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Nutrition and Feeding of Baitfish

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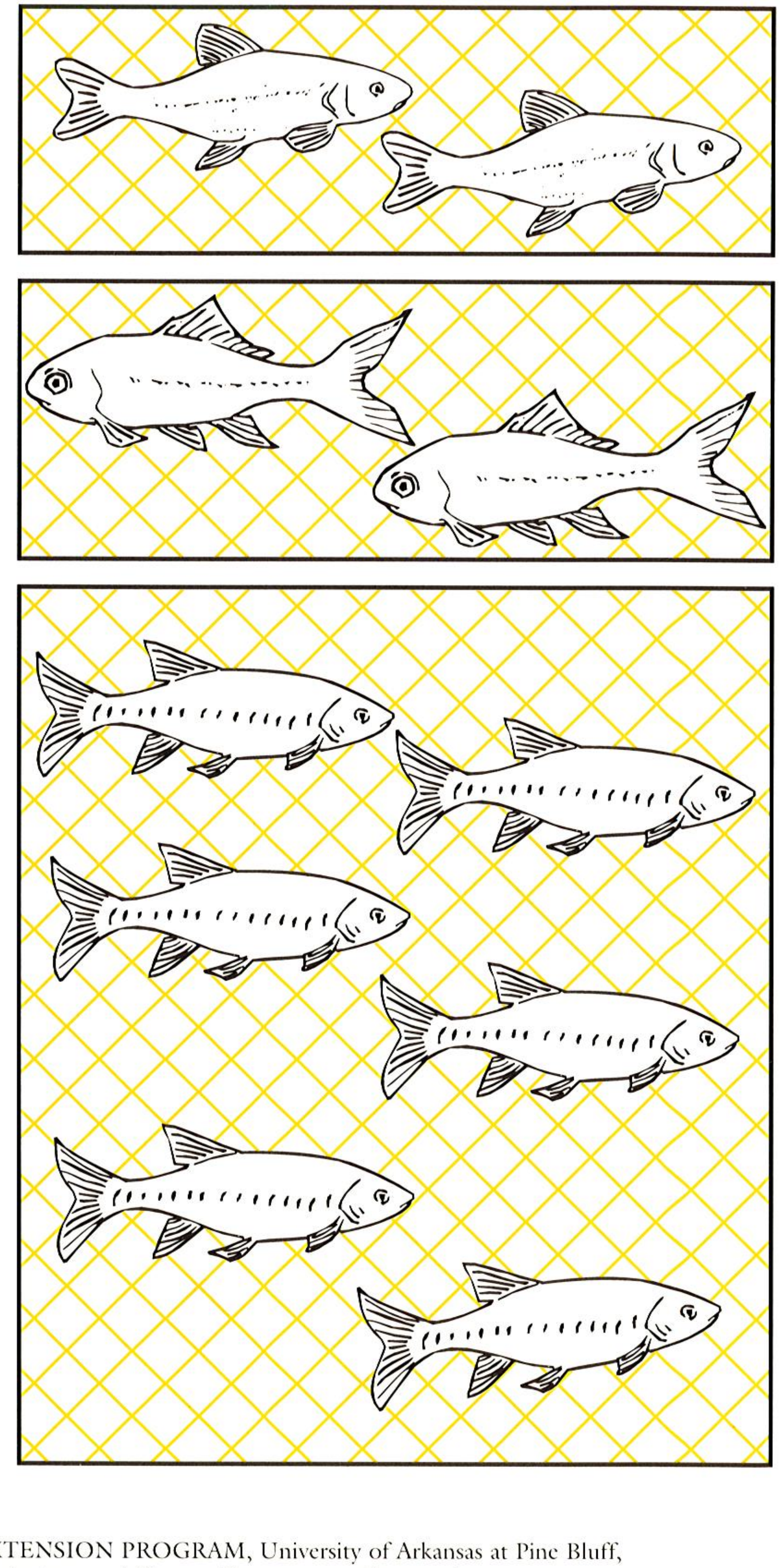

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COVER ART

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PREFACE

This manual is a review of research on the nutrition and feeding of baitfish. Most of the research was conducted in Arkansas, where the bulk of intensive baitfish production occurs. Studies to determine the nutrient requirements of baitfish have focused on macronutrients (especially proteins and lipids), and there is still little information on micronutrient (vitamin and mineral) requirements. This research bias has resulted partly from the belief that many of the micronutrient requirements are met by natural pond foods. This assumption has led to another important line of baitfish nutrition research: determining the relative contributions of natural and prepared feeds to the performance of baitfish in ponds. This manual is intended to highlight the current state of knowledge on baitfish nutrition and feeding practices, and to identify future research needs.

INTRODUCTION

Small fish produced specifically for anglers to attract desirable food or game fishes 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 United States in 1998 was $37.5 million. The golden shiner, *Notemigonus crysoleucas*, accounted for about half of this total. Goldfish, *Carassius auratus*, and the fathead minnow, *Pimephales promelas*, comprised most of the remaining half. Baitfish value is determined primarily by size, which dictates production and marketing strategies. Baitfish production is concentrated in the southern United States, especially in Arkansas, and the majority of fish are spawned and raised in ponds.

The known nutritional requirements of baitfish species are similar to those of other warmwater fish that consume both animal and plant matter, such as channel catfish and common carp; however, many of the specific types and amounts of nutrients required in feeds for baitfish are still unknown. Feeding practices for baitfish also differ from those of foodfish in several important ways (Table 1).

Table 1. Factors that affect feeding and nutrition of baitfish and channel catfish in ponds.

Factor	Baitfish[1]	Channel catfish[2]
Feed cost	18% of total costs	50% or more of total costs
Fish growth	Desired rate depends on target market sizes	Maximum rate is usually desired throughout production cycle
Natural foods	Supply 40% or more of nutrition for non-fry stages in intensive culture when complete feeds are used	Contribution uncertain; may provide some vitamins and minerals for non-fry stages in intensive culture when complete feeds are used
Body composition	Large amount of body fat does not reduce marketability/may be an advantage	Large amount of body fat reduces dressout percentage

[1] Includes golden shiners, goldfish and fathead minnows (Stone, *et al.* 1997).

[2] Robinson and Li (1996).

RELATIVE IMPORTANCE OF NATURAL AND PREPARED FEEDS

Most baitfish producers encourage natural food production by using appropriate fertilization and monitoring regimes. Natural foods are inexpensive sources of protein, energy and micronutrients compared to prepared feeds. However, research has shown that use of manufactured feeds greatly increases baitfish production, even when natural foods are present. There was a need to know how much each food type (natural and prepared) contributed to the nutrition of baitfish before an optimal feed could be formulated. If natural foods provide most of their nutrients, then perhaps an inexpensive supplemental feed could be used to maximize production. However, if baitfish assimilate mostly prepared feed and rely very little on natural foods, then a nutritionally complete feed would probably be required for maximum production. Two pond studies were conducted to determine the relative importance of each food type to the production of golden shiners under different production conditions.

Experiment 1

Stable carbon isotope ratios ($\delta^{13}C$) were used to determine the importance of different food sources for golden shiners in 0.1-acre ponds during an 8-week feeding trial. Fish and their food items (both natural and artificial) contain a "signature" $\delta^{13}C$. Over time, the "signature" of the fish will most closely resemble that of the food item(s) that is/are most important in their diet. In this study, groups of 150 golden shiners (3 lbs/1,000 size) were stocked into floating nets (0.13-in. mesh) within unfertilized ponds. The stocking density was comparable to an intensive level of 220,089 fish/acre. Three nutritionally similar diets with a range of $\delta^{13}C$'s were prepared at the University of Arkansas at Pine Bluff (UAPB). Each diet was fed to fish in one net within each of four ponds at a rate of 4% BW/day divided into two feedings. The $\delta^{13}C$'s of the fish and seston (suspended particulate matter including plankton) were measured at the beginning and end of the study. The ratios of the prepared diets were also measured. At the end of the study, the change in fish $\delta^{13}C$'s in combination with weight gain were used to estimate the relative importance of seston and the prepared diets to the nutrition of the golden shiners. Even when nutritionally complete feeds were fed twice daily, the fish still derived 40-83% of their nourishment from the seston (Table 2).

Table 2. The calculated contribution of seston[1] to the weight gain of golden shiners fed isotopically distinct diets in ponds.

Diet number	Diet $\delta^{13}C$	Average individual weight gain (g)	Pond contribution (%)[2]
1	-24.4	1.01	40.4
2	-21.3	0.96	57.0
3	-16.3	0.93	83.1

[1] Seston is suspended particulate matter, including plankton.

[2] See Lochmann and Phillips (1996) for details.

Experiment 1 established the large contribution of natural foods to the nutrition of golden shiners at a fixed stocking density when the natural food supply was uniform between treatments. However, factors such as stocking density and the quality and quantity of plankton blooms vary widely in commercial baitfish ponds. Some of this variability is seasonal, but even within a season some ponds develop and "hold" a good bloom and some do not. When the amount of natural food per fish is reduced (either because there are more fish in the pond, or the natural food is scarce), prepared feeds may become a more important nutrient source for baitfish. The second experiment attempted to address these variables.

Experiment 2

The effect of production variables such as stocking density, natural productivity (measured by secchi disk), dissolved oxygen and feeding rate on use of foods by golden shiners (*Notemigonus crysoleucas*) in ponds was examined in simultaneous 8-week feeding trials at the University of Arkansas at Pine Bluff (UAPB) and Texas A&M University (TAMU).

Ten 0.1-acre ponds per site were fertilized with defatted rice bran and stocked with golden shiners (initial weight=1.3 g) at a rate of 303,644/acre (UAPB) or 151,822/acre (TAMU). Fish in five ponds per site were fed a nutritionally complete prepared diet at 4% of body weight, while fish in the remaining ponds were not fed. Assimilation of natural foods by "unfed" fish was compared to that of fish fed the prepared diet at each site. Standard production data (weight gain, Secchi depth, dissolved oxygen (DO)) was compared to stable carbon isotope ratio ($\delta^{13}C$) data as an index of fish performance (weight change or fish $\delta^{13}C$, resulting from assimilation of various food sources). Natural productivity (plankton) was consistently lower at TAMU than at UAPB, while temperature and minimum DO was similar between sites. Weight gain of fed and unfed fish stocked at a lower density at TAMU was higher than that of fed and unfed fish, respectively, stocked at a higher density at UAPB. The $\delta^{13}C$ of fed and unfed fish at UAPB changed little during the study, so stable isotopes could not be used to provide any information about their food sources (Figure 1). The $\delta^{13}C$ of fed fish at TAMU approached that of the prepared diet, while that of unfed fish resembled that of the plankton and rice bran (Figure 1). The amount of prepared diet significantly affected fish weight change, but Secchi depth and minimum DO did not. Weight gain increased with increasing feed amount up to a maximum value, then declined with additional inputs. Minimum DO, plankton isotope ratio and the fed/unfed variables significantly affected fish isotope ratio.

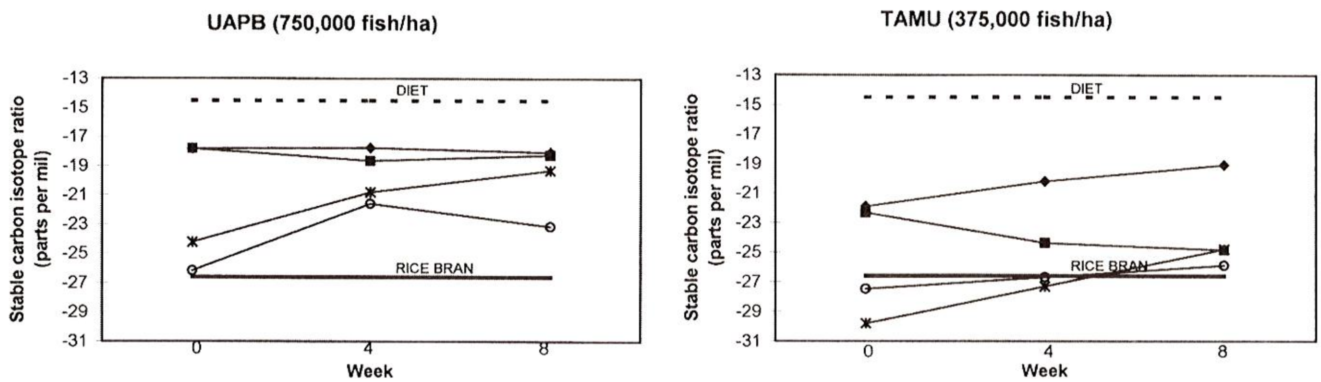

FIGURE 1. Stable carbon isotope ratios (δ^{13}Cs) of fed or unfed golden shiners (fed=diamonds; unfed=squares), fertilizer (rice bran=solid line), plankton from corresponding ponds (fed=circles; unfed=asterisks) and prepared diet (dotted line) in ponds at two sites during an 8-week trial.

This experiment highlighted the importance of two issues:
1) decreased growth of golden shiners at high stocking rates is associated with, not counteracted by, high feed inputs; and 2) greater use of prepared feed by fish at lower densities occurs when natural productivity in ponds is low. The cause of the growth reduction observed at high fish densities despite heavy feeding in this study was not clear. Both living (e.g., plankton) and non-living (e.g., ammonia) components of water quality can become degraded with heavy feed inputs, which could inhibit fish growth directly. In addition, some cyprinid fishes secrete chemical substances that inhibit growth when they are crowded. Additional research is needed to determine the specific cause(s) of growth reduction in golden shiners at high densities when feeding appears to be adequate to support a higher growth rate.

ENERGY-YIELDING NUTRIENTS

Fish need energy to maintain basic metabolic activities and to support growth, reproduction, activity and health. Proteins, carbohydrates and lipids can all be used for energy. Lipids contain about twice as many calories per gram as proteins or carbohydrates. The gross amount of energy contained in feedstuffs and feeds can be measured in the lab. However, the gross energy in a feed ingredient is always higher than the amount of energy that actually can be used by an animal (the available energy), due to the energy that is needed to process the food. Feedstuffs that are hard to digest also provide less available energy to fish. Since there are no digestibility data for different feedstuffs in baitfish, available energy has been estimated mostly from growth on particular diets under specified conditions.

Proteins

The nutritional importance of dietary protein is due primarily to its amino acid content. Fish require certain amino acids (termed "essential") in proteins for growth, tissue repair, general health and reproduction. Fish cannot make the essential amino acids, and they must be provided in the diet. The economic importance of protein for baitfish producers is related to its expense as a feed ingredient. The protein source has a major impact on feed cost. Therefore, both the amount and source of protein must be considered when formulating optimal feeds for baitfish.

Amount

The total dietary protein requirement may be defined as the minimum amount of protein that produces best fish performance (e.g., growth, feed conversion) under a given set of conditions. The total dietary protein requirement is most important economically, since protein is the most expensive component of feeds. In addition to total protein, the balance between protein and energy in a diet is critical. When more protein is added to a diet than is needed for growth and other bodily functions, the excess will be metabolized for energy or used to make energy-storage products (e.g., body fat). Other diet components (carbohydrate or fat) should be used to supply energy because they are usually less expensive. Excess energy in the diet can also reduce feed consumption and growth. The total dietary protein requirement and the protein:energy ratio of golden shiners and goldfish were examined in experiments 1 and 2.

Experiments 1 and 2

In separate feeding trials, juvenile golden shiners and goldfish (0.5 lb/1,000 size) in aquaria were fed semi-purified diets containing graded levels of protein. Weight gain, survival and feed efficiency of golden shiners and goldfish fed the diet with 29% protein was similar to that of fish fed diets with higher protein levels (up to 34%) when fed at 4-7% of body weight (Tables 3 and 4). The ideal dietary energy:protein ratio for growth of golden shiners and goldfish in aquaria was 9.7 kcal of digestible (available) energy per gram of dietary protein. Data from the experiment with golden shiners has been interpreted differently by another author using different statistical methods. However, observations from numerous aquarium and pond studies with golden shiners at UAPB since 1994 indicate that 29% protein is a valid estimate of the minimum dietary requirement for growth of this species.

Table 3. Performance of juvenile golden shiners fed diets differing in protein content for 8 weeks.[1]

Diet number	Dietary protein (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Protein efficiency ratio[3]	Survival (%)
1	21.2	5.3	27^{c}	0.52^{b}	3.3^{a}	100.0
2	25.3	5.6	$31b^{bc}$	0.55^{b}	3.0^{b}	100.0
3	28.9	5.4	34^{abc}	0.61^{a}	3.3^{ab}	85.7
4	31.1	5.5	39^{ab}	0.64^{a}	3.1^{ab}	100.0
5	34.5	5.5	42^{a}	0.65^{a}	2.7^{c}	100.0

[1] Values are means of three groups of 30 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's LSD test.
[2] Feed efficiency = final group weight + weight of mortalities - initial group weight in grams.
[3] Protein efficiency ratio = grams gained/grams dietary protein fed.

Table 4. Performance of juvenile goldfish fed diets differing in protein content for 6 weeks.[1]

Diet number	Dietary protein (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Protein efficiency ratio[3]	Survival (%)
1	21.2	6.0	13^{c}	0.49^{c}	3.1^{abc}	100.0
2	25.3	6.0	15^{bc}	0.53^{bc}	2.9^{bcd}	99.2
3	28.9	5.9	19^{a}	0.61^{a}	3.3^{a}	100.0
4	31.1	6.0	17^{ab}	0.59^{ab}	2.8^{bd}	98.3
5	34.5	6.0	19^{a}	0.63^{a}	2.6^{d}	98.3

[1] Values are means of three groups of 40 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's LSD test.
[2] Feed efficiency = final group weight + weight of mortalities - initial group weight in grams.
[3] Protein efficiency ratio = grams gained/grams dietary protein fed.

In ponds, natural foods contribute to the total amount of protein and energy available to fish, so results might differ from aquarium studies. Therefore, an experiment was conducted to determine the effect of different dietary protein:energy ratios on production of golden shiners in ponds.

Experiment 3

Golden shiners (3 lbs/1,000 size) in ponds were fed diets similar in energy:protein ratios but different in total protein levels (Table 5) to satiation twice daily for 10 weeks. Weight gain of fish fed the diet with 28% protein was higher after four weeks, but by 10 weeks there were no significant differences in weight gain, feed conversion, net yield or yield of individual size classes of fish fed the two diets. The fish fed the diet lower in protein and energy might have consumed more feed than fish fed the diet higher in protein and energy, causing similar production between the two groups. Feed intake was difficult to measure in this study because the two diets differed in pellet flotation. However, most commercial high-protein diets are more expensive than low-protein diets. Therefore, if the fish eat more of the low-protein diet, the production costs of using either diet may be similar. An economic analysis is in progress to address this.

Table 5. Composition (%) of the diets used in a pond feeding trial with golden shiners. The diets were similar in energy:protein ratios but different in percentage of protein.[1]

Ingredient	Diet 1	Diet 2
Soybean meal	45.0	30.0
Menhaden fish meal	2.0	2.0
Cottonseed meal	10.0	0.0
Yellow corn	10.0	20.0
Rice (broken)	0.0	14.95
Wheat (hard red)	13.0	15.0
Wheat shorts	9.95	15.0
Poultry fat	7.0	0.0
Vitamin/mineral premix	3.0	3.0
Vitamin C (Stay-C)	0.05	0.05

[1] The analyzed protein content of diets 1 and 2 was 28 and 22% protein, respectively. The calculated energy to protein (E:P) ratios of diets 1 and 2 were 11.2 and 11.5, respectively.

Source

Aside from total dietary protein, protein quality also affects fish performance. The amount and types of amino acids in a protein source determine its quality. The quantitative amino acid requirements of baitfish have not been determined. However, the essential amino acid patterns of whole-body golden shiners, goldfish and fathead minnows are similar to those of channel catfish, *Ictalurus punctatus*, and common carp, *Cyprinus carpio*, indicating that the essential amino acid requirements are similar for these species.

In practical feeds for minnows, soybean meal is the main protein source because its amino acid content is well balanced, and it is widely available and less expensive than other complete protein sources like fish meal. Several studies with baitfish have shown that fish meal does not provide any obvious benefits over soybean meal as a dietary protein source. A series of studies by Gannam and Phillips 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.

Further work at UAPB compared the relative quality of alternative protein feedstuffs, including worm meal and various fish silages, in practical diets for golden shiners in aquaria. Diets with various protein sources were fed to golden shiners (0.5 lb/1,000 size) in aquaria for 7 weeks. Worm meal was similar to fish meal in its effect on growth of golden shiners, but growth of golden shiners fed the soybean meal diet with no animal protein was as good as that of fish fed diets with animal protein (Table 6).

Table 6. Performance of juvenile golden shiners fed diets differing in protein source for 8 weeks.[1]

Diet number	Protein variable (%)	Initial average individual weight (g)	Average individual weight gain (g)	Survival (%)	Whole-body protein (%)
1	No animal protein (45% soybean meal)	0.23	0.61[a]	98	50.3[ab]
2	Fish meal (5.0)	0.23	0.61[a]	100	49.9[ab]
3	Worm meal (5.1)	0.23	0.47[b]	100	52.5[a]
4	Fish meal (10.0)	0.23	0.71[a]	99	47.3[b]
5	Worm meal (10.7)	0.23	0.70[a]	90	52.7[a]

[1] Values are means of three groups of 30 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's LSD test.

Additional feeding trials were conducted comparing fish silages prepared using various acids with standard fish meal as a protein source for golden shiners. All of the silage sources were neutralized and freeze-dried before they were added to the diets, and analysis showed that the diets were similar in amino acid composition. However, all diets containing fish silage consistently reduced growth. The degree of hydrolysis of the proteins during silage preparation is difficult to control, and this can affect digestibility of the protein source. Despite the mixed success of alternative animal protein sources in diets for golden shiners, both aquarium and pond trials indicate that animal protein sources are not critical in practical diets for growth of small (≥0.5 lb/1,000 size) golden shiners.

Lipids

Fish do not require lipids specifically, but they need and cannot make several components that are found only in lipids. These include the essential fatty acids (EFA). The EFA are required for normal growth, health and reproduction, and they must be provided in the diet. Some fish also require a dietary source of phospholipid such as soybean lecithin, especially at very early stages. Lipids must be present in the diet for normal absorption of fat-soluble vitamins (A,D,E,K). They are energy dense compared to proteins or carbohydrates and may be less expensive than proteins, depending on current market prices for different sources.

Amount

The optimal dietary lipid level for juvenile golden shiners and goldfish was determined in a series of experiments.

Experiments 1 and 2

In separate feeding trials, golden shiners and goldfish in aquaria were fed diets with graded levels of a mixture (50/50%) of cod liver and soybean oils. The lipid mixture contained fatty acids of the n-3 and n-6 families which meet the EFA requirements of most fish species. 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 (Table 7). Survival of golden shiners fed diets with 4.6-14.8% lipid in aquaria was 92% or higher, and feed efficiency was similar among diets. Weight gain and feed efficiency of goldfish declined as dietary lipid increased from 4.5% to 13.3% (Table 8). The highest lipid level (13.3%) significantly reduced weight gain relative to fish fed diets with 7.1% lipid or less. The highest lipid level (13.3%) significantly reduced feed efficiency relative to fish fed diets with 8.9% lipid or less. Survival increased with dietary lipid level, but was 93% or higher in all treatments.

Table 7. Performance of juvenile golden shiners fed diets with different lipid levels for 9 weeks. [1, 2]

Diet number	Dietary lipid (%)	Average individual initial weight (g)	Average individual weight gain (g)	Feed efficiency	Survival (%)
1	4.6	0.22	0.89[b]	0.69	98.3[ab]
2	7.1	0.22	0.97[ab]	0.74	98.3[ab]
3	11.2	0.23	1.00[a]	0.75	100.0[a]
4	12.1	0.21	1.03[a]	0.76	91.7[b]
5	14.8	0.22	0.88[b]	0.68	97.7[ab]

[1] Values represent means of three groups of 20 fish per group.
[2] Means with different superscripts are significantly different ($P<0.05$) as determined by Fisher's protected LSD test.

Table 8. Performance of juvenile goldfish fed diets with different lipid levels for 9 weeks. [1, 2]

Diet number	Dietary lipid (%)	Average individual initial weight (g)	Average individual weight gain (g)	Feed efficiency	Survival (%)
1	4.5	0.47	2.9[a]	0.80[a]	93.3[b]
2	7.1	0.47	2.7[a]	0.79[a]	97.3[a]
3	8.9	0.47	2.4[ab]	0.75[a]	97.3[a]
4	10.3	0.46	2.4[ab]	0.74[ab]	97.3[a]
5	13.3	0.46	1.9[b]	0.68[b]	100.0[a]

[1] Values represent means of three groups of 25 fish per group.
[2] Means with different superscripts are significantly different ($P<0.06$) as determined by Fisher's protected LSD test.

Experiment 3

Golden shiners in aquaria fed practical diets with the same amount of protein and total calories but either 4% or 13% poultry fat for 7.5 weeks had similar growth. However, survival was significantly higher in fish fed the diet with 13% lipid. The reason for the difference was unknown. Trials using similar diets in outdoor systems were conducted for comparison.

Experiment 4

Golden shiners (2 lbs/1,000 size) in ponds (0.1-acre) stocked at 700 lbs/acre were fed supplemental practical diets containing 4% or 13% poultry fat, or 13% menhaden fish oil (Table 9) to satiation twice daily for 12 weeks. Weight gain of golden shiners fed the diet with 4% poultry fat was higher than that of fish fed either diet with 13% lipid (Table 10). Sometimes a high level of non-protein energy (as from lipid) can "free up" some of the dietary protein for additional growth ("protein-sparing effect"), but the effect was not observed in this study. 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. This apparent difference in metabolism of poultry and fish oils by golden shiners needs further study.

Table 9. Composition of the basal supplemental practical diet used in pool and pond studies with juvenile golden shiners and goldfish to determine the effects of different types and amounts of practical lipids.[1]

Ingredient	(% dry diet)
Soybean meal	32.0
Cottonseed meal	17.0
Corn	15.0
Corn starch	9.0 or 0.0
Wheat midds	23.0
Lipid (poultry fat or menhaden oil)	4.0 or 13.0

[1] The supplemental diets contained 24% protein and no added vitamins or minerals. Corn starch and lipid were adjusted to produce diets with approximately equal energy levels and with 4 or 13% lipid from either poultry fat or menhaden oil.

Table 10. Performance of golden shiners in ponds fed diets differing in lipid source and amount for 12 weeks.[1]

Lipid amount (%)	Lipid source	Average individual weight gain (g)	Net yield (kg)	Feed conversion	Whole-body lipid (%)
4	Poultry fat	6.3[a]	22	5.5	11.4*
13	Poultry fat	5.3[b]	27	2.9	10.6*
13	Menhaden fish oil	5.2[b]	24	3.7	14.3**

[1] Values are means of four ponds each stocked at a rate of 925,000 fish/ha (370,000 fish/acre). Individual fish weighed 0.9 grams (2 lbs/1,000 size). Means within columns with different superscripts are significantly different at $P<0.05$. Means within columns with different numbers of asterisks are significantly different at $P<0.10$. Differences were determined by Fisher's LSD test.

Experiment 5

Goldfish (2 lbs/1,000 size) stocked at 600 fish per fertilized pool (1,086-gallon) were fed practical diets (3-6% BW) containing 4% or 13% lipid as poultry fat or menhaden fish oil for nine 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 in goldfish fed either diet with 13% lipid, compared to fish fed diets with 4% lipid (Table 11). Lipid source did not affect goldfish performance. It is likely that the improved performance of goldfish fed the high-lipid diets was due to protein sparing by the lipid. The prepared diets contained only 24% protein, but the plankton might have provided extra protein which was used for growth since energy was provided by the lipid in the prepared diet.

Table 11. Performance of goldfish in pools fed diets differing in lipid source and amount for 12 weeks.[1]

Lipid amount (%)	Lipid source	Average individual weight gain (g)	Net yield (g)	Feed Conversion	Whole-body lipid (%)
4	Poultry fat	0.67^{B}	309^{B}	3.0^{B}	6.3^{ab}
4	Menhaden fish oil	0.65^{B}	312^{B}	3.0^{B}	5.4^{b}
13	Poultry fat	0.82^{A}	378^{A}	2.5^{A}	7.5^{ac}
13	Menhaden fish oil	0.71^{AB}	338^{AB}	2.7^{AB}	7.9^{c}

[1] Values are means of four pools each stocked at a rate of 1 million fish/ha (400,000 fish/acre). Individual fish weighed 0.4 grams (about 1 lb/1,000 size). Means within columns with different lower case superscripts are significantly different at P=0.05. Means within columns with different numbers of upper case superscripts are significantly different at P<0.10. Differences were determined by Fisher's LSD test.

Source

Studies have also been conducted in aquaria to determine the specific type (n-3, n-6 or both) of essential fatty acids (EFA) required by golden shiners fed purified diets. Different types of fats provide different types and amounts of fatty acids. For instance, fish oil contains large amounts of long-chain n-3 fatty acids which originate from algae. These are required by most marine and carnivorous fish. Freshwater fish can generally make the long-chain n-3 fatty acids from shorter n-3 fatty acids found in oils like canola or soybean oil. Fish oil, algae and some fungi also contain substantial amounts of long-chain n-6 fatty acids from which biochemicals (e.g., prostaglandins) involved in inflammatory processes, immune function, reproduction and other critical functions are made. Freshwater fish can usually make the long-chain n-6 fatty acids from shorter n-6 fatty acids found in lipids like poultry fat or soybean oil. Both the n-3 and n-6 fatty acids are probably required for baitfish species.

Results of studies to determine the EFA requirements of golden shiners are summarized in Table 12. These trials have not consistently indicated a specific requirement for n-3 or n-6 fatty acids.

Table 12. Summary of studies at UAPB to determine the types of fatty acids needed by golden shiners. [1,2]

Study #/Length	Initial fish size (lb/1,000)	Lipid sources	Main results
1/9 weeks	0.5	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.
2/11.5 weeks	0.4	soybean, rice bran, canola, cod liver, poultry, olive	No differences in weight gain or survival between diets; survival of fish stressed with low dissolved oxygen was highest in fish fed soybean oil.
3/6 weeks	0.8	soybean, canola, cod liver, soy + cod liver (50/50%), olive	Weight gain of fish fed the soy + cod liver, olive and soybean diets was highest; no differences in survival; fatty acid composition of fish body was similar to that of diets.
4/34 weeks	0.5	Same as study 3	No differences in weight gain between diets; fish fed canola had intact fins, skin and gill covers – those fed olive oil had obvious erosion in these areas; fish fed other lipids were intermediate in appearance.

[1] Source: R. Lochmann and H. Phillips, 2001. Nutritional aspects of health and related components of baitfish performance. In: Lim, C. and Webster, C. (eds.) *Nutrition and Fish Health.* Food Products Press, Binghamton, New York, USA.

[2] Purified diets for all experiments contained 10% lipid, 34% protein and 10 kcal energy/g of protein from casein and gelatin. The different lipid sources were chosen because they contained a variety of fatty acids known to be essential for other fish.

Similar studies with common carp, channel catfish and tilapia also had conflicting results. One study showed that growth and survival of larval goldfish fed diets with cod liver or canola oils was equally good, indicating that a dietary source of long-chain n-3 fatty acids (such as those in fish oils) is not required. However, that study did not consider n-6 fatty acids. Prostaglandins derived from n-6 fatty acids stimulate steroid (sex hormone) production in goldfish, and courtship behavior in fathead minnows. Baitfish probably get substantial amounts of EFAs from natural foods in ponds under most production conditions. However, 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.

Of the fat sources readily available in Arkansas, poultry fat is a good source of n-6 fatty acids but contains very few n-3 fatty acids. Soybean oil and soybean lecithin (a mixture of phospholipids) contain 7-8% of the n-3 fatty acids and are also high in n-6 fatty acids. Soybean lipids (oil and/or lecithin) alone or blended with poultry fat should satisfy the EFA requirements of baitfish for growth.

Phospholipids are important structural components of cell membranes. The EFAs from the diet are incorporated into the phospholipids where they help regulate the nutrients and wastes that enter and leave the cell. Adult fish can make their own phospholipids, but larval or juvenile fish may benefit from having a dietary source.

Commercial mixtures of phospholipids are called lecithins. Soybeans are a primary commercial source of feed-grade lecithins. Practical baitfish diets supplemented with soybean lecithin enhanced growth but did not affect survival of juvenile goldfish relative to diets containing lipid as triglyceride (storage lipid) from either soybean or fish oils (Table 13). Other studies showed that phospholipid supplementation of diets improved both growth and survival of larval goldfish and carp. Phospholipids may improve lipid digestion, absorption and transport in baitfish, as in other fish.

Table 13. Performance of juvenile goldfish fed practical diets supplemented with soy lecithin (LEC), soybean oil (SBO) and/or cod liver oil (CLO) for 6 weeks.[1]

Dietary lipid supplement (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Survival (%)	Whole-body lipid (%)
CLO (4%)	12.0	19.9[c]	0.45[b]	98.3	19.5
CLO (2%) + LEC (2%)	11.9	23.1[ab]	0.51[a]	100.0	22.0
SBO (4%)	11.9	22.1[bc]	0.50[ab]	98.3	23.1
SBO (2%) + LEC (2%)	11.9	23.1[ab]	0.51[a]	100.0	24.8
LEC (4%)	11.9	25.2[a]	0.55[a]	100.0	21.2

[1] Values are means of three groups of 40 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's LSD test.
[2] Feed efficiency = final group weight + weight of mortalities - initial group weight in grams.

Carbohydrates

Unlike proteins and lipids, carbohydrates do not contain specific factors known to be essential for fish; however, they are valuable as inexpensive energy sources in the diet. The types of carbohydrates that are readily available to monogastric (simple-stomached) animals such as fish are sugars and starches. Starches are the main source of available carbohydrates from practical feedstuffs.

Amount

To an extent, calories from different sources such as lipids and carbohydrates are used equally well as energy sources by fish. In other words, carbohydrate can be substituted for lipid and vice versa, up to a point. The optimal dietary carbohydrate:lipid ratio for different species is established in feeding trials using diets with different amounts of carbohydrate and lipid. Weight gain and survival of golden shiners fed laboratory (semi-purified) diets differing in starch content (15%, 30% or 45%) and lipid (15%, 8.3% or 1.7%) was similar, indicating that they perform well over a wide range of dietary carbohydrate:lipid ratios (1:1 to 27:1) (Table 14). The incorporation of different amounts of lipid and starch into the fish tissues (whole body) was evident when the stable carbon isotope ratios of fish and dietary lipids and starches were compared.

Table 14. Performance of juvenile golden shiners fed diets[1] with different lipid and starch content for 8 weeks.[2]

Dietary starch source (amount)	Dietary lipid[3] (%)	Average individual weight gain (g)	Feed efficiency	Survival (%)
Corn (15%)	15.0	0.89	0.70	97.0
Corn (30%)	8.3	0.84	0.68	99.0
Corn (45%)	1.7	0.89	0.70	98.0
Rice (15%)	15.0	0.94	0.73	99.0
Rice (30%)	8.3	0.84	0.66	98.0
Rice (45%)	1.7	0.88	0.70	98.0

[1] Diets were formulated to contain equal amounts of protein and total energy.
[2] Values represent means of three groups of 30 fish per group. Initial average individual weight of fish was 0.2 grams. Means were not significantly different (P>0.05).
[3] The lipid source for all diets was a 50/50% mixture of menhaden fish oil and soybean oil.

Source

In another experiment, weight gain of golden shiners fed diets with 15% carbohydrate from different sources improved with increasing complexity of the carbohydrate: starch>dextrin>sucrose=glucose (Table 15). Results are similar to those for other warmwater omnivorous fish. As stated previously, starches are the main source of available carbohydrate in fish feedstuffs. However, the availability of carbohydrate energy from practical feedstuffs is likely to be different from that of purified ingredients (e.g., corn starch), and this needs to be addressed in baitfish.

Table 15. Performance of juvenile golden shiners fed diets with 15% soluble carbohydrate from different sources for 8 weeks.[1,2]

Dietary carbohydrate source	Average individual initial weight (g)	Average individual weight gain (g)	Survival (%)
Dextrin	0.33	0.84[b]	98.9[a]
Corn starch	0.33	0.97[a]	96.7[ab]
Glucose	0.33	0.64[c]	98.9[a]
Sucrose	0.34	0.61[c]	93.3[b]

[1] Values represent means of three groups of 30 fish per group.

[2] Means with different superscripts are significantly different ($P<0.05$) as determined by Fisher's protected LSD test.

VITAMINS AND MINERALS

Vitamins are organic compounds required in small amounts for normal growth, health and function. They are classified as fat soluble (A,D,E,K) or water soluble (B vitamins, C, etc.). Requirements vary with fish species, age, size and physiological state (e.g., stress, reproductive status).

Fish fry reportedly can absorb some vitamins directly from the water, but natural foods rich in vitamins are also heavily consumed by baitfish fry. Obvious vitamin deficiencies are not common in pond-raised baitfish of any size, probably due to the continued importance of natural foods throughout the production cycle. However, the amounts and types of natural foods and their vitamin content vary seasonally and over time. Also, the amount of natural food per fish is lower at high fish densities (intensive stocking densities). In addition, commercial baitfish diets contain mostly plant feedstuffs since they are cheaper than animal feedstuffs, but animal feedstuffs are better sources of fat-soluble vitamins. These are valid reasons to supplement commercial baitfish diets with the same types and amounts of vitamins and minerals used in diets for channel catfish.

Recently, however, studies with channel catfish have shown that supplemental vitamins can be reduced or eliminated from commercial feeds without reducing fish yield or quality. Therefore, more research is needed to determine suitable levels of supplemental vitamins for commercial baitfish feeds.

Experiment 1

Weight gain and total net yield of golden shiners in ponds fed diets with or without a combination vitamin and mineral supplement (Table 16) for 8 weeks did not differ (Table 17). Presumably, natural-food consumption supplied sufficient vitamins and minerals to maintain overall fish production. However, diet affected the yield of fish in one size class – there were significantly more fish measuring 23/64 to 27/64 inches in width (grader size 23-27) from the ponds receiving diet 2 (with the supplement) than in those that received the unsupplemented diet. Some vitamins (C, E, A) also affect the immune system, and specific indices of health were not measured in this study. Performance of baitfish after harvest (during transport and marketing procedures) also could be affected by dietary vitamin intake during pond production, and this has not been studied.

Table 16. Composition of the basal diet and vitamin/mineral supplement used in a pond study with golden shiners to determine whether supplemental vitamins and minerals are required for good production.[1]

Diet ingredients	(%)
Soybean meal	41.0
Cottonseed meal	10.0
Menhaden fish meal	5.0
Yellow corn	15.0
Wheat (hard red)	15.0
Wheat midds	14.0 or 10.6
Vitamin C (Stay-C)[2]	0.0 or 0.05
Vitamin/mineral premix	0.0 or 3.0
Vitamin/mineral premix ingredients	**Amount**
Copper	0.68 g/lb
Iron	5.44 g/lb
Manganese	16.33 g/lb
Zinc	15.65 g/lb
Cobalt	0.14 g/lb
Iodine	0.34 g/lb
Choline	40.68 g/lb
Folic acid	200.00 mg/lb
Niacin	8.00 g/lb
Pantothenic acid	3.20 g/lb
Riboflavin	1.20 g/lb
Thiamin	1.00 g/lb
Vitamin B_{12}	800.00 ug/lb
Vitamin E	5.00 KIU/lb
Vitamin K	227.50 mg/lb
Vitamin A	0.40 MIU/lb
Vitamin D_3	0.20 MIU/lb

[1] Diets were extruded as 3/32-inch floating pellets containing 32% protein.
[2] Stay-C is a stabilized form of vitamin C produced by Roche Vitamins, Ltd.

Table 17. Performance of golden shiners in ponds fed diets with or without a vitamin/mineral supplement for 8 weeks.[1]

Diet[2]	Average group weight gain (lbs)	Net yield (lbs/acre)	Feed conversion	Survival (%)
Unsupplemented	93.0	789.6	1.9	81.6
Supplemented	104.4	790.4	1.8	68.7

[1] Values are means of four ponds each stocked at a rate of 300 lbs/acre. Individual fish weighed 0.6 grams (1.33 lbs/1,000) initially. There were no significant differences between treatments ($P>0.05$).

[2] The unsupplemented diet contained no added vitamins or minerals. The supplemented diet contained 3% of a vitamin/mineral premix and 0.05% of stabilized vitamin C.

Experiment 2

Cultured baitfish presumably need a source of vitamin C in the diet. An aquarium study was done to address this issue in golden shiners (about 1 lb/1,000 size). Diets with casein (milk protein) or fish meal and either 0 ppm or 250 ppm of vitamin C (Stay-C, Roche Vitamins, Inc.) were fed to golden shiners for 12.5 weeks.

Weight gain was higher, but the survival of golden shiners was not affected by vitamin C in the fish meal diets (Table 18). Conversely, weight gain was not affected, but survival was improved by vitamin C in the casein diets (Table 18). Fish fed the casein diet were also infected with *Columnaris* during part of the study. This unplanned challenge to their immune system might explain the difference in results between the fish fed the fish meal and casein diets, since vitamin C is known to stimulate the immune system. Golden shiners appear to have a dietary requirement for vitamin C, but the requirement is influenced by diet composition and health status.

Table 18. Weight gain, feed efficiency and instantaneous mortality of golden shiner fed casein- or fish meal-based diets containing 0 or 250 mg of ascorbic acid (AA)/kg diet for 12 weeks. [1,2]

Diet type (AA level)	Weight gain[3] (g)	Feed efficiency	Instantaneous mortality T=1	Instantaneous mortality T=2
Casein-no AA	2.97	0.58	0.31	0.71**
Casein-250 AA	2.84	0.61	0.12	0.09*
Fish meal-no AA	2.47[a]	0.64	0.10	0.00
Fish meal-250 AA	3.06[b]	0.67	0.12	0.04

[1] Values for weight gain, feed efficiency and instantaneous mortality (T=1) are means of three replicates (tanks). Each tank contained a group of 30 fish initially. The number of individuals per replicate used to calculate instantaneous mortality (T=2) varied due to differential mortality during T=1.

[2] Treatment means were compared using an unpaired t-test. Means within columns followed by different letters or numbers of asterisks were significantly different at $P<0.05$ and $P<0.06$, respectively.

[3] Mean individual initial weight of the golden shiners was 0.44 g.

Additional experiments are underway at UAPB to define the vitamin C requirement of golden shiners further. Specific signs of vitamin C deficiency such as spinal deformities, hemorrhaging and bulgy eyes have been induced in fish fed diets with no added vitamin C. Another study with golden shiners is in progress to determine the interaction between dietary vitamins C and E.

Some vitamin deficiency signs have been described for goldfish, but quantitative dietary vitamin requirements are still lacking. Goldfish fed purified diets without vitamin A displayed abnormal bleeding, bulgy eyes, scale loss and loss of appetite. Nutritional myopathy (muscle abnormality) attributed to dietary vitamin E deficiency was reported for goldfish fed practical diets with < 26 IU of vitamin E.

Minerals are inorganic substances required in small amounts for normal growth, health and function. They are classified as macro- or trace minerals. Fish can obtain large quantities of some minerals (e.g., calcium) directly from the water, and a dietary source is usually unnecessary. In addition, many practical feedstuffs are rich in minerals, which reduces the need for synthetic dietary supplements. However, many plant feedstuffs contain minerals in unavailable forms. For example, soybean meal and other plant feedstuffs contain 60-70% of their phosphorus as phytate, which cannot be digested by fish. Phosphorus metabolism is closely tied to that of calcium, but phosphorus is not readily absorbed from the water. Therefore, phosphorus supplementation of baitfish diets is important for several reasons. First, commercial feeds for baitfish contain mostly plant feedstuffs. Secondly, cyprinid fishes (including golden shiners, goldfish and fathead minnows) do not have true stomachs that secrete acid to enhance digestion. Mineral availability from common feedstuffs is known to be lower for some fishes that lack acidic digestion. The dietary phosphorus requirements of the main baitfish species are unknown. However, the requirement for common carp (another cyprinid) is 0.6-0.7% of the diet. These requirements are established using highly available forms of phosphorus (e.g., sodium phosphate monobasic). The phosphorus that is unavailable from plant feedstuffs in baitfish diets will be excreted into the pond where it may stimulate undesirably heavy plankton blooms. Therefore, it is important to minimize the amount of unavailable phosphorus in the diet as it reduces both fish production and water quality.

Basic studies to determine both vitamin and mineral requirements of baitfish for growth, survival, optimal health and reproduction are needed. Applied studies in outdoor systems are necessary also, due to the reliance of baitfish on natural foods. However, production and composition of natural foods varies between production units (e.g., ponds) and over time, and it is likely that vitamin and mineral supplementation of commercial baitfish feeds will continue.

FEEDING PRACTICES

Practical Diets

Most semi-intensive and intensive producers use nutritionally complete feeds to double or triple production of baitfish. The composition of diets for different stages of the baitfish production cycle is similar to that for channel catfish. Soybean meal (48% protein, solvent-extracted) is the primary protein source in commercial baitfish feeds, and very little (2-5%) fish meal is used in feeds 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. The oil in marine fish meal is also more prone to oxidation than other fats. Fresh poultry fat (as indicated by low peroxide and TBARS values) is frequently added to baitfish feeds in Arkansas due to the proximity of the baitfish and poultry industries. Poultry fat appears to be palatable and has no known anti-nutritional properties for baitfish. However, baitfish may benefit from a mixture of fats (such as poultry fat and soybean oil), which provides a greater variety of essential fatty acids than any single fat source. Recently, high-fat (13%) diets with lower protein levels (24%) have generated some interest among baitfish producers. The cost of increased dietary lipid may be offset by the reduction in cost due to the lower protein content, depending on current market prices for different feedstuffs. Until the nutrient requirements of baitfish are defined further, a nutritionally complete commercial catfish feed formulation with 28% protein and 5% added fat (as soybean oil and/or poultry fat) should support weight gain and fish health during growout under most production conditions.

Fish Color

For feeder fish, an economical means of enhancing skin color is needed. The primary pigment responsible for the desirable reddish-gold color of goldfish is astaxanthin. This carotenoid pigment cannot be synthesized by the fish and must be provided in the diet. Astaxanthin is found naturally in algae. However, when plankton blooms are poor, supplementation of prepared feeds with carotenoids may prevent color loss or enhance color development of goldfish and rosy reds in ponds. Commercial feeds used for baitfish in Arkansas are very low in total carotenoids (<7 ppm). Synthetic carotenoids are currently expensive, but there are many natural sources that have not been investigated in baitfish diets. In some fish species, these pigments enhance not only color but survival, reproduction and immune function. Preliminary research is underway at UAPB to establish the effects of supplementing practical diets for goldfish with different carotenoids.

Feeding Fry

Commercial minnow meal containing 48-50% protein is applied to ponds containing newly hatched fry. The fry consume the meal, but newly hatched fry of some cyprinids do not utilize prepared feeds well; therefore, the meal may serve more as a fertilizer than a feed. An adequate plankton bloom is probably more critical than prepared feed in meeting the nutrient requirements of baitfish fry in ponds. Some producers are now hatching baitfish eggs indoors in tanks before releasing fry into ponds. The procedures used are modified from those established in France for goldfish larvae, except that live feeds are not emphasized. Feeding regimes for hatchery-produced baitfish fry are still experimental, but diets may consist of finely ground meals, microparticulate diets and other foods (e.g., yeast, egg yolk) with a small particle size (100-250 microns). Regardless of diet, fry maintained indoors for more than a week generally have poor survival. More research is needed on nutrition and feeding regimes for fry maintained indoors. Adequate nutrition will be essential for production and maintenance of high-quality fry characterized by superior growth, survival and stress resistance.

Broodstock Nutrition

Baitfish broodstock receive the same diet as fish during growout or one higher in protein (36%). The number, size and quality of eggs and fry of other fish species (including carp) are known to be affected by the nutrient status of the mother. Some of the nutrients known to be important for successful reproduction in other fish species are essential amino acids, essential fatty acids (20- and 22-carbon fatty acids of the n-3 and n-6 families), vitamins (C and E) and carotenoids. Broodstock nutrition has not been studied in baitfish, but studies will be initiated soon at UAPB.

Winter Feeding

Feeding strategies for baitfish change seasonally. Survival improves and condition of golden shiners during winter is maintained by feeding at a rate of 1-2% BW at afternoon air temperatures of $\geq$45°F (7°C). Increased numbers of fathead minnows in good condition in ponds can be achieved with a feeding rate of 3% BW per day (using a 32% protein feed) from late summer to winter. In summer, many producers reduce feeding rates when water temperatures exceed 86°F (30°C).

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