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Chapter 13

Diet and Nutrition

*Frederic T. Barrows, U. S. Fish and Wildlife Service, Fish Technology Center, 4050 Bridger Canyon Road, Bozernan, Montana 59715, and William **A.** Lellis, National Biological Service, Research & Development Laboratory, R.D. 4, Box 63, Wellsboro, Pennsylvania 16901*

Introduction

The first reported feeding of manufactured diets to walleye occurred in the late 1960s (McCauley 1970). Prior to that, walleye were either released as fry immediately after hatching or raised to fingerlings in fertilized ponds that contained zooplankton as the food source (Smith and Moyle 1943; Dobie 1956). If zooplankton production in the ponds was inadequate to support the desired growth, the fish were either released early or fed live minnows to reduce loss from cannibalism. The high labor costs and unpredictability of culturing minnows spurred interest in developing pelleted dets for the production of fingerling walleyes (Cheshire and Steele 1972).

Initial experiments at converting pond-reared walleye from live feeds to formulated diets were hindered by low feed consumption, high cannibalism, and disease (Nagel 1976). Cheshire and Steele (1972) were successful in growing fingerlings to 100 mm with 18% survival using Canadian formula PR6 trout granules. Granules that had been stored for a year were found to be more acceptable than "fresh granules," perhaps due to a change in pellet texture. Although originally developed for Pacific salmon, Oregon moist pellets and the Abernathy diet were also found to support reasonable growth and survival during early trials (Nagel 1974, 1976).

During the 1970's, larger-scale fingerling production began at several national and state fish hatcheries, using dets formulated for coolwater fish by researchers at the USFWS Spearfish Fish Technology Center (Beyerle 1975). These diets, referred to as the "W" series, were composed primarily of herring and blood meal, soy flour, and fish oil, and were high in both protein (60%) and metabolizable energy (4,200 Kcal/kg). The **W**-16 formulation became the most commonly fed walleye diet at that time (Nickum 1978).

Diet development for walleye intensified in the late 1980s at the USFWS Fish Technology Center in Bozeman, Montana, as part of a multi-state Cooperative Federal Aid Project. Participating members included fishery personnel from Iowa, Illinois, Missouri, Nebraska, South Dakota, Wisconsin, and later Arkansas and North Dakota (Barrows 1990, 1995). Feeds were developed and tested during a 5-year period for several specific life phases, includmg: intensively cultured fry (starter dets); pond-cultured fingerings undergoing habituation to intensive culture (conversion dets); fingerlings acclimated to pelleted diets being cultured to a larger size (grower diets); and fry converting from a starter feed to a grower formulation (transition diets). Factors considered during diet development included the primary objectives of the particular feedmg program; the nutrient requirements and feeding habits of the targeted life stage of the fish; manufacturing technology as it relates to form and behavior of the feed in the intended culture system; and ingredient cost, availability, and functional role in the diet.

Diet development

Starter diets

Starter diets are defined as "those feeds intended to be the first solid food consumed by a fish after hatching." The primary considerations in the manufacture of starter diets are: the feed be readily consumed by the fish; be highly digestible to accommodate a developing, and often not fully functional digestive tract; and have high water stability to reduce bacterial contamination of the culture system and preserve water quality. Consumption can be influenced by feed particle size, shape, color, texture, taste, smell, density, and buoyancy. Cost should not usually be a major consideration when selecting starter diets because only a relatively small quantity will be used, and maximum survival and fish health are of paramount importance during this phase of the culture program.

The first attempts at culturing walleye fry using starter feeds as the sole source of nutrition were largely unsuccessful, with survival rates typically < 10% (Beyerle 1975; Nickum 1978; Colesante et al. 1986; Barrows et al. 1988). By comparison, intensive culture of fry using live feeds produced survival rates as high as 87% through 21 days post hatch (Howey et al. 1980; Hokanson and Lien 1986). Greater success was obtained by first starting fry on live organisms, then converting the fish to formulated diets after the fish were actively feeding (Krise and Meade 1986). Failure of the formulated dets to support adequate growth and survival of the fry was attributed to either rejection of the feed particles, high cannibalism, lack of swim bladder inflation, or excessive tank fouling.

Several technological advances in the late 1980s allowed for significant progress in the development of starter dets for walleye fry. The first was the design of culture systems that minimized cannibalism and water fouling and enabled fry to fully inflate their air bladders (Colesante et al. 1986; Barrows et al. 1988, 1993; Loadman et al. 1989). These designs provided nutritionists the opportunity to present diets to healthy fish and thus concentrate research on formulation, ingredient processing, and particle formation.

The second advance was the development of feed manufacturing techniques that produced small-particle diets that were not only acceptable to fry but also minimized nutrient leaching to the water. Notable among these diets was a series of three closed-formulation feeds referred to as Fry Feed Kyowa (FFK) **A, B**, and C (Biokyowa Inc., Chesterfield, Missouri)' which successfully replaced live feeds for numerous aquatic species. Formulation **A** was designed as a replacement for rotifers, was the most expensive, and comes in the smallest particle sizes. The B formulation was intended to replace artemia, and the C formula was intended to replace minced fish. While the production method for the diets is proprietary, the particles are readily consumed by walleye fry, and the uneaten feed is stable in water for at least 12 hours. Initial tests with fry produced survivals of 28% (Loadman et al. 1989) and 47% (Barrows 1990) to 30 days post hatch. Since 1990, a feeding regimen of FFK-B for 7 days followed by FFK-C for 21 days has become the standard reference for the evaluation of starter diets by the USFWS.

Using FFK diets as controls, an open-formulation starter feed (WS-9112) was developed that produced similar survival as FFK, but growth was slightly slower (Barrows 1991). This feed was composed of krill meal (42%), spray-dried whole egg (25%), ground trout fry and eggs (10%), cod liver oil (7%), liver and yeast extracts (6%), binders, vitamins, and minerals. The diet contained 51% protein and 24% lipid and was processed into spheres using an agglomeration technique known as "marumerization." This technique produces particles that are smoother and more uniform, and there are fewer fines than with standard granules. Subsequent testing revealed that while a portion of the krill meal could be replaced with low-temperature herring meal, fish meal hydrozylates seemed unpalatable to the fry (Barrows 1994). The cost of the diet was reduced by replacing spray-dried egg with commercial grade egg solids, and preparation time was reduced by replacing liver extract with liver meal. The result of those development studies is the WS-9501 formulation (Table 1). Feeding this diet can result in about 45% survival from hatching to 30 days with 95% swim bladder inflation when fed at a particle size of 250-410 um for the first 7 days and 410-725 um thereafter, in cylindncal tanks with a surface spray (Barrows, 1996).

Conversion diets

Conversion diets are defined as "feeds used to transition a fingerling from consuming live zooplankton in a pond environment to consuming manufactured pellets in a tank or raceway environment." The basic assumptions behind a conversion diet are that the stress of habituation is elevated by the radical change in dietary taste and texture, and that a feed intermediate in properties between live and manufactured diets will increase survival. This theory was substantiated by a trial in which survival was increased from 23 to 62% by feeding a commercial starter feed (FFK-C) versus a standard grower diet (W-16) for the first 10 days after pond harvest (Barrows 1990). Diet has been shown to be a major factoring affecting the survival of pond-reared fingerlings to formulated feed, but the importance of strong, healthy fingerlings must be considered.

[1] Use of trade or manufacturer's name does not imply endorsement.

No matter what feed is offered to the fish, if they are too skinny due to a lack of food in the pond, survival will be low.

Similar to a starter feed, the primary considerations in selection of a conversion diet are: the feed be highly palatable; must produce low levels of water pollution; and must contain additional energy to compensate for interrupted feeding. However, unlike a starter feed, the diets may contain less digestible feed ingredients due to the maturity of the gastrointestinal tract, and cost is more important due to the larger quantities of feed required.

Table 1. Percentage composition of selected USFWS walleye diet formulations.

Ingredient	Starter WS-9501	Conversion WC-9504	Grower WG-9206[a]
Krill meal	36.0	15.0	
Herring meal (low temp)	13.4		
Anchovy meal		37.0	49.50
Egg solid	20.0	4.5	
Artemia meal	8.0		
Liver meal	7.0	12.0	
Blood meal			4.75
Soybean meal			12.00
Corn gluten meal		8.0	8.25
Wheat flour		5.0	10.00
Fish oil	4.0	8.0	11.75
Binder (TIC-515)	3.0	3.0	
Binder (CMC)			2.50
Soy lecithin	2.0		
Yeast extract	2.0	2.0	
Vitamin mix-30[b]	3.0	2.0	0.60
Betaine		2.0	
Ascorbic acid	1.0	1.0	0.15
Mineral mix-3[c]	0.1	0.1	0.05
Inositol	0.1		
Choline chloride (70%)	0.4	0.4	0.45

[a] Currently commercially available.
[b] Contributed per kg of diet: vit. A, 10000 IU; vit. D3, 720 IU; vit. E, 530 IU; vit B12, 30 ug; calcium pantothenate, 160 mg; riboflavin, 80 mg; thiamin mononitrate, 50 mg; pyridoxine hydrochloride, 45 mg; folacin, 13 mg; menadione sodium bisulfate, 25 mg; biotin, 1 mg; niacin, 330 mg.
[c] Contributed in mg/kg diet: zinc, 100; manganese, 70; iron, 3; copper, 2; iodine, 1.

The first conversion diets were formulated using herring meal (44%), soybean meal (12%), alfalfa meal (10%), and fish oil (9%) as the primary ingredients (Barrows 1990). Survival rate using this diet (53%) was intermediate between that obtained with a starter diet (71%) and a grower diet (29%). Survival was also increased by incorporation of a feeding stimulant (a substance designed to increase palatability of the feed, Berkley Corp., Spirit Lake, Iowa) at 5% of the total diet. Weight gain during the conversion period was greater when the test diet was marumerized into spheres, as opposed to crumbles formed from pellets, perhaps due to less pollution of the culture tanks or to decreased pellet hardness. The use of propylene glycol as a pellet softening agent had no influence on survival in the marumerized feeds, but it decreased weight gain. Survival was equal whether lighting was continuous or set at 14L:10D.

Formulated with the goal to increase survival, a second series of diets which were higher in palatability was formulated using krill meal, spray dried egg, and cod liver oil as the major ingredients (Barrows et al. 1992). Feeding these dets resulted in survival rates >95% during the 21-day conversion period from live to dry feed, but mortality was unacceptably high during the subsequent transition to grower diets. Feeding smaller particle sizes (500 vs 800 um) or increasing moisture levels (25% vs 10%) increased survival during conversion, but incorporation of binding agents that produce soft, flexible pellets (Qulai Tech Inc., Chaska, Minnesota) did not (Barrows 1994).

This led to a third series of diets which utilized either krill, freeze dried artemia, or low-temperature herring meal as the primary source of protein (Barrows 1995). These diets were fed either dry (9% moisture) or wet

(27% moisture) for 21 days, at which time the fish were gradually converted to a standard grower diet. Final 46-day survival was highest for fish that were fed diets supplemented with freeze dried artemia (86%), followed by krill meal (77%), herring meal (65%), and FFK-C (61%). There was no real advantage to feeding the dets wet, except for a slight improvement in survival among fish fed the krill-based diet. These results indicate that feeding a *dry* diet supplemented with artemia, or a wet krill-based diet (WC-9404, Table 1) for 21 days following pond harvest will result in survival rates >75% through conversion to grower diets.

Transitiondiets

A modified form of the conversion diet, referred to as the "transition diet," is being developed to assist intensively cultured walleye fry convert from starter feeds to grower feeds. This was prompted by the repeated observation that a significant portion (up to 40%) of fry that had been consuming very palatable starter feeds would starve rather than switch to a grower diet. This mortality may be avoided by offering feeds intermediate in composition to the starter and grower diets during the transition period. However, there seem to be other factors involved in how well the fish will switch to the grower diets. Transition diets may be unnecessary in situations where: water temperature is about 21°C; fish are not stressed; fish are consuming the starter diet well and are in good condition; and pathogens are not prevalent. Further research is continuing to determine under which condtions survival can be improved through use of transition diets.

Growerdiets

A grower diet is defined as "a feed used to increase the size of a fish that has completed the early developmental phase of life, has a fully matured digestive system, and is readily consuming manufactured diets." Because the greatest quantity of feed used during an entire production cycle will be a grower diet, feed cost, fish growth rate, and feed conversion ratio become the primary factors that must be considered during formulation. As such, an effective measure of grower feed performance is the cost per lulogram of fish produced, which is an indicator of the overall effectiveness of the feed in a hatchery operation.

The initial focus of the &et development program of the USFWS was to produce a grower feed that equals the survival and growth of W-16 but is less costly to manufacture. An initial experimental diet (WG-8901) was formulated to contain 44% herring meal, 12% soybean meal, 10% alfalfa meal, 9% fish oil, and 8% corn gluten feed as the primary ingredients (Barrows 1990). This diet contained an amino acid profile similar to that of unfertilized walleye eggs, but had less total protein (50% vs 61%) and energy (3,500 vs 4,200 Kcal ME/kg) than W-16. During the 1989 and 1990 trials, the diet produced equal or better survival and growth as W-16, with a projected cost savings of about 20% (Barrows 1990,1991).

Subsequent trials indicated that: menhaden fish oil and cod liver oil served equally well as a lipid source; anchovy fish meal could replace herring fish meal; replacement of alfalfa meal with wheat flour increased growth; and the texturizing agent propylene glycol had a negative effect on weight gain (Barrows 1994, 1995). The resulting diet (WG-9206, Table **1)** contains 48% protein and 3,500 Kcal ME/kg and it has been commercially produced and fed at numerous walleye hatcheries in the **US** for several years. Although it is still more expensive than traditional trout feeds, it is significantly less expensive than W-16. However, it is anticipated that a decrease in grower diet cost will occur as commercial walleye production expands and greater quantities of walleye feed are needed.

Brood stock diets

Presently, there are no diets formulated specifically for reproductively active walleye, nor is there a demand for such dets because brood stock are commonly obtained from the wild immediately prior to spawning. Research on the nutritional requirements of brood stock is both expensive and time consuming, so the knowledge base for the most commercially important fish species is fairly limited. There are several laboratories preparing for long-term studies on the nutritional requirements of sexually mature salmonids, and this information may be applicable to walleye.

Nutritional requirements

To date, very little quantitative research has been published on the nutritional requirements of walleye. Barrows (1987) conducted two experiments to determine the protein and energy needs of fingerlings. In the first trial, protein levels of 50% and 42% produced the greatest growth among 8-g and 50-g fish, respectively, using isocaloric diets (3,470 Kcal ME/kg) that contained herring meal as the primary protein source. Energy density of these feeds was 6.9 Kcal ME/g protein for the small fish and 8.3 Kcal ME/g protein for the larger fingerlings. Carcass fat decreased as dietary protein increased, but carcass protein was unaffected. In the second experiment, a factorial arrangement of dietary protein and energy indicated that a feed containing 51% protein and 3,530 Kcal ME/kg (6.9 Kcal ME/g protein) would produce maximum weight gain in 14-g fingerlings. In a subsequent factorial experiment with 45-g walleye (Barrows 1990), fish fed a dietary combination of 42% protein and 3,600 Kcal ME/kg **(8.6** Kcal ME/g protein) had the greatest weight gain and carcass lipid deposition.

Barrows (1987) reported that supplementation of anchovy fish meal-based diets with synthetic amino acids to match the amino acid profile of unfertilized walleye eggs improved growth of **6-g** walleye. Diets balanced to mimic the amino acid pattern of whole walleye body gave equal performance, but at a lower feed cost than those that mimiced the egg (Barrows 1991). Other studies indicated that **8** mg/kg folic acid, 15 mg/kg pantothenic acid, and **96** mg/kg vitamin C were adequate for normal growth and prevention of vitamin deficiency symptoms (Barrows 1991).

Feed manufacturing technology

The delivery of manufactured feeds to an animal within an aquatic environment offers unique problems not encountered by the terrestrial animal industry. In a terrestrial environment, uneaten feed remains relatively nutritionally stable with time; however, in an aquatic environment feed rapidly deteriorates, losing nutritional value and polluting the culture system. This is an especially severe problem with starter feeds due to their small particle size and high porosity. The process of pelletization is a technique used to overcome some of the difficulties of feeding aquatic animals by packaging a combination of dietary ingredients into a form that can be delivered, consumed, and effectively utilized. The interaction between the manufacturing method and the ingredient characteristics has a significant and varying effect on the final cost, stability, consistency, and acceptability of the diet.

Because walleye remain essentially genetically wild (undomesticated), they often exhibit a reluctance to consume formulated feeds. Until the late 1980s, walleye diets were manufactured primarily using steam pelleting and cold extrusion technology developed for the salmonid industry. Presently, technologies borrowed from the terrestrial animal and pharmaceutical industries are making significant impacts on walleye culture. These technologies include cooking extrusion and the extrusion/marumerization process. However, no one production method can produce **an** optimal feed for all life stages of walleye. Understanding the effects of manufacturing technique on feed performance will help the producer select the feed best suited for a particular culture situation.

Steam *pelleting*

Steam pelleting refers to a process by which a mixture of dry or moist ingredients are mixed with a binder, exposed to steam to activate the binder, then passed through a circular rotating die under pressure to form a solid pellet. Binders usually consist of an indigestible material, often a wood processing by-product such as carboxy-methylcellulose or lignin sulphonate, incorporated at 2 to 4% of the formula weight. No cooking of the carbohydrate fraction occurs during the process, which produces a dense, sinlung particle. Feeds for smaller fish can be produced by crumbling and sifting the larger pellets.

Steam pelleting has been used to produce commercial fish feeds for a longer time period than any other manufacturing technique. The primary advantage of this method is that it adds the least cost to the final feed. Disadvantages include the breakage of pellets during shipping which results in wasted fines, and the release of binders with subsequent pellet disintegration after soaking in water. Crumbled starter feeds also have a very hard texture and sharp edges, qualities that may cause feed rejection by larval or pond-reared walleye. This is still a cost-effective method of feed manufacture, and can provide benefits over other processing methods in some instances.

Cold *extrusion*

Cold extrusion refers to a manufacturing process used widely throughout the food, chemical, and pharmaceutical industries in which no additional heat is added to the ingredient mixture during pelletization. Advantages of cold extrusion over steam pelleting are that smaller intact particles can be formed without crumbling or sifting, and greater amounts of wet ingredients can be incorporated directly into the diets. The lower processing temperatures also eliminate the degradation of some nutrients that can occur with techniques that require heat for pelletization.

The first cold extruders used for fish feeds were probably "pasta-type" machines such as those used to manufacture Oregon Moist Pellets. These machines consist of one or two screws that move a wet mash down a barrel and through a flat plate, producing a noodle which is then cut to form pellets. This type of extruder can generate a pellet as small as 1.0 to 1.5 mm in diameter, depending upon the characteristics and particle size of the ingredients used. Cold extruders can also be designed to discharge from the side of the barrel (called "radial discharge extruders") or through a twin-domed screen (LCI Inc., Charlotte, North Carolina) to produce noodles as thin as 0.5 and 0.3 mm in diameter, respectively.

A two-step pelleting technique known as "extrusion/marumerization" has been adapted from the pharmaceutical industry at the Bozeman Fish Technology Center for the production of small dameter aquatic feeds. Thin noodles produced through cold extrusion are placed into a rotating cylinder (the marumerizer) that contains a variable-speed grooved plate on the bottom. **As** the plate spins the noodles are broken into rods with a length roughly equivalent to the diameter, and the particles are then rounded through impact with each other and the plate groves. The exact shape of the final particle is dependent upon the diet formulation and moisture content. Spheres can be produced, but an elongated egg shape is more common. Centrifugal forces acting upon the feed during marumerization causes a migration of water and finer ingredients to the particle exterior, resulting in surface densification. This imparts a smooth texture and high water stability to the diet, characteristics that seem beneficial in fry feeds.

Cooking extrusion

Cooking extrusion, also referred to as "high-temperature, short-time extrusion," has been used to manufacture breakfast cereals and pet foods for many years. The predominant feature of a cooking extruder is a chamber in which feed is subjected to heat under high pressure. **A** sudden release in pressure occurs as feed exits the chamber, causing dietary carbohydrate to expand into a tight matrix that traps air. If enough carbohydrate is incorporated into the feed, the resulting pellet will float. Although equipment used in cooking extrusion is expensive when compared to steam-pelleting or cold-extrusion, the added sophistication allows for the production of diets with many physical characteristics which are not possible with other pelleting methods.

Cooking extrusion can be used to produce feeds that absorb and retain oils very effectively, even as great as 45 to 50% of the diet. These high-energy dets are used in salmonid hatcheries and net-pen operations to reduce total feed intake and thus lower solid waste discharge from the facility. Energy dense low-pollution diets may have advantages in some walleye culture operations, but the effects of high dietary fat on walleye performance has yet to be investigated.

The high temperatures and pressures employed during cooking extrusion will also increase digestibility of carbohydrates to carnivorous fish (Hilton et al. 1981). This has the advantage of increasing total energy available to the fish, yet it may lead to excess accumulation of glycogen in the livers of some coldwater species (Hilton et al. 1981). It is not known how walleye will react to high levels of digestible carbohydrate in the diet.

Conclusions

In conclusion, three factors should be considered when selecting a feed for walleye. First, does the feed contain the nutrients necessary for optimal growth and survival of the life stage under culture? Second, is the method of feed manufacture consistent with the goals of that phase of production? Third, will the selected feed function in the culture system that is used? By considering each of these topics, the culturist will be able to optimize their feeding program to fit their specific needs.

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