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REVIEW ARTICLE

Adaptation of pikeperch (*Sander lucioperca*) to formulated diets: A review

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Abstract. Pikeperch, *Sander lucioperca* (L.) is a valuable species that is in high demand among consumers due to its nutritional features such as delicious meat, white and soft texture and lack of intermascualr bones. The main barriers in the development of pikeperch aquaculture are the challenges of its larviculture. A major problem in the larval period is that pikeperch must feed on live food, which imposes high costs on producers. Therefore, substituting live food with formulated diets is necessary, but this process cannot be performed easily and it requires an action plan to be successful. The aim of this study was to provide a brief overview of different aspects related to pikeperch nutrition including its natural feeding habits, nutritional requirements, digestive tract ontogeny, and the most common live foods used in pikeperch first feeding. Moreover, different weaning methods in pikeperch culture are provided to introduce an appropriate strategy to assist this fish in adapting to formulated diets.

Keywords: Digestive ontogeny, Formulated diets, Live food, Percids, Weaning.

Introduction

The development of aquaculture depends on introducing new species to culture. The family Percidae has at least four appropriate species for this purpose (Kestemont and Mélard 2000). Among the different percids, pikeperch, *Sander lucioperca* (L.) is an important fish with a pleasant taste and soft, white flesh without small intramuscular bones, which means it is in high-demand and is an expensive product in markets worldwide. This species can live in freshwater, brackish water, and marine water, but generally it prefers freshwaters such as rivers and lakes (Lehtonen and Toivonen 1981). Pikeperch has a wide distribution in the northern hemisphere (Craig 2000), and endemic pikeperch populations are found on the continents of this region including Asia, and Europe. This species has also been introduced to Africa, and some populations inhabit this area, specifically in Tunisia and Egypt (Stepien and Haponski 2015).

As mentioned above, pikeperch is a new species to aquaculture, but it has been reared in extensive aquaculture systems like large earthen ponds in European countries. This traditional method was used as maintenance rather than rearing, because no feed was provided and fish nutritional requirement were met by the natural food in the ponds (Falahatkar and Javid Rahmdel 2021). Currently, pikeperch is used as a biological control against trash fish and other unwanted aquatic species in cyprinid polyculture ponds to boost production output (Steenfeldt et al. 2015,

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Falahatkar et al. 2018). Intensive pikeperch monoculture has been conducted in recirculating aquaculture systems (RAS) since the early twenty-first century in Western Europe (Teletchea and Fontaine 2014). Therefore, it is still a novel field in the aquaculture industry. The Czech Republic, Hungary, Romania, Poland, Ukraine, Denmark, the Netherlands, and Tunisia are the most important industrial producers of pikeperch (FAO 2020a).

Pikeperch is in high-demand; thus, it is a frequent target of commercial and recreational fisheries. Despite increased fishing effort, the value of pikeperch landings have decreased compared with those of the twentieth century (FAO 2020b). Over-fishing and habitat destruction are threatening natural pikeperch stocks. In efforts to combat this, official organizations in countries such as Iran, the Netherlands, Poland, Germany, Hungary, and Finland are conducting pikeperch stock enhancement programs through the controlled spawning of wild brooders; these have produced some good results in recent years (Kucharczyk et al. 2007, Falahatkar et al. 2012, 2018). Wild brooders have high-quality gametes, but they are more sensitive to captive conditions (Falahatkar and Poursaeid 2014). Therefore, different management strategies such as subjecting brooders to hormone therapy (Demska-Zakęś and Zakęś 2002, Zakęś and Demska-Zakęś 2005, Rónyai 2007, Falahatkar et al. 2010, Żarski et al. 2019) and photo-thermal manipulation (Pourhosein Sarameh et al. 2012, 2013, Żarski et al. 2013, Hermelink et al. 2017) are used to enhance gamete supply. In response to the great importance of this valuable species, the European Commission created a comprehensive program in 2005 in partnership with 11 EU Member Countries that aimed at improving pikeperch broodstock management, reproductive cycle manipulation, egg husbandry, and larviculture (Kucharczyk et al. 2007).

The larval stage is perhaps the most critical stage in fish culture. Successfully rearing larvae and fry depends on supplying the appropriate feed to guarantee the health and welfare of the fish. Despite recent achievements in the production of formulated diets for the larviculture of different fish species, live food remains the primary food of choice for the initial stages of fish nutrition. The main challenges in pikeperch larviculture are high mortality rates and the failure of larvae to adapt to artificial feeds. A significant portion of larval mortality can result from the lack of appropriate feed at the weaning stage when larvae have to shift from live feed to formulated diets. The use of formulated diets in pikeperch larviculture has not produced good results. It seems that larvae are unable to recognize or ingest food particles, because the behavior of live food in the water column, including active movement, is crucial in attracting larval attention, and no artificial feed can replicate this behavior (Xu et al. 2003).

Live food organisms provide nutritional advantages, including autolysis, and they are important in maintaining some digestive enzymes in the simple larval digestive tract (Kolkovski 2001). Despite the advantages of live foods in aquaculture, they have limitations such as high costs and difficult production processes. To solve this problem, it is important to shorten the period in which live food is used, which can be accomplished by providing an appropriate formulated diet (Steenfeldt 2015). Failing to supply such a diet can cause major problems such as larval deformities and high mortality rates in pikeperch aquaculture which has been documented by other researchers (Kestemont and Mélard 2000, Kestemont et al. 2007, Kucharczyk et al. 2007). Hence, clearly the lack of access to proper artificial feed is a serious challenge that has a negative impact on the development of pikeperch aquaculture. Accordingly, the aim of the current study was to offer a brief overview of the methods for ensuring pikeperch larvae adapt to shift from live food to a formulated diet.

Natural feeding habits

Pikeperch is a carnivorous fish with distinct features such as a long body, a large mouth, and sharp teeth (Stepien and Haponski 2015). The preferred pikeperch prey depends on its age. Fry begin exogenous feeding on small zooplankton such as rotifers, *Daphnia*, and copepod nauplii. As fry grow (25–30 mm TL), it begins to feed on larger zooplankton such as adult copepods (Galarowicz et al. 2006). With further growth (35–40 mm TL), it tends to prey on benthic invertebrates such as insect larvae including chironomids, etc. Finally, juveniles become piscivorous and prey on smaller fish (Feiner and Höök 2015).

Digestive tract ontogeny

To fully understand larval feeding strategy, it is important to investigate the ontogeny of the fish digestive system. Pikeperch digestive tract ontogeny is similar to that of other carnivorous fishes. Newly hatched larvae have a simple digestive tract without a stomach or pyloric caeca (Mani-Ponset et al. 1994, Ostaszewska 2005). Therefore, the ability of larvae to digest protein is limited (Rønnestad et al. 2007). Additionally, the mouth and anus pores are closed, and there is no connection between the esophagus and the intestine (Hamza et al. 2015). Consequently, larvae cannot take up or ingest food particles, and they are entirely dependent on yolk sac endogenous feeding (Steenfeldt 2015). The yolk sac is a vesicle divided to fat in the anterior and yolk in posterior sections (Mani-Ponset et al. 1994) with a thin duct that links it to the liver. This connection is very important since the yolk sac has no vessels, and this link allows it to use the liver capillary system for necessary exchanges (Ostaszewska 2005, Hamza et al. 2015).

The length and diameter of intestine increase 3 days post hatch (dph). The primary bile duct also appears and connects the intestine and the liver (Hamza et al. 2015). Five dph is a critical time in the larval period, because the opening of the mouth signals the onset of exogenous feeding (Mani-Ponset et al. 1994). The initial diameter of the mouth is 0.36 mm (Hamza et al. 2015). Feed items must fit the mouth size, otherwise larvae are unable to swallow feed particles (Kestemont et al. 1996). Zakęś et al. (2013) observed that feeding of pikeperch larvae with smaller feed particles led to improved growth rates. The pancreatic cells begin execrating digestive enzymes like trypsin, which is necessary for the digestion of protein (Cuvier-Péres and Kestemont 2002). The intestine is divided into the anterior and posterior sections connected by a sphincter. This sphincter ensures digestive enzymes remain in the intestine (Hamza et al. 2015). On 7 dph, the liver begins to deposit fat and glycogen and subsequently grows in size (Ostaszewska and Boruta 2006), and the primary stomach appears. After the mouth opens, esophagus is aslo open. Thus, the connection is made between the mouth cavity and the intestinal lumen, and the intestine begins to excrete proteolytic enzymes (Hamza et al. 2015).

On 9 dph, some transparent vacuoles are detected in the intestine, which contain acidophilic granules that acidify the digestive tract to aid in the digestion of protein macromolecules, but the stomach is not yet fully developed (Watanabe 1984, Govoni et al. 1986). These granules indicate the carnivorous feeding strategy of pikeperch, and similar structures are documented in other carnivorous fish. Other vacuoles are also found in the intestine walls that can store absorbed fat (Hamza et al. 2015). Complete yolk sac absorption occurs on 15 dph simultaneously with full stomach development and the appearance of the pyloric caeca. Stomach shape in juvenile pikeperch is bicipital like the letter Y. Hereafter, fry have no internal food provisions and are fully dependent on exogenous feeding (Ostaszewska 2005). Despite the structural development of the stomach on 15 dph, it is important to bear in mind that pepsin excretion as the primary pyloric proteolytic enzyme begins on 29 dph. From 20 to 30 dph, teeth appear in the jaws, which indicate that fry can actively prey on larger prey like benthic invertebrates. The morphological characteristics of juvenile pikeperch are similar to those of adults, and their nutritional requirements are almost identical (Hamza et al. 2015).

Nutritional requirements of pikeperch

Unfortunately, few studies have been performed on the nutritional requirements of pikeperch. Therefore, information is very limited, and almost no specific pikeperch commercial diet is available on the market. Consequently, salmonid diets are used for pikeperch, but with variable results (Kestemont and Mélard 2000). Some aquafeed companies have attempted to formulate the nutritional requirements of pikeperch (Table 1).

As shown in Table 1, pikeperch has high protein and low fat requirements at the starter stage, while the higher growth rates and organogenesis of larvae and fry require higher quantities of protein. As pikeperch grow they require less protein so diets for the ongrowing stage have lower protein content and are subsequently less expensive. The primary source of crude protein in formulated feed for carnivorous fish is fish meal. Fish meal is the most expensive dietary ingredient, but has many nutritional advantages such as highly digestible protein content, balanced essential amino acids profile, low levels of anti-nutrient factors, and high palatability. Because of the high price and limitation in fish meal production, there is considerable demand for alternative protein sources. One of the major trends in this field is the use of plant-based proteins, but feeds formulated with them are not suitable for obligate carnivorous fish like pikeperch. Therefore, it is more rational to use less expensive, animal-based protein sources like krill meal, slaughterhouse wastes, Gammarus meal, earth worm meal, and bait shrimps to reduce costs (Nogales-Mérida et al. 2019, Falahatkar and Javid Rahmdel 2021).

Co-feeding period

As mentioned before, the co-feeding period is the intermediate larval stage when both internal and external food sources are required. During this period, a major portion of the yolk sac is resorbed, and the remaining part is utilized along with external feed. Following complete yolk sac absorption, pikeperch larvae are wholly dependent on live prey. For pikeperch, this period lasts from 5 dph (simultaneously with mouth opening) until 15 dph when the yolk sac is fully resorbed (Hamza et al. 2015). During co-feeding, pikeperch larvae exhibit slow growth and high mortality rates. Therefore, an appropriate management strategy is needed to ensure larvae survive this challenging period. The few studies that have been conducted on using formulated diets from the onset of exogenous feeding showed poor results, and almost all experts insist on the application of live food for newly-hatched larvae (Kestemont and Mélard 2000, Ljunggren et al. 2003, Bódis et al. 2007, Hubenova et al. 2015).

Improving larval predatory skills is one of the most important advantages of using live food. The movements of live feed organisms stimulate the predation instinct of larval pikeperch, which is a vital skill for juveniles that are released into the natural

Table 1
Nutritional requirements of pikeperch (*S. lucioperca*) at the starter stage (Biomar 2020)

Components	Requirement level
Crude protein (%)	55
Crude fat (%)	15
Nitrogen free extract (%)	13
Crude fiber (%)	0.9
Ash (%)	8.3
Total phosphorus (%)	1.2
Gross energy (MJ/kg)	21.1
Digestible energy (MJ/kg)	18.4

waters as stocking material during restoration programs. Juveniles that lack or have weak foraging abilities cannot acclimate to the wild and have very low survival rates (Falahatkar and Javid Rahmdel 2021). Additionally, the pikeperch larval gastrointestinal tract is unable to excrete digestive enzymes in the first days after hatching, which means that the autolysis affected by the endogenous digestive enzymes of live food is effective for larvae (Ostaszewska 2005). The growth rate variations among individuals in a single population mean that feeding should begin early to avoid mortality caused by starvation. Different organisms can be used as live food in aquaculture, which some of the most important items are described as follow.

Rotifers

Rotifers are among the smallest metazoans with which good results are noted when feeding pikeperch larvae (Yanes-Roca et al. 2018, Imentai et al. 2019). These organisms have several advantages including their small size, slow swimming, extended suspension time in the water column, rapid reproduction, high autolysis, appropriate protein and energy contents, and non-selective filter feeding behavior (Lubzens 1987, Dumont et al. 1995). Rotifers can also be enriched with different vitamin supplements and oils rich in n-3. Additionally, some microalgae used as feed for rotifers have good essential fatty acids profile. *Nanocholropsis occulata* has high amounts of eicosapentaenoic acid (EPA), and *Isochrysis galbana* is rich in docosahexaenoic acid (DHA) (Steenfeldt 2015). These fatty acids are vital for some physiological aspects including organogenesis and eyesight in pikeperch larvae. Commercial products are also available, such as Selco (INVE, Dendermonde, Belgium), that can be used to provide a mixture of vitamins, minerals, and essential fatty acids to pikeperch larvae.

Artemia

Artemia, known as brine shrimp, belongs to the family Artemidae of extremophile salt water zooplankton. The genus includes different species, but *Artemia franciscana*, which is endemic to the Great Salt Lake in Utah, is the most desirable for its small size that is appropriate for small larval mouths. *Artemia* nauplii have high quantities of crude protein (more than 55%) plus canthaxanthin (van der Meeren et al. 2008, Conceição et al. 2010). When environmental parameters are unfavorable, mature *Artemia* produce dormant eggs called cysts. These cysts contain embryos that will grow under the appropriate conditions (Lavens and Sorgeloos 1996). Cysts have good nutritional quality and can be used as food after decapsulating them, but it is better hatch them and feed larvae with nauplii. Since later stages of *Artemia* nauplii have a solid, chitin shell, it is preferred to use newly-hatched instar I nauplii. *Artemia* is one of the best live food items for pikeperch larviculture, and the results achieved are excellent (Kestemont and Mélard 2000, Hamza et al. 2007, Kestemont et al. 2007). It is also possible to enrich nauplii by suspending them for at least six hours in oily emulsions and/or other commercially available products with high quantities of vitamin C and essential fatty acids (Lund and Steenfeldt 2011).

Daphnia

Daphnia spp. are a wide group of Cladocera with both sexual and parthenogenetic reproduction. The latter reproductive strategy is associated with high offspring abundance, which makes these species suitable for aquaculture purposes (Proulx and De La Noüe 1985). Some of their traits such as high protein content, obvious red pigmentation (because of the hemoglobin), and jumping movements are also attractants to fish larvae. Additionally, they have appropriate digestive enzyme profiles that make them extremely useful for larvae. *Daphnia* spp. can produce dormant eggs in disadvantageous conditions, which is an advantage in the live food trade as it simplifies shipment and storage (Lavens and Sorgeloos 1996). Although pikeperch starter stages are commonly fed *Daphnia* spp. (Ljunggren et al. 2003, Bódis et al. 2007), these species have poor essential fatty acid profile (Goulden and Place 1993). Therefore, it is recommended that *Daphnia* spp. are used in combination with other live foods like *Artemia* nauplii. Rasouli Kargar et al. (2014) observed pikeperch larviculture conducted with a combination of *Artemia* nauplii and *Daphnia*, and they concluded that a mixture of the two fed to pikeperch larvae provided the best results in comparison to feeding larvae with these feed items exclusively.

Chironomidae

Chironomids, or bloodworms, are actually midge larvae and not real worms. These organisms have high hemoglobin content and are obviously red. Chironomids are high in crude protein content at more than 55% of dry weight (Bogut et al. 2007), and they are used widely as pikeperch food and to boost growth performance (Bódis et al. 2007, Horváth et al. 2013, Hubenova et al. 2015). Similarly to other insects, chironomids are poor in vitamin C (Nogales-Mérida et al. 2019), so it is important to enrich them with commercial products (Hamidoghli et al. 2014a, 2014b). Despite these advantages, chironomids are relatively large for the small mouth of pikeperch larvae. Therefore, they cannot be used as single feed item and must be pulverized. Pulverized worms can be shaped as pills that can be frozen and stored at low temperatures.

Tubifex

The tubifex worm is in high demand as a live food in pikeperch larviculture due to its high protein content (50–55%) and appropriate lipid content (8–10%) (Rech et al. 2013), which meets most of the nutritional requirements of pikeperch larvae. Good results are noted when using tubifex to wean pikeperch (Bódis et al. 2007, Ebrahimi Yousefi and Vahabzadeh 2014). The nutritional properties of tubifex are competitive with those of *Artemia* (Oplinger et al. 2011); however, because of its large size, tubifex cannot be fed directly to pikeperch larvae. Therefore, it is better to use dried, minced forms as similar as chironomids.

Weaning and formulated diets

Weaning is defined as fish larvae shifting from live food to a formulated diet, which is a critical stage in fish culture. A major problem in this field is larvae responding negatively to the sudden replacement of live food with a formulated diet. Hence, substituting the former with the latter should be done gradually and with precise planning (Kestemont et al. 2007). Therefore, a period in which both feeds are used is proposed to achieve this goal (Ljubobratović et al. 2015). The weaning stage is short and can be conducted in various aquaculture systems, but since larvae and juveniles are highly vulnerable during this shift, it is recommended to conduct this procedure in indoor facilities (Steenfeldt 2015). Furthermore, observing larval behavior during weaning is crucial since cannibalism is a serious problem at this stage that can lead to high mortality (Steenfeldt et al. 2011). The largest larvae form dominance hierarchies that lead to cannibalism (Steenfeldt 2015). Therefore, these larvae should be sorted by size during weaning to avoid this problem (Falahatkar and Javid Rahmdel 2021). Szczepkowski et al. (2011) reported significant reductions in cannibalism and consequently higher survival rates in pikeperch larvae that had been sorted compared with larvae that had not been sorted. These results indicate the necessity of sorting pikeperch during larviculture to reduce mortality rates.

Different trials were conducted to determine the optimal strategy for the weaning stage in terms of diet selection and timing (Table 2). The results indicated that the best age for weaning to commence in

Table 2
Comparison of procedures and results from different pikeperch (*S. lucioperca*) weaning trials

Beginning of weaning (days post hatch)	Primary feed	Weaning diet	Weaning duration (days)	Mortality rate (%)	Source
Not reported (yearling)	Daphnia	Marine fish commercial diet	9	2	Ljunggren et al. (2003)
30	Pond zooplankton	Combination of frozen chironomids and dry feed	21	41.63	Baránek et al. (2007)
35	Pond zooplankton	Chironomid larvae	12	13.3	Bódis et al. (2007)
15	*Artemia* nauplii	Combination of enriched *Artemia* nauplii and commercial trout diet	27	Not reported	Hamza et al. (2007)
19	*Artemia* nauplii	Enriched *Artemia* nauplii or metanauplii	18	84.7	Kestemont et al. (2007)
Not reported (yearling)	Pond zooplanktons and bloodworm	Artificial bloodworm (reshaped commercial dry pellets like chironomid larvae flavored with real chironomid extract)	21	Not reported	Horváth et al. (2013)
42	Pond zooplankton	Combination of frozen chironomids and commercial trout diet	12	18.3	Policar et al. (2013)
36	Pond zooplankton	Combination of frozen chironomid, dried tubifex, and trout dry feed	21	13.94	Ebrahimi Yousefi and Vahabzadeh (2014)
Not reported (juvenile)	Pond zooplankton	Mixture of frozen chironomids and commercial trout diet	10	46.4	Hubenova et al. (2015)
15	Pond zooplankton	Combination of *Artemia* nauplii and commercial dry feed	7	64.9	Ljubobratović et al. (2015)

pikeperch larvae was at least 15 dph, when the yolk sac is fully resorbed, while earlier attempts to wean pikeperch larvae failed because of high larval mortality (Hamza et al. 2007, Steenfeldt 2015). Kestemont et al. (2007) also proposed that the best age for beginning weaning was 19 dph as this resulted in the highest pikeperch larvae survival rates.

Ljunggren et al. (2003) evaluated the effects of three weaning techniques on the growth performance of juvenile pikeperch reared in earthen ponds that fed on natural pond food, specifically *Daphnia*. The fish were divided onto three treatments: 1) a combination of crumbled, cooked egg yolk and commercial marine fish diet at a 50:50 ratio; 2) a combination of zooplankton, mainly *Daphnia*, and a commercial marine fish diet; 3) a commercial marine fish diet. This trial was conducted for nine days and the results showed that the fish in treatment three with only the commercial marine fish diet had the best growth rate. Freshwater fish diets are possibly better choices for pikeperch nutrition compared to marine fish diets because of the calcium (Ca)/phosphorus (P) ratio. The Ca/P ratio is low in freshwater fish diets while high in commercial marine fish feeds. Freshwater species, like pikeperch, require lower Ca/P ratio, and clearly marine diets with higher Ca/P ratios might cause deficiencies in these fish (Kestemont et al. 2007). El Kertaoui et al. (2019), who conducted a study on pikeperch larval nutritional factors, also documented this.

Baránek et al. (2007) performed a three-week comparative trial to compare two methods of weaning juvenile pikeperch. Two treatments including commercial dry feed (treatment A) or a combination of dry feed and frozen chironomids (treatment B), were fed to juvenile pikeperch with an initial weight of 0.45 ± 0.08 g. The results showed that the survival rate in treatment B was almost twice than that in treatment A (58.37 versus 27.87%, respectively). Moreover, final weight and specific growth rate in treatment B were slightly higher than those in treatment A, but the differences were insignificant.

Delaying weaning decreases its success. Policar et al. (2013) conducted a study on juvenile pikeperch in three weight groups of 0.42 ± 0.15 g, 1.66 ± 0.4 g, and 2.95 ± 0.65 g and at different stocking densities. The results showed that the smallest fish had better growth and survival rates. The highest density (8 fish per liter) produced the highest survival rate, but the growth rate was not affected by density.

Using frozen animal-based feeds is an effective approach for shifting to formulated feed during weaning. Bódis et al. (2007) performed a trial for 12 days to determine which feed was appropriate for weaning pikeperch. Experimental treatments included chironomids, tubifex, *Daphnia*, and formulated feed. The results indicated that the best growth performances were with the chironomid and tubifex treatments. The survival rate in the chironomid treatment was significantly higher than that with tubifex. Similarly, Ebrahimi Yousefi and Vahabzadeh (2014) performed an experiment to acclimate juvenile pikeperch to formulated feed. They considered fry with an initial weight of 1.67 ± 0.07 g that were reared in an earthen nursery pond and fed on zooplanktons. The trial was conducted with four treatments of a commercial trout diet, frozen chironomid plus the trout diet, dried tubifex plus the trout diet, and a combination of frozen chironomid and dried tubifex plus the trout diet. In treatments two, three, and four, the natural feeds were replaced with the commercial trout diet gradually daily until day 21. The results of the study showed that the best growth performance was obtained in treatment four with both chironomid and tubifex. These observations revealed that gradually substituting the natural feed with the artificial diet was a far better way of weaning compared to sudden replacement.

A similar trend was reported by Hubenova et al. (2015) in weaning of juvenile pikeperch to dry feed and observations showed that a feeding period with a combination of frozen chironomids and dry feed had the best growth indices. They suggested that frozen chironomids were the best intermediate feed item (Wedekind 2008), which is in line with the previous studies.

Consistent with the studies mentioned above, Horváth et al. (2013) conducted a unique trial for weaning yearling pikeperch with chironomids. They pulverized dry pellets and reshaped them like bloodworms. They also added chironomid larvae extract to the reshaped pellets to stimulate the juveniles. They observed significant enhancement in growth performance in the fish fed this experimental diet compared to controls fed commercial pellets.

Supplementing commercial diets with chemical attractants such as Betaine can improve palatability in formulated diet and produce better growth performance during weaning. Zakipour Rahimabadi et al. (2012) used attractants in pikeperch larviculture and found that Betaine, in amounts of up to 2%, was a good attractant to use in pikeperch starter stage feed.

Some studies have focused on the non-nutritional aspects of weaning like stocking density. For example, Molnár et al. (2004) showed that stocking density correlated positively with juvenile pikeperch survival rates, but no such relationship was observed with growth rate. Baránek et al. (2007), Policar et al. (2013), and Rasouli Kargar et al. (2014) reported similar conclusions.

The studies on pikeperch weaning discussed above indicate that appropriate feeding schemes should include the following fundamental principles. The most important issue is choosing right time to begin weaning. It is recommended to start this process on 15 dph. Attempts to begin weaning earlier led to increased mortality rates due to low capability of digestive tract of larvae. After choosing the proper time, it is vital to have the right strategy to shift to a formulated diet. To achieve this goal, a period in which both types of feed are supplied to the larvae should be considered. In this period, live food must be replaced with artificial feed gradually to avoid inducing shock in larvae and to give them enough time to become acclimated to commercial formulated diets.

Conclusions

The best strategies for weaning pikeperch include beginning it after 15 dph and providing a period during which live food, a formulated diet, and some animal-based frozen or dried protein sources like chironomids or tubifex are given to the larvae as transition feed. It is also necessary to consider some remarks including regular larvae sorting to avoid cannibalism and to provide proper conditions by conducting weaning in RAS. Future studies on pikeperch nutrition during the weaning and ongrowing stages should focus on determining the nutritional requirements of this species in different growth phases, since having accurate information about pikeperch nutritional requirements is indispensable to the formulation of diets exclusively for this species. Experimenting with new, inexpensive, animal-based protein sources for formulated diets is recommended to reduce production costs. These strategies provide the best opportunity to develop pikeperch aquaculture globally.

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