Aquaculture and Fisheries Management 1991, **22**, 335–341

Seasonal production of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in ponds using different feeding practices

J. H. TIDWELL, C. D. WEBSTER & R. S. KNAUB *Community Research Service, Aquaculture Research Center, Kentucky State University, Frankfort, Kentucky, USA*

Abstract. In temperate regions of North America, the culture of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in ponds is constrained to the period mid-November to early April by water temperature. Feeding practice may influence production time. The effects of three feeding practices on growth and body composition of rainbow trout raised in ponds during a 142-day winter growth period were investigated. Feeding practices were (1) hand-feeding to satiation, (2) feeding according to a fish size/water temperature chart, and (3) feeding by demand feeder.

Fish fed to satiation consumed 66% more diet than fish fed according to a feeding chart and 163% more than fish fed by demand feeders. Fish fed to satiation had significantly higher ($P < 0{\cdot}05$) weight gain, harvest weight, specific growth rate, and protein gain with no significant increase ($P > 0{\cdot}05$) in percentage body fat or feed conversion ratio (FCR) compared to the other two treatments. Survival percentage did not differ significantly ($P > 0{\cdot}05$) between treatments. These data indicate that by using satiation feeding, marketable size rainbow trout can be produced in temperate region ponds without increases in percentage body fat or FCR.

Introduction

In temperate regions of the USA, the limited growing season available to both warmwater and coldwater species requires efficient use of pond resources. Sequential production of a warmwater species, i.e. channel catfish, *Ictalurus punctatus* (Rafinesque), during summer months and a coldwater species, i.e. rainbow trout, *Oncorhynchus mykiss* (Walbaum), during winter months, is one technique that has been investigated for increasing annual production (Reagan & Robinette 1976; Tidwell & Mims 1990). Under the constraints of a temperature-restricted growing season rapid growth assumes additional importance. For maximum growth, a high rate of food consumption is required (Lovell 1989a). Several feeding methods have been developed to provide adequate feed amounts.

Hand-feeding to satiation is usually the best assurance of maximum feed effectiveness, minimum waste (Lovell 1989b) and may decrease size variation (Abbottt & Dill 1989). Grayton & Beamish (1977) reported that rainbow trout fed to satiation had higher food consumption and growth rates than fish fed a percentage of bodyweight. However, feed conversion efficiencies may be decreased and carcass fat levels increased in fish fed to satiation (Brett 1979).

Trout feeding charts were originally developed by Deuel, Haskell & Tunison (1937) and adjusted feed levels based on fish length and weight. Piper, McElwain, Orme, McCraven, Fowler & Leonard (1982) recommended a feeding chart developed by Leitritz & Lewis

Correspondence: Dr James H. Tidwell, Aquaculture Research Center, Kentucky State University, Frankfort, Kentucky 40601, USA.

(1976) that adjusted dry feed amounts based on fish size and water temperature. However, large pond size precludes accurate estimates of fish numbers and losses from disease and predation make calculations based on estimated fish population sizes difficult to compute and subject to error (Tipping, Rathron & Moore 1986). Further, feeding charts may not accurately predict the amount of feed that can be consumed by fish for a given water temperature (Piper *et al.* 1982).

A third feeding practice is the use of demand feeders. Demand feeders have been reported to perform well for production of trout (Hardy 1989). Automatic and demand feeders can be labour-saving (Tipping *et al.* 1986) and allow fish to be fed many times throughout the day (Lovell 1989b). Multiple daily feedings have been shown to allow for more rapid growth and more efficient protein gain (Grayton & Beamish 1977). Meriwether (1986) reported that tilapia, *Oreochromis niloticus* (L.), gained 72% more weight when fed by demand feeder than when fed by hand once daily.

The purpose of this study was to evaluate three feeding practices (i.e. satiation, chart and demand) in the seasonal production of rainbow trout in ponds.

Materials and methods

Experimental design

Four hundred rainbow trout (mean individual weight 132·3 ± 4·5 g) were randomly stocked into each of 24 0·04-ha ponds at the Aquaculture Research Center, Kentucky State University. Ponds were randomly assigned one of three feeding regimes: (1) hand-feeding to satiation; (2) feeding according to a feeding table; and (3) feeding by demand feeder. All fish were fed a commercially prepared floating diet (Purina Trout Chow, 40% crude protein and 10% crude fat). There were eight replicates per treatment.

Experimental feeding was begun on 8 November 1989. Fish fed to satiation were offered as much feed as the fish would consume in 20 min twice daily (1000 and 1500 h). Fish fed according to feeding charts received a percentage of body weight adjusted for water temperature and fish size (Piper *et al.* 1982). Half of the calculated feed allowance was offered twice daily (1000 and 1500 h). Daily rates were based on morning temperatures. Calculated fish weights were adjusted every 2 weeks by assuming a feed conversion of 1·5 (Reagan & Robinette 1976). Demand feeders (Red Ewald Inc., Karnes City, TX) were monitored daily so that feed was always available. When approximately 0·25 kg of feed remained in the feeder, feed was removed, weighed, and 2·5 kg of fresh feed was added. During an initial 2-week training period, feeders were manually activated twice daily.

Floating feeding rings, 1·8 m in diameter, were used in all ponds to prevent feed from drifting ashore and allow recovery of uneaten feed. Rings were made from 6-cm diameter plastic pipe and had a 0·58-cm plastic mesh skirt extending 20 cm below the water surface. If ice cover prevented feeding on any pond, other ponds in the treatment were not fed. Forty-six feeding days were lost to ice cover.

Dissolved oxygen and temperature were monitored twice daily (0900 and 1500 h) using a YSI Model 57 oxygen meter. When the dissolved oxygen level of any pond was predicted (by graph) to decline to below 8·0 mg/l, emergency aeration was provided. Ammonia, nitrite and pH, were measured weekly using a DREL/5 spectrophotometer (Hach Co., Loveland, Co).

Table 1. Summary of water quality analyses for ponds containing *O. mykiss* fed by three feeding practices during the period 8 November 1989 to 29 March 1990 (142 days). Each treatment was replicated eight times. Means (±SE) are based on samples taken twice daily for temperature and dissolved oxygen, and weekly for ammonia, pH, and nitrite[1]

	Feeding practice		
Variable	Satiation	Chart	Demand
Temperature (°C)			
AM	$7{\cdot}0 \pm 0{\cdot}2^{a}$	$7{\cdot}0 \pm 0{\cdot}2^{a}$	$7{\cdot}1 \pm 0{\cdot}2^{a}$
PM	$8{\cdot}0 \pm 0{\cdot}2^{a}$	$8{\cdot}1 \pm 0{\cdot}2^{a}$	$8{\cdot}1 \pm 0{\cdot}1^{a}$
Dissolved oxygen (mg/l)			
AM	$10{\cdot}7 \pm 0{\cdot}5^{a}$	$10{\cdot}8 \pm 0{\cdot}5^{a}$	$10{\cdot}8 \pm 0{\cdot}4^{a}$
PM	$12{\cdot}3 \pm 0{\cdot}9^{a}$	$12{\cdot}6 \pm 0{\cdot}7^{a}$	$12{\cdot}6 \pm 0{\cdot}4^{a}$
pH	$8{\cdot}3 \pm 0{\cdot}2^{a}$	$8{\cdot}2 \pm 0{\cdot}1^{a}$	$8{\cdot}2 \pm 0{\cdot}1^{a}$
Total ammonia (as mg/l N)	$0{\cdot}24 \pm 0{\cdot}13^{a}$	$0{\cdot}13 \pm 0{\cdot}10^{b}$	$0{\cdot}04 \pm 0{\cdot}04^{c}$
Nitrite (as mg/l N)	$0{\cdot}005 \pm 0{\cdot}004^{a}$	$0{\cdot}005 \pm 0{\cdot}003^{a}$	$0{\cdot}008 \pm 0{\cdot}008^{a}$

[1]Means within a row having the same superscript were not significantly different ($P > 0{\cdot}05$).

Fish growth and body composition analyses

Fish were not fed 24 h prior to harvest and were harvested on 29 March 1990. Total number and weight of fish in each pond were determined at harvest. One hundred fish were randomly sampled from each pond for individual total lengths (cm) and weights (g). Ten fish were randomly sampled from each pond for dress-out analysis. Fish were dressed by removing head and viscera. Weight of the dressed carcass was reported as a percentage of the whole fish. Carcass and waste (head and viscera) of three fish from each pond were separately homogenized in a blender and individually analysed for protein, fat and moisture. Protein was determined using a LECO FP-228 nitrogen determinator (Sweeney & Rexroad 1987), fat was analysed using ether extraction (Association of Official Analytical Chemists 1984), and moisture determined by placing 15 g of sample in a drying oven (95°C) for 24 h.

Feed conversion ratio (FCR), specific growth rate (SGR), and protein efficiency ratio (PER) were calculated as follows: SGR (%/day) = $(\log W_t - W_i/T) \times 100$, where W_t is the weight of fish at time t, W_i is the weight of fish at time 0, and T is the culture period in days; FCR = total feed given (kg)/total wet weight gain (kg); PER = wet weight gain (kg)/amount of protein fed (kg).

Statistical analysis

Data were analysed by analysis of variance (ANOVA) using the SAS ANOVA procedure (Statistical Analysis Systems 1988). Duncan's multiple range test was used to compare means. Percentage survival, percentage weight gain, SGR, dress-out percentage, and carcass composition (percentage moisture, protein and fat) were transformed to arc sin values prior to analysis (Zar 1984).

Results

Water temperatures were suitable ($\bar{X} = 7{\cdot}2$°C) for rainbow trout culture throughout the study period (Table 1) (Piper *et al.* 1982). Dissolved oxygen concentrations averaged

Table 2. Weight gain, feed conversion, yield, and survival rate of *O. mykiss* cultured using three feeding practices in ponds

Variable	Feeding practice		
	Satiation	Chart	Demand
Stocking data			
Number	400	400	400
Mean weight/fish (g)	130·2 ± 6·3[a]	133·5 ± 4·0[a]	132·7 ± 1·3[a]
Total weight (kg)	52·1 ± 2·5[a]	53·4 ± 1·6[a]	53·3 ± 1·1[a]
Harvesting data			
Culture days	142	142	142
Number	386·8 ± 9·5[a]	374·0 ± 22·2[a]	376·0 ± 28·9[a]
Total weight/pond (kg)	147·8 ± 20·8[a]	113·8 ± 7·4[b]	86·4 ± 22·4[c]
Mean weight/fish (g)	382·0 ± 52·1[a]	304·1 ± 12·3[b]	229·4 ± 54·2[c]
Total weight gain (kg)	94·7 ± 19·1[a]	60·4 ± 6·9[b]	33·1 ± 22·2[c]
Daily gain/fish (g)	1·77 ± 0·34[a]	1·19 ± 0·08[b]	0·68 ± 0·38[c]
Protein gain/fish (g)[2]	111·0 ± 30·1[a]	84·7 ± 9·2[b]	44·9 ± 25·1[c]
Protein efficiency ratio	2·00 ± 0·07[a]	2·10 ± 0·10[a]	1·60 ± 0·28[a]
Specific growth (%/day)	0·74 ± 0·03[a]	0·51 ± 0·01[b]	0·32 ± 0·07[c]
Feed given (kg)	119·5 ± 16·4[a]	72·1 ± 4·6[b]	46·4 ± 18·7[c]
Feed conversion ratio	1·27 ± 0·11[a]	1·21 ± 0·17[a]	2·32 ± 1·95[a]
Survival (%)	96·7 ± 2·4[a]	93·6 ± 5·8[a]	93·9 ± 7·2[a]

[1]Values are means ± SE for eight replications. Means within a row having the same superscript were not significantly different ($P > 0·05$).
[2]Dressed carcass.

11·7 mg/l, overall and were maintained above 7·0 ppm throughout the experiment. Total ammonia levels were significantly higher ($P < 0·05$) in ponds where fish were fed to satiation than in ponds with fish fed according to a feeding chart or by demand feeders. Ponds with fish fed according to a feeding chart had significantly ($P < 0·05$) higher ammonia levels than ponds with demand feeders. There were no significant differences ($P > 0·05$) in pH or nitrite levels among treatments.

Harvest weight (kg fish/pond), weight gain (kg), individual fish weight (g), and total length (cm) were significantly greater ($P < 0·01$) in fish fed to satiation than in fish fed according to a feeding chart or by demand feeders (Table 2). Fish fed using a feeding chart had significantly higher total harvest weight, weight gain, fish weight, and total length ($P < 0·05$) than fish fed by demand feeders. Survival averaged 94·7% overall and did not differ significantly ($P > 0·05$) among treatments.

Protein gain in the dressed carcass was significantly greater ($P < 0·01$) in ponds fed to satiation (110·98 g) than in the two other treatments (Table 3). Fish fed using a feeding chart had significantly higher ($P < 0·01$) protein gain (84·73 g) than fish fed by demand feeder (44·91 g). SGR for fish fed to satiation averaged 0·74% per day and was significantly greater ($P < 0·01$) than fish fed according to a feeding chart (0·51%) or by demand feeder (0·32%). There were no significant differences ($P < 0·05$) in PER or FCR among the three treatments. Protein efficiency ratio averaged 1·9 and feed conversion averaged 1·6.

Average dressed weight, waste weight, and visceral fat weight were significantly higher ($P < 0·01$) in fish fed to satiation than in the other two treatments (Table 3). Dress-out percentage was significantly higher ($P < 0·05$) in fish fed to satiation (72·0%) than in fish fed according to a feeding chart (69·8%) or by demand feeders (69·2%).

Table 3. Dress-out percentage and proximate composition of the dressed carcass and waste (head and viscera) from *O. mykiss* raised in ponds using three feeding practices[1]

Variable	Feeding practice		
	Satiation	Chart	Demand
Dressed weight (g)	279·7 ± 10·4[a]	208·5 ± 8·0[b]	161·1 ± 6·6[c]
Waste (g)	96·0 ± 3·2[a]	78·6 ± 2·7[b]	63·5 ± 2·2[c]
Dress-out (%)	72·0 ± 1·1[a]	69·8 ± 2·4[b]	69·2 ± 1·1[b]
Visceral fat (g)	3·7 ± 0·3[a]	1·8 ± 0·2[b]	0·9 ± 0·1[c]
Proximate composition			
(1) *Carcass*			
Moisture (%)	69·5 ± 0·5[b]	72·5 ± 0·5[a]	72·9 ± 1·3[a]
Protein (%)[2]	65·3 ± 1·2[b]	71·6 ± 1·5[a]	68·6 ± 2·3[ab]
Fat (%)[2]	20·7 ± 0·5[a]	21·0 ± 1·1[a]	19·9 ± 1·4[a]
(2) *Waste*			
Moisture (%)	66·3 ± 0·4[b]	69·6 ± 0·5[a]	70·8 ± 0·4[a]
Protein (%)[2]	42·8 ± 2·0[b]	49·6 ± 1·8[a]	53·2 ± 1·2[a]
Fat (%)[2]	29·1 ± 1·2[a]	23·8 ± 2·0[b]	26·4 ± 1·1[ab]

[1]Values are means ± SE for eight replications. Means within a row having the same superscript were not significantly different ($P > 0{\cdot}05$).
[2]Moisture free basis.

The dressed carcass of fish fed to satiation contained significantly less ($P < 0{\cdot}05$) moisture and protein (on a dry matter basis) than fish fed according to a feeding chart (Table 3). There were no significant differences ($P > 0{\cdot}05$) in crude fat percentage. Moisture and protein were significantly lower and fat significantly higher ($P < 0{\cdot}05$) in the waste (head and viscera) portion of fish fed to satiation than in fish fed according to a feeding chart. No significant differences ($P > 0{\cdot}05$) in body composition variables were found between fish fed according to a feeding chart or by demand feeders.

Discussion

The present study indicates that satiation feeding can significantly increase the growth rate of rainbow trout reared in ponds without negatively affecting feed conversion or body composition. This can greatly increase production potential under the time constraints imposed by seasonal production.

Feeding to satiety allowed fish to be fed at 166% of the level provided by length/temperature charts and 263% of the level provided by demand feeders. Weight gain, harvest weight, protein gain and SGR were significantly higher in ponds fed to satiation than in either of the other two treatments. There were no significant differences in carcass fat percentage or FCR. Although visceral fat weights were significantly higher in fish fed to satiation, changes were small compared to increases in dressed carcass weights.

In almost all fish, greatest growth rate is attained at maximum ration (R_{max}). However, optimum ration (R_{opt}) is at a submaximal point defined by high food utilization efficiency (Brett 1979). It has been reported that trout may require 40 min to 1 h to feed to true satiation (Ishiwata 1969; Brett 1971). Brett (1971) stated that to satiate sockeye salmon, *Oncorhynchus nerka* (Walbaum), required 45 min. In this study, feeding to satiation over a restricted

20-min period, two times per day, produced good growth rates without loss of feed efficiency. Grayton & Beamish (1977) reported that the amount of feed consumed was at a maximum when rainbow trout were fed to satiation two times a day. Average harvest weight for rainbow trout fed to satiation in this study (382 g) was higher than reported for fish fed to satiation once daily in cages (175 g) by Beem, Gebhart & Maughan (1988).

Chart feeding produced larger fish than were produced using demand feeders (304·1 g and 229·4 g respectively). Feed input was increased 58·6% and FCR improved from 2·32 to 1·21 compared to fish fed by demand feeders. Individual weights for fish fed according to a feeding chart were in agreement with the findings of Regan & Robinette (1976), who reported an average individual weight of 309 g when rainbow trout were fed at 3% of body weight and higher than reported by Tidwell & Mims (1990) when fed according to length/temperature charts (259 g).

Although the feeding chart used in this study adjusted for water temperature and fish size, additional biotic and abiotic factors including feed quality, water quality, photoperiod, and rearing density affect feed consumption and growth (Brett 1979; Hardy 1989; Lovell 1989b). Piper *et al.* (1982) stated that at certain temperatures trout will consume more than twice the feed provided by feeding charts. Tidwell & Mims (1990) stated that additional feed amounts above chart allowances could possibly have improved trout growth.

In the present study fish fed by demand feeders performed poorly with significantly lower gains, harvest weights, protein gains, PER and SGR. Although a 2-week training period of manual activation of feeders was employed, some fish did not appear to train well to the feeders. Tipping *et al.* (1986) reported that *O. mykiss* fed by demand feeders had similar harvest weights and better feed conversion than fish fed at recommended chart rates, but stated that the fish fed had been previously acclimated to demand feeders in raceways. Meriwether (1986) reported that tilapia, *O. niloticus*, gained 72% more weight when fed by demand feeder than when fed by hand once daily, but feed conversion was 45% poorer. In this study, growth in fish fed by demand feeder was reduced 61·9% relative to fish fed to satiation and 32·7% compared to fish fed according to a feeding chart. Feed conversion was reduced 91·7% and 82·7% compared to satiation and chart feeding, respectively.

Demand feeders have been reported to perform well for production of salmon and trout (Hardy 1989). However, recommendations may have been directed toward raceway, cage or net-pen systems. These production units confine fish at much higher densities than open pond production. Proximity to the feeder and high density may be important to training fish for the successful utilization of demand feeders.

Acknowledgments

The authors thank Steve Mims, Julia Clark, Danny Yancey, Eddie Reed Jr and Karla Richardson, all of the Community Research Service, Aquaculture Research Center, Kentucky State University, for assistance. This investigation was supported in part by a USDA/CSRS grant to Kentucky State University under Agreement KYX-1283000009.

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