FORMULATION OF DIETS FOR WILD ANIMALS

I.D. HUME

Department of Biochemistry and Nutrition,
University of New England,
ARMIDALE, N.S.W......2351.

1. Introduction

In this paper discussion is restricted to the considerations involved in formulating diets for wild mammals and birds maintained in zoos, game parks and aquaria; reptiles and fish have not been included in any detail.

In contrast to commercial diets for domestic mammals and birds, when diets are formulated for wild animals the emphasis is on maintenance and health of adult animals and successful reproduction and survival of their young, rather than on achieving maximum growth rates, early weaning and minimum generation intervals. Other considerations involved include coat and feather colour and condition, and well-formed faecal stools which are as odourless as possible.

2. General features of nutrient requirements and natural diets of wild animals

It is convenient to divide animals, on the basis of dietary habit, into the three broad categories of herbivore, omnivore and carnivore. In general, the dietary nutrient requirements of herbivores are the least demanding, and those of carnivores the most; omnivores occupy an intermediate position. This is because of microbial activity in some part of the gut of herbivores, and of most omnivores. In the herbivores microbial fermentation takes place in an area of the stomach (e.g. the reticulo-rumen) or of the hind gut (the caecum-proximal colon) or both. In the omnivores microbial activity is generally confined to the hind gut. Microbial synthesis makes the host animal more or less independent of a dietary source of the B complex of vitamins and vitamin K, and at least partially independent of the quality of the dietary protein.

The more highly developed the gut fermentation, and in the case of the hind gut fermenters, the more highly developed the practice of coprophagy (i.e. the ingestion of faeces) the more independent the host animal is likely to be of a dietary source of the B vitamins and vitamin K, and the more tolerant it is likely to be of dietary protein quality. For example, the rabbit, in which coprophagy is highly developed, is independent of a dietary source of the B vitamins thiamine, riboflavin, pantothenic acid, folic acid, biotin and cyanocobalamin, and of vitamin K for growth. The guinea pip, in which copronhagy is not as well developed, requires a dietary supply of thiamine, riboflavin, pantothenic acid, folic acid and vitamin K, and the mouse, which is not coprophagous to any significant extent, requires a dietary source of all the B vitamins and vitamin K for growth (Table 1).

Because of the lack of significant microbial activity in the

Table 1. Qualitative vitamin requirements for growth of rabbits, guinea pigs and mice.

Vitamin	Rabbit	Guinea pig	Mouse
A	+	+	+
B_1 (Thiamine)	-	+	+
B_2 (Riboflavin)	-	+	+
Niacin	+	+	+
B_6 (pyridoxine)	+	+	+
Pantothenic acid	-	+	+
Folic acid	-	+	+
Biotin	-	-	+
Choline	+	+	+
B_{12} (cyanocobalamin)	-	-	+
Inositol	-	-	?
C	-	+	-
D	-	-	+
E	+	+	+
K	-	+	+

Data from National Research Council, National Academy of Sciences, "Nutrient Requirements of Domestic Animals", Nos. 9 and 10.

gut of carnivores these species are completely dependent upon a dietary source of all the essential vitamins, and upon a diet of high protein quality. In the wild these requirements are not likely to pose any special problem. The protein quality of the prey is usually high, the pattern of amino acids being similar to that of the predator. Many carnivores eat the intestinal tract of the prey first, and this ensures a supply of the end products of any microbial activity in the prey species. However, compounded diets fed to carnivores in captivity must provide all of the essential nutrients.

From the above discussion it can be seen that the quality of the diets of animals at the end of a food chain is likely to be superior to that of primary consumers. Also, the diet of carnivores and top carnivores is likely to be much less variable between food items (i.e. prey species) and between seasons than the diet of most herbivores. Associated with this is the fact that carnivores are generally much more fastidious in their feeding habits than most herbivores. This poses special problems in the formulation of diets for some particular carnivorous species, such as many reptiles which will only accept live prey.

Of course there are many exceptions to the above generalisations. For instance the food preferences of the koala are restricted to a few species of *Eucalyptus,* and hence this herbivore must be classed as a fastidious feeder. Another point is that there are really very few *strict* herbivores and *strict* carnivores. For example, many nectivorous birds and bats also eat some insects, and the only strictly carnivorous bear is the polar bear.

3. Zoo diets

Because of the expense, high labour requirement, and sometimes seasonal difficulty in obtaining natural dietary items for wild animals in captivity, the trend, especially in the U.S., has been to replace the natural diet with a commercially compounded mix designed to meet all known nutrient requirements. In order to minimise the number of different commercial mixes used, it is necessary to group species with respect to nutrient requirements, natural food preferences, and feeding behaviour.

Tables 2 and 3 list examples of compounded rations, usually designed as complete diets, marketed by a number of U.S. feed manufacturers. Hallwood Inc., Muskegon, Michigan, provide the most complete analysis of their diets, including average mineral, vitamin and amino acid contents. TDN (Total Digestible Nutrients) values are also provided by Hallwood as a measure of the energy value of their diets. Although now outmoded, TDN values are included in Tables 2 and 3 since they are the only measures of energy value available. Hallwood market four herbivore diets. The Veldt Diet (Table 2) is designed as a pelleted complete ration for both browsing and grazing ungulates. It is simple in composition, low in protein and fat, and high in fibre; consequently its TDN (Total Digestible Nutrients) value is low (55). The Grazing Ruminant Diet is higher in protein content, and lower in fibre than the Veldt Diet, and hence has a higher TDN value (79). It is designed to be fed as a supplement to a hay diet to the grazing antelopes, bovines and ovines. Because it is used as a supplement, it is also suitable for hind gut fermenters such as the elephant, and also

Table 2. General Zoo Diets.

Type & Manufacturer	Species	Principal Ingredients*	Analysis (% of DM)		
VELDT (Hallwood) Complete ration	Both grazing and browsing ungulates	Malt sprouts, annato seed, ground oats, alfalfa meal, peanut hulls, rice hulls, molasses, steamed bone meal	C.P. E.E. C.F. N.F.E. Ash T.D.N.	14.0 3.5 26.0 43.0 7.5 55	(min) (min) (max)
GRAZING RUMINANT (Hallwood) Feed with hay *ad libitum*	Antelope (e.g. impala, gazelle, wildebeest), Bovines, Ovines, Elephant, Marsupials	Dehydrated alfalfa meal, corn gluten meal, ground yellow corn, wheat middlings, ground oats, dried kelp, molasses, soybean meal	C.P. E.E. C.F. N.F.E. Ash T.D.N.	19.0 3.3 8.7 50.0 9.0 79	(min) (min) (max)
OMNIVORE (Hallwood) Complete ration	Bears (all except Polar), canines, hyenas, raccoons, weasels	Ground whole wheat, cooked ground cereals, dried fruit, peanut meal, dried milk solids, meat meal, blood meal, molasses, soy oil, brewer's dried yeast, dried kelp	C.P. E.E. C.F. N.F.E. Ash T.D.N.	20.0 7.7 6.6 53.9 9.9 78	(min) (min) (max)
CARNIVORE (Hallwood) Complete ration	Felines, canines, Polar bear, hyenas, weasels, raptors	Beef, beef by-products, ground turkey, blood meal, dried kelp, brewer's dried yeast, steamed bone meal	C.P. E.E. C.F. N.F.E. Ash T.D.N. B.V.	46.4 31.0 4.8 8.3 7.1 89 78	(min) (min) (max)

* Minerals and vitamins used in all diets in addition to ingredients listed.

for the "ruminant-like" macropod marsupials.

Hallwood's Omnivore Diet (Table 2) is designed to be fed to a broad spectrum of omnivores, including the canines, and is marketed as a complete diet prepared as a 90 g cake. It contains a greater range of dietary ingredients than the herbivore diets, and has a lower fibre content and slightly higher protein and fat contents than the Grazing Ruminant Diet. At the other end of the spectrum is the Carnivore Diet (Table 2) which is high in protein and fat, and low in carbohydrate, both crude fibre and NFE (nitrogen-free extract). Other feed companies such as Albers Milling Company, Los Angeles, California, market both a Feline Diet and a Canine Diet, the Feline Diet being higher in protein content than the Canine Diet, in line with established requirements of these two groups of carnivore (National Research Council, U.S.A., 1972).

Table 3 lists four examples of more specialised diets used in U.S. zoos. The first, Hallwood's Primate Diet, contains a wide range of ingredients in a biscuit form, and is marketed in a number of different flavours in an effort to accommodate the more sophisticated dietary habits of the primates. It contains a stabilised source of vitamin C, since vitamin C is an essential nutrient for all primates, and a source of vitamin D3, required by the New World monkeys (e.g. spider, woolly, squirrel and capuchin), in contrast to the Old World monkeys (e.g. rhesus) which can utilize both vitamin D2 (of plant origin) and vitamin D3 (of animal origin). The manufacturers recommend that the Primate Diet be supplemented with fruit for variety and as an additional source of vitamin C, since the shelf life of vitamin C, even when stabilized, is limited.

Albers Pinniped Diet (Table 3) is designed to replace fresh fish as a food for sea lions and seals, as well as for penguins, cormorants and pelicans. It has not yet been fully tested, but acceptance has apparently been good with the species mentioned above, although not with cetaceans such as porpoises and killer whales.

The Ratite Diet marketed by Zu/Preem, Topeka, Kansas, is included in Table 3 as an example of a complete diet formulation for all graminivorous birds, not only the ratites (the flightless birds). A very specialised avian diet is Hallwood's Flamingo Diet (Table 3), which contains shrimp meal as a natural source, and Flaminol as an artificial source of α and β carotenes to generate and maintain vivid and natural feather pigmentation. The diet is high in protein content, and also high in ash (24%) because of the ground oyster shell; consequently its TDN value is low (68).

The examples listed in Tables 2 and 3 illustrate the point that, compared with commercial diets for domestic animal and bird production, zoo diets tend to contain a greater variety of ingredients, and in many cases probably err on the luxury side of requirements. This reflects:

1. The lack of detailed information available on the nutrient levels required by many wild species.

2. The knowledge that many species in the wild use a broad spectrum of dietary material to satisfy their nutrient requirements.

Table 3. Special Zoo Diets.

Type & Manufacturer	Species	Principal Ingredients*	Analysis (% of DM)		
PRIMATE (Hallwood) Feed with fruit	Great apes, Old World monkeys, New World monkeys (except colabids), marmosets, lemurs, tarsiers, tree shrews	Dried fruits, cooked ground cereals, ground whole wheat, peanut meal, dried milk solids, meat meal, molasses, soy oil, brewers dried yeast, dried kelp, steamed bone meal, sugar, vitamin C (stabilised), vitamin D_3	C.P. E.E. C.F. N.F.E. Ash T.D.N.	20.5 5.7 5.2 42.0 5.4 81	(min) (min) (max)
PINNIPED (Albers)	Sea lions, seals, penguins, cormorants, pelicans Cetaceans (porpoise, killer whale) - not good acceptance	Meat by-products, fish meal, bone meal, fish solubles, deodorized fish oil, corn, irradiated yeast	C.P. E.E. C.F. Ash	68.6 8.6 2.9 12.9	(min) (min) (max)
RATITE (Zu/Preem)	Ostrich Rhea Emu Cassowary	Ground corn, soy grits, ground wheat, oats, dehydrated alfalfa meal, meat and bone meal, dried skim milk, fish meal, whole egg, animal fat, brewers dried yeast, iodized salt	C.P. E.E. C.F. Ash Ca P	23.3 3.9 7.8 11.1 2.0-2.5 1.0	(min) (min) (max) (min)
FLAMINGO (Hallwood) Feed as a thick slurry	Flamingo Scarlet Ibis Roseate Spoonbill	Shrimp meal, fish meal, meat meal, alfalfa, malt sprouts, wheat middlings, brewers dried yeast, kelp, dried milk solids, ground oyster shell, salt, Flaminol	C.P. E.E. C.F. N.F.E. Ash T.D.N.	30.3 3.1 14.5 22.1 24.0 68	(min) (min) (max)

*Minerals and vitamins used in all diets in addition to ingredients listed.

3. The general aim of zoo diets to accommodate the nutrient requirements and feeding habits of as many different species as possible.

Even so, there are numerous species for which commercially prepared substitutes have not been successful.

4. Feeding practices at Taronga Zoo

4.1. Exotic species: The practice at Taronga Zoo, Sydney, N.S.W., has been to use, in the case of many exotic species, a commercial diet marketed for domestic animal production supplemented with natural food items. For instance, the grazing and browsing ungulates are fed a commercial dairy meal together with good quality lucerne hay. The ratites (the flightless birds) are fed a combination of a commercial turkey meal and a mixture of ground beef and shredded cabbage, carrot, fruit and bread. In the case of the carnivores, a diet based on a ground beef brawn, with added minerals and vitamins, is prepared at the zoo. For the giant anteaters a mixture of egg, milk and ground beef, with added minerals and vitamins, is prepared daily at the Zoo.

It is apparent that the Australian zoo market is not large enough to encourage feed manufacturers to produce complete zoo diets of the type used in the U.S.

4.2. Native species: The emphasis with Australian native species at Taronga is still on providing a range of natural dietary components, in some cases supplemented with commercial substitutes (Bergin, 1976). The feeding regimens for marsupials and monotremes at Taronga are listed below:

Small dasyurids (e.g. *Antechinus stuartii* - brown antechinus, *Sminthopsis crassicaudata* - fat-tailed dunnart) - live mice, mince, insects, cheese, dicalcium phosphate and vitamins.

Large dasyurids (e.g. *Dasyurus viverrinus* - native cat, *Sarcophilus harrisii* - Tasmanian devil) - mince, commercial dog kibble, bonemeal, hard-boiled eggs.

Numbat (*Myrimecobius fasciatus*) - termite nests containing live termites and their eggs. This species has not yet been successfully weaned onto artificial diets of any kind.

Bandicoots (Peramelidae) - mince, commercial dog kibble, fruit, carrots, dicalcium phosphate and vitamins. Live insects are a preferred food, and are used if available.

Marsupial mole (*Notoryctes typhlops*) - this species has only been kept successfully at the Arid Zone Research Institute, Alice Springs, N.T., on a diet of live insects and insect larvae.

Pygmy possums and gliders (Burramyidae) - fruit, insects, cheese, bread, honey, sunflower seeds.

Gliding possums (e.g. *Petaurus breviceps* - sugar glider) - fruit, cheese, bread, honey, peanut butter, insects.

Brush-tailed possums *(Trichosurus* spp.), ring-tailed possum *(Pseudocheirus peregrinus)* and greater glider *(Schoinobates volans)* - *Eucalyptus* leaves (several local species should be offered to determine acceptability), fruit, bread, honey, peanut butter, dicalcium phosphate and vitamins.

Wombat (*Vombatus ursinus* - common wombat, *Lasiorhinus latifrons* - plains wombat) - lucerne chaff, commercial sheep pellets and carrots.

Koala (*Phascolarctos cinereus*) - *Eucalyptus* leaves (preference appears to differ between district and time of year, but *E. viminalis* - ribbon gum, *E. rostrata* - river red gum and *E. punctata* - grey gum, are the most readily accepted species).

Potoroos (rat kangaroos, e.g. *Bettongia pencillata* - brush-tailed bettong, *Potorous tridactylus* - long-nosed potoroo) - lucerne chaff, commercial sheep pellets, mince and insects.

Kangaroos and wallabies - fine-stemmed meadow hay, carrots, commercial sheep pellets, and bark as a source of fibrous chewing material. The composition of the sheep pellets varies with availability of various grains. Amprolium (Merck, Sharp & Dohme, Australia) is incorporated into the pellets as a coccidiostat.

Echidna (*Tachyglossus aculeatus*) - lean beef mince, condensed milk, eggs, yoghurt, infant cereal preparation, dicalcium phosphate and vitamins.

Platypus *(Ornithorhynchus anatinus)* - earthworms, uncooked prawns, mealworms, live crayfish.

5. Current research on marsupial nutrition

5.1. Protein requirements of macropods: The first definitive research on the nutrition of macropods was by Moir, Somers and Waring (1956) who described the digestive physiology of the quokka *(Setonix brachyurus)* as being "ruminant-like". Unfortunately this description has been applied by others to all species of kangaroos and wallabies, with no good scientific reason. Certainly the arid and semi-arid zone macropods such as the euro *(Macropus robustus)* and the tammar wallaby *(Macropus eugenii)* are efficient fibre digesters. However, only recently has any research been done on digestion in macropod species from more humid environments. This work, in progress at the University of Mew England, has established that the red-necked pademelon (*Thylogale thetis)*, a small wallaby restricted in its distribution to rain forest along the eastern escarpment of the Great Dividing Range in south-eastern Australia, is significantly less "ruminant-like" than the arid zone macropods (Hume, 1977a, b).

The pademelon was estimated 'to require for maintenance at least'2.5 times the nitrogen per day required by the tammar wallaby (Hume, 1977b) (Table 4). This has implications not only for future management of the pademelons remaining in the wild, but also for maintenance of these wallabies in captivity. If they are to be fed the same hay diet as the larger kangaroos and arid-zone wallabies, sufficient must be offered each day to allow the pademelons to select the higher protein components of the diet. Wastage of a hay diet will be appreciable, but should be expected. If a compounded diet is used, it should be at least 14% crude protein, based on the nitrogen content of the feed consumed by pademelons at or close to nitrogen balance (Hume, 1977b). This can be compared to the 6.5% crude protein diet which would be sufficient to maintain adult euros, based on the data of Hume (1974).

Table 4. Maintenance Nitrogen Requirements* of Some Marsupials and Sheep.

Species	Estimate ($gN/kg^{0.75}/d$)	Reference
Sheep	0.59	Moir & Williams (1950)
Euro	0.18	Brown & Main (1967)
Tammar	0.25	Barker (1968) Hume (1977b)
Pademelon	0.53	Hume (1977b)
Brush-tailed possum	0.20	Wellard & Hume (1976)

*Based on true digestibility of dietary nitrogen.

5.2. <u>Vitamin E and selenium metabolism</u>: The red-necked pademelon is particularly susceptible to a muscular myopathy similar to white muscle disease in lambs. We first observed the condition, characterised by weakness and incoordination in the hind legs, in animals maintained in captivity for six months on a lucerne hay diet. The condition is similar to that observed in quokkas by Kakulas (1961, 1963a), and differs from sheep in that it responds to vitamin E supplements, but not selenium. The condition has been prevented by intra-muscular injection of vitamin E, and by dietary supplementation with crushed wheat and soybean meal. Kakulas (1963b) suggested that the vitamin E requirement of the quokka in captivity was approximately 5 mg/kg body weight/day compared with lambs of 0.23-0.37 mg/kg/day.

The limited work done on mineral metabolism of marsupials suggests that requirements for the trace elements such as copper, cobalt and iron are lower than those of sheep (Barker, 1961, 1962).

5.3. <u>Nutrition of marsupial young</u>: Unlike eutherians, lactose is not the predominant disaccharide in the milk of macropods, or of the brush-tailed possum. Consistent with this is the low intestinal lactase activity in the pouch young of these species. Macropods are also low in sucrase activity, although brush-tailed possums have high levels of activity (Kerry, 1969). The diarrhoea commonly observed in suckling macropods reared on cow's milk is no doubt due in many cases to the osmotic effect of undigested lactose in the intestines (lactose intolerance). Similarly, the addition of sucrose to milk suckled by young kangaroos causes diarrhoa. Once the pouch young macropod begins to eat significant amounts of grass, which stimulates development of the stomach microbial fermentation, disacharide intolerant diarrhoea virtually ceases to be a problem.

The feeding of cow's milk to suckling marsupial young (macropods, bruch-tailed possums and wombats) has sometimes resulted in cataract formation in the lens of the eye. It has been suggested by Stephens *et al.*, (1974) that this is due to their inability to metabolise galactose, and this is supported by low activities of galactokinase and galactose-l-phosphate uridyl transferase, which convert galactose to glucose in erythrocytes. The liver, the principal site of galactose metabolism, has not been investigated in detail, but preliminary results (Stephens, 1976) suggest that activity of the above enzymes is also low in this organ.

On the basis of these results, suckling orphan marsupial young (i.e. macropods, brush-tailed possums, koalas and wombats) should be reared on a milk substitute free of lactose, and for the macropods, also free of sucrose. Glucose Nutramigen (Mead Johnson) is an effective milk substitute for very young marsupials.

6. Conclusions

Understandably, research on the nutrient requirements of wildlife species has lagged behind that on domestic species. However, there is a need for some wildlife nutrition research, first in relation to the physiology and ecology of populations of animals in natural and man-altered environments, and second, because of the potential increase in demand for compounded diets by zoos and game parks as the cost of labour increases and the availability of certain natural food items declines.

Fortunately, because of the emphasis on maintenance of wild species in captivity, rather than on maximum growth rates, definition of nutrient requirements and allowances for specific nutrients (e.g. calcium and phosphorus) need not be as precise as that needed for commercial animal production systems. Thus, in many cases, compounded diets used for commercial animal production can be used for wils species, as seen in some of the feeding practices at Taronga Zoo. Nevertheless, for reasons of economic efficiency, there is room for more precise formulation of zoo diets, even within the limitations imposed by the other considerations which must be taken into account with wild animals, such as specific feeding habits and natural food preferences.

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