LEADBEATER'S POSSUM: NUTRITIONAL AND ENVIRONMENTAL CHALLENGES OF CAPTIVE POSSUMS IN EIGHT ZOOS

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ABSTRACT

Eight zoos participated in a retrospective study by providing diets, post mortems (n = 75) and management practices for captive Leadbeater's possums (*Gymnobelideus leadbeateri*). Data was analyzed for correlation of common factors in the morbidity and mortality of captive possums. The results suggest nutritional factors common to most zoos which may play a role in the morbidity and mortality of captive possums are (1) excess energy intake relative to activity level (2) variable level and quality of dietary protein (3) dietary saturated fat intake (4) a potentially unbalanced dietary linoleic and linolenic fatty acid ratio and (5) a lack of complex dietary carbohydrates and dietary fiber. Common environmental factors that may contribute to the morbidity and mortality of captive Leadbeater's possums include a lack of dense canopy and understorey, a lack of sufficient nest boxes and material, inappropriate housing of breeding pairs, inappropriate social groups and inappropriate lighting. Recommendations include an insect based diet similar to the diet of wild Leadbeater's possums and a "work for food" system integrated with the provision of occupational opportunities. An environment designed to provide an appropriate social group and housing may be essential to reduce stress-related morbidity and mortality. This study emphasizes the important interrelationship of nutrition and environment when meeting the needs of captive animals.

Key Words: nutrition, environment, obesity, stress, pathology

Introduction

Leadbeater's Possum, *Gymnobelideus leadbeateri*, is an endangered marsupial indigenous to approximately fifteen hundred square kilometers in the Victorian Central Highlands of Australia (Smith, 1984a; Myroniuk and Seebeck, 1992). These possums are an endangered species because 75% of the Leadbeater's territory, old Mountain Ash (*Eucalyptus regnans*) forest, is designated for timber production.

Captive Leadbeater's possums have been held on the Australia continent at Healesville Sanctuary, Melbourne Zoo, Currumbin Sanctuary, Taronga Zoo and Gondwanaland (Gifford, 1998). Overseas zoos include London Zoo (United Kingdom), Brookfield Zoo (Chicago, U.S.A.) Toronto Zoo (Canada) and Zoo Poznan (Poland).

Leadbeater's possums are kept in captivity without extensive knowledge about their nutrient needs. The basic diet of captive Leadbeater's possums in all zoos included in this study is a "Leadbeater's mix" which partly originated as a honey and cereal bolus used to trap wild Leadbeater's possums (Lindenmayer, 1995). Possums first kept in captivity readily ate this food and survived but these possums were also kept in outdoor enclosures with the opportunity to ingest familiar plant foods and insects. A decline in breeding success, increased early mortality in offspring and frequent morbidity in captive Leadbeater's possums indicates a need to investigate the nutrient and environmental needs of this species.

In 1998, eight of the institutions holding captive Leadbeater's possums participated in a survey to evaluate the nutritional, management and environmental challenges of captive Leadbeater's possums. This paper presents some results of that evaluation.

Methods

Eight zoos participated in the study, all eight providing answers to a questionnaire on housing and husbandry practices for Leadbeater's possums. In addition, 5 of the 8 zoos provided information sufficient to allow a preliminary nutritional evaluation of the diet, and 7 zoos supplied post-mortem reports for a total of 75 animals (40 females and 35 males).

The basic diet for captive possums is a "Leadbeater's mix" comprised of human infant cereal (mixed cereal, rice pablum or Farex biscuits), honey and egg (whole egg or egg white only). Supplementary dietary items presented free choice to the animals, such as fruit (fresh and dried), mealworms, crickets, moths, fly pupae, mung beans, coconut and alfalfa, were not included in the analysis because ad lib amounts are difficult to quantitate.

Nutritional analysis was restricted to the energy, protein, fat and carbohydrate components of the diet. These were determined from the amount of each component of the 'Leadbeater's mix' reported for each zoo and their respective nutrient content (Health and Welfare Canada, 1988) and summing these to get the total energy, protein, fat and carbohydrate for the ration fed.

Results and Discussion

The energy, protein, fat and carbohydrate content of the Leadbeater's mix at the 5 zoos with sufficient dietary information for analysis is shown in Table 1.

Calories and activity. Excess caloric intake relative to activity level appears to be a major problem for captive Leadbeater's. Eight zoos hold this animal, yet the range of serving size (12.8 g to 20.4 g) and energy (37.7 kcal to 60.7 kcal) suggests disparate feeding practices. Obesity is pervasive and the weight range of captive possums is 130.0 g to 258.4 g compared to wild adult Leadbeater's average weight of 130.0 g (Lee and Cockburn, 1985).

<u>Table 1.</u> A Comparison on a Dry Matter Basis (per serving) of Energy, Protein, Fat and Carbohydrates in Leadbeater's Mix at Six Zoos*

Zoo	As Fed Weight per Daily Serving	Energy (kcal)	Protein grams	Protein %	Fat grams	Fat %	Carbohydrate grams	Carbohydrate %	Total % Dry Matter per Daily Serving
#1	14.8	40.8	0.47	3.2	0.06	0.4	9.95	67.1	70.7
#3	13.3	37.7	0.28	2.1	0.38	2.9	8.30	62.3	67.3
#4**	13.3	40.3	1.02	7.7	0.44	3.3	9.10	68.0	79.0
#5	20.4	60.7	0.58	2.9	3.90	19.2	14.10	69.4	91.5
#6	12.8	39.1	1.20	9.4	0.15	1.2	8.70	68.2	78.8

* Percentages of protein, fat and carbohydrate calculated as proportion of as fed weight
**Values for Zoo #4 may vary depending if soy isolate or soy concentrate used. Values listed here are an average for Zoo #4.

The daily calories ingested by captive Leadbeater's are an important health issue. Marsupials have low BMRs, they have one half the heart rates of placental species of comparable body weight, they utilize torpor states and energy reserves (body fat) last longer than eutherian (placental) species (Hume, 1982). These factors imply lower calorie requirements for possums and even lower calorie requirements for captive possums which lead sedentary lives.

Hume (1982) estimates that wild possums may have field energy requirements 4.8 times BMR (258.2 kcal daily). Lynch (1994) found that wild Leadbeater's possums have a high activity level at night consisting mostly of exits and entries into the nest box. Most zoos, however, report that their possums spend 75% of their nocturnal hours in their nest box. This sedentary lifestyle greatly reduces the energy requirements needed by captive Leadbeater's compared to their wild peers.

Calorie reduction may not suffice as the sole answer to possum obesity. The inactivity of captive Leadbeater's possums may be induced by a lack of a sufficient foliage canopy and understorey. Only three enclosures of twelve provide a canopy and only six enclosures provide an understorey. Enclosures with foliage are sparsely vegetated. Wild Leadbeater's possums live in an environment with a thick canopy of foliage overhead and a thick understorey of foliage beneath them. A canopy and understorey may provide protection from predators, foraging opportunities and psychological security (Birney et al., 1976).

The cost and practicality of maintaining Eucalyptus and Acacia trees in a zoo, especially for overseas zoos, are prohibitive. It may be that the species of foliage is not as important as the density of cover and understorey. There are many inexpensive, indigenous plants, for example, that may do well in an indoor enclosure yet offer dense cover.

Lack of a foraging challenge, for captive Leadbeater's possum, creates much idle time, destroys opportunity for activity, discourages lack of motor and neural development in the young and encourages obesity in all ages. Food could be offered to the possums by a dispenser system ("work for food") that requires them to forage. Wild Leadbeater's possums, for example, often spend several hours feeding because the flow of exudates is slow (Lee and Cockburn, 1985; Jelinek et al., 1995).

Dietary Protein. The range of dietary protein provided by the Leadbeater's mix among the six zoos is 2.1% to 9.4% with an average of 4.6%. It is estimated that protein represents is 20% of the diet of wild possums (Lindenmayer et al., 1994; Smith, 1995). The remaining 80% being exudates and gums.

Invertebrates may be the only source of protein for wild Leadbeater's possums (Lindenmayer et al., 1994; Smith, 1984b; Jelinek et al., 1995). Acacia gums do have some nitrogen content that varies with water stress, but the possums appear to depend on insects for protein (Lindenmayer et al., 1994). Many invertebrates are excellent protein sources (Barker 1997). Analyses of feces of wild possums suggests that Leadbeater's possums ingest tree crickets, beetles, moths, butterflies, spiders and lerp insects (Smith, 1984b; Lee and Cockburn, 1985).

As of 1998, all the zoos were providing live insects and all were uncertain if they were ingested by the possums because insects are released into an enclosure and their fate after release is not monitored. Zoo #5 adds pureed crickets to their Leadbeater's mix but the quantity is minute (0.33 grams) per serving. Pureed insects, at a 20% dietary level, should be used to ensure a minimum protein intake. For example, at least 10 g domestic crickets or 6 g black crickets may be needed at a 20% dietary protein level. Additional, live insects can be offered for food and/or environmental enrichment.

Some captive possums live longer than wild Leadbeater's. Increased age in captive possums may require dietary changes as they age. Modifying the dietary protein level and profile of amino acids may be important in resolving the 35.9% incidence of renal disease evident from the postmortem data.

Saturated fat. One third of post mortem reports on Leadbeater's reveal disease processes associated with fat metabolism. These diseases include obesity, xanthogranulomas, hepatic lipidosis, renal lipidosis and coronary atherosclerosis. The nutritional component (dietary fat and/or impaired fat metabolism) may be linked to egg yolk (Zoos #3, #4 and #5) and the human infant cereal (all the zoos). The saturated fat (as fed) in 100 g of infant cereal is 23.4 g (Industrial Laboratories of Canada Inc., Mississauga, Ontario, Canada) compared to 3.4 g for 100 g of whole egg (Health and Welfare Canada, 1988).

N-6:n-3 ratio. An unbalanced n-6:n-3 ratio may be common to all the zoos. The zoo diets appear to provide an n-6:n-3 of approximately 20.5:1 alone from the cereal formulated for human infants used in the Leadbeater's mix (Industrial Laboratories of Canada Inc., Mississauga, Ontario, Canada). An unbalanced n-6:n-3 ratio may interfere with the normal functioning of enzymes involved in fatty acid elongation and desaturation, the formation of eicosanoids and the incorporation of fatty acids into tissue lipids (Krajcovicova-Kudlackova et al., 1997). Eicosanoids, for example, include leukotrienes that are important in inflammatory immune responses. The incidence of acute and chronic inflammatory conditions in Leadbeater's possums appears to be 44%.

In contrast, exclusion of the human infant cereal and inclusion of pureed crickets would change the apparent n-6:n-3 ratio to 1:50 for domestic crickets and 1:31 for black crickets (Crampton Nutritional Laboratory, McGill University, Montreal, Canada). It is important to note that we do not know the appropriate n-6:n-3 ratio for this species. Salem and Pawlosky (1994) found that human infant diets high in n-6 and low in n-3 do not support normal neural development.

Another reason to discourage the use of human infant cereal for Leadbeater's possums is the deleterious effect that a lack of dietary linolenic acid has on membrane fluidity, membrane receptor function and enzyme activity (Meydani, 1994). A relative linolenic acid deficiency can also produce low density lipoprotein (LDL) particles that are more susceptible to oxidation (Turpeinen et al., 1998). Oxidative stress is a preexisting condition to atherosclerosis because the oxidized LDL causes lesions in arterial walls. These lesions collect debris which contributes to thinning of the blood vessels. Research suggests that the fatty acid composition of cellular membrane lipids is independent of calories provided by fat but dependent on type and ratio of fatty acids (Sprecher et al., 1994).

Complex Dietary carbohydrate and fiber. The comparison of diets fed captive Leadbeater's (Table 1) suggests that the percentage of dietary carbohydrates may be less than that of wild possums. The range in the zoo diets is 43.4% to 69.4% with an average of 63.1%. Wild possums ingest carbohydrates in exudates and tree gums which may provide 80% of the total daily energy requirements for Leadbeater's (Lindenmayer et al., 1994; Smith, 1995).

Wild possums appear to primarily obtain soluble and insoluble fiber from exudates and insects, respectively. Plant exudates include soluble polysaccharides that should be included in the captive diet. A possible substitute is pectin that is a polysaccharide, plant-based, soluble and inexpensive. Necropsies of Leadbeater's possums indicate disease processes such as coronary atherosclerosis, hepatic lipidosis and colitis. These diseases can be modulated by soluble dietary fiber. Dietary fiber is also important in lipid metabolism to modify the ratios of fatty acids (Felippe et al., 1997). The neutral detergent fiber (NDF) components in adult crickets are chitin and ingested plant compounds and may approximate 19.1% of dry matter (Crampton Nutritional Laboratory, McGill University, Montreal, Canada). It is not known, however, if Leadbeater's have chitinase necessary to digest nutrients from chitin (Barker 1997). The chitin may be a source of insoluble fiber in the possums' diet and may utilize the possum's gut morphology of enlarged cecum.

A logical deduction is that the captive possum diet is highly digestible and does not utilize the digestive capabilities of the possums' gastrointestinal tract. The captive possums' current diets are low in soluble and insoluble fiber and the possums may not have been utilizing microbial digestion. This suggests initial inefficiency of digestion if they are changed to a diet with soluble and insoluble fiber.

Post mortem results and immune compromise. Post mortems indicate a 53% incidence of immune compromise based on the occurrence of opportunistic pathogens in animals as young as eight months. Booth (1995) suggests that diseases of captive Leadbeater's possums in an Australian zoo are analogous to immune compromised disease processes often found in organisms under social stress. Stress causes an increase in free glucocorticoid concentration in blood plasma that results in a decrease in immunological reactivity, a decrease in immunoglobulin concentration, decreased resistance to parasites and ulceration of the gastrointestinal tract (Bradley et al., 1980).

Table 2 presents the percent incidence of possible immune-mediated and/or stress related pathology found at post mortem (n = 75) of Leadbeater's possums. The information indicates that captive possums may be stressed and immune compromised beyond their ability of physiological and psychological adaptation.

Wild, female Leadbeater's possums appear to be the aggressive and vigilant sex of this species. This may explain why female captive possums are most likely to develop immune compromised or stress-related health problems than male captive possums. For example, female post mortems to male post mortems is 40:35 but the ratio of females developing immune compromised or stress-related health problems is 61:33 (Table 2).

Possible immune stressors found in management surveys are a lack of dense canopy and understorey; lack of sufficient nest boxes and materials; inappropriate housing of breeding pairs; inappropriate social groups; and, inappropriate lighting. The lack of a dense canopy and understorey may increase the perception of vulnerability of captive possums.

A lack of sufficient nest boxes and materials may render the nest box insufficient as a secure living area. The entrances to nest boxes of captive Leadbeater's are usually larger than those made by wild possums. Most of the captive possum nests are made of wood but some nest boxes are made of plexiglass or have an area of clear plexiglass or glass to allow viewing that may make the possums feel vulnerable. All zoos provide nest boxes but the ratio of nest boxes to possums is usually much less than those used by wild possums. Wild Leadbeater's possums usually have several nest sites per colony and practice "den-swapping" (Lindenmayer, 1996). Den-swapping may be a predator defense and/or a territorial defense. Prohibition of this behaviour because of a lack of nest boxes may be an environmental stressor for the possums.

Wild possums make large, complex nests of woven bark strips (Lindenmayer, 1996) that are more complex than any nests created by other possum species (Smith et al., 1982). Captive Leadbeater's nests have little resemblance to the wild possums' creations and this may be due to lack of appropriate nesting materials. Nesting material offered to captive Leadbeater's possums should allow them to weave nests. The implication is that the material must resemble the stringybark (Eucalyptus sp.) available in the Mountain Ash forests. Stringybark may not be readily available but substitutions may be acceptable to the possums. For example, shredded paper is often in long, stringy pieces and rodents make dense nests from it. Pieces of string and yarn and strips of cloth may also be acceptable.Breeding pairs may to be housed inappropriately.

Two of five zoos attempting to breed Leadbeater's possums have the breeding pair on exhibit which may not provide the possums with sufficient isolation for successful breeding. A sparse canopy and understorey also does not provide sufficient isolation for successful breeding and raising of progeny. Forced pairing of possums has resulted in violence to the male from the female (Peach, 1985) and this may indicate that the possums need more control over their environment and social relationships.

Table 2. Percent Incidence of Possible Immune-mediated and/or Stress Related Pathology at Post Mortem (n = 75) of Leadbeater's Possums at Seven Zoos

Disease	Percent Incidence	Sex Ratio F = Female; M = Male
Respiratory infections	28.0%	15F:6M
Infections (mandible, visual system, digits, muscles, meningoencephalitis, liver abscess, spleen abscess, bladder, vaginal, peritoneum, prostate)	26.3%	12F:8M
Glomerular Nephritis	24.0%	13F:5M
Enlarged/congested Spleen	16.0%	4F:8M
Sepsis (Yersinia, Pseudomonas, E. coli, *Serratia marcessina*)	9.3%	5F:2M
Dermatitis, alopecia, fungal keratitis	9.3%	6F:1M
Gastric ulcer, gastroenteritis, colitis	7.9%	5F:1M
Adrenal Necrosis/Atrophy	4.0%	1F:2M
Overall sex ratio for incidence of these diseases: 61F:33M		

The social grouping of captive possums may also be inappropriate. Wild Leadbeater's live in a colony of up to nine individuals (Lee and Cockburn, 1985) and the colony may be important for social behaviours, group territorial defense and rearing of young. Captive possums are usually housed individually or in pairs. Two possums must be more vigilant individually than each individual in a nine-member colony. A small social group may also increase the stress burden of female Leadbeater's possums who are the vigilant sex of this species.

The type of light used for indoor possum enclosures should also be considered inappropriate. All indoor enclosures use artificial light schedules on a reverse schedule but synchronized with day lengths in Australia. Most are lit with a blue or red light to illuminate the possums to zoo visitors during the possums' nocturnal period. The effect of this illumination on the possums' activities and physical and psychological health is unknown. Nocturnal illumination may result in reduced use of open space and restricted foraging activity (Julien-Laferriere, 1997). Only three of seven indoor enclosures provide dusk and dawn periods and this should be a requirement for all indoor enclosures. Dusk and dawn periods provide a reliable signal (zeitgeber) for environmental changes and allows gradual physiological adjustment to a different light source.

Only one indoor enclosure provides ultraviolet light (UV) and all indoor enclosures would benefit from UV light during the light (day) period when the possums are in their nest, since this will reduce environmental opportunistic pathogens. Forty-four percent of Leadbeater's possum postmortems (n = 75) revealed opportunistic pathogens (Yersinia sp., Streptococcus sp., Cryptococcus sp., E. coli, Bacillus sp., *Toxoplasma gondii*, Psudomonas sp., *Serratia marcessin*a).

UV radiation rapidly decreases colonies of gram-negative bacteria in a fifty-minute exposure period with a 90% kill rate (Degiorgi et al., 1996). Enclosures that provide a dense canopy would particularly benefit the use of UV light, since bactericides and other chemicals used in cleaning would be ineffective on the complex surfaces of dense foliage and may damage the plants.

One enclosure in the survey is equipped with black light (ultraviolet A or UVA). It is unknown what effect it may have on Leadbeater's possum. UVA is a component of natural light and is most often used for captive reptiles (Gehrmann, 1997). UVA stimulates social and reproductive behaviours in reptiles but it has also been associated with agonistic behaviours (Gehrmann,1997) and it has inhibited growth in female panther chameleons (*Chamaelo pardalis*) (Ferguson et al., 1996).

This study did not investigate the vitamin and mineral composition in the diet of Leadbeater's possums. Diseases, however, found at post mortem that may result from inappropriate vitamin and mineral nutrition were evident in possums (Table 3). Since both plants and insects which feed on plants vary in mineral composition seasonally (Barker, 1997) this is an area which needs to be addressed for the Leadbeater's possum, for which micronutrient needs are unknown.

Table 3. Pathology that May Result from Inappropriate Vitamin and Mineral Supplementation Found During Post Mortem of Leadbeater's Possums (Kirk et al, 1990; Fraser, 1991)

Pathology at Post Mortem	Possible Cause	Percent Incidence
Accelerated renal failure	excess of dietary phosphorus	35.9%*
Fatty liver	riboflavin deficiency pantothenic acid deficiency impaired use of methionine choline deficiency	16.0%
Gastrointestinal inflammation	niacin deficiency	7.9%
Renal fibrosis	vitamin B6, pyridoxine deficiency	1.3%
Alopecia	biotin deficiency	1.3%

* Percent incidence of renal disease

CONCLUSIONS

Dierenfeld (1997) says that the proper feeding management of wild animals in captivity requires applied nutritional sciences and husbandry skills. The results of this study indicate that it is essential to integrate diet and environment when providing for Leadbeater's possums. The nutritional requirements of an animal go beyond dietary components. Reducing negative stressors, introducing positive stressors and allowing speciated social interactions ensures that the foods eaten by the possums are used to maintain health and not maintain a state of fear, stress and disease. This requires an integration of the nutritional and behavioral sciences as well as a sense of ethical responsibility to successfully maintain endangered species in captivity.

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