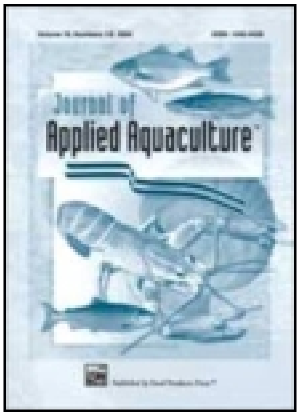

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Impact of Low Catfish Prices on Economically Efficient Feeding and Optimal Stocking Densities of Channel Catfish, Ictalurus punctatus, in Multi-Batch Production in the U. S. South

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Impact of Low Catfish Prices on Economically Efficient Feeding and Optimal Stocking Densities of Channel Catfish, *Ictalurus punctatus*, in Multi-Batch Production in the U. S. South

Siddhartha Dasgupta
Carole Engle

ABSTRACT. Channel catfish, *Ictalurus punctatus*, prices fell to historically low levels in 2002 in the U.S., but little economic research has been done on optimal farm management during times of very low prices. A Just-Pope catfish production function was used to estimate minimum catfish prices and maximum feed prices at which various feeding rates would be economically efficient. Optimal stocking and feeding rates were estimated for very low catfish price levels. Low catfish prices require lower stocking and feeding rates to operate at profit-maximizing levels. However, results showed that the very low prices of 2001-2002 would require farmers to stock at densities less than 10,000/ha to be able to feed at 2% of the pond biomass. Even maintenance feeding (1% of pond biomass) is not economically efficient at prices below $1.43/kg. However, stocking rates below 10,000/ha will not generate adequate revenue to cover debt-servicing requirements for long-term capital investment loans. Thus, farmers must adopt management strategies that

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will satisfy the multiple business requirements of servicing debt and meeting fish-delivery schedules. The results of this analysis provide guidance on the relationships among prices of catfish and feed, with stocking and feeding rates, to provide a basis for these difficult decisions. doi:10.1300/J028v19n02_04 *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com>*

KEYWORDS. Catfish price, production economics, risk aversion, *Ictalurus punctatus*

INTRODUCTION

The channel catfish, *Ictalurus punctatus*, industry has grown at a rapid pace over the last two decades in the United States. Processed volume increased by 309% during 1984-2004 as acreage in catfish production increased by 144% (NASS 2005). Catfish prices fluctuate from year-to-year and over time (Figure 1). Prices fell to levels below estimated costs of production in 1982, 1992, and again between 2001 and 2003. Prices paid to catfish farmers began to decline in June 2001 and declined steadily throughout 2001 (Figure 2). Prices stabilized in 2002, but at his-

FIGURE 1. Catfish prices and production costs, 1975-2004.

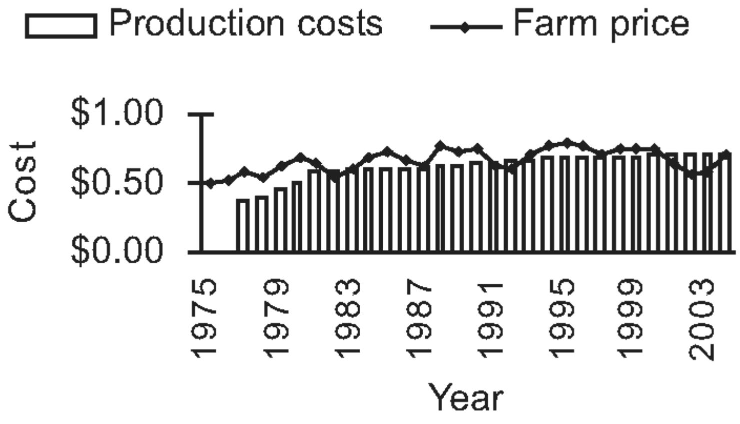
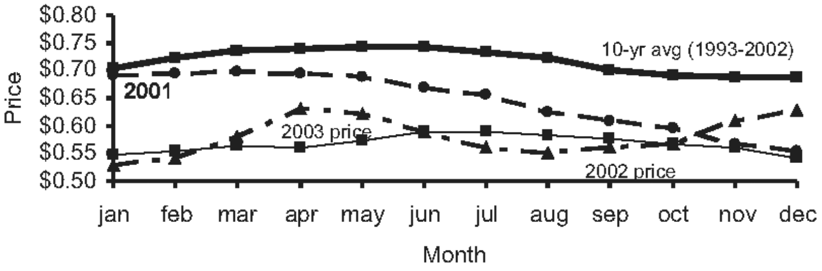


FIGURE 2. Average price paid to catfish produced, 1991-2004.



torically low levels. Prices in 2003 demonstrated some movement, but remained below long-term average levels.

Economic theory indicates that maximum profits will occur at a level of production that is less than maximum yield (Baumol and Blinder 2002). Profit-maximizing stocking rates can be calculated if the technical relationships among inputs and outputs are known as well as the respective input and output prices. Losinger et al. (2000) developed a catfish production function from survey data for the four major catfish-producing states. Profit-maximizing stocking rates vary as the ratio of catfish price to fingerling varies and were estimated at 16,942 to 21,312 fingerlings/ha for common price levels. Profit-maximizing feeding levels vary with the ratio of catfish price to feed price and were estimated for common ranges from 7,171 kg/ha/year to 11,211 kg/ha/year.

Dasgupta et al. (2002) extended the work of Losinger et al. (2002) to demonstrate that, under certain conditions, profit-maximizing feeding rates may not be biologically feasible. Historical feed rates, on occasion, have reached levels that result in a profit-maximizing feeding rate below the minimum amount of feed required for fish to maintain weight. If a farmer were to feed at these low "profit-maximizing" feeding rates that result from very high feed prices, fish would lose weight and perhaps be subjected to nutritional stress.

The very low catfish prices of 2002 have raised questions related to optimal feeding strategies under adverse financial conditions. Low catfish prices reduce revenue received by the farm that reduces levels of operating capital available to the farm. Moreover, the maximum limit on operating lines of credit often is based on the value of fish inventory. As prices fall, the value of fish inventory falls, and the maximum amount of operating capital that can be borrowed also falls. The combination of reduced revenue and reductions in the maximum amounts of operating lines of credit can severely restrict cash available for feeding during times of low fish prices. Feed costs comprise from 42 to 45% of total costs of producing catfish and 52 to 54% of the total operating costs (Engle and Kouka 1996). Feeding at efficient levels can have a large effect on farm profitability.

Catfish farms that are highly leveraged, face debt-servicing requirements that add additional strain on cash available for feeding and operations. Low catfish prices can result in greater financial risk if farms are managed with high levels of debt capital.

Dasgupta et al. (2002) examined the overall issue of short-run biological efficiency versus economic efficiency with a principal focus on the impact of varying price levels of feed inputs. Impacts of low catfish prices were not explored in detail. This paper extends the work of Dasgupta et al. (2002) by exploring the impact of low catfish prices on economically efficient feeding rates. The analysis further evaluates optimal stocking densities and feeding rates under increasing levels of producer risk aversion. This analysis identifies the lower bound for catfish price and the upper bound for feed price (during low prices) that will still allow feeding based on economic efficiency criteria.

MATERIALS AND METHODS

The methodology used in this paper is adopted from Dasgupta et al. (2002). The concept of economic efficiency used in this paper refers jointly to technical and allocative efficiency (Chavas and Aliber 1993). This means that producers are assumed to operate at the boundary of the production frontier (i.e., technical efficiency) and use the lowest cost-input combination (i.e., allocative efficiency).

A catfish production function, originally estimated in Losinger et al. (2000), was used to calculate the optimal stocking density and feeding rate for risk-neutral and risk-averse producers. This production function was based on survey data collected by the USDA, National Agricultural Statistics Service, as a part of USDA's Catfish 1997 study (APHIS 1997). This survey included commercial catfish farms practicing primarily multi-batch production methods. The sample size for this analysis was the 181 farms that provided useable data, out of the 301 total respondents from Alabama, Arkansas, Louisiana, and Mississippi. Further information about the dataset can be found in Losinger et al. (2000).

Both Losinger et al. (2000) and Dasgupta et al. (2002) discussed the estimated Just-Pope catfish production function that underlies the current analysis (Just and Pope 1978). Equation (1), taken from Dasgupta et al. (2002), outlines the estimated mean and variance of annual output (t-ratios appear below their corresponding coefficient estimates; Exp = exponentiation operator).

$$
\begin{aligned}
\text{Yield (y)} &= F + G \times \varepsilon, \\
\text{where } F &= \text{expected yield} \\
&= \text{Exp}\Big[\underset{(-0.231)}{-1.805} + \underset{(2.777)}{0.153}\,\text{Ln (FarmSize)} + \underset{(2.313)}{3.872}\,\text{Ln(Stock Density)} \\
&\qquad \underset{(-3.728)}{-3.265}\,\text{Ln(FeedRate)}\ \underset{(-1.985)}{-0.185}\,\text{Ln(Stock Density)}^2 \\
&\qquad + \underset{(3.852)}{0.229}\,\text{Ln(FeedRate)}^2\ \underset{(-1.062)}{-0.00001}\,\text{FeedRate} \\
&\qquad \times \text{Ln(FarmSize)}\Big]; \\
G &= \text{yield variance} \\
&= \text{Exp}\Big[\underset{(-2.739)}{-1.273} - \underset{(-5.382)}{0.365}\,\text{Ln(FarmSize)} \\
&\qquad + \underset{(3.653)}{0.979}\,\text{Ln(PondSize)} + \underset{(2.815)}{2.815}\,\text{Wponds}\Big]
\end{aligned}
\tag{1}
$$

ε is a standard normal-error term; and Wponds is a dummy variable that is equal to one for farms with watershed ponds and 0 otherwise.

Optimal stocking density and annual feeding rates can be derived by maximizing the expected utility of stochastic income with respect to stocking density and feeding rate. Since information on utility functions of catfish producers and their risk preferences were unavailable, Dasgupta et al. (2002) used maximization of the certainty equivalence of per-hectare income as their decision rule. This technique is discussed in detail in Dasgupta et al. (2002). This decision rule (maximizing the certainty equivalence of risky income with respect to stocking density and annual feeding rate) provided the following first-order conditions (FOC):

$$
\text{Stocking density FOC: } \frac{\partial F}{\partial\,\text{Stock Density}} = \frac{\text{wstk}}{\text{Ep} - \lambda \times \text{Vp} \times F} \tag{2}
$$

Feeding rate FOC:

$$\frac{\partial \mathrm{F}}{\partial \mathrm{FeedRate}} = \frac{\mathrm{Ewfeed} + \lambda \times \mathrm{FeedRate} \times \mathrm{Vwfeed}}{\mathrm{Ep} - \lambda \times \mathrm{Vp} \times \mathrm{F}} \tag{3}$$

where Ep = expected catfish price ($/kg); Vp = variance of catfish price; wstk = fingerling price; Ewfeed = expected feed price ($/kg); Vwfeed = variance of feed price; λ = Arrow-Pratt coefficient of absolute risk aversion ($\lambda = 0$ for risk-neutral and $\lambda > 0$ for risk-averse producers), and F = expected annual yield. Assuming that the second-order sufficiency conditions hold (Silberberg 1990), solving Equations (2) and (3) simultaneously provide the optimal stocking density and feeding rates for different catfish prices, feed prices, fingerling prices, and producer risk preferences. Dasgupta et al. (2002) indicated that, since stocking density and feeding rate were the two variable inputs that significantly influenced yield (Equation 1), the annual income used in their calculations was the annual revenue over stocking and feeding costs.

Dasgupta et al. (2002) reported the maximum catfish feed prices that allow economically efficient applications of feed at the minimum growth-promoting feeding rate. This minimum annual feeding rate was assumed to be 2% of the catfish biomass for 210 days/year. The restricted annual maintenance feeding rate was assumed to be 1% of the catfish biomass for 210 days/year. The average catfish biomass was assumed to be 0.23 kg in a multi-batch production system (Dasgupta et al. 2002). Since the data available for this analysis consisted of total feed fed per year (kg/ha/year), for purposes of this analysis, it does not matter whether this amount was fed on a daily or every other day basis. Equation (3) was used to derive a lower bound for catfish price and an upper bound for feed price (when catfish prices are low) to determine the economic conditions allowing efficient feeding at the minimum growth-promoting rates.

Price data used in this study were also taken from Dasgupta et al. (2002). For example, catfish prices from 1980 to 2001 were obtained from the USDA; the standard deviation of catfish prices was $0.117/kg (USDA 2002). Catfish feed prices (1980 to 1997) were available in Hanson and Hopper (2000). Catfish producers were assumed to purchase feed at a contracted price, thus avoiding feed price risk, that is, Vwfeed = 0. Fingerling price, which has been relatively stable over time (Engle and Kouka 1996), was kept fixed at $0.055/head, which was the Losinger et al. (2000) sample average. All monetary figures are reported in U.S. dollars for the year 2001.

RESULTS

Table 1 reports the minimum catfish price at which feeding at 2% of a catfish pond's biomass would be economically efficient (i.e., Equation 3 will be satisfied). Stocking density was fixed at 10,000/ha, 15,000/ha, or 20,000/ha because commercial producers often predetermine stocking

TABLE 1. Minimum catfish price ($/kg) that allows efficient feeding for different stocking densities, feed prices and producer risk preferences. The feed prices reported in parentheses correspond to the case where risk-averse producers buy feed at an uncertain price. All monetary figures are reported in 2001 dollars (U.S.).

Stocking density (no/ha)	Minimum growth promoting feeding rate (kg/ha/year)	Coefficient of absolute risk aversion (λ)	Catfish feed price ($/MT)	Minimum expected catfish price ($/kg)
10,000	9,660	0[a]	220	1.85
10,000	9,660	0	330	2.77
10,000	9,660	0.001[b]	220	1.88
10,000	9,660	0.001	330	2.80
10,000	9,660	0.005	220	2.00
10,000	9,660	0.005	330	2.92
15,000	14,490	0	220	2.07
15,000	14,490	0	330	3.11
15,000	14,490	0.001	220	2.12
15,000	14,490	0.001	330	3.15
15,000	14,490	0.005	220	2.29
15,000	14,490	0.005	330	3.33
20,000	19,320	0	220	2.76
20,000	19,320	0	330	4.17
20,000	19,320	0.001	220	2.83
20,000	19,320	0.001	330	4.23
20,000	19,320	0.005	220	3.05
20,000	19,320	0.005	330	4.44

[a] $\lambda = 0$ indicates profit-maximizing, or risk-neutral, producers.
[b] $\lambda > 0$ indicates risk-averse producers.

densities based on size of fish stocked, extension recommendations (typically ranging from 15,000/ha to 16,250/ha), farm-management traditions, and opinions of other producers. The two feed prices in Table 1 represent typical prices paid by U.S. catfish producers.

As stocking density increases, producers need to receive progressively higher catfish prices to justify feeding at 2% of the catfish biomass in a pond. For example, at a stocking rate of 10,000/ha, producers need to receive a price of $1.85/kg to economically justify feeding at 2% of the catfish biomass in a pond. For a stocking rate of 15,000/ha, price would have to be $2.07/kg and $2.76/kg for stocking rates of 20,000/ha. Average catfish prices paid by processors to farmers during 2001 fell to a low of $1.32/kg in October and $1.21/kg in December (USDA 2002). Because these prices are lower than the minimum prices estimated in Table 1, stocking densities would have to be less than 10,000/ha in order for economically efficient feeding to occur at 2% of a pond's biomass.

This effect would be even higher at feed rates greater than 2% of pond biomass. Feeding at higher rates increases risk to the catfish farmer because of the higher feed cost. If output price drops after feeding at high rates, farmers could lose more than if they had fed at lower rates.

Risk-averse producers require a higher catfish price to feed at the same intensity as risk-neutral (or profit maximizing) producers (Table 1). This can be understood from the right-hand-side of Equation (3): $\frac{\mathrm{Ewfeed}}{\mathrm{Ep} - \lambda \times \mathrm{Vp} \times \mathrm{F}}$ (we assume $\mathrm{Vwfeed} = 0$). The term $(\lambda \times \mathrm{Vp} \times \mathrm{F})$ represents the marginal risk premium associated with the uncertain catfish price, that is, it represents the marginal cost charged by risk-averse producers to operate in an economic environment that is uncertain due to unpredictable output price. The effect of the marginal risk premium is to reduce the marginal income of catfish. Consequently, risk-averse producers require a higher lower bound on catfish price at which they would efficiently feed at the same rates as risk-neutral producers. For example, from Table 1, a more risk-averse ($\lambda = 0.001$) farmer stocking at 10,000/ha would require a minimum catfish price of $1.88/kg as compared to a risk-neutral farmer, $1.85/kg at feed prices of $220/metric ton (MT).

Table 2 indicates the maximum feed price at which economically efficient feeding can occur at 2% of a pond's biomass for a given catfish price and stocking density. Catfish prices have been intentionally constrained at either $1.21/kg or $1.43/kg to reflect the low processor-to-producer prices of 2001 (USDA 2002). For these low catfish prices, feed price ($170/MT) was substantially below commercial feed prices observed in recent years. Thus, economically efficient feeding at 2% of the catfish

TABLE 2. The maximum catfish feed price that would allow efficient feeding at minimum growth-promoting feeding rates for three stocking densities, three producer risk aversion levels, and four catfish prices. All monetary figures are reported in 2001 dollars (U.S.).

Stocking density (no/ha)	Minimum growth promoting feeding rate (kg/ha/year)	Coefficient of absolute risk aversion (λ)	Expected deflated catfish price ($/kg)	Maximum deflated feed price ($/MT)
10,000	9,660	0[a]	1.21	144
10,000	9,660	0	1.43	170
10,000	9,660	0.001[b]	1.21	141
10,000	9,660	0.001	1.43	167
10,000	9,660	0.005	1.21	115
10,000	9,660	0.005	1.43	152
15,000	14,490	0	1.21	129
15,000	14,490	0	1.43	152
15,000	14,490	0.001	1.21	124
15,000	14,490	0.001	1.43	147
15,000	14,490	0.005	1.21	105
15,000	14,490	0.005	1.43	128
20,000	19,320	0	1.21	96
20,000	19,320	0	1.43	113
20,000	19,320	0.001	1.21	92
20,000	19,320	0.001	1.43	109
20,000	19,320	0.005	1.21	74
20,000	19,320	0.005	1.43	92

[a] $\lambda = 0$ indicates profit-maximizing, or risk-neutral, producers.

[b] $\lambda > 0$ indicates risk-averse producers.

biomass in a pond cannot be achieved for stocking densities above 10,000/ha. For catfish farmers to feed at economically efficient levels at the low prices of 2001-2002, feed prices (deflated) would have to fall below $170/MT.

Some farmers choose to hold catfish, to wait for higher prices. Tables 3 and 4 relate to catfish and feed-price boundaries in which economically efficient feeding is feasible at maintenance feeding rates (1% of the

TABLE 3. Minimum catfish price ($/kg) that allows efficient feeding at maintenance feeding rates for different stocking densities, feed prices, and producer risk preferences. The feed prices reported in parentheses correspond to the case where risk-averse producers buy feed at an uncertain price. All monetary figures are reported in 2001 dollars (U.S.).

Stocking density (no/ha)	Maintenance feeding rate (kg/ha/year)	Coefficient of absolute risk aversion (λ)	Catfish feed price ($/MT)	Minimum expected catfish price ($/kg)
10,000	4,830	0[a]	220	1.59
10,000	4,830	0	330	2.38
10,000	4,830	0.001[b]	220	1.61
10,000	4,830	0.001	330	2.40
10,000	4,830	0.005	220	1.70
10,000	4,830	0.005	330	2.49
15,000	7,245	0	220	1.42
15,000	7,245	0	330	2.14
15,000	7,245	0.001	220	1.46
15,000	7,245	0.001	330	2.17
15,000	7,245	0.005	220	1.58
15,000	7,245	0.005	330	2.30
20,000	9,660	0	220	1.46
20,000	9,660	0	330	2.19
20,000	9,660	0.001	220	1.50
20,000	9,660	0.001	330	2.23
20,000	9,660	0.005	220	1.66
20,000	9,660	0.005	330	2.39

[a] $\lambda = 0$ indicates profit-maximizing, or risk-neutral, producers.

[b] $\lambda > 0$ indicates risk-averse producers.

pond's biomass). As expected, the minimum catfish price in Table 3 ($1.42/kg) is lower than the corresponding catfish price in Table 1 ($1.85/kg) (feeding at 2% of pond biomass), and the maximum feed price in Table 4 ($220/MT) is higher than the corresponding feed price in Table 2 ($74/MT).

TABLE 4. The maximum catfish feed price that would allow efficient feeding at maintenance feeding rates for three stocking densities, three producer risk aversion levels, and four catfish prices. All monetary figures are reported in 2001 dollars.

Stocking density (no/ha)	Maintenance feeding rate (kg/ha/year)	Coefficient of absolute risk aversion (λ)	Expected deflated catfish price ($/kg)	Maximum deflated feed price ($/MT)
10,000	4,830	0[a]	1.21	168
10,000	4,830	0	1.43	198
10,000	4,830	0.001[b]	1.21	165
10,000	4,830	0.001	1.43	195
10,000	4,830	0.005	1.21	152
10,000	4,830	0.005	1.43	183
15,000	7,245	0	1.21	187
15,000	7,245	0	1.43	220
15,000	7,245	0.001	1.21	181
15,000	7,245	0.001	1.43	216
15,000	7,245	0.005	1.21	162
15,000	7,245	0.005	1.43	196
20,000	9,660	0	1.21	182
20,000	9,660	0	1.43	215
20,000	9,660	0.001	1.21	176
20,000	9,660	0.001	1.43	209
20,000	9,660	0.005	1.21	152
20,000	9,660	0.005	1.43	185

[a] $\lambda = 0$ indicates profit-maximizing, or risk-neutral, producers.

[b] $\lambda > 0$ indicates risk-averse producers.

Table 3 shows that the smallest listed catfish price is $1.42/kg for efficient feeding at the 15,000/ha stocking density. Catfish prices paid by processors to producers during 2001 varied from $1.34/kg in September to $1.21/kg in December (USDA 2002). This implies that efficient feeding, at maintenance feeding rates, would not be feasible during 2001 for stocking densities of either 10,000/ha or 20,000/ha. Economic efficiency with maintenance feeding is possible at a stocking density of 15,000/ha when catfish price is in the \$1.40-\$1.50/kg range, provided the feed price is sufficiently low (\$220/MT). At the 15,000/ha stocking density, the difference in the minimum catfish price and the 2001 wholesale price is fairly small.

Table 4 reports that economically efficient maintenance feeding is achievable for a 15,000/ha stocking density, \$1.43/kg catfish price, and a feed-price upper bound that is in the vicinity of \$200/MT. At a \$1.21/kg catfish price, the maximum feed price allowing efficient maintenance feeding is \$187/MT for risk-neutral producers stocking at 15,000/ha. Since catfish feed prices are greater than \$187/MT (in 2001 U.S. dollars), maintenance feeding will not be economically efficient if expected catfish price drops to \$1.21/kg. For a risk-neutral producer stocking at 15,000/ha, the maximum allowed feed price for efficient maintenance feeding is \$220/MT at a catfish price of \$1.43/kg. Since the \$220/MT feed price is relatively close to real-world feed prices, maintenance feeding is economically efficient for risk-neutral producers stocking at 15,000/ha and receiving at least \$1.43/kg for catfish.

Stocking density affected results of this analysis. The 15,000/ha stocking density, in particular, produced results that differed from both the 10,000/ha and the 20,000/ha stocking densities. Minimum catfish price (Table 3) is lower and the maximum feed price higher (Table 4) at a stocking rate of 15,000/ha as compared with the other two stocking densities. This is because the marginal product (MP) of feed at 15,000/ha stocking density (when feeding is kept at a maintenance rate) is greater at the 15,000/ha stocking density than at either 10,000/ha or 20,000/ha. This fact, when combined with the risk-neutral version of equation (3), makes it clear that the expected catfish price (or expected feed price) boundary is lower (or higher) at the 15,000/ha stocking density than the corresponding price boundaries at the two other stocking densities.

Table 5 outlines the optimal stocking density and annual feeding rates for low catfish prices. Optimal stocking rates for profit-maximizing producers ($\lambda = 0$) were estimated to be between 16,000/ha and 18,000/ha. These estimates are relatively close to recommended stocking densities identified through catfish research, that is, 16,250/ha (Heikes 1996). Stronger levels of risk aversion induce progressively lower optimal-stocking densities. Table 5 also shows that, when catfish prices are low, the optimal feeding rate was consistently below the minimum growth-promoting annual feeding rate.

Table 5 also presents optimal stocking densities and feeding rates for maintenance feed rations (1% of pond biomass). The certainty equivalence-maximizing first-order conditions (Equations 2 and 3) were satisfied

TABLE 5. Optimal stocking density and feeding rate for different catfish and feed prices and risk-aversion parameters. Fingerling price is kept fixed at \$0.055. Assume producers purchase feed at a contracted price, that is, variance of feed price = 0. Assume catfish price standard deviation = \$0.117/kg. All monetary figures are reported in 2001 dollars.

Arrow-Pratt risk aversion coefficient (λ)	Expected catfish price (\$/kg)	Expected feed price (\$/MT)	Optimal stocking density (no/ha)	Optimal feeding rate (kg/ha/year)	Minimum feeding rate at 2% of pond biomass (kg/ha/year)
Feeding at 2% of pond biomass					
0	1.21	220	16,674	9,429	16,107
0	1.43	220	18,408	11,051	17,782
0	1.21	330	15,969	7,173	15,426
0	1.43	330	17,629	8,407	17,030
0.001	1.21	220	10,494	7,650	10,134
0.001	1.43	220	11,836	9,089	11,434
0.001	1.21	330	9,965	5,742	9,626
0.001	1.43	330	11,240	6,822	10,858
0.005	1.21	220	9,377	4,322	9,058
0.005	1.43	220	10,752	5,673	10,386
0.005	1.21	330	8,789	2,978	8,490
0.005	1.43	330	10,078	3,908	9,735
Feeding at 1% of pond biomass					
0	1.43	220	17,550	8,480	8,880
0.001	1.43	220	16,970	7,650	8,197
0.005	1.43	220	No solution	No solution	No solution

for only a limited number of the price and risk-aversion scenarios. For example, no optimal solution was found for a catfish price of \$1.21/kg or less. Similarly, there were no optimal stocking and feeding rates for feed prices of \$330/MT or higher. However, for a \$1.43/kg catfish price and \$220/MT feed price, the profit-maximizing stocking density was 17,550/ha and feeding rate was 8,480kg/ha/year. As the coefficient of risk aversion (λ) increased, the optimal stocking and feeding rates decreased to 16,970/ha and

7,650kg/ha/year, respectively ($\lambda = 0.001$). If λ increased to 0.002, the optimal stocking density fell to 16,270/ha and the optimal feeding rate was reduced to 6,670 kg/ha/year. However, if λ became too high (e.g., $\lambda = 0.005$), the optimal conditions were not satisfied, implying that under conditions where profit-maximizing producers operate efficiently, sufficiently risk-averse producers were unable to optimize their stocking density and feeding rate.

DISCUSSION

This study showed that, at current industry stocking rates of 16,000/ha, economically efficient feeding for continued catfish growth is not possible. At low catfish prices, farmers can only feed to maintain fish weight until such time as prices come back up, or feed at levels to meet the farm's cash-flow obligations. Feeding catfish for biomass gain will only result in greater losses at the low catfish prices of 2001-2002. Table 5 showed that the certainty equivalence-maximizing feeding rate is lower than the minimum growth-promoting feeding rate when catfish prices were low. Table 5 also illustrated that the difference between the optimal annual feeding rate and the minimum growth-promoting feeding rate narrows as catfish price increases.

Moreover, the optimal feeding rates indicated in Table 5 are closer to maintenance feeding rates than to feeding rates calculated at 2% of the pond biomass. This finding provides further support that feeding at growth-promoting rates is not economically efficient when catfish price is at the low 2001-2002 levels. The optimal stocking density reported in Table 5 is closer to 15,000/ha than either 10,000/ha or 20,000/ha. This optimality is reached when catfish price is in the neighborhood of $1.40/kg and feed price is in the neighborhood of $200/MT, and also provides further support for the results in Tables 3 and 4. Finally, the optimal stocking density and feeding rates are reduced for more risk-averse farmers. For sufficiently large λ, the risk premiums charged were too large to allow joint satisfaction of stocking and feeding optimality conditions.

While this paper is useful in outlining catfish and feed price boundaries that allow efficient feeding, the true power of the results is evident in prescribing a stocking density and feeding rate at which economic optimality is satisfied in conjunction with meeting the minimum biological conditions. At very low catfish prices, farmers would ideally stock and feed at lower rates. This analysis indicated an optimal stocking density of

15,000/ha with a maintenance feeding regimen for catfish prices of $1.40/kg and feed prices of $200/MT. However, farms must meet debt-servicing obligations that may require greater stocking and feeding rates. Fish delivery commitments to processing plants and the long 18-month production cycle may also dictate higher stocking and feeding rates than those estimated in this analysis. In such situations, the farmer should make farm decisions based primarily on cash-flow budgets until such time as fish prices reach levels that allow for profitable production. Spreadsheet models (found at *www.uaex.edu/aquaculture*) are available to assist growers to make specific decisions on harvesting, stocking, and feeding in each pond to meet cash flow obligations across the farm. Additional research is needed to examine effects of various management strategies on debt servicing and loan repayment by catfish farmers. Nevertheless, these results provide some insight into the important economic relationships among catfish and feed prices and stocking and feeding rates and levels of catfish and feed prices at which the farm should switch to prioritize meeting financial obligations from attempting to maximize profits. Understanding these relationships provides a basis for improved farm decision making.

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