Aquatic Animal Nutrition for the Exotic Animal Practitioner

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KEYWORDS

• Fish nutrition • Fish medicine • Aquatic animal diets • Koi nutrition
• Tropical fish nutrition • Aquarium nutrition

KEY POINTS

- Fish have higher protein requirements and lower carbohydrate requirements than most other exotic animals.
- There are essential amino acids and vitamin requirements that must be addressed by diet.
- Omega-3 fatty acids are required by aquatic species.
- Essential amino acids and omega-3 fatty acids are best provided by fish meal protein in the diet.
- Most minerals can be obtained from the water.
- Fish have lower basal energy requirements than land animals because of their ability to excrete ammonia without first forming uric acid or urea.
- Nutritional needs are variable for many species depending on temperature, season, age, day length, and other external cues.
- In addition to the proper food, behavioral needs must be addressed for proper nutrition.
- Improper nutrition leads to health problems similar to many other species.

NUTRIENT REQUIREMENTS FOR FOOD SELECTION

Proteins

Proteins in fish, just like other animals, are the building blocks of the body. They are used to form muscle, skin, and other tissues. They are essential for immune function, catalyzing reactions, and replicating DNA. They are also used for energy. In fish, proteins are more important than carbohydrates as an energy source. Part of the reason is

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that fish have lower energy requirements than mammals.[1] There are also significant differences in carbohydrate metabolism in fish that are discussed further later.

As a percentage basis in the diet, there is some dispute in the research. The percentage based on studies varies from 25% to 55% of the diet.[1–6] The low end of this range is based on the need to use the minimal protein amount in production fish in order to save money. The best consensus is a range of 35% to 45% for herbivorous and omnivorous fish, and 40% to 55% for carnivorous fish.[2–4] These percentages are general guidelines and depend on many other factors. The percentage of proteins needs to be balanced as a percentage of the total dietary energy because fish eat only enough to meet dietary energy requirements. Proteins in excess of this need could lead to deficiency in one or more of the other nutrients.[3,4]

The quality of protein is as important, or more important, than the amount. The protein must be bioavailable and provide all essential amino acids. Essential amino acids are those that are unable to be produced by the organism from other constituents.

Research on several different species of fish has identified the same 10 essential amino acids, which are similar to those for many other species of animals.[1,2,4,6–9] Among the essential amino acids, arginine seems to be one of the most important to consider in supplementation (**Box 1**). Fish seem to have a greater need for arginine than do mammals.[1,2,8] In mammals, the urea cycle can act as a source for arginine, but fish lack this ability.[2] As a percentage of the total protein in the diet, the essential amino acids should compose 50% to 60%.[2,5,7] This amount helps prevent deficiency in amino acids when fish eat to their total energy requirements.

The best source of protein is animal protein. Fish meal provides the best choice for the source of essential amino acids and digestibility of proteins.[3,6,7,10] If greater than 50% of the protein is plant protein there can be decreased complement activity in the immune system.[6] Sometimes availability and cost require that a mixture of fish protein and other protein sources be used. Alternative protein sources should first be other animal proteins. If vegetable proteins are used, soybean meal is the best source.[1,2]

Fat

Fats in the diet provide a valuable energy source. Fats are also deposited in the body to provide thermal insulation from the surrounding environment of an organism. In fish,

Box 1
Essential amino acids in aquatic animals

1. Arginine
2. Histidine
3. Isoleucine
4. Leucine
5. Lysine
6. Methionine
7. Phenylalanine
8. Threonine
9. Tryptophan
10. Valine

Data from Refs.[1,2,4,9]

fats are deposited in a way that helps to streamline the body and reduce resistance in the water when swimming. In addition, fats are precursor molecules for many hormones and sterols such as cholesterol, estrogen, and testosterone.

Fats should constitute 15% to 25% of the diet.[4,9] Unlike mammals, fish have a specific requirement for n-3 fatty acids. All fish have a requirement for 18:2 and 18:3 n-3 fatty acids, in which the numbers indicate fatty acids with a chain 18 units long with 2 or 3 double bonds, respectively.[1,2,4,7] There is also evidence that marine fish are unable to lengthen the chains of fatty acids, which leads to requirements for 20:5 and 22:6 n-3 fatty acids in their diets.[4,7]

Fish oils are the best source for all of these requirements. Vegetable oils, with few exceptions, are poor sources of n-3 fatty acids.[7,10] Other animal fats and oils have higher degrees of n-6 fatty acids. Increased n-6 fatty acids can contribute to cardiologic or inflammatory diseases.[7]

Aside from proteins, fats are the most important energy source for most fish. In periods of food deprivation, lipids were the most important energy sources for most fish species.[11] As with other species, excess fats can cause obesity in fish, which is becoming one of the most common preventable diseases in fish.[3]

Carbohydrates

In most species, carbohydrates are a primary energy source in the diet. Blood glucose levels are generally tightly controlled in a narrow range by insulin and other hormones. In fish, the control of blood glucose is less evident. Plasma glucose values are highly variable between species and even within species depending on life stage, feed intake, temperature, and other variables.[11] Various studies have shown fish to be insulin resistant.[6,11] In some studies, after injection of dextrose, fish took more than 24 hours to return to normal blood sugar levels.

The levels returned to normal faster in omnivorous fish than in carnivorous fish.[11] During times of decreasing temperature, omnivorous fish tend to store more glycogen in the liver. This glycogen was depleted during a time of food deprivation in fasting carp in one study.[12] There is also some indication that melatonin affects the uptake of carbohydrates in preparation for a period of food deprivation in response to shortened day length.[11]

Most carbohydrates are poorly digested by fish, with a digestibility of 20% to 40% in most species.[2] Carbohydrates in the form of starches are more digestible. Increased dietary starch content yielded higher levels of glycogen in the liver, and this glycogen was used during food deprivation in an omnivorous fish.[4,11] Several studies indicate that 10% of the diet as starch is the optimal level.[7,11] The total carbohydrates in the diet for omnivorous fish should be 25% to 40% and less than 20% for carnivores.[4] Higher glucose levels affect liver function.[7,11]

Vitamins

A variety of studies have assessed the vitamin requirements of different fish. Although the studies are mainly performed on production fish, similar needs were found in diverse species, and results were similar to many land animals.[4,7] These findings have been used to support the ability to generalize for ornamental species until further studies are conducted on these species; however, caution should be used in this interpretation, especially with fat-soluble vitamins. Further studies should be conducted on common ornamental species to determine vitamin requirements in the diets.

The studies conducted to date indicate that most water-soluble vitamins and several fat-soluble vitamins should be supplemented. It seems that vitamins A, C, D, E, and K are all likely to require supplementation in fish diets.[6,13]

Vitamin A deficiency has been shown to cause skeletal deformity in fish. Larvae deprived of vitamin A developed lordosis, kyphosis, scoliosis, retarded growth, and impairment of bone and cartilage metabolism.[13] Excesses of vitamin A were also implicated in the deformities through compression and fusion of vertebrae.[13]

Vitamins C and E have been found to help the immune response in fish.[1,7] Daily requirements of vitamin C have been found to be 25 to 50 mg/kg of feed in several different species of fish. Ten times the daily dose of vitamin C has also been found to be safe and to help the function of the immune system.[1,9,14]

One of the biggest concerns with vitamins is stability in the food. Vitamins are made labile by temperature changes, moisture, and exposure to light. Water-soluble vitamins may also leach from food items in less than 1 minute when put in the water for feeding.[3,7] Vitamin stability is the limiting factor in the storage time for food. Vitamin C is one of the most labile and stabilized vitamin C (L-ascorbyl-2-polyphosphate) should be used. Even with stabilized vitamin C, the storage time for food should be no longer than 90 days.[3,9]

Minerals

Minerals are stable natural elements that are required by the organism for normal function. Some examples are sodium, potassium, magnesium, calcium, and phosphorus. For most elements required by fish, there is little need for supplementation in the diet. Most minerals required by fish are obtained easily from the water.[1,4,6,7] Even fresh water of moderate hardness has been shown to provide adequate calcium for fish to compensate for dietary inadequacies.[4]

The only mineral that has been identified in fish that must be supplemented in the diet is phosphorus. Phosphorus is generally found in water in concentrations that are too low to meet the needs of the fish without dietary supplementation.[1,4,5,7] Because many fish do not have a true stomach, the phosphorus in fish diets must be highly soluble to be absorbed well by some species.[1] Forms such as phylate are biologically unavailable to fish.[5] As a percentage of the diet, 0.3% phosphorus is recommended.[5]

In order for this advice to be supported, the practitioner must ensure that water quality is adequate. For trace elements to be absorbed in adequate amounts to meet the requirements of the fish they must be present in the water. A freshwater system using reverse osmosis water of low hardness may not meet the needs of the fish without the addition of aquarium salts, trace elements, and/or calcium. Infrequent water changes can also lead to depletion of trace elements in fresh or salt water. The frequency of water changes needed to avoid this problem depends on many factors including the size of the system, number of animals in the system, hardness of the water, and pH. The best way to manage important trace elements in water is to test levels weekly to biweekly.

Some trace elements can also be harmful in levels not much higher than those necessary to meet the needs of the animals. Copper is a good example. Copper is required for red blood cell production and for the health of the immune system; however, there are some species of fish that cannot tolerate copper levels of 0.15 ppm in the water even for short periods of time. Chronic toxicity can occur with less than 10% of that concentration.[15] Invertebrates, elasmobranchs, and copper-sensitive fish have issues with toxicity at far lower levels.[16–18] In addition to copper, zinc, nickel, and several other minerals have a low therapeutic index. Detailed information on mineral toxicity is outside the scope of this article.

Probiotics

With the continuing awareness of the overuse of antibiotics in medicine, clients are becoming more interested in the potential benefits of probiotics. With evidence-based

medicine, practitioners must strive to make recommendations based on research and empirical evidence. There is some good proof that some probiotics not only are safe but that they help digestion and help reduce disease. In order to be effective, bacteria used in probiotics must tolerate bile and the acidity of the stomach to enter the intestinal tract. They must also adhere to the intestine and must effectively compete against pathogenic bacteria. Lactic acid bacteria have been tested for these parameters. *Lactococcus lactis*, *Lactobacillus plantarum*, and *Lactobacillus fermentum* all tolerated oral administration and effectively adhered to intestinal mucosa. When challenged with pathogenic bacteria, all strains effectively competed and reduced mortality.[19] Another study tested levels of a commercial prebiotic added to a basal diet. Common carp fed the diet with 1.5 g/kg of the commercial prebiotic had reduced mortality when challenged with *Aeromonas hydrophila* infection.[20]

Color Enhancers

One unique aspect of nutrition with aquatic animals is the addition of color enhancers. Many fish species are valued for the coloration of the scales and skin. Pigments involved in coloration include melanin, carotenoids, and guanine. Melanin and guanine can be produced by most fish and do not need to be supplemented in the diet.[6] Carotenoids are used in many feeds to enhance the coloration of fish. Many different carotenoids are offered on the market and clients often have questions regarding recommendations. Choices include synthetic materials, yeasts, bacteria, and fungi. One study compared 2 algae (*Chlorella vulgaris* and *Haematococcus pluvialis*) and 1 cyanobacteria (*Arthrospira maxima*) with a synthetic astaxanthin. They were tested for the results on goldfish and 2 variety of koi. The best results were obtained from the 2 algae, with *C vulgaris* giving the best results.[21] This finding allows a good recommendation for a natural product rather than synthetic products to clients concerned with color enhancement in their fish.

Fiber

Fiber is the material in terrestrial plants that is indigestible to vertebrates. There is little fiber in aquatic plants, and therefore fiber should play a minor role in the diet of aquatic animals (**Box 2**). The fiber content should be less than 5%.[6]

Medicated Feeds

There are many commercially available medicated feeds, and the practitioner should expect some questions regarding their use. Most of the medicated feeds available

Box 2
Summary of nutrition requirements

	Herbivore and Omnivore	Carnivore
Protein	35–45%	40–55%
Fat	15–25%	15–25%
Carbohydrate	25–40%	<20%
Fiber	<5%	<5%

Proteins primarily fish meal and other animal protein.
Fats with a significant source of n-3 fatty acids.
Carbohydrates as starch.
Vitamins A, C, D, E, K and B vitamins.
Phosphorus 0.3%.
Data from Refs.[1–4,6,7,10,11]

were designed for specific needs of commercial food fish production. Those available to pet owners and hobbyists are often not regulated by the US Food and Drug Administration and may have no empirical evidence for their use. In the author's experience, many of the foods contain inappropriate antibiotics; unknown concentrations of medication; or a mixture of antibiotic, antifungal, and antiparasitic medications. The author cautions clients regarding use of these products because of potential development of drug resistance and unnecessary side effects of multiple medications. However, many people see their use as a less expensive alternative to proper diagnosis and treatment based on an accurate working diagnosis, or they use the feeds at the advice of well-intentioned paraprofessionals or retailers.

Summary and Practical Applications

Using this information in a practical situation can be challenging. There are hundreds of commercial foods available, and even more homemade diets. Often the practitioner is asked to evaluate a diet by the client with little time for preparation.

With most commercial foods, only the American Association of Feed Control Officials (AAFCO) minimum information and ingredients list may be available for review. This list allows evaluation of the percentage of protein (should be 30%–50%), crude fat (minimum listed only), crude fiber (should be <5%), and moisture (no set guideline, but may affect interpretation of protein and fat in some foods).

The ingredients list should be evaluated next. In a good-quality food, fish meal or other animal protein should be one of the first ingredients. Little plant protein should be listed. If plant protein is listed, soy is best; other plant proteins should be low on the list of ingredients. Vitamin sources can be identified. The practitioner should look for stabilized vitamin C and a list of other vitamins. A source of digestible phosphate can be identified along with other mineral supplementation. In addition, identify the color enhancers used in the food, if any.

For more detailed evaluation, the manufacturer of the diet normally needs to be contacted. The practitioner should be cautioned that some information may be deemed proprietary by the manufacturer and may not be available for evaluation. If too little information is shared on request, the author generally recommends a different diet. Additional considerations based on common types of fish in the ornamental fish industry are discussed later.

FOOD SELECTION: OTHER CONSIDERATIONS

Energy

Following an understanding of the individual requirements for fish, an understanding of the fundamental differences in the energy requirements of fish helps practitioners guide clients away from some of the most common mistakes related to nutrition. The information presented earlier helps with food selection recommendations, but the biggest nutritional problem for aquatic animals is overfeeding. Owners often have difficulty judging the amount of food to be offered. The typical mammal uses 30% of the energy intake for basal metabolic energy requirements. This figure is only 3% to 5% for fish because fish readily excrete ammonia through the gills and have little need to convert ammonia through the urea cycle for excretion.[1]

Overfeeding contributes to the 2 most common food-related health issues: obesity and poor water quality. Obesity can be addressed best by following the previous recommendations when selecting food. Aquatic animals generally eat to meet their energy requirements. Obesity is likely a sign that the selected food has low dietary energy compared with the level of proteins, lipids, or other essential elements. The

excess intake of proteins or lipids in excess of what is required for energy needs is then converted to stored fat.[1,4]

Organic material is naturally converted to ammonia through digestion or decomposition. In most species, ammonia is further converted to urea and sometimes to uric acid. The urea cycle is absent or greatly reduced in fish, and ammonia is effectively removed through the gills into the surrounding water. Overfeeding of protein leads to increased ammonia in the water of the pond or aquarium through excretion of ingested foods or decomposition of uneaten foods.[1,4,6] Ammonia and ammonium are toxic to fish. Biological filtration converts ammonia to nitrites, then to nitrates in a healthy system (**Fig. 1**). Each step is less toxic, and nitrates are either removed through water changes or conversion to nitrogen gas. The efficiency of biological filtration is limited by the size of the system and surface area for the growth of bacteria in the biological filter. Any ammonia in excess of what can be converted will cause health issues with the inhabitants of the system.[1,6,9,14]

Food Formulations

The formulation of the feed has a great deal to do with the acceptance by the animal and the delivery of nutrients in an aquatic environment. Fish diets are available as live foods, liquid food, frozen foods, pellets, and flakes. The formulation must ensure that the nutrients are effectively delivered to the fish and digested properly. There are unique challenges for aquatic animal diets that must be considered.

Most diets do not involve live feeding, but some fish do require live food. In general, larval fish require live food for survival. In one study, fish larvae raised initially on dry food showed 100% mortality by 15 days compared with 100% survival in larvae raised

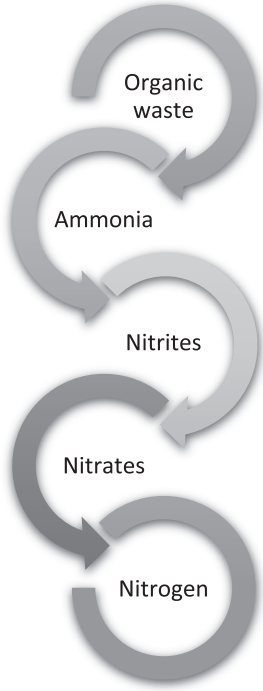

Fig. 1. Ammonia cycle.

on live food up to 15 mg body weight.[22] Live food has the advantage of stimulating natural behavior in fish and may offer enrichment. The drawback is the potential for introduction of parasites or disease. There are also the ethical implications of placing prey in an enclosed space with their predator.

Liquid and frozen diets are similar. Most are prey-based diets containing small crustaceans, eggs, or other prey in a liquid base, often starch based. The liquid may be supplemented with vitamins or minerals. The liquid diets are packaged fresh. Liquid diets have short shelf lives, but can offer good nutritional profiles and a diet that resembles the natural food that fish eat in the wild.[2] Frozen food has a longer shelf life and a reduced chance of introducing disease, but caution must be used regarding the stability of vitamins with freezing.

Pellets and flakes are dry foods. They are the most prevalent commercial diets available to hobbyists. The extrusion process used to make these diets allow feeds to have higher energy content and increases the digestibility of the nutrients. Gelatinization of starch in this process also increases the stability of the diet and availability of vitamins.[4] Vitamins must be added after the heating process to avoid breakdown of vital bonds.[7] Flakes are floating foods that need to be eaten at the surface. Pellets can be either floating or sinking foods depending on the formulation, allowing fast-sinking pellets to be used for bottom-feeding fish and slow-sinking pellets for those that feed in the center of the water column. Pellets are also available in different sizes and shapes (**Fig. 2**).

Storage

Proper storage of any diet is one of the most important considerations to ensure that proper nutrition is delivered to the fish. With regard to storage of food, temperature, humidity, and lighting can all affect the viability of the diet offered. Improper storage of foods with regard to these considerations can lead to decreased nutritional value at best and fatal toxicity at worst.

With prolonged storage, fats and vitamins can oxidize and undergo damaging changes from the oxidation. Polyunsaturated fatty acids, which are present in most fish diets, can oxidize and become rancid, especially if there is inadequate vitamin E

Fig. 2. Various food formulations.

or other antioxidants in the diet. The rancid odor is usually difficult to detect among the normal smells associated with fish meal. Many owners do not detect rancid food until there is loss of numerous fish and other possible causes are exhausted.[3,7] Oxidized fats can form toxic compounds that result in anemia, splenomegaly, ascites, and nephrosis.[3] Many fish are able to detect the tastes of the rancid fatty acids and avoid toxicity from ingestion, but may instead incur nutritional deficiencies or hepatic lipidosis.[4]

Vitamins are also oxidized in storage, particularly the fat-soluble vitamins. Continuing to use feed that has oxidized vitamins can result in health problems secondary to hypovitaminosis. The clinical signs of vitamin deficiencies are often nonspecific and easily confused with other health issues, again making these conditions difficult to detect.[2,3,7] Any animals showing outward signs of illness should have supplemental vitamins offered as part of the treatment plan, particularly vitamins B and C. Requirements for these vitamins are especially profound during periods of stress.[4,7]

Increased humidity during storage can lead to growth of molds on the foods. Molds on food can produce aflatoxins. Many fish can detect oxidation products associated with this and consequently have decreased food intake, resulting in nutritional deficiencies. If the aflatoxins are consumed they can be toxic to the fish.[4] The toxicity of the dose is usually measured in parts per billion. Aflatoxins are usually not detected by smell, therefore food hygiene and storage conditions must be appropriate.

Any consultation involving illness in fish should include a review of food storage in the history. If the current food has been stored for longer than 90 days, it should be replaced.[3] A maximum of 90 days' storage should also be advised to any clients during preventative medicine screenings or on any care sheets published for client information (**Box 3**).

Behavioral Considerations

The nutritional makeup of the food and the form of the food only matter if the food is ingested by the fish. There are many behavioral considerations that factor into acceptance of food items. Some are similar to other species and some are unique to aquatics. A comprehensive evaluation by species is beyond the scope of this article, but it is appropriate to introduce some of the behavioral considerations to help the practitioner in evaluations and to introduce ideas in order to ensure that behavioral concerns are addressed or that the need for further research is not overlooked. The author has divided these considerations into sensory, social, and environmental concerns for ease of summarizing.

Fish have most of the same senses as land animals. Some have excellent senses of taste, olfaction, sight, or hearing. As previously discussed, many fish recognize the taste or smell of oxidized oils and avoid rancid food. It has also been shown that carnivores prefer alkaline or neutral foods, whereas herbivores tend toward acidic foods.[4]

Box 3
Storage of Food

Protect from light

Protect from moisture

Keep between 70–85 F

Use within 90 days

Data from Refs.[2–4,7]

In addition to the normal senses, fish have a lateral line: a sensory organ running the length of the body from rostrum to tail and located roughly parallel to the spine. The lateral line detects low-frequency vibrations and pressure changes. Elasmobranchs have the ampullae of Lorenzini, specialized organs that detect electrical impulses. These senses are key in detecting prey in the wild.[16] Fish rejecting food may respond to foods that are a different color, size, smell, or taste. The feel of the food may also be a factor.[1,4] Eels have been shown to prefer foods with a soft texture.[1]

Social factors are those behavioral patterns that are either innate or responses to other animals in the system that affect how the fish eats. Eels are a good example of this as well. Eels, gobis, and many other fish have innate drives to hide or inhabit closed spaces.[3] In the wild as well as in captivity they roam only a short distance in the open. Sinking food or focused feeding with tongs or droppers may be required for them to get the necessary dietary food intake. Other fish occupy a specific area in the water column: near the surface, near the bottom, or in the middle. Food may need to be delivered into those areas to ensure that adequate nutrition is offered to those fish.[1,4] The caretaker also has to observe closely for submissive fish who may have decreased food intake or delayed eating.[3] Water-soluble vitamins may be lost once in the water for as little as 30 seconds.[3,7] This loss may lead to vitamin deficiency in submissive fish.

Environmental factors that have been found to affect the feeding habits of fish in the wild include temperature, lighting, tides, lunar cycles, depth, and seasons. Many of these factors are limited to wild conditions, but others are possible to duplicate in captivity and can be used to help improve nutrition. Tides likely increase feeding by increasing available food. Likewise, full moons increase ambient light and may increase feeding activity by making prey easier to locate for nocturnal feeders.[4] In captivity, artificial tidal movement is created in some systems and water pumps increase water flow to create circulation patterns in tanks, although these usually benefit filter-feeding invertebrates more than fish. Lighting is something that can be controlled in most systems. Artificial lighting systems are available for indoor aquariums that effectively simulate the spectrum of light to which fish are exposed in natural conditions. Modern lighting systems can be programmed to simulate sunrise and sunset by slowly varying light levels. They can also simulate lunar cycles with low-level lighting that changes on a 28-day cycle. Many can also create simulated storms or cloud cover moving across the aquarium. Seasonality can be simulated by adjusting day length with the programming. Lighting can be used to adjust fish to meal feeding in most cases.[4]

For outdoor fish, natural rhythms affect the fish and the caretaker needs to understand the influences of these processes and adjust accordingly for care. In general, food intake decreases with shortening days and decreasing water temperatures. Food intake increases as the water temperature increases again and the days increase in length.[4] As feed intake decreases, the caretaker should reduce the food offered to avoid water quality problems. Feeding times should be adjusted to allow digestion to be completed at the warmest part of the day.[2,4]

SPECIFIC RECOMMENDATIONS

Koi

Koi are some of the most frequently treated fish in private practice. Many clients with koi participate in wellness programs and are interested in consultations with veterinarians for preventative medicine. Discussions on nutrition are an important part of that care. In addition, considering nutrition during any treatment plan for an unhealthy

koi is essential to successful treatment. There has been research in koi nutrition, much of which is discussed earlier.

There are a large number of commercially available koi diets on the market. Evaluating and recommending diets should be done similarly to the summary earlier in this article. The main protein source should be fish meal. Protein, fat, and carbohydrate requirements are similar to other omnivorous fish, although carbohydrate levels may be slightly higher than in diets for other omnivorous fish. As omnivores, koi are more tolerant of carbohydrates and are likely to use the carbohydrates for energy during periods of starvation.[7,11] However, if there are edible plants or algae in the pond, they are likely to get the carbohydrates needed from grazing in the pond.

Koi also have a need for vitamin C. Specific requirements are not known for koi, but other fish have been found to need 25 to 50 mg/kg in feed for routine supplementation.[1,9] This amount is the author's recommendation for feed, again keeping in mind that it should be stabilized vitamin C and that the feed should be stored for no longer than 90 days.[3,9,15] If being treated for injury or illness, additional vitamin C should be supplemented at up to 10 times this level per day.

Koi tend to significantly decrease their energy output and food intake as temperatures decrease in the pond and as the length of days decrease over the winter months. This change is important for reproductive physiology of the fish and helps avoid reproductive diseases. Many hobbyists and food companies recommend transitions to different diets for the winter. The author could find no reliable research to support the need for this change. As energy output decreases, caretakers should be advised to reduce feeding amount and frequency over the winter, but there should be no need to change the diet.

Tropical Aquarium Fish

Most pet ornamental fish are tropical freshwater or saltwater fish. There are hundreds of species of fish represented in the pet trade. There is a lack of information available for many of these species. There is also likely a wide range of needs for these different species. Although there is some information available for the needs of a few species, the needs for all the inhabitants of a specific aquarium are difficult to determine objectively. As such, the recommendations in this area are largely based on generalized nutritional research, the author's experience, and discussions with other practitioners and aquarists. The most important recommendation for caretakers is recognition of the species in the tank as carnivorous, omnivorous, or herbivorous to help in selection of diets.

For tropical freshwater fish, there are a variety of commercial flaked and pelleted foods available on the market. The author generally recommends evaluating these foods according to the information in the summary given earlier. Fish meal as a primary protein source is desirable, along with soy and other vegetable proteins in smaller amounts. A stable source of vitamin C and the availability of B vitamins and vitamins A, E, D, and K should be found in the ingredients. It is also advisable to observe fish in the aquarium during feedings. Not all fish come to the surface to eat floating flakes in a timely manner. If not all are eating flaked food, then sinking pellets should be used: slow-sinking pellets for fish that stay near the middle of the water column and fast-sinking pellets for those that stay near the bottom of the aquarium.

For tropical marine fish, the author often recommends that a variety of foods be rotated. There are several commercial systems designed for this type of feeding. A variety of shrimp, seaweeds, algae, and eggs can be offered on a rotating basis.

The hope with this is that any unknown nutritional deficiencies are avoided by offering a variety of protein sources to the aquarium inhabitants. Again, careful observation during feeding times should be recommended to ensure that all inhabitants have the opportunity to eat food in a timely manner. The same recommendations apply to these diets for vitamin and mineral supplementation.

Marine Invertebrates

Reef aquariums are gaining popularity as they become easier to maintain. Therefore, it is good for the practitioner to have some knowledge of corals and other invertebrates. Extensive coverage is beyond the scope of this article, but the practitioner should be prepared to correct the basic incorrect elements of so-called common knowledge in the hobby. Many sources state that there is no need to feed invertebrates. Many invertebrates maintain themselves by feeding on algae or other plant sources in the system, but this is not universally true. Any crustaceans should be observed closely and supplemental food should be offered at least weekly even if they are eating algae.

Corals obtain energy from a commensurate relationship with the single-celled photosynthetic organisms known as zooxanthellae. Although this relationship provides most of the nutritional requirement of the coral, it depends on a specific intensity and wavelength of light. It also provides full nutrition for few corals. Most need to be fed with plankton or other food sources (**Fig. 3**).[17,18]

Elasmobranchs

Although uncommon in veterinary practice, elasmobranchs (sharks and rays) are sometimes encountered. Two important considerations should be noted. First, B vitamins should be a consideration in the diet because many of the frozen fish used in the diets contain thiaminases that affect thiamin levels in the diet. Second, iodine needs to be supplemented at high levels for most elasmobranchs. Without proper iodine supplementation, elasmobranchs are more prone to goiter.[16] In addition to supplementation of iodine in the diet, the levels in water should be tested. The level of iodine in the water may be more important than that in the diet. A recent study showed that reduction of iodine in the water after the addition of ozonation led to goiter even in sharks that were given iodine supplements in their diets.[23]

Fig. 3. Coral with extended tentacles ready to feed.

SUMMARY

Nutritional advice is an important part of aquatic animal medicine, just as in any other branch of medicine. There are many areas of fish nutrition that vary greatly from that of other species, and many areas in which research is lacking. As aquatic animals become more popular and more people consider a relationship with a veterinarian to be an important part of the hobby, this research is likely to be completed. The practitioner should keep up with all information available in order to give the best advice possible for their patients.

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