Percids

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Introduction

Fishes of the family Percidae are found in temperate climates throughout the northern hemisphere. There are over 160 species in North America, but only three are of commercial or aquacultural interest. The yellow perch (*Perca flavescens*), sauger (*Stizostedion canadense*) and walleye (*Stizostedion vitreum vitreum*) are important foodfish in much of North America (Lindsay, 1980; Engle *et al.*, 1990; Cox and Karahadian, 1998). The blue pike (*Stizostedion vitreum glaucum*) once inhabited Lake Erie and contributed to the commercial harvest. However, this subspecies is thought to be extinct. There are two ecological equivalents in Europe, the Eurasian perch (*Perca fluviatilis*) and the pike-perch or zander (*Stizostedion leucioperca*), which are also commercially important and considered highly prized foodfish. The two perches, walleye and pike-perch are receiving significant interest as aquaculture species, as well as various hybrids (Lynch *et al.*, 1982; Held and Malison, 1996).

Current aquacultural production levels are not known, but are generally thought to be less than 5 million pounds (2.3 million kg) annually for each of the respective species. This production does not include propagation and rearing in public hatcheries where fish are destined for stocking in public bodies of water.

This chapter will focus on those species for which nutritional research has been conducted; yellow perch, walleye and Eurasian perch. Nutritional requirements for the pike-perch are unknown.

Nutrient Requirements

There are few published nutritional requirements for any of the percids. The quantitative requirements and recommended macronutrient concentrations that exist are presented in Table 16.1. For yellow perch, requirements for crude

Table 16.1. Quantitative nutritional requirements, initial weight of fish used, type of diet fed and references for percids. Values expressed as a function of dry matter in the diet.

Species	Nutrient	Requirement	Initial weight (g)	Type of diet	Reference
Yellow perch	Crude protein	21–27%	18–27	Semipurified	Ramseyer and Garling (1998)
	Protein : energy	20–22*	18–27	Semipurified	Ramseyer and Garling (1998)
	Lipid	6–8%	25	Purified	Cartwright *et al.* (1998)
	Lysine	1.1–1.3%	17	Purified	Twibell *et al.* (1998)
	Methionine†	1.0%	4	Purified	Twibell *et al.* (2000)
	Methionine‡	0.85%	8	Purified	Twibell *et al.* (2000)
	Arginine	1.4%	11	Purified	Twibell and Brown (1997)
	Choline	600 mg kg^{-1}	16	Purified	Twibell and Brown (2000)
Walleye	Crude protein	51%	8	Practical	Barrows *et al.* (1988)
	Protein : energy	144, 51/3530§	8	Practical	Barrows *et al.* (1988)
	Crude protein	42%	50	Practical	Barrows *et al.* (1988)
	Protein : energy	116, 42/3600§	50	Practical	Barrows *et al.* (1988)
	Crude protein	53%	127	Practical	Tidwell *et al.* (1999)
Eurasian perch	Crude protein	40–49%	3	Semipurified	Fiogbe *et al.* (1996)
	Lipid	12%	22	Practical	P. Kestemont, unpublished
	Lipid	15%	34	Practical	Xu *et al.* (2000)

* Expressed as g crude protein MJ^{-1} metabolizable energy.
† In the presence of 0.03% cyst(e)ine.
‡ Methionine requirement determined in diets containing 51 : 49 cyst(e)ine : methionine.
§ Expressed as mg crude protein $kcal^{-1}$ gross energy.

protein, protein : energy ratio, lipid, lysine, methionine, arginine and choline are available. Optimal dietary crude protein was reported to be in the range of 21–27% of the diet, although the highest weight gain was observed in fish fed 34% crude protein (Ramseyer and Garling, 1998). The optimum crude protein-to-metabolizable energy ratio was reported to be 20–22 g crude protein MJ^{-1} (Ramseyer and Garling, 1998). Metabolizable energy values from rainbow trout were used for calculation of the energy component as there are no values for perch. Ramseyer and Garling (1994) formulated diets to mimic the essential amino acid pattern of whole, juvenile yellow perch, and this is considered one of the better essential amino acid profiles for fish (Wilson and Poe, 1985). Determination of the minimum dietary crude-protein concentration for fish using the whole-body pattern of essential amino acids is a new approach and offers promise of more precise formulations and a rapid method of developing diets for new aquaculture species (Brown, 1995). Earlier, Calbert and Huh (1976) fed juvenile yellow perch dietary crude-protein levels of 27, 40 or 50% and reported no significant differences in weight gain. Some of the essential amino acid requirements of yellow perch were recently determined using diets containing 33–34% dietary crude protein.

The lysine requirement of yellow perch is one of the lower requirements reported for fish, whereas the requirements for methionine and arginine are more similar to those for other species (NRC, 1993). Twibell *et al.* (1998) reported that the dietary lysine requirement of juvenile yellow perch was 1.1–1.3% of the diet. A series of studies were conducted to determine the methionine requirement of yellow perch (Twibell *et al.*, 2000). In the first study, diets contained 0.03% cyst(e)ine, and the methionine requirement was 1.0–1.1% of the diet. In the second study, supplemental cyst(e)ine was added to the diet and a sparing effect on the methionine requirement was observed; 51% of the methionine requirement was spared by the addition of cyst(e)ine. A ratio of 51 : 49 cysteine (Cys) : methionine (Met) was used in the third study and the total sulphur amino acid requirement was 0.85% of the diet. The dietary arginine requirement for juvenile yellow perch was reported as 1.4% of the diet (Twibell and Brown, 1997).

Twibell and Brown (2000) conducted a study to determine the choline requirement of yellow perch using a ratio of 51 : 49 Cys : Met and total sulphur amino acid concentration of 0.85%. The conversion of sulphur amino acids to choline was thus limited (Kasper *et al.*, 2000). In the same study, phosphatidylcholine (PC) was evaluated as a choline supply. The choline requirement was approximately 600 mg kg^{-1} diet and dietary PC could meet the choline requirement. This study demonstrated that perch are capable of using PC as a source of choline, but, when the choline requirement was met by choline-chloride (Cl), there was no beneficial effect of dietary PC at the dietary concentrations used.

Cartwright *et al.* (1998) fed four lipid sources (menhaden, cold-pressed soybean, coconut and tallow) alone or in combination and reported that juvenile yellow perch gained significantly more weight when fed either menhaden fish-oil or cold-pressed soybean oil at 6% of the diet. Within each lipid source, weight gain significantly decreased as dietary lipid concentration increased to 12 and 18% of the diet. Additionally, there were no significant differences in weight gain of fish fed a 1 : 1 mixture of menhaden fish-oil and cold-pressed soybean oil at any of the dietary concentrations tested (6, 12 or 18%). Feeding rates recommended from these studies with yellow perch were 3–4% of body weight per day for juvenile fish.

While the essential fatty acid requirement of yellow perch has not been quantified, Dabrowski *et al.* (1993) identified docosahexaenoic acid (DHA) (22:6n-3) as the predominant fatty acid in phospholipids of yellow perch and reported a decrease as eggs hatched and fry grew. Further, both DHA and eicosapentaenoic acid (EPA) (20:5n-3) were higher in juvenile yellow perch than in their major food item, which was *Daphnia*. Thus, the long-chain n-3 fatty acids may be important in larval diets for yellow perch. Thongard *et al.* (1995) reported that juvenile yellow perch fed diets deficient in linolenic acid exhibited decreases in DHA in polar lipids. This finding supports the earlier findings that DHA in eggs and fry is important and that linolenic acid would be a logical area of study as the essential fatty acid in perch.

Low dietary ascorbic acid (vitamin C) intake of yellow perch resulted in decreased hepatic concentrations of this vitamin in 6 weeks, but overt signs of deficiency did not develop until 8 months (Dabrowski and Ciereszko, 1996). Thus, ascorbic acid is required in diets of yellow perch, but no quantitative requirement was identified. Spinal deformities have been relatively common in yellow perch reared in tank-culture situations from larvae and may indicate insufficient vitamin C in the selected prey items or starter diets.

Optimal dietary crude protein concentrations for juvenile walleye appear to decrease as the fish grow from 8 to 50 g. The optimal crude-protein level for fish with an initial weight of 8 g was 51%, while that for fish with an initial weight of 50 g was 42% (Barrows *et al.*, 1988). Similarly, the optimal dietary crude protein-to-energy ratio decreased from 144 mg $kcal^{-1}$ to 116 mg $kcal^{-1}$ as initial fish size increased from 8 to 50 g. Energy concentrations considered optimal in these studies were 14.7 and 15.1 MJ metabolizable energy, respectively. Metabolizable energy values were from feedstuffs fed to rainbow trout, as none have been determined for walleye.

Tidwell *et al.* (1999) compared the growth of walleye fingerlings reared in ponds and fed diets differing in crude-protein concentration. Fish with an average initial weight of 127 g were fed practical fish-meal-based diets with either 44% or 53% crude protein. Walleye fed the higher crude-protein concentration gained more weight (177 g per fish) than fish fed the lower concentration (129 g per fish). However, there was no statistical difference in total harvest weight (1910 and 1691 kg ha^{-1}, respectively). This study indicated an advantage of feeding higher-protein feeds for the grow-out phase of walleye production in ponds relative to the protein level found in commercial salmonid feeds.

The effect of the dietary ascorbic acid level on the performance of walleye fingerlings was evaluated by MacConnell and Barrows (1993). A dietary level of 100 or 200 mg kg^{-1} supported near-maximum growth of walleye with an initial weight of 3 g. This level of dietary ascorbic acid is similar to that targeted in practical diets for rainbow trout. Fish fed an unsupplemented purified diet gained significantly less weight and exhibited deficiency symptoms not previously reported for trout or catfish. In production situations, walleye were commonly observed with a broken isthmus, which resulted in death of the fish. This typically occurred during times of stress, such as elevated temperature, crowding or feeding outdated feeds. This study documented that low vitamin C intake resulted in a breaking of the cartilage that attaches the isthmus to the lower jaw. Other deficiency symptoms, such as twisting of the cartilage in the gill filaments, are also observed in trout and catfish. Spinal deformities and abnormalities are more common in trout and catfish, and breakage of the isthmus is the first macrosymptom observed in walleye.

The optimal dietary crude-protein requirement for juvenile Eurasian perch has been quantified. Fiogbe *et al.* (1996) estimated the requirement as 36–56% of the diet, depending on the mathematical model chosen, and recommended 40–49% in practical diets. Kestemont *et al.* (2001) (Universitaires Notre Dame de la Paix, Namur, Belgium) observed significantly better weight gain in juvenile Eurasian perch fed 12 or 18% dietary lipid as menhaden oil with ethoxyquin, compared with fish fed 6% menhaden oil or fish fed 12 or 18% lipid without ethoxyquin. In a subsequent study, juvenile perch gained significantly more weight when fed practical diets containing 19% dietary lipid compared with fish fed 12% (Xu *et al.*, 2000). Weight gain of fish fed 15% dietary lipid was not significantly different from fish fed either 12 or 19%. There are no other dietary requirement estimates for the Eurasian perch.

Diet Development

Our ability to continue quantifying nutritional requirements for percids has been enhanced in recent years by the identification of experimental diets that are accepted by percids and support rapid growth. In a series of studies, Brown *et al.* (1996) offered four different experimental formulations to juvenile yellow perch and compared the weight gain and feed efficiency of fish fed various commercial diets (Table 16.2). The weight gain of fish fed a purified diet containing approximately 10% intact protein in the form of vitamin-free casein and gelatin (9 : 1), with the remainder of the amino acids supplied in crystalline form, was not significantly different from that of fish fed the best practical diet. The weight gain of fish fed a diet containing vitamin-free casein with supplemental L-arginine-hydrochloric acid (HCl), dextrin and fish oil was 79% of the weight gain observed in fish fed the best commercial diet. In the same study, fish were offered two other experimental diets: one containing only vitamin-free casein as

Table 16.2. Mean weight gain and feed conversion ratio (FCR) of juvenile yellow perch (initial weight 5 g) fed a variety of experimental and commercial diets for 10 weeks. Values are means of three replications. Means within the same column and with the same letter designation were not significantly different.

	Weight gain*	FCR†
Experimental diets: predominant source of crude protein		
Casein/arginine	167.7b	3.1b
Crystalline amino acids	215.0a	1.8a
Commercial diets‡		
Catfish (36/6)	127.8c	2.9c
Trout (36/8)	174.7a,b	2.3a
Trout (45/15)	212.1a	2.3a

* Expressed as a percentage of initial body weight.
† Calculated as g dry weight of feed fed g^{-1} wet weight gain of fish.
‡ Values in parentheses are the guaranteed concentrations (%) of crude protein/fat supplied by the feed manufacturers, respectively.

the source of amino acids and one containing vitamin-free casein and gelatin. Fish fed both diets exhibited poor feed acceptance and these dietary treatments were terminated prior to completion of the study. This study was repeated with larger yellow perch with an average initial weight of 51 g.

The larger perch accepted all four experimental diets. The weight gain of perch fed the vitamin-free casein and L-arginine-HCl was significantly greater than that of fish fed the other diets, but not significantly different from that of fish fed the best practical diet (Table 16.3). The weight gain of fish fed the diet containing crystalline amino acids as the primary source of amino acids was not significantly different from that of fish fed vitamin-free casein or the vitamin-free casein and gelatin combination. The weight gain of perch fed the crystalline amino acid diet was 84% of the weight gain observed in fish fed the best practical diet, while weight gains of perch fed the other two experimental diets were 74–76% of that observed in fish fed the best practical diet. These results indicated that several experimental formulations are accepted by yellow perch and can be used in future nutritional research. Additionally, there appear to be ontogenic differences in acceptance of experimental diets and weight gains of fish.

These same experimental diets were also fed to juvenile walleye with an initial weight of 13 g (Bharadwaj *et al.*, 2000). The weight gain of fish fed a salmon grower diet was numerically higher than that of fish fed a trout grower diet, but the values were not significantly different. Similarly, the weight gain of

Table 16.3. Mean weight gain and feed conversion ratio (FCR) of yellow perch (average initial weight 51 g) fed a variety of experimental and commercial diets for 10 weeks. Values are the means of three replications. Means with the same letter designation were not significantly different.

	Weight gain*	FCR†
Experimental diets: predominant source of protein		
Casein	47.5b,c	5.0b,c
Casein/gelatin	48.1b,c	5.1c
Casein/arginine	64.6a	4.0a
Crystalline amino acids	53.1b	4.7b
Commercial diets‡		
Trout (33/8)	43.3c	5.9c
Trout (38/12)	38.7c,d	6.5c,d
Trout (40/10)	63.4a	4.4a
Trout (50/17.5)	46.3b,c	5.7b,c
Catfish (36/4)	46.0b,c	5.7b,c
Catfish (32/3.5)	10.2e	25.8e

* Expressed as a percentage of initial body weight.

† Calculated as g dry weight of feed fed g^{-1} wet weight gain of fish.

‡ Values in parentheses are the guaranteed concentrations (%) of crude protein/fat supplied by the feed manufacturers, respectively.

fish fed the diet containing a predominance of crystalline amino acids was not significantly different from that of fish fed the best commercial diets. However, the weight gain of walleye fed the other three experimental diets was significantly lower than that of fish fed the best diets: 13–20% of the weight gain observed in fish fed the best commercial diets.

Using the data developed with yellow perch, experimental diets for the Eurasian perch were formulated using casein and L-arginine-HCl as the basal supply of essential amino acids. These diets were not accepted well by the Eurasian perch (Kestemont *et al.*, 1997). Since that time, basal diets have included cod-muscle meal as a primary source of essential amino acids and as a flavour additive.

While several experimental diets have been identified for further nutritional research with percids, it seems clear that there are differences in the acceptance and utilization of the various formulations by members of the same family of fishes.

Larval Diets

All percids are comparatively small when they first hatch (~4–7 mm total length) and feeding small larval fish remains difficult. While several new dry larval diets have been developed in recent years, acceptance of these diets, resulting weight gain and survival remain highly variable and often comparatively low (NCRAC, 1994, 1996). Recently, in both laboratory and production-scale studies, survival rates of larval walleye fed only formulated diets have been comparable to rearing in fertilized ponds and switching to formulated diets (Barrows *et al.*, 1993; Moore *et al.*, 1994; Moore and Olson, 1998, 1999). Additionally, developments in larval-diet manufacturing methods offer promise for percids and a variety of small-egged species (Barrows and Hardy, 2000). A summary of the known studies on feeding larval percids was recently presented by Kestemont and Melard (2000) and will not be repeated here.

At present, the most common method of mass propagating larval percids in commercial aquaculture is in fertilized outdoor ponds. In these situations, larval percids feed on the available zooplankton. Rotifers and copepods are important nutritional sources at this stage, although mouth-gape measurements indicate that perch larvae can consume prey or food particles as large as 190 µm (Schael *et al.*, 1991). Thus, several taxonomic groups of zooplankton are potential prey items, including some strains of *Artemia* exhibiting smaller size of nauplii. After approximately 30–45 days, percids are of sufficient size and developmental stage to be trained to accept formulated diets. This transition can be accomplished in ponds or tanks by simply offering feed on a regular basis, often with an automatic feeder. Malison *et al.* (1994) took advantage of the photopositive nature of larval yellow perch and developed an automatic feeder that floats in ponds with attached lights. At night, the perch are attracted to the light and then learn to accept the diet offered at the site.

Production Diets

Practical diets fed to percids are usually formulated to meet the requirements for salmonids (Brown *et al.*, 1996; Melard *et al.*, 1996) or sea bass (Fontaine *et al.*, 1997), since nutrient requirement information for percids is limited and percids are, to varying degrees, piscivorous. Initial diets for percids in North America have been the soft-moist diets containing approximately 20% moisture and mostly fish products as ingredients (Brown *et al.*, 1996). Once perch and walleye accept formulated diets, the dry salmonid diets can be offered and variations of those formulations are most often used as grow-out diets.

Brown *et al.* (1996) conducted two studies evaluating various practical diets formulated for other species but fed to North American percids. Yellow perch with an initial weight of 5 g and fed a practical diet formulated for rainbow trout gained more weight than fish fed a similar diet formulated for channel catfish (Table 16.2). Both diets contained 36% crude protein. However, the trout diet contained 8% lipid and the catfish diet contained 6% lipid and a higher level of plant proteins. Feeding higher crude-protein (45%) and lipid (15%) concentrations in a feed formulated for trout did not result in higher weight gains. However, higher dietary crude-protein and lipid concentrations were effective with larger perch.

Perch with an initial weight of 51 g gained more weight when fed a commercial trout diet containing 40% crude protein and 10% lipid (40/10) than fish fed diets with 33/8, 38/12 or 50/17.5 (Table 16.3). The weight gain of the larger perch was generally better when fed diets formulated around the nutritional requirements for trout than those for catfish.

In a recent study conducted by Bharadwaj *et al.* (2000), walleye fed diets formulated for trout and salmon had greater weight gains than fish fed a practical trout grower diet that lacked fish-meal. Juvenile walleye in that study also gained more weight when fed the salmonid diets compared with fish fed a modification of a diet for walleye, WG-9206 (Barrows and Lellis, 1996). However, the WG-9206 diet was modified and contained a nutritionally complete mineral premix instead of the supplemental mineral premix used in the original formulation.

There are apparently no evaluations of practical diets fed to Eurasian perch or pike-perch. However, it seems clear that diets formulated around the nutritional requirements of trout or salmon will be better choices for practical diet selection in the short term than diets formulated for catfish. The nutrient-dense diets developed for salmonids in Europe have not been evaluated with percids. While salmonid or sea-bass diets seem adequate at this point, diets for percids may be quite different once the nutritional requirements for the target species have been quantified for the various life-history stages.

Feeding Practices

Current culture systems for percids include earthen ponds, raceways, cages and tank systems. However, all systems are relatively small in size when compared with earthen ponds used for catfish production in the southern USA or raceway systems for trout in the western USA. This is probably a reflection of the fact that percid aquaculture is in the early stages of development. With smaller culture systems, hand-feeding remains the most common method of dispensing diets to most percids. Most walleye diets are dispensed by way of automatic feeders, as walleye tend to be skittish or nervous. Additionally, the percids are generally slow feeders, particularly the yellow perch. Thus, feeding by hand tends to be more efficient. As mentioned earlier, special feeding practices are employed when feeding the early life-history stages.

Automatic feeders are virtually mandatory when feeding larval and early juvenile stages of percids. Not only are percids small at hatching, but also their digestive tract is not completely developed, necessitating continual dietary inputs. Recommendations for feeding larval walleye include the use of automatic feeders that deliver feed almost continuously throughout the entire day (24 h) (Barrows *et al.*, 1993; Moore *et al.*, 1994). As the fish grow, the feeding frequency decreases into the range of every hour throughout the entire day to eight to ten times during normal working times. Circular tanks with a strong water flow are considered necessary to prevent water fouling and to facilitate cleaning when high feeding rates and continuous feeding are employed.

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