

Mammal Nutrition: Basic Knowledge and Black Holes

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Introduction

An underlying goal in captive wildlife feeding programs, incorporating both *in situ* and *ex situ* management and research aspects, should be to provide optimal diets to the species in our care. In doing so, we must strive to meet both the physiological as well as the psychological needs of the animals, at the same time keeping in mind economic considerations. Zoo nutrition is continually comparative – anatomically, behaviorally, and physiologically. In developing zoo diets, we rely on three main sources of information, each with specific limitations: 1) natural history information – very often, no data exist on the nutrient composition of diets although specific ingredients may be known; 2) historical records – until recently, there have been no standardized records-keeping systems for diet management in zoos, and many diets were developed on a “trial and error” basis, often with no justification or documentation; 3) domestic animal models – while the basis of most laboratory research on nutritional requirements, the application of domestic animal information is limited, or simply not suitable, for many species in captivity.

More recently, scientific studies have focused on select species or problems associated with zoo animal nutrition. Several examples where combining data from field and captive diets, along with management/medical records, and domestic models, are outlined below which have led to improved zoo animal nutrition.

Carnivores

General principles of carnivore nutrition will apply across animal classes, including carnivorous birds and reptiles. When fed a whole prey-based diet, all carnivores consume proteins and fats from the muscle, vitamins from organs and gut contents, minerals from bones, and abrasives/roughage in the hide, feathers, hooves, teeth, gut contents, etc. For the most part, the nutritional requirements of zoo felids and canids, which have been extensively researched and documented through the pet food industry, can be met by properly balanced commercial pet foods, or properly-supplemented meat-based diets.

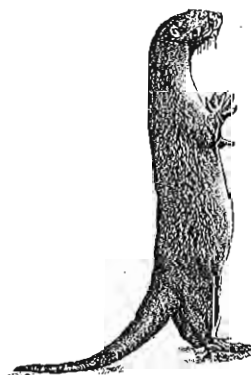
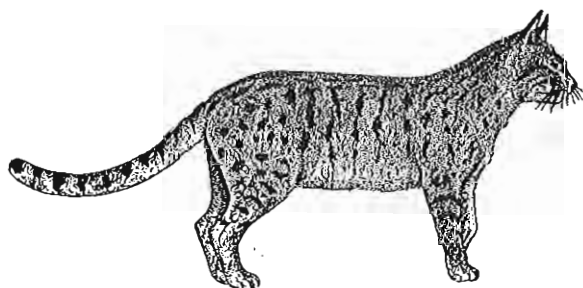
Felids are considered obligate carnivores, with a number of physiological specializations that set them apart from other, more omnivorous, meat-eaters. Cats cannot effectively utilize carbohydrate as an energy source, thus depend on higher concentrations of fats and proteins in the diet. They

are also dependent on dietary sources of pre-formed vitamin A (with increasing evidence of a dietary need for vitamin D), arachadonic acid (an essential fatty acid), have a dietary requirement for taurine (one of the amino acids), and cannot convert tryptophan to niacin. Physiological requirements of cats would be met by the consumption of a whole-prey diets, but a lean meat-based diet – solely – would be deficient in minerals, essential fatty acids, and both fat- and water-soluble vitamins. Additionally, teeth and gum health are adversely affected by soft diets fed to carnivores.

Zoo carnivores encounter a number of health problems with links to diet including: soft stools (from an excess of carbohydrate), tooth/gum and bone disease (from mineral imbalances or a lack of abrasives), obesity (lack of exercise and/or high nutrient density foods), and feline urinary syndrome (mineral imbalances). Comparison with natural feeding patterns of free-ranging canids provides some clues to potential diet changes in zoos which may prove beneficial. Perhaps one of the greatest problems in captivity, however, is obesity simply due to eating too rich caloric density with little exercise.

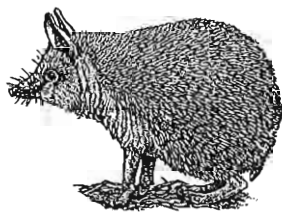
Tooth and gum disease are still common in carnivores that don't receive abrasives (i.e. ribs, shank bones) a minimum of once per week; studies have shown that twice per week is even more beneficial. Improper Ca:P ratios can also lead to weakened teeth and bones, ricketts, and/or osteomalacia. All meat diets predispose to this condition, as they are low in Ca and high in P. One should aim for a dietary Ca:P ratio of 1:1 to 2:1, to duplicate the level found in vertebrate whole prey. If whole prey cannot be offered and muscle meat is the staple diet for carnivores, whole bone should be included (approximately 20% of total weight of the meat plus bone) – but must, of course, be eaten to be effective. If bone is not consumed, and a suitable mixed supplement is not locally available for carnivores, major lacking nutrients can be supplied by a variety of local

ingredients. A calcium supplement should be added to the meat: Mix approximately 10 g calcium carbonate per 1 kg fresh meat. Fresh liver should be added to the meat-calcium mixture at a level not to exceed 10 g per 1 kg meat in order to supply vitamins A and D. Cod-liver or other fish oil containing 8000-10000 IU/g vitamin A, and a 400 IU/g vitamin D supplement can replace liver at a level not to exceed 1 g per 1 kg meat. Fish oil would also be a good supply of essential omega fatty acids.



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Piscivores: Fish-based diets must be minimally supplemented with thiamin (vitamin B1) and vitamin E to provide 100 mg/kg and 200 mg/kg dry weight, respectively. This is equal to 25 mg B1 and 50 mg vitamin E/kg of fresh fish. These supplements are specifically required in diets for piscivores because dead fish release the enzyme thiaminase to initiate the decomposition process, which also destroys thiamin. Additionally, the polyunsaturated fatty acids of aquatic tissues oxidize rapidly, necessitating the supplementation of additional vitamin E as an antioxidant. If fresh, healthy whole fish are properly stored, thawed, and consumed, there should be no additional need for supplemental minerals or vitamins.



Insectivores: Insectivorous carnivores should also be considered specialist carnivores. Insects, with no internal skeleton, are poor sources of calcium, thus inherently provide imbalanced Ca:P ratios. For captive feeding programs, invertebrates must be supplemented with Ca by either feeding them a high Ca diet, shaking in calcium carbonate to coat them, or (preferred) both. A suggested insect diet that has proven useful incorporates ground dry dog food or avian pellets mixed with calcium carbonate in a ratio of 80% feed to 20% calcium carbonate. This provides an 8% Ca diet to the insects, which should be fed for no more than 2 days prior to feeding the invertebrate to the insectivore.

Some interesting data on mineral content of pinhead crickets (smallest nymph stage) recently compiled shows much higher (and apparently adequate) levels of Ca compared with adults fed the same diet. Mineralization of various cricket stages needs to be examined in controlled studies, but may have health implications. It is possible that the larger relative gut lumen to overall body size of the smaller crickets provides a proportionately greater contribution of cricket diet to the overall nutrient content of the cricket. Hence the addition of Ca supplements to the diet of the nymph crickets may underlie the results observed, but controlled experiments have not been published. We simply do not see the same problems with rickets in, for example, captive *Dendrobates* frogs fed pinhead crickets as many other species of amphibians or reptiles fed the adult sizes.

Fat-soluble vitamins

The vitamin A content of insects is another arena for which little or no published data exist, and deserves further work. Most insects have little or no measurable amounts of preformed vitamin A. We may be seriously overfeeding insectivores in captivity if they are not adapted for high dietary levels of this nutrient. Particular cases of vitamin A toxicosis have been documented in anteaters and tamanduas. Carotenoids, such as β -carotene and others, have been identified in many invertebrates and may serve as potential (and safe) precursors for vitamin A in insectivores, but conversion ability or activity of tissues has not been examined in reptiles or amphibians. The

carotenoid pigments may, however, serve as coloring agents for animals eating these prey items, which can also be an important facet of zoo dietary management. Specific health benefits of carotenoids have not been identified in any zoo species.

With respect to more typical carnivores (obligate carnivores), carotenoid content of the diet probably plays little to no role in vitamin A nutrition, as conversion appears limited due to enzyme inactivity. A high incidence of veno-occlusive liver disease in zoo cheetahs has been associated with high-A diets, however, and may also be affecting carnivorous and especially piscivorous (fish-eating) birds. Captive diets for zoo carnivores should be formulated to contain no more than perhaps 10,000 to 15,000 IU vitamin A per kg dry matter. It is probably not necessary, and possibly detrimental, to add vitamin A supplements to the diets of species consuming whole prey including fish, as laboratory analysis has shown feeder rodents, birds, and fish species to contain vitamin A levels $\geq 10,000$ IU/kg dry matter.

Vitamin D is receiving much active research attention due to the fact that more species are exhibited indoors under artificial lights, and demonstrating signs of rickets and osteomalacia. These problems appear to be less prevalent in tropical climate zoos, but quantitative studies have not been conducted. Recent research has documented that both felids and canids appear to require a dietary source of preformed vitamin D, as conversion from sunlight through epidermal precursors does not appear adequate, but little detailed information on the vitamin D content of whole prey items is available in the published literature.

Vitamin E should be added to meat-based diets that contain high levels of polyunsaturated fats (fish- or pork-based), to provide diets that contain between 50 and 200 IU vitamin E per kg dry matter.

Lastly, vitamin K is the fat-soluble vitamin least studied, as it is generally in adequate quantities in plant-based diets or provided by microbial synthesis to any animals that have foregut fermentation or practice coprophagy. There is inferential evidence, but no quantitative data, that vitamin K may be found in natural diets of anteaters and tamanduas (termites) due to the microbial flora in these insects. Supplementation of vitamin K in diets for these species is necessary in zoos to prevent internal hemorrhage from deficiency. Interactions among all the fat-soluble vitamins should be considered when evaluating zoo diets, as antagonisms and synergisms among them do occur.

Primates

Calitrichids: With a body mass 105 to 700 g, the marmosets and tamarins may have an increased energy requirement compared with other New World primates (150 to 160 kcal/kg body mass/day). From recent studies, New World primates appear to not have a need for higher levels of dietary protein as was recommended previously, utilize vitamin D3 exclusively (rather than both D2 and D3 as Old World primates), and, like all primates, have a dietary requirement for vitamin C.

All callitrichids show adaptations for active foraging, with the teeth of marmosets short-tusked for gouging bark, and tamarin teeth longer-tusked. A wide variety of feeding habits exists within the Callitrichidae, with different species considered to be primarily: Frugivores, Gummivores (with a more complex gut structure), or



Insectivores. In addition to the primary food items above, native diets also incorporate nectars, exudates, flowers, other plant parts, soil, eggs, and small vertebrates. As such, nutrient considerations in major foods of these feeding categories should be considered.

Fruits provide good sources of water, sugars, vitamin C, and carotenoids. Some are high in fiber, but most are poor sources of minerals and low in protein. Wild figs are an exception, and have been shown to contain up to 9 times the Ca content of domestic figs. Native fruits may be nutritionally superior to those grown domestically, but direct comparisons are few. Vegetables — many of the stalk and fleshy vegetables cultured for human consumption are more similar in chemical composition to native fruits consumed by primates. Root and tuber vegetables contain less water than fruits in general, thus provide more nutrient density. They can be good sources of carotenoids and vitamin C, have moderate to high protein and fiber content, but are still poor sources of many minerals (often with an inverse Ca:P ratio). Green vegetables, on the other hand, are higher in protein and fiber, and often excellent sources of vitamins C, E, and carotenoids. Levels of Ca and P are adequate and meet a minimal 1:1 Ca:P ratio in most leafy green parts.

Insect composition has already been discussed, but gums and exudates provide a unique feed source of potentially fermentable carbohydrates. While not high in protein, some gums have been shown to be good mineral sources, balancing the lack of Ca in insects when animals consume gums in addition to invertebrates.

Common dietary health problems seen with callitrichids in captivity include iron storage disease, metabolic bone disease, as well as a wasting syndrome of unknown etiology.

Folivorous Primates and Apes - Species for which we have successfully utilized field data to improve captive diet composition include various species of foregut-fermenting primates (langurs), as well as gorillas. Duplication of low protein, high-fiber diets through the use of high-fiber biscuits and browse species available in captive feeding situations have minimized intestinal problems commonly seen in these species. Zoo diets often contain too much soluble CHO and protein, and too little fiber, which can

contribute to health problems seen in these species. With these species, combined nutrient requirement information from domestic ruminants and primates probably provides the most suitable model, but is currently under review. General National Research Council (NRC) recommendations for non-human primates currently form the basis of dietary nutrient composition for all captive primates, and have recently been reviewed in include six separate feeding groups of primates (NRC, 2003).

Similar field-based information can also be applied to feeding hindgut-fermenting folivorous primates (such as the howling monkeys), which also consume diets rather moderate in protein, high in fiber, and contain high levels of secondary plant compounds such as tannins in nature. Increased fiber levels, and decreased fat (elimination of animal protein - eggs and meat) has decreased cholesterol levels and led to fewer health problems (obesity, strokes, and cardiovascular) in captive gorilla populations – as has been shown in vegetarian compared with omnivorous humans. Some chemical constituents of native forages once felt to actually decrease diet quality are increasingly found to have beneficial components, and warrant much further investigation in relation to animal nutrition. Information on the nutrient composition of foods consumed by all primates in their native habitats will add immensely to our limited knowledge of dietary requirements for these species.

In general, however, is it recommended that a formulated biscuit (either commercially obtained or prepared from local ingredients) be utilized to supply known concentrations of proteins, fats, minerals, and vitamins in the diets of captive primates.

Examples of recipes successfully adapted for captive primate feeding programs, successfully implemented in Africa, South America, and Asian facilities, will be discussed and provided in the upcoming workshop. These nutritionally balanced portions of the diets should comprise a minimum 30 to 50% of the diet, with locally available produce and browses provided to supply additional nutrients and/or for enrichment purposes.



Hoofstock

Herbivores have adapted numerous methods of utilizing roughage-based diets to meet their nutrient requirements through microbial breakdown and transformation in the gastrointestinal tract. Ruminants and some non-ruminant herbivores (sloths, hippos, colobines, macropod marsupials) utilize pre-gastric microbial fermentation to break down cell wall constituents, whereas perissodactyls primarily rely on post-gastric fermentation. Some small herbivores (rodents, rabbits) must routinely practice coprophagy to obtain nutrients provided by the microbes (protein, water, enzymes, vitamins, minerals) to meet their

relatively higher nutrient requirements compared with the larger herbivores. The gastrointestinal microbial population is an integral component of the feeding strategy of most herbivores, and feeding the whole animal relies essentially upon feeding the microbes properly, which in turn supply nutrients to the animal.

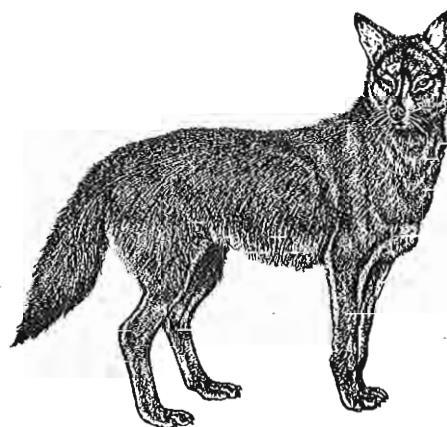
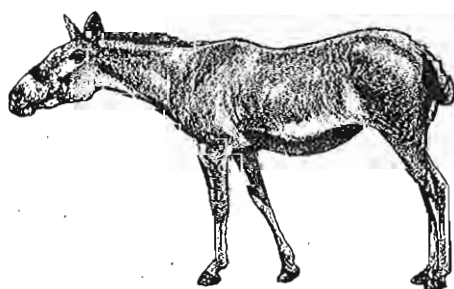
Although various degrees of selective behavior differentiate herbivores into feeding categories (grazers, browsers, folivores, granivores, frugivores, nectarivores), the basis of captive feeding programs for hoofstock is good quality forage. Plants comprise cell contents (sugars, fats, starches, protein, soluble minerals) which are digested with endogenous enzymes, and cell wall constituents (hemicellulose, cellulose, lignin) which must be degraded exogenously. The breakdown of structural carbohydrates into volatile fatty acids (VFAs) used as an energy source by herbivores depends upon the microbial population, gut anatomy, and the chemical composition of the forage itself. As a rule of thumb, hoofstock will consume 1 to 3% of body weight in total dry matter daily (and about twice that amount of water). Fresh (green chop, browses) or dried forages (hays, browses) should be utilized to provide a minimum of 50% of calculated energy requirements for most species.

Legumes and/or a mixture of grasses and legumes can be readily utilized by most selective feeders (concentrate selectors, intermediate feeders), whereas good quality grasses should form the staple diet for less selective, grazing species. Routine analysis of forages utilized should be incorporated into the feeding program to provide basic information on fiber, protein, and mineral content (supplemental information that would also be useful includes details of vitamin, sugar, and fat constituents). Once the chemical composition of forages is known, the need for, and appropriate composition, of supplemental concentrates, grains, pellets, or other dietary additions can be more accurately assessed. All herbivores should have constant access to fresh water and iodized salt. Captive diets should be evaluated based upon local conditions utilizing similar livestock species and feeding practices as the physiologic models.

Neonates

Young growing animals of all species require higher concentrations of nutrients (protein, energy, vitamins, minerals) than needed for mature maintenance, and often benefit from housing conditions that allow separate rations for adults compared with young (creep feeding for hoofstock, or hand-supplementing). A very brief categorization of mammalian milk compositional differences across species can illustrate this point.

Although mother-rearing is preferred, hand-rearing is sometimes necessary, and duplication of proper milk composition must be the starting point:



Horses and rhinoceros have a very dilute milk (90% water, high sugar content, low fat) and can be successfully raised on skim milk. Due to the nutrient dilution, however, they must be fed perhaps every 0.5 to 2 hours. **Primates** have milks of intermediate fat and water content, with a very low protein and high sugar concentration. Human milk replacement formulas, therefore, are more suitable replacement milks for non-human primates than cow's milk. **Cow's** milk is rather intermediate in all constituents (water content, and solids fat, CHO, and protein). Cow milk is the preferred substitute for captive bovids including most antelope species, as well as elephants, pigs, and camelids. **Dog** milk is high in solids and protein, with a high fat and low sugar content. Goat/sheep milk, or cow's milk with added lactase and egg yolk, has been used as a suitable substitute for some rodents, deer, and other carnivores including cat. These species should be fed perhaps 5 times/day, in a meal size no more than about 4% of body weight (20% total body weight in milk intake per day). **Rabbit** milk is quite concentrated, high in fat and protein, and very low in sugar. Some rodents and bears also have milks simulating this category. High fat milk (add egg?), with added lactase (yogurt) has been used successfully with rabbits, when fed no more than 2 to 3 times per day. The final category includes **marine mammals**, with milks containing essentially no sugar solids, only fats and proteins. These species are fed infrequently (twice daily).

Combining the limited resources of personnel, animals, time, and money in both zoo- and field-based conservation programs is one method by which the field of comparative animal nutrition can make a rapid and essential contribution to the survival of species - both in captivity and in the wild. Good health is imperative for reproduction; thus, sound nutrition becomes a basic foundation for conservation.

