

The Effects of Size Grading on Production Efficiency and Growth Performance of Yellow Perch in Earthen Ponds

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Abstract.—The culture of yellow perch *Perca flavescens* has received considerable interest in the Midwest and elsewhere in the USA as a result of the decline of wild populations and their high market demand. In this study, the effects of size-grading on the production efficiency and growth performance of food-sized yellow perch were determined in six 0.1-ha ponds by grading fingerlings into three size-groups (mean initial size): small (5.3 g), large (18.3 g), and unsorted (11.3 g). The mean percentage of marketable production from large-group ponds was significantly greater than that from the small- and ungraded-group ponds. The final biomass of large size-groups was 77% and 27% greater than that of small and ungraded groups, respectively, although no significant differences in total production were detected among the three size-groups. Size-sorting of fingerling yellow perch did not result in improved growth of the small-fish group. No significant differences in growth rates among the three groups were detected in either the first half-year (winter–spring) or the second half-year (summer–fall) period. The growth performance of the three groups indicates that yellow perch populations under culture conditions experience a bimodal growth pattern, with two distinct size-groups. The coefficient of variation (CV) in both weight and length for the small-group fish increased about 80%, whereas the CV in the ungraded and large groups showed some reduction. The results indicate that grading by size should be advantageous to those wishing to culture yellow perch to food fish size in the second year. The significantly different results for the percentage of fish reaching market size among the large (65%), ungraded (53%), and small (35%) groups suggest that perch should be selectively graded by at least the end of one year of intensive culture to increase the number of individuals with the potential to reach market size.

Yellow perch *Perca flavescens* is an important recreational and aquacultural species in the Midwest and elsewhere in the USA. Especially during the past 20 years, yellow perch aquaculture has received considerable interest because of the decrease of wild populations of yellow perch and their high market demand (Erickson, unpublished data; Baldwin et al. 2000). A survey of wholesale and retail buyers of yellow perch products indicated many buyers would easily double their purchases if it were more available (Riepe 1998).

Despite this opportunity, rapid expansion of the yellow perch aquaculture industry has not occurred. Malison (2000) estimates that Midwest aquaculture operations contribute less than 90,800 kg of yellow perch per year. One reason hindering expansion has been the lack of reliable, research-based information on methods for yellow perch production. Open pond culture is the most widely used method of culturing yellow perch to market size. Evidence from producers and our recent study suggests that production of 3,300–5000 kg/ha is

achievable (Malison 2000; Wallat and Tiu, unpublished data).

Yellow perch exhibit sexually dimorphic growth, females growing faster and larger than males (Scott and Crossman 1973; Schott et al. 1978; Schott 1980). Schott et al. (1978) speculated that many males would not reach market size (≥ 20 cm) in ponds by the end of their second year. Production strategies that address this issue need to be developed. In recirculating systems, yellow perch are often graded and separated by size to achieve optimal growth and production. In ponds, fingerlings harvested at the end of the first growing season show a large variation in size. Studies are needed to determine whether grading fingerlings after the first growing season would increase the production efficiency and growth performance of year-2 yellow perch in pond culture.

Size-grading is used in the culture of many commercial fish species in an attempt to improve growth and survival and increase biomass gain (Gunnes 1976; Huet 1986; Baardvik and Jobling 1990; Popper et al. 1992; Kamstra 1993). This practice is based on an assumption that larger individuals suppress the growth of smaller, subordinate fish (McIntyre et al. 1979). In some fish

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species, dominant individuals exhibit greater growth rates than subordinates (Brown 1946; Magnuson 1962; Jobling 1985, 1995; Koebele 1985), and several mechanisms have been proposed to explain how larger dominant individuals suppress the growth of small subordinates (Wirtz 1974; Koebele 1985; Wallace et al. 1988). Competition for food seems to be particularly important in governing growth (Magnuson 1962; Wallace and Kolbeinshavn 1988; Jobling and Koskela 1996); in the absence of competition from larger individuals, smaller individuals avoid the negative effects of a dominance hierarchy and may achieve higher growth rates (Purdom 1974). However, evidence suggests that size-grading may not remove this effect in all species, such as in Arctic char *Salvelinus alpinus* (Baardvik and Jobling 1990), European eel *Anguilla anguilla* (Kamstra 1993), channel catfish *Ictalurus punctatus* (Carmichael 1994) and turbot *Scophthalmus maximus* (Sunde et al. 1998).

The goals of this study were to (1) determine whether grading fingerlings after the first growing season would increase the production efficiency of food-sized yellow perch and (2) evaluate the effects of size-grading on the growth performance of yellow perch.

Methods

Pond conditions and stocking.—The study was conducted at the Ohio Center for Aquaculture Development, South Centers of Ohio State University, Piketon. In October 2001, 2 weeks before the anticipated stocking date, six ponds were drained and allowed to dry. Less than 1 week before stocking, the ponds were filled with well water. The water-surface area of each experimental pond was 0.1 ha and average water depth was approximately 1.0 m.

The fish were propagated in indoor tanks and nursed in ponds by the fertilization method for the first 2 months. At the completion of the nursery, juveniles from each pond were pooled, restocked, and raised in six 0.1-ha ponds for additional 4 months with commercial feed. At the end of October 2001, year-1 fingerlings (mean, 11.3 g) were harvested, pooled, and used for present study. Fingerlings were divided into three size-groups: ungraded, small, and large. One-third of the fingerlings were separated out to represent an ungraded population. The remaining two-thirds of the fingerlings were passively graded, using a bar grader (1.5 cm spacing), into two groups: small (≤ 8.5 cm; mean, 5.3 g) and large (> 8.5 cm; mean, 18.3

g). Each size-group had two replications, resulting in six culture ponds with a density of 30,000 fish/ha.

Feeds and feeding.—AquaMax Grower commercial sinking feed (45% protein, 16% fat; Purina Mills, St. Louis, Missouri) was used throughout the experiment. Fish were fed 1% of body weight (BW) over the winter. As water temperatures increased to above 10C, feeding rates were adjusted to 2% BW from the middle of March, then to 3% BW from May, based on an assumed survival of 100% and estimated biomass. Daily ration was distributed over the entire surface of each pond twice daily at 0900 hours and 1600 hours.

Samples and harvest.—In May 2002, all ponds were sampled ($N = 50$) to check fish externally for overall health condition and to establish new feeding amounts. Samples were individually weighed and measured. All six ponds were drained and harvested in November 2002. Fish from each pond were group-weighted (drained weight) to the nearest 0.1 g to determine total harvest weight. A group of approximately 1,000 fish from each pond was individually counted and then separated first by mechanized and then by hand-grading, to determine the percentage of market size (≥ 20 cm) and nonmarket size (< 20 cm) fish from each group. The remaining fish from each pond were put through a mechanical grader to separate marketable and nonmarketable fish. Bulk weights of these groups were also taken.

Measurement and calculation.—Measurements of dissolved oxygen (DO) and temperature were taken twice daily, morning and afternoon, with YSI 51B DO meter (Yellow Spring Instrument, Yellow Spring, Ohio). Any pond with dissolved oxygen levels at or below 5.0 mg/L was aerated with electrical aerators, until dissolved oxygen levels stabilized above 7.0 mg/L.

For individual measurements, fish were weighed to the nearest 0.1 g and measured to the nearest millimeter. Absolute growth rate (AGR) was calculated according to the formula

$$\text{AGR} = (W_2 - W_1)/T \times 100,$$

where W_1 and W_2 are fish weight at the start and end of a growth period, respectively, and T is the time in days between weighing.

A one-way analysis of variance (ANOVA), followed by Duncan's test, was used to test for differences among means for AGR, dissolved oxygen, and temperature. We used the Kruskal-Wallis test to assess differences in harvest weight, mar-

TABLE 1.—Mean \pm SE total production, marketable production, body weight (BW) by marketable and nonmarketable sizes, survival, and feed conversion ratio (FCR) of yellow perch cultured in ponds for 1 year after stocking with ungraded, small, and large fingerlings (see text for size-group definitions). Pooled data from the two graded groups are also presented. Within columns, means followed by different letters are significantly different ($P \leq 0.05$) by ANOVA.

Grading group	Total production		Marketable production	
	(kg)	(kg/ha)	(kg)	(%)
Ungraded	193.2 \pm 13.4 z	1,909.6 \pm 132.4 z	101.5 \pm 5.8 zy	52.6 \pm 0.6 y
Small	139.3 \pm 48.5 z	1,376.3 \pm 478.9 z	49.1 \pm 19.5 y	34.6 \pm 2.0 x
Large	245.9 \pm 14.9 z	2,430.5 \pm 147.3 z	159.1 \pm 15.2 z	64.5 \pm 2.3 z
Pooled	192.6 \pm 37.1 z	1,903.4 \pm 366.7 z	104.7 \pm 33.3 zy	49.6 \pm 8.7 y

marketable production, feed conversion ratio, and survival rate among three groups.

Results

Water Quality

No significant differences in water temperature were evident among the three group ponds ($P > 0.05$). Figure 1 presents the range and frequency distribution of water temperatures in a representative experimental pond for the duration of experiment. The mean water temperature was 16.3°C over the period of experiment. Over half (50.3%) of the total recordings of water temperatures ($N = 330$) during the culture period were above the temperature needed for growth of yellow perch. The levels of dissolved oxygen over the 1-year experiment in the ungraded, small, and large-fish ponds were 10.2 \pm 3.8 (mean \pm SE), 10.5 \pm 4.2, and 10.2 \pm 4.0 mg/L, respectively. The concentration of dissolved oxygen for six ponds was less than 5.0 mg/L for 2.0% of the total 1,947 recorded observations. No significant differences were detected in mean levels of dissolved oxygen throughout the period of experiment among the three groups ($P = 0.263$), although there were differences ($P < 0.05$) for some individual months. The pH of the water in the ponds ranged from 7 to 8, which was desirable for growth of yellow perch.

Production Structure

The mean total marketable production from the large-group ponds was significantly greater ($P < 0.05$) than that from the small-group ponds (Table 1), though total nonmarketable production did not differ significantly among the three groups. Significant differences ($P < 0.05$) were also found in the size (body weight) percentage of both marketable and nonmarketable fish among the ungraded, small, and large groups (Figure 2). The final biomass of the large group was 77% and 27% more than that of small and ungraded size-groups, respectively (Figure 3), although no significant differences in total production were detected among three groups. Intergroup comparison revealed that the feed conversion ratios differed significantly between large and small groups, although the differences between each graded group and the ungraded group were not significant ($P > 0.05$). Survival rates did not differ among the three groups. Comparison of pooled data from the two graded groups with data from the ungraded group showed that total production, marketable production, survival, and feed conversion ratio were very similar (Table 1; Figure 2).

On an individual weight basis, the mean marketable size differed significantly ($P < 0.05$) among the small, large, and ungraded groups; moreover, mean nonmarketable body weight in the

TABLE 2.—Mean \pm SE body weight (BW) and total length (TL), on selected day, along with coefficients of variation (CVs), differences in CV for small, ungraded, and large fish groups and the absolute daily growth rate (AGR) for body weight. See text for size-group definitions and the calculation of AGR.

Grade	Day 0				Day 181	
	BW		TL		BW	
	Mean	CV	Mean	CV	Mean	CV
Ungraded	11.3 \pm 0.4	82.2	94.3 \pm 0.9	22.1	24.2 \pm 1.6	67.3
Small	5.0 \pm 0.1	21.6	77.8 \pm 0.3	6.5	11.9 \pm 0.7	61.1
Large	16.8 \pm 0.6	57.7	109.4 \pm 1.0	16.6	33.0 \pm 1.6	49.9

TABLE 1.—Extended.

Grading group	Market BW (g)	Nonmarket BW (g)	Survival (%)	FCR
Ungraded	124.9 ± 15.6 z	43.0 ± 8.3 y	96.5 ± 1.5 z	1.6 ± 0 zy
Small	104.3 ± 13.7 x	34.1 ± 12.5 y	96.0 ± 1.0 z	1.1 ± 0.2 y
Large	115.7 ± 12.8 y	64.9 ± 3.8 z	91.0 ± 8.5 z	1.8 ± 0.2 z
Pooled			93.3 ± 3.8 z	1.4 ± 0.2 zy

large group was significantly greater ($P < 0.05$) than in other two groups (Table 1).

Growth Performance

Growth during the experimental period is shown in Figure 4. There were no significant differences in initial mean weight between the two replicates within each grading group. During the first half-year (winter to spring), fish in all groups grew slowly because of low temperature and limited feeding. No significant differences ($P > 0.05$) in absolute growth rates among three groups were detected during this period, although the growth rates of fish in the large group were 125% greater than for those in the small group (Table 2). The coefficient of variation ($CV = 100 \cdot SD/mean$) in both weight and length for the small group of fish increased about 80%, whereas the CV in the ungraded and large groups showed some reduction (Table 2). The distribution of size frequency during the same period is shown in Figure 5. Initially, frequency distributions in all three groups were highly skewed. At day 181, weight distributions in all groups developed into two distinct size-groups with two dominant peaks.

Daily growth rates in the second half-year (from May to October) were relatively high for all groups but did not differ significantly ($P > 0.05$) among three size-groups, although the AGR of the small group was 32% less than that of the large group. Over the whole-year experimental period, the

growth rates and patterns of the two large-fish replicates were very similar (Figure 4).

Discussion

In pond culture conditions, temperature and dissolved oxygen are the two most important water quality factors with respect to fish growth. Reported temperature for growth of yellow perch ranges from approximately 11°C to 26°C with optimum temperatures ranging from 23°C to 25°C (Hokanson 1977). Malison (2000) reported that levels of dissolved oxygen as low as 3.5 mg/L did not affect the growth of yellow perch.

We are confident that the observed differences in growth rates and production among the three grading groups were not attributable to temperature or dissolved oxygen because these conditions were similar in all groups in the present experiment, although the stocking densities (biomass) differed.

Our findings demonstrate that the mean marketable production from the large-group ponds was significantly higher than that from the small-group ponds, the final biomass of the large group being 77% and 27% greater than for the small and ungraded groups, respectively. The results indicate that grading by size should be advantageous to those wishing to culture yellow perch to food fish size in the second year. The different results for percentage of fish reaching market size among the large (65%), mixed (53%), and small (35%) groups

TABLE 2.—Extended.

Grade	Day 181		BW, day 365	Days 0–181		Days 182–365	
	TL			CV differences		AGR (BW)	AGR (BW)
	Mean	CV		BW	TL		
Ungraded	118.4 ± 2.4	20.1	64.1 ± 37.2	-14.9	-2.0	7.0	34.0
Small	97.3 ± 1.8	18.0	86.6 ± 47.7	39.5	11.5	4.0	28.0
Large	132.1 ± 2.0	15.0	100.4 ± 26.0	-7.8	-1.6	9.0	37.0

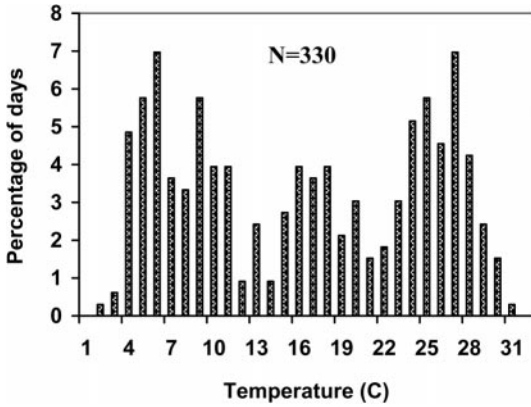


FIGURE 1.—Range and frequency distribution of daily bottom water temperatures, rounded to the nearest whole number, in a representative experimental pond used in the grading grow-out experiment of yellow perch from November 2001 to November 2002.

suggest that yellow perch should be selectively graded by at least the end of 1 year of culture, to increase the number of individuals with the potential to reach market size. Elimination of the smallest 10–20% of year-1 fish from further food fish growout efforts will streamline operations and lead to increased operational efficiency and profitability. Further, the relatively successful growth of even the small groups indicates that culturists can be reasonably confident in selling these small groups to recreational pond owners. The data appear to indicate that the small groups of fish, although slower growing, do have the potential to reach the sizes (≥ 20 cm) desired by anglers.

The principal challenge faced during this ex-

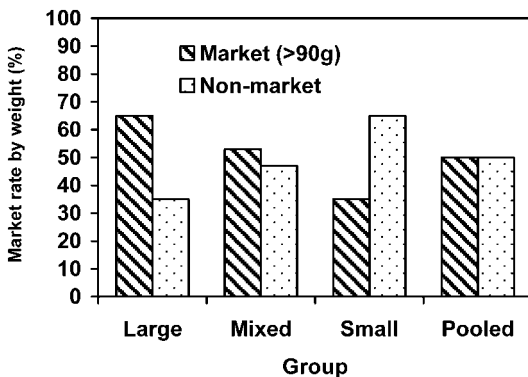


FIGURE 2.—Percentages of yellow perch of marketable weight (>90 g) and nonmarketable weight of that were harvested from large-, mixed-, and small-group ponds. Pooled data from the two graded groups are also shown. See text for size-group definitions.

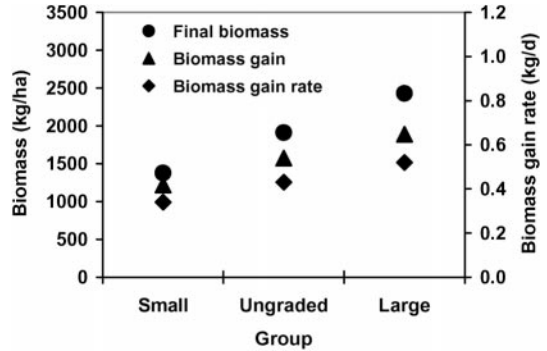


FIGURE 3.—Mean final biomass, biomass gain, and biomass gain rate for small, ungraded, and large size-groups.

periment was the unusually high summertime air temperatures, which led to warmer water temperatures. For several weeks in July and August, water temperature in the ponds exceeded 28°C, and on several days climbed briefly above 30°C. Hokanson (1977) indicated that a lethal temperature for yellow perch is 32°C and that at temperatures above 26°C they show signs of stress in behavior and reduced growth. Thus, disease and mortalities can be expected under conventional aquaculture conditions (Hokanson 1977). Tidwell et al. (1999) found that yellow perch reared at 28°C had significantly higher feed conversion ratios, and significantly lower survival and net protein utilization than those raised at 20°C or 24°C. Temperatures near 28°C appear to be sufficient to represent chronic stress conditions, as manifested by reduced feeding (Tidwell et al. 1999). Hence, we believe that these high temperatures during the

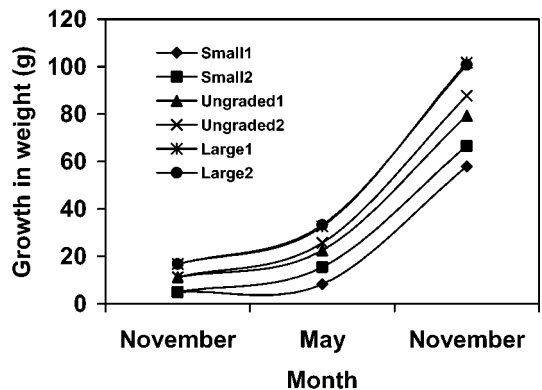


FIGURE 4.—Growth of small, ungraded, and large groups of yellow perch in the experimental period from November 2001 to November 2002. Results for two replicates of each group are shown.

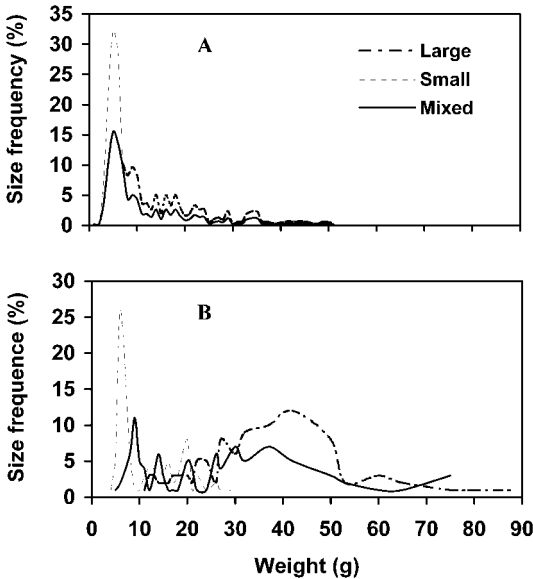


FIGURE 5.—Weight distribution of small, ungraded, and large groups of yellow perch at (A) the start and (B) the end of the first half (days 0–181) of the experiment. Replicates are pooled.

present experiment may have had an effect on the production and growth of yellow perch in all the groups, although quantifying that effect is difficult. In a trial similar to this one, but performed in 2001 when average pond temperatures were nearer the optimal range, ungraded populations of perch at the same stocking density (30,000/ha) reached a high of 60% market size (G. K. Wallat et al., unpublished data); in comparison, the result for 2002 was only 53%. We believe that more than 65% of the large-fish group in the 2002 study reported here would have reached market size if pond temperatures had been more optimal throughout the study.

However, when pooled data from the two graded groups were compared with that from the ungraded group, the production and marketable weights were very similar, indicating that the size-grading of yellow perch did not improve the total and marketable production. The reason for this is that size-sorting of fingerling yellow perch did not result in improved growth in this study.

Size-sorting of the fingerlings did not increase growth rates in this experiment. Although we anticipated better growth in the small-fish groups than in the unsorted groups—given the greater size variance in the latter, with possible negative effects of social interactions (Jobling 1982; Knights 1987),—we found no differences in growth rate

between the small and ungraded groups. Similarly, when Barki et al. (2000) graded fingerling silver perch *Bidyanus bidyanus* into two groups (small and large), they found that size-grading did not improve growth over that of mixed controls. Jobling and others also found that size-grading did not improve growth in Arctic char (Wallace and Kolbeinshavn 1988; Baardvik and Jobling 1990), European eel (Kamstra 1993), and turbot (Strand and Øiestad 1997; Sunde et al. 1998), whereas size-grading has been shown to result in improved growth of juvenile Atlantic salmon *Salmo salar* (Gunnes 1976), gilthead sea bream *Sparus auratus* (Popper et al. 1992), and Nile tilapia *Oreochromis niloticus* (Brzeski and Doyle 1995).

The CV of both weight and length increased in the small-fish groups during the first half of experimental period but remained stable or decreased in the mixed and large groups. Similar results have been reported in juvenile European eel (Wickins 1985) and Arctic char (Wallace and Kolbeinshavn 1988). The increase in CV observed in the present study in the small groups may suggest competition or hierarchical effects among juvenile yellow perch. Jobling (1982) stated that an increase in CV size sometimes occurs in populations where the growth of some individuals is suppressed by competition. Alternatively, the changes in size distribution in the present experiment may have originated from inherent genetic differences in the growth capacity of the fish. We speculate that size CV in fish was not necessarily the result of social interactions but rather was a consequence of differences in metabolism, utilization of food resources (Doyle and Talbot 1986), and genotypic-specific growth and oxygen affinity (Imsland et al. 1997). Yellow perch exhibit sexually related dimorphic growth in which females inherently grow faster and reach a larger ultimate size than males (Scott and Crossman 1973; Schott et al. 1978; Schott 1980). The feed conversion ratios of the large-fish group were detected to be significantly more than in the small group in the present experiment. Further studies need to be conducted to explain this because faster-growing fish usually have lower feed conversion ratios.

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