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Chapter 9

Aquaculture of Walleye as a Food Fish

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Introduction

Food-size walleye

A food-size walleye is defined as the size that is acceptable for a given market (Figure 1), but the smaller the acceptable size, the faster the turnover time in the culture system. The premises we used to define the minimum live weight of a food-size walleye are based on portion size and fillet dress-out percentage; a 40% dress out for a skin-on fillet would require a live weight of 1.25 lbs (567 g) to obtain two 4-oz slun-on fillets (Summerfelt et al. 1996).

Culture systems for raising food-size walleye

The technology selected to raise food-size walleye is critical for the success of commercial culture. The lack of a real commercial system means we must speculate about production strategies. Both extensive and intensive culture systems arc examined.

Pond culture of phase I and phase II fingerlings has been a viable commercial enterprise for many years at many locations in the north central region, especially Minnesota. Presently, the entire crop of fingerlings is marketed to individuals, angler groups, lake associations, and public agencies for stoclung (Kinnunen 1996). In a 1991 survey of fish producers in the 12 states of the north central region, 16.4% of the 295 respondents reported that they were raising walleye; walleye represented **8%** of total gross sales for the region, and ranked fourth of 61 cultured species (Hushak 1993).

A scenario of pond culture of food-size walleye is given, and although some aspects are speculative because of research gaps of various aspects of the process, the facts are not encouraging for successful production of walleye to food-size in ponds. The culture practice for raising walleye to food size in ponds might proceed as follows: Phase I fingerlings (1.25-to 2.5-in [32-64 mm]), would be harvested from ponds, and habituated to formulated feed either in intensive culture or after restocking ponds at a density appropriate for growth to an advanced size. Phase I fingerlings must be harvested because fish density must be known before grow-out to phase II fingerlings can occur. Although we are not aware of any report describing habituation of walleye to formulated feed in ponds, they have been converted to feed in cages in ponds (Blazek 1996; Bushman 1996; Harder and Summerfelt 1996; Stevens 1996).

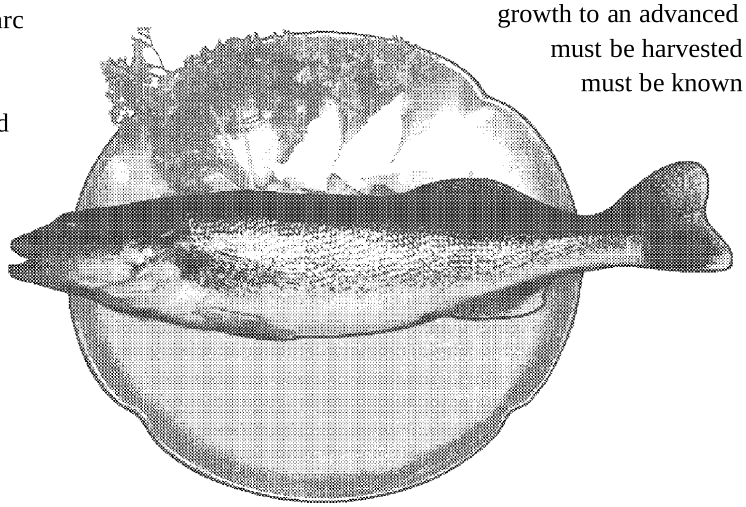


Figure 1. A food-size walleye and a standard 10-in (254 mm) dinner plate for comparison.

After stocking grow-out ponds at an appropriate density, fingerlings would be raised to the end of the growing season to a size known as “phase II fingerings”. The average size of phase II fingerling by the end of the first summer may be 5 to **8** in (127-203 mm). Stevens (1996) reported that fingerlings reached “about 8 in (203 mm) by the fall of the first year in southern Iowa, but a 10-in (254 mm) average may be reached in the southern part of the north central region. Although phase II fingerlings must be overwintered, overwintering walleye fingerlings in Iowa has been accomplished with minimal mortality providing ponds are adequately aerated (Bushman 1996). Bushman (1996) fed caged walleye at the rate of 1% of their body weight per day from November through April, but the fish did not grow and their condition declined over-winter.

The culture routine would continue in the second summer. Stevens (1996) said that most fish reached 12 to 14 in (305-356 mm) by the end of the second summer. Based on the experience of Stevens (1996) and Bushman (1996), the short growing season in Iowa precludes walleye reaching food-size until the middle to latter part of the third summer. The culture interval needed to reach food-size would be even longer in northern Michigan, Minnesota, North Dakota, Wisconsin or Canada.

Major impediments to the success of a pond culture strategy will be the long turnover time from fry to market size; potential winterlull; and although walleye may tolerate temperatures up to 90°F (32°C) for short periods (Collette et al. 1977), prolonged high summer temperatures may result in summerkills as well.

On the other hand, intensive culture of walleye fingerlings is a well-established practice. Phase I pond-raised fingerlings are commercially available in abundant supply, and they can be habituated to formulated feed in intensive culture with survival rates as high as 90% (Nagel 1996). Also, if ponds are not available to produce phase I fingerlings, fry can be cultured intensively by feeding them brine shrimp or formulated feed (Colesante 1996; Moore 1996; Moode and Mathias 1996; and Summerfelt 1996b). Facilities for intensive culture of fry allow use of out-of-season spawning to obtain fry at least twice per year. Once feed-trained fingerlings (i.e., fingerlings that are habituated to formulate feed) are produced, there are many commercial feeds suitable for grow-out to food size in intensive culture (Stettner et al. 1992; Bristow 1996), and open formula Qets have been developed for specific life stages of walleye (Barrows and Lellis 1996).

Flow-through culture can be used to produce phase II fingerlings and for grow-out to food size. It is the major cultural technology used for raising rainbow trout. Phase I walleye fingerlings are often habituated to formulated feed in raceways; many public agencies use this technology to produce phase II fingerlings. It should not be difficult to raise walleye to food size in raceways or circular tanks, although the tanks would have to be covered in order to reduce light intensity to levels suitable for light-sensitive eyes of walleye; walleye cannot be cultured in full sunlight. The major constraint to flow-through culture of walleye is the requirement for an abundant supply of water in the range 68-77°F (23.8-25°C). Growth rates of walleye at temperatures <60°F (15.5°C) are nearly zero. Thus, the major constraint to general use of flow-through culture is the availability of sufficient water sources with desirable water temperatures. In northern parts of the **U.S.** and Canada, ground water temperatures are typically <50°F (10°C), and it is impractical to heat water for a single-pass system.

Recycle systems are a third technology that can be used for walleye culture (Summerfelt 1993). The advantages of recycle culture systems for raising walleye to food size are the same as those for other species: controlled water temperature that creates a 12-month growing season; low water requirements relative to production capabilities; a small volume of concentrated waste; and the ability to locate a facility close to major markets. In recycle culture, fish are stocked at high densities, raised on pelleted feeds, and there is an intentional effort to minimize the use of new water to ≤5% or less of total system volume per day. The effluent from the culture tanks can undergo several treatment processes before it is returned to the culture tank: clarification to remove solids; nitrification (biofiltration) to convert ammonia to nitrate; reaeration or reoxygenation; and disinfection by passing water through tubes with UV lamps or by ozone injection (Summerfelt 1996).

Recycle systems can be used to culture walleye anywhere in North America because the volume of water used is typically ≤5% of the water requirements needed for a single-pass system (Summerfelt 1996). If water needs to be heated to obtain the desirable temperature for growth, it must be reused if it is to be economic. Hushak's (1993) survey of fish producers in the North Central Region indicated that 89% used ponds, but a surprising 14% used some form of recycle system to produce a variety of fishes. There are many recycle culture facilities in the Midwest and elsewhere that raise food-size tilapia, and others that raise hybrid striped bass. Moode and Mathias (1996) have designed a recycle culture system for walleye for sites as far north as Winnipeg, Canada. Summerfelt (1996) provides design criteria for large-scale recycle system for walleye culture.

Objectives

The objectives of this chapter are to report dissertation research by Summerfelt (1993) in which walleye were raised in a recycle system for one year and to review selected topics related to intensive culture of walleye as a food fish. Data from the literature are used to analyze growth of walleye in relation to temperature and fish size. This information, as well as other factors that influence success of walleye culture in a recycle facility, is examined to determine the feasibility of culturing walleye to food size.

Walleye cultured in a recycle culture system

Background

Summerfelt (1993) raised walleye in 264-gal (1,000 L) circular tanks in a recycle system used for research on nitrification and clarification. Walleye were raised in the recycle system until they were 368 days old. That study is used here as a basis for estimating how long it would take to raise walleye to food size.

Upon introduction of the 55-day-old pond-raised fingerlings to the intensive culture system and during the interval of training fingerlings to formulated feed, the temperature was held at 68°F (20°C) to prevent an outbreak of columnaris. During the rest of the culture period, the average temperature was 93.4°F. The maximum temperature observed was 80.6°F during the summer. Turbidity usually ranged from 15 to 30 NTU’s. However, during short and irregular intervals when the biofilter sloughed biofilm, turbidities reached 120 NTU's. Light intensity at the water level was about 10 lux.

Fish

Fingerlings were obtained July 17, 1990 from Welch Lake, a 57-acre (23 ha) production site of the Iowa Department of Natural Resources Spirit Lake Hatchery (Jorgensen 1996). Parent fish were from Spirit Lake and East and West Okoboji Lakes in northwest Iowa. Fry were stocked in Welch Lake when they were 3 days old. Fingerlings were stocked into the culture tanks when they were 55 days old; they averaged 1.8 in (46.4 mm) long and weighed 298.4/lb (1.52 g). At the end of a 30-day training interval (84 days old) the fish averaged 90.7/lb and 3.4 in (200/kg and 87 mm).

Feeding

Fish were fed 16% of their body weight per day in the 3-week interval they were habituated to formulated feed. Feeding rates and feed sizes were altered as the fish grew (Table 1). Feeding rates now used for habituation fingerlings are considerably less, and recommendations for that process are described by Bristow (1996), Flowers (1996), and Nagel (1996).

Fish density

Fingerlings were stocked at 35.2 fish/ft^3 (1,250/m^3), a density of 0.38 lb/ft^3 (6.25 kg/m^3). Walleye were grown to a density of 4.5 lb/ft^3 (72.1 kg/m^3). **A** density of 6.0

Table 1. Feed type and size used in walleye growout experiment.

Fish weight (g)	Feeding rate (% BW/day)	Feed size	Feed type'
5	16.0	**4** crumble	Biotrainer
11	8.0	**2.4**(3/32-in)	BioDry
15	6.0	3	BioDry
40	5.0	4	BioDry
80	4.0	6	BioDry
160	3.0	8	BioDry
250	1.8	9.5	WG9015

[1] Biotrainer and BioDry feeds were from Bioproducts, Warrenton, Oregon: walleye grower diet (WG9015) was from Nelson & Sons, Murray, Utah.

lb/ft^3 (96.2 kg/m^3) was attempted for a short period, but it was discontinued because dissolved oxygen ≥5 mg/L could not be maintained with only diffused air; pure oxygen was not used.

Length-weight relationship

Because the relationship between fish length and weight is curvilinear when expressed arithmetically, a log-log (base 10) transformation of length-weight data was used to obtain a straight line fit (Figure 2).

The log-log equation was: $\log_{10}(W) = 2.929 \log_{10}(L) - 4.91$, where $\log_{10}(W)$ is the log base 10 of the weight of the fish in grams and $\log_{10}(L)$ is the log base 10 of the length of the fish in millimeters. Using this equation, a 16.3-in walleye (415 mm) would have a calculated weight of 1.25 lb (567 g). The calculated weights of walleye from 1 to 20 in (25-508 mm) are presented in Table 2.

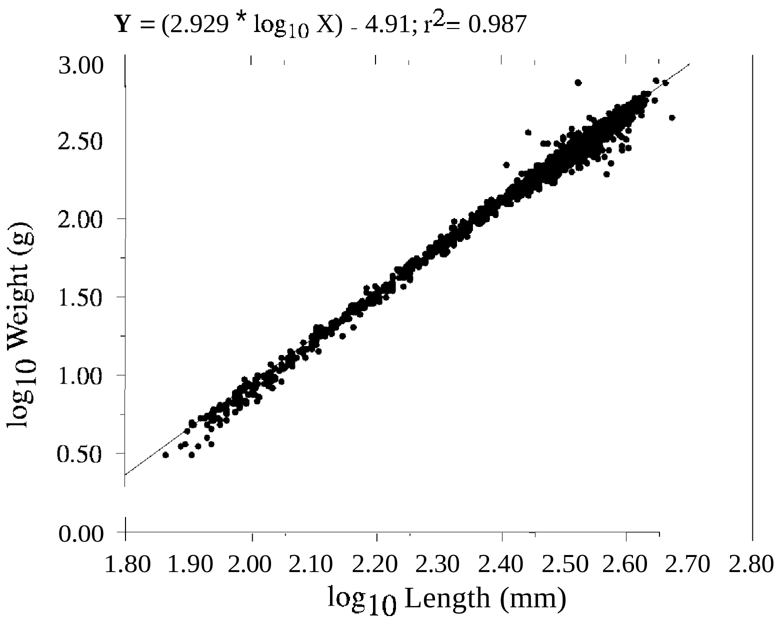


Figure 2. Logarthmetic relationship between length and weight of walleye grown in a recycle system (data from Summerfelt 1993). Graph is of 2801 measurements of length and weight of walleye 55 to 532 days old.

Length-weight data for fish 1 to 10 in (25-254 mm) total length from Piper et al. (1982) that represented fish with a condition factor similar to walleye was used to calculate the following equation: $\log_{10}(W) = 3.033 \log_{10}(L) - 5.136$. Data generated from this equation indicates that a 1.25-lb walleye would be 15.7 in (398.8 mm) (Table 2).

Robustness, or plumpness, can be expressed by the condition factor (k):

$$k = \frac{w\,(g) \times 100{,}000}{L(mm)^3}$$

Where w is the weight in grams and L the length in millimeters. The value 100,000 is used to produce a k value that will be near 1.0. The mean k value for fish raised by Summerfelt (1993) was 0.895; the k value calculated for data from Piper et al. (1982) is 0.835; and the k value for the data calculated with the equation for W_s is 0.938. Mean k values reported for wild populations (sexes combined) range from 0.81 to 1.23 (Coby et al. 1979). Carlander (1950) reported that k values >1.02 were excellent, 0.89-0.97 average, and values <0.83 were poor. In wild populations, food availability seems to be the major factor affecting k values (Colby et al. 1979).

Although gender differences in length-weight relationship or condition factor of walleye have not been found in natural populations (Colby et al. 1979), the k-value may be affected by genetic dfferences among populations, the size of fish used for the computation (larger fish tend of have larger k-values), and environmental factors, a standard weight (W_s) for each length can be calculated from an equation that is based on data for many walleye populations (Murphy et al. 1990). The equation for W_s **is:** $\log10(W_s) = 3.180 \times \log10(L) - 5.453$, where W_s is the standard weight of the fish in grams. The length of a walleye that weighed 1.25-lb (567 g) would be 15 in (480.8 mm). Data for computing W_s were from wild caught walleye which had a more robust body form than the cultured walleye reported by Summerfelt (1993).

W_s may be used to compute relative weight (Wr), which is the ratio of the observed weight (W_o) that of the W_s for a fish of a given length: $W_r = (W_o/W_s) \times 100$. Table 2 provides data for W_s for walleye from 1 to 20 in (25.4-508 mm) from Murphy et al's (1990) equation, and relative weight from calculated weights from L-**W** equations generated from data from Summerfelt (1993) and from Piper et al. (1982).

Table 2. Calculated weight and relative weight (Wr) of walleye from length-weight regression equations of Summerfelt (1993) and Piper et al. (1982), and Murphy et al's (1990) data on standard weight (W_s).

Length	Summerfelt (1993)		Piper et al. (1982)		Standard weight
inches (mm)	lbs (g)	W_r	lbs (g)	W_r	(W_s) lbs (g)
1 (25.4)	0.004 (0.160)	155.0	0.0003 (0.127	122.9	0.0002)(0.100)
2 (50.8)	0.0027 (1.220)	130.3	0.0023 (1.04)	111.0	0.0021 (0.94)
3 (76.2)	0.0088 (4.002)	117.7	0.0078 (3.56)	104.6	0.0075 (3.40)
4 (101.6)	0.0205 (9.294)	109.5	0.0188 (8.51)	100.2	0.0187 (8.49)
5 (127.0)	0.0394 (17.867)	103.5	0.0369 (16.75)	97.0	0.0381 (17.26)
6 (152.4)	0.0672 (30.476)	98.9	0.0642 (29.11)	94.4	0.0680 (30.82)
7 (177.8)	0.1055 (47.869)	95.1	0.1024 (46.47)	92.3	0.1109 (50.32)
8 (203.2)	0.1560 (70.780)	92.0	0.154 (69.67)	90.5	0.1696 (76.95)
9 (228.6)	0.2203 (99.939)	89.3	0.220 (99.58)	89.0	0.2467 (111.91)
10 (254.0)	0.3000 (136.07)	87.0	0.302 (137.1)	87.6	0.3449 (156.45)
11 (279.4)	0.3966 (179.89)	84.9	0.404 (183.0)	86.4	0.4670 (211.84)
12 (304.8)	0.5117 (232.103)	83.1	0.525 (238.3)	85.3	0.6159 (279.36)
13 (330.2)	0.6469 (293.43)	81.4	0.670 (303.8)	84.3	0.7944 (360.34)
14 (355.6)	0.8037 (364.56)	79.9	0.838 (380.3)	83.4	1.0055 (456.1)
15 (381.0)	0.9837 (446.20)	78.6	1.033 (468.8)	82.5	1.2522 (568.0)
16 (406.4)	1.1884 (539.04)	77.3	1.257 (570.2)	81.8	1.5375 (697.39)
17 (431.8)	1.4193 (643.79)	76.1	1.511 (685.3)	81.0	1.864 (845.67)
18 (457.2)	1.6780 (761.12)	75.0	1.797 (815.1)	80.4	2.2360 (1,014.2)
19 (482.6)	1.9659 (891.72)	74.0	2.117 (960.3)	79.7	2.655 (1,204.5)
20 (508.0)	2.2846 (1036.28)	73.1	2.474 (1,122.0)	79.1	3.126 (1,417.9)

Growth rate

Fish were 84 days old at the end of the interval when they were habituated to formulated feed. At that time they were 3.4 in (87 mm) long and weighed 90.7 fish/lb (5.0 g). After an additional 284 d (368-d old), they grew to an average of 342.5 mm and 342 g. We use data from this group of fish to examine two questions:

1) How long must walleye be cultured to reach the minimum market size of 1.25 lb (567 g)?
2) Will growth rates show a sudden change as fish undergo sexual maturity?

Walleye had not reached market size by 368 days, therefore, an estimate of their age at 1.25 lb (567 g) requires extrapolating their growth history (Figure 3). There was a good fit of fish weight-age data for both the largest 20% and the average fish; r^2 values were 0.99 and 0.98, respectively. An estimate of the days needed to reach 567 g would be <410 days (13.5 months) for the largest 20% of the population and 480 days (15.8 months) for the average fish. We used the largest 20% as an indicator of what might be achieved with domestication and selective breeding (Kapuscinski 1996).

Growth rates declined continuously with increase in age (Figure 4). The rectilinear change from 55 to 368 days does not suggest a sudden change related to onset of sexual maturity. However, because sex was not determined, gender differences are masked. In wild populations, males are typically younger and undergo sexual maturation at a smaller size than females (Scott and Crossman 1973).

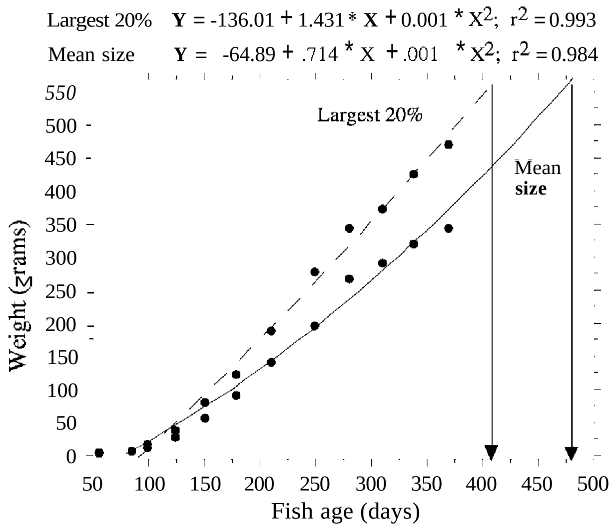


Figure 3. Growth curves for the average and the largest 20% of the walleye in an experimental recycle system raised at an average temperature of about 23°C. Extrapolation of the growth curves suggest that it will take 410 days for the fastest 20% of the population and 480 days for the average fish to reach food-size (1.25 lb [567 g]).

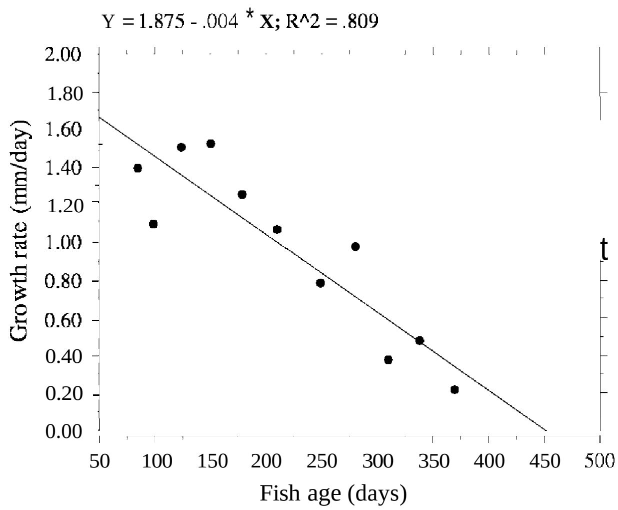


Figure 4. Growth rates (mm/day) of walleye raised in a recycle system from 84 to 368 days. Data for growth rates are plotted at the end of the growth interval for which the rate was determined (e.g., the first interval was from 55 to 84 days, the last from 337 to 368 days).

Review of walleye growth

Growth rate determines how long it will take any fish to reach a market size. Data for reports on intensive culture of walleye are summarized in Table 3. These data can be used to examine the relationship between temperature and growth, optimum temperature for growth, and another opportunity to determine whether growth rate decreases with the onset of sexual maturity.

Growth rate, expressed in in/d (mm/d) or as UGR (unit growth rate), which is growth rate as a function of temperature (cm/d/°C) (Westers 1987), declines with increasing fish age (Figure 5). The regression coefficient (r^2) indicates that size accounts for about 40-42% of variability in growth rate.

The mean growth rate for the data in Table 3, which is a mean of means, was 0.0240 in/day (0.61 mm/d)—0.72 in/month— at a mean temperature of 71.4°F (21.9°C).

If walleye has a precisely defined optimum temperature for growth, a display of bivariate data on growth rate and temperature should

Table 3. Summary of research on growth rates (mm/d and unit growth rates [UGR]) of walleye fingerlings raised in intensive culture. UGR is mm/d per °C (Westers 1987).

Temperature °F (°C)	Length: Initial in (mm)	Length: Final in (mm)	Growth rate: in/d (mm/d)	Growth rate: UGR	Length of grow-out (days)	Reference
71.6 (22)	1.2 (31.5)	4.2 (108)	0.026 (0.67	0.0031	113	Nagel (1976) (1975 data)
69.8 (21)	4.9 (124)	6.6 (168)	0.025 (0.63)	0.030	70	Barrows et al. (1988)
69.8 (21)	4.6 (117)	6.7 (170)	0.024 (0.62)	0.030	85	Malison et al. (1990)
69.6 (20.9)	2.7 (68.1)	4.8 (123)	0.032 (0.82)	0.039	65	Kuipers (1990)
69.6 (20.9)	2.7 (68.1)	5.1 (129)	0.036 (0.920)	0.044	65	
76.5 (24.7)	3.3 (84.5)	6.2 (157.3)	0.033 (0.848)	0.034	84	
62.6 (17)	5.8 (146.9)	6.1 (156)	0.0047 (0.12)	0.0007	73	Siegwarth and Summerfelt (1990)
69.8 (21)	5.7 (145.2)	7.0 (178.3)	0.018 (0.45)	0.0021	73	
73.4 (23)	12.3 (313)	13.5 (344)	0.010 (0.26)	0.0011	119	Yager (1991)
73.5 (23)	10.2 (258)	12.9 (329)	0.021 (0.54)	0.0023	131	
77 (25)	6.9 (176.2)	8.5 (215.6)	0.022 (0.55)	0.0022	72	Siegwarth and Summerfelt (1992)
67.6 (19.8)	6.3 (159.2)	7.9 (200.4)	0.023 (0.58)	0.0029	70	Stettner et al. (1992)
67.3 (19.6)	8.8 (224)	10.2 (259)	0.013 (0.32)	0.0016	98	
69.3 (20.7)	11.2 (285.3)	12.8 (323.9)	0.012 (0.31)	0.0015	126	Siegwarth and Summetfelt 1993
75.2 (24)	3.4 (87)	13.6 (345)	0.036 (0.90)	0.0037	286	Summerfelt (1993)
20.5	68.1	90.6	0.804	.0039	28	Kuipers and Summerfelt (1994)
20.5	68.1	96.5	1.016	.0050	28	
20.1	69.3	84.1	.529	.0026	28	
24.9	69.3	87.2	.640	.0026	28	
69.4 (20.8)	2.7 (67.9)	3.4 (85.7)	0.025 (0.636)	0.0031	28	
77.4 (25.2)	2.7 (67.9)	3.4 (90.6)	0.032 (0.810)	0.0032	28	
74.3 (23.5)	3.0 (76.2)		0.024 (0.58)	0.0025	104	Flickinger (1996)
			0.021 (0.53)	0.0023	104	
			0.017 (0.45)	0.0019	222	

show a domed (parabolic) curve with a peak at the optimum temperature. We plotted information from Table 2 and applied the equation for a parabola (second degree polynomial) to determine an optimum temperature (Figure 6). The regression coefficients were not statistically significant ($p \geq 0.05$); therefore, inferences drawn from Figure 6 are only suggestive. The graph suggests no growth at culture temperature <60.0°F (15.6°C). The maximum growth rate, 0.00288 in/day (0.7307 mm/day) would be at a temperature of 74.1°F (23.4°C); however, the dome of the parabola is quite flat, and the optimum temperature may be from 73.4-75.0°F (23.0 to 23.9°C). The graph (Figure 6) suggests no growth at a temperature ≤60.0°F (15.6°C).

Reported optimum temperature for growth of fingerling walleye ranged from 71.6°F (22°C) (Smith and Koenst 1975) to 78.8°F (26°C) (Hokansen and Koenst 1986), but Hokansen and Koenst (1986) found that optimal temperature was higher at lower light intensity; 26°C was optimal at 5 lux. Cai and Summerfelt (1992) estimated that the optimal temperature for metabolism of juvenile walleye was 25.3°C at 45 lux. Lack of agreement among these reports may be related to size of the experimental fish, genetics, nutrition, or cultural conditions. Fish should not be handled for grading or transportation at temperatures >75°F (23.9°C).

Carrying Capacity

The first requirement in the design of a system to produce food-size walleye is to determine the system carrying capacity. The carrying capacity is based upon available oxygen and the production of metabolites (ammonia), both of which are functions of the species of fish and life stage. Carrying capacity establishes the maximum quantity of feed that can be sustainably fed in a given system for a given set of conditions and avoids under- or over-utilization of the culture system. Once the biomass and feed loading have been determined, feeding and stocking/harvesting strategies can be developed to optimize growth and to maintain the culture facility at or near its maximum carrying capacity.

The carrying capacity is the maximum weight of fish that can be sustained in a given volume of culture space and at a given flow rate before oxygen is depleted or production of fish metabolites deteriorates water quality to the point that fish are stressed and growth declines. Meade (1988), Colt (1991), Colt and Orwicz (1991),

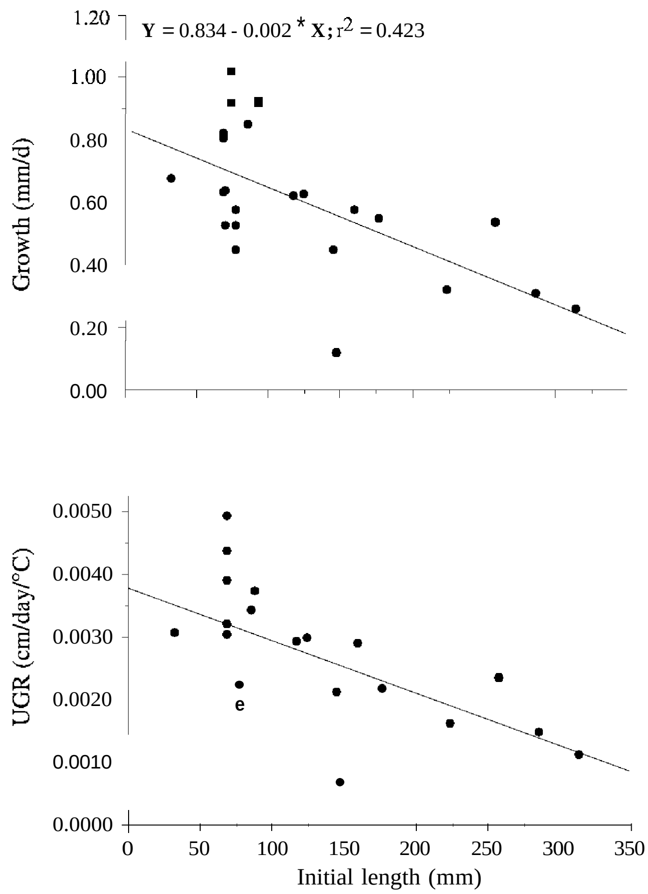


Figure 5. Growth rates of walleye relative to length (data from Table 2).

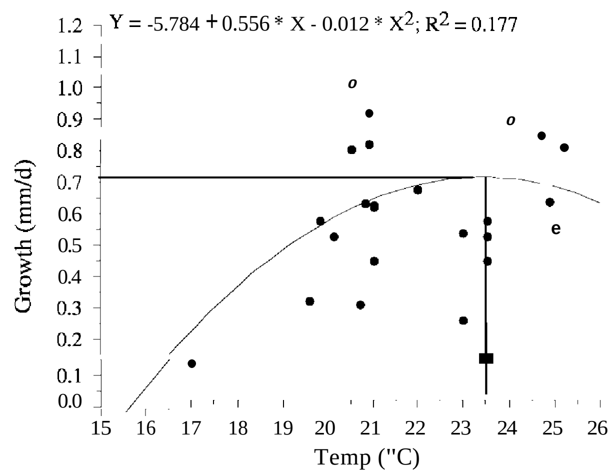


Figure 6. Growth rate-temperature data from Table 2 fitted with second degree polynomial equation. The optimal growth rate calculated from the equation is 0.0288 in/d (0.731 mm/d) at 74.1°F (23.4°C).

Losordo and Westers (1994), and Soderberg (1995) have shown how to calculate the carrying capacity of an intensive culture system based upon oxygen consumption and ammonia production (i.e., metabolic functions). Calculation of carrying capacity, oxygen demand, and biofilter surface area requirements of a recycle system commonly use metabolic functions per unit of feed fed. Metabolic functions per unit of feed fed depend upon species, life stage, feed quality, and water temperature. In general, about 0.2-0.5 lb (200-500 g) of oxygen is consumed and 0.027-0.032 lb (28.0-32 g) total ammonia nitrogen (NH_3-N) is produced for every 1.0 lb (kg) of feed consumed (Summerfelt 1996).

The sensitivity of a species to crowding is an important factor in determining the economic feasibility of its culture. **A** potential aquaculture species must be able to tolerate crowding because a commercial facility must maximize the use of space and raise fish at high density. Density, the mass of fish supported per unit culture volume, (e.g., lbs/ft^3, lbs/gal, kg/m^3, g/L) is a quantitative expression of the degree of crowding. Piper et al. (1982) describes a density index (D = W N L, where D = density index, W the carrying capacity [lbs/ft^3], **V** the volume (ft^3), and L, fish length [in]) to determine the carrying capacity (W = DI X V X L) of a hatchery raceway for any species of fish for which a density index has been determined. Held and Malison (1996) reported a density index of <0.15 lb/ft^3/in of fish length for walleye, which is 30% of the 0.5 value used for rainbow trout (Piper et al. 1982). **A** density index of 0.15 indicates a maximum density of 2.4 lb/ft^3 for a 1.25 lb (567g)) walleye at the time of harvest . Summerfelt (1993) raised 0.5-1.5 lb (227-681 g) walleye at a density of 3.72 lbs/ft^3 (60 kg/m^3) in a recycle culture system with ambient oxygen. That data suggests a density index between 0.21 to 0.32 lb/ft^3/in.

Loading, which is an expression of mass of fish supported per unit flow (e.g., lb/gpm, kg/Lpm), is a useful measure of carrying capacity of an intensive culture system. Flickinger (1996) suggests that walleye growth with ambient oxygen conditions (at about 5,000 ft[1,524 m] above sea level) was reduced (i.e., loading was exceeding carrying capacity) at loading above 2 lbs/gpm (0.24 kg/Lpm), which is about 20% of the permissible carrying capacity of 10.4 lbs/gpm (1.25 kg/Lpm) for a 10-in (254 mm) rainbow trout at 5,000 ft (1,524 m) at a temperature of 60°F (15.5°C). Current research at Iowa State University (1,000 ft above sea level [304.8 m]) in a recycle system indicates that a loading of 3.3 lb/gpm (0.4 kg/Lpm) is not excessive for 10- to 14-in (254–356) walleye if available oxygen is sufficient.

Feeding Strategies

Improved feed utilization leads to improved water quality, fish growth and health, and better production economics. Feeding strategy, ration level, feed composition, amount of fines in the feed, and amount of uneaten feed all affect feed utilization (Westers 1992). Feeding fish to satiation with a high quality feed is particularly important in order to maximize growth. Uneaten feed is the leading contributor to poor feed utilization; uneaten feed can be as much as 30% or more of the total feed (Seymour and Bergheim 1991). Reducing wasted feed is particularly important in water re-use systems because uneaten feed places an additional load on solids removal and the biofiltration system. In recycle aquaculture, reducing wasted feed can effectively increase carrying capacity because loading is a function of amount fed.

Because fish feed makes up the single largest operating expense (Blyth et al. 1993; Wade et al. 1996), reducing feed wastage will decrease operating expenses. Reducing the amount of uneaten feed will also reduce nutrient discharge and/or requirements for downstream treatment at aquaculture facilities, an important criterion if the water must be treated before release.

Feed utilization and growth rate (i.e., production) can be increased with feeding strategies that allow fish to control the amount of food that is available (Hankins et al. 1995; Thorpe and Cho 1995). Several methods for feeding fish to satiation were reviewed by Hanluns et al. (1995). The way fish are fed has a large impact on the amount of feed consumed and the amount of waste feed generated. Fish feeding has traditionally been done by hand, with motorized units, or with units which dispense feed upon demand by striking a feedmg actuator. Each method has shortcomings. Feeding methods which are not based upon directly observing fish feeding generally waste the most feed. Feeding mechanically requires the presumptive calculation of feeding rates by charts and/or growth rate estimation. Conservative (sub-optimal) estimates are generally made to reduce the amount of wasted feed. Hand feeding is labor intensive and increases operating costs, and it can fail when it is difficult to observe feeding, as with walleye. Demand feedmg fails when feeders are improperly set or when fish trigger the actuator but do not actually feed. Also, demand feeding does not always feed fish to satiation, which is required to maximize growth.

Because walleye do not feed at the surface, but consume feed while it is sinking, it is difficult to observe feeding. One method of feeding walleye to satiation would be to watch the effluent stand-pipe or solids trap for uneaten feed pellets while hand feeding (Figure 7). If the feed is delivered slowly over the course of a half-hour, fish will feed to satiation, and feedmg can be terminated after waste feed is seen in the tank effluent.

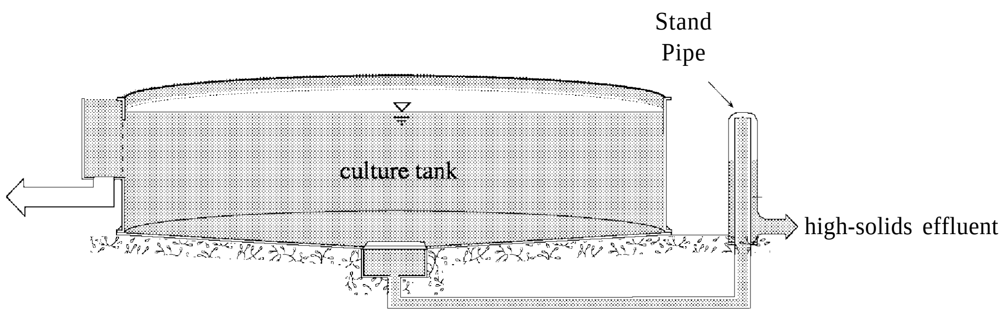
Another method consists of an automatic feeding control device that uses ultrasound to detect uneaten feed. Ultrasonic waste feed controllers are a new technology that can be used to feed fish to satiation with minimal wasted feed (Juell 1991; Juell et al. 1993; Summerfelt et al. 1995). The device uses an ultrasonic probe in the tank effluent pipe to detect uneaten feed and then turns off the feeder after a pre-set quantity of waste feed has been detected (Figure 7). Rainbow trout fed to satiation with the ultrasonic waste feed controller were 64% heavier and had the same feed conversion (1.15) as rainbow trout that were fed using a feeding schedule based upon growth rate estimates (Durant et al. 1995).

Stocking and harvesting strategies

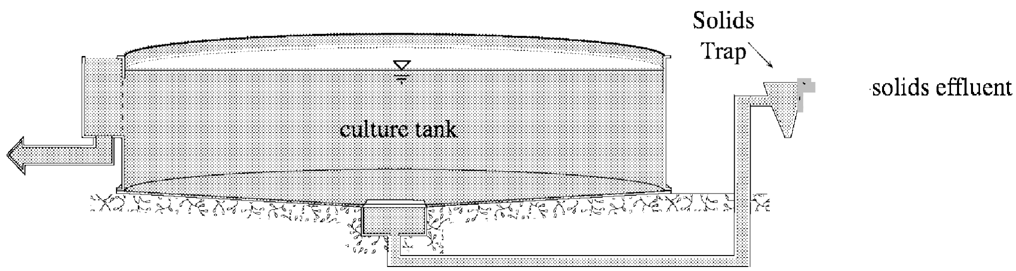
Optimizing fish stocking and harvesting strategies can maximize production per unit system volume because they maintain the culture system at or near its biomass capacity, and they also can increase product value by providmg uniformly sized fish for the market (Summerfelt et al. 1993; Hanluns et al. 1995). There are three main methods for stocking and harvesting fish that can be used to accomplish these goals: batch culture (BC); concurrent batch stocking and harvesting (CBSH); and concurrent mixed-stoclung and graded harvesting (CMSGH) (Summerfelt et al. 1993; Hankins et al. 1995). It is easier to understand these procedures if one visualizes a facility with many culture tanks, perhaps 12 or more. BC is the practice of stocking all tanks in the facility at the same time with fish of the same age. Because growth rate of fish in separate tanks is about the same, fish in all tanks are harvested when the average fish reaches market size. This results in a large harvest in a relatively short interval. The sub-market-size fish that are graded out during harvest may be placed in one or a few of tanks and retained 1-2 months longer to raise them to market size. Then the process is repeated with another group of fish. The advantage of BC is that stoclung and harvest are done infrequently, and feed types and sizes are similar for all tanks throughout the production cycle. In BC, the system's overall production is equal to the maximum biomass obtained at harvest, and it can be predicted by applying growth models which acount for temperature, food, and size of fish (Ricker 1979; From and Rasmussen 1984; Hewett and Johnson 1987; Bjorndal 1988). However, in the course of a production cycle, average fish density is about half the carrying capacity, thus annual production from the facility is about half that which can be obtained using the other two strategies and it does not provide a steady supply of fish for the market (Summerfelt et al. 1993).

CBSH uses the production capacity more efficiently because it uses one or several tanks of a multiple tank facility for fish of different ages. It is like the BC system except that each batch of fish is cultured in one or a few of the total number of tanks in the culture system. It requires the availability of small fish year-around for restocking. CBSH procedure involves three steps: (1) one or several tanks within a facility that has many tanks are stocked with fish of similar size; (2) fish in each group of tanks are cultured independently of fish in the other tanks until the average size within a tank reaches market size; and **(3)** harvesting all fish in each tank when mean length reaches market size. Advantages of CBSH are continuous operation at or near the carrying capacity of the facility, and continuous stocking and harvest (Watten 1992). Disadvantages of CBSH are frequent stoclung and harvest, and addtional costs are involved for keeping several feed sizes on hand at all times, and increased labor costs to inventory and culture several size groups at the same time. If a supply of fingerlings can be obtained year round, the CBSH strategy would probably be most effective method used to produce walleye because it does not mix fish of dfferent sizes in the same tank.

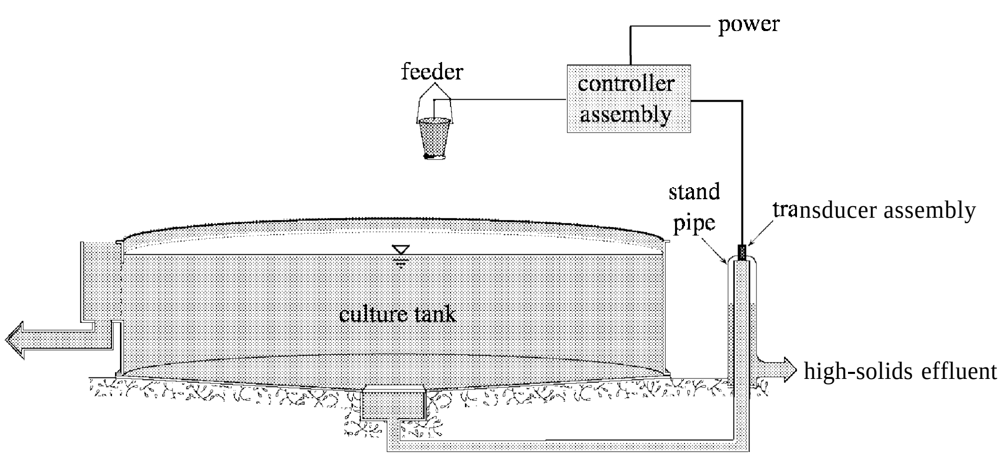
CMSGH procedure involves stocking and culture of fish of different sizes together in the same tank and continuous harvest of the market-sized fish by frequent grading. CMSGH would not be suitable for walleye because the larger cohorts of walleye would probably



(a) hand feed until waste feed is detected leaving the effluent stand pipe;



(b) hand feed until waste feed is detected in the solids trap;



(c) mechanically feed until waste feed is hydracoustically detected in the effluent.

Figure 7. Feeding strategies for intensive culture of walleye.

eat smaller, newly stocked fish. Frequent grading also places stress on the fish that can affect growth and incidence of disease.

Prospects

The chapters and case studies in the Walleye Culture Manual provide many reasons to develop food-size walleye culture at this time:

- Walleye is characterized as having white meat with very light delicate flavor; it is classified in the low fat and high protein category of food fishes.
- Walleye has widespread name recognition as a sport fish and has a favorable reputation as a food fish.
- A commercial market for food-size walleye already exists in the **U.S.,** but these are wild fish imported from Canada as frozen 6- to 8-oz (170-227 g) skin-on fillets.
- The market price for walleye is among the highest of freshwater fish; the $6.97/lb ($15.35/kg) price for skin-on fillets was 7.8% more than the price for cultured salmon fillets in the same markets (Summerfelt 1996a;
- Substantial information exists on the biology of walleye (Collette et al. 1977; Colby et al. 1979; Craig 1987).
- The information in this culture manual demonstrates that a strong foundation of aquacultural technology for walleye exists — broodstock capture, methods to spawn walleye, out-of-season spawning, egg incubation, options for pond-culture of fingerlings, habituation of pond-raised fish to formulated feed, production scale systems for intensive culture of fry, feeds, limited development of domestic broodstock.
- Fillet yield for processed walleye is similar to channel catfish but 10% higher than tilapia.
- The standard 4 oz portion size allows use of 1.25 lb (568 g) fish as minimum harvest weight, a size which can be produced in <16 months in intensive culture (Figure 3).
- Walleye have been found to be tolerant of high density culture in recycle aquaculture systems.
- An abundance of fingerlings are commercially available for habituation to formulated feed, and they can be raised on a variety of commercially available feeds.

Although all of these propositions have been thoroughly documented, the reality is that commercial culture of walleye to food-size is nearly non-existent. The few commercial efforts to produce walleye to food-size have been unprofitable. Stevens (1996), an early pioneer in cage culture of walleye and entrepreneur in the commercial production of food-size walleye, raised walleye to 1.5 to 2.0 lb (0.68-0.91 kg) in cages. However, because of the relatively short growing season for fish in southern Iowa, the fish did not reach market size until the middle to latter part of the third year and the enterprise was not economically viable. Bushman (1996) concluded that because of the short growing season, cage culture in ponds in northeast Iowa would be unprofitable. In 1989, Aquaculture Inc., Rolla, Missouri, developed a relatively large-scale commercial facility, with circular tanks and a single-pass of ground water, for the explicit purpose of raising walleye to food-size (NCRAC 1990). Their efforts to culture walleye to food-size have terminated. Likewise, research on walleye culture to food size has also been limited, and few reports have been published (Summerfelt 1993; Flickinger 1996; Held and Malison 1996; Yager and Summerfelt 1996).

Although there are needs for additional research, especially integrated research that takes fry to finished product on a production scale basis, many of the essential biological issues needed to develop walleye as a new aquaculture species have been addressed in this manual.

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Culture of Walleye to Food Size

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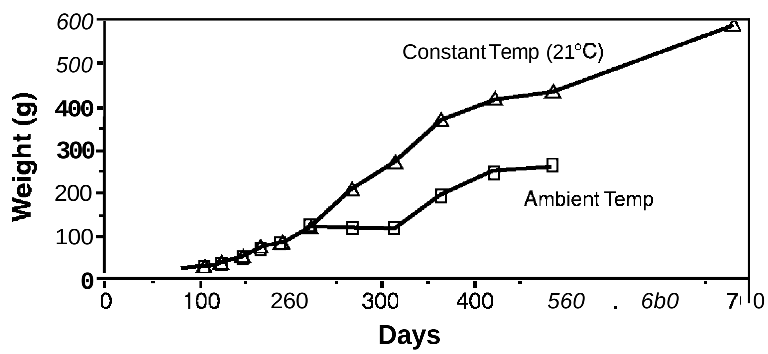
Introduction

The success of culture systems for raising walleye fingerlings and advanced fingerlings coupled with the limited supply and high market value of walleye fillets, has spurred interest in developing methods to produce food-size walleye. Traditionally, the food market for walleye consists of fish that yield two 8-oz (230-g) fillets. Assuming a 50% yield, fish for the food market have to be ≥ 2 lb (0.9 kg). While considerable information is available on various walleye fingerling production techniques, information on the production of walleye to food size is scarce. To fully realize the potential of commercial production of walleye for the food market, significant research on post-juvenile culture is needed.

Findings

As part of a series of studies comparing various production characteristics and reproductive development of diploid and triploid purebred and hybrid walleye, we have generated some data on post-juvenile growth of walleye. In one study, we evaluated the growth rate of walleye raised under either constant temperature (70°F [21°C]) and photoperiod (16 h light: **8** h dark), and conditions that approximated the ambient temperature and light regimen found in southern Wisconsin (39–70°F [4–21°C]; 8-16 h light). All fish used were the offspring of wild broodfish collected from southern Wisconsin lakes during the spring spawning season. Eggs were stripped, fertilized, and incubated in our laboratory. Newly hatched larvae were stocked into fertilized, 0.5-acre (0.2-ha), production ponds, and after about six weeks of pond culture, fingerlings were harvested and stocked into indoor 60-gal (223-L) flow-through fiberglass tanks to be trained to accept formulated feed and acclimated to intensive culture conditions. Growth studies were initiated after this process was completed, and they continued until the fish reached sexual maturity. Fish were cultured in 200-gal (757-L) flow-through fiberglass tanks located in darkened rooms and provided with in-tank (underwater) lighting and airstone aeration. Water quality was maintained at a high level (e.g., dissolved oxygen not less than 6 ppm, and density indices (as calculated by Piper et al. [1982]) at the end of the experiment were <0.15 lb/ft^3/in of fish length (0.94 kg/m^3/cm). After culture for almost 2 years at constant temperature of 70°F (21°C) the fish had not attained the 2 lb (0.9 kg) market size (Figure 1). However, because of our use of small tanks and low stocking densities, we consider these data to be limited in their application to large-scale commercial culture.

Figure 1. Growth of walleye cultured under constant and ambient conditions in circular, flow-through, tanks.



During the study, fish were fed to near satiation twice daily using appropriately-sized sinking trout pellets. The somewhat sluggish response to sinking rations exhbited by larger walleye made it difficult to determine when the fish would stop feeding. Accordingly, the presence of excess food in the tanks was monitored several hours after feeding, and was used to adjust feeding rates. By the end of the experiment, all of the fish held at 70°F (21°C) consumed feed at a rate of 1–2% body weight/d. As one might expect, the fish experiencing winter conditions showed little feeding response (they consumed <0.25% body weight/d). We have recently tested the use of floating trout pellets to feed larger walleye, and while we do not yet have any performance data, acceptance of the floating diet was surprisingly good. The use of floating feed has the advantage of providmg a more visible feeding response and, therefore, gives a more immediate indication of the overall health and well-being of the fish. It also makes it easier to measure uneaten food, and thereby obtain more accurate feed conversions.

When raising walleye > 8 in (20 cm) in tanks on formulated feed, we found that about 10% of a population over a year's time stopped eating and slowly starved to death. Except for their emaciated condition, these fish appeared healthy. At present, we cannot explain the cause for this problem. Occasionally, however, we have found a preponderance of females (70–80%) in groups of large walleye raised in our laboratory, which suggests that the die off was mostly males.

Female walleye reach a larger ultimate size than males, and are generally longer and heavier within a given year class. Becker (1983) indicated that in the wild this size difference is especially apparent in walleye >2 years. We are currently undertaking a study to identify the size when sexual dimorphism begins under intensive culture conditions, and to determine if sexually related growth patterns will be important to commercial aquaculturists. We have recently developed a method to produce all-female populations (Malison et al. 1994). To accomplish this, walleye fingerlings were fed a diet containing 17 α-methyltestosterone which induced sex inversion in genotypic females. When these females mature they produced viable spermatozoa that were used to fertilize normal eggs, and the resultant offspring were 100% female. While this procedure does require the use of a hormone (a practice needing FDA approval if used commercially), it has the advantage that only a small number of broodfish and no fish destined for the table need to be treated with the hormone.

In addition to our experience in raising adult walleye in flow-through indoor tanks, we have also raised adult walleye in ponds, either unconfined or confined in floating net pens. The walleye held in net-pens were exposed to rather high light levels for various reasons, including the shallow depth (4 ft [1.2 m]) of the net-pens that were used. These fish exhbited stressful behavior and mortality quickly exceeded 50%. Whether this result was due to the high light conditions or other variables was not determined. Walleye in the open pond culture system were not fed formulated feed; instead the pond was stocked with live forage. Over an 8-month period (September–April) the survival (>85%) and overall condition (as evidenced by normal reproductive development and robust body conformation) of these fish was quite good.

Before a large commercial aquaculture industry based on the production of food-size walleye can develop, we need to gain a more thorough understanding of factors such as loading and density limits, growth, feed conversion, and other performance parameters of large walleye produced under various conditions (e.g., raceways, open pond, net pens, etc.).

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Production of Food Fish

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Introduction

The following is a report of my experience with raising walleye to advanced sizes from several research projects conducted from 1987 through **1989** at Colorado State University. Only small numbers of walleye were raised in tanks and cages, and culture conditions were altered several times to find conditions that would promote faster growth and improve food conversions. The value in reporting tlvs information is to provide data on a topic for which little information has been published. Commercial producers should not expand these results into business plans. Walleye used in our studies were derived from wild broodstock.

Training

Environmental conditions

Pond-cultured walleye fingerlings, 3-in total length **(8-**cm), were stocked into a dark green-colored, 4-ft (1.2-m) diameter circular tank at a density of 25 fish/ft^3 (516 fish/m^3). Water flow was about 3 gal/min (11 L/min), and the temperature was a nearly constant 67°F (19°C). The tank was covered with a sheet of black plastic that had three slits for adding feed. Submerged lighting was provided by a 15-w bulb in a partially submerged hatching jar weighted with two bricks.

Feeding

Twice a day for the first five days, fish were fed thawed krill at a rate of 2% of body weight/d. Krill was slowly poured through the slits in the plastic cover. In about two days, the fingerlings fed ravenously on the krill and were fed to satiation. This is the only food for which I have seen walleye go into a feedmg frenzy. Five days into the training, walleyes were given only a little krill to excite them, and then they were given krill-based commercial fish feed initially at 3.5% of body weight/d, that had been specially screened for the largest particles that occurred during milling (this ration is normally sold in only small sizes as a starter feed). Each day, less krill was added until only krill-based fish feed was offered. Also, to compensate for growth during training, the amount of pelleted feed was gradually increased from 3.5% to 4% of initial body weight/d. In similar fashion, the fingerlings were converted from the krill-based feed to an early experimental BioMoist diet (Bioproducts, Inc., Warrenton, OR); 98% were trained to accept the BioMoist diet. We obtained about 90% survival with a second group of 1.5 in (3.5 cm) fingerlings that were trained in a similar manner.

Tank culture to food size

Environmental conditions

Tank culture was done indoors in 4-ft (1.2-m) diameter circular tanks or in halves of plastic 55-gal (208-L) drums. To overcome the skittish behavior problem of walleye in tank culture, we covered some culture tanks.

Water was heated to 72–77°F (22–25°C), dependmg on how well a water heater kept up with needed flows. No diseases were encountered at the higher temperatures. Tanks were cleaned as needed, and walleye were always weighed in 0.5% salt (NaCl) solution, a practice that may reduce stress and prevent disease.

Feeding

Belt feeders were used on the tanks and the cages. Condensation on the belts caused some problem with mold growing on the fines that adhered to the belt. Food was placed on the belts either in perpendicular strips so fish would be fed in 3-h intervals, or in a smooth layer to provide nearly continuous feeding. Differences in growth between feeding methods was not significant. In trials 1 and 2, a feeding rate of 3% of body weight was used. Most of the time, the larger fish in trial 3 were fed at 1.5% of body weight per day but when food conversion was poor, as little as 0.8% of body weight was fed in an attempt to reduce waste.

Results

In three trials, ranging from 104 to 222 days, walleye growth ranged from 0.45–0.5 mm/d, with food conversions ranging from 2.5 to 3.7 (Table 1). Differences in growth rates of walleye raised in covered and open tanks were too variable to prove any beneficial effect from the cover. Similarly, no significant growth benefit could be attributed to external lighting, internal lighting, no lighting, or photoperiods of various lengths. Submerged lighting, however, reduced the skittishness of the fish and made it easier for fish to be observed. **As** might be expected, when excess feed accumulated in the tanks the water quality deteriorated.

For the most part, mortality was low, usually an occasional fish seems to stop feedmg and becomes emaciated. However, on a couple occasions, 20% mortality occurred after we attempted to grade the walleye. We used commercial grader boxes, but walleye just stayed in the box. The grader box had to be raised and shaken to grade the walleye, and this created considerable mortality.

Table 1. Growth and food conversions of food-trained walleye reared for 104 to 222 days in indoor tanks.

	Trial 1 104 days	Trial 2 104 days	Trial 3 222 days
Initial			
number/lb	20	**30**	3
number/kg	45	*70*	6.8
Final			
number/lb	6	10	1.3
number/kg	14	22	2.8
Growth			
inches/day	0.024	0.021	0.017
millimeters/day	0.58	0.53	0.45
Food conversion			
mean	2.7	**2.5**	3.7
range	1.5–3.6	1.5–3.2	0.9–9.2

Cage culture

Methods

In the summer, walleye were cultured in ponds in 1-yd^3 (0.8-m3) cages with 1/2-in (13-cm) bar measure mesh. Cages were covered with a solid plywood lid. Water clarity, based on Secchi disk measurements, generally exceeded the depth of the cage, which resulted in rather high light intensity in the cage. Water temperature in the ponds ranged from 60–85°F (16–30°C), but it was typically around 75°F (24°C).

We experimented with feeding only at night for 46 d, but there was no obvious difference in growth rates of fish fed in the day compared with night-only feeding. Raccoons attracted to the feeders were a nuisance at times. Fish were fed at 3% of body weight until the last two weeks when they were fed at 2.5%.

Results

In the first cage trial (Table 2), walleye grew and converted food similarly to walleye in tanks (Table **1).** Final density in the cage was 0.42 lb/ft^3 (6.6 kg/m^3). Density was low because few fish were available for this trial. Cage trial 2 was more successful, walleye growth was higher than in the first cage trial or in the two tank trials (Table 2). Final density in this trial was 2.15 lb/ft^3 (34.5 kg/m^3).

Table 2. Growth and food conversions of food-trained walleye reared 80 to 123 days in cages.

	Trial 1 80 days	Trial 2 123 days
Initial		
number/lb	*5.5*	5.0
number/kg	12	11
Final		
number/lb	3.1	1.6
number/kg	6.6	**3.5**
Growth		
inches/day	0.019	0.034
millimeters/day	0.63	0.85
Food conversion		
mean	3.1	**3.0**
range	1.3–9.9	1.5–4.8

Discussion

In tank culture of walleye, water flows were adjusted to provide loadings (weight of fish per unit water flow per minute) of 3 lb/gal/min (360 g/L/min), or less. Subsequently, however, our experiments indicated that walleye growth slows above a loading of 2 lb/gal/min (240 g/L/min). Perhaps the growth rates were affected because of a high loading. High loading implies low oxygen, high ammonia, or both. I have observed that growth of largemouth bass slows at 3 lb/gal/min (360 g/L/min) and ceases at 5 lb/gal/min (600 g/L/min), but rainbow trout can be successfully raised at loadings well above 5 lb/gal/min (600 g/L/min). If further research supports the necessity for loading of 2 lb/gal/min (240 g/L/min), or less, to grow walleye at a reasonable rate, it will require more than 1,000gal/min (3,785 Wmin) water flow to produce 1 ton (2,000 lbs, 909 kg) of walleye in a flowing water system.

Growth rates in tanks were disappointing, however, growth rates in cages were about 1 in/mo (25 mm/mo), which probably is acceptable in commercial production. Based on these observation, the underlying reason for poor growth of walleye to commercial size in our tank culture experiments seems to be the effect of stressful rearing condtions, especially after walleye reach 8 in (20 cm). In tanks, walleye were easily startled from activity in the room. Perhaps there is a need for revisions in the culture environment, but domestication of walleye stocks to obtain a fish that is more amenable to confinement seems to be a logical approach to this problem.

Food conversions reported here are a little misleading, because the diets had high moisture content. Moisture content was 14% in an experimental form of BioDry feed, 20% in BioDry Grower, and 26% in an experimental form of BioMoist feed. Correction to a standard moisture content for pelleted feed would decrease food conversions somewhat, but they still would be higher than expected for commercially reared, domesticated fishes.

Walleye reared at Colorado State University were barely minimum market size of 2-oz (57-g) fillets, and larger markets exist for 4-, 6-, and 8-oz fillets (personnel communication, Morey Fish Company, Golden Valley, MN). For our largest fish, walleye approaching 14 in (35 cm) and weighing 13.3 **oz** (377 g) had a hand-filleting dressing percentage of 42% (range 39–46%). Similar-sized wild walleye dressed out at 45% (range 43–46%). In a taste test, participants could not differentiate cultured walleye from wild walleye on the basis of taste, but they did correctly identify cultured walleye on the basis of texture.

Yager, T. K., and R. C. Summerfelt. 1996. Sensory evaluation of fillets from intensively cultured walleye . Pages 237–240 *in* R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Sensory Evaluation of Fillets from Intensively Cultured Walleye

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Introduction

"The walleye is considered to be one of the best eating (sic) of all freshwater fishes " (Carmichael et al. 1991), a sentiment echoed in many cook books: "But by any name the walleye is one of the most delicious of freshwater fishes. Its snow-white flesh is both delicately and distinctively flavored, and it invariable comes as a delightful surprise to a diner who tastes it for the first time" (Cameron and Jones 1983).

Scientific proof for the well-regarded reputation of walleye as a food fish is not needed. However, intensive culture of walleye to a food-size fish is a new endeavor, therefore it is important to know whether walleye cultured in a recycle system will acquire an undesirable off-flavor and aroma that would be quickly recognized by the consumer who may compare the taste to walleye harvested from pristine Canadian lakes, the major source of food-size walleye sold in the U.S. (Summerfelt 1996). Taste and odor problems affecting the palatability of pond cultured channel catfish have been known for many years (Lovell 1974). Raising walleye to food size on a commercial basis in a recycle culture system also raises concerns regarding potential off-flavor problems. Recycle aquaculture is especially attractive in Canada and states with short growing seasons. A report on walleye culture in recycle systems is presented in this manual (Summerfelt and Summerfelt 1996).

To avoid marketing fish with off-flavors, most contemporary commercial recycle aquaculture facilities raising tilapia or hybrid striped bass place fish that have reached market size in a purge tank to depurate for up to 14 days to remove the off-flavors. Commercial producers of tilapia and hybrid striped bass typically use 2 to 5 days depuration time, but the literature review by Persson (1984) indicates a range from 5 to 18 days may be needed to purge a muddy odor from channel catfish, but it depends on temperature and intensity of the off flavor problem. The review by Stickney (1993) indicates that channel catfish with a geosmin problem can depurated within a few days.

The objective of this research was to assess the organoleptic qualities—those characteristics (aroma, flavor, and texture) that are evaluated by one's senses—of cultured walleye. Walleye raised in an intensive, recycle system (Recycle), and in an intensive, single pass, flow-through system (Flow-through) were compared with walleye purchased from a local store (Store).

Methods

Tastepanel

The taste panel members were students, faculty and staff of Iowa State University (ISU) that responded to an advertisement that was distributed to a few department offices on campus. The only prerequisite for acceptance of panelists was that they not dislike eating fish. Panelists were told that they were eating walleye, but they were not told anything else about the three groups of walleye they evaluated. Three trials were conducted on July 11, 13, and 14, 1990. Each taste panel consisted of 12 to 14 individuals untrained in sensory analysis.

Sensory evaluation

Panelists were instructed to follow a specific protocol for the sensory evaluation. They were given forms to record their assessment of taste, aroma, firmness, flakmess, and an overall rating (not an average) for each fish portion. The instructions told them to use their sense of smell to evaluate aroma; to use their fork to evaluate flakiness and firmness; and to taste a sample to evaluate flavor. Their responses were entered on a form

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where they had to choose an option to which we assigned a 5-point scale (they were not given the point scale, only the options): 5=like extremely, 4=like, 3=neutral, 2=dislike, and 1=dislike extremely.

The portions were 1-in (25 mm) squares, about 1/2-in (12.5 mm) thck of slunless pieces of flesh from the dorsal musculature. Fish portions were baked at 325°F (163°C) for 6 minutes on aluminum broiling pans. Fish portions were not battered, or seasoned (i.e., unsalted). After preparation, samples were placed in small color-coded cups. Samples were presented to panelists in the cups on a paper plate. Panelists were seated in a test kitchen at tables with dividers to separate individual panelists and to ensure privacy. Water and salted soda crackers were provided and panelists were asked to use the cracker and water to cleanse their palates between samples.

There were 13 panelists for trial 1, 12 for trial 2, and 14 for trial 3. Daily means for each parameter were used for statistical evaluation (i.e., there were only 3 replicates of each parameter). Scores were statistically analyzed using analysis of variance (ANOVA) procedures to determine significant differences among groups; posthoc tests of differences between each of the three treatments were done with Fisher's PLSD.

Biochemical analysis

Samples of fish portions used in the sensory evaluation were analyzed for percent protein, fat and moisture and for concentration of NaCl and 2-thiobarbituric acid (TBA). Concentrations of NaCl were determined by the Quantab method (AOAC 1975). Fat content was determined by ether extraction and moisture was measured during this process (AOAC 1990). Protein was determined by difference between the sum of fat and moisture and 100%.TBA is a measure of the level of oxidative rancidity (Tarladgis et al. 1960; Tarladgis et al. 1964; Koniecko 1979). In this procedure, TBA combines with malonaldehyde, a compound produced by the oxidative breakdown of unsaturated fatty acids, to produce a red color, the intensity of the color as measured with a spectrophotometer is proportional to the level of rancidity of the sample.

Table 1. Chemical composition of randomly selected samples of fish portions used in the sensory evaluation. Samples were small pieces of skinless fillets removed from walleye raised in a recycle or flow-through culture systems compared with samples of walleye purchased frozen from a supermarket (store).

	Recycle	Flow-through	Store	p-value for ANOVA'
Protein (%)	20.6a	20.4a	21.1a	0.712
Fat (%)	0.10a	0.38a	1.62b	0.015
Moisture (%)	78.3a	78.2a	76.3a	0.230
NaCl (%)	0.14a	0.20a	0.94b	0.003
TBA (ppm)	0.44a	0.18a	7.36b	<0.001

[1] p-values 50.05 are statistically significant; values in row with same letter are not significantly different at 0.05 level.

Results and discussion

Biochemical composition

Proximate analysis of samples of skinless fillets used in the sensory evaluation indicated that there were similar levels of protein and moisture in all samples (Table 1). The frozen samples from the store had significantly ($p \leq 0.05$) more fat, salt (NaCl), and higher levels of TBA than the samples from the two groups of cultured walleye. Differences in biochemical composition of the two groups of cultured walleye were not statistically significant for any of the parameters.

Yurkowski (1989) reported that wild caught walleye from central Canada had a fat content of 1.4%, which is similar to the fat content of our store-bought fish, but substantially higher than either group of cultured walleye. Although we did not know how long the store-bought fillets were in storage before we purchased them, the measurements of TBA suggest some oxidative rancidity of fatty acids had taken place. If the organoleptic characteristics of walleye degrade due to rancidity of its fat, then it is useful to note that the cultured fish had a lower fat content than wild caught fish. Given the problem with breakdown of fats, it seems prudent to avoid raising fish with high fat content, especially if the fish is to be processed and frozen. Geosmin, not rancid fat, is the primary chemical responsible for off-flavor in freshly slaughtered, pond-raised channel catfish (Stickney 1993).

Sensory *evaluation*

Differences in organoleptic scores among the three groups of fish (store, flow-through, and recycle) were small and not statistically significant (Table 2). This suggests that the consumer can find the taste and aroma of freshly processed cultured walleye, including walleye raised in a recycle system, equal to a frozen walleye. However, comments made by a few panelists after the test offer other insights into the findmgs. They said that one of the samples (the store bought fish) "seemed to be seasoned' and that the others (the two groups of cultured walleye) were "somewhat bland". The chemical analysis indicate that the store-bought samples had a significantly higher salt (4.7 to 6.7 times greater) content than either group of cultured walleye, suggesting that the frozen samples had been treated with salt sometime before freezing. Thus, the sensory evaluation might have been biased in favor of the store-bought fish because of its salt content. Paradoxically, it was our personal opinion that the store-bought fish had an off-flavor and undesirable aroma, which we now assume to be a degree of rancidity that is reflected by high levels of TBA. We think that the salty flavor of the store-bought fish enhanced the sensory evaluation of that product sufficiently to overcome a problem with rancid fat.

A taste test with similar implications to the present one, 53% of panelists that tasted fresh, farmed chinook salmon and previously frozen wild-caught chinook preferred the fresh farmed fish (Koch 1991). The importance of that test and the present evaluation of wild versus cultured walleye is that a fresh product is preferred or at least equal to that of a frozen product of wild-caught fish.

In deference to purveyors of frozen walleye, we remind the reader that the frozen walleye used in this study were not a representative sample of all frozen walleye present on the **U.S.** market or even that of the two supermarkets in Ames, Iowa. The store-bought fish were very small samples of what was in stock at the time of this study. What we perceive to be rancidity problem in the store-bought fish cannot be attributed to any specific member of the dstribution chain involved from the capture of the fish to the retailer. On the other hand, the tank cultured fish were not depurated before slaughter, they represent fish taken directly from the culture tanks.

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Table 2. Mean sensory evaluation on a scale of 1-5, where 1 was "dislike extremely" and 5 "like extremely") of walleye intensively cultured in flow-through and recycle systems walleye purchased frozen from a local supermarket. Differences among the treatment groups were not statistically significant ($p \geq 0.05$).

	Scores for sensory evaluation				
Treatment group	**Taste**	**Aroma**	**Firmness**	**Flakiness**	**Overall'**
Flow-through system	3.8	3.7	3.8	3.9	3.7
Recycle system	3.6	3.8	4.1	4.0	3.8
Store-bought fish	3.4	3.5	3.9	3.9	3.4

[1] This is an independent, composite assessment, not the average of the other scores.

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Live Weight-Dressed Weight Relationships of Walleye and Hybrid Walleye

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Introduction

Dressed yield is the percentage of the live weight obtained for a specific processed product. The live weight-dressed weight relationships for different forms of a food-fish product strongly influences which form of the dressed product will be marketed, as well as the overall economic feasibility for commercial production. Obviously, processed yield affects the live weight of the fish needed to yield fillets of a commercial size (Table 1). Also, if dressing percentage increases substantively with fish size, it may be practical to relate fish size at harvest to the size at which maximum dressed yield is obtained.

Table 1. Hypothetical live weight of fish required to yield two 4- or 6-oz (114-170 g) fillets.'

Dressed yield	Live weight of fish	
% of live weight	4-02 (114 g) fillets	6-02 (170 g) fillets
40	1.25 lbs (568 g)	1.88 lbs (851 g)
45	1.11 lbs (504 g)	1.67 lbs (756 g)
50	1.00 lbs (454 g)	1.50 lbs (681 g)

[1]No assumptions made relative to effects of fish size on dressing percentage.

Information on dressing percentage is essential for cost/benefit or break-even analysis for walleye food-fish production. A highly processed form of the fish (slunned fillets) results in more waste, higher processing costs per unit weight, and a more expensive final product. For example, for rainbow trout, yield from a 0.55 lb (250 *g)* fish was 77.7 to 86.0% after evisceration (gills and viscera removed, but head, tail, and all fins retained), 69.0 to 75.3% for boned fish (spine and ribs removed but all fins and the head and tail remained on the fish), and 55.7-60.3% for filleted fish (skin and scales remained, but all fins, head and tail were removed) (Smith et al. 1988).

Objective

We evaluated dressing percentage (dressed yield) and carcass characteristics of three year-classes (fish hatched in the same year are members of the same year-class) of walleye and two year-classes of hybrid (interspecies cross between female walleye and male sauger) walleye grown under intensive culture. The objective of this study was to obtain information on the dressed yield of walleye, and to determine whether yield is a function of fish size and gender. Data were obtained on yield for slun-on and skinless fillets; the relative weight of the head, scales, and skin; and the relationship between body weight and fillet yield.

Market forms

The most common forms of dressed fish are (Dunn 1974; Plutt 1986):

(1) Whole: No processing.

(2) Whole dressed (drawn): Fish that have been eviscerated and the gills have been removed; the scales, head, tail, and all other fins remain.

(3) Pan dressed or dressed (Figure 1): Eviscerated and head, tail, scales, and fins removed. The pectoral and pelvic fins are removed with the head, or separately, but the dorsal and anal fins are removed by incision

Present addresses: [1]U.S. Army Corps of Engineers Center, 190 5th Street East, St. Paul, MN 55101. [2]The Conservation Fund's Freshwater Institute, PO Box 1746, Shepherdstown, WV 25443. [3]Route 1, Box 121, Fullerton, NE 68638.

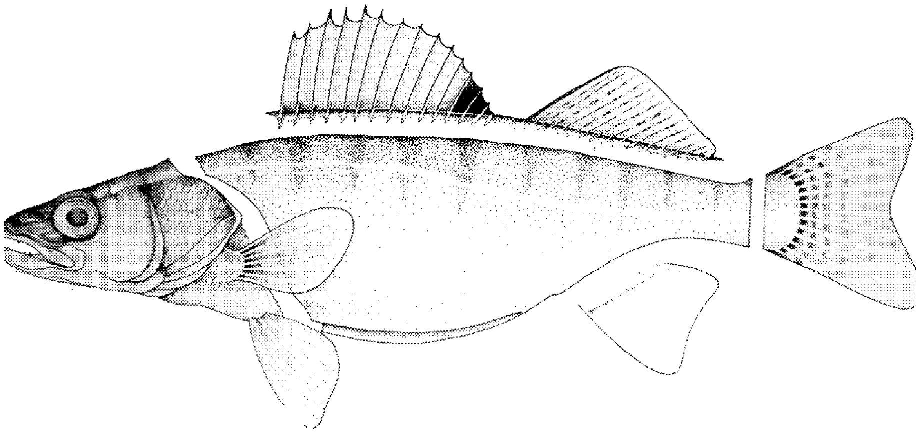

Figure 1. Dressed walleye: eviscerated and with head, tail, and fins removed.

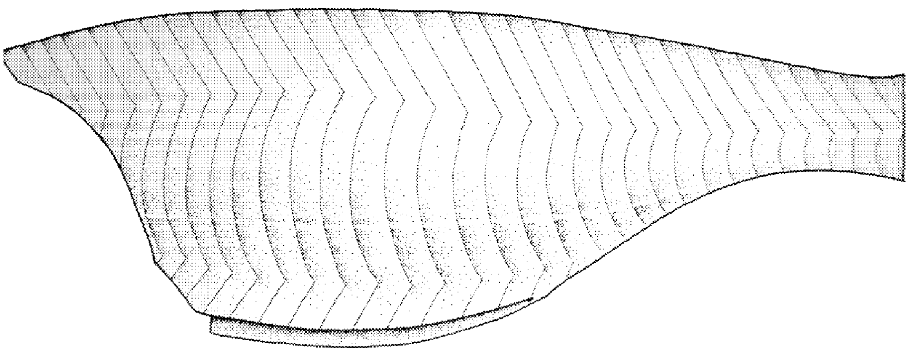

Figure 2. Skinless walleye fillet is about 40% of live weight.

on each side of the fins to the depth of the vertebral column.

(4) Steaked: Body cross-sectioned into pieces 5/8- to 1-in (15.9-25 mm) thick. Steaked fish contain a cross-section of the back-bone. Cultured walleye will probably not be steaked because it requires a large (> 4 pounds) dressed fish.

(5) Filleted: Pieces of fish flesh that are cut lengthwise away from the backbone after scaling a whole dressed fish. Most retail sales are of skin-on fillets, but some consumers prefer skinless fillets because of the rubbery nature of the skin and taste problems that develop in frozen products from oxidative rancidity in the fatty layer underlying the skin.

The most common processed product for walleye is a scaled, skin-on fillet (Figure 2). For comparison, trout are sold whole dressed, dressed, boned, or filleted, but whatever form, because of their small scales, trout and salmon are commonly marketed with scales on, however, walleye have much larger scales that must be removed for marketing as dressed or filleted forms. Channel catfish are marketed as whole dressed fish, regular fillets (skinless), shank fillets, fillets strips, nuggets, and steaks (Foster and Waldrop 1972).

Source of fish

Fish used in this study were raised in intensive culture on formulated feed in the aquaculture facilities at Iowa State University (ISU). When fish were processed, they were 227 to 783 days old (i.e., 7.5-26 months). The condition factor for each group is given for the date they were processed. The condition factor, **k** = (weight [g] x 100,000)÷ L $(mm)^3$, is a measure of the robustness or degree of well-being of a fish. Piper et al. (1982) gives a value for walleye in English units, called C, which equivalent to a k value of 0.835.

Three year-classes (1987, 1988, and 1994) of walleye were studied. All year-classes were first pond-raised then converted (habituated) to formulated feed. The 1987 year-class was from Spirit Lake, Iowa (Spirit Lake walleye, SLW). They were pond-raised for about 55 days, then habituated in a 28-day interval to formulated feed in intensive culture (Kuipers and Summerfelt 1994). Thereafter, some of the 1987 year-class of SLW were used in feeding experiments by Stettner et al. (1992) in 120-L tanks; then raised in 277-L tanks until the final processing (467 days posthatch).

Samples of the 1987 year-class were processed at 151, 160, 170, 357, and 467 days posthatch to determine whether fillet percent changed with live weight. The fish were 0.7 lbs (307 g) at 467 days posthatch (Table 2).

Three groups of the 1988 year-class were used. One was another year-class of SLW converted (habituated) to formulated feed over a 28 days by Kuipers and Summerfelt (1994); thereafter they were transferred to 1,000-L tanks a recycle system for the next 701 days in a study by Peterson (1992). They were processed on June 17, 1990 when they were 783 days posthatch. A few were held until July 11-14, when they were processed for use in a sensory evaluation by Yager and Summerfelt (1996).

The other two groups of the 1988 year-class were Rock Lake (Wisconsin) walleye (RLW), and hybrid walleye (RLH). The hybrids were produced by crossing sauger males, obtained near Bellevue, Iowa on the upper Mississippi River, with female RLW. RLW were half-sibs to RLH. Fish were initially raised in ponds to 40-60 mm at the Lake Mills State Fish Hatchery, Lake Mills, Wisconsin, then habituated to formulated feed in a study by Malison et al. (1990). RLW and RLH were transported to the ISU aquaculture facility October 17, 1988 when they were about 5.7-5.9 in (145-150 mm). They were raised in experiments by Siegwarth and Summerfelt (1990, 1992, and 1994) in 120-L tanks to 783 days (25.7 months), the small tanks seemed to reduce their growth potential (Siegwarth and Summerfelt 1994). Six months prior to the end of that study, about 200 each of the RLW and RLH were transferred to 1,000 L tanks for growout until they were processed to obtained measurements of dressed weights, which was June 17, 1990 when they were 783 days posthatch. At that time, mean length of the three cohorts of the 1988 year-class was 15.5 in (393 mm) for the SLW, 13.8 in (352) for the RLW, and 13.8 in for the RLH walleye (Table 3). A few of the RLW were raised another 24 days until July 11-14 when they were processed for use in a sensory evaluation (Yager and Summerfelt 1996).

The 1994 year-class included walleye and three interspecific hybrids which are designated by their place of origin: Spirit Lake hybrids

Table 2. Fish age and size and dress out percentages for the 1987 year-class of Spirit Lake walleye (SLW).

	Sex (number in sample)		
	Males (54)	**Females (69)**	**p-value[1]**
Fish age and size			
Fish age (day)			
Mean	227	239	0.52
Range	151-467	151-467	
Length			
Mean: inches (mm)	9.8 (248.4)	9.9 (252.1)	0.65
Range: inches	7.9-13.6	4.6-15.3	
(mm)	(200-345)	(117-388)	
Weight: lbs (g)			
Mean	0.30 (134.9)	0.33 (151.1)	0.28
Range	46-470	49-470	
Condition factor (k)	0.81	0.92	0.26
Processing characteristics[2]			
Head length (% total length)	24.4	24.7	0.30
Head weight	15.0	16.0	0.07
Scales	4.0	2.7	0.39
Skin	9.0	8.1	0.39
Fillets, skin-on	43.2	41.0	0.04
Fillet, skinless	34.2	32.9	0.23

[1]The p-value for unpaired t-test of difference between males and females; p-values ≤ 0.05 are considered statistically significant.
[2]Except for head length, the parameters are expressed as percent of total live weight.

(SLH), Mississippi River hybrids (MRH), and Rock Lake hybrids (RLH). Hybrids were produced by crossing female walleye with sauger collected from the Mississippi River near Genoa, Wisconsin. All groups of this cohort were raised from hatching under intensive culture on formulated feed in the ISU aquaculture facilities until they were processed September 21, 1995, when they were 516 days old. Mean length was 12.1 in (308 mm), and the mean weight was 0.6 lb (270 g).

Table 3. Fish size and dress out percentage for groups in the 1988 year class at about 783 days posthatch.'

	Sex (number in sample)		
	Males	Females	p-value[2]
Fish size			
Length (mm)			
Spirit Lake walleye (SLW)	387.0 (5)	396.5 (26)	0.38
Rock Lake walleye (RLW)	338.0 (6)	355.4 (21)	0.15
Rock Lake hybrid (RLH}	329.6 (5)	360.7 (9)	<0.01
Weight (g)			
Spirit Lake walleye	578.4 (5)	648.1 (26)	0.04
Rock Lake walleye	380.3 (6)	441.3 (21)	0.19
Rock Lake hybrid	324.6 (5)	431.9 (9)	0.03
Condition factor (k)			
Spirit Lake walleye	1.00 (5)	1.05 (26)	0.47
Rock Lake walleye	0.97 (6)	0.98 (21)	0.88
Rock Lake hybrid	0.91 (5)	0.91 (9)	0.95
Processing characteristics[3]			
Head length (mm)			
Spirit Lake walleye	24.4 (3)	25.0 (21)	0.50
Rock Lake walleye	24.1 (5)	24.9 (10)	0.20
Rock Lake hybrid	25.4 (5)	25.0 (9)	0.59
Head weight (%)			
Spirit Lake walleye	9.8 (2)	12.9 (19)	0.02
Rock Lake walleye	13.3 *(5)*	15.5 (10)	0.12
Rock Lake hybrid	14.5 *(5)*	13.9 (9)	0.54
Skin *(Y₀)*			
Spirit Lake walleye	8.4 (2)	5.9 (19)	0.83
Rock Lake walleye	8.3 (5)	5.3 (10)	0.21
Rock Lake hybrid	6.9 *(5)*	7.8 (9)	0.22
Fillet, skin-on (%)			
Spirit Lake walleye	44.5 (2)	39.3 (19)	0.06
Rock Lake walleye	40.5 (5)	36.6 (10)	0.10
Rock Lake hybrid	39.6 (5)	38.7 (9)	0.61
Fillet, skinless (%)			
Spirit Lake walleye	36.1 (5)	33.4 (26)	0.10
Rock Lake walleye	32.2 (6)	31.3 (21)	0.56
Rock Lake hybrid	32.7 *(5)*	30.9 (9)	0.21

[1]The large number of data entries for this table did not allow presentation in both English and metric units.
[2]The p-value for unpaired t-test of difference between males and females; p-values ≤ 0.05 are considered statistically significant.
[3]Except for head length, the parameters are expressed as percent of total live weight.

Results

Gender differences in size

Female walleye and female hybrid walleye were longer, heavier, and they had a larger **k** value than males in all year-classes (Tables 2, 3 and 4). However, differences in k values between males and females were not statistically significant within any year-class. Gender differences in length and weight of SLW of the 1987 year-class were slight and not statistically significant, perhaps because the fish were relatively young (227-239 days old) (Table 2). However, gender diferences in size between SLW of the 1988 year-class were not statistically signficiant and neither were differences of RLW. Gender differences in length and weight of the 1988 RLH were signficiant, females were considerably larger than males (Table 3). Gender differences in length and weight of fish 576 days old were statistically significant; however, female RLH and MRH were larger than male hybrids.

Head size

Head length (percent of total length) was slightly larger for female than male walleye, but slightly larger for male than female hybrid walleye; however, dfferences between the sexes were not statistically significant (Tables 2 and 3). Head weight (% total weight) was also larger in females than males. The differences in head weight between males and females was statistically significant in the 1988 year-class of **SLW** but not in the 1998 year-class of RLW or RLH (Tables 2 and 3).

Scales and skin

The scales of walleye, which has large, conspicuous, ctenoid scales, represented 2.7-4.0% of live weight (Table 2). For the 1987 cohort of SLW at a mean age of 228 days posthatch, and a mean weight of 0.3 lbs, the skin (without scales) represented 8.4% of live weight, a rather substantial amount (Table 3). For the two 1988 cohorts of walleye (SLW and RLW), skin was 8.4-8.3% of live weight for males and 5.3-5.9% for females, but quite the opposite for RLH, which was 6.9% for males and 7.8% for females.

Fillets

Obviously, slun-on fillets have a higher processing yield than skinless fillets, but the magnitude of the difference is the important factor (Tables 2 and 3). For SLW, the difference between skin-on and skinless fillets (sexes combined) was 8.4% in the 1987 year-class and 5.9% in the 1988 year-class. The 1987 SLW had a mean weight of 0.31 lbs (139 **g)** when processed (Table 2) compared with 1.39 lbs (629.3 g) for the 1988 year-class of SLW that were 716 days old when processed (Table 3). The expected increase in processing percentage did not occur with an increase in fish weight. In both 1987 and 1988 year-classes of SLW, processing percentage for slun-on fillets was greater for males than females; the difference was statistically significant for the 1987 year-class and nearly so (p = 0.06) for the 1988 year-class. Processing yield for skin-on fillets was substantially greater for male than female RLW and RLH walleye of the 1988 year-class, even though female fish were larger than male fish for the same

Table 4. Fish size and dress out percentage for groups in the 1994 year-class at about 516 days.'

	Sex (number in sample)		
	Males	Females	p-value[2]
Fish ***size***			
Length (mm)			
Spirit Lake hybrids (SLH)	299.1 (11)	318.0 (14)	0.10
Rock Lake hybrids (RLH)	294.7 (26)	316.1 (40)	<0.01
Mississippi **R.** hybrid (MRH)	293.2 (15)	313.5 (24)	0.01
Rock Lake walleye (RLH)	307.6 (5)	313.8 (7)	0.75
Weight (g)			
Spirit Lake walleye hybrids	259.8 (11)	326.6 (14)	0.04
Rock Lake walleye hybrids	226.8 (26)	294.9 (40)	<0.01
Mississippi River hybrids	216.2 (15)	280.0 (24)	<0.01
Rock Lake walleye	269.8 (5)	273.1 (7)	0.96
Condition factor **(k)**			
Spirit Lake walleye hybrids	0.96 (11)	0.99 (14)	0.64
Rock Lake walleye hybrids	0.90 (26)	0.92 (40)	0.46
Mississippi River hybrids	0.86 (15)	0.92 (24)	0.35
Rock Lake walleye	0.87 (5)	0.88 (7)	0.74
Processing characteristics[3]			
Fillet, skinless			
Spirit Lake walleye hybrids	35.7 (11)	33.5 (14)	0.10
Rock Lake walleye hybrids	35.3 (26)	34.8 (40)	0.45
Mississippi River hybrids	34.9 (15)	34.1 (24)	0.36
Rock Lake walleye	36.2 (5)	35.3 (7)	0.64

[1]The large number of data entries for this table did not allow presentation in both English and metric units.
[2]The p-value for unpaired t-test of difference between males and females; p-values 20.05 are considered statistically significant.
[3]Except for head length, the parameters are expressed as percent of total live weight.

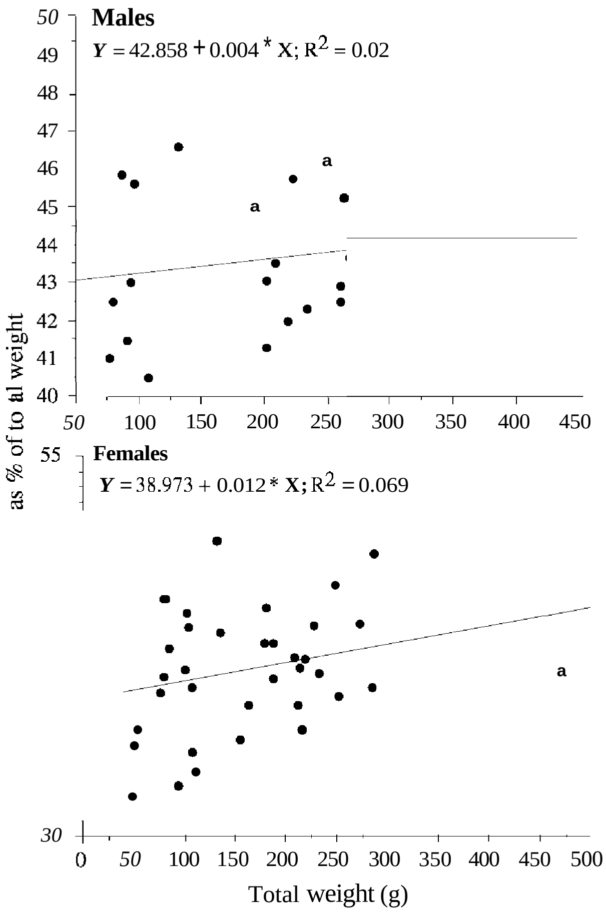

Figure 3. Relationship between skin-on fillet weight as percentage of total weight and total weight of walleye from the 1987 year class. The regression coefficients for both male and female walleye were not significant and the coefficient of determination indicates that weight accounts for only 2 to 6.9% of the variability in relative fillet weight.

groups, but the differences were not statistically significant

For sexes combined, the mean processing percentage for skinless fillets was 33.2% for the 1987 year-class, 31.5-33.9 for the 1988 year-class, and 34.4-35.7 among the four year-class cohorts of the 1994 year-class, which is remarkabaly close agreement among a diversity of years, fish ages, and size. Differences in processing percentages for skinless fillets between male and female walleye and hybrid walleye were not statistically significant for any year-class, but in every (eight groups of three year-classes) comparison, the dressed yield was higher for males than females.

Processing percentage* and *fish size relationship

One of the arguments for harvesting larger fish is the assumption that the processing percentage increases with size. We conducted a regression analysis of fillet yield-fish weight relationship for all year-classes, and stocks within year-classes, and for the six age groups within the 1987 year-class. Only three of the coefficients of determination (r^2) were greater than 0.10 (i.e., body weight did not account for more than 10% of the variability in yield). Of all the regression coefficients (i.e., slope of the regression), only one, the combined data for the 1987 cohort, was statistically significant; however, even in that case, the r^2 for that relationship was only 0.066, which means that for the best fitting regression, weight would account for 6.6% of the variability of processing percentage. Albeit the regressions was not statistically significant, dressed yield of skin-on fillets showed a slight increase with fish size (Figure 3).

We also examined head weight and processing yield of fillets in relationship to fish age (Table 5). The analysis for five age-groups (151-467 days old) of the 1987 year-class indicated significant differences in head weight, and yield of skinless fillets by fish size groups, but there was not a trend for the older (i.e., larger) fish to have higher processing percentages. For example, the highest processing percent for skin-on fillets was 44.5% at 151 days, but that value did not differ significantly from values of 40.7 and 42.5 at 170 and 357 days, respectively. Likewise, a comparison of the processing yield of the 1987, 1988, and 1990 year-classes, which were different ages when they were processed (467 maximum for 1987, 783 for 1988, and 516 days posthatch for 1990 year-class), did not indicate a trend for processing percentages to increase with age (i.e., weight).

Processing percentages and stock differences

An analysis of processing percentages for head weight and both skin-on and skinless fillets for 1988 and 1990 year-classes indicated some statistically significant differences among stocks in the 1988 year-class.

In the 1988 year-class, the relative head weight of SLW (12.65%) was less than that of RLW or RLH, and the skinless fillets of SLW were larger than of either RLW or RLH. However, dfferences among the mean processing percentage for slunless fillets of the four groups of the 1990 year-class were not statistically significant. These analyses do not indicate higher processed yields for hybrid walleye compared with walleye.

Table 5. Comparison (analysis of variance, ANOVA)) of processing percentages of walleye and hybrid walleye: p-values ≤ 0.05 are statistically significant. Means with a letter in common in the same column are not statistically different (p ≥ 0.05, Fisher's PLSD test).

Age (days posthatch) and year-class	Head weight (% total wt)	Fillet: skin-on (% total wt)	Fillet:skinless (% total wt)
*1987 (**151-467** days old)*			
151	14.8a	44.5a	36.1a
160	16.0a,b	39.3b	31.2b
170	18.0b	40.7a,b	31.5b
357	15.0a	42.4a,b	35.3a
467	——		41.2c
p-value for F-test	0.005	0.062	0.001
*1988 (**783** days old)*			
Spirit Lake walleye	12.65a	39.83a	33.94a
Rock Lake walleye	14.77b	37.93a	31.54b
Rock Lake hybrid walleye	14.13b	39.05a	31.52b
p-value for F-test	0.010	0.313	0.006
*1990 (**516 days** old)*			
Spirit Lake walleye hybrids			34.49a
Rock Lake walleye hybrids			34.96a
Mississippi River hybrids			35.71a
Rock Lake walleye			35.72a
p-value for F-test			0.472

Discussion

Defining a food-size walleye

References defining a food-size walleye were not found but traditionally, in Canada, the actual size of a fish serving (referring to all fish, not just walleye) was 6 to 8 ounce (180 to 225 g) (Iredale and York 1985). Presumably, that was for scaled, but skin-on fillets. A large midwest fish company indicated a market for 4-, 6-, and 8-oz fillets (Flickinger 1996) Cookbooks provide another perspective on portion sizes (Table 6). They generally indicate 0.25 lbs, or 4 oz (114) for fillets and slightly larger portions (0.31 lb, 142 g) for steaks.

Assuming that a 4-6 oz (114-227 g) shn-on fillet is the market size product, the minimum live weight that is needed to for a 4-oz (114 g) or 6-oz (170 g) skin-on fillet would range from 1.0 to 1.88 lb (454-851 g), depending on processing percentages.

Processing percentages of marketable product for walleye have been based on assumptions or approximations. It is probable that the Freshwater Fish Marketing Corporation (FFMC) of Canada (see Summerfelt 1996 for an description of this quasi-government entity), which processes 6.7 to 10.9 million lbs (5.0 million kg) of walleye annually, has a substantial body of information on processing percentages of food-size, wild-caught walleye, but it was not unavailable. Stettner et al. (1993) assumed a 40% processing percentage for a 1.87 lb (849 g) fish would provide two 6-oz (170 g) skin-on fillets. Held and Malison (1996) assumed a 50% yield (the form, skinless or skin-on was not specified) for a 2-lb (900 g) food-size fish. Stevens (1996) reported dressout yield of 45–50% for skin-on fillets. Flickinger (1996) reported 42% (range 39-46%) processing percentage for cultured walleye weighing 0.83 lb (377 g), and 45% (range of 39-46%) for wild caught walleye of similar size. Assuming that Flickinger (1996) used a scaled, but skin-on fillet processed in a similar manner to our procedures, the 42% yield for his cultured walleye is similar to those in this study. We obtained means for slun-on fillets from a high of 44.5% for males from **SLW** in the 1988 year-class to a low of 36.6% for female RLW.

Using an average yield of 40%, the minimum, food-size walleye would be 1.25 lbs (504 g) live weight to obtain two, 4-oz (114 g) slun-on fillets. Channel catfish are typically harvested at 1.25 lbs (568 g) (Foster and Waldrop 1972). A 1.88 lbs (853 g) walleye would be needed to obtain two, 6-oz (170 g) fillets with a 40% processed percentage. Faster growing fish have a smaller head to body size than a slower growing fish. Perhaps, with genetic selection, optimal environmental conditions for fast growth, and skillful processing procedures, processed percentage for walleye can reach 45%, which would reduce the requirement for live weight of the cultured fish to 1.11 lbs (504 g) to obtain two 4-oz (114 g) fillets, or 1.67 lb (756 g) to obtain two 6 **oz** (170 g) fillets. For now, a value of 40% seems to be the most valid estimate or processing percentage for skin-on fillets.

Table 6. General recommendations (buying guides) for portion sizes for different forms of fish.

Form	Serving size[1] lbs (g)	Reference
Whole	0.75 (340)	Dunn (1974)
Whole dressed (drawn)	0.5 (227)	Dunn (1974)
	0.5–0.75 (227–340)	Plutt (1986)
Pan dressed (dressed)	0.5 (227)	Dunn (1974)
Steaked	0.33 (151)	Dunn (1974)
	0.25–0.50 (114–227)	Plutt (1986)
	0.31 (142)	Hachfeld and Eykyn (1992)
Fillets	0.33 (151)	Dunn (1974)
	0.25–0.50 (114–227)	Plutt (1986)
	0.25–0.50 (114–227))	Darling et al. (1989)
	0.22-0.25 (99–114)	Hachfeld and Eykyn (1992)

[1]The information may have been given for 2, **4**, or ***6*** servings, but for comparative purposes the values are expressed for a single serving.

Obviously, processing percentage is a function of the skill and/or time taken to fillet the fish. In the present study, we endeavored to process fish with reasonable speed to approximate the speed used in a commercial facility using hand processing. There are tradeoffs relative to time and processed percentage. An experienced production worker may obtain a smaller processed yield in an effort to obtain a higher total volume of fish processed per unit time, especially if the worker is paid by the pound of fish processed. By comparison, we may have been slower than a production line worker but our processed yield might have been higher because of our emphasis on maximizing processing percentages of the dressed product.

We think it is appropriate to define a food-sized walleye as whatever size can be marketed for human food. **A** flexible definition of the market size allows for the traditional size, but also for a smaller size that can be brought to market faster. **A** faster turnover time can be obtained if walleye are harvested at the inflection point of the growth curve (i.e., at the size [age] when growth rates decline) and sold at a smaller than traditional size, perhaps not much larger than yellow perch. Yellow perch are usually marketed at 7.5 to 8 inches (190-203 g), or 5 fish per pound live weight (3.2 oz, 90.8 g) per fish. Perch of this size yield two 0.67 **oz** (19.0 g) fillets with a 42% fillet yield. In January 1996, the price for yellow perch was $2.50/lb ($5.50/kg) live weight, $8.00–9.00 ($27.50–$19.80/kg) per pound for a skin-on fillet wholesale, and $11.00–12.50/pound ($24.70–$27.50/kg) retail (Chris Starr, Bayport Aquaculture, personal communication). Most of that product is sold in restaurants, not retail. Restaurants use about **6** oz (170 g) of fish per serving, similar to the traditional **6** oz size for walleye fillets.

In summary, fillet sizes range from 0.67 oz for yellow perch to 4.4 oz for channel catfish, with a generic buying guide of 4 oz (114g) for fish fillets of 5.3 oz (150 g) per serving (Dunn 1974). This range in size is smaller than the traditional 6-8 oz size for walleye fillets. However, for a frame of reference, we recommend using 1.25 lb (567g) as the minimum size for cultured walleye. **A** 40% dressout yield for slun-on fillets would produce two 4 oz fillets.

Processed yield and fish size relationship

The dressing percentage of both sexes of channel catfish was positively correlated with body weight for 13-month old fish but not for 22-month-old catfish (Dunham et al. 1985). We did not find an relationship between fish size or age and processing percentages for the size range of fish in the study. Regression analysis consistently showed a slight positive slope (i.e., dressout percentage increases with fish weight), but the coefficient of determination (r^2) did not indicate more than 10%($r^2 = 0.10$) of the variation in fillet percentage was related to fish weight. Although statistically significant differences in the fish age-percentage dressout occurred, there were no overall trends to the data that suggested processed percentages increased with age or size. This is an important finding because it does not support a assumptions that processed percentage will increase by raising fish to larger size than the minimum size needed for to achieve the smallest acceptable fillet.

Yield of walleye and hybrid walleye

We did not find a consistent difference between processed percentages for walleye and hybrid walleye; i.e., processing yield would not be improved by culturing hybrid walleye. SLW had smaller relative head weight and larger processed yield of skinless fillets than RLW or RLH. This difference and growth comparisons we have made between SLW and other stocks in the Midwest provide evidence to recommend the SLW as a source of broodstock for domestication. Dressed yield for rainbow trout showed significant differences attributable to the strain of the trout but not between two diet types (Smith et al. 1988).

Skin-on and skinless fillets

The reduction in processed percentage from skin-on to slun-off fillets was as high as 8.4% for males from one cohort. The loss from removal of the skin would seem to require skin-on fillets as a matter of practice; however, the price of skinless walleye fillet can be as much as 32% greater than skin-on fillets based on observations I have recorded in regional fish markets. If consumers are willing to pay more for slunless fillets, then the loss in production from removal of the skin may be acceptable providing higher processing costs for labor or equipment do not exceed the differential in prices of the two types of fillets.

Comparative dressout yield

The head of walleye is a smaller percentage of body weight (9.8-15.5%) than the 21.6-23.6% reported for channel catfish (Dunham et al. 1985). Head weight as a percentage of body weight of female walleye was usually larger than that of males. In channel catfish, the relative head weight of 13 month old males is larger than same aged females, but 22 month old female catfish had a larger head than 22 month old male catfish (Dunham et al. 1985).

It is reasonable to assume a dressout yield for skin-on walleye fillet is 40%. This seems to be a reasonably good value compared with several other species. Plante (1996) reported that "typical" fillets yields for common food-fish are 32% for tilapia, 40-45% for channel catfish, and 60% for salmon. Chettleburgh (1991) gives 32% as processing yield of skinless fillets for tilapia. However, fillet values for channel catfish are quite variable. McGilberry et al. (1989) reported that regular fillets" are about 43.5% of the live weight, which would be two 4.4 oz (125 g) fillets, but Wolters et al. (1991) reported 28.8% dress-out percentage for fillets of female diploid channel catfish and 27.9% for fillets from male catfish. They processed catfish by removing fillets from whole fish, then they slunned the fillet on a mechanical slunner. Heidinger and Kayes (1993) reported that dressout yield for yellow perch is 37–40%, with exceptional value of 42%, which is nearly identical to values for walleye.

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