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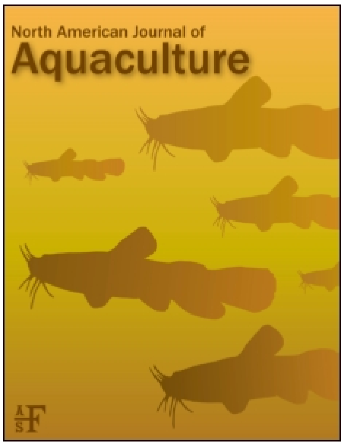

North American Journal of Aquaculture
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t926380648

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First published on: 09 January 2011

To cite this Article Torrans, Eugene L.(2008) 'Production Responses of Channel Catfish to Minimum Daily Dissolved Oxygen Concentrations in Earthen Ponds', North American Journal of Aquaculture, 70: 4, 371 — 381, First published on: 09 January 2011 (iFirst)

To link to this Article: DOI: 10.1577/A07-102.1

URL: http://dx.doi.org/10.1577/A07-102.1

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North American Journal of Aquaculture 70:371–381, 2008
American Fisheries Society 2008
DOI: 10.1577/A07-102.1

[Article]

Production Responses of Channel Catfish to Minimum Daily Dissolved Oxygen Concentrations in Earthen Ponds

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Abstract.—This study determined the effects of the minimum daily dissolved oxygen (DO) concentration on the production parameters of channel catfish *Ictalurus punctatus* in earthen ponds. Fifteen 1-acre ponds (five ponds per treatment) were managed as high-oxygen (minimum DO concentrations averaging 4.37 ppm or 54% air saturation from June through September), medium-oxygen (minimum DO concentrations averaging 2.68 ppm or 33.2% air saturation), or low-oxygen treatments (minimum DO concentrations averaging 2.32 ppm or 28.7% air saturation) using one 5-hp electric paddlewheel aerator per pond. Fish in the high-, medium-, and low-oxygen treatment ponds were fed a mean total of 14,008, 13,212, and 12,607 lb/acre of 28%-protein floating feed, respectively. Net production paralleled the total amount of feed fed, averaging 5,772, 5,278, and 5,113 lb/acre in the high-, medium-, and low-oxygen treatments, respectively. Individual fish weight at harvest also showed a similar trend, averaging 1.37, 1.33, and 1.30 lb in the high-, medium-, and low-oxygen treatments, respectively. No visible stress responses were observed in any ponds during this study. Total aeration averaged 5,245, 2,518, and 1,337 hp-h/acre in the high-, medium-, and low-oxygen treatments, respectively. Treatments with higher minimum DO concentrations had significantly higher nitrite-nitrogen, suspended solids, chlorophyll *a*, and pH and lower Secchi disk visibility, alkalinity, and hardness; however, no water quality parameters exceeded the normal acceptable range for channel catfish. While the cost of electricity must be considered, maintaining a minimum daily DO concentration of 2.3–2.5 ppm is suggested as a compromise between maximizing both the amount of feed fed and fish production while minimizing aeration costs.

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During the past 35 years, average production rates for channel catfish *Ictalurus punctatus* in commercial ponds have increased from 1,600 lb/acre (Bureau of Sport Fisheries and Wildlife 1970) to nearly 4,000 lb/acre (USDA 2003). This increase in production is due largely to higher stocking and feeding rates made possible by increased aeration.

Increased aeration reduces the frequency and magnitude of dissolved oxygen (DO) depletions, allowing higher feeding rates (Hollerman and Boyd 1980). As of 2003, the industry averaged 1.9 hp/acre of permanently installed electric paddlewheel aerators used for routine aeration (USDA 2003). These aerators are normally activated at night in response to periodic DO measurements and turned off in the morning when the DO concentrations begin to increase as a result of photosynthesis. Additional portable tractor-powered units (with an industry average of one per two ponds) are available for emergency use (USDA 2003) if the electric units cannot maintain the desired DO concentration.

This aeration capacity allows for an average feeding rate of 108 $lb \cdot acre^{-1} \cdot d^{-1}$ during the peak feeding months (USDA 2003). Some individual commercial ponds may have up to 6 hp/acre of electric aerators in place and with proportionally higher feeding rates may produce over 15,000 $lb \cdot acre^{-1} \cdot year^{-1}$ (Charlie D. Hogue, Mississippi Cooperative Extension Service, Brooksville, personal communication).

While the relationship between aeration intensity (expressed as hp/surface acre) and the maximum safe feeding rate is generally accepted, the effects of a fluctuating DO concentration on channel catfish in a pond environment are poorly understood. Channel catfish mortalities may be expected in ponds when the DO concentration falls below 1.0 ppm (Moss and Scott 1961; Chowdhury 1971; Durborow et al. 1985), and channel catfish raised in ponds typically exhibit lower feed intake following episodes of acute but sublethal oxygen stress (Tucker et al. 1979). However, most catfish farmers have come to believe that if catfish do not show a visible stress response to low DO (such as swimming near the water surface [i.e., aquatic surface respiration] or congregating in the outflow from a well or an aerator), the DO concentration is not limiting. There is a lack of empirical data to support this, however.

Channel catfish generally show no adverse effects of exposure to DO concentrations above 70% saturation and can live and grow under long-term exposure to

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Received December 4, 2007; accepted March 24, 2008
Published online October 13, 2008

mildly hypoxic conditions (60–70% saturation), although at a slightly reduced efficiency. Feed intake may be less than that under normoxic conditions, resulting in a reduced growth rate (Andrews et al. 1973; Carlson et al. 1980; Buentello et al. 2000). With increasing hypoxia (30–60% saturation), feed intake and growth are further reduced (Andrews et al. 1973; Carlson et al. 1980; Buentello et al. 2000). As a greater proportion of feed is going to maintenance than to growth, the food conversion ratio (FCR) may be poorer (Andrews et al. 1973). At even lower oxygen concentrations, long-term (Carlson et al. 1980) and even short-term survival may decrease (Chowdhury 1971).

However, the growth, food intake, and even survival of channel catfish are negatively affected to a greater degree at constant (low) DO concentrations than when DO concentrations fluctuate between high and low values daily (Carlson et al. 1980), as they normally do in a pond environment. These observations can largely be explained by the physiological responses of catfish to hypoxia. As the DO concentration falls below the saturation level, channel catfish can maintain oxygen uptake at control levels through pronounced hyperventilation, largely through greater branchial stroke volume (Burggren and Cameron 1980). The increased perfusion of the gills is complemented by preferentially shunting blood to essential tissues (such as the nervous system or ventilatory muscles) and using anaerobic glycolysis and other anaerobic pathways. The result is an elevation of the blood lactic acid concentration and a posthypoxic repayment of the oxygen debt. The magnitude of these events will depend on both the degree and extent of hypoxic exposure.

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Exposure to mild hypoxia can be survived indefinitely, but with reduced efficiency (poorer growth). As the degree of hypoxia increases, performance (feed consumption, growth, and eventually FCR) decreases further, until at an even lower concentration survival is reduced.

Pond studies indicate that there is less consumption of feed (Hargreaves and Steeby 2000) or feed conversion (Lai-fa and Boyd 1988) when DO declines to approximately 2.0 ppm, well above the DO concentration at which catfish exhibit visible oxygen stress. In a pond study in which the daily low DO concentration was controlled with a commercial pond oxygen monitoring system, Torrans (2005) observed a 6% decrease in feed consumption when the morning DO declined to 2.6 ppm and a 45% decrease when the DO declined to 1.7 ppm. Thus, it appears that catfish feed consumption is affected at DO concentrations too high to elicit a visible stress response.

The purpose of this study was to further quantify the effects of the daily minimum DO concentrations on the feed consumption, feed conversion, growth, and production of channel catfish grown in earthen ponds, with the ultimate goal of developing practical aeration recommendations for the industry based on empirical data.

Methods

This study was conducted in 15 1-acre ponds at the Delta Western Research Center, Indianola, Mississippi. Ponds were aerated with one 5-hp electric paddlewheel aerator in each pond. Five ponds were randomly assigned to each of three treatments: a high-oxygen (with aeration initiated when the DO concentration declined to approximately 5.0 ppm), a medium-oxygen (with aeration initiated when the DO concentration declined to approximately 3.0 ppm), and a low-oxygen treatment (in which we wanted to maintain the DO concentration below 2.0 ppm without producing a visible stress response). The paddlewheels were turned off in individual ponds after sunrise when the DO was at or above 3.0 ppm and increasing. Start and stop times were recorded for each paddlewheel.

The DO concentration in the high-oxygen treatment ponds was established so that comparisons could be made with other studies that began aeration at a similar DO concentration (e.g., Torrans 2005). Having similar high-oxygen "control" values allowed for comparison among different studies conducted in different years, even those with different stocking and feeding rates.

The ponds were stocked on April 13–14, 2003, with an average of 5,057 channel catfish per acre; the fish were from an unselected commercial strain with a mean fish weight of 0.080 lb. There were no significant differences among treatments with respect to the number of fish stocked, mean fish weight, or total weight stocked (Table 1).

Fish were fed once daily with a 28%-protein commercial floating feed (Delta Western Catfish Feed, Indianola, Mississippi). A practical attempt was made to feed fish in each pond as much as they would consume at each feeding without wasting feed.

The DO in all ponds was measured and recorded every 2 h through the night with a YSI Model 55 polarographic DO meter (YSI Inc., Yellow Springs, Ohio). Measurements were made where water returned to the aerators at an approximate depth of 18 in. The water temperature from a representative pond was recorded during each oxygen check.

Ponds were sampled weekly in the morning to measure chloride, pH, ammonia, nitrite, chlorophyll *a*, suspended solids (fixed, volatile, and total), Secchi disk visibility, alkalinity, and hardness. Chloride was determined using the silver nitrate method, and pH

TABLE 1.—Stocking, harvest, and production data for channel catfish in experimental ponds. Values are means ± SEs of five acre earthen ponds per oxygen treatment, together with the *P*-values from a one-way ANOVA. Values in a row followed by different letters are significantly different (Duncan's multiple-range test; $P < 0.05$).

Variable	Treatment[a] High oxygen	Medium oxygen	Low oxygen	*P*
Number stocked per acre	5,082 ± 29	5,031 ± 34	5,058 ± 40	0.60
Mean fish weight stocked (lb)	0.078 ± 0.003	0.083 ± 0.002	0.080 ± 0.003	0.49
Total weight stocked (lb)	394 ± 13	415 ± 10	405 ± 12	0.48
Total feed fed (lb)	14,008 ± 409 z	13,212 ± 142 zy	12,607 ± 272 y	0.02
Mean fish weight harvested (lb)	1.37 ± 0.04	1.33 ± 0.07	1.30 ± 0.04	0.64
Total weight harvested (lb)	6,167 ± 309	5,693 ± 214	5,518 ± 224	0.21
Number harvested	4,521 ± 287	4,317 ± 204	4,254 ± 179	0.69
Survival (%)	89.1 ± 6.1	85.8 ± 3.6	84.1 ± 3.8	0.75
Aeration time (hp-h/acre)	5,245 ± 173 z	2,518 ± 40 y	1,337 ± 67 x	<0.0001
Net production (lb/acre)	5,772 ± 301	5,278 ± 217	5,113 ± 225	0.20
Food conversion ratio	2.44 ± 0.09	2.52 ± 0.08	2.48 ± 0.11	0.87

[a] High oxygen = 4.37 ppm, medium oxygen = 2.68 ppm, and low oxygen = 2.32 ppm.

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was determined using a SensION1 portable pH meter (Hach Company, Loveland, Colorado). Total ammonia nitrogen (TAN) and nitrite-nitrogen (NO_2-N) were determined using the phenate method and diazotization, respectively (Boyd and Tucker 1992). Un-ionized ammonia nitrogen (NH_3-N) was calculated as a function of TAN, temperature, and pH (Emerson et al. 1975). Chlorophyll *a* (a measure of phytoplankton biomass) was determined spectrophotometrically after chloroform–methanol extraction (Lloyd and Tucker 1988). Suspended solids, Secchi disk visibility, alkalinity, and hardness were determined using standard methods (APHA et al. 1998).

Fish were harvested in November and early December after feeding activity ceased owing to low water temperatures. Ten batches of 25 fish each (250 total fish) from each pond were counted and weighed to determine average fish weight before harvest. Fish were bulk-weighed at harvest using standard commercial fish loading equipment, the final fish numbers being estimated from the total yield and the average weight of the fish sampled.

Stocking, production, and other annual data were analyzed by means of the analysis of variance (ANOVA) procedure of SAS/Analyst Application version 9.1 (SAS Institute 2003a, 2003b). Mean comparisons among these data were made using Duncan's multiple-range test. Water quality and monthly oxygen, feed, and aeration data were analyzed with repeated-measures ANOVA, repeated measurements being taken on replicate ponds at approximately weekly (water quality) or daily intervals (minimum DO, feed, and aeration) during the study. The covariance structure, autoregressive of order 1, was used in the repeated measure model. Mean comparisons were made using a least-significant-difference test. Differences in treatment means were declared significant at $\alpha = 0.05$.

Results

Dissolved Oxygen

Morning (minimum) DO concentrations averaged 6.0 ppm (68.0% air saturation) or more in all treatments from stocking in mid-April through the end of the month (Figure 1). There were no significant differences among treatments. As water temperatures increased through July, the minimum DO concentrations decreased in all treatments.

The mean minimum DO concentration in the high-oxygen treatment was significantly higher than that in the other two treatments every month of the study except April. From June through September the minimum DO concentration in the high-oxygen treatment averaged 4.37 ± 0.11 ppm (mean ± SE; 54% saturation), with a monthly mean range of from 4.18 ± 0.07 to 4.58 ± 0.09 ppm (53.2–55.2% saturation; Figure 1). These were the 4 months with the highest daily feeding rates, in which over 72% of the feed was consumed (Figure 2a).

The minimum DO concentration in the medium-oxygen treatment ponds was significantly higher than that in the low-oxygen treatment ponds every month except April and August, averaging 2.68 ± 0.07 ppm (33.2% saturation) from June through September compared with 2.32 ± 0.09 ppm (28.7% saturation) for the low-oxygen treatment ponds during the same months (Figure 1).

Feed

Fish in the high-oxygen treatment ponds were fed a mean total of 14,008 lb/acre (Table 1; Figure 2b). Fish in the medium-oxygen treatment ponds were fed

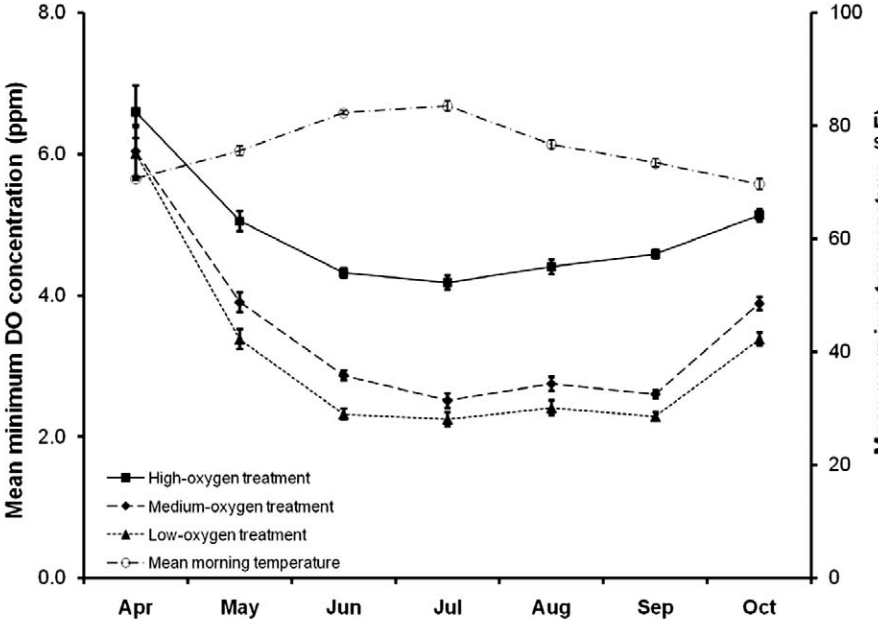

FIGURE 1.—Minimum daily dissolved oxygen (DO) concentrations (means ± SEs) in the high- (4.37 ppm), medium- (2.68 ppm), and low-oxygen (2.32 ppm) treatments in the study ($N = 5$ ponds per treatment), along with the water temperatures at approximately the time that the DO concentrations were measured.

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13,212 lb/acre, and fish in the low-oxygen treatment ponds were fed 12,607 lb/acre, significantly (10.0%) less than in the high-oxygen treatment. Cumulatively, the channel catfish in the high-oxygen treatment ponds were fed more feed than those in the low-oxygen treatments from August through October, and those in the medium-oxygen treatment ponds were fed an intermediate amount (Figure 2b).

On a monthly basis, the fish in the high-oxygen treatment ponds were fed significantly more feed than those in the low-oxygen treatment in August and September and more than those in the medium-oxygen treatment only in September (Figure 2a). The feeding rates in all treatments were highest in September, averaging 101, 92, and 88 $lb \cdot acre^{-1} \cdot d^{-1}$ in the high-, medium-, and low-oxygen treatments, respectively (Figure 2a).

The FCR was higher than expected but not significantly different among treatments, ranging from a low of 2.44 for the high-oxygen treatment ponds to a high of 2.52 for the medium-oxygen treatment ponds (Table 1).

Production

The trends in net production paralleled the total amount of feed fed, averaging 5,772, 5,278, and 5,113 lb/acre in the high-, medium-, and low-oxygen treatments, respectively (Table 1). While this appears to be a meaningful trend, net production did not differ significantly among treatments. Mean survival and mean weight at harvest showed a similar trend to decrease as the treatment minimum DO decreased, but as with net production these differences were not significant (Table 1).

Aeration

Total aeration averaged 5,245, 2,518, and 1,337 hp-h/acre for the year in the high-, medium-, and low-oxygen treatments, respectively (Table 1). These values were all significantly different. The mean daily aeration values in the three treatments (Figure 3a) were all significantly different every month except April, when aeration in the medium- and low-oxygen treatments was similar. Aeration increased with increasing water temperature through July, the month with the highest water temperature (83.5°F). While feeding rates continued to increase through September (Figure 2a), aeration rates decreased after July as water temperatures decreased (Figures 3a, b).

Water quality

The ponds with higher aeration rates tended to have increased turbidity, the high-oxygen treatment ponds having significantly lower Secchi disk visibility and higher fixed, volatile, and total suspended solids than the low-oxygen treatment ponds (Table 2); the

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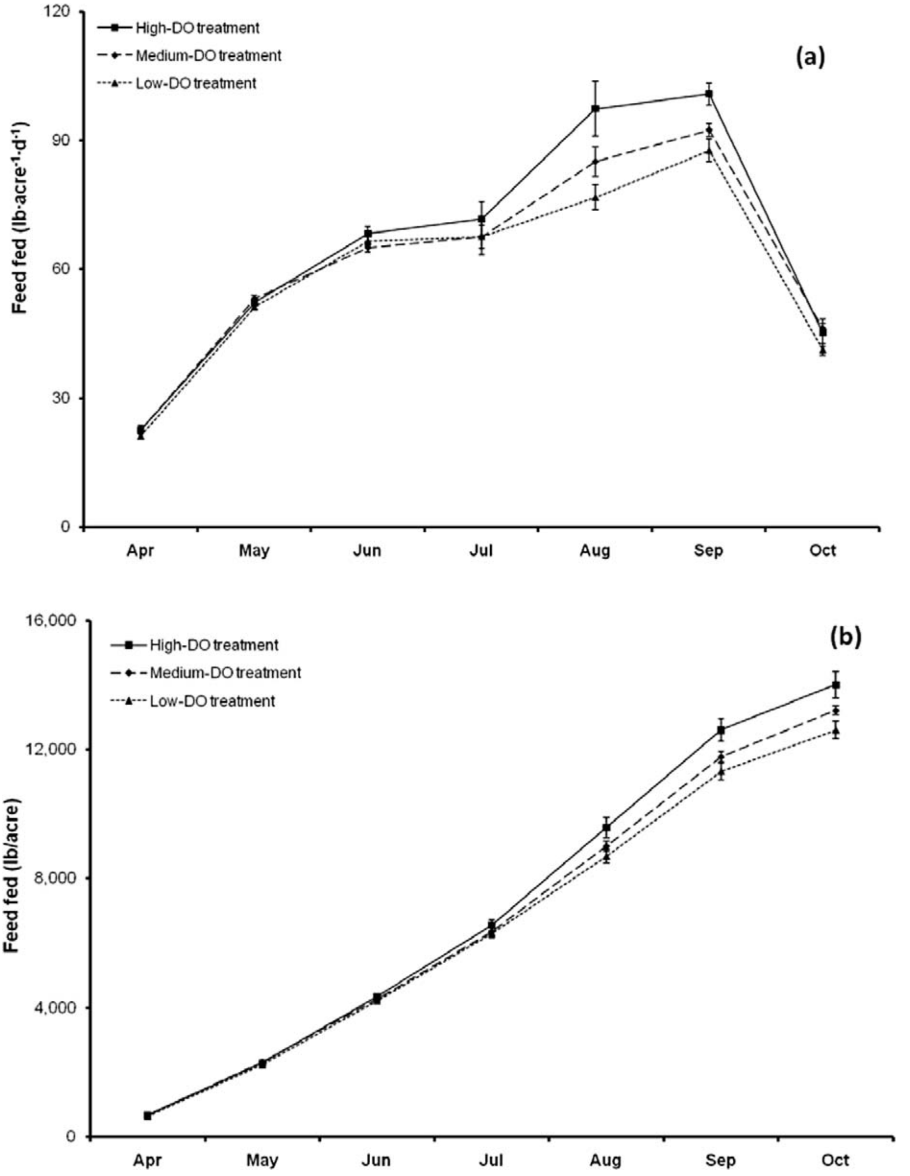

FIGURE 2.—**(a)** Monthly feeding rate and **(b)** cumulative amount of feed fed to channel catfish maintained at the dissolved oxygen (DO) concentrations described in Figure 1. Values are means ± SEs for the five 1-acre ponds in each treatment.

medium-oxygen treatment ponds tended to be intermediate. The high- and medium-oxygen treatment ponds had similar levels of chlorophyll *a* (averaging 353.2 and 361.6 ppb, respectively), which were significantly higher than that in the low-oxygen treatment ponds (with 305.8 ppb).

No critical water quality parameters exceeded the normal acceptable range for channel catfish. Total ammonia nitrogen (Table 2) averaged less than 0.56 ppm in all treatments (with maximum individual sample values for the high-, medium-, and low-oxygen treatments of 5.23, 2.31, and 2.18 ppm, respectively). Un-ionized ammonia-nitrogen averaged less than 0.029 ppm (with maximum individual values for the high-, medium-, and low-oxygen treatments of 0.41, 0.14, and 0.24 ppm, respectively). Neither of these parameters differed significantly among treatments over the course of the study.

Nitrite-nitrogen was significantly higher in the high-oxygen treatment ponds than in the others but only

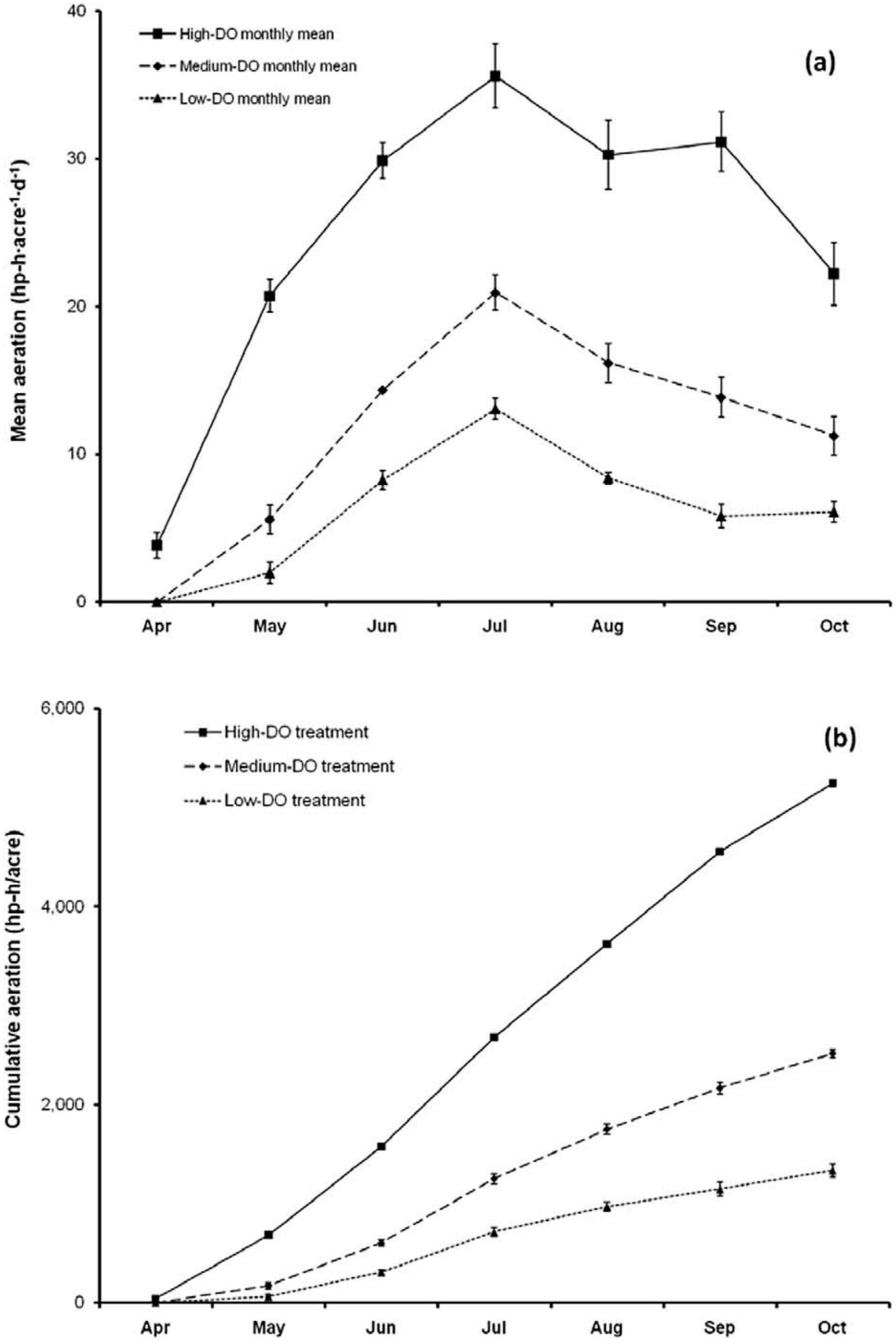

FIGURE 3.—**(a)** Monthly aeration and **(b)** cumulative aeration in experimental channel catfish ponds with the dissolved oxygen (DO) concentrations described in Figure 1. Values are means ± SEs for the five 1-acre ponds in each treatment. Aeration in the high-oxygen treatment was significantly greater than that in the other treatments in all months; aeration in the medium-oxygen treatment was significantly greater than that in the low-oxygen treatment in all months except April.

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TABLE 2.—Mean values for water quality parameters measured at weekly intervals in experimental channel catfish ponds, together with the P-values from a repeated-measures ANOVA. Values in a row followed by different letters are significantly different (least-squares means; $P < 0.05$).

Parameter	Treatment[a]			Pooled SE	P
	High oxygen	Medium oxygen	Low oygen		
Nitrite-N (ppm)	0.080 z	0.051 y	0.036 y		
Total ammonia-N (ppm)	0.47	0.44	0.56	0.05	0.20
Un-ionized ammonia-N (ppm)	0.026	0.021	0.029	0.003	0.19
pH	8.01 z	7.96 zy	7.93 y	0.02	0.02
Secchi disk depth (in)	4.53 y	4.80 zy	5.02 z	0.13	0.04
Total suspended solids (ppm)	142.0 z	111.1 y	103.8 y	5.4	<0.001
Volatile solids (ppm)	39.2 z	40.3 z	34.1 y	1.7	0.02
Fixed solids (ppm)	101.8 z	71.4 y	70.4 y	5.0	<0.001
Chlorophyll *a* (ppb)	353.2 z	361.6 z	305.8 y	16.5	0.04
Total alkalinity (ppm)	206.0 y	214.2 y	233.7 z	5.2	0.01
Total hardness (ppm)	214.0 y	222.8 y	228.8 z	4.7	0.09

[a] High oxygen = 4.37 ppm, medium oxygen = 2.68 ppm, and low oxygen = 2.32 ppm.

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averaged 0.080 ppm (with maximum individual values for the high-, medium-, and low-oxygen treatments of 0.93, 0.65, and 0.59 ppm, respectively). Since chloride levels were maintained at or above 100 ppm through the periodic addition of salt, a nitrite concentration of up to 10 ppm could be tolerated (Tomasso et al. 1980).

The pH was significantly higher in the high-oxygen treatment ponds (pH = 8.01) than in the low-oxygen treatment ponds (pH = 7.93); the pH of the medium-oxygen treatment ponds was intermediate (pH = 7.96) (Table 2). The lowest alkalinity and hardness values occurred in the high-oxygen treatment ponds (206 and 214 ppm, respectively), with significantly higher values in the low-oxygen treatment ponds (234and 229 ppm, respectively). The medium-oxygen treatment ponds had intermediate values that were not significantly different from those of the high-oxygen treatment ponds.

Discussion

The actual minimum DO concentration from June through September averaged 4.37 ppm for the high-oxygen treatment and 2.68 ppm for the medium-oxygen treatment. This was as expected and slightly lower than the DO concentration at which aeration was initiated. The low-oxygen treatment averaged 2.32 ppm, or 0.32 ppm higher than the DO at which we had stipulated aeration to be initiated. The night oxygen crew checked ponds on a 2-h schedule. If the DO in a low-oxygen treatment approached 2.0 ppm during one of their scheduled checks, they turned the aerator on, believing that if they waited until the next check (in 2 h) the DO would probably have decreased enough to cause stress or kill the fish. Thus, the resulting minimum DO concentration in the low-oxygen treatment was higher than anticipated and desired. This could have only been avoided if the night crew checked ponds on a 30–60-min schedule (impractical at this facility), or if an automated oxygen monitoring and control system were used.

The minimum DO concentrations in the low-oxygen treatment ponds averaged 2.32 ppm (28.7% air saturation) during the 4 months with the highest water temperatures and highest feed input (Figures 1, 2a). Based on laboratory studies of channel catfish held at constant DO concentrations, one would expect this to have resulted in a growth rate reduced by over 50% (Andrews et al. 1973; Carlson et al. 1980) and reduced survival (Carlson et al. 1980). However, while the amount of feed fed was reduced by 10%, growth and net production showed a decreasing trend at lower minimum DO concentrations but did not differ significantly among treatments (Table 1; Figure 2b). Thus, while a minimum daily DO concentration of 2.32 ppm did have a measurable effect, the effects produced with a diurnally cycling DO concentration were less than would be expected at a similar constant DO concentration, as was also reported by Carlson et al. (1980) in a laboratory study.

Increasing the minimum DO concentration requires increased aeration (Figure 3a), with more aerators operating at once and at least some aerators operating for more hours during the day. This increased aeration, and presumably increased turbulence, resulted in increased fixed solids (Table 2), a measure of nonalgal turbidity. Other estimates of turbidity (Secchi disk visibility, total suspended solids, and volatile solids) were also significantly affected by treatment, but these could also be at least partly due to higher chlorophyll *a* concentrations (resulting from greater nutrient input in

Table 3.—Summary of channel catfish production data from Torrans (2005). Values are converted from metric to English units for comparison with the present study. Values within a row in the same year followed by different letters are significantly different (ANOVA; $P \leq 0.10$).

	2001		2002	
Variable	High DO	Low DO	High DO	Low DO
Minimum DO (ppm; Jun–Sep)	4.5 z	2.6 y	4.4 z	1.7 y
Feed fed (lb/acre)	18,961 z	17,750 y	37,330 z	20,500 y
Final mean weight (lb)	0.9	0.82	1.68	1.15
Net production (lb/acre)	6,057	6,193	20,765 z	9,550 y
Food conversion ratio	3.13	2.87	1.8	2.2
Survival (%)	59	66	83	62

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the form of feed) in the higher oxygen treatments. Torrans (2005) also observed a lower Secchi disk visibility, and higher total suspended solids, fixed solids, and chlorophyll *a* in ¼-acre ponds with increased aeration and greater feed input.

One would expect that ponds with the highest feed input would also have higher TAN values, but this was not the case. While not significantly different, highest TAN values were seen in the low-oxygen treatment of this study, and also in the low-oxygen treatments in both years of the study of Torrans (2005). However, nitrite-nitrogen values were significantly higher in the high-oxygen treatments of both studies. The lower TAN in the high-oxygen treatment could be explained by an increased nitrification rate resulting from the higher DO concentrations (Avnimelech et al. 1986), increased volatization resulting from increased mechanical aeration (Weiler 1979), or an increase in ammonia utilization by the denser phytoplankton bloom (Hargreaves and Tucker 1996). In addition to increased nitrification rates at higher DO concentrations (Avnimelech et al. 1986), the significantly higher nitrite-nitrogen concentrations seen in the high-oxygen treatments of both studies could partially result from resuspension of sediment nitrite (Hollerman and Boyd 1980).

The significantly higher pH in the high-oxygen treatment, also reported by Torrans (2005), probably resulted from increased aeration, which removes free CO_2, thereby raising the pH (Hargreaves and Brunson 1996). The significantly lower alkalinity and hardness in the high- and medium-oxygen treatments of this study could have resulted from the increased pH (and decreased CO_2), resulting in the precipitation of $CaCO_3$ (Wetzel 1975).

The significant effect of minimum DO concentrations on the amount of feed fed (arguably one of the most important production parameters on a commercial catfish farm) that was observed in this study agrees well with the results of Torrans (2005), who conducted a similar study using automated oxygen monitoring and control equipment in smaller (¼-acre) ponds (Table 3). In both this study and that of Torrans (2005), the high-oxygen treatment ponds were maintained with a minimum DO concentration of 4.4–4.5 ppm from June through September (the four peak feeding months), and fish were fed to satiation daily. The total amount of feed fed and net production in the high-oxygen treatment was then used as the control (100%) value in each study, allowing comparison of lower-DO treatments between studies. In both studies the amount of feed fed (Figure 4) and net production (Figure 5) begin to decrease as the minimum DO concentration falls below 3.0 ppm and decrease rapidly when the minimum DO concentration falls below 2.5 ppm.

At an average minimum DO concentration of 2.7 ppm (this study), the amount of feed fed was 94.7% of the control value (Figure 4; Table 1). At minimum DO concentrations of 2.6 ppm (Torrans 2005) and 2.3 ppm (this study), the decrease in the amount of feed fed was significant, averaging 6.3% and 10.0%, respectively. At the lowest minimum DO concentration examined (1.7 ppm; Torrans 2005), the amount of feed fed was significantly less than that of the high-oxygen controls by 44.1% (Figure 4).

Net production and the amount of feed fed showed nearly identical decreasing trends as minimum DO concentrations decreased (Figure 5). However in both studies, the variability in net production (calculated as the coefficients of variation) were approximately twice as high as the variability in the amount of feed fed. This is probably due to the cumulative effect of variable survival, amount of feed fed, and FCR on net production. Thus, while the trend was similar, the decrease in net production was not statistically significant until the minimum DO declined to 1.7 ppm (Torrans 2005).

Maintaining a minimum DO concentration of 2.3–2.5 ppm is suggested by the data as a practical target for commercial catfish farms. All treatments main-

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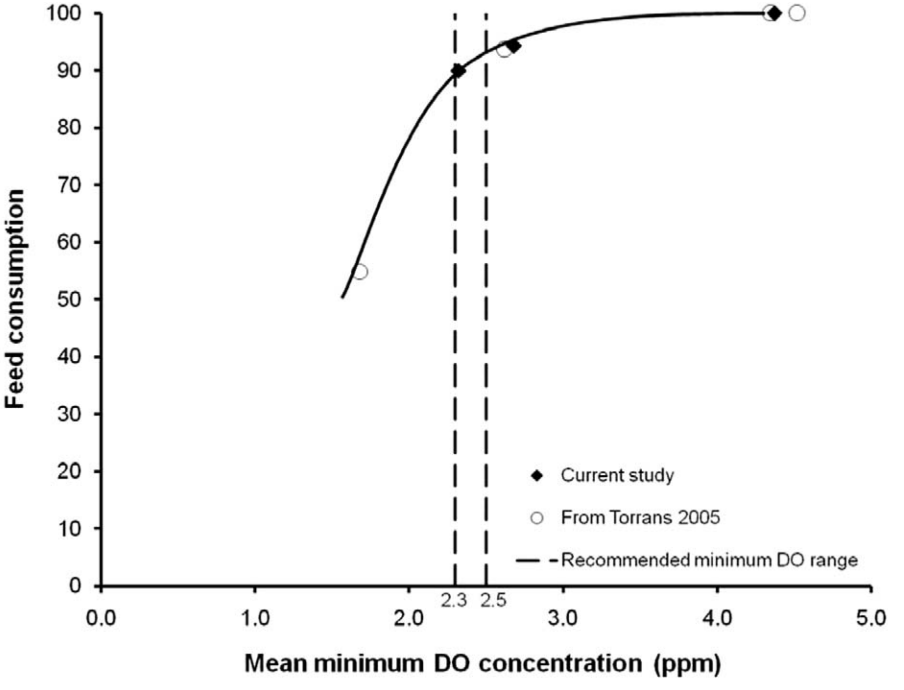

FIGURE 4.—Effect of minimum dissolved oxygen (DO) concentration on the amount of feed consumed by channel catfish. The DO concentration is the treatment average minimum concentration for June–September; the amount of feed consumed is expressed as a percentage of that in the high-oxygen (control) treatment. Data derived from Torrans (2005) are presented for comparison. The dashed vertical lines show the range of recommended minimum DO concentrations.

tained within or below this concentration demonstrated a significantly lower amount of feed fed (Figure 4), as did one of two treatments maintained slightly above this concentration (2.6 ppm; Torrans 2005). At the only DO concentration tested below this range (1.7 ppm; Torrans 2005), the reduction in net production was also significant (Figure 5).

While some production may be sacrificed with a minimum DO concentration of 2.3–2.5 ppm, significant savings on aeration are possible. In this study, aerator usage was decreased from 5,245 hp-h/acre to 1,337 hp-h/acre by maintaining the minimum DO concentration at 2.3 ppm rather than 4.4 ppm, a savings of US\$320 $\cdot$ acre^{-1} $\cdot$ year^{-1} (at an electric rate of \$0.11/kWh).

Conclusions

1. Minimum DO concentrations of 2.68 and 2.32 ppm from June through September resulted in trends toward smaller size at harvest and lower net production compared with controls maintained at 4.37 ppm; at the lower DO the amount of feed fed was reduced by 10%. When minimum DO concentrations were maintained at 1.7 ppm (Torrans 2005), the amount of feed fed and net production were reduced by 45% and 54%, respectively.

2. Dissolved oxygen can affect channel catfish production parameters at concentrations above those eliciting a visible stress. While no behavioral responses to low DO were observed in either this study or that of Torrans (2005), trends toward reduced size at harvest and significantly lower net production, reduced the amount of feed fed, or both were observed in both studies.

3. Higher DO concentrations or aeration rates may result in reduced TAN and un-ionized ammonia even with higher feeding rates. While nitrite-nitrogen may increase with increased feeding and aeration rates, the harm from high nitrite-nitrogen can be prevented by adding salt, a routine practice on commercial catfish farms.

4. While all input costs vary and must be considered in any management plan, maintaining a minimum DO concentration of 2.3–2.5 ppm is suggested as a practical trade-off between aeration costs and production.

Acknowledgments

I thank D. Holifield and the staff at the Delta Western Research Center for their execution of this project and T. Walls for conducting the water quality

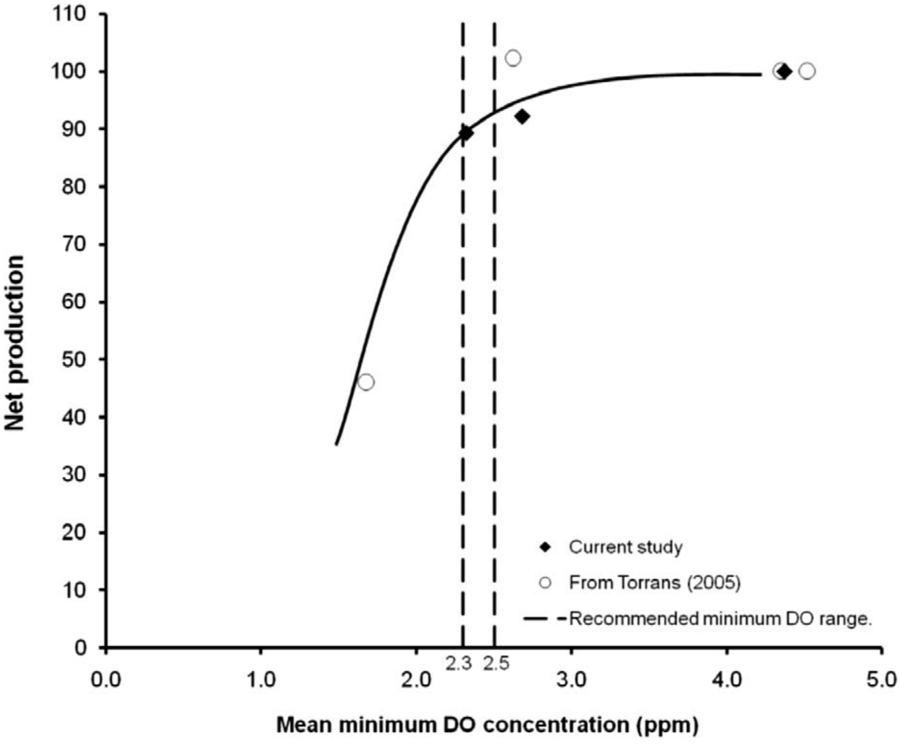

FIGURE 5.—Effect of minimum dissolved oxygen (DO) concentration on the net production of channel catfish. The DO concentration is the treatment average minimum concentration for June–September; net production is expressed as a percentage of that in the high-oxygen (control) treatment. Data derived from Torrans (2005) are presented for comparison. The dashed vertical lines show the range of recommended minimum DO concentrations.

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analyses. I also thank B. Bosworth, B. Green, B. Ott, B. Peterson, G. Waldbieser, and G. Whitis for their helpful reviews of the manuscript. This project was conducted with funding provided by U.S. Department of Agriculture, Agricultural Research Service, Current Research Information System Project 6402-13320-003-00D. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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