

Amphibian diet and nutrition

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Diet

Amphibians are a very diverse group of vertebrates; however, in general their feeding is opportunistic with food up to gape width being ingested. Amphibians such as frogs and toads only target moving prey and prefer elongated prey such as crickets or insect larvae that move across their field of vision. However, many aquatic amphibians will target food by scent and will consume inert food. The suitability and range of live feeds are assessed in the Amphibian Population Management Guidelines (Schad 2007). Because we cannot simulate the natural diet of many wild amphibians, that often eat 100's to 1000's of prey daily, we have to provide nutrition using a few invertebrate species of relatively large size (McWilliams 2008).

When most amphibians in captivity were wild captured and for pets or for display the main concerns with diet were obesity or starvation. However, even under these constraints several gross nutritional deficiencies from vitamin imbalance were sometimes apparent. The most noted of these were nutritional metabolic bone disease (NMBD) and squamous metaplasia. These diseases appear widespread in amphibians and are often only noticed when affected individuals show gross symptoms including gross skeletal deformities and the inability to feed. Both the calcium and phosphorus composition of many feeder insects are low or imbalanced, and many insects are high in lipids and low in protein.

Consequently, without supplementation most amphibian diets appear to be very poor. One suggested method to redress some nutritional problems is the harvesting of wild insects for feed. Wild insect harvest can be accomplished by a variety of methods including nets, lights at night, and from substrates. However, the use of harvested insects for live feed is only practical in regions with a high productivity of insects. These regions are the tropical and subtropical throughout the year and also some temperate regions during the warmer months. Consequently, the main challenge to the supply adequate nutrition for amphibians involves addressing the deficiencies found in the range of feeder invertebrates bred in captivity, and where possible replacing live feed by nutritionally balanced composition feed.

The factors affecting the choice of a feeding regime for a particular species depend on its feeding mode and nutritional requirements. For amphibians needing live feed the prey size is important, and with aquatic amphibians feeding on inert feed artificial composition feed may be refrigerated. Frequency of feeding is important and depends on the primary energy and nutritional requirements of the species, and their seasonal activity and breeding cycle. For energetic species such as *Dendrobates* spp. there should be insects remaining in the enclosure between feedings so that the animals are feed *ad libitum*. More sedentary species such as some members of the frog genera *Ceratophrys*, *Dyscophus*, *Litoria*, and *Pyxicephalus* and salamanders such as *Ambystoma* are prone to obesity and feeding rates should be adjusted accordingly.

The balance between consumption and metabolic rates has a profound effect of amphibian, growth and development. Consumption, digestion, assimilation and metabolic rates are strongly influenced by temperature. Digestion, assimilation, and metabolic rates generally increase with increased temperature, and feeding increases to a peak then declines as temperatures become too high. However, nutritional deficiencies may have subtle effects and only be diagnosed in extreme cases when life threatening symptoms occur (Li et al 2008; Pessier 2008). Because of this, good growth should not be taken as evidence that a diet is sufficient. Growth can be achieved with nutritionally unbalanced diets, resulting in poor health and high levels of pathology.

Good body condition and health are required for successful reproduction, particularly to get high quality eggs from females. Feeding times should be based on the animal's natural feeding behaviour, with nocturnal species fed last thing of the day. Using feeding bowls or hand-feeding techniques can aid in monitoring consumption and provide ready access to cryptic burrowing feeder invertebrates such as mealworms. The life stage of invertebrates affects their digestibility. Goncharov et al. (1989) with a large range of species showed that digestibility is the highest for larvae of the house fly (*Acheta domestica*) lower for newborn mice (*Mus musculus*) and the cinereous cockroach (*Nauphaeta cinerea*), and the lowest for *A. domestica* imago (Serbinova & Tkacheva, pers. comm.).

Nutrients

The proximate composition for feed, including the calcium/phosphorus ratio and lipid/protein ratio, has mainly received the focus of amphibian nutrition. However, recent studies have shown that the adequate provision of micro-nutrients may be major requirement for balanced nutrition. In particular with current knowledge these are Vitamins D₃, Vitamin A, and carotenoids. The levels of micro-nutrients, minerals, and protein and lipid percentage composition and type all vary between prey species. There are also general regional differences in prey nutritional composition. For instance in cold climates all thermo-regulators tend to have higher levels of unsaturated fatty acids to retain metabolism and flexibility, and in tropical rainforests with leaching the levels of minerals and vitamins may be lower. There is an established commercial industry for the production of amphibians for consumption. The development of this industry has been supported by nutrition studies of both larval and adult stages.

Lipids

Lipids (oils and fats) are important in amphibian diet both in their quantity and quality. Too greater percentage of lipids in the diet can lead to either obesity, or an imbalance in the diet in respect to protein or other nutrients. Not only must the amount of lipids be optimal but also the types of lipids. In particular the amounts and types of saturated and unsaturated fatty acids must be balanced. Insects range from less than 10% to more than 30% fats on a fresh weight basis, and are relatively high in the essential C18 fatty acids, oleic acid (18:1), linoleic acid (18:2) and linolenic acid (18:3) (DeFoliart, 1991). The Coleoptera (beetles and weevils) are generally particularly high in C 18:2 while the Lepidoptera (butterflies and moths) are particularly high in C 18:3 (Fast, 1970).

The essential fatty acids, provide precursors for the hormone-like compounds needed for localized metabolic regulation in many tissues, to regulate cellular lipid metabolism, are required for growth (Dadd 1983), and regulate the fluidity of the membranes in thermo-conforming organisms (Stanley-Samuelson et al 1988). Vertebrate metabolic studies show that vertebrates are poor at metabolising new forms of fatty acids and so they should be provided in diet. For a discussion of unsaturated fatty acids in diet see Li et al. (2009). The best current method to provide greater amounts of unsaturated fatty acids, and probably all special and micro-nutrients, is through feeder invertebrate dietary supplementation (Li et al. 2009).

Protein and carbohydrates

As insectivores amphibian diets will naturally be 30% to 60% protein (McWilliams 2008). For instance

Commercial diets for the bullfrog (*Rana catesbeiana*) showed pathology at 16% protein and good health and growth at 23% protein (Coppo and Mussart, 2005). Martínez et al. (2004) showed that *Rana perezi* juveniles showed the best growth and health when fed trout fodder with a composition of 46% protein, 22% lipids, and 13.5% carbohydrates. 45% protein was found the optimum for *R. catesbeiana* tadpoles (Carmona-Osalde et al., 1996). There is probably only a negligible amount of calorific value in carbohydrates from amphibian diets. Amphibians fed diets with excessive fibre have developed intestinal blockage, but the effects of the amounts of digestible carbohydrate is unknown (McWilliams, 2008).

Minerals

Macro-minerals; Calcium and phosphorus

For example, Yoshimi et al. (1996) found that frogs crickets raised on cricket diet then dusted with mineral supplement developed hypercalcemia and tissue mineralization from too much of either dietary calcium or vitamin D₃. Calcium can be absorbed through the skin of adult amphibians (Kingsbury and Fenwick, 1989), and through the gills in larvae (Baldwin and Bentley, 1980).

Micro(trace)-minerals; Iodine deficiency in tadpoles can cause spindly leg and retard or prevent metamorphosis (Wright and Whitaker, 2001).

Vitamins

Vitamin A

A deficiency of vitamin A can develop in captive amphibians if they do not have a source of dietary vitamin A. Amphibians cannot synthesize carotenoids, including vitamin A (retinal) (Wright 2006). However, it is not known if vitamin A precursors are dietary essentials. Vitamin A promotes healthy skin, it is a yellow pigment in amphibian colour (Frost-Mason et al. 1994); and required for calcium metabolism. Too little Vitamin A (hypovitaminosis A) causes "short tongue syndrome" (reduced ability to capture live prey with the tongue), with lethargy, weight loss and finally death (Li et al., 2009; Pessier et al., 2005; Wright 2006). Excessive Vitamin A develops in captive amphibian animals through feed enriched with too much vitamin A; amphibians fed mammalian livers and/or whole immature rodents are at risk for developing hypervitaminosis A include NMBD, anemia, liver disease and weight loss (Crawshaw 2003). Li et al. 2009 showed that enriching crickets with fish oils and carotenoids improved growth and prevented squamous metaplasia.

Vitamin D

For a review of Vitamin D₃ in amphibians see Browne and Antwis (2009), and in '[UV-B, Vitamin D₃ and amphibian health and behaviour](#)'. Too much Vitamin D₃ (hypervitaminosis D) can come from over supplementing feed or from diets of goldfish (Frye 1992). A deficiency of vitamin D₃ can be related to a dietary deficiency and low UV-B and causes bone deformities, seizures, oedema, poor growth, reproductive problems, muscle weakness, anorexia, gut stasis and constipation. Hatching failure can occur even in females without sufficient exposure to UVB on an adequate diet with adequate vitamin D₃ and calcium (Ferguson et al. 2002).

Other nutrients

Feeder invertebrates for amphibians should be supplemented with beta-carotene to prevent eye and skin disease, and to improve skin colour (Dierenfeld and Fidgett, 2006). There are a wide range of nutrients that amphibians could require, and these should be included in nutritional

Nutrient supplementation in feeder invertebrates

There are many vitamin/mineral mixes available for dusting live feeder invertebrates. An alternative is to use ground human vitamin tablets. Do not use Vitamin A if provided in a form of Vitamin A as beta-carotene (Wright and Toddes, 2004).

Feeder crickets may be used both internally and externally as carriers of nutrition supplements, and invertebrates with elastic skins such as wax worms can be injected with nutritional supplements. However, for many species what is generally considered good diet is a range of readily available invertebrate prey items, including crickets, mealworms, springtails, and worms. In nature, the gut contents of amphibians' prey, including micronutrients, may provide essential nutrition. The importance of many micronutrients is still not certain. For instance the production of toxin in poison dart frog skin depends on a specific ant prey that contains the micronutrients from plants (Li et al. 2009).

Tadpoles can change their growth and development rates and even their size at metamorphosis in response to diet and nutrition. In captivity tadpoles in the same group often show great variation in growth rates and metamorph size. These problems are usually caused by unequal availability of food due to exploitative or interference completion. Exploitative completion can be minimised by the provision of large amounts of food, and in some species interference competition can be minimised by methods to prevent individual recognition and the formation of hierarchies (Browne et al 2003).

Some experimental considerations

In studies of diet and temperature there must be several replicate boxes for each diet or temperature study. We tested two boxes with 8 frogs each at two temperatures and achieved statistical differences (Browne and Edwards, 2003). Proximate studies comparing prey items - or especially for salamanders, artificial inert food - may be conducted thus avoiding the expensive analysis of diet. The effect of a diet can then be compared between prey supplemented with vitamin powders and prey fed various supplementary foods. The amount of food consumed should be recorded in temperature studies and the temperature recorded in nutrition studies. Responses to different diets or temperatures may be growth in weight and length, time to sexual maturation, prey preference and consumption, and metabolic efficiency.

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