STATE SPACE TIME SERIES MODELING OF THE EFFECT OF FEEDING RATE ON DISSOLVED OXYGEN AND SUCCESSIVE FEED CONSUMPTION IN CHANNEL CATFISH CULTURE PONDS

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INTRODUCTION

Channel catfish farming is one of the largest industries in Mississippi. When the economic multiplier of the economic impact of catfish farming is considered, it ranks as the second largest cash crop in the state. Most of the industry is concentrated in what is known as the Delta region, or western part of the state encompassing the Mississippi River's alluvial plain. Farmers typically grow catfish to market-size (approximately 500 g) in large (4-8 ha) earthen ponds at high densities. The densities of catfish in these ponds can be in excess of 25,000/ha. Farmers feed the catfish pelleted feeds comprised mainly of grain products, with some additional animal products included. These feeds are fed at very high daily rates in order to maximize the growth of the fish; fish are typically fed to satiation (i.e., as much as they will eat). Due to the high rate of organic input to the pond system, problems may arise with maintaining proper water quality to ensure the health of the fish.

The most common water quality problem is the maintenance of dissolved oxygen in the pond water. Most farmers attempt to maintain dissolved oxygen levels of 4.0 ppm in their ponds; exposure to lower oxygen levels can stress fish, increasing disease susceptibility, induce stress-related mortality, or even directly suffocate fish. Dissolved oxygen levels fluctuate with temperature; more oxygen can dissolve in cool water than in warm water. Dissolved oxygen also fluctuates during the course of a day. During daylight hours, phytoplankton produce oxygen, generally resulting in the highest oxygen readings of the day being recorded in the afternoon. But at night, photosynthesis cannot occur and the life forms in the pond continue to respire, so the lowest oxygen concentrations are generally recorded at dawn. These fluctuations can be severe, and the severity can be more pronounced when densities of fish and feeding rates are at their highest, which can also be the point of highest profit potential for the farmer. Therefore, almost all of the day-to-day management effort at catfish farms involves maintenance of minimal oxygen levels, in addition to feeding the fish.

Cole and Boyd (1986) demonstrated high sustained feeding rates negatively affect water quality in channel catfish culture ponds. They reported dissolved oxygen levels at dawn were negatively correlated with feeding rate. Ponds fed at sustained rates of less than 56 kg/ha required little aeration to maintain satisfactory levels of dissolved oxygen, but the need for aeration increased dramatically at rates over 84 kg/ha. Even with constant aeration, sustained feeding rates over 168 kg/ha resulted in dissolved oxygen levels lethal to channel catfish. Randolph and Clemens (1976) observed that low, non-lethal dissolved oxygen concentrations often resulted in a decrease in channel catfish use of demand feeders, suggesting that low dissolved oxygen concentrations may affect the appetite and feed consumption of channel catfish.

Tackett et al. (1988) reported high daily variation in amount of feed consumed among channel catfish in ponds fed using demand feeders. They observed increased variation at the highest study density; daily differences averaged as high as 61% for 259-g fish stocked at 3468/ha. This suggests daily variation in feed consumption may be quite high at commercial culture densities. Anecdotal reports from personnel at the South Farm Aquaculture Research Unit of Mississippi State University suggests feeding activity may be negatively related to feeding activity of the previous day. Information is lacking on the short-term interrelationships between variation in feeding rate and dissolved oxygen fluctuations in culture ponds.

Nutritional research is being conducted at the South Farm Aquaculture Unit with channel catfish, using methods similar to channel catfish farmers, except with ponds that are much smaller in size (0.05 ha). Fish are fed to satiation daily, and temperature and dissolved oxygen levels are recorded twice daily (morning and afternoon). We used time series analysis techniques to search for patterns in these daily observations which would indicate autocorrelation and allow construction of statistical models to describe the interrelationships between the organic input and dissolved oxygen. Using this information, predictive models may be developed which would help farmers to identify periods in which low dissolved oxygen levels may be expected.

METHODS

Channel catfish averaging 150 g were stocked into three 0.05 ha ponds at the South Farm Aquaculture Unit on 5 July 1994 at a density of 12, 850/ha. Fish were fed a 32% protein, floating, experimental feed, with a formulation similar to commercial feeds. Daily satiation feedings were accomplished by initially offering the fish a small amount of feed, with additional offerings supplied as long as the fish consumed what had been previously offered. As feeding activity slowed to cessation, offerings were discontinued and the amount fed was recorded. Temperature and dissolved oxygen were measured each morning and afternoon using a Yellow Springs Instrument Company Model 57 Temperature/Dissolved Oxygen Meter in each of the three ponds. Morning dissolved oxygen and temperature were measured at approximately 0430-0530 and afternoon values were measured at approximately 0200-0300 in an attempt to measure dissolved oxygen at its typically lowest and highest points throughout a 24-hour period. Supplemental aeration was provided on a near constant basis.

Data from the period 13 July 1994 - 12 October 1994, constituting 92 daily observations, were subjected to multivariate time series analysis using state space methodology. The STATESPACE Procedure in SAS version 6.04 was used to construct models for each of the three ponds, describing the autocorrelative patterns and interrelationships between the 92 ordered, daily observations of amount of feed fed to fish in the pond, morning dissolved oxygen concentrations, and morning water temperatures. Models were also constructed for amount of feed fed, afternoon dissolved oxygen concentrations, and afternoon water temperatures. Fish were not fed on seven non-consecutive days throughout the study period; daily feed amounts were recorded as zero on those days, but were changed to a minimal amount for analyses. Minimal amounts were used in place of zero values to ensure the data approximated normality, an assumption of state space statistical methodology. Data were also transformed to the natural log of original values to ensure normality. Analyses were conducted on differenced (subtraction of the value of a particular variable from each successive value) data to ensure that the assumption of stationarity (the lack of a trend over the time series) was met.

RESULTS

Daily amounts of food fed to fish were highly variable (Figure 1). In Pond A, daily feed amounts ranged 0 - 5881 g/day and averaged 3353 g/day with a coefficient of variation (CV) = 40.3%. Daily feed amounts ranged 0 - 8165 g/day and averaged 3672 g/day (CV = 41.8%). In Pond C, daily feed amounts ranged 0 - 4837 g/day and averaged 2628 g/day (CV = 49.79%).

Water temperatures for both morning (Figure 2) and afternoon (Figure 3) remained consistently between 24-32 °C for the first two-thirds of the observation period, but dropped to approximately 16 °C over the final third of the observation period.

Morning dissolved oxygen concentrations (Figure 4) followed a slightly increasing trend as water temperatures decreased. Morning dissolved oxygen concentrations in Pond A ranged 4.0 - 9.2 mg/l and averaged 6.0 mg/l (CV = 17.5%). In Pond B, morning dissolved oxygen ranged 4.3 - 9.6 mg/l and averaged 6.1 mg/l (CV = 15.4%). Morning dissolved oxygen ranged 4.3 - 8.8 mg/l in Pond C and averaged 5.9 mg/l (CV = 16.0%).

Dissolved oxygen concentrations were more variable in the afternoon (Figure 5) than in the morning and no clearly discernible trend was apparent. Afternoon concentrations were often higher than the saturation point of oxygen in water of that temperature, indicating high rates of photosynthetic activity. In Pond A, afternoon dissolved oxygen concentrations ranged 5.7 - 12.7 mg/l and averaged 8.25 mg/l (CV = 19.6%). Afternoon dissolved oxygen ranged 5.6 - 11.1 mg/l in Pond B and averaged 7.7 mg/l (CV = 15.1%). In Pond C, afternoon dissolved oxygen ranged 4.6 - 15.2 and averaged 9.0 mg/l (CV = 18.7%).

The models describing morning concentrations of dissolved oxygen are as follows:

Pond A: $O_t = -0.080F_{t-1} + -0.088F_{t-2} + \varepsilon_t$

Pond B: O_t = No significant relationships detected

Pond C: O_t = No significant relationships detected

Where O_t = morning dissolved oxygen at time t, F_{t-1} = amount fed one day before time t, F_{t-2} = amount fed two days before time t, and ε_t = error. For Pond A, morning dissolved oxygen concentrations appear to be negatively related to the amount of feed fed to fish over the preceding two days. However, past values of the amount fed, morning dissolved oxygen, or morning water temperature were not useful in predicting the current values of morning dissolved oxygen in Pond B and Pond C.

No effective models could be developed for afternoon dissolved oxygen concentrations using the present data, because no significant interrelationships were observed among the variables. Afternoon dissolved oxygen did not appear to be dependent upon past values of amount fed, afternoon dissolved oxygen, or water temperature.

The models describing the amount of food fed to fish are as follows:

Pond A: No significant relationships detected

Pond B: No significant relationships detected

Pond C: $F_t = -0.591F_{t-1} + \varepsilon_t$

Where F_t = amount of food fed at time t, F_{t-1} = amount fed one day before time t, and ε_t = error. For Pond C, the amount of feed fed to fish is negatively related to the amount fed the previous day. For Pond A and Pond B, past values of amount fed, morning and afternoon dissolved oxygen, or morning and afternoon water temperature were not useful in predicting amount of food fed to fish.

DISCUSSION

State space modeling of the interrelationships between feeding rates, water temperature, and dissolved oxygen concentration seemed to indicate the functioning of these interrelationships were pond-specific, varying among the ponds. Morning dissolved oxygen concentration was significantly affected by feeding rate from previous days in Pond A, but had no significant effect in Pond B or Pond C. Also, apparent appetite of fish, as indicated by amount of food offered during satiation feeding, was significantly affected by the amount fed during the previous day in Pond C, but amount fed on previous days had no significant effect in Pond A or Pond B.

Observed feeding activity did not appear to be affected by prior oxygen levels of previous days. In our use of state space methodology, only oxygen values from 24 hour prior intervals were considered; we did not consider the effect of oxygen level at the time of feeding. Randolph and Clemens (1976) reported changes in feeding behavior of individual catfish using demand feeders during periods of low dissolved oxygen levels. Although low dissolved oxygen at the time of feeding may affect consumption, oxygen concentrations of previous days appeared to have no effect in our study. Randolph and Clemens (1976) also observed that only the larger, dominant individuals refrained from eating during periods of low dissolved oxygen and the smaller, less-dominant individuals generally continued to consume food. This suggests social hierarchy may attenuate the effect of low dissolved oxygen on total amounts of feed fed to ponds because at lower oxygen levels less-dominant fish may eat more feed than they are normally able. Additionally, dissolved oxygen concentrations observed during our study were never below the 4 mg/l level considered stressful to channel catfish, which may also account for the lack of a significant effect of low oxygen periods on feeding behavior.

The lack of any interrelationship involving afternoon dissolved oxygen concentrations seems to indicate afternoon dissolved oxygen was independent of daily variations in the amount of organic input from feeding fish and of water temperature across the observed range. Cole and Boyd (1986) showed that high feeding rates can result in deteriorated water quality when consistently high feeding rates are used. Cole and Boyd (1986) found increases in chlorophyll-*a* concentrations, indicative of increases in phytoplankton biomass, at higher sustained feeding rates. They also found ponds fed sustained rates over 56 kg/ha/day required much more aeration to ensure sufficient dissolved oxygen than ponds fed up to 56 kg/ha/day. Average feeding rates in our study ranged from 53 kg/ha/day for Pond C to 73 kg/ha/day for Pond A. The inclusion of some index of biomass and meteorological variables related to photosynthetic activity may enhance the effectiveness of state space methodology in this application.

Although Cole and Boyd (1986) demonstrated that high feeding rates sustained over the course of culture can negatively impact water quality, information is lacking as to the effects of short-term fluctuations in feeding rate. We have shown that day-to-day fluctuations in the amount of food fed to channel catfish in ponds can affect dissolved oxygen and feeding behavior on successive days. The mechanisms underlying these interrelationships are unclear. Oxygen consumption rates of fish can double within 1 to 6 hours after a fish eats due to the metabolic demands of digestion (Tucker and Robinson 1990). Daily variations in feed consumption may lead to daily variations in oxygen consumption of fish. Daily variations in total biological oxygen demand for the pond as a whole may also result as waste products and wasted feed are utilized by the microbial community of the pond.

Food consumption in fish may fluctuate in an inverse fashion with the amount fed in successive periods if their gastric evacuation rate is different than their rate of consumption (Trudel and Boisclair 1993). Fish which had consumed large meals the day before may not have evacuated all food consumed before the next feeding and this may influence food consumption during the next feeding. Incomplete gastric evacuation may also reduce aggressiveness of feeding, and feeding personnel may assume fish have reached satiation earlier than if aggressive feeding behavior is observed. Conversely, small meals and complete evacuation may lead to larger amounts fed on successive days.

The amount of food fed may also affect water quality parameters other than dissolved oxygen. Cole and Boyd (1986) found total ammonia-nitrogen was positively correlated with sustained feeding rate in channel catfish ponds. Long-term exposure to elevated concentrations of un-ionized ammonia can result in poor growth of channel catfish (Robinette 1976; Colt and Tchobanoglous 1978). Using satiation feeding practices may lead to "pulses" in organic input from feeding which could lead to subsequent pulses in total ammonia-nitrogen. If these short-term fluctuations in total ammonia-nitrogen are severe enough to induce stress, feeding behavior of channel catfish could be affected.

The utility of state space methodology in modeling the interrelationships between amount of food fed to fish, dissolved oxygen, and water temperature could have been limited in application to this data set by several factors inherent to this data set. Data from a longer time period could have enhanced the statistical power of the analysis, allowing increased ability to detect significant relationships. The point at which feeding to satiation is complete is an inherently subjective decision on the part of the person feeding the fish. Factors other than the feeding activity of the fish may have interfered with this decision, such as weather, preconceived notions about the appetite of the fish, etc. Dissolved oxygen levels during this study remained in ranges considered non-stressful to channel catfish; exposure to lower, stressful levels of oxygen may result in measurable changes in feeding behavior. Avoidance of supplemental aeration could also change the observed patterns in dissolved oxygen concentrations during culture and heighten the effects of dissolved oxygen on the interrelationships between water quality and amount of feed fed to fish.

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REFERENCES

Cole, B.A., and C.E. Boyd. 1986. Feeding rate, water quality, and channel catfish production in ponds. Progressive Fish-Culturist. 48:25-29.

Colt, J., and G. Tchobanoglous. 1978. Chronic exposure of channel catfish, *Ictalurus punctatus*, to ammonia: effects on growth and survival. Aquaculture. 15:353-372.

Randolph, K.N., and H.P. Clemens. 1976. Some factors affecting the feeding behavior of channel catfish in culture ponds. Transactions of American Fisheries Society. 105:718-724.

Tackett, D.L., R.R. Carter, and K.O. Allen. 1988. Daily variation in feed consumption by channel catfish. Progressive Fish-Culturist. 50:107-110.

Trudel, M., and D. Boisclair. 1993. An in-situ evaluation of the day-to-day variation in the quantity of food consumed by fish. Canandian Journal of Fisheries and Aquatic Sciences. 50:2157-2165.

Tucker, C.S., and E.H. Robinson. 1990. Channel catfish farming handbook. Van Nostrand Reinhold, New York.

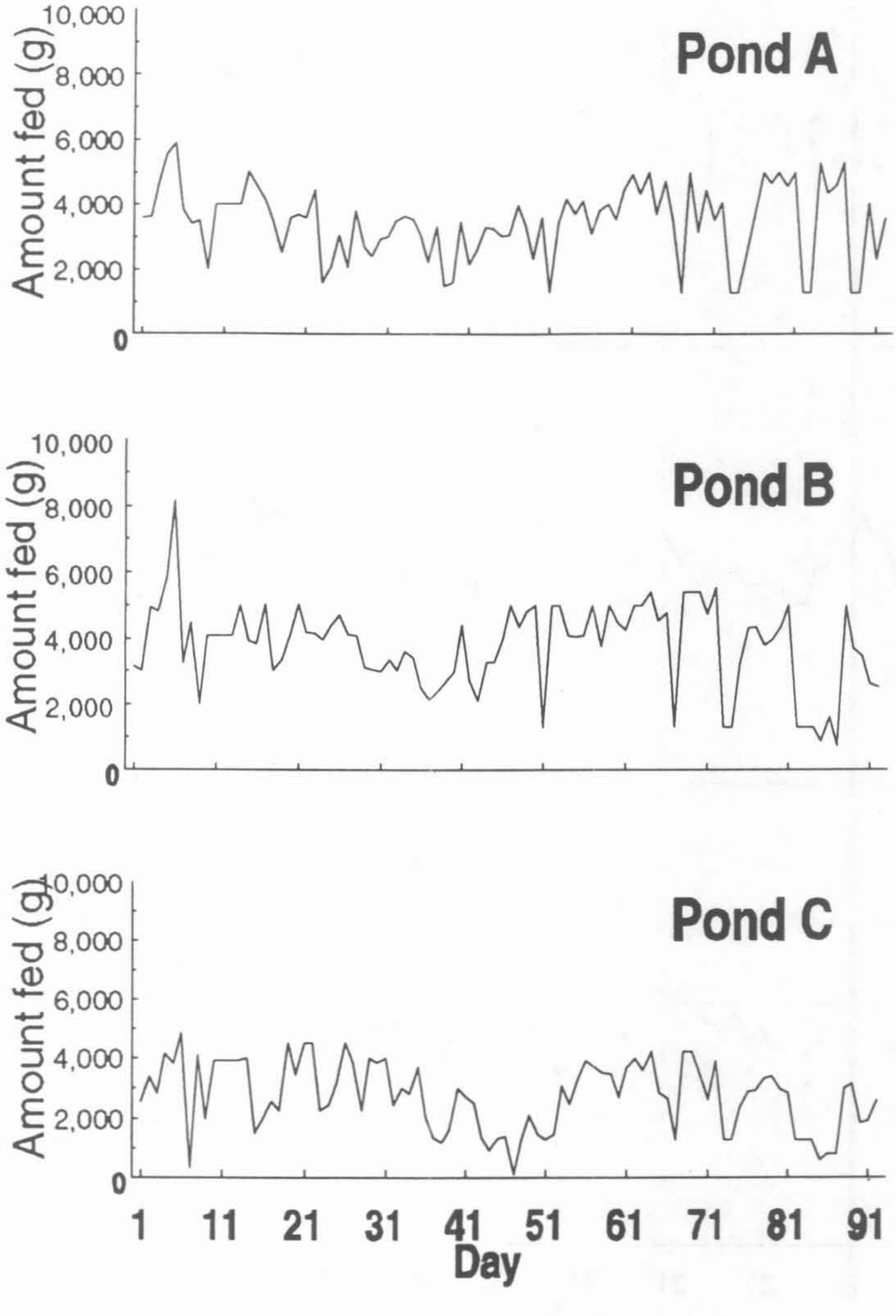


Table 1. Daily (n=92) amounts of feed (g/day) fed to channel catfish in three ponds 13 July - 12 October, 1994.

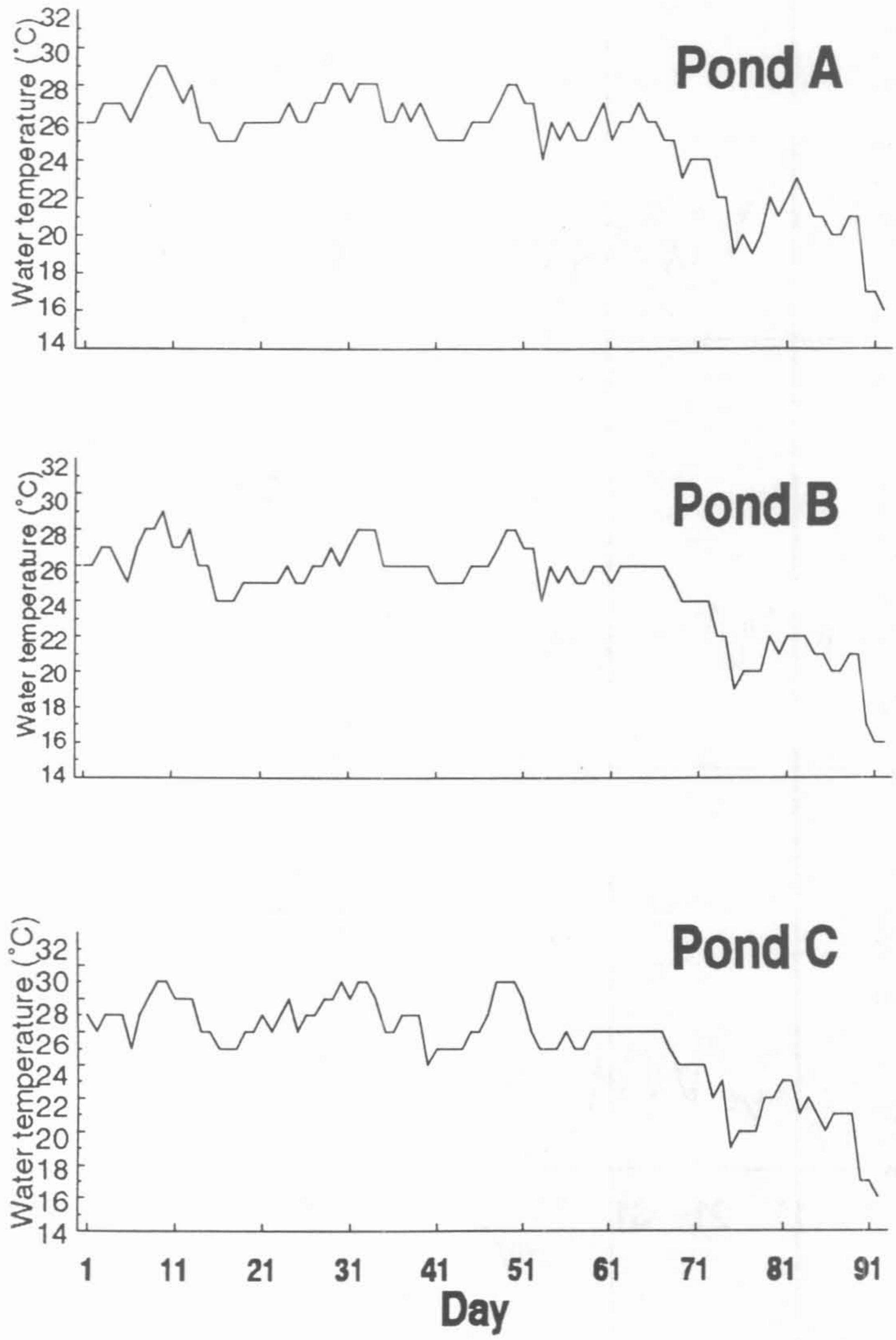
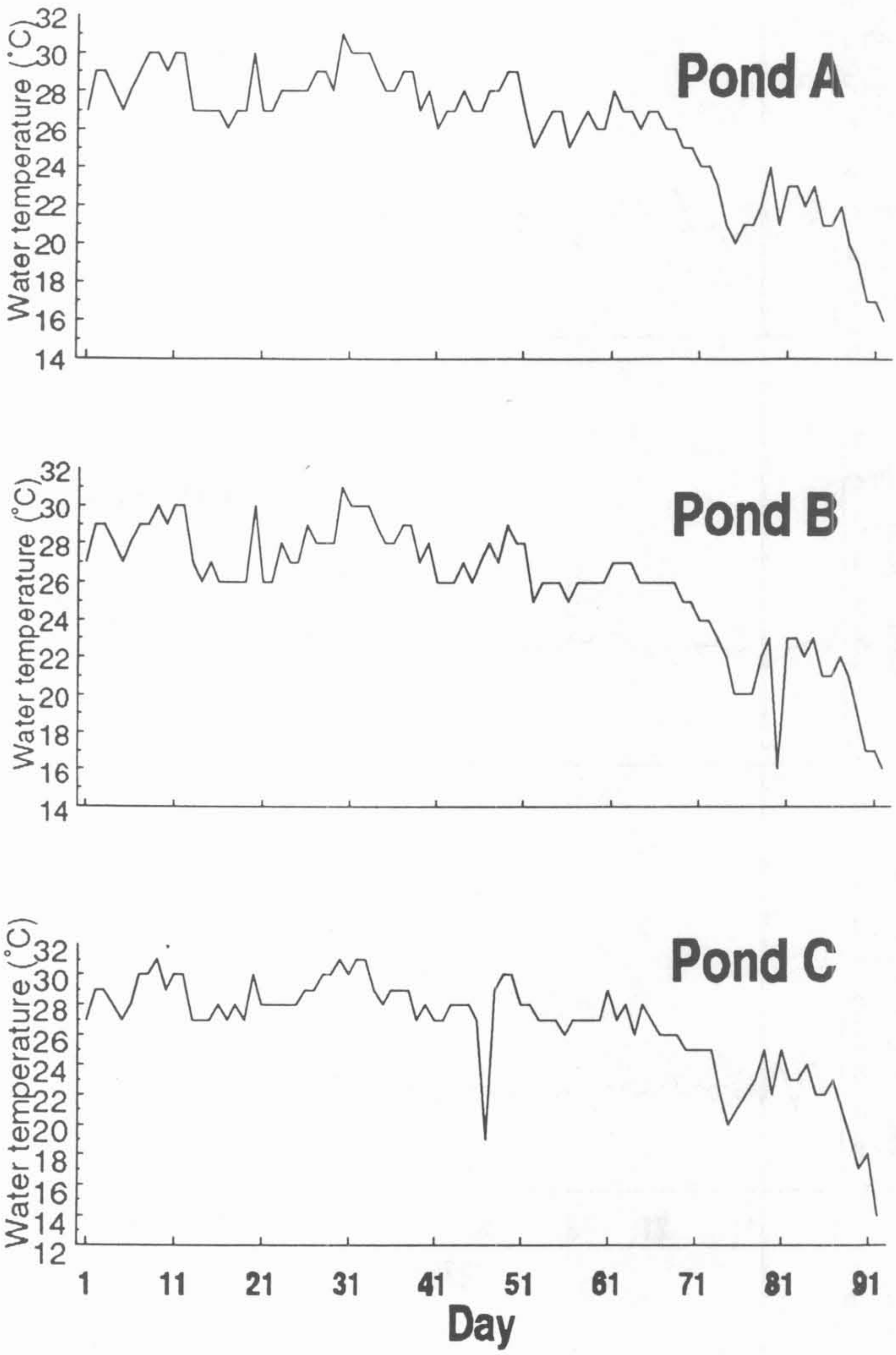


Table 2. Daily (n=92) water temperatures (°C) recorded between 0430-0530 in three channel catfish culture ponds 13 July - 12 October, 1994.



<u>Table 3</u>. Daily (n=92) water temperatures (°C) recorded between 1400-1500 in three channel catfish culture ponds 13 July - 12 October, 1994.

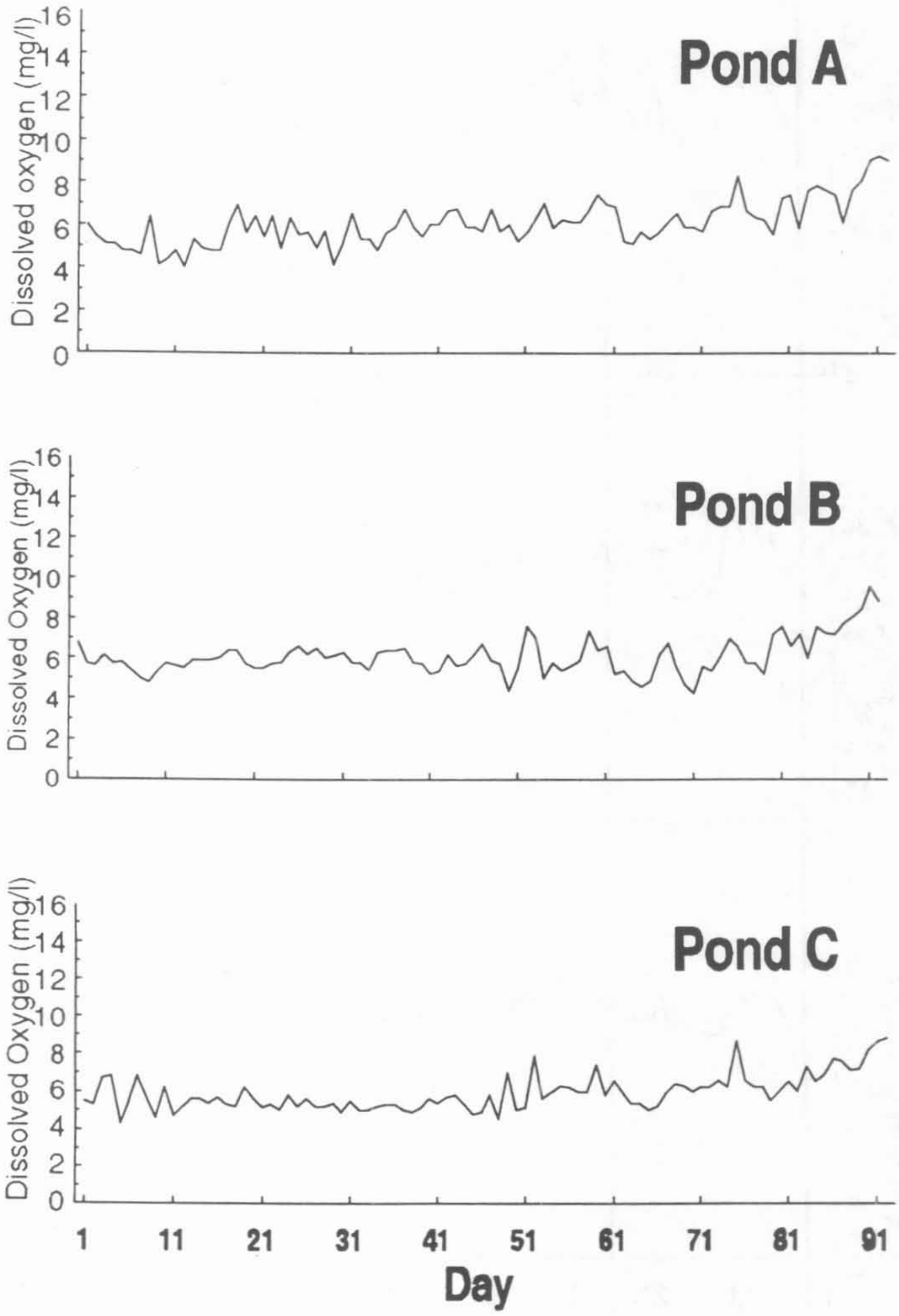


Table 4. Daily (n=92) dissolved oxygen (mg/l) recorded between 0430-0530 in three channel catfish culture ponds 13 July - 12 October, 1994.

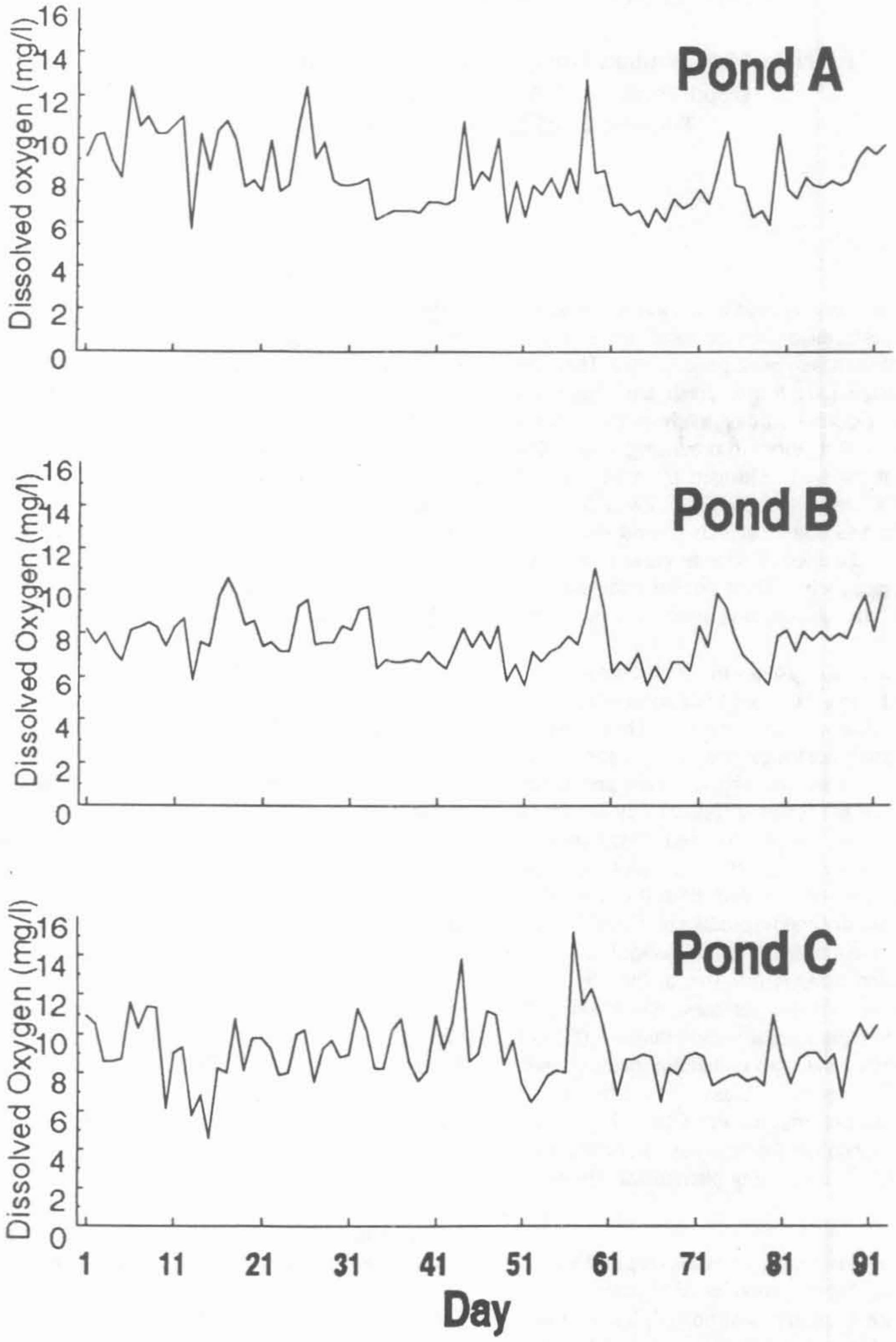


Table 5. Daily (n=92) dissolved oxygen (mg/l) recorded between 1400-1500 in three channel catfish culture ponds 13 July - 12 October, 1994.