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Effect of Culture Temperature on Growth, Survival, and Biochemical Composition of Yellow Perch *Perca flavescens*

JAMES H. TIDWELL, SHAWN D. COYLE, JEFF EVANS, CHARLES WEIBEL, JONATHAN MCKINNEY, KIM DODSON, AND HALIMAH JONES

Aquaculture Research Center, Kentucky State University, Frankfort, Kentucky 40601 USA

Abstract

Juvenile yellow perch *Perca flavescens* were evaluated under controlled conditions in tanks for 13 wk to determine the effect of temperature on growth to advanced sizes under intensive culture conditions. Yellow perch weighing 6.6 ± 1.5 g were stocked into nine 4,755-L tanks at 131 fish/m³ (625 perch/tank). There were three replicate tanks per temperature (20, 24, and 28 C). Perch were fed to apparent satiation twice daily using a 45% crude protein diet with 16% crude fat. After 93 d the perch in the 24 C treatment were significantly larger ($P < 0.05$) than those in the 20 C and 28 C treatments, which were not significantly different ($P < 0.05$) from each other. Yellow perch raised at 28 C had significantly higher ($P < 0.05$) feed conversion ratios and significantly lower ($P < 0.05$) survival and net protein utilization than perch raised at 20 C or 24 C. Whole body moisture was significantly higher in ($P < 0.05$) yellow perch raised at 20 C which also had significantly higher levels of arachidonic acid (20:4 n-6) and docosohexaenoic acid (22:6 n-3). The ratio of palmitic acid (16:0) and palmitoleic acid (16:1 n-6) had a positive correlation ($P < 0.05$) with culture temperature. These data indicate that 24 C may be an optimum temperature for yellow perch. At 20 C survival and feed conversion are good but growth rates are reduced. Temperatures near 28 C appear sufficient to represent chronic stress conditions.

In the north-central region of the U.S., demand for yellow perch *Perca flavescens* exceeds supply due to harvest restrictions on wild populations. This has resulted in increased interest in them as an aquaculture species. Temperature is the single-most pervasive environmental factor in poikilothermic animals (Stickney 1979). Temperature can affect fish growth directly by controlling feed consumption, nutrient requirements, and food passage time (Smith 1989a). Brown et al. (1994) reported that differences existed in responses to extreme temperatures in yellow perch from different geographical sources, though all responded similarly at near optimal temperatures. However, temperatures reported as optimum for growth of juvenile perch vary. Hokanson and Kleiner (1974) reported the optimum temperature for feeding and rearing perch to be 23.9 to 27.8 C, while Huh et al. (1976) reported the optimum temperature for yellow perch fed formulated diets to be 22 C. Also, temperature may not affect all important culture variables in the same way. Andrews and Stickney (1972) found that feed conversion in channel catfish was most efficient at 18 C, while growth rate was highest at 30 C. Culture temperature may also affect the amount of lipid deposited, as well as its fatty acid profile, due to the role of unsaturated fatty acids in maintaining bio-membrane fluidity (Sargent et al. 1989). These changes could affect the nutrient demands of the fish, as well as their organoleptic attributes, when raised at different temperatures. The objective of this study was to evaluate growth, survival, and biochemical composition of yellow perch raised at different temperatures.

Materials and Methods

The study was conducted in nine 4,775-L rectangular tanks designed as pond microcosms and housed within a greenhouse located at the Aquaculture Research Center, Kentucky State University, Frankfort, Ken-

tucky, USA. The greenhouse was 60% covered by black plastic to reduce ambient light levels. On 19 August 1997 each tank was stocked with 625 juvenile yellow perch (131/m^3) averaging 6.6 ± 1.5 g ($\bar{x}$ ± SD) in weight. Fish were fed a commercial salmonid diet (45% crude protein, 16% crude lipid, Nelson and Sons, Murrary, Utah, USA) to apparent satiation twice daily.

Water in each tank received a constant water flow of approximately 4 L/min. Dissolved oxygen levels were maintained by constant aeration. Water was recirculated through three heat pump units (AquaLogic, San Diego, California, USA) to maintain temperatures, with each heat pump supplying three replicate tanks. Each temperature treatment (three tanks) constantly recirculated through its associated heat pump to maintain temperature, with approximately 25% of the total volume being replaced daily by a constant flow of approximately 1 L/min of water from a storage reservoir. Temperatures in all tanks were maintained at 24 C for a 14-d conditioning period. Beginning 2 September 1997 (Day 1) temperatures were gradually adjusted (over a 3-d period) to achieve treatment temperatures of 20, 24, or 28 C, with three replicate tanks per temperature.

Water temperature and dissolved oxygen concentration were determined twice daily using a YSI Model 57 dissolved oxygen meter (YSI Instruments Co., Yellow Springs, Ohio, USA). Total ammonia-nitrogen (TAN), and nitrite-nitrogen were determined weekly according to outlined procedures for a Hach DR/2000 spectrophotometer (Hach Co., Loveland, Colorado, USA) in water samples collected from each tank at approximately 1300 h. The pH of each tank was determined weekly at 1300 h using an electronic pH meter (Hanna Instruments, Ltd., Mauritius). Un-ionized ammonia was calculated based on TAN, temperature, and pH according to Boyd (1979).

A sample of > 50 fish from each tank was collected every 3 wk, group weighed to the nearest gram, counted and returned to their respective tank. On 4 December 1997 all fish from each tank were captured, bulk weighed, and counted. From each tank 150 randomly selected individuals were also individually weighed and measured for total length. Five fish from each tank were randomly selected for chemical analyses. These fish were sacrificed, homogenized in a blender, and a pooled sample for proximate analyses was frozen. A separate pooled sample of 2–3 fish was immediately frozen in liquid nitrogen (−196 C) and stored (−40 C) for subsequent fatty acid and amino acid analyses by a commercial analytical laboratory (Woodson-Tenent Laboratories, Dayton, Ohio, USA).

Specific growth rate (SGR, % body wt/d) was calculated as $SGR = [(\ln W_f - \ln W_i)/t] \times 100$, where W_f = mean weight at the end of the period, W_i = mean weight at the beginning of the period, and t = time in days of the period (Ricker 1975). Feed conversion ratio (FCR) was calculated as FCR = weight of feed fed (g)/live weight gain (g). Protein Efficiency Ratio (PER) was calculated as g wet weight gain/g crude protein fed. Percentage Protein Deposited (PPD) was calculated as PPD = [(final body protein − initial body protein) × 100]/total protein fed.

Data were analyzed by one-way analysis of variance (ANOVA) using Statistix Version 4.1 (Statistix Analytical Software 1994) to determine the effects of temperature on growth, condition factor, feed conversion, body composition, and survival. All percentage and ratio data were transformed to arc sin values prior to analysis (Zar 1984).

Results and Discussion

Measured temperatures were maintained very near target treatment temperatures, averaging (±SD) 20.2 (0.1), 23.7 (0.1), and 27.3 (0.2) C over the study period. Dissolved oxygen concentrations were significantly different ($P < 0.05$) among all three treatments. This was primarily due to the decreased solubility of oxygen at increasing

TABLE 1. *Overall means (± SD) for total ammonia-nitrogen, un-ionized ammonia, nitrite, and pH of tanks in which yellow perch were raised at three water temperatures. Means within a row followed by different letters are significantly different (P < 0.05).*

Variable	Culture temperature (C)		
	20	24	28
Total ammonia-nitrogen (mg/L)	0.67 ± 0.02a	0.55 ± 0.40a	0.67 ± 0.92a
Un-ionized ammonia (mg/L)	0.08 ± 0.00b	0.11 ± 0.01a	0.12 ± 0.01a
Nitrite (mg/L)	0.04 ± 0.00b	0.09 ± 0.00a	0.09 ± 0.01a
pH	8.37 ± 0.04b	8.42 ± 0.01ab	8.47 ± 0.03a

temperatures (Boyd 1979). If compared in terms of oxygen concentrations as a percentage of saturation, all treatments averaged > 80% saturation. There were no significant differences in total ammonia-nitrogen (TAN) concentrations ($P > 0.05$) (Table 1). The concentration of un-ionized ammonia was significantly higher ($P < 0.05$) in the 24 and 28 C treatment tanks (0.114 and 0.122 mg/L, respectively) than in the 20 C treatment (0.077 mg/L) (Table 1). The amount of TAN in the un-ionized form is increased by increasing temperature and pH (Boyd 1979). Since TAN was not higher in those treatments, higher un-ionized ammonia concentrations were primarily due to increased temperature and higher ($P < 0.05$) pH levels in the 24 and 28 C treatments. Nitrite concentrations were also significantly higher ($P < 0.05$) in the 24 and 28 C treatments, (0.085 and 0.087 mg/L, respectively), though levels were not likely sufficient to cause health problems (Boyd 1979).

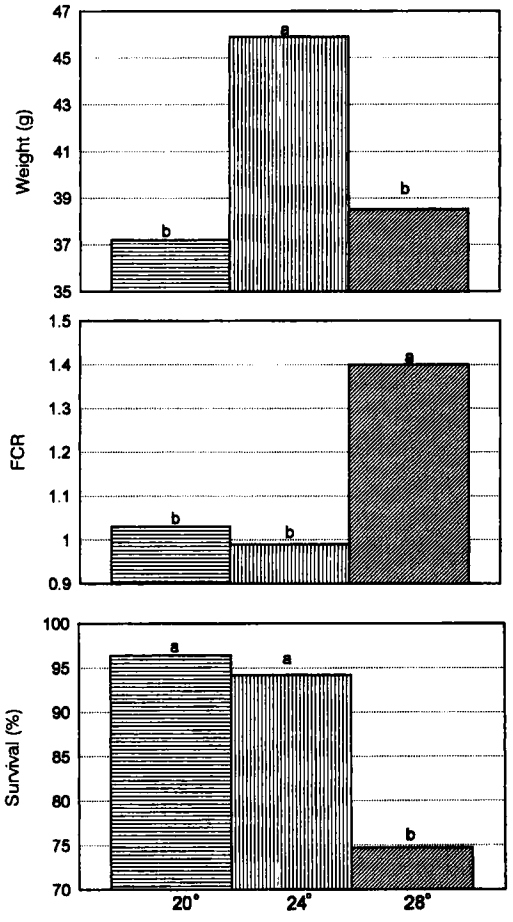

FIGURE 1. *Average individual weight (g), feed conversion ratio (FCR), and survival (%) of yellow perch raised at 20, 24, or 28 C for 93 d. Each bar represents a mean of three replicate tanks.*

After 93 d, yellow perch juveniles raised at 24 C had significantly higher ($P > 0.05$) mean weights (Fig. 1), individual gains and specific growth rates (2.20) than yellow perch raised at 20 C or 28 C (Table 2). These variables did not differ significantly ($P > 0.05$) between perch raised at 20 C or 28 C. Specific growth rates calculated on data (experiment 3) presented by Ramseyer and Garling (1998) ranged from 0.80 to 1.56 on yellow perch raised at 20.0 C for 8 wk. Fontaine et al. (1995) reported a SGR of 1.0 in European perch *P. fluviatilis* raised in cages at an average temperature of 22.5 C.

Feed conversion ratio was significantly higher ($P < 0.05$) for fish raised at 28 C than for fish raised at 24 C or 20 C (Fig. 1). These data indicate that yellow perch

TABLE 2. *Final total lengths, weight gains, specific growth rates, protein efficiency ratio, condition factor, percentage protein deposited, and carcass composition after 93 d. Values are means ± SE of three replicates. Means within a row followed by different letters are significantly different* ($P < 0.05$).

Variable	Culture temperature (C)		
	20	24	28
Total length (cm)	13.95 ± 0.23b	15.42 ± 0.38a	14.07 ± 0.44b
Weight gain (%)	459 ± 29b	672 ± 11a	514 ± 42b
Specific growth rate (%/d)	1.85 ± 0.1b	2.20 ± 0.0a	1.95 ± 0.1b
Protein efficiency ratio	1.61 ± 0.05b	2.52 ± 0.36a	2.07 ± 0.36ab
Percentage protein deposited	25.8 ± 0.9b	45.5 ± 6.7a	12.1 ± 0.9a
Carcass composition at end of treatment (% of wet weight)			
Moisture (%)	70.6 ± 0.41a	69.5 ± 1.3ab	68.9 ± 0.6b
Protein (%)[1]	59.7 ± 1.2a	58.9 ± 4.3a	54.8 ± 0.5a
Lipid (%)[1]	27.5 ± 0.2a	31.7 ± 3.2a	30.0 ± 3.5a
Ash (%)	11.1 ± 1.2a	10.9 ± 1.7a	12.1 ± 0.9a

[1] Dry weight basis.

convert feed less efficiently at 28 C. This may be due to both higher metabolic maintenance demands at increased temperatures (Smith 1989b) and increased gastric emptying rates which can reduce nutrient assimilation (Smith 1989a).

Temperature is known to affect the chemical composition of aquatic organisms (Landau 1992). In this study, culture temperature had no significant effect ($P > 0.05$) on whole body lipid, protein, or ash concentrations in yellow perch (Table 2). These results differ from Stickney and Andrews (1971) who reported an almost linear increase in total carcass lipid of channel catfish with an increase in environmental temperature. However, moisture content was significantly influenced being higher ($P < 0.05$) in perch raised at 20 C than in those raised 28 C. Love (1980) reported that cod *Gadus morhua* showed increased moisture content in the muscle tissue when living in cold water, despite active feeding. He attributed this to reduced food absorption, producing a functional malnutrition despite full stomachs.

It has been suggested that properties of fish tissue proteins are affected by the environmental temperature at which they are synthesized (Love 1980). If differences were of significant magnitude, nutritional requirements could potentially differ for fish cultured at different temperatures. Catfish diets for winter feeding normally contain less protein than those used at higher temperatures (Lovell 1989). In this study, fish cultured at 28 C had significantly higher ($P < 0.05$) whole body concentrations of arginine (% of total amino acids) than perch raised at 24 C (Table 3). Threonine levels were higher ($P < 0.05$) in perch raised at 28 C than in those cultured at 20 or 24 C. Perch raised at 28 C had significantly lower ($P < 0.05$) concentrations of leucine than those raised at 20 C or 24 C. Lysine levels were significantly higher in perch at 20 C than in those at other temperatures. Although statistically significant, these differences do not appear sufficient to justify adjustments in feed formulations.

Body lipids of fish from warm waters tend to be more saturated than those of fish from cooler waters (Gopakumar and Nair 1972). Leslie and Buckly (1976) demonstrated that fish can adjust their pattern of biosynthesis of fatty acids rapidly according to the prevailing temperature. In the present study several significant differences in fatty acid composition were identified, though the actual magnitude of some differences was fairly small.

Palmitic acid (16:0) was significantly lower ($P < 0.05$) and palmitoleic acid (16:1 n-6) was significantly higher in fish raised

TABLE 3. *Amino acid composition (% of total amino acids) of yellow perch raised at three water temperatures. Values are means ± SD from three replicate tanks per treatment. Diet composition is included for comparative purposes. Means followed by a different letter are significantly different (P < 0.05).*

Amino acid	Culture temperature (C)			Feed
	20	24	28	
Arginine	6.36 ± 0.08ab	6.16 ± 0.26b	6.69 ± 0.20a	4.70
Cystine	0.92 ± 0.02a	0.97 ± 0.08a	0.95 ± 0.02a	0.72
Histidine	2.43 ± 0.07a	2.52 ± 0.15a	2.33 ± 0.20a	3.28
Isoleucine	3.38 ± 0.38a	3.26 ± 0.13a	3.21 ± 0.05a	3.24
Leucine	7.32 ± 0.07a	7.26 ± 0.15a	6.89 ± 0.11b	7.20
Lysine	8.53 ± 0.13a	8.18 ± 0.19b	8.18 ± 0.14b	6.36
Methionine	2.90 ± 0.08a	3.00 ± 0.52a	2.81 ± 0.19a	1.84
Phenylalanine	3.98 ± 0.06a	3.91 ± 0.10a	3.98 ± 0.08a	3.92
Threonine	5.06 ± 0.05b	4.99 ± 0.11b	5.29 ± 0.03a	4.37
Tryptophan	ND	ND	ND	ND
Tyrosine	3.13 ± 0.03a	3.10 ± 0.10a	3.10 ± 0.11a	2.19
Valine	4.03 ± 0.38a	3.93 ± 0.11a	3.88 ± 0.05a	5.23

at 20 C than those raised at 24 C or 28 C (Table 4). Lewis (1962) proposed that the ratio of 16:0 to 16:1 could be used as an index of the temperature of marine ectotherms. For these data this ratio was calculated and regressed on culture temperature for each replicate yielding a highly significant regression ($P < 0.01$; $r^2 = 0.85$) described by the equation, ratio = 0.6444 + 0.0246 (temp, C). Although Rodegker and Nevenzel (1964) reported that their data on marine invertebrates did not support the applicability of this index, these data on yellow perch strongly support the index proposed by Lewis (1962), even over a fairly limited temperature range.

TABLE 4. *Fatty acid composition (% of total fatty acids) of yellow perch raised at three culture temperatures. Values are means (± SD) of three replicate tanks per treatment. Fatty acid composition of the feed is included for comparative purposes. Means within a row followed by different letters are significantly different (P < 0.05).*

Fatty acid	Culture temperature (C)			Feed
	20	24	28	
14:0	6.18 ± 0.3a	6.42 ± 0.24a	6.74 ± 0.15a	8.52
16:0	19.03 ± 0.16b	20.29 ± 0.51a	20.46 ± 0.81a	21.51
16:1 n-7	17.04 ± 0.36a	15.91 ± 0.40b	15.59 ± 0.31b	10.47
18:0	1.53 ± 0.06a	1.49 ± 0.02a	1.59 ± 0.08a	3.98
18:1 n-9	21.64 ± 0.33a	21.94 ± 0.67a	20.71 ± 0.63a	13.23
18:2 n-6	7.78 ± 0.09a	7.25 ± 0.10a	7.54 ± 0.49a	6.57
18:3 n-3	1.83 ± 0.24a	1.92 ± 0.16a	1.86 ± 0.17a	1.87
18:4 n-3	1.23 ± 0.149a	1.40 ± 0.069a	1.41 ± 0.06a	2.03
20:4 n-6	1.71 ± 0.05a	1.53 ± 0.07b	1.59 ± 0.07b	2.11
20:5 n-3	6.47 ± 0.39a	6.68 ± 0.31a	7.02 ± 0.32a	13.47
22:6 n-3	10.79 ± 0.56a	9.40 ± 0.22b	10.06 ± 0.32ab	8.12
Saturates	27.33 ± 0.54a	28.90 ± 0.65a	28.98 ± 0.94a	35.71
Monenes	39.80 ± 0.74a	38.80 ± 0.48ab	37.58 ± 0.78b	26.54
Diene	7.78 ± 0.09a	7.25 ± 0.10a	7.63 ± 0.52a	6.74
PUFA	32.88 ± 0.19a	32.03 ± 1.31a	32.92 ± 1.52a	30.93
n-3	20.33 ± 0.23a	19.40 ± 0.38a	20.35 ± 0.84a	23.46
n-6	12.20 ± 0.07a	12.20 ± 1.22a	12.12 ± 0.71a	11.36
n-3/n-6	1.67 ± 0.03	1.60 ± 0.16	1.68 ± 0.04	2.06

Arachidonic acid (20:4 n-6) was significantly higher ($P < 0.05$) in perch cultured at 20 C than in perch cultured at 24 C or 28 C. Docosahexaenoic acid (22:6 n-3; DHA) was also significantly higher in perch raised at 20 C than in those raised at 24 C. This agrees with Kayama et al. (1963) who reported that guppies *Lebistes reticulatus* raised at 17 C possessed higher levels of DHA than those raised at 24 C. However, DHA levels in perch raised at 28 C were not significantly different ($P > 0.05$) than those raised at 20 C or 24 C.

For summary categories, only monounsaturated fatty acids (monenes) showed a significant response to culture temperature, being significantly higher ($P < 0.05$) in fish cultured at 20 C (39.8%) than in perch cultured at 28 C (37.6%). Comparisons of tissue and diet compositions indicate that the monenes palmitoleic (16:1 n-7) and oleic (18:1 n-9) acids were deposited at much higher levels than those found in the diet (Table 4). These results agree with Tidwell and Robinette (1990) who found that catfish also tend to preferentially deposited 16:1 n-7 and 18:1 n-9 above levels in dietary lipids.

Survival of yellow perch juveniles was significantly lower ($P < 0.05$) in perch raised at 28 C (Fig. 1) than in perch raised at 20 C or 24 C, which were not significantly different ($P > 0.05$). The primary cause of mortality was *Columnaris spp.* Malison et al. (1998) reported that, compared to other fishes, yellow perch demonstrate a large physiological stress response to intensive culture conditions, which is increased at higher temperatures. These data likely indicate that 28 C is above the thermal optimum for yellow perch and represents actual stress conditions. When culture temperatures are too high, susceptibility to pathogens is increased, while the virulence of the pathogen itself is also increased (Laws 1981).

In summary, at 24 C growth, survival, and feed conversion appear optimal. At 20 C feed conversion and protein utilization remain good but growth rate is reduced approximately 20%. Temperatures near 28 C appear to be high enough to cause stress to yellow perch, resulting in reduced growth, survival, and feed conversion efficiency. Culture temperatures in the range of 20–28 C did affect some body composition components; however, adjustments in feed formulations for different culture temperatures do not appear to be justified.

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Literature Cited

Andrews, J. W. and R. R. Stickney. 1972. Interactions of feeding rates and environmental temperature on growth, food conversion, and body composition of channel catfish. Transactions of the American Fisheries Society 101:94–99.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn University, Agricultural Experiment Station, Auburn, Alabama, USA.

Brown, P., K. Wilson, J. Wetzel, J. Mays, F. Binkowski, and S. Yeo. 1994. Culture characteristics of juvenile yellow perch (*Perca flavescens*) from different geographical locales grown at three temperatures. World Aquaculture '94, Book of Abstracts.

Fontaine, P., L. Tamazouzt, and B. Capdeville. 1995. Fitness of common perch *Perca fluviatilis* for on growing in floating cages and in recirculated systems. Pages 38–41 *in* P. Kestemont and K. Dabrowski, editors. Workshop on aquaculture of percids, short communications. Presses universitaires de Namur, Namur, Belgium.

Gopakumar, K. and M. R. Nair. 1972. Fatty acid composition of eight species of Indian marine fish. Journal of Science Food Agriculture 23:493–496.

Hokanson, K. E. F. and C. F. Kleiner. 1974. Effects of constant and rising temperatures on survival and developmental rates of embryonic and larval yellow perch *Perca flavescens* (Mitchill). Page 437 *in* J. S. Blaxter, editor. The early life history of fish. Springer-Verlag, New York, New York, USA.

Huh, H. T., H. E. Calbert, and D. A. Stuiber. 1976.

Effects of temperature and light on growth of yellow perch and walleye using formulated feed. Transactions of the American Fisheries Society 105:254–258.

Kayama, M., Y. Tsuchiya, and J. F. Mead. 1963. A model experiment of aquatic food chain with special significance in fatty acid conversion. Bulletin of Japanese Society Scientific Fisheries 29:452–458.

Landau, M. 1992. Introduction to aquaculture. John Wiley & Sons, New York, New York, USA.

Laws, E. A. 1981. Aquatic pollution. John Wiley & Sons, New York, New York, USA.

Leslie, J. M. and J. T. Buckley. 1976. Phospholipids composition of goldfish (*Carassius auratus L.*) liver and brain and temperature-dependence of phosphatidyl choline synthesis. Comparative Biochemistry and Physiology 53B:335–337.

Lewis, R. W. 1962. Temperature and pressure effects on the fatty acids of some marine ectotherms. Comparative Biochemistry and Physiology 6:75–89.

Love, R. M. 1980. The chemical biology of fishes, volume 2. Advances 1968–1978. Academic Press, New York, New York, USA.

Lovell, T. 1989. Nutrition and feeding of fish. Van Nostrand Reinhold, New York, New York, USA.

Malison, J. A., J. Mellenthin, A. B. Head, L. S. Procarione, T. P. Barry, and J. A. Held. 1998. Cortisol stress responses and growth of yellow perch (*Perca flavescens*) reared under selected intensive culture conditions. Aquaculture '98 Book of Abstracts.

Ramseyer, L. J. and D. L. Garling, Jr. 1998. Effects of dietary protein to metabolizable energy ratios and total protein concentrations on the performance of yellow perch *Perca flavescens*. Aquaculture Nutrition 4:217–223.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board Canada Bulletin 191.

Rodegker, W. and J. C. Nevenzel. 1964. The fatty acid composition of three marine invertebrates. Comparative Biochemistry and Physiology 11: 53–60.

Sargent, J., R. J. Henderson, and D. R. Tocher. 1989. The lipids. Pages 153–218 *in* J. E. Halver, editor. Fish nutrition. Academic Press, New York, New York, USA.

Smith, L. S. 1989a. Digestive functions in teleost-fishes. Pages 331–421 *in* J. E. Halver, editor. Fish nutrition. Academic Press, New York, New York, USA.

Smith, R. R. 1989b. Nutritional energetics. Pages 1–29 *in* J. E. Halver, editor. Fish nutrition. Academic Press, New York, New York, USA.

Statistix Analytical Software. 1994. Statistix user's manual, version 4.1. Analytical Software, Tallahassee, Florida, USA.

Stickney, R. R. 1979. Principles of warmwater aquaculture. John Wiley & Sons, New York, New York, USA.

Stickney, R. R. and J. W. Andrews. 1971. Combined effects of dietary lipids and environmental temperature on growth, metabolism, and body composition of channel catfish (*Ictalurus punctatus*). Journal of Nutrition 101:1701–1710.

Tidwell, J. H. and H. R. Robinette. 1990. Changes in proximate and fatty acid composition of fillets from channel catfish during a two-year growth period. Transactions of the American Fisheries Society 119:31–40.

Zar, J. H. 1984. Biostatistical analysis, second edition. Prentice-Hall, Englewood Hills, New Jersey, USA.