helpless and under-developed in relation to placental mammals. The neonate continues to develop within the pouch of the female. In addition to the physical characteristics of the neonate, marsupial milk is dramatically different from the milk of placental mammals and goes through changes in composition over the lactation period. We will only refer to specific information available on hand-rearing *Dendrolagus* species and general marsupial information in this discussion. Those persons who attempt to rear macropod marsupials, including *Dendrolagus* species, are encouraged to refer to the AZA Infant Diet Notebook (Amand 1994) for further detailed information and literature citations on the topic.

The number of tree kangaroos hand-reared successfully to weaning is extremely low. Records from five hand-rearing cases of *D. lumholtzi* were reviewed. These animals were rescued from free-ranging dams in Australia which were killed by vehicular traffic or other causes (See Chapter 7-Joey Growth and Development). A single male *D. goodfellowi* joey, from a set of twins, which was ejected from the dam's pouch at the age of 35 weeks, was reared to weaning at the San Diego Zoo. The protocol used for this single animal is presented here, along with important data from the *D. lumholtzi* cases and other macropod marsupials.

Young macropods are typically identified and aged using physical measurements of specific anatomical features and body weights, and then compared to established charts for the species. An "age factor" value is used to identify the stage of development of a pouch joey in relation to these physical measurements. The age factor is described as the ratio of the joey's age to the age of the species at full emergence from the pouch. For example, at the age of full emergence from the pouch, a joey is described as age factor 1.00. Prior to full emergence, the age factor is less than 1.00.

No charts have been developed for *Dendrolagus* species of known ages younger than age factor 0.90. However, the physical measurements of a single male *D. goodfellowi* joey from age factor 0.90 to 1.24 is provided in Figure 3.1. Additionally, growth data for this animal is provided in Table 3.7.

If hand-rearing a tree kangaroo joey should be necessary, the following information should be collected on a daily basis, at a consistent time:

- Measure from crown to rump
- Measure the foot - base of claw to heel
- Measure the tail - underside, base to tip
- Weigh the joey

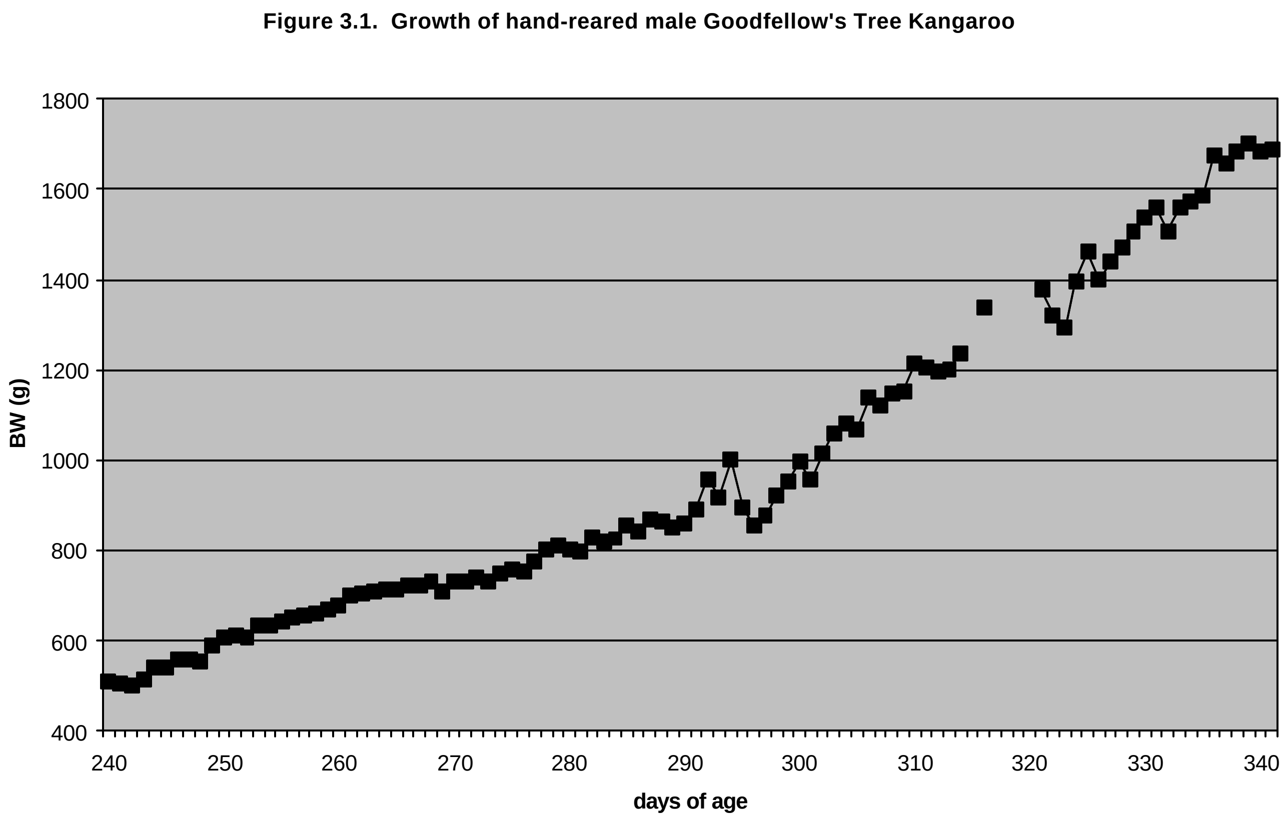

Figure 3.l: Zoological Society of San Diego Records - 1995. Mark Edwards . Ph.D.

Collection of this type of data in relation to the animals' known age will ultimately allow the development of growth/age charts similar to those available for other marsupials.

Early studies of marsupial milk composition clearly indicated that the composition differs from that of cow's milk (Bolliger and Pascoe 1953). These variations in nutrient composition from those seen in placental mammals have been supported by further studies (Lemon and Barker 1967; Green et al. 1980). In general, the protein content of macropod milk tends to increase from approximately 3% at birth to 10% when the joey has left the pouch. The lipid fraction gradually increases from about 1.5% at birth to 10% when the joey is completely out of the pouch. The carbohydrate fraction is what makes marsupial milk truly unique. The concentration of carbohydrates increases from 4% to 12% from birth to out of the pouch respectively.

Due to the unique nutrient composition of marsupial milks, identifying a milk-replacer which approximates maternal milk has been problematic. A number of products have been used successfully by Australian zoos and wildlife rehabilitators, including:

- Biolac®, a series of marsupial milk replacers
- Divetalact®, a low lactose milk formula for domestic livestock
- Digestalact®, a low lactose milk formula for humans
- Wombaroo®, a series of marsupial milk replacers

Due to the limited availability and higher cost of Australian products, the single animal reared in North America (ZSSD) was fed a formula using:

- Esbilac®, a bitch's milk replacer

Esbilac® (210 ml) was not used alone as the sole ingredient, but was pre-treated overnight with 2 ml of a lactase enzyme preparation (Lactaid®), and blended with vegetable oil (3 ml) and whole milk yogurt (10g). (See Chapter 7; Appendix E - Lactase pretreatment protocol).

The selection of appropriate nipple size is also a challenge. A T3 size nipple (Biolac - Smith Marsupial Nipples) was used by ZSSD staff for their single case. Many institutions are faced with making their own nipples, as those manufactured for domestic livestock or humans are too large. With the growing number of wallabies in private collections, some companies have begun to market macropod nipples (Appendix C).

Due to the limited sample size it is difficult to advise specific feeding quantities or schedules for *Dendrolagus* species. However, if one is faced with hand-rearing a joey, the standard calculations to determine the maximum safe stomach volume (50 ml/kgBW) per individual feeding should be observed. The total quantity offered in a 24 hour period and the frequency of feedings will depend on the caloric density of the formula selected.

The weaning period seems to be a particularly difficult transition for hand-reared folivorous species, including tree kangaroos. The dramatic change in food sources and their relative digestibility seem to be the principal reason for loss of appetite, bloating, and even death during this period. Additionally, if the individuals are reared in the traditional sterile zoo nursery setting, the transition may be confounded by the lack of appropriate microbial organisms in the gastrointestinal tract. These organisms are typically transferred from the dam and her environment to the joey in a variety of methods such as coprophagy and grooming.

In an attempt to increase the likelihood of a successful weaning, the single male *D. goodfellowi* joey was subjected to a single transfaunation treatment. The animal was fed a fecal bolus collected from the dam to establish gut flora at the age of nine months. There is no quantitative evidence that this procedure was effective, or even necessary, however, the weaning process did not present the typical problems stated above. (See Chapter 7-Joey Growth and Development).

APPENDIX A: Suggested temperate non-toxic plant species whose leaves may be used for supplemental feeding of tree kangaroos. This is a partial list composed of browse species listed by the Woodland Park Zoo and the Bronx Zoo. Species availability of browse will depend on geographic location and season. **Always check for toxicity when selecting browse materials.**

SALICACEAE	*Populus alba*	Eastern White Poplar
	Populus balsamifera	Balsam Poplar
	Populus nigra	Lombardy Poplar
	Populus grandidentata	Bigtooth Poplar
	Populus tremuloides	Quaking Aspen
	Salix amygdaloides	Peachleaf Willow
	Salix babylonica	Weeping Willow
	Salix fragilis	Crack Willow
	Salix nigra	Black Willow
FABACEAE	*Gleditsia triacanthos*	Honeylocust
ACERACEAE	*Acer negundo*	Box Elder
	Acer nigrum	Black Maple
	Acer platanoides	Norway Maple
	Acer saccharum	Sugar Maple
	Acer saccharinum	Silver Maple
BETULACEAE	*Betula allegheniensis*	Yellow Birch
	Betula papyrifera	White Birch
MORACEAE	*Morus alba*	White Mulberry
	Morus rubra	Red Mulberry
FAGACEAE	*Fagus grandifolia*	American Beech
ROSACEAE	*Amelanchier spp.*	Serviceberry
VITACEAE	*Vitis spp.*	Wild Grape
	Pueraria lobata	Kudzu

Appendix B. Selected calculated macro-nutrient composition of food items commonly included in diets fed to captive tree kangaroos in North America (dry matter basis).

Manufactured Feeds Item Description	DM (%)	GE (kcal/g)	CP (%)	EE (%)	Ash (%)
Leafeater (Marion Zoological, Inc)	91.40	4.85	25.44	5.43	6.39
Leaf-eater Primate Diet (Mazuri/PMI)	92.00	nd	25.00	5.43	7.30
Low Fiber Herbivore Pellet (ZSSD)	90.10	nd	17.60	4.20	7.90
ADF-# 16 Herbivore Pellet (Mazuri/PMI)	92.00	nd	18.59	3.48	8.04

Appendix B (cont'd). Selected calculated macro-nutrient composition of food items commonly included in diets fed to captive tree kangaroos in North America (dry matter basis).

Manufactured Feeds Item Description	NDF (%)	ADF (%)	ADL (%)	Ca (%)	P (%)
Leafeater (Marion Zoological, Inc)	21.30	16.04	1.39	1.05	0.71
Leaf-eater Primate Diet (Mazuri/PMI)	26.80	17.40	nd	1.12	0.73
Low Fiber Herbivore Pellet (ZSSD)	33.20	17.10	4.30	0.78	0.69
ADF-# 16 Herbivore Pellet (Mazuri/PMI)	31.50	16.80	nd	0.86	0.74

APPENDIX C: Sources of products mentioned in text[1].

Animal Feeds

Leafeater Diet	Marion Zoological, Inc. 2003 E. Center Circle Plymouth, MN 55441, USA Phone: (800) 327-7974 www.MarionZoological.com
Leaf-Eater Primate Diet	Mazuri® / PMI® Feeds 1401 S. Hanley Rd Saint Louis, MO 63144, USA Phone: (800) 227-8940 www.MAZURI.com

Hand-rearing Formulas

Biolac® Marsupial Milk Replacer	Resource International 675 Gooseberry International Layfayette, CO 80026, USA Phone: (303) 666-0924 http://cabb.cowleys.com.au/biolac
for additional information contact	www.biolac.comm.au
Esbilac®	Pet-Ag, Inc. Bitch's Milk Replacer 261 Keyes Ave Hamshire, IL 60140, USA Phone: (800) 323-0877 www.petag.com
Divetalac® Low Lactose Animal Milk Replacer	Sharpe Laboratories 12 Hope Street Ermington, NSW 2115, Australia Phone: (02) 9858-5622 www.australianwildlife.com.au

for additional information contact
www.petalia.com.au/templates/prodsvblist.cfm?group_no=2117

APPENDIX C: (continued)

Digestalact® Low Lactose Human Milk Replacer	Sharpe Laboratories 12 Hope Street Ermington, NSW 2115, Australia Phone: (02) 9858-562
Lactaid® Lactase Enzyme Preparation	www.lactaid.com
Wombaroo Marsupial Formulas Marsupial Milk Replacer	Wombaroo Food Products 22A Chasewater Street Lower Mitcham, S.A. 5062, Australia Phone: (08) 8277-7788 WOMBAROO@adelaide.on.net
	Cooinda Downs Pastoral 35 Wellington Drive Balgownie, NSW 2519, Australia bronwyn@cooinda.com

Hand-rearing Equipment and Consultation:

Biolac and teats	Geoff and Christine Smith P.O. Box 93 Bonnyrigg, NSW 2177, Australia Phone: (02) 9823-9874
Wombaroo, teats and bottles	www.users.on.net/wombaroo
No longer supplies equipment or milk, but is available for consultation on Australian fauna	Helen's Fauna Nursing Service Helen George Moss Vale Road Beaumont, NSW, Australia Phone: (244) 651 3280

[1]Commercial companies or products are mentioned in this publication for the sole purpose of providing specific information. Mention of a company or product does not constitute a guarantee or warranty of products by the Tree Kangaroo SSP®, the American Zoo and Aquarium Association, or the authors over products of other companies not mentioned.

TABLE 3.1: Body weight measured among captive, adult specimens of two tree kangaroo species (*Dendrolagus matschiei* and *D. goodfellowi*).

Species	Sex	BW (kg)	*n*
D. matschiei	female	9.10 ± 0.46	3
	male	9.15 ± 1.22	4
D. goodfellowi	male	9.89 ± 1.36	5

TABLE 3.2: Recommended minimum nutrient concentrations for diets fed to tree kangaroos[1]. *

Nutrient	Minimum Conc	Nutrient	Minimum Conc
Crude protein (%)	15	Fiber components	
Lysine (%)[2]	0.8	Neutral detergent fiber (%)	25
Crude fat (%)	2.5	Acid detergent fiber (%)	15
Crude fat (%) (Max)	5	Lignin (%) (Max)	10
Ash (%) (Max)	10	Total sugars (%) (Max)	10
Minerals		Vitamins	
Calcium (%)	0.8	Thiamin (ppm)	2.5
Phosphorus (%)	0.4	Riboflavin (ppm)	5.0
Sodium (%)	0.2	Vitamin B6 (ppm)	2.0
Potassium (%)	0.8	Vitamin B12 (ppb)	20
Magnesium (%)	0.2	Niacin (ppm)	30
Iron (ppm)	60	Folate (ppb)	600
Iodine (ppm)	0.3	Biotin (ppb)	100
Copper (ppm)	10	Choline (ppm)	1000
Cobalt (ppm)	0.2	Pantothenate (ppm)	12

Manganese (ppm)	40	Vitamin A (IU/kg)	4000
Selenium (ppm)	0.2	Vitamin D (IU/kg)	800
Zinc (ppm)	80	Vitamin E (IU/kg)	100

[1]All values are expressed on a dry matter basis.
[2]Nutrient requirement for monogastric species.
* varied activity/stress may affect nutritional needs.

TABLE 3.3: Revised diet (Diet B), as offered, for single adult *D. matschiei* tree kangaroo housed at the NZP's Conservation and Research Center, after October, 1988.

Food Category	Amount (g)	Percent of Total Diet
Leafeater biscuit[1]	54	18.0
Leafy greens (e.g., kale, spinach)	105	35.0
Vegetables (e.g., carrot, celery)	105	35.0
Fruits (e.g., banana, apple)	36	12.0
Tea, leaves	1/2 tsp	-

[1]Marion Zoological, Plymouth, MN

TABLE 3.4: Body weight (BW) and dry matter intake (DMI) of five adult male *D. goodfellowi* tree kangaroos housed at the Zoological Society of San Diego (M.S. Edwards, unpublished data).

Animal ID	*n*	BW (kg)	DMI (g/d)	DMI (% BW)
M0282252	5	10.35	351	3.39
M0590408	5	10.25	278	2.71
M0592321	5	8.02	234	2.92
M0592471	5	9.20	307	3.28
M0595041	6	11.65	223	1.91
Mean ± s.d.		9.89 ± 1.36	279 ± 52.75	2.84 ± 0.59

TABLE 3.5: Weekly maintenance diet, as offered, for a single adult *D. goodfellowi* tree kangaroo housed at the Zoological Society of San Diego[1].

Food Item	Amt (g)	Weekly Schedule						
		Su	M	T	W	Th	F	Sa
Low fiber herbivore pellet[2]	215.0	X	X	X	X	X	X	X
Leafeater biscuit[3]	34.0	X	X	X	X	X	X	X
Spinach	176.7	X			X			
Kale	139.6		X					X
Greens, collard	129.7			X		X		
Greens, dandelion	236.3						X	
Turnip	25.0	X			X			
Carrot	35.0		X			X		X
Yam	25.0			X			X	
Green beans	30.0		X				X	
Corn, on cob	88.2			X		X		
Broccoli	75.5	X						
Tomato	100.0				X			X
Celery	24.0	X						
Banana, with peel	81.5	X	X	X	X	X	X	X

[1] A single 1 m section of browse plant material is offered in addition to this diet. Species selected varies based on season and availability of mature plant material
[2] Zoological Society of San Diego Formulation.
[3] Marion Zoological, Plymouth, Mn.

TABLE 3.6: Selected nutrient composition (DMB) of mean daily diet, as offered, for a single adult *D. matschiei* and *D. goodfellowi* tree kangaroo, respectively, at the National Zoological Park/Conservation Research Center (NZP/CRC) and Zoological Society of San Diego (ZSSD), and recommended minimum nutrient concentrations for tree kangaroos.

Nutrient	NZP/CRC (Diet A)[1]	NZP/CRC (Diet B)[2]	ZSSD	Minimum Conc
Dry Matter (%)	nd	nd	46.61	nd
Crude Protein (%)	12.19	21.98	18.36	15.0
Lysine (%)	0.57	1.17	0.98	0.80
Crude Fat (%)	2.84	4.64	4.20	2.50
Ash (%)	6.60	6.96	7.76	10.0 (Max)
NDF (%)	4.67	16.71	28.23	25.0
ADF (%)	nd	9.41	14.36	15.0
ADL (%)	nd	0.82	3.28	10.0 (Max)
Calcium (%)	0.60	0.89	0.78	0.8
Phosphorus (%)	0.40	0.56	0.64	0.4
Sodium (%)	0.30	0.31	0.40	0.2
Iron (ppm)	56	166	323	60
Se (ppm)	nd	0.26	0.38	0.2
Vitamin A (IU/kg)	4559	5134	6022	4000
Vitamin D (IU/kg)	456	1151	1188	800
Vitamin E (IU/kg)	48	171	311	100

[1] prior to October, 1988.
[2] after to October, 1988.

TABLE 3.7: Physical measurements (mm) opportunistically collected from a single, hand-reared male Goodfellow's tree kangaroo (*Dendrolagus goodfellowi*) raised at the San Diego Zoo and age factor estimates[1.]

Days of Age	Crown-Rump measurements (mm)	Tail measurements (mm)	Hind foot measurements (mm)	Age factor
247	nd	305	60	0.90
253	205	325	62	0.93
260	215	325	62	0.95
267	235	335	65	0.98
274	260	350	68	1.00
281	260	350	70	1.03
288	260	350	72	1.05
295	270	355	78	1.08
302	nd	Nd	nd	1.10
309	nd	380	75	1.13
316	280	390	80	1.15
323	280	410	80	1.18
331	336	418	81	1.21
338	340	420	85	1.24

[1]age factor estimates are based upon an observation of full emergence of a single joey from a *D. goodfellowi's* tree kangaroo pouch at 273 days.

REFERENCES

Amand, W.B. 1994. *AZA Infant Diet Notebook*. Wheeling, WV.

Archer, M. 1985. *The Kangaroo*. McMahon's Point, New South Wales: Kevin Weldon Pty. Ltd.

Bauchop, T. 1978. Digestion of leaves in vertebrate arboreal folivores. In: *The Ecology of Arboreal Folivores*. (G.G. Montogomery, ed.). Washington, D.C.: Smithsonian Institution Press.

Beddard, F.E. 1923. *Mammalia*. London: MacMillan and Company Limited.

Bolliger, A., and J.V. Pascoe. 1953. *Australian Journal of Science* 15: 215-217

Collins, L. R. 1973. *Monotremes and Marsupials*. pp. 250-255.Washington, D.C.: Smithsonian Institution Press.

Crandall, L.S. 1964. Family Macropodidae. In: *Management of Wild Mammals in Captivity.* Pp 33-34. Chicago: The University of Chicago Press.

Crook, G.A., and G. Skipper. 1987. Husbandry and breeding of Matschie's tree kangaroo (*Dendrolagus m. matschiei*) at Adelaide Zoological Gardens. *International Zoo Yearbook* 26: 212-216.

Dabek, L. and W. Betz. 1998. *1998 Field Report Tree Kangaroo Conservation Program*. AZA Tree Kangaroo Species Survival Plan.

Dawson, T.J., and Denny, M.J.S. 1969. Seasonal variation in the plasma and urine electrolyte concentration of the arid zone kangaroos *Megaleia rufa* and *Macropus robustus*. *Australian Journal of Zoology* 17: 777-784.

Dawson, T.J., and A.J. Hulbert. 1970. Standard metabolism, body temperature and surface areas of Australian marsupials. *American Journal of Physiology* 218: 1233-1238.

Drake, B. 1984. Response: (Tree Kangaroo Predation). *Thylacinus* 9(3):15-16.

Flannery, T. 1990. *Mammals of New Guinea*. Pp: 89-109. Carina, Queensland: Robert Brown and Associates.

George, G.G. 1982. Tree-kangaroos, *Dendrolagus* spp.: their management in captivity. In: *The Management of Australian Mammals in Captivity.* (D.D. Evans, ed.) pp. 102-107. Melbourne: Zoological Board of Victoria.

Goss, L.J. 1940. Muscle dystrophy in tree kangaroos associated with feeding of cod liver oil and its response to alpha-tocopherol. *Zoologica* 25: 523-524.

Green, B., K. Newgrain, and J. Merchant. 1980. *Australian Journal of Biological Science* 33: 35-42.

Heath, A., S. Benner, and J. Watson-Jones.1990. A case study of tree kangaroo husbandry at CRC. In *AAZPA Regional Conference Proceedings.* 5l8-527. Wheeling WV: AAZPA. Edited version in Roberts and Hutchins, eds. 1990. 25-32.

Hume, I.D. 1982. Digestive physiology and nutrition of marsupials. Cambridge: Cambridge University Press

Husson, A. M., and F. W. Rappard. 1958. Note on the taxonomy and the habits of *Dendrolagus ursinus temminck* and *D. leucogenys matschiei* (Mammalia: Marsupialia). *Nova Guinea,* n.s. (9Pt.1): 9-18.

Kleiber, M. 1932. Body size and metabolism.
Hilgardia 6: 315-353.

Laurence, W.F. 1990. Effects of weather on marsupial folivore activity in a north Queensland upland tropical rainforest. *Australian Mammalogy* 13(1): 41-47.

Lemon, H., and S. Barker. 1967. *Australian Journal of Experimental Biology and Medical Science* 45: 213-219.

MacKenzie, W.F., and K. Fletcher. 1980. Megavitamin E responsive myopathy in Goodfellowi tree kangaroos associated with confinement. In: *The Comparative Pathology of Zoo Animals* (R.J. Montali and G. Migaki, eds.). Washington, D.C.: Smithsonian Institution Press.

Martin, R. 1992. Of koalas, tree-kangaroos and men. *Australian Natural History (ANH)*24(3): 22-31. Published by the Australian Museum.

McNab, B.K. 1988. Energy conservation in a tree-kangaroo (*Dendrolagus matschiei*) and the red panda (*Ailurus fulgens*). *Physiological Zoology* 61(3): 280-292.

Messer, M., and D. M. Walker. N.d. Milk substitutes for marsupials: in theory how good (or bad) are they? In *Urban Wildlife.* L. Vogelness, D. Spielman, T. Bellamy, M. Messer, and D.M.Walker, 99-124. Sydney:Post Graduate Committee in Veterinary Science, University of Sydney.

Mitchell, P.C. 1916. Further observations on the intestinal tracts of mammals. *Proceedings of the Zoological Society of London* (1916) 183-251.

Moir, R.J. 1968. Ruminant digestion and evolution. In: *Handbook of Physiology*, Section 6-V. (C.F. Code, ed.). pp. 2673-2694. Washington, D.C.: American Physiological Society.

Moir, R.J., M. Somers, and H. Waring. 1955. Studies on marsupial nutrition. I. Ruminant-like digestion in a herbivorous marsupial (*Setonix brachyurus* Quoy and Gaimard).

Mullett, T., D. Yoshimi, and J. Steenberg. 1988. (updated 1990) *Tree Kangaroo Husbandry Notebook*. Seattle:Woodland Park Zoological Gardens.

Mullett, T., D. Yoshimi, and J. Steenberg.1989. *Tree Kangaroo Husbandry Notebook Survey Results*. Seattle: Woodland Park Zoological Gardens.

NRC (National Research Council). 1981. *Nutrient Requirements of Goats*. Washington, D.C.: National Academy of Sciences.

NRC (National Research Council). 1989. *Nutrient Requirements of Horses*. Washington, D.C.: National Academy of Sciences.

Nowak, R.M. 1991. *Walker's Mammals of the World* (5th ed.)Vol 1. pp. 99-100. 0Baltimore: Johns Hopkins University Press.

Procter-Gray, E. 1984. Dietary ecology of the coppery brushtail possum, green ringtail possum and Lumholtz's tree kangaroo in north Queensland. In: *Possums and Gliders* (A.P. Smith and I.D. Hume, eds.). Pp 129-135. Sydney: Australian Mammal Society.

Procter-Gray, E. 1985. The behavior and ecology of Lumholtz's tree-kangaroo (*Dendrolagus lumholtzi*) (Marsupialia: Macropodidae). Ph.D. diss., Harvard University. Abstract in *Dissertation Abstracts International* 46(4B): 1087.

Robbins, C.T. 1983. Wildlife Feeding and Nutrition. New York: Academic Press.

Steenberg, J. 1988. The management of the Matschie's tree kangaroo (*Dendrolagus matschiei*) at the Woodland Park Zoo. *AAZPA Regional Conference Proceedings*. pp. 95-111. Wheeling, WV.

---. 1995-1996. Personal communication.

Steenberg, J., and C. Harke. 1989. Predation on a Nicobar pigeon by a Matschie's tree kangaroo. *Thylacinus* 9: 14-15.

Troughton, E. 1965. *Furred Animals of Australia* (8th ed.) Sydney: Angus and Robertson.

Ullrey, D.E. 1989. Nutritional Wisdom. *Journal of Zoo and Wildlife Medicine* 20(1): 1-2.

Warnell, K.J., and O.T. Oftedal. 1988. *Tree Kangaroo Diet Recommendations*. Washington D.C.: National Zoological Park.

Whitehead, M. 1986. Tree kangaroos. In *The Management of Marsupials in Captivity*. Edited by: J. Partridge, London: Association of British Wild Animal Keepers. Also available in *Proceedings of Symposium of the Association of British Wild Animal Keepers*, 1986, 42-53.

Yadav, M. 1979. Kidney types of some Western Australian macropod marsupials. *Mammalia* 43(2): 225-233.

Zoological Society of San Diego. 1995. Records: Goodfellow’s Joey Growth Data