Topics in Medicine and Surgery

Nutritional Support of Amphibians

Catherine A. Hadfield, MA, VetMB, MRCVS,
Leigh A. Clayton, DVM, Dip. ABVP (Avian),
Sandra L. Barnett, BA, MA

Abstract

Poor body condition is a common presenting sign in amphibians, and nutritional support of the animal can be critical. Indications and contraindications for assisted feeding in amphibians will be discussed, focusing on adult anurans (e.g., frogs, toads) and urodelans or caudates (e.g., salamanders, newts, sirens). Support can include restoring hydration, syringe feeding a liquid diet, force-feeding prey items to larger amphibians, and encouragement of free feeding. In all cases, the underlying cause—most commonly suboptimal husbandry—should be investigated and corrected.

Key words: **nutritional support; assisted feeding; amphibian; anuran; caudate; diet**

Nutritional support should be considered in amphibians showing weight loss, inappetance, or poor body condition.

Signs of poor body condition in amphibians include reduced muscle mass over the limbs and vertebral column, creating a prominent urostyle and transverse processes (Figs 1 and 2). It is important to compare individual body condition with the species' normal; for example, muscle cover over the limbs in the Hylidae (tree frogs) is typically limited, while stubfoot toads (*Atelopus* spp) should have relatively prominent transverse processes. Amphibians in poor body condition may also present with a concave abdomen and lethargy. On palpation, transillumination, and at necropsy, it may be possible to identify gonadal atrophy, the absence of coelomic fat bodies, and a distended gall bladder. In most amphibians, fat is stored in coelomic bodies and around the heart. Amphibians do not generally store fat in the subcutaneous space, although some Bufonidae (true toads) use inguinal fat bodies.[1] In aquatic individuals with inappetance, generalized edema may be seen.

Differential diagnoses for an amphibian showing poor body condition or weight loss can be divided into reduced food intake, malabsorption and maldigestion, or increased energy requirements. The most common cause of poor body condition in an amphibian is inadequate food intake due to suboptimal husbandry, so it is essential to collect a full history on the animal.

Common husbandry errors that can decrease food intake include inappropriate housing, temperature, humidity, light (spectrum, intensity, and photoperiod), water quality, and diet (size, source, type, and frequency and timing of feeding). Population issues should also be considered, such as the number, size, age, sex, and species of animals held together; inappropriate groupings can lead to elevated levels of stress and reduced food intake.[2-5]

Reduced food intake can also be due to ocular disease such as lipid keratopathy, which has been associated with high cholesterol in the diet of Cuban tree frogs (*Osteopilus septentrionalis*).[6-8] Furthermore,

From the National Aquarium in Baltimore, Baltimore, MD 21202 USA.

Address correspondence to: C. A. Hadfield, National Aquarium in Baltimore, Pier 3, 501 East Pratt St., Baltimore, MD 21202. E-mail: khadfield@aqua.org

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Figure 1. American bullfrog (*Rana catesbeiana*) in poor body condition with prominent dorsal spinous processes, transverse processes, and urostyle, and a small coelom.

reduced food intake can be due to oral, musculoskeletal, or neurological disease, most commonly secondary nutritional hyperparathyroidism (SNHP), which has been related to inappropriate calcium, phosphorus, and vitamin D_3 levels in the water and diet, renal disease, imbalance of fatty acids, and hypervitaminosis A.[9] Other differential diagnoses related to inadequate food consumption include trauma, neoplasia,[10] toxin exposure, thiamine deficiency, and hypovitaminosis A, which can cause squamous metaplasia of the tongue in Wyoming toads (*Bufo baxteri*) and prevent prey acquisition.[11]

Malabsorption or maldigestion can be caused by gastrointestinal parasitism or other gastrointestinal or pancreatic disease such as neoplasia. The authors have often seen poor body condition associated with high levels of gastrointestinal nematodes, although in the literature most identified species are reported as nonpathogenic (e.g., *Aplectana* spp, *Cosmocerca* spp, *Cosmocercoides* spp).[12] Some highly pathogenic nematodes that target other viscera, such as the lungworm *Rhabdias* spp, are excreted in the feces, and can be difficult to distinguish on fecal examination. Anthelmintic treatment should be initiated if there is any doubt over the parasite classification.

Catabolic states can develop secondary to any disease (commonly Gram-negative bacterial septicemia, mycobacteriosis, nephropathy, neoplasia, toxin exposure), and during vitellogenesis. Prognosis with many of these conditions is poor.

It should be noted that some animals will show a physiological fast. Such fasting is evident during aestivation in some Sirenidae (sirens), Leptodactylidae (e.g., tropical frogs: Budgett's frog, *Lepidobatrachus asper*), Bufonidae (e.g., Sonoran desert toad, *Bufo alvarius*), and Ranidae (e.g., true frogs: ornate-horned frog, *Ceratophrys ornata*).[13] Suppression of the feeding response is also noted during the breeding season,[2] and after feeding.[14,15]

Contraindications for assisted feeding include an animal that is dehydrated or moribund, or if gastrointestinal obstruction is suspected. A gastrointestinal obstruction may present as inappetance, failure to defecate, a distended coelom, an abnormal position in the water, respiratory distress, and circulatory shock. Survey and contrast radiography, ultrasound, endoscopy, and a coeliotomy can help with the diagnosis. The obstruction may be functional (e.g., SNHP) or mechanical (e.g., gastrointestinal foreign body which is often substrate, soft tissue mass, intussusception, torsion, and organomegaly).

An animal in poor body condition is likely to have a compromised immune system and is often an indicator of suboptimal husbandry or disease. The cause should be identified and corrected. Nutritional support, after correcting any fluid deficits, often improves outcome. Even if a very limited

Figure 2. Green frog (*Rana clamitans*) in excessive body condition.

workup is requested, clinician should not wait until the animal is feeding on its own; the animal is more likely to improve once it is in a positive caloric balance.

Normal Feeding

Adult anurans and all life stages of salamanders, newts, sirens, and caecilians are strictly carnivorous or insectivorous. Studies of the stomach contents of wild amphibians are limited in terms of sample size, species, and geographic area but include some Bufonidae,[16-18] Hylidae,[19] Leptodactylidae,[19,20] Ranidae,[21] Pelobatidae (spadefoot toads),[18] and Fraser's clawed frog (*Xenopus fraseri*).[22] Prey items comprise primarily a wide variety of invertebrates, particularly insects; however, many species of large amphibians also feed on fish, amphibians, reptiles, birds, and small mammals. When fish was added to the diet of a colony of American bullfrogs (*Rana catesbeiana*), they showed improved growth and a reduction in skeletal disease.[23] Several of these studies have also found grit and plant material in the stomachs, especially in the dry season. Such material is usually considered to be ingested concomitantly with prey[19]; however, the Brazilian tree frog (*Xenohyla truncata*) is thought to ingest up to 40% fruit material on a dry matter basis,[24] and the adult Indian green frog (*Rana hexadactyla*) is also thought to ingest significant plant material.[25] There is no evidence that amphibians produce enzymes to digest chitin, cellulose, or keratin.[26]

Ultimately, the dietary requirements of most species and life stages of amphibians are unknown. For the purpose of short-term nutritional support, it is sufficient to assume they should be fed a diet with high protein (approximately 50%), moderate fat (approximately 45%), and low carbohydrate and fiber (less than 5%), with a positive calcium to phosphorus ratio and adequate levels of vitamins A, B_1, D_3, and E.[9]

Healthy anurans and caudates should show an immediate response to live prey, whether they use a sit-and-wait strategy (e.g., Ranidae) or are active hunters (e.g., Bufonidae). The response is based primarily on visual cues and consists of orientation, approach, and capture.

Most terrestrial anurans and caudates use their long muscular tongue and associated secretions to capture prey.[10,27] Aquatic species such as the Pipidae (clawed frogs), Sirenidae, Proteidae (neotenic salamanders), and Ichthyophiidae (fish caecilians) use negative pressures created by opening the mouth to pull prey in.[10] Teeth are usually homodont and polyphodont and, when present, are used to hold prey which are usually swallowed whole.[10] Efficient swallowing can involve coordinated activity of the head, tongue, mandible, hyoid, eyes, and forelimbs.[28,29] Retraction of the eyes is not essential for swallowing in the northern leopard frog (*Rana pipiens*)[29] or for caecilians, which have highly reduced eyes. Feeding methods can be modified based on prey type and size.[30-33] Peristalsis moves the ingesta along the wide, short esophagus (Fig 3), assisted by mucus secretions and cilia.[26,27] Upper and lower esophageal sphincters exist,[26,27] but are rarely appreciated grossly. The stomach lies on the left side of the coelom and has storage, contractile, and proteolytic functions.[27] The gastrointestinal tract is short and simple (Fig 4).[26,27]

Figure 3. Oral cavity of a smooth-sided toad (*Bufo guttatus*) showing wide oral cavity without teeth, and wide esophagus just dorsal to the glottis.

Larval anurans (tadpoles) may be herbivorous, omnivorous, or carnivorous, depending on the species. Cannibalism is relatively common and some are obligate egg-feeders, such as the strawberry poison frog (*Dendrobates pumilio*). The ingesta are moved through the ciliated esophagus into the dilation that makes up the stomach. Digestion is limited to the small intestine.[34]

Figure 4. Gastrointestinal tract of a smooth-sided toad (*Bufo guttatus*). The esophagus, stomach, and proximal duodenum are highlighted within the white lines.

Methods of Nutritional Support

Restoring hydration, syringe feeding of a liquid diet, force-feeding of prey items, esophagostomy or gastrostomy tube placement, and encouragement of feeding by providing optimal environmental conditions should all be considered. This is not meant as a sequence, but rather a list of the options available; the response must be tailored to the individual case. For example, if the animal is debilitated, fluid balance should be restored with a gradual change onto syringe feeding. At all times, environmental parameters should be kept as close as possible to the species optimum to encourage the animal to ultimately feed on live prey. Alternatively, if the animal is thin because of suboptimal husbandry, and there are no other concerns, the environment should be corrected, feeding encouraged, and syringe or force-feeding used as necessary.

Restoring Hydration

Amphibians can dehydrate rapidly because of their nonkeratinized skin, which is semipermeable, either focally (e.g., some Bufonidae, all Hylidae)[35] or diffusely (e.g., Dendrobatidae, poison frogs). Many amphibians are not able to concentrate their urine or adapt to dry habitats.

The simplest way to rehydrate a terrestrial amphibian is to increase relative humidity to the upper limit of the species' preference with misting, and to bathe the animal in physiologically acceptable water. The water should be maintained within the upper preferred optimum temperature zone for the species, have adequate dissolved oxygen, and be free of nitrogenous wastes, chlorines, and chloramines. The latter can be achieved by using spring water or passing water through a new carbon filter. Aerating tap water for 24 hours before use eliminates chlorine but not chloramines.

Electrolyte solutions can be provided via a bath, or given intracoelomically in all amphibians or subcutaneously in anurans at a rate of 20 mL/kg once a day. These techniques are discussed in detail elsewhere,[36] but the target is to reach an osmolality and pH similar to that of amphibian plasma (200-240 mOsm/kg and pH 7.0-7.4). A simple solution can be made by adding 1 part 0.45% saline solution to 1 part 2.5% dextrose. Where possible, solutions containing sodium lactate should be avoided because clinically ill amphibians are prone to acidosis.[37-39]

In aquatic species, inappetant animals will often show fluid accumulation rather than dehydration. Removal of this fluid can be accomplished by aspiration or bathing in hypertonic fluids, or potentially by the administration of diuretics.[36]

Syringe Feeding of Liquid Diet

Syringe feeding is straightforward and practical in adult anurans and in many caudates; it is used routinely in animals over 0.2 to 0.3 g in body weight. In other groups, including Typhlonectidae (caecilians) and Sirenidae, anesthesia is recommended for handling and assisted feeding.[40]

Many food options are available for syringe feeding amphibian species. Powdered foods made for insectivorous reptiles and amphibians include Oxbow Carnivore Care (Murdock, NE USA), Advanced Nutrition Support Enteral Insectivore and Carnivore (Rock Solid Herpetoculture, Thaxton, VA USA), and Mazuri Amphibian & Carnivorous Reptile Gel (Purina Mills Inc., St. Louis, MO USA), which can be used as a liquid if the water is not boiled before mixing. Contact details are available (Table 1). These products should be reconstituted daily with suitable water and kept refrigerated until used. If these foods are not available, most complete feline diets are acceptable for short-term supplementation.

Feline diets that may be used as amphibian nutritional supplements include Feline CliniCare (Abbott Laboratories, North Chicago, IL USA), Waltham's Feline Concentration (Leicestershire, UK), and Hill's A/D (Topeka, KS USA).

As with mammals, there are several important considerations. The temperature of the food should be close to the animals' ambient temperature, and the food should be of a suitable consistency to be administered by a syringe for large amphibians or a microliter pipette system (Eppendorf; Brinkman Instrument Services Inc., Westbury, NY USA) for small amphibians and volumes less than 50 μL.

Liquid supplements can be given initially at 1% of body weight once a day. Some products need more water to develop a consistency that can pass easily through small pipette tips, so it is important to take into account the increase in volume of water to obtain the same caloric value as the properly reconstituted formula. Volume should be increased over 2 to 3 days to 2% to 4% of body weight.

Alternatively, the volume required can be based on formulae for caloric needs of healthy, resting amphibians—for example, 0.02 $(BW)^{0.84}$ for anurans and 0.01 $(BW)^{0.80}$ for caudates at 25°C (77°F)—while taking into account the increased caloric requirements of a compromised animal.[9,41] However, in all cases, the clinical response is the most important factor when providing nutritional support.

The anuran or caudate should be manually restrained around the pelvic and pectoral girdles, with 1 forefoot restrained to prevent any possible musculoskeletal injury.[40] While handling the animal, moistened, powder-free gloves should be worn to prevent trauma to the animal's delicate skin, to minimize the transfer of potential pathogens, and to protect the clinician from any toxins released by the patient. The mouth can be opened with a plastic card or spatula, although the authors prefer a guitar pick for medium to large amphibians (Fig 5), or polyester-coated "Never Tear Paper" (Xerox Corp., Rochester, NY USA) for very small frogs. The speculum should be placed into or just beside the filtrum and slid evenly over the bottom jaw to avoid putting point pressure on the bones or on one side of the jaw. Uneven speculum pressure can cause fractures of the mandible or mandibular symphysis, particularly in any case of SNHP. Caution should be taken with many of the more aggressive species that can inflict a painful bite, such as the horned frogs (*Ceratophrys* spp). In these cases, 2 plastic cards may be used to separate the mandible and maxilla. Other common amphibian defense strategies in response to restraint are lung inflation, noxious secretions from the skin and parotid glands (*Bufo* spp), micturition, vocalization, tail autotomy (caudates), and rolling.

The food should be placed in the back of the mouth with a syringe or micropipette (Fig 6). An alternative feeding method is to use a metal gavage tube, red rubber catheter, or intravenous catheter to

Figure 5. Using a guitar pick to open the mouth of a milky tree frog (*Phrynohyas resinifictrix*).

Table 1. Contact details for products that can be used to syringe feed amphibians

Product	Contact details
Oxbow Carnivore Care	www.oxbowhay.com info@oxbowhay.com (800) 249 0366
Advanced Nutrition Support Enteral Insectivore and Carnivore	www.RockSolidHerpetoculture.com myorder@rocksolidherpetoculture.com (540) 626 3081
Mazuri® Amphibian & Carnivorous Reptile Gel	www.Mazuri.com (800) 227 8941

Figure 6. Using a micropipette to feed a 1.5-g black-eyed tree frog (*Agalychnis moreletti*).

place the food into the wide and short esophagus or into the stomach, which sits in the cranial third of the left coelom. Placement of food lower into the digestive tract will ensure intake and reduce the risk of aspiration pneumonia. However, based on necropsies and histology, aspiration pneumonia has not been identified following assist feeding, although it has been seen following gastrointestinal contrast studies using barium.

Some medications can be administered in the food, including antibiotics, which are recommended for debilitated amphibians because of the high incidence of bacterial septicemia. Other common oral medications include anthelmintics, and nutritional supplements in cases of secondary hyperparathyroidism, thiamine deficiency, or hypovitaminosis A (Table 2). Treatment in the food reduces handling and stress of the patient.

While on assisted feeding, the animal should be weighed at the same time daily and before feeding (Fig 7). Each bowel movement should be recorded with a time and description. Prey items should be offered regularly, and the feeding response should be monitored. Once the animal is seen to be eating, gradually withdraw the supplemental feeding and continue to weigh daily. The affected animals should continue to be monitored closely, with regular weights and fecal examinations, because many of the primary conditions may recur.

Table 2. Common oral medications used in amphibians

Drug name	Recommended dose
Enrofloxacin	10 mg/kg PO SID for min of 7 d[45]
Metronidazole	50 mg/kg PO SID for 3d[46]
Fenbendazole	100 mg/kg PO q14 d for 2 doses[46]
Calcium glubionate	1 ml/kg PO SID for min of 30 d[36]
Vit A	2 IU/g IM q72hrs or 1 IU/g PO SID[47]
Vit B_1/thiamine	25 mg/kg PO prn[9]
Vit B complex	1 ml/gallon bath[36]

Force-Feeding of Whole Prey

If an amphibian can be manually restrained, force-feeding may be attempted. Many terrestrial and aquatic amphibians will swallow whole prey, or pieces of prey, if they are placed in the mouth or touched to the edge of the mouth. To increase digestibility of the prey, it can help to remove the

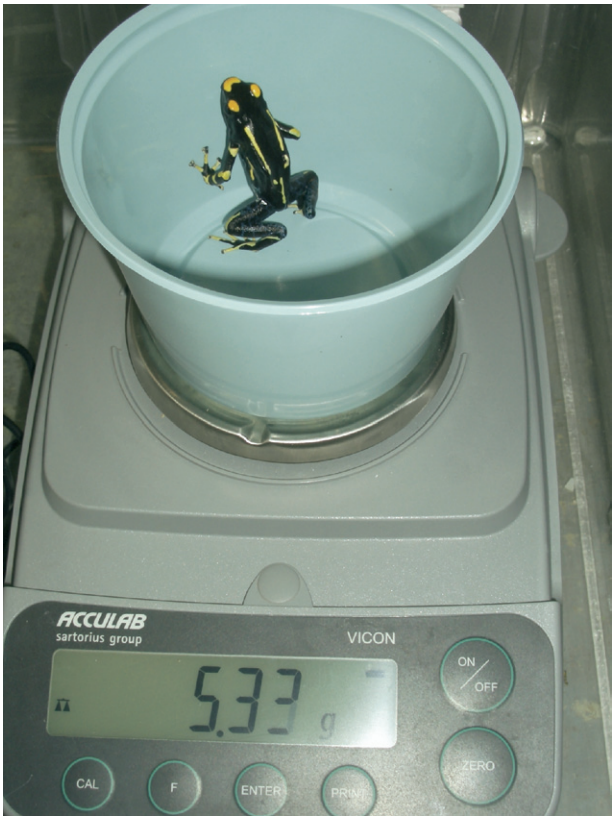

Figure 7. Using a reliable scale to weigh a dying poison frog (*Dendrobates tinctorius*). A secure lid should always be used.

head and legs from large insects, use frozen and thawed fish, and skinned rodents. It is possible to add a powdered pancreatic enzyme (e.g., Prozyme, various manufacturers) to increase digestibility. Although force-feeding can be useful in large amphibians fed fish and rodents, it is more problematic for small amphibians because of the difficultly in handling appropriately sized small invertebrates, and their relatively large amounts of indigestible chitin. For small amphibians, syringe feeding of a liquid diet is preferred.

Esophagostomy or Gastrostomy Tube

Indications for long-term tube placement include severe oral or esophageal disease, such as fractures and neoplasia. Although these methods of assisted feeding may be practical in large, terrestrial amphibians, the authors are not aware of any reports of esophagostomy tube placement in amphibians of any size.

Encouraging Normal Feeding

At all times, every effort should be made to encourage normal feeding by providing optimum environmental parameters for the species in question, including temperature gradient, relative humidity, light spectrum, intensity and photoperiod, and optimal water quality in the tank or water bowl.[42] All environmental parameters should be closely monitored. The affected animal should be isolated in a small enclosure to facilitate prey capture, reduce competition, reduce the risk of disease transmission, and improve monitoring. Substrate should allow fecal monitoring and prevent small areas where prey items can hide or escape. For most terrestrial amphibians, this can consist of unbleached damp paper towels, although some animals such as *Bufo* toads show a preference for darker substrates.[5] Care must be taken to change the towelling daily to reduce buildup of infectious organisms. To protect the patient, the enclosure lid should be lightly covered in plastic wrap to prevent the substrate from drying or the patient escaping. With very small amphibians that eat newly hatched crickets (pinheads), moist paper towelling often traps and drowns pinhead crickets. The addition of a small piece of cork for the crickets to climb can be helpful in prolonging their life. Several hides should be provided for the amphibian to help minimize stress (e.g., small plants, plastic cups).

Many adult amphibians will feed only on live prey, although some species, such as the African clawed frog (*Xenopus laevis*), African bullfrog (*Pyxicephalus adspersus*), and the axolotl (*Ambystoma mexicanum*), will feed on dead rodents or fish, or compounded food such as Mazuri Amphibian & Carnivorous Reptile Gel. If the feeding response is decreased, live prey items should be tried, as they are more likely to stimulate a feeding response. The maximum size of prey items is usually considered to be two thirds of the amphibian's jaw diameter, although smaller prey may be more easily swallowed[29] and, in some instances (e.g., many Dendrobatidae), may be all that the animal is capable of catching.

The most common prey items available for captive amphibians include: fruit flies (*Drosophila hydei* and *D. melanogaster*), ants (various genera), crickets (*Gryllus* spp, *Acheta* spp), locusts (*Melanoptus* spp), springtails (*Collembola* spp), and blackflies (*Musca* spp). Some of these live prey items tend to have a poor calcium content, inverse calcium-to-phosphorus ratio, and low vitamin A content. Beetle larvae such as superworms (*Zophobas* spp), mealworms (*Tenebrio* spp), and waxworms (*Galleria* spp or *Achroia* spp) are available, but should not be a principal dietary component because of their high lipid content, poor calcium-to-phosphorus ratios, and low sulfur amino acids. Other invertebrates that are routinely available for terrestrial and aquatic amphibians include brine shrimp (*Artemia* spp), water fleas (*Daphnia* spp), glass shrimp (*Palaemonectes* spp), various crayfish, earthworms/nightcrawlers (*Lumbricus* spp), redworms (earthworm larvae), silkworms (*Bombyx* spp larvae), bloodworms (Chironomidae midge larvae), whiteworms (*Enchytraeus* spp), blackworms (*Lumbriculus* spp), and tubifex worms (*Tubifex* spp). Whiteworms and tubifex are relatively high in lipids and should be a minor component of the total diet.

Of the vertebrate prey species commonly used, freshwater feeder fish are available (e.g., guppies, mollies, goldfish, smelt), as are different stages of rats or mice, although many captive rodents are high in lipids and vitamin A and have been implicated in SNHP.

All small terrestrial prey should be dusted immediately before feeding with a suitable, within date, vitamin and mineral dust that includes calcium and vitamins A, B_1, D_3, and E. Options include RepCal calcium with vitamin D_3 and Herptivite (RepCal Research Laboratory, Los Gatos, CA USA), Dendrocare (Holland), Frog and Toad Cricket Dust or Frog and Toad Fruit Fly Dust (Rock Solid Herpetoculture, Thaxton, VA USA), or Nutrobal (VetArk, Winchester, UK). Frozen fish, if used, should be supplemented with vitamin B_1.

The source, toxin exposure, parasite load, and historic and recent ("gut-loading") feeding history of the prey items should be considered,[43] although the

priority is getting the amphibian to feed. Long-term diet corrections can be made once this has been achieved.

Timing of feeding is also critical: morning for diurnal frogs and dusk for nocturnal frogs. Misting immediately before feeding terrestrial species may help, because some animals (e.g., Dendrobatidae) are more active after rain.[44] If the food is not eaten within a reasonable time (usually 1-2 hours if fed appropriately), it should be removed to prevent spoiling, loss of nutrients, and potential trauma to the amphibian. Feeding frequency depends on the species and size, but for most small captive amphibian species it is twice a day.

If the animal is showing no feeding response, first try a smaller food size; sick animals sometimes will eat if offered the same food as normal but in a smaller size. If unsuccessful, tong-feeding can be tried in large amphibians. For smaller amphibians, it can help to chill the insects for 10 to 20 minutes at about 4°C to slow their activity.

Larval anurans are usually maintained on small invertebrates, fish flake food, and compounded plankton and algal feeds such as Sera Micron (Sera, Germany) and Tetra Plecomin (Tetra, Germany). If the larvae are not feeding well, options are usually limited to improving husbandry (temperature, water quality, photoperiod, and housing) and correcting dietary issues. With regard to the latter, it is important to consider not only the type of food but also how it is presented. For example, larval stubfoot toads are surface clingers and will only eat algae that are firmly attached to a hard surface. Some large larval forms, such as the American bullfrog, can be syringe fed.

Conclusion

Nutritional support is practical and straightforward in most amphibians, and should be initiated in an inappetant or thin amphibian if hydration is adequate and there is no evidence of gastrointestinal obstruction. A variety of foods are available, including powdered and liquid foods that can be administered by syringe or micropipette, and a great range of prey items that can be free-fed, tong-fed, or force-fed in larger amphibians. It is essential to try to identify the underlying cause of the anorexia, and any inappropriate husbandry parameters should be immediately corrected. Even if the amphibian begins eating on its own, it is important to continue to closely monitor the animal as the problem may recur in either the individual or group.

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