

Chapter 22

Feeding and Nutrition of Percid Fishes During Ongrowing Stages

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Abstract In the context of inland aquaculture diversification in Europe, some percid fishes, namely Eurasian perch and pikeperch, are receiving increasing attention from scientists and fish farmers. Significant improvement in the knowledge of percid fish feeding and nutrition during their ongrowing stage has been achieved during these last two decades. The relative importance of different abiotic and biotic factors on feeding activity of percid fishes was investigated. Among them, water temperature, feeding frequency, photoperiod and fish density were identified as factors of prime importance. Rearing European percid fishes at a high density in relatively warm water (22–27 °C) and fed three meals per day with a day length of up to 12 h a day significantly improve fish feeding activity, and, in the same way, the growth performances. Optimization of growth performances under artificial conditions was also investigated through the characterization of their nutritional requirements in terms of protein, lipid and carbohydrate. Depending on the fish life stage, artificial diets containing 43–50 % protein, 13–18 % lipid and 10–15 % carbohydrate cover the nutrient requirements of percid fishes and support the highest growth performance. Moreover, recent advances in the use of alternative oil sources in percid nutrition suggest a high potential of these species to biosynthesize HUFA when fish oil is replaced by plant oil rich in PUFA. In this context of fish ingredients replacement by plant sources, it could be of high interest to investigate the possibility of replacing fish meal by plant products in the future.

Keywords Eurasian perch • Pikeperch • Feeding • Nutrition • Growth • HUFA

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22.1 Introduction

Eurasian perch and pikeperch are receiving increasing attention as new fish species in inland aquaculture diversification. Indeed, the Percidae family have a large geographic distribution in Europe and are appreciated by consumers for their nutritional and organoleptic qualities. Under natural conditions, percid fishes are shoaling, opportunistic predators, feeding on prey ranging from zooplankton to fish (Thorpe 1977). In aquaculture environment, growth optimization is of paramount importance for profitability. To this end, it is essential to define their behaviour and performance in control conditions. In this chapter, we will focus our attention on feeding and nutrition of percid fishes during on-growing stages.

22.2 Feeding of Percids

In controlled environments, growth is positively correlated with food consumption. This consumption depends essentially on the feeding frequency and level, and together defines the total quantity of food ingested per day, or food ration (Brett and Grove 1979). Several indices can be calculated to characterize the effects of feeding level on fish growth. The food ration modulates the feed efficiency (FE) and is a measure of the efficiency of fish in converting the feed intake into increased body mass. On the contrary, the food conversion rate (FCR) corresponds to the ratio of feed intake to weight gain. The food ration also modulates the specific growth rate (SGR), commonly used to determine the nutritional value of a diet. The SGR is defined as the increase in fish mass per unit of time. These parameters are defined below:

Feed efficiency (FE) = $(W_f - W_i) / \text{Total Feed Intake (TFI)}$

Food conversion rate (FCR) = $\text{TFI} / (W_f - W_i)$

Specific growth rate (SGR) ($\% \text{ day}^{-1}$) = $100 \times (\ln W_f - \ln W_i) / \Delta t$

where W_i , W_f = the initial and final fish weight and t = time (days)

Numerous factors influence fish growth and resulting nutritional value. Experimental units and fish are influenced by abiotic and biotic factors, with high degrees of interactions, which will modulate fish behaviour and physiology. Temperature, feeding frequency, food ration, photoperiod and tank colour are among the abiotic factors of prime importance while life stage, gender, size heterogeneity and density are usually considered as the main biotic factors modulating fish growth performances.

22.2.1 Influence of Abiotic Factors on Growth Performance

22.2.1.1 Temperature

Among the parameters which modulate feeding activity, water temperature is of prime importance. Percids are temperate but quite thermophilic fish species and display the fastest growth at relatively warm temperatures (22–27 °C). The

modulation of growth performances by temperature has been investigated by Mélard et al. (1995) using 1.9 g Eurasian perch fed a commercial salmonid feed and reared at 22.9 °C or 26.5 °C. During this experiment, fish were fed with automatic feeder at a feeding level of 1.7 % for 12 h per day. After 144 days, the authors concluded that there were no significant differences in growth rate between the groups maintained at 22.9 °C (SGR=1.76 % day⁻¹) and 26.5 °C (SGR=1.86 % day⁻¹) despite a final mean body weight 14.5 % higher in the group reared at 26.5 °C. Moreover, FCR was not significantly affected by temperature (2.95 at 22.9 °C and 2.82 at 26.5 °C). According to these authors, the absence of significant differences could be explained by the fact that both temperatures were within the optimal thermal range of perch growth, but also because of high variability of individual fish body weight observed within each group (coefficient of variation of body weight: 21.6–25.4 %). However, an infestation by a ciliate (*Heteropolaria sp.*) at 26.5 °C contributed to continuous mortality suggesting this temperature is too high for intensive rearing of Eurasian perch juveniles. As concluded by the authors, a temperature of 23 °C appeared optimal for growth of Eurasian perch juveniles fed three times a day at 23 °C (SGR=1.76 % day⁻¹). Similar conclusions were reported by Mélard et al. (1996). Growth of 15-g fish reared at 27 °C was 12 % lower than at 23 °C. Similarly, 100-g Eurasian perch reared at 10 °C displayed a 20 % lower growth compared to fish reared at 23 °C (Mélard and Kestemont 1995). Thus, a rearing temperature of 23 °C can be applied during ongrowing life stages of Eurasian perch to optimize its growth.

Comparatively, pikeperch display a higher temperature preferendum. Wang et al. (2009) investigated the influence of this factor on growth performances and feed efficiency of 6.4 g pikeperch juveniles. The higher value of SGR (SGR=2 % day⁻¹) was obtained when juveniles were fed one or three times a day at 28 °C, while the lower SGR was in juveniles reared at 20 °C (SGR: 1.2 % day⁻¹) and fed one time a day. Similarly, the feed efficiency increased from 0.73 at 20 °C to 0.97 at 28 °C. An increase of the feeding frequency from three times/day to six times/day did not affect the growth performances. These observations were reinforced by the results of Ronyai and Csengeri (2008) who investigated the growth performance of 84 pikeperch at 20 and 25 °C. In this trial, fish reared at 25 °C exhibited a higher SGR compared to fish maintained at 20 °C at the same feeding rate (Table 22.1). These results suggest that the pikeperch is one of the most thermophilic Percid species studied so far and that it could be comparable to what is found in some Cyprinids such as the tench (*Tinca tinca*) and the European catfish (*Silurus glanis*) as well as the African catfish (*Clarias gariepinus*). However, different conclusions have been raised by Frisk et al. (2012), investigating the thermal optimum for pikeperch by the use of ventilation frequency as a predictor of metabolic rate. As suggested by these latter authors, a temperature of 28 °C is very close to the critical temperature since it significantly increased the Q₁₀-values for MO₂ consumption. Based on this variable, Frisk et al. (2012) defined an optimal temperature range between 10 and 27 °C. However, in this experiment, larger individuals were used compared to the experiments described above, and this can influence the optimal temperature of pikeperch. Indeed, as mentioned by Morita et al. (2010), lower temperatures are required to induce maximal growth rates in larger fish.

Table 22.1 Effects of temperature (T°C), feeding level and feeding frequency on growth performance and feed efficiency (FE) of pikeperch

	T°C	Duration (days)	Food frequency	Daily food ration	Photoperiod	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)	FE	FCR	
A	22.3	42	AF	1.2 %		25.4	47.9a	1.52a	-	0.77ab	
	22.3	42	AF	1.6 %		25.5	60.3b	2.05b	-	0.75a	
	22.3	42	AF	2.0 %		25.6	69.4c	2.38c	-	0.79b	
B	20	126	AF	0.90 %	20L:4D	84 ± 19	247 ± 4	0.81 ± 0.01a	-	-	
	20	126	AF	1.22 %	20L:4D	84 ± 19	260 ± 18	0.91 ± 0.04b	-	-	
	20	126	AF	1.35 %	20L:4D	84 ± 19	278 ± 9	0.97 ± 0.00c	-	-	
	20	126	AF	1.70 %	20L:4D	84 ± 19	267 ± 6	0.99 ± 0.02c	-	-	
	25	126	AF	0.90 %	20L:4D	84 ± 19	240 ± 4	0.80 ± 0.00a	-	-	
	25	126	AF	1.22 %	20L:4D	84 ± 19	275 ± 19	0.93 ± 0.05b	-	-	
	25	126	AF	1.35 %	20L:4D	84 ± 19	314 ± 0	1.03 ± 0.01d	-	-	
	25	126	AF	1.70 %	20L:4D	84 ± 19	306 ± 2	1.08 ± 0.01d	-	-	
	C	20	56	1 meal/day	-	12L:12D	6.4 ± 0.4	12.0 ± 0.4a	1.10 ± 0.07	0.81 ± 0.05	-
		20	56	3 meals/day	-	12L:12D	6.4 ± 0.4	13.0 ± 0.4ab	1.30 ± 0.07	0.75 ± 0.05	-
		20	56	6 meals/day	-	12L:12D	6.4 ± 0.4	13.3 ± 0.4ab	1.30 ± 0.07	0.63 ± 0.05	-
		24	56	1 meal/day	-	12L:12D	6.4 ± 0.4	14.3 ± 0.4b	1.50 ± 0.07	0.92 ± 0.05	-
24		56	3 meals/day	-	12L:12D	6.4 ± 0.4	16.9 ± 0.4cd	1.80 ± 0.07	0.97 ± 0.05	-	
24		56	6 meals/day	-	12L:12D	6.4 ± 0.4	16.3 ± 0.4c	1.60 ± 0.07	0.72 ± 0.05	-	
	28	56	1 meal/day	-	12L:12D	6.4 ± 0.4	17.6 ± 0.4cd	2.00 ± 0.07	1.02 ± 0.05	-	
	28	56	3 meals/day	-	12L:12D	6.4 ± 0.4	20.8 ± 0.4e	2.10 ± 0.07	1.14 ± 0.05	-	
	28	56	6 meals/day	-	12L:12D	6.4 ± 0.4	18.1 ± 0.4d	1.80 ± 0.07	0.74 ± 0.05	-	

Modified from Zakeš et al. (2003) (A), Rónyai and Csengeri (2008) (B), and Wang et al. (2009) (C)

Values are means ± SD. Values in each column with common letter are not significantly different (P > 0.05)

AF: Automatic feeder

22.2.1.2 Feeding Ration and Feeding Frequency

As mentioned previously, optimal fish growth is dependent on several factors. Among them, the influence of feeding ration and feeding frequency are of prime importance to optimize fish growth performances. Fontaine et al. (1997) investigated the effects of feeding level (1, 2, 3 % BW day⁻¹) on growth performances of 10 g Eurasian perch juveniles reared at 21.4 °C for 84 days (Table 22.2). In this experiment, feed was distributed at the frequency of four meals per day. Among the three different feeding levels tested, 2 % of biomass appeared optimal since it supported a SGR of 1.7 % day⁻¹ and a FCR close to one. Indeed, despite a similar FCR at a feeding level of 1 % BW day⁻¹, the growth rate was much reduced. On the contrary, an increase of the feeding level to 3 % slightly improved growth rate but resulted in a reduced feed utilization (FCR=1.53). More recently, Fiogbé and Kestemont (2003) estimated the optimum daily ration for different sizes of Eurasian perch at the optimum temperature of 23 °C (Table 22.2). This experiment was conducted on initial body weight of 0.22, 0.73, 1.56 and 18.9 g. Fish were fed with an automatic feeder at daily feeding levels ranging from 1 % to 20 % of fish biomass, depending on the initial fish size. Authors concluded that the optimum feeding rate decreases from 7.4 % to 5.1 %, 4.5 % and 2.2 % BW day⁻¹ for fish of 0.22, 0.73, 1.56 and 18.9 g initial body weight, respectively (Table 22.3). SGR values decreased with increase of fish weight at the optimal feeding rate. As described in this study, the low feeding level (2 % BW day⁻¹) significantly affected the survival of Eurasian perch, with an estimated survival of 51.5, 71 and 75 % for fish of 0.22, 0.73 and 1.56 g respectively. This mortality could be explained by a nutrient deficiency at early stages, but also by the high cannibalism rate which occurs at these fish sizes (0.73 and 1.56 g initial weight). Indeed, as reported by Kestemont et al. (2003), low food availability influences size heterogeneity in predatory species such as Percids and thus contributes to increased cannibalism. Moreover, the use of an automatic feeder at the low feeding level may contribute to increased growth heterogeneity. Indeed, food is monopolized by some dominant individuals, the predictability of food distribution in space and time with an automatic feeder contributing to reduce the accessibility of food for the dominated fish (Kadri et al. 1996).

Zakęś et al. (2003) investigated the effects of feeding levels (1.2, 1.6 and 2 % BW day⁻¹) on growth of 25 g pikeperch during 42 days (Table 22.1). In this experiment, food was distributed by automatic feeders during 19 h day⁻¹. The highest growth rate (SGR=2.38 % day⁻¹) was obtained in the group fed a ration of 2 % BW day⁻¹. However, feed was most efficiently utilised by fish fed an intermediate ration (1.6 % BW day⁻¹). Based on its lowest SGR (1.52 % day⁻¹), the group fed 1.2 BW day⁻¹ could be considered the only feed restricted group. The authors estimated that feeding rate of at least 2 % of biomass at 22 °C could be optimal for 25 g pikeperch juveniles. More recently, Bódis and Bersényi (2009) investigated the effects of three different feeding levels (2 %, 4 % and 6 %) on early 3.5 g pikeperch fed for 8 weeks in cages. In the present experiment, fish fed 2 % BW day⁻¹ exhibited the best FCR (0.77) while the worst FCR was observed in the 6 % BW day⁻¹ treatment. However, the maximal growth rate (SGR=3.7 % day⁻¹) was obtained in pikeperch fingerlings

Table 22.2 Influence of the daily food ration, temperature (T°C), photoperiod, sex and initial fish size on growth performances of Eurasian perch

	Daily food ration	Duration (days)	T°C	Food frequency	Photoperiod	Initial density (kg.m ⁻³)	Gender	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)	FCR
A	1 (% biomass day ⁻¹)	21	23	AF	8D:16L	1.46	ND	0.73	0.9±0.30a	0.83 ^a	-
	4 (% Zbiomass day ⁻¹)	21	23	AF	8D:16L	1.46	ND	0.73	1.2±0.1ab	2.52 ^a	-
	8 (% biomass day ⁻¹)	21	23	AF	8D:16L	1.46	ND	0.73	1.5±0.2b	3.52 ^a	-
	0.3 (% biomass day ⁻¹)	28	21.5	AF	8D:16L	7.2	ND	18.9	16.8±1.9a	-0.42 ^a	-
	2 (% biomass day ⁻¹)	28	21.5	AF	8D:16L	7.2	ND	18.9	22.2±1.2b	0.58 ^a	0.30±0.15
	3 (% biomass day ⁻¹)	28	21.5	AF	8D:16L	7.2	ND	18.9	24.6±1.5b	0.95 ^a	0.45±0.05
	1 (% biomass day ⁻¹)	84	21.4	4 meals/day	8D:16L	2.3	ND	10.4±0.2	22.3±0.5a	0.88±0.09a	1.08±0.03a
	2 (% biomass day ⁻¹)	84	21.4	4 meals/day	8D:16 L	2.3	ND	10.4±0.3	47.9±2.4b	1.77±0.22b	1.01±0.04a
	3 (% biomass day ⁻¹)	84	21.4	4 meals/day	8D:16L	2.3	ND	10.6±0.2	52.8±1.7c	1.86±0.08c	1.53±0.06b

C	1.2 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	M	9.8±0.8	52.7±5.6	1.68±0.01	0.88±0.05
	1.2 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	F	12.6±0.4	89.7±3.8	1.98±0.00	0.88±0.05
	4.2 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	M	12.1±0.1	63.6±8.6	1.65±0.16	1.02±0.10
	4.2 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	F	14.8±1.0	91.0±12.4	1.84±0.08	1.02±0.10
	14.3 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	M	11.9±1.2	58.3±8.8	1.57±0.02	1.04±0.11
	14.3 pellets fish ⁻¹ min ⁻¹	100	18	AF	24L:0D	4.8 ^a	F	12.6±0.8	81.1±10.9	1.88±0.19	1.04±0.11

Modified from Fiogbé and Kestemont (2003) (A), Fontaine et al. (1997) (B), and Juell and Lekang (2001) (C)

In the same experiment, values with same letter are not significantly different among treatment conditions ($P > 0.05$). Values are means ± SD
AF Automatic feeder

^aValues estimated from data of Fiogbé and Kestemont (2003) and Juell and Lekang (2001)

Table 22.3 Maintenance, optimum and maximum daily feeding rate (% body weight day⁻¹) for different fish sizes of Eurasian perch reared at 23 °C (Fiogbé and Kestemont 2003)

Body weight (g)	Maintenance	Optimum	Maximum
0.22	1.7	7.4	17.6
0.73	2.5	5.1	6.7
1.56	1.8	4.5	6.4
18.9	0.8	2.2	3.7

fed a 6 % daily ration at 24–25 °C. The effects of temperature and feeding frequency on growth performances of larger pikeperch (150–180 g) were investigated by Rónyai and Csengeri (2008). These authors concluded that maximum feeding rates of 1.25 and 1.15 % of BW day⁻¹ were optimal at 25 °C and 20 °C, respectively. Not surprisingly, different optimum feeding levels have been deduced from studies conducted on different life stages. Indeed, as it is well established, the maximal feeding rate is dependent on the initial fish size and decreases with fish weight.

The influence of feeding frequency on growth rate of pikeperch juveniles was investigated by Zakęś et al. (2006) on 4.8 and 21 g juveniles. At the end of a 6-week trial, the feeding frequency (one meal, three meals or continuous feeding per day) did not significantly affect the growth performance of 4.8 g juveniles. Similarly, FCR values were not significantly different among experimental conditions. Results obtained with 21 g juveniles reared for 8 weeks provided similar results. Indeed, SGR values (1.00–1.04 % day⁻¹) as well as FCR (0.81–0.83) were not significantly affected by feeding frequencies. These results seem to indicate that pikeperch are able to adapt to different feeding conditions. Indeed, fish that are fed less frequently can adapt to such conditions by consuming larger amounts of feed during each meal. In a long feeding schedule, this can lead to increased gut capacity and hyperphagia (Jobling 1983; Ruohonen and Grove 1996). In the study of Zakęś et al. (2006), this statement cannot be confirmed since the feeding rate did not influence the FCR. However, in addition to the feeding rate, it is also important to consider the time of each meal. For example, studies conducted on salmonid species indicated that 1 h of feeding was sufficient for fish to eat to satiation (Elliott 1975). In the study of Zakęś et al. (2006), fish were fed once a day during 3 h or three times a day during 1 h. The 3 h feeding time per day may be enough to feed fish to satiation, independently of the feeding frequency. More recently, Wang et al. (2009) evaluated the optimal daily frequency on growth of 6.4 g juveniles pikeperch reared at 20, 24 and 28 °C (Table 22.1). In this experiment, fish were hand fed one, three or six times a day for 56 days. The authors concluded that optimal feeding rates were estimated at 1.5, 1.8 and 2.0 % of the fish body weight at 20, 24 and 28 °C respectively with a frequency of three times a day. The increase of feed frequency (six times a day) did not significantly improve the growth parameters. According to Jobling and Johansen (1999), repeated feeding throughout long periods of the day can increase swimming activity of fish, resulting in energy expenditure and lower growth rate. Moreover, as concluded by Brett and Grove (1979), although any food ration between the maintenance level and the maximum one causes weight gain, the highest weight gain per

unit of added ration is obtained before the maximum feeding level, at a level considered as optimum in terms of biological conversion.

22.2.1.3 Photoperiod, Intensity and Wavelengths of Light

Artificial environments that are very different from natural habitats may negatively affect fish behaviour. Among environmental factors, duration of light can profoundly affect fish. The light can be characterized by its day length (DL), intensity and quality (longer wavelengths), which modulate the feeding activity, and consequently, the growth rate capacities (Boeuf and Le Bail 1999; Brännäs et al. 2001).

Considering that Eurasian perch show a typical diurnal feeding activity when fed with self-feeders (Anthouard and Fontaine 1998), one might hypothesize that day length and intensity can influence growth, as it was already described in other perciform species such as juvenile sunfish (*Lepomis cyanellus*) (Gross et al. 1965). Indeed, in nature, the feeding success of diurnal predator fish species such as Eurasian perch is directly modulated by contrast between the prey and its background (Endler 1987; Utne-Palm 1999). For example, changing light intensity may affect the behaviour of fish and modify the activity levels, thus altering predation risk and affecting feed intake (Craig 1977; Helfman 1978, 1981).

Jourdan et al. (2000) investigated the influence of day length (DL) on growth in 5.1 g Eurasian perch for 112 days (Table 22.4). Fish were fed at optimal feeding rate as defined by Mélard et al. (1996) and maintained under lighting conditions for 12, 18 and 24 h per day. As described by the authors, specific growth rates recorded at 18 h (SGR = 1.78 % day⁻¹) and 24 h (SGR = 1.77 % day⁻¹) were significantly higher than the SGR value calculated from fish reared at 12 h of DL (SGR = 1.36 % day⁻¹). This increase of growth performance with increase of DL is in accordance with results obtained in juveniles of green sunfish *Lepomis cyanellus* (Gross et al. 1965), yellow perch (*Perca flavescens*) (Huh et al. 1976) and Sliptnose rockfish *Sebastes*

Table 22.4 Influence of photoperiod on growth of Eurasian perch juveniles (males and females) reared during 112 days in a recirculation system at 23 °C. Fish were fed on demand with self-feeder

Photoperiod	Gender	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)
12L:12D	M	5.2±0.7	25.3±4.1a	1.41 ^a
12L:12D	F	5.2±0.7	29.2±1.6A	1.54 ^a
18L:6D	M	4.9±0.3	39.5±3.8b	1.86 ^a
18L:6D	F	4.9±0.3	47.3±14.7B	2.02 ^a
24L:0D	M	5.4±0.6	44.4±2.5b	1.88 ^a
24L:0D	F	5.4±0.6	49.6±8.3B	1.98 ^a

Modified from Jourdan et al. (2000)

Values with same letter for each gender are not significantly different among photoperiod conditions ($P > 0.05$). Values are means ± SD

^a SGR = $100 \times (\ln W_{\text{final}} - \ln W_{\text{initial}}) / \Delta t$ (% day⁻¹). Values calculated from the initial and final mean weights

diploproa (Boehlert 1981). However, increase of DL affected also the weight heterogeneity, with a maximal coefficient of variation at the continuous light (CV: 54.1 %). Indeed, continuous light accentuates fish interactions, aggressiveness and cannibalism in territorial fish species such as Percidae. As a result of cannibalism, the survival rate was significantly reduced when fish were reared under continuous light (76 %), compared to 18 h and 12 h DL (89 and 88.2 % respectively). As mentioned by the authors (Jourdan et al. 2000), the DL may also modulate gonad development. Indeed, despite few effects of DL on the final weight of males and females, the decrease in DL from 24 to 12 h induced a stimulation of gonadal development in males. This gonad development can be explained by the fact that a 12 h DL in this experiment was close to the natural day length in September, when gametogenesis begins (Sulistyo et al. 1998). In addition, it was well described that males can develop their gonads as soon as they are 150–260 days old (5–25 g). Thus, an increase of DL prevents an early maturation of males (Fontaine et al. 1997). Contrary to male gonads, the modification of DL did not affect the ovarian development at an early stage (5–40 g). Indeed, the maturity of females occur later (up to 40 g) than males, thus, they were immature at the development stage in this experiment. However, as observed in other fish species like turbot *Scophthalmus maximus* (Imsland et al. 1997), an increase of DL could delay the age at the first maturity in Percids.

Light intensity is also an important factor affecting many behavioural and biological processes in fish such as growth (Trippel and Neil 2003) and onset of sexual maturity (Porter et al. 1999). For example, pikeperch are a crepuscular predator inhabiting turbid waters (Ali et al. 1977) and it displays some retinal adaptations such as *tapetum lucidum* (Zyznar and Ali 1975) and macroreceptors (Braekevelt et al. 1989), improving vision under low ambient light. Since this species prefers turbid waters, this factor may have significant impact on rearing results. Usually, excess light intensity results in an increase of stress level associated with a decrease of feed intake and survival. According to this adaptive response to the natural environment, Luchiari et al. (2006) and Kozlowski et al. (2010) investigated the effects of light intensity on growth performance of pikeperch. Luchiari et al. (2006) reported that pikeperch prefers low intensity environments. Indeed, fish of two initial weights (6.68 ± 1.26 g and 36.90 ± 10.89 g) reared at 25–300 lx and 1–50 lx, respectively, showed a preference for the lowest light intensity. Similarly, Kozlowski et al. (2010) showed a significant preference of pikeperch juveniles of 6.1 g and 42.2 g to the lowest intensity used for each development stage (45.1 lx and 1.2 lx, respectively) (Table 22.5) when fish were fed 24 h day⁻¹ with automatic band feeders. While the survival and the body weight variation coefficient were not affected by the light intensity in this experiment, the specific growth rate was significantly modulated by the light intensity. Thus, 6.68 g juveniles exhibited significant higher SGR (SGR = 3.61 % day⁻¹) at 45.1 lx compared to 385 lx (SGR = 3.37 % day⁻¹). Moreover, the FCR value decreased from 1.09 at the high intensity to 0.97 at the low one for 6.1 g juveniles. According to the experimental conditions tested in both studies, the light intensity preferendum decreased with the increase of fish weight. It is well known that fish sensitivity to light is not only species specific, but also dependent on the ontogenic stage (Blaxter 1969, 1975). More precisely, a shift from

Table 22.5 Growth of two fish size groups of pikeperch reared under different light intensities (mean value \pm SD) and constant daylight during 56 days. Fish were fed continuously with an automatic feeder

Light intensity (lux)	Temperature ($^{\circ}$ C)	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)	FCR
385.7 \pm 36.8	24.4 \pm 0.9	6.1	40.6 \pm 1.1a	3.37 \pm 0.03a	1.09 \pm 0.01a
45.1 \pm 8.2	24.4 \pm 0.9	6.1	45.9 \pm 1.3b	3.61 \pm 0.03b	0.97 \pm 0.01b
8.0 \pm 1.2	23.6 \pm 0.5	42.2	108.6 \pm 0.6a	1.69 \pm 0.01a	0.80 \pm 0.01a
1.2 \pm 0.3	23.6 \pm 0.5	42.2	113.0 \pm 1.5b	1.76 \pm 0.02a	0.78 \pm 0.01a

Modified from Kozłowski et al. (2010)

Different letters in the same column indicated significant differences (for each experiment separately) ($P < 0.05$)

positive phototaxis to negative phototaxis occurs during ontogeny. For example, Bulkowski and Meade (1983) observed that larval walleye preferred high light intensity (7800 lx) from day 1 post-hatch until the eighth week of life (TL from 9 to 33 mm), while individuals older than 8 weeks exhibited a preference for low intensity (2–4 lx). Similar results have been obtained from studies investigating the performance of Eurasian perch under artificial environments (Tamazouzt et al. 2000). Differences in light intensity preferences that occur in pikeperch during its ontogenetic development can be attributed to the changes that occur in the eye, especially in connection with the development of the reflective membrane. This reflective membrane increases retinal sensitivity by reflecting light back. The *tapetum lucidum* appears in the walleye during the first month of life. For the pikeperch, it is probable that this *tapetum lucidum* is fully developed in juveniles around 15 cm. Curiously, Strand et al. (2007) who investigated the effects of light intensity on growth performance of Eurasian perch juveniles did not confirm the results obtained on pikeperch juveniles. Indeed, no significant differences of feed intake or SGR were observed between fish reared at 200 and 1100 lx. Moreover, as mentioned by the authors, the increase of swimming activity of perch juveniles at 2200 lx compared to 200 lx, which may indicate a state of stress, did not significantly affect the energy expenditure in this experiment. The discrepancy of these results can be explained by the fish weight used in the different studies described above. In the experiment of Strand et al. (2007), large juveniles of 59.6 g were reared for only 3 weeks. As the growth rate decreases with the increase of individual weight of fish, the duration of this experiment might be not long enough to significantly influence physiological responses.

Recently, Luchiarri et al. (2009) investigated the influence of the longer wavelengths of light on the growth, the feed intake and the feed efficiency of juvenile pikeperch. Fish of about 33 g were reared for 42 days under white light or specific wavelengths corresponding to the blue (λ 435 nm), green (λ 534 nm), yellow (λ 564 nm) or red (λ 610 nm) spectra. Fish were maintained individually in each tank and fed in excess twice a day. Based on the results of this study, the increase in light wavelength within the visible spectrum improves the growth rate and the feed efficiency of pikeperch juveniles despite no effect on feed intake (Table 22.6). Indeed, fish reared with the red ambient colour exhibited a significantly higher SGR (SGR=2.37 %

Table 22.6 Influence of the ambient color on the growth rate of pikeperch reared during 42 days at 22 °C under constant daylight. Fish were fed twice daily

Ambient color (λ_{\max} , nm)	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)
White	37.1 ± 8.5	72.1 ± 14.9	1.59 ± 0.34
Blue (435)	46.2 ± 13.8	87.0 ± 14.3	1.56 ± 0.35
Green (534)	38.5 ± 7.0	95.9 ± 23.5	2.15 ± 0.51
Yellow (564)	36.1 ± 7.2	88.2 ± 18.5	2.12 ± 0.39
Red (610)	39.8 ± 11.5	106.1 ± 24.7*	2.37 ± 0.64*

Modified from Luchiari et al. (2009)

Significant differences of the color treatments from the white colour (control) are indicated by an asterisk in each column ($P < 0.05$). Values are means ± SD

day⁻¹) compared to other conditions (SGR of 1.59–2.12 % day⁻¹). This increase in growth performance in the long-wavelength (red) environment may be related to the enhancement of visual sensitivity in the ambient where the visual pigments are able to maximize photon capture (Cohen and Forward 2002).

22.2.1.4 Tank Colour

Light can modulate the feeding activity and, thus, the growth performances of Eurasian perch and pikeperch. In connection with these factors, feed detection and feeding success of carnivorous fish species such as Percids are also under control of contrast between the prey and its background, depending on the tank colour (Endler 1987). In general, the highest growth rates of fish larvae were obtained when light conditions and tank colour optimize the contrast between the feed and the background (Barahona-Fernandes 1979; Henne and Watanabe 2003). According to Strand et al. (2007), feed intake of Eurasian perch juveniles (59.6 g) is significantly higher for fish reared in white tanks compared to black at low light intensity (220 lx). Correspondingly, fish growth rates were higher in white tanks. However, tank colour did not significantly influence the growth rate of fish at a higher light intensity (1100 lx). Indeed, feed intake was also affected by the interaction between light intensity and tank colour. Thus, as suggested by the authors, a high feed intake in lighter tanks (1100 lx) was probably a consequence of an increase of the feed visibility, due to the feed's higher contrast against the background colour of the tank. In this experiment, energy efficiency did not differ between treatments suggesting that none of the colour/light combinations were more stressful to the Eurasian perch at this fish size. This lack of light/tank colour effects on stress can be partially explained by the fact that, as most fish species, Eurasian perch are able to modify its body colour in response to tank colour (Mairesse et al. 2005). For example, Eurasian perch juveniles reared in dark tank exhibited a dark colour body while perch maintained in white tank were very pale. This morphological adaptation avoids energy expenditure to the physiological stress response (Sloman et al. 2000; Wendelaar Bonga 1997).

22.2.2 Influence of Biotic Factors on Feeding Activity

Among the various factors which interact in rearing conditions, biotic factors such as genetic origins, fish size and sexual dimorphism as well as stocking density may contribute to influence the growth performances of percid juveniles.

22.2.2.1 Genetic Origin

To date, juvenile Eurasian perch have been mainly obtained from wild breeders, without any genetic selection that would result in improved survival and growth performances in culture conditions. Consequently, high variations of fry quality according to the genetic quality of the breeders were observed year by year. Apart from low survival at different developmental stages, the development of intensive culture of Eurasian perch is strongly limited by slow growth compared to that of other fish species such as salmonids (Grignard et al. 1996; Kestemont and Dabrowski 1996; Kestemont et al. 1996; Tamazouzt et al. 2000). The potential of Eurasian perch domestication was investigated by Mandiki et al. (2004) by comparing under similar rearing conditions the performances of fish from wild populations from Finland, Poland, France, Belgium and Italy. In small juveniles (1.27 g), growth heterogeneity, growth rate and feed efficiency did not significantly differ between French and Belgian stocks. In contrast, growth rate and feed efficiency in large juveniles (31.8 g) were higher in French stocks than in Belgian. Growth performances of juveniles from Poland were higher than those of French and Belgian stocks. As reported for other fish species such as salmonids, this difference of growth potential between stocks may be related to a genetic variation between populations (Thodesen et al. 2001; Henryon et al. 2002). Thus, as it was achieved with carps (Vandeputte et al. 2002), it is of high interest to select wild breeders based on their growth performances to improve the domestication process of percids. This suggestion is reinforced by the results of Mairesse et al. (2007) who compared the growth performances between wild perch juveniles and domesticated ones for 103 days. As mentioned by the authors, the domestication process seems to improve the growth performance of Eurasian perch. The positive effect of domestication on growth was previously reported for more domesticated fish species such as trout or salmon (Huntingford 2004; Mambrini et al. 2004).

22.2.2.2 Life Stage

It is well established that growth rate varied highly with the fish ongrowing stage. For example, larval development is associated with high growth rate and high energy consumption for metamorphosis. At the opposite end, adult stage is characterized by low energy requirement and low growth rate. During ongrowing stage, growth rate also varied with the weight of fish. Such decrease of the maximum growth rate

with fish size has been reported by Brett et al. (1969) in sockeye salmon. As suggested by the authors, growth rate is size-specific at any given temperature, but an optimum temperature coincides with optimum metabolic scope, greatest tolerance to oxygen debt and maximum sustained speed. For example, SGR values of juvenile Eurasian perch reared at 22–23 °C decrease from 1.7 % day⁻¹ to 0.7 % day⁻¹ for fish of 1.9 g and 48.3 g respectively. Similarly, maximum specific growth rate of Eurasian perch reared at 23 °C decreases with increasing body weight, from 5.06 % for fish of 0.22 g to 1.14 % for fish of 18.9 g (Fiogbé and Kestemont 2003).

Even if no studies have investigated so far the effect of initial size of pikeperch on maximal growth rate, comparison of results obtained from several experiments suggest a similar answer to the one of Eurasian perch. Thus, 1.36 g pikeperch reared at 23.2 °C until a final mean weight of 28.1 g displayed a SGR of 3.36 % day⁻¹ (Schulz et al. 2006). Similarly, a SGR of 3.37 % day⁻¹ was obtained from juvenile pikeperch of 6.1 g maintained at 24.4 °C until a final mean weight of 40.6 g (Kozłowski et al. 2010). On the contrary, larger pikeperch juveniles exhibited a SGR of only 1.59 % day⁻¹ when they were reared from an initial mean weight of 37.0 g to a final mean weight of 72.0 g at 22 °C. However, it can be speculative to compare the growth capacities of juvenile pikeperch from different experiments, since, as it was described in this chapter, several factors (rearing temperature, feeding frequency, feed ration, photoperiod), can influence fish growth. For example, the relative low SGR (SGR = 1.8 % day⁻¹) obtained from pikeperch fingerlings of 6.4 g maintained at 24 °C can be due to a relative short day length period (12L:12D) compared to others studies (Wang et al. 2009).

22.2.2.3 Gender

In percids, although some environmental factors may induce size heterogeneity (Thorpe 1977), individual growth rate also depends on gender (Scott and Crossman 1973). Females grow faster than males (Malison et al. 1988). This sexual dimorphism appears at a 110 mm length in yellow perch. Indeed, an earlier sexual maturation in males compared to females favours this dimorphism (Craig 1987; Tanasichuk and MacKay 1989). Similar growth dimorphism was also observed in Eurasian perch reared in floating cages (Fontaine et al. 1995).

As suggested by Fontaine et al. (1997), sexual growth dimorphism is partially under control of feeding levels. Thus, relative low feeding level (1 and 2 %) decreases the intraspecific growth variability in Eurasian perch, in response to an inhibition of the sexual dimorphism proceeds. On the contrary, an increase of food supply to a level close to the maximal feeding level (3 %, four meals per day) allowed the females to express their growth potentialities that are superior to those of males (Fontaine et al. 1997; Mélard et al. 1995). In addition, males can develop their gonads from 150 to 260 days (5–25 g), which is relatively earlier in comparison to females (up to 40 g). As a result, energy allocation to testis development cannot be used for fish growth and reduces growth rate of males compared to females. Moreover, difference of growth rate also results from a higher feed consumption and feed conversion efficiency in females compared with males (Malison et al. 1988).

Surprisingly, an experiment focused on the effect of feed supply rate on growth of Eurasian perch juveniles seems not to confirm this information (Juell and Lekang 2001). Indeed, 10 g Eurasian perch reared in recirculated system at 18 °C and fed different ration (1.2; 4.2; 14.3 pellets fish⁻¹ min⁻¹) displayed similar SGR values. Moreover, only a slight effect of the feed supply on the sexual growth dimorphism was observed in each experimental condition. The discrepancy of these results with the previous experiments can be explained by the modulation of growth rate by all the factors described before, such as the relative low rearing temperature (18 °C) and the continuous light used during this trial. Indeed, as described by Jourdan et al. (2000), a continuous light inhibited ovarian development, and potentially influence growth heterogeneity between males and females.

According to Kadri et al. (1996), the mode of food distribution is also an important factor affecting size heterogeneity between males and females. These authors suggested that, to prevent food monopolization by some dominant individuals, the food should be presented in such a manner that it is unpredictable in time and space. For example, an experiment conducted by Tamazouzt (1995) on very low density (1.4 kg.m⁻³) of Eurasian perch suggested that restricted feed rations would induce inter-individual competition, with a clear emergence of female dominance. In such situations, the larger individuals, which are most of time females, inhibited the feeding behaviour of the smaller ones. Thus, higher growth rates and lower size heterogeneity could be achieved through the production of monosex female population (Malison et al. 1986) or sterile triploid fish (Malison et al. 1993).

22.2.2.4 Density

Growth heterogeneity is a central problem in aquaculture, especially in predatory fish species such as percids. In relation to the density, the availability and quality of food control the dominance hierarchies, individual growth and cannibalism, and thus, contribute to the success of the ongrowing process. At early stages (around 1–10 g), increased density has a positive effect on fish growth. For example, increased stocking density from 400 to 10,000 fish m⁻³ resulted in a 67 % increase in growth rate (0.2 g fish⁻¹ day⁻¹ at the highest density and 0.12 g fish⁻¹ day⁻¹ at the lowest density) for 1 g Eurasian perch reared at 23 °C during 74 days. This seems to originate from a density-dependent inhibition of territorial and agonistic tendencies that potentially limit the access to food. This hypothesis is supported by the growth heterogeneity observed at each stocking density, since coefficients of variation of fish body weight at the end of the trial decreased from 98.4 % to 57.9 % with increasing stocking density (Mélard et al. 1996).

Perch are a social species. Thus, hierarchies established at the low density could decrease access to food, whereas at higher levels such restriction is not observed (Mélard et al. 1996). Indeed, when density is low, the motivation to maintain a territory can outweigh the motivation to forage (Hecht and Uys 1997), and this might explain why growth was slowest at the lowest stocking density. Within a limited space, the available territory is limited when density is high. This decrease

of heterogeneity with the increase of the density may also be due to the learning capacity of the fish reared at high density to feed on the artificial pellets more quickly than fish maintained at lower density. However, this decrease of heterogeneity with the increase of density can only be valid if the daily food ration is not a limiting factor. Indeed, as explained by Fiogbé and Kestemont (2003), a decrease of daily food ration from 20 % (% biomass) to 2 % contributes to increase heterogeneity by enhanced dominance hierarchies and competition for food. However, as already mentioned, the feeding method can contribute to reduce the heterogeneity when the daily food ration is low. In fact, one or two meals per day instead of a continuous feeding by automatic feeders help to reduce the monopolization of food by dominant individuals, and thus growth heterogeneity. Interestingly, opposite results were observed from larger juveniles (Mélard et al. 1996). Indeed, the growth of Eurasian perch reared at 2080 individuals m^{-3} was 20 % lower than for fish reared at 308 individuals m^{-3} after 103 days of trial. Similarly, the effect of density on growth heterogeneity was not significant at this development stage. Finally, the maximal production rate (0.8 $\text{kg m}^{-3} \text{day}^{-1}$) was achieved at a 60 kg m^{-3} stocking biomass.

Effects of density on the growth rate were also investigated in 0.91-g pikeperch (Molnár et al. 2004). In this experiment, pikeperch were reared at three initial densities; 1.25, 1.66, and 2.08 kg.m^{-3} for 4 weeks at 23 °C and fed ad libitum twice a day. According to these authors, the initial density did not significantly influence the growth parameters in this experiment. Indeed, similar SGR values (5.95–6.12 % day^{-1}) were recorded among experimental conditions. Moreover, the initial density did not affect the cannibalism and survival. These results can be explained by the low initial variability of fish weight at the beginning of the experiment. Indeed, as explained by Zakęś (2012), size variability considerably affects the success of rearing, particularly survival. If fish size varies strongly, loss due to cannibalism tends to increase. In the experiment of Zakęś (2012), fish weighing 0.7 g BW, with high heterogeneity exhibited a final survival of 50 % after 8 weeks, while in groups of uniform body weight of 1.1 g, the survival percentage recorded was up to 90 % (Zakęś, unpublished data).

22.3 Nutrition

22.3.1 Diet Composition

The majority of the gross energy of feed is contained in proteins, lipids and carbohydrates. The energetic contribution of each macronutrient can be determined from the standard values corresponding to the physiological fuel value. According to the National Research Council (NRC 2011), these values are 39.5 kJ.g^{-1} for lipids, 23.7 kJ.g^{-1} for proteins and 17.2 kJ.g^{-1} for carbohydrates. In aquaculture, artificial feeds tend to be formulated according to each species dietary requirements, with the best balance of protein, lipid and carbohydrate levels. Nevertheless, the optimum balance in nutrient not only depends of the fish species but also of its life stages. Indeed, higher dietary protein and lipids levels are required during fast-growing life

stages such as larval and juvenile stages than grow-out fish. For example, crude protein and crude lipid requirements of the rainbow trout (*Oncorhynchus mykiss*) decrease respectively from 45 % to 50 % and 16–18 % for fry to 35–40 % and 14–16 % for brood-stock (Hardy 2002).

Currently, no feeds have been manufactured yet to cover specifically the pikeperch and Eurasian perch nutrient requirements. As Eurasian perch and pikeperch are freshwater carnivorous species, feed dedicated to salmonids have been frequently used in percid aquaculture. However, recent advances in the nutrition of percid fish have been completed that will define the practical diets for these species during their ongrowing stage.

22.3.2 Protein Requirements

Dietary protein is the single source of nitrogen for constructing amino acids and proteins in fish. Protein is also used as a source of energy for metabolism. The optimal dietary protein level depends on several factors including the trophic level, the life stage, the amino acid balance in diet proteins, the total energy content of the food and the feeding level. In addition, protein level incorporation in the diet depends also the digestibility of these proteins. Evaluation of protein quality in food can be estimated with the protein retention ratio (PER), as below: $PER = \text{weight gain} / \text{food protein intake}$. In general, the required level of dietary protein is higher at low feeding rates. However, protein sparing occurs when energy levels in the diet are sufficient to “spare” protein from being used as an energy source. In normal fish metabolism, about 14–15 % of energy is supplied by protein, but this non-productive use of protein can be reduced if a correct balance of carbohydrate (for herbivorous species) or lipid (for carnivorous species) is used in the diet.

According to fish species, life stages, protein sources and environmental conditions, protein requirements range from 30 % to 50 % (NRC 2011). In North-American walleye, a percid close to pikeperch, protein requirements for 8 g juveniles was estimated at 51 %, while for larger individuals of this species (50 g), the protein requirement decreases to 42 % (Barrows et al. 1988; Brown and Barrows 2002). The characterization of the protein requirement at early life stages of pikeperch was investigated by Schulz et al. (2007) (Table 22.7). In this experiment, 1 g fish were fed six experimental diets containing graded protein levels (26, 33, 40, 47, 54, 61 %) for 56 days. The increase of protein dietary level from 26 % to 54 % induced a significant increase in SGR (2.44–3.11 %), a significant decrease in food conversion ratio (FCR) value (2.45–1.88), but did not affect survival rate. The higher protein incorporation level (61 %) did not increase fish growth. This observation was supported by the protein efficiency ratio (PER) which decreased from 1.12 in fish fed 54 % dietary protein to 0.91 in those fed 61 % dietary protein. Thus, according to authors conclusions, protein level around 54 % (and 10 % lipids) seems optimal for growth of pikeperch juveniles. This conclusion is reinforced by the study of Schulz et al. (2008) showing that the best feed conversion ratio and specific growth rates on 1.35–1.4 g pikeperch juveniles were obtained in dietary treatments contain-

Table 22.7 Effects of dietary protein level on growth performances of juvenile pikeperch and Eurasian perch

	Duration (days)	Protein level (%)	Lipid level (%)	Initial weight (g)	Final weight (g)	SGR (% day ⁻¹)	FE	FCR	PER	
Eurasian perch	73	20	–	2.97±0.50	3.01±0.60a	0.01±0.42a	–	22.76±10.10a	0.001±0.42a	
	A	73	30	2.70±0.40	4.18±0.60b	0.60±0.11b	–	7.58±1.70b	0.23±0.08b	
		73	40	–	2.71±0.43	5.95±1.00c	1.08±0.15c	–	4.62±0.70c	0.38±0.09c
		73	50	–	2.95±0.20	6.96±0.60d	1.18±0.16c	–	3.91±1.00d	0.42±0.13c
		73	60	–	2.91±0.40	7.28±0.60d	1.26±0.20c	–	3.81±0.60d	0.43±0.06c
B	123	49.2	11.9	36.8±0.8	123.0±2.4a	0.98±0.03	0.76±0.04a	–	1.37±0.07a	
	123	46.6	16.3	37.3±1.5	140.3±5.0b	1.08±0.05	0.86±0.09ab	–	1.65±0.17b	
	123	43.2	22.2	37.9±0.1	130.0±7.5ab	1.00±0.05	0.93±0.01b	–	1.94±0.03c	
Pikeperch	56	26	10	1.09±0.01	4.28±0.18a	2.44±0.07a	–	2.45±0.06a	1.72±0.04a	
	C	56	33	10	1.01±0.04	5.04±0.19ab	2.88±0.05bc	–	2.01±0.07b	1.66±0.07a
		56	40	10	1.08±0.08	5.01±0.29ab	2.75±0.13b	–	2.06±0.15b	1.36±0.10b
		56	47	10	1.06±0.05	5.20±0.32bc	2.84±0.13b	–	1.97±0.07b	1.18±0.04bc
		56	54	10	1.05±0.03	6.01±0.59c	3.11±0.1c	–	1.88±0.18b	1.12±0.12c
D	56	61	10	1.00±0.06	5.45±0.23bc	3.03±0.05bc	–	1.96±0.06b	0.91±0.03d	
	56	47	9	1.40±0.01	7.35±0.49a	2.98±0.09a	–	1.94±0.09a	1.08±0.05ab	
	56	47	17	1.37±0.03	9.50±0.08b	3.46±0.05c	–	1.56±0.04b	1.33±0.04c	
	56	54	9	1.40±0.02	7.57±0.63a	3.01±0.16a	–	1.82±0.07ac	1.02±0.10a	
	56	54	17	1.38±0.03	9.43±0.83b	3.43±0.17cb	–	1.57±0.08b	1.17±0.06bc	

Modified from Fiogbé et al. (1996), Mathis et al. (2003) (B), and Schulz et al. (2007, 2008) (C, D)

Values are means ± SD. Different letters in the same column and the same experiment indicated significant differences ($P < 0.05$)

ing 47–53 % dietary protein and 17 % dietary lipid (Table 22.7). Comparatively, Eurasian perch juveniles of 2.9 g exhibited also the best growth performances with relative high dietary protein levels (40–50 %) (Fiogbé et al. 1996). Moreover, an increase of the dietary protein level from 0–30 % to 40–60 % increased also the survival rate (from 17 % to 83 %). Thus, a dietary protein level of 36.8–43.6 % should be enough for 2.9 g Eurasian perch and an increase of this value up to 45 % will not significantly improve the growth.

The dietary protein requirement was also investigated in larger Eurasian perch and pikeperch. Mathis et al. (2003) evaluated the effects of three protein/energy ratios ($25, 22$ and 19×10^{-3} mg kJ^{-1}) on Eurasian perch of 35 g BW until a commercial size (150 g) (Table 22.7). After a 18-week period, the SGR did not significantly differ among groups while the FE and PER values increased significantly when the dietary protein level decreased. However, the decrease in protein and increase in lipid level in the diet resulted also in increased lipid deposition in liver and viscera, supported by an increased hepato-somatic index (HIS) and viscero-somatic index (VSI). This observation suggested that the protein/energy ratio 19×10^{-3} mg kJ^{-1} is too low to reach optimum protein synthesis and lipids (energy) are stored in visceral tissues. Finally, the best growth was obtained from fish fed a protein/energy ratio of 22×10^{-3} mg kJ^{-1} , corresponding to 46.6 % protein and 16.3 % lipid in the diet. The similar protein level requirement was deduced from an experiment on 51.1 g pikeperch fed for 10 weeks with graded protein contents (34, 43, 50 %) (Nyina-wamwiza et al. 2005) (Table 22.7). In this experiment, the best SGR and FE values were obtained when fish were fed with 43 % and 50 % protein levels in the diet. Thus, authors concluded that the optimal protein incorporation ranged from 43 % to 50 %. In addition to the identification of the protein level requirement for Eurasian perch and pikeperch, the amino acid composition requirement was also investigated by Fiogbé et al. (1996). According to this author, the amino acid proportions remain rather similar between the different ongrowing stages, reflecting the use of these nutrients in equal proportions for tissue synthesis. Essential amino acid requirements are presented in Table 22.8 and compared to those of channel catfish and rainbow trout. The relative proportion of essential amino acid required in food for these species are globally similar. However, leucine, threonine and valine requirements are much closer to the ones of Rainbow trout which is also a carnivorous fish species. Since amino acid composition of whole body of pikeperch and Eurasian perch is very close (Fiogbé et al. 1996; Zakęs and Demska-Zakes 1998), we can suggest that amino acids requirement indicated in Table 22.8 may be used for pikeperch nutrition.

22.3.3 Lipid Requirement

Fish oil is the main source of lipids in diets formulated for finfish aquaculture. Triglycerides are the dominant constituent of fish oil but fat soluble vitamins such as vitamin A and vitamin D have also been recorded. As suggested by the relatively high amount of fatty acids in fish, it is an essential source of metabolic energy for

Table 22.8 Comparison of essential amino acid requirements (% proteins) Eurasian perch juveniles with those of catfish and rainbow trout

Essential amino acids	Eurasian perch	Catfish	Rainbow trout
Arginine	4.02	4.3	4
Histidine	2	1.5	1.8
Isoleucine	3.26	2.6	2.8
Leucine	4.99	3.5	5
Lysine	5.24	5.1	6
Methionine	1.92	–	–
(Methionine+cysteine)	2.19	2.3	3.3
Phenylalanine	2.77	–	–
(Phenylalanine+tyrosine)	5.22	5	6
Threonine	3.34	2	4.1
Tryptophan	–	0.5	0.6
Valine	3.75	3	3.6

Modified from Lovell (1991) and Fiogbé et al. (1996)

growth, reproduction and swim. This provision of metabolic energy is obtained by β -oxidation of fatty acids to produce ATP (Sargent et al. 2002). Interestingly, different pattern of accumulation of certain dietary fatty acids are observed among fish tissues, indicating a selective retention of these fatty acids, with respect to the need and specificity of each tissue. For example, saturated (16:0) and monosaturated fatty acids (18:1n-9, 20:1n-9 and 22:1n-11) are mainly accumulated in viscera and liver of percoid fish to produce energy. Fish oil is also characterized by high level of highly unsaturated fatty acids (HUFA), mainly represented by EPA (20:5n-3) and DHA (22:6n-3) of the n-3 series and ARA (20:4n-6) of the n-6 series. These HUFA can also be used to produce energy by β -oxidation but they are preferentially incorporated as structural component in cell membranes. Indeed, incorporation of HUFA in membrane bilayers, according to their physical properties, modulates its fluidity. In addition, HUFA from cell membrane can also be used as precursor to eicosanoid synthesis. These eicosanoids are signalling molecules which exert complex control over many bodily systems, mainly in inflammation or immunity. In aquaculture experiments, HUFA have been found to be critical for maintaining high growth, survival and reproductive rates and low food conversion efficiencies.

Eurasian perch and pikeperch exhibit relative low lipid content in muscle compared to salmonids. Indeed, in percids, the triglyceride energetic source is mainly deposited in liver and viscera. The mean lipid level in whole body of wild fish ranged from 1 % to 2 % (% wet weight) and 0.64–1.88 % (% wet weight) for Eurasian perch and pikeperch respectively (Mairesse et al. 2007; Schulz et al. 2006; Zakęś and Demska-Zakes 1998).

Kestemont et al. (2001) investigated for the first time the effect of graded lipid levels (6, 12, 18 %) in isoproteic diet (40 % crude protein) on growth and nutritional status of 22.7 g Eurasian perch (Table 22.9). In addition, the importance of stabilized lipid in menhaden oil through addition of ethoxyquin as antioxidant was evaluated.

Table 22.9 Effects of dietary lipid level on growth performances of juvenile pikeperch and Eurasian perch

	Lipid level (%)	Duration (days)	Initial weight (g)	SGR (% day ⁻¹)	FE	FCR	PER	% lipid whole body	% lipid muscle	% lipid viscera	% lipid liver
Eurasian perch	6 + eth	56	22.3 ± 0.7	1.08 ± 0.07a	0.41 ± 0.08a	–	–	–	1.10 ± 0.21a	35.3 ± 6.2a	9.4 ± 3.3
	12 + eth	56	22.1 ± 0.8	1.40 ± 0.09b	0.68 ± 0.09b	–	–	–	1.28 ± 0.13ab	42.6 ± 1.4ab	8.5 ± 3.2
	18 + eth	56	22.3 ± 0.5	1.42 ± 0.05b	0.60 ± 0.12b	–	–	–	1.47 ± 0.37ab	46.9 ± 6.2b	8.5 ± 0.5
	6	56	22.0 ± 0.5	0.97 ± 0.04c	0.35 ± 0.06a	–	–	–	1.52 ± 0.17b	31.8 ± 2.9a	9.7 ± 1.1
	12	56	22.2 ± 0.7	0.51 ± 0.06d	0.21 ± 0.03c	–	–	–	1.55 ± 0.86ab	34.0 ± 4.5a	11.1 ± 3.9
B	18	56	22.3 ± 0.5	0.30 ± 0.04d	0.12 ± 0.04d	–	–	–	0.98 ± 0.15a	35.6 ± 4.9a	7.4 ± 3.7
	12	70	35.9 ± 1.5	0.43 ± 0.01a	0.53 ± 0.05a	–	1.16 ± 0.10a	–	5.1 ± 0.14a	64.9 ± 1.8a	12.4 ± 0.1a
	15	70	33.1 ± 3.1	0.53 ± 0.02ab	0.64 ± 0.07a	–	1.45 ± 0.17a	–	5.1 ± 0.42a	78.8 ± 2.5b	17.0 ± 0.9b
	19	70	33.7 ± 2.3	0.57 ± 0.03b	0.80 ± 0.01b	–	1.93 ± 0.03b	–	5.0 ± 0.41a	71.9 ± 3.0a	23.8 ± 3.1c
	6	70	21.0 ± 1.7	0.26 ± 0.00a	–	3.76 ± 0.07ab	0.59 ± 0.01a	8.9 ± 0.2a	7.7 ± 0.2a	39.9 ± 0.7a	–
C	10	70	21.2 ± 1.2	0.34 ± 0.07b	–	2.93 ± 0.23a	0.80 ± 0.12b	10.7 ± 0.2b	7.6 ± 0.1a	44.6 ± 1.2b	–
	14	70	20.8 ± 3	0.21 ± 0.02a	–	4.65 ± 0.53b	0.48 ± 0.05a	10.3 ± 0.1b	7.7 ± 0.1a	50.5 ± 0.7c	–
	6	42	22.1 ± 5.6	10.6 ± 1.1a	–	–	–	7.4 ± 0.5a	–	–	–
D	12	42	22.1 ± 5.6	9.8 ± 2.6a	–	–	–	8.5 ± 0.8a	–	–	–
	18	42	22.1 ± 5.6	11.6 ± 1.4ab	–	–	–	7.4 ± 1.3a	–	–	–
	24	42	22.1 ± 5.6	13.4 ± 1.4b	–	–	–	11.6 ± 0.2b	–	–	–

Modified from Kestemont et al. (2001) (A), Xu et al. (2001) (B), Zakeš et al. (2004) (C), and Molnár et al. (2006) (D). Values are means ± SD. Different letters in the same column and the same experiment indicated significant differences ($P < 0.05$)

The authors reported that the growth rate was significantly affected by both the presence of ethoxyquin and lipid levels. The best SGR value was obtained in the group fed 18 % lipid+ethoxyquin ($\text{SGR} = 1.42 \text{ \% day}^{-1}$). Moreover, higher weight gain and feed efficiency were obtained in groups fed 12 % and 18 % dietary lipids with ethoxyquin while the lowest ones were obtained in groups fed the same lipid levels, but without ethoxyquin. These results showed that juvenile Eurasian perch are highly sensitive to oxidized lipid and the necessity to add antioxidants in formulated diets. More precisely, the absence of ethoxyquin reduced the concentrations of some HUFAs as showed in the liver, muscle and viscera. Indeed, a marked decrease of EPA was detected in all analysed tissues while the tissue concentration of DHA remained stable. The relatively high level of DHA in these tissues and its stable concentration between dietary conditions suggest a more important function of DHA than EPA in fish physiology. Considering only the results of fish fed graded levels of stabilized lipids, it appears that the increase from 12 % to 18 % lipid levels did not enhance weight gain and SGR value. At the histological level, in the liver, increase of the dietary lipid level (18 %) induced an increase in glycogen storage, and then lipid droplets, both in size and abundance, which could result in "steatosis" state. Indeed, since lipids are metabolized in the liver, its histological structure can often be influenced by the quantitative and the qualitative lipid profile compositions of the diets fish consume. Thus, based on these findings, 12 % lipid level with antioxidant may be considered to an optimal level for Eurasian perch juveniles while an excess of dietary lipid may have detrimental effects on fish health. Similar recommendations have been deduced from an experiment conducted on the same species fed with three dietary fat levels (12, 15 and 19 % lipids and 42/46 % protein) for 10 weeks (Xu et al. 2001) (Table 22.9). In this study, growth, feed efficiency and PER were correlated with dietary fat levels. In addition, the increased fat level in the diet increased the lipid deposition in viscera and liver but did not affect significantly the lipid level in the muscle. This increase in fat deposition was supported by an increase of the hepato-somatic index (HSI) and the viscera-somatic index (VSI) values. Based on the growth parameters and the nutritional state of fish among treatments, incorporation of 15 % fat in the diet may be optimal for Eurasian perch juveniles. More recently, the fatty acid profile of muscle, liver and mesenteric fat were compared between large wild and cultured Eurasian perch of 116 g and 119.3 g respectively (Jankowska et al. 2010) (Table 22.9). In this experiment, the artificial diet was composed of 16 % crude fat, close to the value recommended above, and 45 % crude protein. Similar concentrations of saturated fatty acid (SFA) and unsaturated fatty acids (UFA) in muscles, liver and mesenteric fat were found between wild and reared Eurasian perch. However, a higher proportion of MUFA were found in fish, corresponding to a higher MUFA concentration in the diet. Analogously, the higher content of PUFA in natural feed induced a higher amount of these fatty acids in wild fish. The fatty acid composition in the tissues reflecting the fatty acid proportions in the diet was previously described (Bell et al. 2002; Geay et al. 2010; Sargent et al. 1999). This observation is also supported by the difference of arachidonic acid (ARA) level between wild and reared fish. Indeed, the relatively large amount of ARA in tissues of wild Eurasian perch corresponds to

a rather high level of this fatty acid in natural prey. From a nutritional point of view, this high amount of ARA suggests a relatively high importance of this fatty acid for both membrane composition and eicosanoid synthesis. However, the use of commercial diet in intensive rearing of Eurasian perch produces fish whose muscle lipids do not diverge from those of wild fish in terms of EPA and DHA contents, the most valuable to a consumer.

As for Eurasian perch, Zakeš et al. (2004) determined the effect of graded lipid content in iso-nitrogenous diets (6, 10 and 14 % lipids, 45 % protein). In this experiment, 210 g pikeperch were reared during 70 days (Table 22.9). As mentioned by the authors, the increase of dietary lipid content was correlated to an increase of this macronutrient in fish body. Indeed, the lipid content in fish body fed 10 % lipids was significantly higher than in group fed 6 % lipids. However, a further increase in dietary lipid (14 %) did not significantly increase the body lipid content. In addition, similar to the Eurasian perch, an increase of dietary lipid affects the viscera biochemical composition, with an increase from 39.9 % to 50.5 % lipids (% of wet weight), while no differences in the amount of lipids in the muscle were detected between groups (7.6–7.7 % of wet weight). Indeed, as in Eurasian perch, pikeperch accumulate excess energy mainly into viscera and liver but not into muscle (McClelland et al. 1995; Xu et al. 2001). Increased dietary energy by increasing lipid content improved the protein utilisation efficiency. As explained above, lipids are primarily used by fish to meet energy requirements, and thus allow protein utilisation as a building material (protein-sparing effect) (Cho and Kaushik 1990). This was partially confirmed in this experiment since the increase of lipid level from 6 % to 10 % resulted in an increased protein efficiency ratio (PER) from 0.59 to 0.80 and a decrease of the feed conversion ratio (FCR) from 3.76 to 2.93. As concluded by the authors, the optimal lipid incorporation in feed should be around 10 % to guarantee the fastest weight gain and the most effective feed utilisation (FCR and PER) at this size (210 g). Molnár et al. (2006) also investigated the effects of graded fat levels in the diet, but at an early life stage of pikeperch. In this experiment, 22 g pikeperch were fed three different dietary fish oil levels (6, 12 and 18 % lipids, and 44 % protein) (Table 22.9). As previously reported, increase of fat level from 6 % to 18 % in the diet induced a decrease of the FCR (from 1.2 to 1.1). Similarly, the increase of dietary fat level induced an increase of the fat deposition into the viscera but did not affect the lipid composition in the muscle. Based on these findings, a diet containing 18 % of lipid may be suggested as optimal for 22 g pikeperch juveniles.

Optimal dietary content of each nutrient depends on the balance between protein, lipid and carbohydrate incorporations. Thus, the dietary lipid level should be considered according to the protein level. Nyina-wamwiza et al. (2005) investigated the effects of the dietary balance of protein/lipid/carbohydrate (P/L/C) in diet on growth, feed efficiency and body composition of 51.1 g pikeperch during 10 weeks. In particular, several inclusion levels of lipid (10, 16 and 22 %) were tested. As described by the authors, when fish were fed diets containing 34 % of protein (low level), the lipid content in carcass increased from 5.7 % to 10.1 % (% wet weight) with the increase of dietary lipid content (from 10 % to 22 %). Similar results were also found in fish fed diets containing 43 % protein. These increments in body lipid

by increasing dietary lipid level in the diet are supported by the studies described above (Zakęś et al. 2004; Molnár et al. 2006; Jankowska et al. 2010). Similar observations have been also reported in Atlantic salmon *Salmo salar* (Hillestad and Johnsen 1994), in carp *Cyprinus carpio* (Zeitler et al. 1984), and in European seabass *Dicentrarchus labrax* (Peres and Oliva-Teles 1999). Interestingly, protein sparing effect did not result in better growth with reduction in carcass lipid in fish fed high dietary lipid levels (16 and 22 %), suggesting that pikeperch might not be capable of sparing protein through the utilization of dietary lipid efficiently when dietary protein level is high. Similar results have been observed in Murray cod *Maccullochella peeli peeli* (De Silva et al. 2002), common dentex *Dentex dentex* and European seabass (Company et al. 1999). Based on this conclusion, the proximate nutrient requirements for 51.1 g juvenile pikeperch are between 10 % and 16 % lipids, with a minimum protein requirement of 43 %. More recently, the energetic balance between protein and lipid was investigated by Schulz et al. (2008) on young pikeperch of 1.35–1.40 g. During this experiment, fish were fed six experimental diets containing three dietary levels of lipid (9, 13, 17 %) combined with two levels of dietary protein (47 % and 54 %) for 56 days. As concluded by the authors, the best SGR and FCR values were obtained from fish fed the highest lipid levels (17 %). Contrary to the study of Nyina-wamwiza et al. (2005), in this experiment, the increase of dietary lipid level suggested a clear protein-sparing effect between 9 % and 17 % in pikeperch nutrition. Similarly, Mathis et al. (2003) also reported a significant protein sparing-effect up to dietary lipid level of 16.3 % in 35 g Eurasian perch. Differences of growth responses between these studies (Mathis et al. 2003; Nyina-wamwiza et al. 2005; Schulz et al. 2008) could also be influenced by fish size, since higher dietary lipid levels are beneficial for faster growing juveniles with high metabolic rates in contrast to slower growing older ones.

In conclusion, according to the life stage and the relative amount of dietary protein, incorporation of fish lipid ranging from 13 % to 18 % in the diet may improve growth of Eurasian perch and pikeperch while higher levels of lipid may have detrimental effects on fish health and nutritional value.

22.3.4 Carbohydrate Requirement

The digestibility of carbohydrates in fish is low in comparison to protein and lipid, and inappropriate level of this nutrient in aquafeeds may have negative effects on growth, metabolism and health (Wilson 1994; Erfanullah and Jafri 1998; Li et al. 2012).

The determination of optimal dietary carbohydrate level for Eurasian perch and pikeperch nutrition is poorly documented. Nyina-wamwiza et al. (2005) investigated the nutrient balance of protein, lipid and carbohydrate in nutrition of 35 g juvenile pikeperch. More precisely, three graded levels of carbohydrate (10, 15, 20 %) were fed during this experiment. Fish fed higher carbohydrate diets (15, 20 %) resulted in better growth and FE than fish fed low carbohydrate (10 %) diets at the same protein level. Finally, the best growth performances among dietary treatments were registered for fish fed diets containing 43 % protein/22 % lipid/20 % carbohydrate and 50 %

protein/16 % lipid/20 % carbohydrate. It has been reported that balance between dietary lipid and carbohydrate affects protein sparing, yielding the best growth rate when carbohydrate and lipid are supplied in equal caloric quantities. Beneficial effect of carbohydrate inclusion in diet was also deduced from an experiment on Eurasian perch (Abro et al. 2013). Based on the results of this study, incorporation of 15–20 % carbohydrate added to diets may improve growth performance. This conclusion is supported by the increase of the amylase activity in the proximal intestine until 20 % carbohydrate, but a decrease of its activity when carbohydrate inclusion is over 20 % (Abro et al. 2013).

22.3.5 Vitamin and Mineral Requirements

Most of the vitamins are not synthesized by fish or at a rate sufficient to cover the fish needs. Vitamin requirements (ascorbic acid, para-aminobenzoic acid and inositol) was investigated by Aoe and Masuda (1967) and Halver et al. (1969) on fish species of aquaculture interest such as rainbow trout and Atlantic salmon. More recently, Tacon (1992) and De Silva and Anderson (1995) characterized the effects of vitamin deficiencies or excess on fish physiology. Among the consequences identified by the authors, growth rate reduction, skin damaged and malformations are mainly observed.

Vitamin requirements for pikeperch and Eurasian perch are poorly documented. Currently, pikeperch and Eurasian perch are fed salmonid feeds, with vitamin requirements adapted to rainbow trout and Atlantic salmon nutrition. The absence of significant negative effects on percid physiology suggests that salmonids and percids have very close vitamin requirements. However, complementary experiments may be necessary to define the specific vitamin requirements for percids at the different life stages.

For fish, minerals can be assimilated from diet or from the environment, through osmotic mechanisms. The concentration of each mineral element in body tissues is closely related to its functional role. Minerals are involved as constituents in bones and teeth but also as ionic states in body fluids for osmotic balance and integration activities (nervous and endocrine systems). They play also a crucial role as enzymes and organic compounds in tissues. Mineral composition has been characterized for pikeperch juveniles (Özyurt et al. 2009) but complementary experiments should be necessary to define their optimal incorporation levels in diet.

22.4 Replacement of Marine Ingredients by Alternatives Sources

22.4.1 Economic Context

Future growth of aquaculture activity will need protein and oil sources greater than current fishmeal and fish oil production can satisfy. Thus, continuous increase of aquaculture production is fundamentally unsustainable if fish meal and fish oil remain the

primary protein and oil sources used in aquafeed. In this context, the use of alternative such as plant ingredients has been investigated over the last two decades. Currently, 25–50 % of fish meal is replaced by plant meal in feeds for carnivorous fish species without reduction of growth performances, depending on species and life stage. According to the recent interest of Eurasian perch and pikeperch to the diversification of inland aquaculture, the possibility of using plant ingredients in aquafeed was investigated over the last decade. However, no experiments have been conducted on Eurasian perch and pikeperch in order to evaluate the possibility of fish meal replacement by alternative source proteins such as vegetable meal. In contrast, the effects of fish oil replacement by plant sources in food of Eurasian perch and pikeperch is well documented.

22.4.2 Effects of Fish Oil Replacement by Vegetable Oils

The relatively high level of HUFA content in muscle is maintained through the use of fish oil rich in HUFA. At the opposite, plant oil are devoid of HUFA and are rich in their C18 PUFA precursors, α -linolenic acid (ALA, C18:3n-3) and linoleic acid (LA, C18:2n-6). This absence of HUFA content in plant oils has variable consequences on fish health and fish growth, according to fish species. Indeed, it is well described that freshwater fish species such as salmonids fed a diet rich in C18 PUFA are able to maintain a certain degree of desaturase and elongase activities to produce HUFA, including EPA and DHA through the use of the “sprecher pathway”. At the opposite, marine carnivorous fish species have limited endogenous capacities to biosynthesise HUFA from PUFA when fish oil is replaced by plant oil in fish farmed diet (Tocher et al. 2001, 2006; Zheng et al. 2004).

Eurasian perch and pikeperch are carnivorous freshwater species. However, at early development stages, they consume relatively small food items such as insects and zooplankton. The effects of plant oil inclusion in diets on growth performance of Eurasian perch were investigated by Xu and Kestemont (2002). During this 10-week experiment, fish were fed four experimental diets composed of 16 % cod liver oil (CLO), olive oil (OO), safflower oil (SO), or linseed oil (LO). Vegetable oils were notably characterized by different proportions of C18 precursors of the n-3 and n-6 series. LO contained high ALA level, SO contained high LA level, while OO contained low levels of both C18 fatty acids but high level of oleic acid (18:1). The lowest growth rate (30 %) and feed efficiency (0.86) were observed in fish fed the OO diet. LO and SO-fed fish increased significantly in growth response and in improved feed efficiency (1.10–1.23) compared to OO fish. However, the highest growth rate (141.7 %) and feed efficiency (1.28) were recorded in control fish fed the CLO diet. According to author’s suggestion, the differences of weight between CLO and LO diets may be attributed to the better palatability of the CLO diet. In addition to an effect of oil source on fish growth performances, the total lipid content in viscera, muscle and liver were also affected by the dietary treatment. The liver lipid content of LO fish was the highest among the four dietary fat treatment

groups, and the lipid content of liver in CLO fish was significantly higher than that of OO diet-fed fish, while no significant differences in liver lipid between OO and SO diet-fed fish were observed. In fish fed CLO diet, the fatty acid composition in tissues were characterized by high n-3 HUFA content and low n-6 HUFA content. This relative high n-3 HUFA concentration, especially DHA, was already described in the “Lipid requirement part” as a key fatty acid in fish physiology. Interestingly, DHA and total n-3 fatty acids in the liver of OO fish were significantly higher than those in SO fish, but they were significantly lower than those in LO and CLO fish, suggesting that n-3 desaturations were inhibited by the SO diet rich in 18:2n-6 and stimulated by the use of LO diet rich in C18:3n3. This observation is also supported by the relative high amount of desaturation and elongation products of 18:2n-6 found in fish fed SO diet, showing that desaturation enzyme also favouring 18:2n-6 substrate when dietary 18:3n-3 content was low. Thus, the use of LO rich in C18:3n-3 facilitates similar level of n-3 HUFA in fish tissues to those of CLO fish, supporting that Eurasian perch exhibited capacities to bioconvert the precursor into EPA and DHA in order to compensate a deficiency of these HUFA in the diet. Similar conclusions on the HUFA biosynthesis capacities and the importance of the n-3/n-6 ratio of C18 precursors in diet were deduced from a nutritional challenge in juvenile Eurasian perch where four diets were formulated using three different lipid sources (cod liver, safflower and linseed oils) in variable proportions (Blanchard et al. 2008). More recently, the HUFA endogenous synthesis of Eurasian perch fed with vegetable oil was confirmed by Henrotte et al. (2011) through the measure of the desaturation and elongation activities of the [1-14C]18:3n-3 and [1-14C]18:2n-6 substrates in hepatocytes. A significant increase of these activities were recorded from hepatocytes of fish fed the LO diet (with a high n-3/n-6 ratio), compare to the control diet (menhaden oil). Interestingly, the higher desaturation and elongation activities recorded with the [1-14C]18:3n-3 substrate in comparison to the [1-14C]18:2n-6 substrate reinforced the idea that these enzymes tended to favour the synthesis of n-3 HUFA than n-6 HUFA.

The effects of plant oils on the growth performance of pikeperch juveniles and its ability to biosynthesise n-3 HUFA are well documented (Kowalska et al. 2011; Molnár et al. 2006; Müller et al. 2012; Schulz et al. 2005; Zakęs et al. 2010). Schulz et al. (2005) demonstrated that 50 % replacement of fish oil (FO) by linseed oil (LO) or soybean oil (SO) did not affect the growth performance of 14.9–15.6 g pikeperch. Interestingly, triglyceride and phospholipid compositions were not affected in the same manner in response to the use of vegetable oils. Indeed, 50 % replacement of fish oil by vegetable oils (LO and SO) induced a significant decrease of the n-3 HUFA in triglycerides while the concentrations of these HUFA remained relatively stable in phospholipids. This physiological response underlines the key role of HUFA incorporated in phospholipid in the control of the membrane bilayer fluidity. High dietary α -linolenic acid content in LO diet and equal EPA and DHA contents in triglyceride and phospholipid of LO and SO diets, yielded significant increases of relative amounts of EPA and DHA in triglyceride and EPA in phospholipid of whole fish fed LO diet. This observation suggests that, as for Eurasian perch, pikeperch exhibited capacities to synthesise n-3 HUFA from their ALA precursor. However,

desaturation and elongation capacities of pikeperch for ALA did not produce enough EPA and DHA amounts in either LO or SO fed fish compared with levels of FO fed fish. Furthermore, as observed in Eurasian perch, in contrast to the high dietary ALA level, the extreme relative reduction of ALA in different tissues of LO fed fish indicates that this fatty acid could be metabolized to produce energy. Finally, partial replacement of fish oil by linseed oil in diet of pikeperch seems not to reduce the growth performance and the muscle nutritional value. This conclusion is also supported by other experiments using linseed oil in replacement to fish oil (Kowalska et al. 2010, 2012).

The effect of total replacement of fish oil by plant sources was characterized by Molnár et al. (2006), Kowalska et al. (2010), and Zakeš et al. (2010). Molnár et al. (2006) demonstrated that total replacement of fish oil by linseed oil at two different incorporation levels (12.7 and 17.8 %) did not significantly affect the growth rate and the feed conversion ratio of 63 g pikeperch, compared to the control group (commercial diet). In addition, total HUFA proportion remained constant between dietary treatments. Similarly, Zakeš et al. (2010) investigated the impact of total replacement of fish oil (80 % of total lipid in the diet) by rapeseed (RO), soybean (SO) and sunflower (SFO) oils on growth rates of pikeperch. Interestingly, the improved values for feed conversion ratio (FCR), apparent net protein retention (ANPR), apparent net energy retention (ANER) and apparent lipid retention (ALR) indicated that the diets tested in this experiment were highly digestible and assimilated by pikeperch juveniles. Similar conclusions on growth performances have been deduced from an experiment on 59 g juvenile pikeperch where fish oil was totally replaced by linseed oil or peanut oil. However, in this experiment, significant reduction of n-3 HUFA contents were observed in whole body, fillet, viscera and liver of fish fed vegetable oils. The discrepancy of these results may be explained by the duration of the experiment and the fish life stage.

As described above, linseed oil provided the best results on fish growth performances and allowed maintaining relatively high n-3 HUFA contents in tissues through the bioconversion of the n-3 precursor, in comparison to other vegetable oils. However, arachidonic acid (ARA, 20:4n-6) derived from linoleic acid (18:2n-6) is also of prime importance in fish physiology since it is involved in the production of eicosanoid molecules. Thus, despite the relative low content of this n-6 HUFA in fish tissues compared to n-3 HUFA, maintaining sufficient ARA content in fish needs to be taken into account in feed formulation. In this context, the effect of a blend of vegetable oils with different n-3/n-6 ratios of C18 precursors was investigated. Kowalska et al. (2010) showed that the amount of n-6 PUFA in whole body, viscera, fillet and liver was the highest in fish fed with a blend of peanut and linseed oils (72/28). However, ARA level decreased significantly in these tissues compared to those of fish fed control diet (72 % fish oil and 28 % soy oil). In a second experiment conducted by the same author, opposite results were obtained (Kowalska et al. 2012). The authors tested two blends of vegetable oils: 70 % sunflower oil and 30 % linseed oil (70SFO/30LO) versus 30 % sunflower oil and 70 % linseed oil (30SFO/70LO) with a n-3/n-6 ratio of 0.70 and 1.35 respectively. The growth performances were similar between the dietary treatments while the fish fed 30SFO/70LO diet displayed

a significantly higher DHA level in whole body. In parallel, the use of this diet seems to increase the ARA content in tissues even when significant differences were identified between dietary treatments. Thus, based on the biochemical composition of fish tissues, the diet 30SFO/70LO with n-3/n-6 dietary ratio of 1.35 was the most advantageous for feeding pikeperch juveniles with vegetable oil based diets.

In addition to growth performances and lipid composition in fish tissues, the use of vegetable oil can also influence the histological structure of internal organs. Among them, intestine and liver are the most important tissues impacted by the dietary lipids since they are directly involved in the lipid metabolism in fish. Characterization of the histological picture of liver from pikeperch juveniles fed diets containing either rapeseed (RO), soy (SO) or sunflower (SFO) oil source was investigated by Zakęś et al. (2010). Feeding pikeperch diets supplemented with vegetable oil was reflected in the morphological structure of the liver and the degree of vacuolization of the hepatocytes. In the group SO, an increase of the degree of lipid vacuolization, liver parenchyma degeneration, necrosis and congestion was observed. These changes were less pronounced from fish fed RO and SFO diets. Similar consequences on liver histology were observed by Kowalska et al. (2010, 2012). They also demonstrated that supplementing feed with vegetable oils with low contents of C14:0 and C16:0 acids and of EPA and DHA caused a significant decrease in the degree of hepatocyte vacuolization, an increase in the supranuclear zone of the enterocytes, and an accumulation of lipid droplets in the enterocytes combined with localized sloughing of the intestinal epithelium. Changes such as these can occur when the transport of hydrolysed lipid products to the circulatory system is impaired, and the lipids are stored in the liver (Ostaszewska et al. 2005). All these changes could be connected to the lipid metabolism disorders in the fish organs, underlying an imbalance of fatty acid composition in diet when fish oil is replaced by vegetable oil.

In conclusion, pikeperch and Eurasian perch display relatively high capacities to biosynthesise n-3 HUFA when fish oil is replaced by a blend of vegetable oils including linseed oil, with n-3/n-6 ratio close to 1.6. However, these capacities are still insufficient to maintain high n-3 HUFA level in fish tissues. In consequence, the use of a partial substitution of fish oil by vegetable oil can be suggested. Moreover, despite absence of effects on growth performances, excess of dietary vegetable oil induces alteration of liver structure. This might indicate limited application of these types of lipid sources in percid nutrition.

22.5 Conclusions

In the context of inland aquaculture diversification in Europe, special attention has been given to percids over the last decades. To this end, the impact of abiotic and biotic factors on feeding activity of percid fishes was investigated. Among them, water temperature, feeding frequency, photoperiod and fish density were identified as factors of prime importance. Rearing European percid fishes at a high density in

relatively warm water (22–27 °C) and fed three meals per day with a day length of up to 12 h a day significantly improve fish feeding activity, and, in the same way, the growth performances. Optimization of growth performances under artificial conditions was also investigated through the characterization of their nutritional requirements in terms of protein, lipid and carbohydrate. Depending on the fish life stage, artificial diets containing 43–50 % protein, 13–18 % lipid and 10–15 % carbohydrate cover the nutrient requirements of percid fishes. Moreover, recent advances in the use of alternative oil sources in percids nutrition suggest a high potential of these species to biosynthesize HUFA when fish oil is replaced by plant oil rich in PUFA. In this context of fish ingredients replacement by plant sources, it could be also of high interest to investigate the possibility of replacing fish meal by plant products in the future.

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