

Captive Double-crested Cormorant *Phalacrocorax auritus* Predation on Channel Catfish *Ictalurus punctatus* Fingerlings and Its Influence on Single-batch Cropping Production

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Abstract.—We studied the effects of captive double-crested cormorant *Phalacrocorax auritus* predation on channel catfish *Ictalurus punctatus* inventories from research ponds with and without alternative prey during the years 1998–2000. In 1998, predation by two groups of captive cormorants on ponds without alternative prey produced inventory reductions relative to a control pond that were equivalent to 10.2 (516 g) and 10.5 (608 g) catfish/bird per d. In 1999 and 2000 individual cormorants foraging on 0.02-ha pond halves for 10 d (500 cormorant d/ha) stocked with both catfish and golden shiners *Notemigonus crysoleucas* produced inventory reductions at harvest (7.5 mo after predation occurred) averaging approximately 7 and 9 catfish/bird per d, respectively. In 1999, two ponds averaged a 30% reduction in fish inventoried and a 23% loss in biomass from ponds stocked at 12,355 fish/ha using a single batch cropping system. Production losses from predation were not apparent at a third pond where disease reduced the catfish population by more than 50%. In contrast, two ponds with more modest disease problems in 2000 had additive predation losses that exceeded those observed in 1999. Observations of cormorants foraging during 1999 and 2000 suggested that differences in catfish predation between these years may have been related to less shiner utilization by cormorants in 2000. However, based on availability, there was no preference for shiners over catfish (Chesson's $\alpha < 0.41$) in either year, although shiners were a more readily manipulated prey. Despite the possible moderating effects of alternative prey utilization, we conclude that cormorants can cause significant economic losses to catfish at harvest.

Depredations caused by the double-crested cormorant *Phalacrocorax auritus* have been a concern to channel catfish *Ictalurus punctatus* producers for many years (Stickley and Andrews 1989). In a 1996 national survey of catfish producers, depredations by cormorants were the most widely cited wildlife problem. Losses due to cormorants were cited by 77% of Mississippi producers, 66%

of Arkansas producers, and 50% of Alabama producers (Wywialowski 1999).

Observational studies provided the first evidence of the potential for cormorants to impact catfish production. Based on observations of the smaller subspecies of Florida cormorant (*floridanus* subspecies), Schramm et al. (1984) estimated that on average, each bird consumed 19 catfish fingerlings daily, ranging in size from 8 to 16 cm. The authors assumed the average catfish weighed 16 g and estimated Florida cormorants consumed 304 g of catfish daily, but argued that this estimate was conservative.

Similarly, Stickley et al. (1992) observed the larger subspecies of cormorant foraging on selected catfish ponds in the delta region of Mississippi. Because they could not keep track of individual foraging activity, they recorded the numbers of birds on ponds and the number of fish seen captured over specified time intervals and related this as the number of fish eaten per cormorant-h of foraging activity. Over the course of the study, they observed a mean of 30.5 cormorants per pond and an average of five catfish consumed per cormorant-h. Although it is difficult to precisely determine from these data the amount of catfish that an individual cormorant consumes per day, telemetry studies have indicated that individual cormorants spend about 1 h/d foraging (King et al. 1995).

In addition to catfish, averaging 12 cm in length, Stickley et al. (1992) observed cormorants consuming large numbers of gizzard shad *Dorosoma cepedianum* in situations where the wild-spawned fish had invaded catfish ponds. Based on these obser-

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ations Stickley et al. (1992) suggested that cormorants may prefer shad, possibly because they were more readily manipulated and swallowed. Given this, Glahn et al. (1995) suggested the availability of more readily manipulated alternative prey may help mitigate losses of catfish to cormorants.

Consistent with findings of Stickley et al. (1992), food habits studies in the delta region of Mississippi revealed that catfish, averaging 16 cm in length, comprised about 54% and 50% (wt/wt) of the diet of cormorants at catfish farms and roost sites, respectively (Glahn et al. 1995). Most of the remaining diet was gizzard shad, averaging about 12 cm in length.

Glahn and Brugger (1995) developed a bioenergetic model physiologically specific to *P. auritus* and predicted that these cormorants consume 504 g of fish/bird per d during the winter months. Using the bioenergetic model and data on numbers and diet of wintering cormorants in the delta region of Mississippi, Glahn and Brugger (1995) projected that during the winters of 1989–1990 and 1990–1991, cormorants consumed 18 and 20 million catfish fingerlings, respectively. Based on the replacement cost of fingerlings, the annual cost to producers in this region was calculated at approximately \$2 million. Considering that cormorant populations in this region have more than doubled in recent years, Glahn et al. (2000) projected the annual loss to replace fingerlings during the winters of 1996–1997 and 1997–1998 at approximately \$5 million.

Despite a recognized need for more research regarding catfish losses due to cormorant predation (Erwin 1995), there have been no studies verifying losses with and without alternative prey being present in ponds. Furthermore, no study has demonstrated the extent that cormorant foraging on fingerlings actually reduces catfish production at harvest.

The objectives of our study were to determine: 1) the number and biomass of cat-

fish fingerlings removed/bird per d by captive cormorants foraging on research ponds; 2) the impact of cormorant predation on yield at harvest in research ponds simulating a single-batch grow-out pond containing readily manipulated alternative prey; and 3) differences in captive cormorant selection and handling time of catfish and readily manipulated alternative prey.

Methods

Study Animals and Facilities

All cormorants were captured at night roosts in the delta region of Mississippi using methods described by King et al. (1994). Captured cormorants were physically examined for any injuries, weighed, and individually identified with a numbered leg band. Cormorants were held in captivity at the USDA National Wildlife Research Center testing facility in Starkville, Mississippi. This 0.4-ha facility is completely enclosed with chain-link fencing and netting and is divided into three compartments, each containing a 0.04-ha catfish pond approximately 1-m deep. In all predation trials (1998–2000), a prescribed number of channel catfish fingerlings were stocked into each pond. In 1999 and 2000, golden shiners *Notemigonus crysoleucas* obtained from local bait fish producers were also stocked as an alternative cormorant prey to simulate field situations where both shad and catfish were available. Golden shiners were used as a surrogate for shad because they were the most similar commercially available fish in both physical and behavioral characteristics and wild spawn shad are very difficult to capture, transport, and maintain alive.

1998 Predation Trial

Between 16 January and 30 January 1998 the three 0.04-ha ponds were stocked with 3,000 (75,000/ha) catfish fingerlings each. At stocking, samples of fish were weighed to determine their average weight. The fish were maintained in these ponds for 7 wk, and fish mortalities were checked 4–

5 times per wk. Throughout the study, dissolved oxygen levels of ponds were checked daily, and fish in each pond were fed 1.5 kg of a 32% protein floating catfish feed per d. During the evening of 8 March 1998 six and nine cormorants were placed on each of two ponds, while the third pond was excluded from cormorant use. Cormorants used in this trial were part of a telemetry package attachment study in which some birds were equipped with a backpack harness that did not interfere with their foraging ability (King et al. 2000). Midway through this testing period, an additional cormorant was inadvertently added to the pond with nine birds for an average of 9.5 birds on this pond over time. On 18 March 1998, after 8.5 d of foraging, all cormorants were removed from the ponds. Between 23 March and 24 March we completely inventoried all catfish and weighed samples of catfish from each pond to determine their mean weight. We summarized these data by comparing inventories of catfish with the numbers of catfish stocked. We subtracted the number of fish missing from the control pond to correct for non-predation related fish losses from ponds where cormorants foraged. Biomass of fish consumed was estimated by multiplying the number of catfish depredated times the mean weight of fish sampled at inventory.

1999 Predation Trial

We divided each of the three research ponds in half with a plastic mesh screening material to separate fish populations, and covered one pond half with netting to prevent cormorant predation. We simulated a commercial grow-out pond stocking rate (12,355 fish/ha) by stocking each 0.02-ha pond half with 250 catfish fingerlings (Tucker and Robinson 1990). In addition, we stocked each pond half with 5 kg of golden shiners, or the amount we estimated that cormorants would need to survive if they chose to forage exclusively on shiners. We used the largest shiners available to us from our supplier, averaging 18.2 g/fish or

a mean (\pm SEM) of 274.00 ± 5.48 , ($N = 6$) per pond half, and stocked all fish on 4 January 1999.

Throughout the study we checked dissolved oxygen levels at least twice daily and bubble aerators placed in each pond half were turned on when dissolved oxygen dropped below 3 mg/L. We initiated periodic low-level fish feeding on 27 January 1999 with a 32% protein (0.3-cm) floating pellet, and ultimately shifted to satiation feeding with a 0.5-cm floating pellet during the summer months until 17 October 1999.

To monitor fish mortality, we recorded and removed all dead fish daily from all pond halves. When mortalities exceeded two dead fish per d, we submitted fish to the diagnostic laboratory at the Mississippi State University College of Veterinary Medicine and followed their recommendations concerning a treatment regimen.

We completely inventoried all catfish by seining and scrapping ponds (hand removing all remaining fish from drained ponds) on 19 and 20 October 1999, respectively. In addition to counting all catfish, we individually weighed about half of all fish counted to estimate the total biomass of fish in each pond half. Although we attempted to count the shiners remaining, spawning of these fish in some ponds precluded an accurate count. We summarized catfish production data by comparing inventories with and without cormorant predation. Fish losses (number and biomass) from predation were assumed to be the difference in the inventory between paired pond halves with and without predation.

The predation treatment consisted of one cormorant per unprotected pond half foraging for ten consecutive d. This foraging activity simulated 30 cormorants foraging on a 6-ha pond (Stickley et al. 1992) for 100 d (500 cormorant d/ha). Cormorants were placed on each test pond during the evening of 22 February 1999 and removed on the evening of 4 March 1999.

Cormorant foraging activity was monitored during the treatment period, by ob-

serving birds from an elevated observation tower during two 3-h sessions each d. The first session started at 0830 h and ended at 1130 h. The second session started at 1330 h and ended at 1630 h. These time periods were selected because cormorants are almost exclusively diurnal (Hatch and Weseloh 1999). During the 3-h sessions each of the three cormorants was sequentially observed continuously for 50 min. The daily sequence of focal observations was varied randomly.

During these observations the duration of primary activities (foraging and loafing), fish species captured, total prey length, and the extent of time needed to manipulate fish for swallowing (handling time) were recorded. Cormorants were considered to be foraging during sequences of diving or slow swimming with the bird's head under water (peering). To obtain more data on the ratio of catfish to shiners captured, observers recorded all fish seen captured by cormorants on test ponds not intensively observed.

We summarized observational data by determining the amount of time that cormorants devoted to foraging and the number of catfish captured during this time. The number of catfish captured per d was determined from the number of catfish captured per h by the total time cormorants spent foraging per d. Total foraging time was estimated by extrapolating the percent of time that cormorants foraged during observations, and the number of daylight hours available for foraging. We summed the observed number of catfish and shiners captured for each cormorant, and compared these data to the number of these fish stocked using Chesson's alpha (α) as a measure of prey selection preference (Chesson 1978). We used a *t* test to compare mean prey handling times and observed prey length between catfish and shiners.

2000 Predation Trial

The 2000 trial was identical to the trial in 1999, with a few exceptions. Fish were stocked in ponds about 1 mo later (9 Feb-

ruary 2000) than in 1999, and inventoried about 3 wk earlier (25 and 26 September). The same total biomass of golden shiners was used per pond half (5 kg); however, shiners were smaller, averaging only 5.9 g/fish or a mean (\pm SEM) of 809.17 ± 37.96 ($N = 6$) fish per pond half. The feeding regimen and water quality monitoring paralleled that used in 1999, but feeding had to be suspended periodically due to repeated disease outbreaks in test ponds. We summarized fish production data in an identical manner and, where appropriate, combined it with the 1999 data and analyzed differences in production using a paired *t* test. Although a different group of test birds was used, the predation treatment was identical and applied during the first 10 d of March. Observation data were collected and summarized in an identical manner and combined and compared with 1999 data using a *t* test.

Results

1998 Predation Trial

There was an inventory shortage of 548 catfish from the pond where six cormorants foraged for 8.5 d, while 837 catfish were missing from the pond where approximately 9.5 cormorants foraged for the same period. In contrast, only 13 fish were missing from the control pond, which was consistent with the negligible disease-related mortality observed on all ponds. Assuming equal disease-related mortality across all ponds, cormorants were estimated to consume 535 and 824 catfish or 10.5 and 10.2 catfish/bird per d. We calculated mean catfish weight at inventory for all ponds using five samples of 50 fish each ($N = 5$). Mean (\pm SEM) fish weight for ponds with six and 9.5 cormorants were 57.9 ± 2.5 and 50.6 ± 3.3 grams, respectively. The mean (\pm SEM) fish weight from the control pond was 41.7 ± 0.7 g ($N = 5$). Assuming that mean fish weights changed little over the 2-wk test period, cormorants were estimated

TABLE 1. Harvest inventory and predation production losses of channel catfish from paired 0.02-ha research pond halves with (Depredated) and without (Protected) cormorant predation simulating 500 cormorant d/ha (one cormorant/0.02-ha pond half for 10 d) that had been initially stocked with 15 to 18 cm fingerlings at a rate of 12,355 catfish/ha (250 catfish/pond half) using a single-batch cropping system. Each pond half was also stocked with 5 kg of 8–10 cm golden shiners to serve as an alternative prey for cormorants. Two repetitions of this study, each involving three enclosed research ponds, were conducted during the growing seasons of 1999 and 2000, but catastrophic disease problems at one pond in the 2000 study precluded analysis.

Year/ pond #	Protected pond half inventory		Depredated pond half inventory		Catfish production losses from predation		
	Number	Biomass (kg)	Number	Biomass (kg)	Number	% (Number)	% (wt/wt)
1999							
1	90	48.0	107	62.3	0	0	0
2	242	116.8	180	95.2	62	25.6	18.5
3	237	114.9	158	83.0	79	33.3	27.8
2000							
1	191	94	110	42.7	81	42.4	54.6
3	146	56.0	45	18.0	101	69.1	67.9

to consume between 516 and 608 g of catfish per d.

1999 and 2000 Predation Study

We calculated mean catfish weight at stocking for all ponds using five samples of 50 fish each ($N = 5$). The weights of catfish stocked in 1999 and 2000 were similar, averaging 37.05 ± 0.43 g and 39.58 ± 1.46 g, respectively. Consistent with the 1998 trial, disease-related fish mortality was mostly negligible during the 1999 study. The exception to this was Pond 1, where 70 and 67 catfish mortalities were recorded in the protected and depredated pond halves, respectively, during an outbreak of Proliferative Gill Disease (PGD) during April and May 1999. Compared to Ponds 2 and 3, the observed mortality and the lack of a predation effect were conspicuous in Pond 1 in 1999 (Table 1). The predation effect in Ponds 2 and 3 averaged 70.5 catfish or about 7 catfish/bird per d (Table 1). This corresponded to an average loss of 29.5% in the number of fish harvested (Table 1). However, the loss in biomass of fish harvested was less, averaging 23.1% (Table 1). This was due to individual fish weights being significantly larger ($t = -2.203$, $N = 199$, $P = 0.029$, and $t = -2.327$, $N = 196$, $P = 0.021$, ponds 2 and 3, respectively) in

depredated versus control pond halves (Table 2). Consistent with larger fish losses in depredated pond halves, the amount of feed fed in depredated pond halves was consistently lower (Table 2).

In contrast to the 1999 study, the incidence of disease was a major factor in the 2000 study. After repeated outbreaks of PGD, *Ichthyophthirius multifiliis*, and *Columnaris Flexibacter columnaris*, resulting in a 90% loss of catfish, Pond 2 was omitted from the study. Observed disease losses were more moderate in Pond 1 and Pond 3 (Table 2). Despite the moderate disease losses, both ponds showed an additional predation effect (Table 1). Inventory shortages due to predation averaged 91 catfish/pond or 9.1 catfish/bird per d. This represented a loss of 36.4% in the number of fish stocked and a 55.7% loss relative to the protected ponds. The loss in total biomass of surviving fish was 61.2%, due to individual fish weights in the depredated pond halves either being significantly ($t = 4.173$, $N = 188$, $P = 0.0001$) lower (Pond 1) or not being different ($t = -0.623$, $N = 169$, $P = 0.5344$, Pond 3) from the protected pond halves (Table 2). Consistent with 1999 data, the amount of feed fed in 2000 was inversely proportional to fish losses (Table 2). For the combined 1999 and 2000 stud-

TABLE 2. Harvested fish weight (g/fish), feed fed, and observed and total losses of channel catfish inventories during 1999 and 2000 growing seasons at paired 0.02-ha research pond halves with and without cormorant predation and stocked with 250 (15–18 cm) fingerlings and 5 kg of variable size golden shiners.

Year/pond #	Depredated half (yes or no)	Grams/fish ($\bar{x} \pm \text{SEM}$)	Feed fed (kg)	Losses	
				Observed	Total
1999					
1A	no	532.9 \pm 16.8	106.33	70	160
1B	yes	582.4 \pm 18.0	86.72	67	143
2C	no	482.8 \pm 11.8	156.99	1	8
2D	yes	529.0 \pm 18.0	139.91	4	70
3E	no	485.0 \pm 11.1	156.44	3	13
3F	yes	525.6 \pm 13.3	126.94	4	92
2000					
1A	no	492.0 \pm 19.5	145.42	24	59
1B	yes	387.7 \pm 15.6	58.98	20	140
3E	no	383.4 \pm 13.6	92.05	56	104
3F	yes	399.4 \pm 19.9	33.86	53	205

ies, there was a significant overall decrease in the number ($t = 2.985$, $N = 5$, $P = 0.020$) and biomass ($t = 2.316$, $N = 5$, $P = 0.041$) of catfish produced at harvest with cormorant predation simulating 500 cormorant d/ha. However, there was no overall increase ($t = -0.481$, $N = 5$, $P = 0.327$) in individual fish weights (g/fish) with predation.

Differences in predation losses at harvest between the 1999 and 2000 studies were revealed from analysis of observational data. During these observations cormorants spent a mean of 9% of their time foraging,

and based on 11.5 h of daylight spent approximately 1 h foraging each d. Based on calculations from observations, cormorants consumed more ($t = -4.7079$, $N = 6$, $P = 0.0093$) catfish/d during 2000 than 1999 which paralleled observed inventory reductions (Table 3). This was consistent with shiners on average comprising 43.6% of the fish seen captured in 1999, compared to only 9.2% in 2000. However, based on availability, Chesson's alpha (\pm SE) revealed no preference for shiners in either 1999 ($N = 3$, $\alpha = 0.41 \pm 0.16$) or 2000 ($N = 3$, $\alpha = 0.03 \pm 0.02$). Despite lack of

TABLE 3. Foraging activity, catfish capture rates, and inventory shortages during 1999 and 2000 predation studies of individual captive double-crested cormorants enclosed over 0.02-ha research pond halves stocked with 12,355 catfish/ha and 5 kg of golden shiners to serve as an alternative prey.

Year/bird #	Time foraging (%)	Time foraging ^a (h)	Foraging rate (catfish/ha)	Foraging rate (catfish/d)	Inventory shortage (catfish/d)
1999					
19	8.5	0.97	6.95	6.77	—
20	11.9	1.37	5.32	7.28	6.2
23	4.8	0.55	20.28	11.10	7.9
2000					
4	11.6	1.33	11.40	15.20	8.1
5	6.5	0.75	14.90	11.14	—
6	10.9	1.25	13.40	16.74	10.1

^a Calculated from the percent of time foraging times 11.5 daylight hours.

preference, shiners were more readily manipulated by cormorants. Handling times for shiners relative to catfish were different ($N = 139$, $t = 8.77$, $P = 0.0001$), averaging only 1.29 ± 0.51 sec for shiners ($N = 44$) and 41.41 ± 4.57 sec for catfish ($N = 95$). Observed prey length was different ($N = 138$, $t = 21.73$, $P = 0.0001$) between prey types, averaging 7.48 ± 1.62 cm for shiners ($N = 44$) and 15.75 ± 2.83 cm for catfish ($N = 94$) in both yr.

Discussion

On an exclusive diet of catfish fingerlings, groups of cormorants consumed only slightly more g of catfish than predicted from bioenergetic modeling (Glahn and Brugger 1995). Several factors may explain these conservative predictions. First, bioenergetic modeling only estimates the fish needed to meet energetic demands, not the maximum that could be consumed. Second, Glahn and Brugger (1995) projected that more fish biomass would be needed in the spring to build fat reserves. Corresponding to this loss in fish biomass was the consumption of slightly in excess of 10 catfish/bird per d, averaging between 51 and 58 g each. The number of fish consumed by cormorants will likely vary with fish size. Schramm et al. (1984) conservatively estimated that the smaller Florida cormorant consumed 19 fingerlings/bird per d, but these fish were smaller, averaging approximately 16 g.

By offering cormorants a choice between catfish and a more easily manipulated prey during the 1999 and 2000 studies, we attempted to more realistically simulate cormorant foraging under field conditions. Captive cormorants in our study spent a similar amount of time foraging as transmitter-equipped cormorants in the field (King et al. 1995), with cormorants in both cases spending about 1 h foraging each d. Additionally, captive cormorants captured between 5.3 and 20.3 catfish/h of foraging, which corresponds to the range of capture

rates reported by Stickley et al. (1992) on commercial catfish ponds.

In 1999–2000, predation-related inventory reductions indicated that cormorants removed from 7 to 9 catfish/bird per d. Based on the average biomass of catfish when stocked, cormorants consumed approximately 260 and 356 g of catfish/d, respectively. Thus, in comparison to the 1998 trial, the utilization of alternative prey appeared to reduce the impact of cormorant predation on catfish (Glahn et al. 1995). However, social facilitation of cormorant groups during the 1998 trial may have increased the intake of catfish per bird.

Although a number of factors may account for the variation in rates of catfish consumption between the 1999 and 2000 studies, the observed difference in diet composition between study years may reasonably account for most of it. The smaller size of shiners in the 2000 study may be responsible for cormorants in our study showing no preference for catfish over a more readily manipulated prey. Glahn et al. (1998) found that cormorants foraging in natural waters appeared to prefer gizzard shad over smaller (6–9 cm) threadfin shad. It is possible that cormorants simply prefer a larger prey, or they may have swallowed some of the smaller shiners underwater therefore underestimating observed predation. Because shiners spawned during this study, we were unable to estimate numbers predated by counting shiners remaining at harvest. Our results are in contrast to observations by Stickley et al. (1992), which suggested that shad was preferred over catfish. Although shad may not be preferred by cormorants, they do comprise over 30% and 40% of the diet of cormorants collected from catfish farms and winter roosts in the delta region of Mississippi, respectively (Glahn et al. 1995). In contrast to the 2000 study, the diet composition and catfish predation rates from the 1999 study may be more representative of expected predation-related catfish losses under field conditions.

Observed predation losses had a variable

effect on catfish biomass at harvest. In the 1999 study, two ponds experiencing negligible disease problems had a 30% loss in the number of fish harvested, but fish harvested from the depredated pond half were larger due to density-dependant factors on growth (Tucker and Robinson 1990). This resulted in only a 23% loss in total fish biomass. In contrast, no predation-related production loss was observed in a third pond experiencing a disease-related loss exceeding 50% of the fish stocked. However, ponds experiencing more modest disease-related losses in the 2000 study had large predation-related production losses. In 2000 the percent loss in biomass either equaled or exceeded the percent loss by number, presumably because stocking density had been decreased from disease mortality. With the exception of ponds suffering large production losses from disease, predation losses at harvest appeared to be additive and paralleled the expected number of fingerlings lost at the time of predation.

Some practical implications can be drawn from this study for single-batch 6-ha commercial ponds stocked at 12,355 fish/ha receiving 3,000 cormorant d of predation (i.e., 30 cormorants foraging for 100 d) over the winter months. Based on the more conservative loss estimates of our 1999 study and assuming golden shiners were suitable surrogates for shad, cormorants foraging on catfish ponds with shad as alternative prey would remove about 30% of fingerlings stocked. This equates to approximately 22,000 fish at a replacement value of approximately \$2,200 (Glahn and Brugger 1995). However, the corresponding 20% biomass production loss at harvest would amount to a loss of 6,800 kg of catfish valued at \$10,500 (assuming \$1.54/kg), or 5 times the value of fingerlings lost. Further economic considerations of these data are discussed in detail by Glahn et al. (in press).

Confinement of cormorants and differences in scale between our research ponds and commercial ponds may have affected

observed predation levels and consequently extrapolation of results to field situations. Despite these factors and the probable moderating effects of alternative prey utilization, we conclude that cormorants can cause significant economic losses to catfish production at harvest. Although these studies provide some preliminary insight regarding possible effects of cormorant predation on yield at harvest, further studies are needed to examine the effects of cormorant social facilitation, alternative prey size and density, different stocking rates of catfish, and multiple-batch cropping of catfish (Tucker et al. 1992; Erwin 1995).

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