30 Baitfish

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Introduction

Small fish produced specifically for anglers to attract desirable food- or game fish are referred to as 'baitfish'. Goldfish and the rosy red variety of fathead minnows may also be marketed as 'feeder' fish, which are meant for consumption by piscivorous pets. Baitfish and 'feeder' fish are raised under similar conditions, and nutrition and feeding practices for these species are considered together.

The total value of baitfish (including 'feeder' goldfish) sold in the USA in 1998 was $37.5 million (USDA, 2000). The golden shiner, *Notemigonus crysoleucas*, accounted for about half of this total. Goldfish, *Carassius auratus*, and the fathead minnow, *Pimephales promelas*, collectively comprised the remaining half. Baitfish value is determined primarily by size, and this feature dictates production and marketing strategies. Baitfish production is concentrated in the southern USA, especially in Arkansas, and the majority of fish are spawned and raised in ponds. Other fish species, such as white suckers, *Catostomus commersoni*, are sometimes preferred as bait outside the southern USA and in other countries. In some regions (such as the north-central USA), the distinction between wild-caught and cultured baitfish is not always clear and prepared diets may not be used (J.L. Gunderson, University of Minnesota, 2000, personal communication).

The known nutritional requirements of baitfish species are similar to those of other warm-water omnivores, such as channel catfish and common carp. However, quantitative requirements of many nutrients for baitfish species are still unknown. Feeding practices for baitfish also differ from those of foodfish in several important ways (Table 30.1).

Table 30.1. Major production factors that affect feeding and nutrition of baitfish and channel catfish in ponds.

Factor	Baitfish*	Channel catfish†
Feed cost	18% of total costs	≥ 50% of total costs
Fish growth	Rate is manipulated to achieve desired market sizes (variable)	Maximum rate is desirable throughout production cycle
Natural foods	Provide 40% or more of nutrition for non-larval stages in intensive culture in presence of prepared diets	Uncertain contribution; may provide some micronutrients for non-larval stages in intensive culture in presence of prepared diets
Body composition	Large amount of body fat does not reduce marketability/ may be advantageous for fish vigour	Large amount of body fat reduces dressing percentage and shelf-life

* Includes golden shiners, goldfish and fathead minnows (Stone *et al.*, 1997).
† From Robinson and Li (1996).

Nutrient Requirements

Protein and amino acids

The essential amino acid ratios of the whole body of golden shiners, goldfish and fathead minnows are similar to those of channel catfish, *Ictalurus punctatus*, and common carp, *Cyprinus carpio* (Gatlin, 1987), indicating possible similarities in essential amino acid requirements among these species. Lochmann and Phillips (1994a) determined that growth, survival and feed efficiency of golden shiners and goldfish fed semipurified diets with 29% protein in aquariums was similar to that of fish fed diets with higher protein levels when fed at 4–7% of body weight (BW).

A.L. Gannam and H. Phillips (unpublished) found that there were no differences in weight gain or yield of golden shiners in ponds fed practical diets with only vegetable proteins versus diets with 5, 10 or 20% fish-meal. The primary vegetable-protein source for all diets was soybean meal. Alternative protein feedstuffs, including fish silage and worm meal, have been tested for golden shiners in aquaria. Worm meal supported growth similar to that of fish fed diets containing an isonitrogenous amount of fish-meal, while diets containing fish silage reduced fish growth (R. Lochmann and H. Phillips, unpublished). However, golden shiners fed diets with only vegetable protein (soybean meal) performed as well as fish fed diets with fish- or worm meal. Therefore, there is no need for animal protein sources in practical diets for juvenile (0.5 g in weight) golden shiners in aquariums or ponds. In ponds, consumption of biota by baitfish probably further reduces the need for supplemental high-quality protein sources.

Golden shiners (1.3 g) in ponds were fed diets similar in energy : protein ratios but different in crude protein levels (22 or 28%) to satiation twice daily for 10 weeks. The weight gain of fish fed the diet with 28% protein was higher after 4 weeks, but by week 10 there were no significant differences in weight gain, feed conversion, net yield or yield of individual size classes of fish fed the two diets (R. Lochmann and H. Phillips, unpublished).

Energy

The optimal dietary protein : energy ratio for growth of golden shiners and goldfish is 103 mg protein $kcal^{-1}$ (Lochmann and Phillips, 1994a). Energy requirements for maintenance of goldfish increase with temperature between 20 and 26°C (Pannevis, 1993). In general, both energy and protein requirements for maintenance of goldfish decrease with increasing fish size (Pannevis and Earle, 1994). Goldfish appear to select their diet based on energy density (Sanchez-Vazquez *et al.*, 1998). Available energy of feedstuffs for baitfish is estimated mostly from growth under optimal conditions (Stone *et al.*, 1997). De Silva *et al.* (1997) documented an alteration in apparent total dry matter and apparent protein digestibility in goldfish in the presence of a stressor (sublethal cadmium levels). Results varied depending on the digestibility marker used (chromic oxide or fibre). When chromic oxide (Cr_2O_3) was used as a marker, small quantities of chromium were absorbed by the goldfish and digestibility coefficients were underestimated (De Silva *et al.*, 1997). Stable carbon isotope data are another index of nutrient assimilation in baitfish. Whole cooked maize is not assimilated well by golden shiners, while maize-gluten meal, maize starch and lipids are readily assimilated (Lochmann and Phillips, 1996, 2000).

Lipids and fatty acids

The optimal dietary lipid level for juvenile golden shiners and goldfish was determined in feeding trials using graded levels of a mixture of 1 : 1 ratio of cod-liver and soybean oils. The lipid mixture contained 18-carbon, as well as 20- and 22-carbon fatty acids of the n-3 and n-6 families, which encompasses the essential fatty acid (EFA) requirements of most fish species (Watanabe, 1982). The weight gain of golden shiners fed diets containing 34% protein and 7–12% lipid was higher than that of fish fed diets with lower or higher lipid levels (SRAC, 1998). Feed efficiency and survival of golden shiners were not affected by dietary lipid levels ranging from 3 to 15%. Optimum weight gain and feed efficiency of goldfish were obtained with diets containing 3–6% lipid (SRAC, 1998). Survival increased with increasing dietary lipid level, but was 93% or higher in all treatments.

Golden shiners in aquariums fed isonitrogenous and isocaloric practical diets with either 4% or 13% poultry fat for 7.5 weeks had similar growth, but survival was higher in fish fed the diet with 13% lipid (Lochmann and Phillips, 2001).

Similar diets were also used in ponds (0.04 ha) and outdoor pool (4137 l) studies. Golden shiners (0.9 g) in ponds stocked at 796 kg ha^{-1} were fed practical diets containing 4 or 13% poultry fat or 13% menhaden fish-oil to satiation twice daily for 12 weeks (R. Lochmann and H. Phillips, unpublished). The weight gain of fish fed the diet with 4% poultry fat was higher than that of fish fed diets with 13% lipid. The net yield of fish fed the three diets was similar, implying a higher survival rate among fish fed the diets with 13% lipid. Whole-body lipid of the golden shiners fed the diet with 13% menhaden fish-oil was higher than that of fish fed the diets with 4 or 13% poultry fat ($P = 0.07$). This apparent difference in metabolism of poultry and fish-oils by golden shiners needs further study.

Goldfish (0.9 g) stocked at 600 fish per fertilized pool (3 m diameter × 1.5 m depth) were fed practical diets (3–6% BW) containing 4 or 13% lipid as poultry fat or menhaden fish-oil for 9 weeks. These supplemental diets contained 24% protein and no added vitamins or minerals. Average individual weight gain, feed efficiency, net yield and whole-body lipid were significantly higher ($P < 0.05$) in goldfish fed diets with 13% of either lipid source, compared with fish fed diets with 4% lipid (R. Lochmann and H. Phillips, unpublished). Lipid source did not affect goldfish performance. Presumably, the improved performance of goldfish fed the high-lipid diets was due to a protein-sparing effect of dietary lipid.

Studies have also been conducted in aquariums to determine the qualitative EFA requirements of golden shiners fed purified diets (Lochmann and Phillips, 2001). Results are summarized in Table 30.2. These trials have not consistently indicated a specific requirement for n-3 or n-6 fatty acids or for 18-carbon or longer-chain fatty acids of either family. The ratio of n-3 : n-6 fatty acids in the diets ranged from 0.06 (rice-bran oil) to 9.0 (cod-liver oil). Similar studies with common carp (Watanabe *et al.*, 1975a,b), channel catfish (Dupree, 1969; Stickney and Andrews, 1972; Satoh *et al.*, 1989a,b), and tilapia (Kanazawa *et al.*, 1980; Takeuchi *et al.*, 1983; Chou *et al.*, 2000) also yielded conflicting results. Pozernick and Wiegand (1997) found that growth and survival of larval goldfish fed diets with cod-liver or canola oils was equally good, indicating that a dietary source of n-3 highly unsaturated fatty acids (HUFAs) is not required. However, they did not consider n-6 fatty acids. Prostaglandins derived from arachidonic acid (20:4n-6) stimulate steroid production in goldfish (Wade *et al.*, 1994; Mercure and Van Der Kraak, 1996) and courtship behaviour in fathead minnows (Cole and Smith, 1987). Until the qualitative and quantitative EFA requirements of baitfish are established, dietary sources of both n-3 and n-6 fatty acids should be provided to support normal growth, health, appearance and reproduction in these species.

Phospholipid supplementation in diets for baitfish species may be beneficial. Practical diets supplemented with soybean lecithin enhanced growth but did not affect survival of juvenile goldfish (Lochmann and Brown, 1997) relative to diets containing lipid as triglyceride from either soybean or fish-oils. Phospholipid supplementation of semipurified diets improved both growth and survival of larval goldfish (Szlaminska *et al.*, 1993) and carp (Geurden *et al.*, 1995). Phospholipids may facilitate lipid digestion, absorption and transport in baitfish, as in other fish (Hertrampf, 1992).

Table 30.2. Summary of studies to determine qualitative essential fatty acid requirements of golden shiners (data from Lochmann and Phillips, 2001)*.

Study no./length	Initial fish weight (g)	Lipid sources†	Main results
I/9 weeks	0.21	Soybean, rice bran, canola, cod-liver, poultry	No differences in weight gain or survival between diets; whole-body lipid was higher in fish fed vegetable vs. animal lipids
II/11.5 weeks	0.19	Soybean, rice bran, canola, cod-liver, poultry, olive	No differences in weight gain or survival between diets; mortality of fish stressed with low dissolved oxygen was lowest in fish fed soybean oil
III/6 weeks‡§	0.35	Soybean, cod-liver, soy + cod-liver (50/50%), olive, canola	Weight gain of fish fed the soy + cod-liver (E), olive (U) and soybean (E) diets was highest; no differences in survival; whole-body fatty acid profiles reflected dietary patterns
IV/34 weeks	0.22	Same as study III	No differences in weight gain between diets; survival was higher in fish fed ethanol-extracted diets, regardless of lipid source. Fish fed canola had intact fins, opercula and integument; those fed olive oil had pronounced erosion of these structures; fish fed other lipids were intermediate in appearance

* Purified diets for all experiments contained 34% protein and 10 kcal energy g^{-1} of protein from casein and gelatin. Diets were supplemented with 10% lipid from various sources. Diets were fed to fish in triplicate tanks per treatment at 5–7% BW divided into two daily feedings.

† Lipids used were whole oils or fats extracted commercially from plants and animals (approximately 80% triglycerides).

‡ Experiment was terminated after 6 weeks due to massive mortality from an unidentified disease.

§ One series of five diets contained the lipid sources shown in table (U = unextracted diets); a second set of five diets contained the same lipids but the casein, gelatin, dextrin, cellulose and carboxymethylcellulose were extracted with boiling ethanol to minimize lipid content (E = extracted diets).

Carbohydrates

Weight gain and survival of golden shiners fed semipurified isocaloric and isonitrogenous diets with 15%, 30% or 45% starch were similar, indicating that they perform well over a wide range of dietary levels of carbohydrate : lipid ratios (Lochmann and Phillips, 2001). In another experiment, the weight gain of golden shiners fed diets with 15% carbohydrate from different sources improved with increasing complexity of the carbohydrate: starch > dextrin > sucrose = glucose (Lochmann and Phillips, 2001). Results are similar to those for other warm-water omnivores (NRC, 1993). Survival of golden shiners was lower in fish fed sucrose than in those fed dextrin or glucose, but the value was 93% or higher in all treatments.

Vitamins and minerals

Natural foods consumed by baitfish in ponds are rich sources of vitamins and minerals, but the amounts and types vary with the composition of the natural food supply. Therefore, commercial baitfish diets are supplemented with the same types and amounts of vitamins and minerals used in diets for channel catfish (Lovell, 1989). Few studies have addressed vitamin and mineral nutrition in baitfish. Weight gain and total net yield of golden shiners in ponds fed diets with or without a combination vitamin and mineral supplement for 8 weeks did not differ (Lochmann and Phillips, 1994b). Presumably, natural foods supplied sufficient vitamins and minerals to maintain overall fish production.

A preliminary aquarium study was performed to determine whether or not golden shiners (0.4 g) have a dietary requirement for ascorbic acid (AA). Fish-meal- or casein-based diets supplemented with either 0 or 250 p.p.m. AA (Stay-C, Roche Vitamins, Inc.) were fed to golden shiners for 12.5 weeks. Weight gain was higher but survival of golden shiners was not affected by AA supplementation of the fish-meal diets, while the reverse was true with the casein diets. No AA-deficiency signs (e.g. scoliosis, lordosis, severe fin erosion, etc.) were observed in golden shiners fed fish-meal diets with or without AA. There were significant differences in total AA, reduced AA, and % AA content of whole bodies of golden shiners fed AA-supplemented and AA-unsupplemented diets (Lehmann *et al.*, 2001a). Golden shiners appear to have a dietary requirement for AA, but the requirement is influenced by diet composition.

Goldfish fed purified diets without vitamin A displayed haemorrhaging, exophthalmia, scale loss and anorexia (Jones *et al.*, 1971). Nutritional myopathy attributed to dietary vitamin E deficiency was reported for goldfish fed practical diets with 26 mg kg^{-1} or less of vitamin E (Huerkamp *et al.*, 1988). Quantitative dietary requirements of these vitamins, however, have not been determined.

The metabolism of some minerals such as calcium, phosphorus, magnesium and selenium has been studied in baitfish species used in toxicological or biomedical studies (Ichii and Mugiya, 1983; Houston, 1985; Kleinow and Brooks, 1986). A preliminary study of mineral availability from fish-meal for goldfish was conducted by Sugiura *et al.* (1998), but the study was terminated early due to technical difficulties. These studies could serve as a basis for establishing dietary mineral requirements for baitfish, which are currently unknown.

Practical Diets

Some baitfish producers use only agricultural by-products (e.g. cottonseed meal, rice bran) as a diet, but semi-intensive and intensive producers use compounded diets to double or triple production. The composition of diets used for different stages of the baitfish production cycle are similar to those for channel catfish (Lovell, 1989; Stone *et al.*, 1997). However, pond fertilization to stimulate natural food production is considered critical for successful baitfish production, regardless of production intensity and prepared feeds used. Commercial minnow meal containing 48–50% protein is applied to ponds containing newly hatched fry. These small fish consume the meal, but newly hatched fry of some cyprinids do not utilize prepared feeds well (Dabrowski and Culver, 1991). Therefore, the meal may serve more as a fertilizer than as a feed. When the fish are approximately 2 cm in length, they are offered an extruded pellet (floating or 'slow-sink') or crumble containing 28–32% protein. This diet is used until the fish are harvested. A similar diet or one with a higher protein level (36%) is fed to baitfish brood-stock.

Soybean meal is the primary protein source in commercial baitfish diets and very little (2–5%) fish-meal is used in diets for juveniles and adults. Some producers believe that fish-meal supports superior baitfish performance in ponds, but there is no experimental evidence to support this. Due to the proximity of the baitfish and poultry industries in Arkansas, poultry fat is frequently added to baitfish diets. Poultry fat appears to be palatable and provides satisfactory performance.

Recently, high-fat (13%) diets with lower protein levels (24%) have generated some interest among baitfish producers. The cost of increased dietary lipid is offset by the reduction in cost due to the lower protein content, making the diet a viable alternative for most producers. For feeder fish, economical means of enhancing skin colour are needed. The synthetic carotenoids used to enhance colour in salmonids are too expensive for use in feeder-fish diets, and further research is needed to identify more economical alternatives.

Feeding Practices

Because of the large impact of natural foods on baitfish produced in ponds, the need for nutritionally complete feeds throughout the production cycle is debatable. When desirable plankton blooms can be maintained in production ponds, supplemental feeds may be sufficient to maintain production. However, in ponds where blooms are sparse or cannot be maintained, baitfish production may be improved by the use of nutritionally complete diets (Lochmann *et al.*, 2001b). The desired market size of the fish strongly influences the feeding frequency used, but the type of diet (supplemental or complete) could be altered to control size and also to maintain fish health.

Feeding practices by baitfish producers are highly variable. Some of the variability is related to species. Stocking, feeding and production rates are highest for goldfish, followed by golden shiners and fathead minnows. Most fathead-minnow producers use little or no prepared feed, while some goldfish producers feed up to 23 kg ha^{-1} day^{-1} (2% of BW). For golden shiners, 11 kg ha^{-1} day^{-1} is considered a high feeding rate. Most farms feed once daily, but fish are fed more often when rapid growth is desired. Diet is usually applied to ponds by blowers mounted on trucks.

Some producers in the USA are now hatching baitfish eggs indoors in tanks before releasing fry into ponds. The procedures used are similar to those described by Kestemont (1995) for goldfish larvae, except that live foods are not used. Feeding regimes for hatchery-produced baitfish fry are still experimental, but diets generally consist of a mixture of finely ground meals, microparticulate diets or other foods (yeast) with a small particle size (100–250 μm). After the fry are moved into ponds, they receive the same feeds as fish spawned in ponds.

Feeding strategies for baitfish change seasonally. Survival improves and the condition of golden shiners during winter is maintained by feeding at a rate of 1–2% BW at afternoon air temperature of 7°C or higher (McNulty *et al.*, 2000). Increased numbers of fathead minnows in good condition in ponds can be achieved with a feeding rate of 3% BW day^{-1} (using a 32% protein feed) from late summer to winter (Ludwig, 1996). In summer, many producers reduce feeding rates when water temperatures exceed 30°C.

Production of golden shiners in indoor recirculating systems has been attempted in some areas (north-central and north-eastern USA) with restricted outdoor growing seasons. Nutritionally complete feeds are essential for the successful production of fish in these systems. Commercial salmonid diets have been fed to golden shiners in these systems (G. Raisanen, Alexandria Technical College, Minnesota, 2000, personal communication). In some cases, growth and survival have been adequate, but fish developed pathological signs, such as ‘bent backs’ and other anomalies, which made them unmarketable. To date, culture of golden shiners in recirculating systems has not been successful and lack of an adequate diet may be a cause. Due to the lack of information on nutrient requirements of baitfish, diets developed for tilapia, carp or channel catfish may be used. However, the nutritional benefits derived from natural foods in ponds may be difficult to duplicate economically in indoor systems.

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