Nutrition of zoo animals

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Summary

The topic of zoo animal nutrition is as diverse as the number of species potentially found in any given zoological institution. Advancement in the science of comparative nutrition and application of that science to routine animal husbandry practices has expanded over the past decade. For the purposes of this review, a brief history of the discipline of zoo animal nutrition is provided. An overview of the step–wise process of formulating wild animal diets is discussed. Additionally, three primary areas of recent development are considered: psittacine nutrition, nonhuman primate nutrition and nutrition of highly selective feeders, specifically giant pandas. The role and need to enhance professional staff with personnel trained in nutrition is considered.

Keywords: zoo animals, comparative animal nutrition, diet formulation, husbandry, psittacines, nonhuman primates, giant pandas

Introduction

Man has maintained collections of wild animals for thousands of years. Perhaps the earliest evidence of such animal collections is found on a stone tablet dated 2300 B.C., describing a group of rare animals in the Sumerian city of Ur (Koebner 1994). Since that time, the role of wild animals in captivity has evolved from symbols of greatness and power for those that controlled them to environmental ambassadors representing the message of their species and ecosystem.

Yet, the simple fact remains, whether these animals were a possession of a Roman emperor, part of a collection maintained in the Garden of Intelligence (Zhou Dynasty, 1027–221 B.C.) or a critical breeding contributor in an orchestrated species recovery program, they all had to be fed.

There are few references to the importance or types of foods used to maintain captive wildlife in these early collections. Roman emperor Nero (37–68 A.D.) was said to have occasionally presented a dinner guest who displeased him to his pet tiger ‘Phoebe’ (Koebner 1994). When supplies of food necessary to satisfy the polar bear kept in the Royal Menagerie at the Tower of London were low, the caretaker would allow the animal to harvest his own food from the Thames River (Koebner 1994).

In the 1930s, H.L. Ratcliffe pioneered the concept of complete, formulated diets at the Philadelphia Zoo, PA, USA (Ratcliffe 1940, Ratcliffe 1947, Ratcliffe 1966). Application of these significant improvements in nutrition across the industry were slow to be adopted, due to the unqualified faith that diets approximating the kinds of foods eaten in the wild would be adequate for the majority of zoo animals (Oftedal and Allen 1996a). Some zoo animals survived in captivity despite these diets, so the inappropriate diets became accepted as adequate and sometimes considered essential for a species to thrive.

In one of the first publications produced from the scientific application of nutrition to the care of wild animals in captivity, the then current knowledge of comparative animal nutrition was described as “on the border of ecology and chemistry” (Crawford 1968). During the 1950s and 1960s, advances in comparative nutrition moved slowly, perhaps due to the lack of financial incentive associated with domestic animal nutrition. Despite this, dietary specializations were frequently cited as a primary factor influencing the survival and longevity of multiple species under captive conditions (Crandall, 1964).

As an example of the continually evolving attitude toward the importance of balanced nutrition as part of animal health, most zoos have disallowed or have tightly regulated the feeding of animals by public visitors. Several North American companies now produce foods, as part of their standard product catalogue, specifically to meet the needs of non–domestic animal species.

Today, most animal care personnel working in zoos do not have training in nutrition (Allen 1996). However, in North America, professionally trained nutritionists were added to the animal care staff at Metro Toronto Zoo in 1975, Smithsonian’s National Zoological Park in 1978, the Chicago Zoological Society in 1980, the Zoological Society of San Diego in 1994 and Disney's Animal Kingdom in 2001, among others.

Diet formulation for the novel species

One of the most significant challenges facing the applied zoo animal nutritionist is formulation of a diet, presentation and allocation of that diet (dietary husbandry) and evaluation of the specimen(s) response for a species that has never, or rarely, been maintained in a managed environment. Even if a species has a history of being managed in a zoo environment, it can no longer be assumed that traditional zoo diets are adequate, even when little evidence of frank nutritional deficiency is observed (Oftedal and Allen 1996a).

Multiple authors have previously reviewed the systematic process of information gathering, critical review and analysis to develop the aspects of a captive feeding program for a species (Ullrey 1995; Oftedal and Allen 1996a). The basic aspects of this complicated and time–consuming process are presented here.

Species feeding strategy and nutritional ecology

Observations of the targeted species' basic feeding ecology can be useful for developing diets for captive specimens. On the most fundamental level, one should determine if the species is observed to be herbivore, omnivore or carnivore. Further definition of the specific food types consumed if, for example, the species is a browsing herbivore, a selective insectivore or a generalist omnivore influenced by seasonal food availability, will provide further valuable insight.

In conjunction with these observations, biologists may have characterized the contribution of various foods to the total diet of the free–ranging species. In selected cases, some of those foods may have been scrutinized for their nutrient content. There is a common belief among non–nutritionists that if foods consumed by wild animals could be chemically defined through sampling and analysis, the components and delivery of diets for captive animals would be known with some certainty (Allen 1996). Although this information can be useful, alone it does not provide sufficient quantitative information to formulate diets for captive animals (Oftedal and Allen 1996a).

Gastrointestinal tract morphology

The primary function of the digestive system is to extract energy and essential nutrients from components of an animal's environment in support of metabolic processes (Klasing 1998). Gastrointestinal tract morphology and physiology, along with anatomy of the oral cavity, usually correlate well with the natural diet (Stevens and Hume 1995; Koutsos *et al.* 2001a). Reviews of vertebrate digestive physiology and anatomy, such as those of Chivers and Langer (1994) and Stevens and Hume (1995) are among the references that are invaluable for persons responsible for diet formulation.

In many texts, diagrams of gastrointestinal tract anatomy show the esophagus as the entry point into this organ system. It is essential to appreciate the contributions of the oral cavity, teeth and associated structures to acquisition, manipulating and processing food items before they are further broken down into their constituents in distal portions of the gastrointestinal tract. Maintaining good oral health is a key facet in successful longevity of many zoo animal specimens (Allen *et al.* 1996; NRC 2003).

Although information about a species digestive system is one of the most helpful tools when formulating diets for wild animals, there are some species that defy simple categorization (Ullrey 1995). One such species, the giant panda (*Ailuropoda melanoleuca*), will be discussed further in this manuscript.

Known and/or extrapolated species requirements

When reviewing the qualitative nutrient needs of animal tissues, the similarities among species are greater than their differences (Ullrey 1995). The primary differences between species are related to types of foods consumed, the processing of those foods by gastrointestinal tract modifications, and absorption of nutrients from the lumen of the digestive system.

With limited controlled studies conducted with wildlife to quantitatively determine nutrient requirements, animal nutritionists are often required to apply similar information from domestic species models. Models should be selected based on similarities of gastrointestinal tract morphology and basic feeding strategy. For example, the domestic cat (*Felis domestica*) is the most applicable model for a serval (*Felis serval*), an African felid, but perhaps also for the tamandua (*Tamandua tetradactyla*), a strict insectivore (carnivore) from the Neotropics.

One should consider that energy and nutrient requirements determined for domestic animals often support specific performance criteria (e.g. growth, high production lactation, fibre production). Zoo animals are rarely required to 'produce' at these levels and may be compromised by excessive energy and nutrient intake (Allen and Oftedal 1996). Longevity is often an objective in zoos, although it is not in domestic animal operations (Oftedal and Allen 1996a).

Foods available for zoo animals

The foods consumed by free–ranging specimens are typically not available, or not accessible in adequate quantities, to support zoo animal collections. Therefore, foods utilized in zoo animal feeding programs tend toward those that are important in human agriculture, such as harvested forages, commercially grown fruits and vegetables, fish, meat and dairy products, and formulated feeds for domestic animal species, including dogs and cats.

Choices should be made on the basis of nutrients foods bring to the total diet, not an attempt to substitute what one perceives to be analogous food 'types' (e.g. fruits consumed by free–ranging animals are not nutritionally equivalent to fruits cultivated for human consumption) (Oftedal and Allen 1996b).

Specimen derived influences on diet and nutrition

Although diets for wildlife have most frequently been formulated on the species level, for application across all specimens of that species at a given institution, there will always be conditions that necessitate modification of the species diet for a given individual. Nutritional management of medical conditions such as diabetes, renal insufficiency, surgical recovery and weight management are becoming more frequent, especially with the refinement of zoo animal medicine and increasing longevity of zoo animal specimens.

Management of these cases becomes increasingly more challenging with the constraints of modern zoo exhibitry. Specimens are no longer housed in single species enclosures, but multi–species exhibits are more the rule, rather than the exception. These species combinations become more complex as they evolve from mixed groups of herbivores in open–range enclosures to exhibits that integrate, for example, herbivorous ungulates, omnivorous primates and carnivorous mustelids. Nutritional management for such groups is elevated from the specimen level to the entire group, with strategic feeding locations and temporal distribution of diets so each specimen receives the appropriate foods, as well as preventing a sympatric species from consuming a diet that may be detrimental to its short– and long–term health.

Effect of food costs on zoo animal diets

Food costs for zoological institutions can be one of their single largest budget line items, and therefore, are often targeted as an area to achieve savings. Of course, all zoos must function within the limits of their resources and costs must be scrutinized as part of any financially solvent organization. However, the long–term costs to the health of the animal collections should be considered when making short–term compromises on the quality of foods and diets offered to specimens. Given that capture in the wild is no longer an appropriate method of stocking most types of zoo animals, zoo feeding programs must be designed to provide nutritional support for breeding programs that will enhance self–sustaining, captive animal populations (Oftedal and Allen 1996a).

The challenge for the zoo nutritionist is, in balancing the information described above with practical application and experience, to make appropriate choices as part of the animal management team for the specimens under their oversight.

Psittacine nutrition

The advances in psittacine nutrition have followed three principal stages: diets formulated based on the food habits of wild birds; nutrient standards based on established requirements for domestic poultry; and now, application of data generated from research populations of easily propagated species such as budgerigars (*Melopsittacus undulatus*) and cockatiels (*Nymphicus hollandicus*) (Koutsos *et al*. 2001a).

The role of protein and amino acids in the diet of psittacines has been of particular interest to nutritionists as well as clinical veterinarians. The consumed portion of seed–base diets may be higher in protein than users anticipate. When two seed–based diets were analyzed with and without the inedible portions (i.e. shells, hulls), they contained 14% and 17% versus 18% and 23% crude protein (dry matter basis) respectively (Ullrey *et al*. 1991). However, seed–based diets are low in essential amino acids, particularly lysine (Ullrey *et al*. 1991; Koutsos *et al*. 2001a). When limiting amino acids are offered in sufficient supply, the levels of dietary protein in natural ingredient diets adequate for maintenance, growth and egg production are 10 to 15%, 13.2 to 20%, and 13.2%, respectively (Koutsos *et al*. 2001a).

The breeding season of some free–ranging psittacines is associated with the seasonal availability of high protein foods, suggesting that amino acid nutrition is a major determinant of reproductive output (Sailaja *et al*. 1988). This interaction was demonstrated in captive cockatiels, when an increase in dietary protein produced a subsequent egg lay increase (Koutsos *et al*. 2001a).

Elevated levels of dietary protein have been suggested to be involved in the etiology of renal dysfunction and gout in psittacines. Koutsos *et al*. 2001b demonstrated that adult male cockatiels consuming dietary crude protein concentrations of 20%, 35% or 70% for 11 months not only maintained body mass and general condition, but exhibited neither uric acid precipitates nor articular gout upon post mortem examination. Birds consuming the 70% crude protein diets did possess hepatic sinusoidal and periportal lipogranulomas which, the authors suggest, may be indicative of liver damage.

Overall, energy, protein and calcium requirements are lower in psittacine birds than in poultry during all stages of life (Koutsos *et al*. 2001a). In the absence of specific research on trace nutrient requirements of these species, it is suggested that vitamin and trace mineral concentrations recommended for poultry (NRC 1994) continue to be applied.

As a result of some of this work, the number of nutritionally complete diets formulated for psittacines has increased significantly over the past decade. There is still a great deal of variation in nutrient concentration and ingredients across various diets. Unfortunately, for the consumer who may have limited understanding of avian nutrition, there are no regulatory guidelines for minimum standards of nutritional adequacy for these diets.

One apparent marketing strategy for these foods is inclusion of intense flavors and scents, suggesting these characteristics enhance diet palatability and acceptance by the bird. Although avian taste acuity is generally poorer than that of mammals, avian taste thresholds are more sensitive to compounds that are 'ecologically relevant' (i.e. secondary plant metabolites for granivores, sugars for nectarivores) and less sensitive to those compounds not likely encountered in natural diets (Koutsos *et al*. 2001a). This implies that the inclusion of flavours and scents may play a greater influence on the human caregiver than on the bird consuming the diet.

The use of nutritionally complete manufactured diets has proven to be optimal for growth and reproduction of many captive psittacines (Koutsos *et al*. 2001a). Ullrey *et al.* (1991) demonstrated the efficacy of nutritionally complete extruded particles versus seeds fed together with commercial fruits and vegetables. Across eight different psittacine species, the fledgling success was considerably greater when the complete diet was offered in place of seeds (90% versus 66%, respectively).

In conclusion, many of the conditions of malnutrition diagnosed in captive psittacines are not a function of unique species requirements, but the result of birds consuming a nutritionally inadequate diet. Research efforts to elucidate the nutrient requirements of psittacines are supported by the economic importance of these birds as companion animals. Although only a few of the more than 350 species are routinely maintained as companion animals, the information generated for these species fills critical voids to improve the care of other avian species and provides an important baseline from which species specific research can be initiated.

Primate nutrition

Among mammals, the order of primates is unique in that each specific type of gastrointestinal tract arrangement (simple, hindgut fermentation, foregut fermentation) is represented. Additionally, the range of feeding strategies across the order is equally diverse. This diversity of digestive physiology (and feeding strategies) had not previously been reflected in the dietary husbandry of captive individuals.

In part, due to the recognition of these gastrointestinal tract (GIT) diversities, in conjunction with improved methods of characterizing fibre components in foods, there have been significant advances in our understanding of fibre utilization by primates. Edwards and Ullrey (1999a; 1999b) demonstrated the relative apparent digestibility of NDF (neutral detergent fibre) and ADF (acid detergent fibre) by primates with foregut fermentation (colobines), hindgut fermentation (howlers) and simple gastrointestinal tracts (ruffed lemurs) was comparable with that seen in domestic mammalian species with similar gastrointestinal adaptations (Table 1). However, within each GIT, there were no statistical differences in either apparent digestibility of NDF or ADF between the two diets (15ADF, 30ADF) ($P < 0.01$).

Formulation guidelines for fibre concentrations in diets of selected primate species were developed based on these, and results of other investigations (Table 2) (NRC 2003). These concentrations guidelines are not meant to represent minimal requirements for fibre, but appear to be consistent with general primate health.

Increasing fibre intake of captive primates may also promote increased time spent feeding, reduce aberrant behavior, help to regulate obesity and contribute to improved stool quality. Increased fibre intake can be achieved through the replacement of non–fibrous foods (e.g. commercially available fruits) with the higher fibre foods (e.g. leafy vegetables, browse plants). Plant materials used in animal diets may include leaves, twigs, shoots, flowers, and fruits (Oftedal *et al*. 1996). Any plants used in primate, or other captive animal diets should be carefully scrutinized for safety and resulting consumption routinely monitored. An extensive list of plant species that have been demonstrated for safe use in primate diets, and selected nutrient composition of those plants, is included in *Nutrient Requirements of Nonhuman Primates* (NRC 2003).

The over 250 species of nonhuman primates play a diverse role in our ecosystem: they are research animals, education animals, and rare, endangered and threatened animals that are free–living or maintained in various institutions for conservation purposes. Significant advances in the field of primate nutrition are summarized in NRC (2003). Although the publication addresses multiple aspects of primate nutrition, it also identifies gaps in our understanding of the topic, so that scientists may initiate research needed to further our knowledge and improve animal health.

Highly specialized species

Morphologic and nutritional adaptations of a species are a product of evolutionary pressures influenced by ecological conditions (e.g. food availability). These adaptations may enable a species to thrive and procreate, or ultimately lead to their extinction. These pressures sometimes result in highly specialized species, able to utilize an abundant resource that is under– or not utilized by other species in that ecosystem, thus avoiding or minimizing resource competition. Such specialized species, especially those that are highly selective feeders, may have compromised their ability to rapidly adapt to other food sources during periods of food restriction in the free–ranging state or when fed

Table 1 Apparent digestibility (%) of neutral detergent (NDF) and acid detergent fibre (ADF) in two extruded diets (15ADF, 30ADF) for primates grouped by gastrointestinal tract (GIT) type (Edwards and Ullrey 1999a; Edwards and Ullrey 1999b)[1,2].

GIT Type	15ADF %, NDF	30ADF %, ADF	%, NDF	%, ADF
Simple	20.4	9.4	20.7	12.6
Hindgut fermenter	44.8	42.2	47.4	40.6
Foregut fermenter	77.1	79.7	74.7	71.3

[1] 15ADF diet contained 24% NDF, 15% ADF (dry matter basis); 30ADF diet contained 42% NDF, 29.6% ADF (dry matter basis)
[2] Gastrointestinal type (GIT) groups include: simple, *Varecia variegata*; hindgut fermenter, *Alouatta caraya, A. seniculus, A. paliata*; foregut fermenter, *Colobus guereza*, *Trachypithecus francoisi*, *Pygathrix nemaeus*

Table 2 Proposed fibre concentrations (dry matter basis) of extruded diets for primate species grouped by relative ability to utilize plant cell wall (NRC 2003)[1].

Fibre form and percentage	Species
Group 1 (NDF 10, ADF 5)	*Callithrix* spp. *Cebuella* sp. *Leontopithecus* spp. *Macaca* spp. *Saguinus* spp.
Group 2 (NDF 20, ADF 10)	*Pan troglodytes* *Varecia variegata*
Group 3 (NDF 30, ADF 15)	*Alouatta* spp. *Colobus* spp. *Nasalis larvatus* *Propithecus* spp. *Pygathrix nemaeus* *Semnopithecus entellus* *Trachypithecus* spp.

[1] These concentrations were reported to have desirable effects on gut health and faecal consistency. Complete diets with higher fibre concentrations are difficult to extrude with present technology, and waste is unacceptably high

alternative diets in zoos. Examples of such species would include koalas (*Phascolarctos cinereus*) and the giant panda (*Ailuropoda melanoleuca*) (Schaller *et al.* 1985).

The giant panda, a member of the order Carnivora, has a typical, simple carnivore gastrointestinal tract with no caecum (Raven 1936; Davis 1964; Ullrey 1995). Despite the apparent lack of gastrointestinal tract modifications typically associated with herbivorous mammals (e.g. compartmentalized foregut, sacculated hindgut), pandas have specialized to feed on a fibrous plant resource (i.e. bamboo) available in unlimited amounts during all seasons (Schaller *et al.* 1985).

In captivity, the ‘herbivorous carnivore’ has been maintained on a variety of diets, many of which are significantly different, in nutrient composition and ingredients, than the foods the species consumes in the wild (Mainka *et al.* 1989; Dierenfeld *et al.* 1995). Captive diets used to provision giant pandas were typically higher in crude protein, fat and simple carbohydrates and lower in structural carbohydrates when compared to bamboo. Such diets have been implicated as one of the primary risk factors for morbidity and mortality of captive giant pandas associated with gastrointestinal disease (Qui *et al.* 1993).

In 1996, the research oriented loan of two adult giant pandas to the Zoological Society of San Diego from the People’s Republic of China created a rare opportunity to redefine the nutritional management of the species. This was the first long–term loan of the giant pandas to a zoological institution in the United States since the gift of two specimens to the National Zoological Park in 1972. Since that time, studies of giant and red pandas (*Ailurus fulgens*) had revealed a great deal about their feeding and digestive strategies (Schaller 1985; Warnell 1988; Warnell *et al.* 1989). Advances in feed formulation and manufacturing allowed the large–scale production of higher fibre diets for leaf–eating species. Using these results, new husbandry practices had been developed with the smaller–sized red panda. These findings and improvements, combined with a fresh perspective for enhancement and logistical support from staff members allowed a novel approach to feeding a highly selective, large–bodied herbivorous species.

The goals of the revised feeding program are two–fold: to offer sufficient quantities of natural forage (e.g. bamboo) to encourage natural feeding behavior, promote healthy gastrointestinal function, and maintain all stages of the life cycle; and, when supplemental foods are offered, those foods would not diminish the positive benefits of the primarily bamboo diet. In conjunction with these dietary modifications, all aspects of daily husbandry (i.e. food intake, body weight, faecal consistency and production) are quantified to document the efficacy of the protocols, as well as provide supportive information for other research efforts with the specimens.

Two animals, each housed and fed separately, were fed *ad libitum* bamboo from fourteen species. Daily fresh–weight food intake was 7.27 kg (4.3% BW) and 7.28 kg (4.2% BW) for the male and female, respectively. Initially, the bamboo browse provided 77% and 74% of the male and female's daily food intake (dry matter basis), respectively (Edwards and Zhang 1997).

Daily faecal output is evaluated using a six point faecal consistency score (FCS): 1 = dry, crumbly; 5 = high moisture, loose; M = mucous. Faeces scored as badly formed (FCS 4), loose (FCS 5) or mucous (FCS M) were 12.3% and 0.62% of those produced by animals consuming 53% and 70% bamboo (dry matter basis), respectively. Overall, faecal consistency was correlated with bamboo intake ($r^2 = -0.64$) (Nickley *et al.* 1999).

In contrast to other strictly herbivorous species, the physical characteristics of the individual faecal boluses produced by giant pandas suggest little or no mixing of digesta in the gastrointestinal tract. This apparent absence of mixing may contribute to the adverse response (i.e. poor faecal consistency, production of mucous stools) of the gastrointestinal tract to food items that are dissimilar to bamboo in nutrient content. As a result, the supplemental portion of the diet offered to the giant pandas is contained in a high fibre matrix comparable to bamboo leaves. The strategy is to deliver amino acids, minerals and vitamins in a food item that the gastrointestinal tract processes as if it were additional bamboo material (Edwards *et al*. 1997).

To further elucidate the extent of mixing that may occur within the gastrointestinal tract of giant pandas, three animals were fed a single pulse bolus of 110 yellow acetate 1 mm beads. Three hours after ingestion of the first marker bolus, each animal consumed a second pulse bolus of 110 orange acetate 1 mm beads. All faeces produced was collected hourly following delivery of the first marker bolus until a minimum of 90% of each marker type was recovered.

The mean retention time, including transit time ($R_{git} + TT_1$), was calculated according to Blaxter *et al.* (1956): $R_{git} + TT_1 = \Sigma[(Y_i \cdot t_i) / \Sigma(Yi)]$, where Y_i is the concentration of the marker in a given sample, and t_i is the time between dosing and the collection of a given sample. Transit time (TT_1) was determined as the time between dosing and first appearance of the marker in the faeces. R_{git} was determined as the difference between $R_{git} + TT_1$ and TT_1. Percent of marker overlap was calculated as the number of markers of separate colours that appeared together in faecal boluses in relation to the total dose consumed.

Preliminary results of marker passage are provided in Table 3. These results support the theory that giant pandas consuming a primarily bamboo diet have little or no mixing of the solid phase digesta in the gastrointestinal tract. Additionally, these results suggest that as bamboo intake declines, as seen in the geriatric Male 1, digesta passage is slowed, digesta retention increases, and the subsequent opportunity for digesta mixing increases.

With over six years of applied experience providing nutrition support for four individual giant pandas, including a lactating female, growth of a juvenile/subadult, and a geriatric male, the dietary husbandry protocols have continued to evolve and improve. The bamboo species palate has been expanded to include 21 species and/or cultivars, with a fundamental shift toward the use of temperate bamboos preferentially over tropical species (Table 4). It is important to note that although a diverse number of bamboo species are offered, none of the species consumed by free–ranging animals is available in

Table 3 Preliminary results of transit time (TT_1), total mean retention time (R_{git}) and percent overlap of two particulate markers fed to giant pandas consuming varying amounts of bamboo dry matter relative to bodyweight (Edwards 2003).

Animal	DMI % of BW	Bamboo intake, % DM	TT_1 (h)		R_{git} (h)		Marker overlap %
			yellow	orange	yellow	orange	
Female 1	4.9	83	6	6	0.06	1.65	0
Female 2	6.6	91	6	6	0.00	0.90	0
Male 1	2.2	47	11	11	2.94	6.79	78

sufficient supply to constitute the bulk of the offered diet for these specimens. Inclusion of those species would be one step further in the refinement of these practices.

These dietary husbandry guidelines have now been adopted by three additional institutions holding the species worldwide and have helped to standardize the level of care provided between institutions. Standardization allows for more consistent comparison between and across populations. This is a significant achievement for an industry often restricted from producing publication quality results, due to limited population sizes.

Conclusions

Our understanding of nutrition, as a science, has progressed rapidly over the past century (Oftedal and Allen 1996a). Regular advances in comparative animal nutrition are also achieved although innovations may occur at a less rapid rate, perhaps as a function of the vast number of species considered by the discipline.

The importance of nutrition in zoo management has been recognized by most, due in part to the prevalence of human nutrition issues in the media and the economic importance of nutrition in domestic animal production. However, enrichment of specialized staff with personnel trained in nutritional sciences has been slow to respond to these realizations.

Allen (1996) indicated as of 1994, only six North American zoos employed trained nutritionists as part of their professional animal care staff, with a small group of others that utilize nutrition consultants to fill the void. Nine years later, those figures are relatively unchanged. However, two fundamental changes have occurred since that earlier report: first, institutions with established nutrition programs have fortified them with the addition of trained associate positions, student–training programs and on–site laboratory support; second, those institutions that have recently recognized the contributions that an on–staff nutritionist can make to daily husbandry challenges have chosen to fill that role with consultants or grant–supported contractors in the absence of trained nutritionists to fill the available positions.

The role of the applied animal nutritionist goes far beyond that of diet formulation and evaluation. As part of the animal management team, zoo animal nutritionists provide insight and perspectives to all aspects zoological institution: education, conservation, improved animal health and research, which enable it to move toward achieving its fullest potential.

Table 4 Bamboo species used as forage for feeding giant pandas (*Ailuropoda melanoleuca*) at the Zoological Society of San Diego.

Scientific name	**Common name**[1]
Bambusa beechyana	beechy bamboo
Bambusa glaucescens	hedge bamboo
Bambusa multiplex	golden goddess bamboo
Bambusa oldhamii	Oldham bamboo, giant timber bamboo
Bambusa textillis	weaver's bamboo
Bambusa tuldoides	punting pole bamboo
Bambusa ventricosa	budda's belly bamboo
Bambusa vulgaris "green"	ncn
Bambusa vulgaris cv. Vittata	painted bamboo
Bashania fargesii	ncn
Chimnobambusa quadrangularis	square bamboo
Dendrocalamus brandisii	ncn
Fargesia fungosa	ncn
Fargesia nitida	ncn
Phyllostachys aurea	golden bamboo
Phyllostachys aureosulcata	yellow groove bamboo
Phyllostachys bambusoides	Japanese giant timber bamboo
Phyllostachys bambusoides cv. Castillion	ncn
Phyllostachys nigra	black bamboo
Phyllostachys vivax	ncn
Pseudosasa japonica	arrow bamboo

[1] ncn = no common name

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