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Abstract
Walleye is a prized sport and food fish and is often on the menu of white tablecloth restaurants throughout the Great Lakes/ North Central Region (NCR) of the U.S. Commercial fisheries for walleye in the Canadian portion of Lake Erie, inland lakes in Canada, and a few tribal fisheries in U.S. These sources provide fish that are distributed by brokers for retail food chains and restaurants. The Freshwater Fish Marketing Corporation (FFMC) of Winnipeg, Canada, purchases 7 to 11 million lbs (3.2 to 5 million kg) of walleye each year, and then processes, packages, and markets them to the U.S. The FFMC purchases most fish from Aboriginal fishers.

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Comments
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North Central Regional
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Production of Walleye as Potential Food Fish

by R.C. Summerfelt, R.D. Clayton, J.A. Johnson, and R.E. Kinnunen

Walleye is a prized sport and food fish and is often on the menu of white tablecloth restaurants throughout the Great Lakes/ North Central Region (NCR) of the U.S. Commercial fisheries for walleye in the Canadian portion of Lake Erie, inland lakes in Canada, and a few tribal fisheries in U.S. These sources provide fish that are distributed by brokers for retail food chains and restaurants.

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Because of their popularity and limited supply, walleye are a high value species, with retail prices in the range from $6 to 12/lb ($13 to 26/kg) for skin-on fillets, equivalent to the priciest seafood in Midwest supermarkets (Figure 1).

Figure 1. Supermarket price of skin-on walleye fillets in central Iowa, compared with that of other species.

How valuable are cultured walleye?

As a point of reference, in July 2008, tribal fishers received $2.00/lb ($4.40/kg) for whole wild caught walleye from a Michigan processing facility; the processor retailed the fillets for $6.00/lb ($13.20/kg). There were no additional costs for distribution, brokerage fees, or markup required by other retail markets.

The well-developed commercial markets for walleye and its high market value suggest an opportunity for fish farms to culture walleye for food-fish markets. The small producer must understand that the quantities of fish needed for a full-time processing facility will exceed their production, and that they will rarely have the opportunity to market to chain supermarkets or franchise restaurants.

Inevitably, the small producer must master direct marketing to consumers and to farmer's markets, in addition to periodic sales to local, owner-operated food markets, and to small but upscale "white tablecloth" restaurants.

After adjustment using the average Consumer Price Index (CPI), the retail price of walleye fillets at supermarkets and specialty fish markets from 1987 to 2010 ranged from $7.63 to $16.95/lb for May 2010 (Figure 2). The slope of the line in that interval showed an upward trend in the price, which is a positive indicator for potential culture.

An effective business plan must focus as much or more effort on strategies for niche marketing as for fish culture. This fact sheet describes a cultural process for producing walleye to a size suitable for marketing as a food fish. The reader should examine other North Central Regional Aquaculture Center (NCRAC) publications for economic and marketing information: Hushak 1993; Swann and Riepe 1994; Riepe 1998 and 1999.

This fact sheet builds on the foundation of cultural technology for walleye that has been described in the Walleye Culture Manual (WCM), which is an extensively illustrated reference for walleye culture that was prepared with support from the NCRAC.

The WCM is available on the web, www.ncrac.org/Topics/walleyemanual.htm, and can be downloaded, chapter by chapter.

How are walleye currently cultured?

The majority of walleye cultured by both public and private producers are raised to fingerling size to stock lakes for recreational fishing. There are many commercial producers of walleye fingerlings in the NCR, especially in Minnesota, and Wisconsin, but there are also fingerling producers in Iowa, Ohio, and Michigan. Little, if any food-sized walleye are currently cultured in the United States.

Pond-raised fingerlings can be habituated (trained) to manufactured (pelleted) feed in indoor facilities, then raised to food size in either cages in ponds, indoor or outdoor raceways, circular tanks, or recirculating systems used for production of other species (e.g., hybrid striped bass, yellow perch).

Private producers of walleye fingerlings have the opportunity to utilize information on cultural technology for on-growing fingerling walleye for a size suitable for food-fish markets. Research-based information on production of food-size walleye and hybrid walleye has been described several times (Seigwarth and Summerfelt 1993; Summerfelt and Summerfelt 1996; Stevens 1996; Coyle et al. 1997). The economics and marketing of walleye food fish have been reported by Edon (1994), Makowiecki (1995), O'Rourke (1996), Riepe (1998, 1999), and Mahoney (2003).

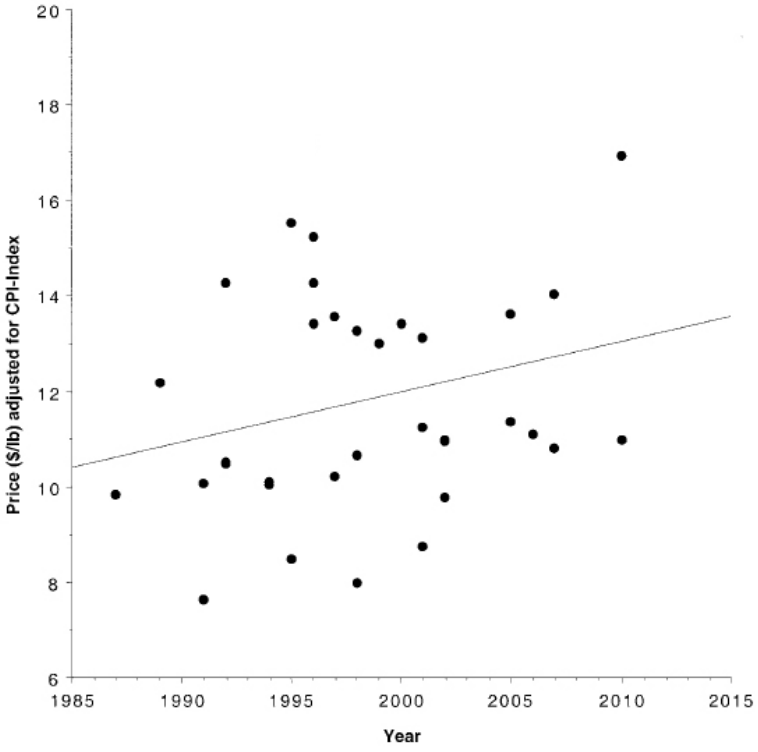

Figure 2. Retail price of walleye fillets in central Iowa, 1987-2010. Prices were adjusted with Consumer Price Index (CPI) to reflect 2010 values.

Surveys conducted by Mahoney (2003) in 2000 and 2003 showed that walleye were the clearly preferred fish in consumer perceptions, scoring the highest in comparison to orange roughy, cod, and sunfish in each category of appearance, flavor, mouth feel, and overall.

What size walleye is most desired?

Frozen skin-on fillets is the type of walleye purchased by the majority of restaurants and wholesalers (Riepe 1998). An 8- to 10-oz (227–284 g) fillet is the most common/desired size for both restaurants and wholesalers. A skin-on fillet of that size would require a live weight of 1.7 to 2.2 lbs (0.75 to 1.0 kg), assuming a 45% dressout yield.

The smallest product in the survey of Midwest restaurants and wholesalers was a 4-oz (113 -g) fillet (Riepe 1998). Fillets of this size comprised only 5% of the fresh fillets but 20% of the frozen fillets purchased by restaurants, and 12% and 9%, respectively by wholesalers.

Riepe (1998) pointed out that opportunities exist for selling different sizes of products, but walleye producers of food fish need to shop around to find buyers willing to accommodate their (i.e., the seller's) preferences regarding product forms and sizes.

What is the minimum food size for walleye?

A food fish is defined as the size that is acceptable for the market. Thus, market size is of major importance for fish culture because the less time it takes to raise fish to the required market size means reduced costs for feed and operation, and faster turnover of stock.

Similar considerations have been given for striped bass and its hybrids in South Carolina. Smith and Jenkins (1985) proposed a production model for pan-sized (0.66 to 1 lb, 300 to 450 g) fish that can be produced within a year in temperate climates; basically, a model plan for walleye.

As previously noted the minimum size for the current walleye market is ca. 4-oz (113-g) fillet. A fish that will yield two 4-oz (113-g) skin-on fillets would require a live weight of 1.25 lb (570 g) with 40% yield. Published studies have noted higher yields of skin-on fillets from 43-45% (Summerfelt et al. 1996a) up to 50-55% (G. Fischer, UWSP-Northern Aquaculture Demonstration, Wisconsin, personal communication).

However, to achieve a production model where fish can be marketed in one season (i.e., from spawning to harvest in October), a smaller size will be required. A 10-in (25-cm) walleye will weigh about 4.8 oz (136 g) and a 14-in (35-cm) walleye will weigh 14 oz (400 g). The standard market size of cultured yellow perch (0.33 lb, 151 g) yields two 1.1-oz (32-g) fillets at a 45% dress out (Hart et al. 2006). Therefore, perhaps markets for yellow perch would also accept walleye fillets of similar size.

Our experience indicates that yield of skinless fillets of different cohorts is related to the skill of the technician, the speed at which fillets are processed, and the relative robustness of the fish.

What system is best for culturing walleye?

Walleye are adaptable to both pond and tank culture systems, but overwhelmingly, ponds are the cultural system for rearing fry to fingerling size for stocking. In the NCR, however, it is unlikely that producers north of the borders of Michigan-Ohio, Wisconsin-Illinois, Minnesota-Iowa, or Nebraska-South Dakota, will be able to raise walleye in ponds to a 0.33-lb (151-g) market size in one growing season.

If young of the year fingerlings are transferred from ponds to an indoor facility for habituation, and then maintained over-winter at a temperature suitable for growth (≥ 68˚F, 20˚C) they can be grown to a food size in 16 to 18 months. Summerfelt and Summerfelt (1996) produced in intensive culture a 1.25-lb (567-g) walleye in 16 to 18 months, and Malison et al. (2003) grew walleye in indoor tanks to 0.5 lb (227 g), 12 in (30 cm) in 477 d (~16 months) at 70˚F (21˚C).

What are the desired carcass qualities?

Besides palatability, dress-out or carcass yield is an important characteristic for production of fish for the food market. Skinless fillets from tank-cultured walleye had protein content of 20.5%, and a fat content of 0.1 to 0.4%, values which place them in the low fat and high protein category of food fishes (Yager and Summerfelt 1996).

Walleye fillets are generally sold with skin-on (scaled). Relative to live weight, the yield of skin-on fillets was 44% for males and 39 to 41% for two cohorts of female walleye from Spirit Lake, Iowa (Summerfelt et al. 1996b). Rock Lake, Wisconsin walleye and hybrid walleye (saugeye) had slightly lower yields. Differences in head weight account for gender differences in yield of skin-on fillets—the head weight of males were less than the head weight of female fish from Spirit Lake, Iowa.

What are the three phases of walleye production?

Phase I. Fry to fingerling in ponds.

Detailed procedures for pond culture are described in the Walleye Culture Manual for both drainable (Summerfelt 1996) and undrainable ponds (Kinnunen 1996). A key to success during Phase II is to reduce stocking during pond culture (Phase I) to produce a fingerling with good condition. Fingerlings 600 to 800/lb (0.76 to 0.57 g) were obtained with a fry stocking density of 50,000/acre (20,234/ha).

Phase II. Habituation (training) pond-reared fingerlings to formulated feed in tanks.

The habituation process has been described by Kuipers and Summerfelt (1994), Flowers (1996), Malison and Held (1996), and Nagel (1996).

Keys to feed training:

- Culture system with covered tanks or a dark room with tanks equipped with submerged lights
- Larger fingerlings to start the habituation process
- Grading of fingerlings to uniform size to reduce cannibalism
- Otohime™ feed (Reid Mariculture, Campbell, California) for initial habituation

Tank size: The dimensions of the culture tank is a matter of economy of scale, but circular tanks from 5 to 20 ft (1.5 to 6.1 m) diameter have been used. Rectangular tanks are also suitable, but circular tanks are self-cleaning and are more favorable to the condition and health of the fish.

Light: Light is a critical issue as walleye are sensitive to light intensity. There are three options for dealing with light:

1) use uncovered tanks with low intensity (~ 10 lux) overhead lighting (Kuipers and Summerfelt 1994),
2) cover tanks with low intensity in-tank lighting (Nagel 1996), or
3) use a dark room with no tank covers, but with low intensity, in-tank lighting situated under the feeder (Rathbun Fish Hatchery[RFH] procedure).

Fish size and condition: The RFH in southern Iowa starts with pond-reared walleye that are about 1.8 in (45 mm) total length and weigh 0.02 to 0.03 oz (0.57 to 0.75 g). Survival at RFH during the habituation interval on a production scale has been as high as 92%. Whatever the size, fish should be graded to obtain uniform size in each tank.

Water temperature and growth: Water temperature during the habituation interval will have a major impact on growth, and that will ultimately impact the size at harvest (Table 1). For example, at RFH, the temperature during 2007 habituation interval was 6.1˚F (3.4˚C) warmer than in 2008, which resulted in 21 g and 27 mm (~1 in) difference in size on October 1, 2008, when the fish were harvested. In addition, whereas 91% of the fish at harvest in 2007 were greater than 9 in (23 cm), only 63% reached that size in 2008 (Table 1).

Feed and Feeding: Note since the publication of the Walleye Culture Manual, BioKyowa Fry Feed is no longer available in the United States.

During the first 10 d fingerlings are fed 100% of a specialty diet, preferably the Otohime feed, or EPAC (INVE Aquaculture, Inc.). Feed size is about 1 mm to start.

Although one may be tempted to use a less expensive starter diet, survival will decrease, costing the culturist the price of the fish that did not survive, which would likely be more expensive than the higher cost of the specialty feed.

The specialty diet (Otohime C2) is systematically reduced until day 17 when the fish are on 100% of a growout diet. They can be maintained in the same site for another week or moved to the growout site. Feeding rate and frequency are important to survival. During the habituation interval, the initial feeding rate is 6 to 8% body weight per d, with feeding frequency of 5 minutes, 18 to 22 hours/d. Initial density of 0.19 lb/ft^3 (3 kg/m^3) is suitable.

The traditional growout feed is the walleye grower formulation (WG).

- Day 1-10:100% C2, 0.900 to 1,400 µm (0.9 to 1.4 mm)
- Day 11-12: 75% C2, 25% 1 mm WG
- Day 13-15: 50% C2, 50% 1 mm WG
- Day 16-17: 25% C2, 75% 1 mm WG
- Day 18-24: 100%, 1 mm WG
- Day 25-28: 100%, 2 mm WG

The WG feed is an open formula described in the Walleye Culture Manual (Barrows and Lellis 1996). It has 47% crude protein and 17% crude fat. Only one mill has manufactured this feed (Nelson and Sons, Inc., Murray, Utah), and availability has been seasonal; however, highly specialized diet formulations (e.g., WG) are not required for juvenile walleye (Summerfelt and Clayton 2007). The price of the WG feed is higher than other feeds from the same source, but not all commercial feeds produce similar growth rates (Stettner et al. 1992). A substitution of soy oil for fish oil lowered the price of the WG diet by 10 cents per pound without a significant difference among diet treatments in relative growth, specific growth, or survival (Clayton et al. 2008). The feed, however should not have less than 45 to 50% protein.

Disease: Most mortality occurs in the first 8 d of feed training and results from a combination of handling stress, disease, lack of feed acceptance, and cannibalism. Although cannibalism is a frequent concern, it generally accounts for much less mortality than disease. Columnaris disease (*Flavobacterium columnare*) is a major cause of disease in the first week of feed training and is more prevalent at temperatures above 68˚F (20˚C).

When columnaris occurs, treatment is required. The most effective treatment has been with diquat dibromide but it is not a FDA/CMA approved drug. Diquat, however, may be used with an approved INAD (Investigational New Animal Drug). A quick reference guide to the FDA/CVM web site should be consulted for approved drugs (Available: www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/de-

Table 1. Mean water temperature during the culture interval and fish size at the end of Phase II and III; and size distribution of walleye cultured at Rathbun Fish Hatchery in 2007 and 2008.

	2007	2008
Temperature °F (°C)		
Phase II (June - July)		
Mean	75.6 (24.2)	69.5 (20.8)
Range	70-82 (21.1-27.8)	63-74.2 (17.2-24.2)
Phase III (July - October 1)		
Mean	75.6 (24.2)	74.6 (23.7)
Range	68-81 (20.0-27.2)	69-81 (20.6-27.2)
Fish data end of Phase III		
Length, in (mm)	9.9 (251)	9.1 (230)
Weight, oz (g)	4.8 (137)	3.9 (110)
Length Distribution at Harvest	%	%
7-7.9 in (178-200 mm)	1.0	4.0
8-8.9 in (203-226 mm)	7.8	33.4
9-9.9 in (229-251 mm)	44.4	57.9
10-10.9 in (254-277 mm)	44.1	4.7
11-11.9 in (279-302 mm)	2.7	0.0
Total	100.0	100.0

fault.htm June 2010). Treatment is usually 15 to 18 mg/L for 1 to 2 h for 3 to 4 consecutive d.

Hydrogen peroxide is an approved drug (35% PEROX-AID, NADA 141-255) for use with freshwater-reared coolwater finfish to control external columnaris disease. Although hydrogen peroxide at 50 mg/L (ppm) for 60 min significantly reduced mortality in walleye infected with external columnaris (Rach et al. 2003), it is toxic to walleye at concentrations that do not harm other species. Clayton and Summerfelt (1996) reported a lethal concentration (LC50) of 145 mg/L from a 1 h exposure. To provide a safety margin, they recommended that fingerling walleye not be exposed to more than 50 mg/L. Diquat has a much larger safety margin.

Phase III. Growth of feed-trained fingerlings to market size.

Fish should be graded before stocking for Phase III culture to reduce cannibalism. Grow-out may be done in tanks, raceways, or cages. It would be best to shade the fish from bright light. Although RFH does not shade their tanks, the water supply has a natural turbidity due to suspended solids in the lake water. A water temperature of 75 to 77˚F (24 to 25˚C) provides for optimum growth but fish should not be handled or stressed at that temperature or risk outbreak of columnaris disease. There is no growth at temperatures less than 59˚F (15˚C). A 16L:8D photoperiod is appropriate for indoor culture, but research has not been done to define the relationship between photoperiod and growth, or the likely interaction between photothermal conditions and reproductive development. Onset of sexual maturity will not be a problem in the first summer, but will slow growth rate by the end of the second summer. Water quality must be monitored for dissolved oxygen, pH, nitrites and ammonia.

Feed, Feeding, and Growth: After habituation, fish may be fed WG or a high quality salmonid feed. Feeding rates after habituation should start at 6 to 8% body weight per d, then gradually reduce to 4%, 3%, and 2% depending on water temperature. At RFH walleye grow to 9 to 10 in (230 to 254 mm), 3.9 to 4.8 oz (110 to 137 g) in about 155 d from stocking ponds with 2-d old fry to October 1 with 80% survival (Johnson and Rudacille 2008, 2009). Their experience demonstrates that with optimum temperature walleye can reach a market size in one summer (Tables 1 and 2).

Processing: In the Great Lakes region there are some small-scale aquaculture producers who manage the hurdle of processing their own fish using an established Hazard Analysis and

Table 2. Size and fillet characteristics of 181 d posthatch juvenile walleye (hatched May 2 and processed October 30, 2009) that were cultured in indoor tanks at Rathbun Fish Research Facility.

	English	Metric
Whole fish		
Length inches/mm	9.7	245.8
Weight lb/g	0.315	143.1
Number of fish per lb or kg	3.2	7.0
Individual Fillets		
Fillets, skin-on[2] oz/g	1.23	35.0
Fillets, skin-off oz/g	1.01	28.7
Yield (both fillets as % wet weight)[3]		
Fillets, skin-on	48.7	48.7
Fillets, skin-off	39.9	39.9
Summerfelt et al. 1996 Table 2 values		
Fillets, skin-on (%)	42.1	
Fillets, skin-off (%)	33.6	

[1]Wr = $(w_o/w_s)100$, where w_o = observed weight and w_s = standard weight of each specimen of the measured length (Murphy et al. 1990).

[2]Scales were not removed.

[3]Skin-on fillets in that study were scaled and both skin-on.

Critical Control Points (HACCP) program. Or they can have their product processed by a commercial processor.

Variable Production costs: Production costs at a commercial facility will vary with economy of scale and the local infrastructure for aquaculture. For propriety reasons, it is difficult to obtain economic information from private producers, therefore, data presented from the 2008 operation at the Rathbun Hatchery serves as an example of a large production operation. The variable costs were about $1.10 for a 10 in (254 mm) fish. Most of the expenses were in Phase III (73%) when all inputs (i.e., feed costs) are substantially greater. Although costs per pound of feed were higher in Phase II for specialty feeds, the Phase II interval is short. Note that fixed costs, e.g., building construction can be substantial.

At Rathbun, the use of a raw water supply contributed to a constant problem treating ich, *Ichthyoptherius multifilis*, which made chemical costs a substantial part of total costs (Figure 3).

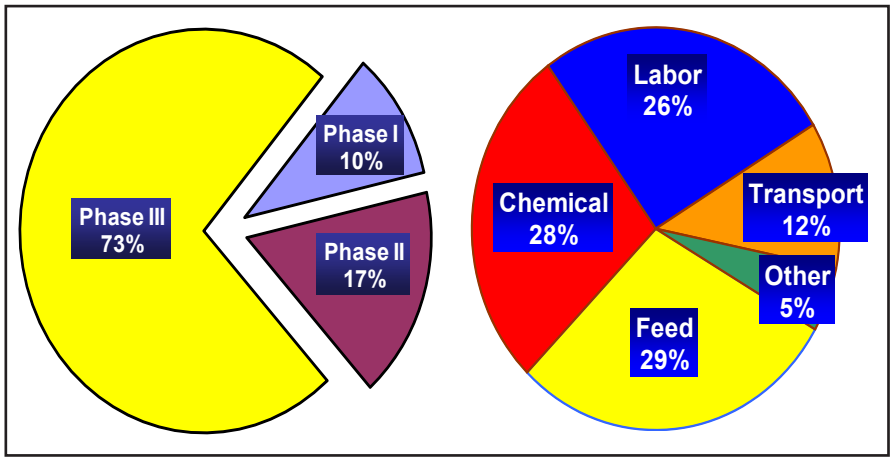

Figure 3. Production costs for the 5-month, three phase production process (left): Phase I is pond culture of fry to June fingerling, Phase II is the habituation of pond-reared fish to formulated feed (indoors); and Phase III is the growout to fall (outdoor tanks). Total variable costs (right) for the 2008 culture season at Rathbun Fish Hatchery to produce a 9-10 inch (228-254 mm) walleye with 80% survival from fry was $1.10 per fish.

Advice that favors success

Start with robust (good condition), pond-reared fish that have no signs of disease.

- Transport fingerlings from pond site to growout facility in 0.5 to 1% salt, NaCl (8 lbs/100gal for a 1% solution).
- Maintain the temperature of transport water at or below 68˚F (20˚C) to reduce problem with columnaris disease.
- Conscientiously follow light and feeding protocols during Phase II culture.
- Do not substitute lower cost starter diets for the specialty diets in Phase II.
- Develop niche markets that will accept a petite fillet, about 1.1 to 1.4 oz (31 to 40 g) size.

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