CORMORANT DEPREDATION LOSSES AND THEIR PREVENTION AT CATFISH FARMS: ECONOMIC CONSIDERATIONS

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Abstract: Although several piscivorous birds are involved in depredation conflicts with southern aquaculture, the double-crested cormorant causes some of the most widespread and significant problems to catfish, the dominant industry. Unlike other agriculture commodities, catfish losses due to predation cannot be directly measured, so we review several approaches taken to estimate these losses. Although these approaches are valid for predicting the costs of simply replacing these fish at the time of predation, they have been criticized because they failed to consider the functional relationships between predation and output parameters at harvest. Recent controlled experiments are reviewed that confirm previous estimates of predation losses and start to examine output parameters at harvest with and without cormorant predation. In the latter case, enterprise budgets suggested that the 20% production loss observed at harvest from simulating 30 cormorants feeding at a 6-ha catfish pond for 100 days (500 cormorant-days/ha) resulted in a 111% loss of profits. These results confirm previous estimates suggesting that efforts to repel these birds from ponds are well justified and are economically reasonable. We review cost estimates of the most widely used method at catfish farms, "the harassment patrol" and the limitations of this procedure. In addition to the harassment patrol, most Mississippi catfish farmers in recent years have participated in a cormorant roost dispersal program each winter. We review the costs of these programs and the benefits incurred. Although very little attention has been paid to the effect of changes in culturing practices on mitigating predation losses, increasing fish stocking rates is a current trend in the industry. We examine data from research ponds stocked at these high fish densities and relate various levels of observed fish mortality to production at harvest. Assuming that the observed fish mortality was caused by cormorant predation, regression models suggest a higher threshold for cormorant predation impact at these stocking rates.

Key words: aquaculture, channel catfish, depredations, double-crested cormorant, *Ictalurus punctatus, Phalacrocorax auritus,* resource economics, wildlife damage control

The aquaculture industry in the southern United States is primarily devoted to the cultivation of channel catfish *(Ictalurus punctatus).* In fact, catfish production accounted for more than half the value of all aquaculture products in the United States and annual live fish production is valued at approximately US$600 million (U.S. Department of Agriculture 2000). About 92% of all U.S. catfish acreage is located in Alabama, Arkansas, Louisiana and Mississippi, with about 70% of that production occurring in Mississippi (USDA 2000). The growth of the catfish industry in Mississippi has been amazing. The first catfish pond in Mississippi was constructed in 1965 (Wellborn 1987), but the most rapid growth occurred during the 1980s when the industry more than doubled in size (Mott and Brunson 1997). Currently, catfish production in Mississippi involves 360 producers and slightly in excess of 41,000 ha of ponds (USDA 2000). About 90% of these ponds are concentrated in northwest Mississippi. This region comprises 16,000 km² of the Mississippi River alluvial plain and is commonly known as the Mississippi Delta. Catfish ponds are interspersed with cotton, soybean, rice and corn fields in this intensively farmed region. Although much of the Mississippi Delta has been drained for farmland, more than 10% of the original wetland habitat remains. These areas consist of cypress swamps and bayous and provide ideal breeding and wintering habitats for many species, including fish-eating birds.

Catfish cultivation in the Mississippi Delta, as well as cultivation elsewhere, is characterized by large intensive pond systems (Tucker and Robinson 1990). The average Mississippi Delta catfish farm comprises 130 ha, with an average pond size of 6 ha (Mott and Brunson 1997). These ponds are shallow, ranging from 1 to 2 m in depth and stocked with extremely high fish densities, ranging from 10,000 to 250, 000 fish/ha. High densities make these fish highly vulnerable to predation and losses from disease. Three types of ponds are involved in catfish production (Tucker and Robinson 1990). Brood fish ponds hold breeding stock from which eggs are harvested. Eggs are hatched into fry in raceways and then transferred into fingerling/fry ponds. Fingerling ponds are stocked at densities of at least 100,000 fish/ha and fish are raised in these ponds until they reach "stocker" size of 10-20 cm. Stocker size fish are then used to stock food fish or "grow out" ponds.

Food fish ponds comprise about 90% of the ponds in production and are typically stocked at densities between 10,000 and 25,000 fish/ha. Some farmers use a single-batch cropping system, where one group of fingerlings is grown to marketable size (0.5 kg) and then the entire pond is completely harvested. However, most farmers use a multi-crop or "continuous cropping" system that eliminates draining the pond at harvest (Tucker and Robinson 1990). This technique involves repeated seining (3-6 times annually) with a mesh size that captures harvestable size (0.5 kg) fish while allow-

ing smaller fish to pass through (Mott and Brunson 1997). Fish that are removed are replaced immediately with "stocker size" fish. This cropping system has stabilized both flow of fish to processors and cash-flow to producers, but has created a wider distribution of small fish that are vulnerable to predation.

Although a number of piscivorous bird species are involved in depredation problems on catfish, the double-crested cormorant *(Phalacrocorax auritus)* is the species most often cited by catfish producers to be of serious concern (Wywialowski 1999). The increasing conflict between cormorants and the catfish industry have been chronicled through population trends of wintering cormorants in the Mississippi Delta. With the rapid growth of the Mississippi catfish industry in the 1980s came a corresponding increase in the number of cormorants spending the winter in this region (Glahn and Stickley 1995). Prior to 1980 few cormorants probably remained there for the winter (Glahn and Stickley 1995) and historically populations were small (Lewis 1929). However, during the 1980s the number of cormorants during Christmas Bird Counts increased dramatically (Glahn and Stickley 1995, Jackson and Jackson 1995). Since 1990, mid-winter counts of this species doubled from approximately 30,000 birds in 1990, when biologists began conducting roost censuses, to 67,000 birds in 1998 (Glahn et al. 2000a). Increases in these wintering populations are clearly linked to the rapid recovery of the North American breeding populations that have increased over 1000% since 1970 (Dolbeer 1991, Tyson et al. 1999). Cormorants traditionally arrive in the Mississippi Delta in November and depart by mid-April (Aderman and Hill 1995). The wintering birds congregate at night in bald cypress *(Taxodium distichum)* or tupelo gum *(Nyssa aquatica)* trees that are typically over water in oxbow lakes and other naturally occurring wetlands in the Mississippi Delta (Aderman and Hill 1995, Glahn et al. 1996). From a dynamic number of active night roost sites, cormorants travel only about 16 km to forage on catfish ponds (King et al. 1995). Thus, depredations are temporarily highly concentrated on ponds in close proximity to active roost sites, but shifts in roosting activity (King 1996) cause depredations to be a widespread problem. The importance of roost proximity was evident from a 2-year, large-scale food habits study of roosting cormorants in the Mississippi Delta (Glahn et al. 1995). Overall, catfish occurred in 55% of the specimens and comprised about 50% of diet biomass, with the remaining diet being primarily gizzard shad, a ubiquitous forage fish of the Mississippi River drainage that also invades catfish ponds. However, catfish comprised about 75% of the diet of cormorants roosting in close proximity to catfish ponds. While roosting birds distant from the catfish industry had diets composed of only 14% catfish.

We review published and unpublished data that examine the economic impact of cormorants on the catfish industry and the costs and limitations of the most commonly used strategies to prevent or mitigate cormorant depredations on catfish. Considering the industry trend of increasing fish stocking rates, we construct regression models that relate simulated cormorant predation to production at harvest to help define thresholds of cormorant predation on production at these higher fish stocking rates.

ASSESSING CORMORANT DEPREDATION LOSSES

Unlike other agricultural commodities, commercial catfish cropping systems make direct measurement of depredation losses extremely difficult, if not impossible. Widespread losses from other causes, primarily disease, further confound attempts to directly measure losses. Thus, quantifying catfish losses due to cormorant predation has relied on producer surveys, bioenergetic projections, observational extrapolations and most recently, controlled experiments with captive birds on research ponds.

Producer Surveys

Producer surveys and bioenergetic modeling have been widely used to obtain estimates of depredation losses over a large geographic area. In 1988, Stickley and Andrews (1989) surveyed 281 Mississippi catfish farmers and found that 87% believed fish-eating birds to be a problem. Although the researchers did not attempt to quantify losses due to cormorants from this survey, they were able to ascertain that farmers on average were spending US$7,400 annually harassing birds, primarily cormorants, from their ponds. This equated to US$2.1 million spent by all producers. Wywialowski (1999) surveyed catfish producers nationwide about wildlife-caused losses in 1996. In Mississippi, where 77% of the farmers believed cormorants to be a problem, losses to the industry were estimated at US$2.8 million and these producers reported spending US$5.7 million for controlling losses. Although estimates of loss from these surveys may be subjective at best, producers are probably able to provide reasonable estimates of their control costs.

Bioenergetic Modeling

To obtain a more objective estimate of depredation losses, Glahn and Brugger (1995) used data on cormorant populations, diet and other parameters to construct a bioenergetics model of catfish consumed by cormorants wintering in the Mississippi Delta. Based on this model, cormorants were estimated to consume approximately 500 grams of fish/bird/day, resulting

in cormorant depredation losses of approximately 20 million catfish fingerlings per year during the winters of 1989-90 and 1990-91. Based on the replacement value of these fingerlings at the time they were removed by predation, the value of these fish was approximately US$2 million. Based solely on the wintering cormorant population doubling in recent years, Glahn et al. (2000a) used the model to predict that cormorants were currently removing 49 million fingerlings, valued at US$5 million. In both cases, fingerlings, ranging primarily from 10 to 20 cm in length, had an average value of approximately US$0.10 each. Although this value might adequately define the economic loss to catfish producers selling these fish from fingerling ponds, it probably does not define the actual economic loss of this predation from food fish ponds, where the typical value of each fish at harvest is US$1.00 (0.7 kg/fish @ US$1.54/kg), a 10-fold increase. Considering other compensating factors occurring between predation and harvest, more information was needed to relate cormorant predation to food-fish production losses at harvest.

Glahn and Brugger (1995) also grossly estimated the "standing crop" of prey size catfish during these winters and calculated that cormorants might be consuming 4% of the "standing crop." Although current predation losses are probably significantly higher (Glahn et al. 2000a), the percent loss of the "standing crop" may be similar to the previous estimate because of a combination of increased acreage and increased stocking rates. Like most bird damage problems (Besser 1985), cormorants inflict relatively small losses to the catfish industry overall. However, like most bird damage problems, cormorant depredations are not equally distributed, but are concentrated at ponds in close proximity to cormorant roosts (Mott et al. 1992, King et al. 1995). Thus, to study the economic impact of cormorant predation, one must consider localized effects on a pond scale.

Observational Estimates

During the winter of 1989-90, Stickley et al. (1992) studied cormorant predation on 14 catfish ponds in situations where cormorant predation was considered a problem. Because foraging activity of individual cormorants could not be ascertained without marked individuals, procedures involved keeping a running tally of cormorants foraging on the pond and recording the number of fish seen in the bills of cormorants on the entire pond at specified intervals. In addition, data were collected on the time cormorants took to swallow the fish after surfacing with a fish. Although large numbers of individual cormorants used these ponds over time, an average count of approximately 30 birds was recorded on these ponds throughout these observations. Based on these data and the number of catfish caught, Stickley et al. (1992) calculated that on average 5 catfish were

eaten per cormorant-hr of foraging activity. However, these rates were highly variable and ranged from 0 to 28 catfish/cormorant-hr. Considering an average number of approximately 30 cormorants feeding on these ponds throughout an 8-hr day (Stickley et al. 1992), cormorants preying upon catfish at this rate would remove 120,000 catfish in 100 days. Based on simple replacement costs from the bioenergetics model, this would cost the farmer US$12,000.

Captive Cormorant Trials

To further elucidate the impact of cormorants on catfish production, 2 captive cormorant trials were conducted as part of a continuing study (Glahn, unpublished data). In the first trial, 2 groups of 6 and 9 cormorants each were allowed to forage for 8.5 days at each of 2 research ponds stocked with 75,000 fingerling (15 cm) catfish/ha. A third control pond was stocked in an identical manner, but was excluded from cormorants. Based on catfish inventories, corrected for natural mortality at the control pond, cormorants were estimated to consume between 10.2 and 10.5 catfish/bird/day. Based on average weights of these fish at the time of predation, cormorants consumed between 516 g and 608 g of catfish/bird/day. Although these data, helped confirm the daily food demand predicted by the bioenergetics model (Glahn and Brugger 1995), it did not simulate field situations where, at most, catfish make up 75% of the diet. Nor did it consider production at harvest, because inventories were made immediately after predation occurred.

To address these questions, Glahn (unpublished data) split each of three 0.04 ha ponds in half and stocked each pond half with 15-18 cm catfish at a recommended rate of 12,355 fish/ha using a single-batch cropping system (Tucker and Robinson 1990). Ponds were also stocked with an equal biomass of golden shiners (a shad surrogate) to serve as a "buffer prey" and help simulate diet composition of cormorants in the field. After protecting half of each of the 3 ponds with netting, 1 cormorant was allowed to forage from each 0.02-ha unprotected pond half for 10 consecutive days. Cormorant feeding in this study was meant to simulate the average number of cormorants (30) observed by Stickley et al. (1992) on a commercial 6-ha pond for 100 days (500 cormorant-days/ha). Following this predation period in February, fish were maintained in pond halves for 7.5 months using satiation feeding and were completely inventoried when they reached harvestable size in October.

Correcting for mortality from other causes, Glahn (unpublished data) calculated that cormorants preying on both catfish and shiners consumed approximately 7 catfish/bird/day, closely simulating their expected diet composition of catfish in the field. Like individual transmitter-equipped birds in the field (King et al.

1995), captive cormorants spent a relatively small percentage of their day foraging. Thus, this study probably grossly underestimates the extent of cormorant foraging activity observed by Stickley et al. (1992). Cormorant foraging activity in this captive study resulted in a 30% decline in catfish numbers. At a commercial 6-ha pond scale stocked at 12,355/ha this would represent a loss of approximately 22,000 fish at a simple replacement cost of US$2,200.

However, the economics of catfish production is largely a function of the biomass of harvestable fish produced (Tucker et al. 1992). From sampling weights of fish inventoried, Glahn (unpublished data) calculated a 19.6 % biomass production loss from cormorant predation. The difference between the 30% loss in number and the 20% loss in biomass was a function of compensatory growth attributed to lower fish densities where predation occurred. At a commercial pond scale the 20% loss in production would correspond to a loss of 6,800 kg valued at US$10,500 or almost 5 times the value of the fingerlings lost. Assuming this ratio is approximately correct, catfish production losses to Mississippi Delta catfish farmers from cormorant predation may currently approach US$25 million (i.e., 5 times the projections of Glahn et al. [2000a] or 8.6% of all catfish sales in Mississippi [USDA 2000]).

Profit Losses from Predation

To examine the economic effects of cormorant predation on net returns (profits) we used the data from Glahn (unpublished data) in an enterprise budget (Table 1) using standard budgeting techniques for the average 130-ha farm (Engle and Kouka 1996). A 6-ha commercial-scale pond using a single-batch cropping

system stocked at 12,355 fish/ha was the budget unit. The 3 principal variables in these budgets were the amounts of feed fed in pond halves with and without predation, the biomass of fish harvested and harvesting costs with and without predation at the 6-ha pond scale. Other variable costs of production (i.e., labor, supplies, equipment operation maintenance, water-well operation, disease control and interest on capital loans, etc.) were adapted from Engle and Kouka (1996). Ownership costs (Engle and Kouka 1996) were fixed costs related to depreciation, interest on loans, taxes and insurance.

With cormorant predation simulating 500 cormorant-days/ha, the catfish yield at harvest was reduced from 5,795 kg/ha to 4,659 kg/ha, and resulted in a decrease in gross revenue of 20%. However, the cost of feed fed was 15% less, while the costs of harvesting and interest on operating capital were 20% and 7% less, respectively, in the scenario with cormorant predation. Assuming revenues based on a 10-year average sale price of US$1.54/ha (Engle and Kouka 1996), net returns (profits) without predation were US$1189.29/ha, but with cormorant predation, decreased by 111% to -US$132.12/ha (Table 1). Thus, cormorant predation, simulating that previously observed under field conditions (Stickley et al. 1992), might be more devastating to farm profits than one might first suspect. This is because of rather narrow profit margins in the catfish industry (Engle and Kouka 1996).

MITIGATING PREDATION LOSSES

Like most wildlife damage problems, mitigating losses entail employing 1 or a combination of 3 basic strategies: 1) physically separating the wildlife from the

Table 1. Enterprise budget with and without cormorant predation simulating 500 cormorant days/ha for one 6-ha grow-out (food fish) pond using a single-batch cropping system stocked at 12,355 fish/ha. Other variable costs include the cost of fingerlings, labor, management, tractor fuel and maintenance electricity for aeration, well operation, vehicle repairs and maintenance, disease and predation control and office costs and supplies. Ownership costs are annual prorated costs of depreciation, interest on investments, taxes and insurance.

Item	With predation (US$)	Without predation (US$)
Gross Revenue	$43,050	$53,550
Variable costs:		
Feed	$9,906	$11,615
Harvesting	$2,460	$3,060
Interest on capital	$2,082	$2,252
Other variable costs	$15,778	$15,778
Total variable costs	$30,226	$32,705
Income above variable costs	$12,824	$20,845
Ownership costs	$13,626	$13,626
Total costs	$43,852	$46,331
Net return (profits)	-$802	$7,219

resource, 2) managing the wildlife responsible for the damage, and 3) managing the resource being impacted. Here we summarize these basic strategies in the context of reducing cormorant predation losses to the catfish industry.

Although the surest way to prevent cormorant predation on catfish would be to exclude the ponds with netting or overhead wires, the practical design of such systems to encompass a >6-ha catfish pond has not been devised (May and Bodenchuk 1992, Littauer et al. 1997). Largely, this is because existing levee systems of catfish farms are too narrow to accommodate supporting structures needed to span long distances. Likewise, many catfish farmers find them impractical due to their interference with multiple pond harvests per year (Mott and Brunson 1997). However, the biggest constraint on such systems is cost. In 1997, the cost of both material and labor to construct an exclusion system over a 40-ha farm was estimated at US$1 million (Littauer et al. 1997).

Frightening and Lethal Control Strategies

Due to the practical limitation of exclusion techniques, cormorant predation control has focused almost exclusively on frightening strategies, reinforced with lethal control (Wywialowski 1999). Despite the widespread use of frightening strategies, very little is known about the overall effectiveness of the typical "harassment patrol" for reducing cormorant predation (Stickley and Andrews 1989). However, Stickley and King (unpublished report) did observe a short-term >90% reduction in cormorant use of ponds when human effigies, periodically replaced by shooters, were used to supplement harassment patrols. However, cormorants can quickly return to ponds after being harassed or simply move from pond to pond on the same complex, negating efforts to reduce predation (Reinhold and Sloan 1999). A typical frightening program at a large (200-ha) farm with high cormorant pressure could require continuous harassment by 1 or more personnel driving pond levees and would cost almost US$20,000 annually (Littauer et al. 1997). This is consistent with Wywialowski (1999) reporting that Mississippi catfish producers on average spent almost US$9,000/year for wildlife damage control and that these control costs varied with catfish sales. Considering cormorant predation losses estimated from observations, Stickley et al. (1992) concluded that these efforts to repel cormorants were well justified and economically reasonable based on replacement costs alone. Assuming harassment patrols are effective in reducing predation, our economic analysis confirms this conclusion. However, the effectiveness of this procedure is likely to vary greatly and cormorants are reported to habituate to this harassment (Reinhold and Sloan 1999).

To reinforce harassment patrols, limited killing of birds has been often recommended (Hess 1994, Mastrangelo et al.1995, Littauer et al.1997). Although the take of cormorants was previously limited under depredation permits issued by the U.S. Fish and Wildlife Service, catfish farmers are now allowed to shoot an unlimited number of cormorants at their farms under a depredation order issued by the U.S. Fish and Wildlife Service in March 1998 (U.S. Fish and Wildlife Service 1998). Limited information exists as to the effectiveness of lethal shooting in reducing depredations. However, Hess (1994) evaluated the unlimited take of cormorants at several catfish farms and found that only 290 cormorants were killed in over 3,000 person-hours of shooting by farmers. He attributed the low rate of kill to cormorants learning to avoid being shot and reported that fewer cormorants attempted to use pond complexes where shooting was deployed. Although cost-effectiveness varied among pond complexes, Hess (1994) felt that such procedures might be cost-effective in situations where there were large numbers of cormorants in the vicinity of these ponds.

To help reduce the number of cormorants in the vicinity of catfish ponds, Mott et al. (1992) initiated preliminary trials of night roost harassment procedures. They found that cormorants were easily dispersed from roosts after several evenings of harassment with pyrotechnics. This resulted in a significant reduction of cormorants either foraging on ponds or loafing in the vicinity of these roosts. This reduction of cormorants on ponds and day roosts ranged from 75% to 90% and was attributed to cormorants changing their foraging activity patterns after being relocated. However, localized movements among roosting locations suggested that all roosts would have to be harassed simultaneously for depredations in the area to be reduced overall.

In conjunction with Wildlife Services personnel and catfish farmers in the Mississippi Delta, Mott et al. (1998) coordinated the dispersal of roosting cormorants over a large geographic area where catfish ponds and cormorants were concentrated. The results of this 2-year study indicated that cormorants shifted their roosting activity away from the intensely harassed area to locations along the Mississippi River, where they are less likely to forage on catfish (Glahn et al. 1995). In response to this shift in roosting populations, cormorants in the vicinity of catfish ponds were reduced by approximately 70%, compared to a previous winter without intensive harassment (Mott et al. 1998). Based on the costs of pyrotechnics and labor, the total costs of these programs were calculated to be US$16,757 and US$32,302 during the winters of 1993-94 and 1994-95, respectively. However, the average cost to each participating catfish producer was only US$419 and US$557 during the 2 winters, respectively. Although the savings

to producers from reduced cormorant predation was not estimated, producers in the intensely harassed area reported spending less on harassment patrols, resulting in average annual savings during the winters of 1993-94 and 1994-95 of US$1,406 and US$3,217, respectively.

Possibly due to this cost-effectiveness, cormorant roost dispersal programs have continued to be carried out by Wildlife Services and catfish farmers in the Mississippi Delta, and to a lesser extent elsewhere (Glahn et al. 2000a). Although recent studies show that these programs continue to have the desired effect of shifting cormorants away from areas of highest catfish concentration in Mississippi, these effects are temporary at best (Glahn et al. 2000a). Logistic limitations of this procedure in damage reduction have been further exacerbated by doubling of the wintering population in recent years and a similar increase in the number of known roost sites (Glahn et al. 2000a). This has resulted in increased costs of implementing this program to maintain cormorant numbers in the protected area at levels equaling those recorded before the start of roost harassment efforts (Glahn et al. 2000a).

Population Management

Because of the negative effects of increasing cormorant populations and the limited efficacy of present damage management efforts, proposed strategies to manage these conflicts have focused on reducing cormorant populations to biologically and socially acceptable levels (Reinhold and Sloan 1999, Glahn et al. 2000b). To these ends, USDA-Wildlife Services has been working cooperatively with the U.S. Fish and Wildlife Service in developing the management alternatives of an Environmental Impact Statement and a national management plan to address conflicts caused by increasing cormorant populations. Ultimately, the results of such a management program should be assessed from the standpoint of resource economics (Werner 2000). However, little is known about the costs of such a program or what might be considered economically acceptable population levels.

Catfish Culturing Practices

With the emphasis of alleviating depredations focused largely on managing either cormorant populations or their distribution, little attention has been paid to the effects of catfish culturing practices on mitigating predation losses. However, a number of possible alternatives have been proposed by several authors (Barlow and Bock 1984, Moerbeek et al. 1987, Mott and Boyd 1995). These include reducing pond size, delaying stocking and reducing stocking rates. Although implementation is seemingly thwarted by tradition, such strategies may be simply flawed based on economic risk assessment. For example, reducing pond size would

facilitate the installation of bird exclusion systems, but pond construction cost, a major capital expenditure, increases as pond size decreases (Garrard et al. 1990). Although new ponds being built have decreased slightly in size from 6 ha to 4.8 ha (Hanson, unpublished report), there is no information to suggest that these might be small enough to make exclusion practical. Delaying stocking of fingerlings until late spring after cormorants leave is also often suggested (Glahn et al. 1995, Mott and Boyd 1995, Mott and Brunson 1997). However, delaying stocking is not compatible with the multi-batch cropping system and may increase the risk of more devastating stress-related disease outbreaks that are prevalent at water temperatures later in the spring.

Although reducing stocking rates of fingerlings would seemingly reduce predator efficiency (Barlow and Bock 1984), it is counterintuitive to improving net returns. Engle and Kouka (1996) suggest that due to inflation pressures on the costs of catfish production, yields must be increased to counteract flat catfish pricing. To increase yields the trend in the industry is to increase stocking rates (CEAH 1997), because the costs of fingerlings has remained relatively inexpensive (Engle and Kouka 1996). This increase in stocking rates (up to 25,000 fish/ha) has come despite research suggesting that increased stocking did not necessarily result in an increase in net returns (Tucker et al. 1992). Although the increase in stocking rates, feeding rates and improved pond aeration have increased yields, this more intensive culture has intensified problems from disease and bird depredations (Engle and Kouka 1996).

Stocking Rates and Thresholds of Predation

To examine the possible effects of cormorant predation at higher stocking rates we adapted research pond production data (Hanson and Li, unpublished

$$y = -0.00014x^2 - 1.39477x + 5849.92717$$
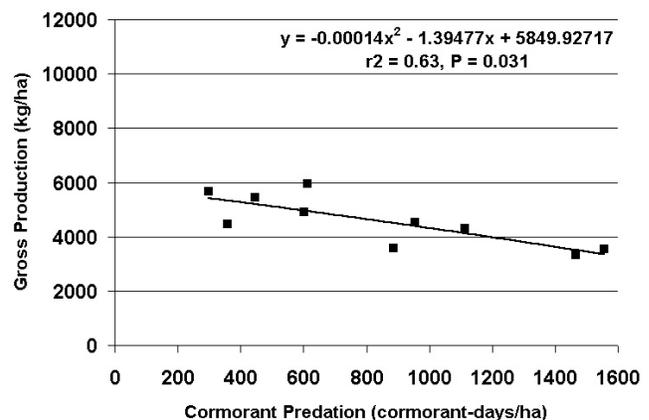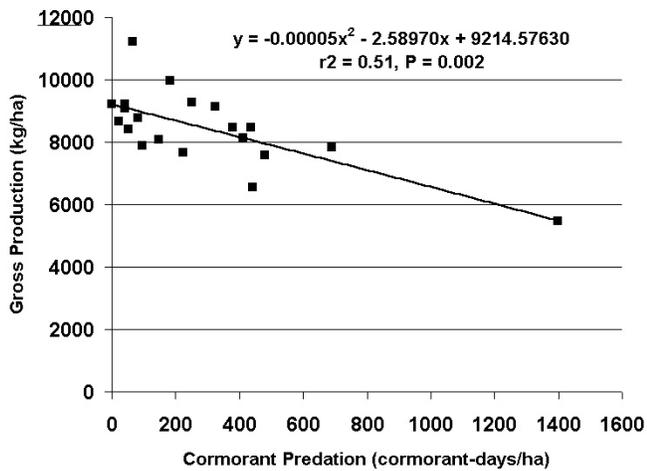$$r2 = 0.63, P = 0.031$$

Fig. 1. The relationship between simulated cormorant predation (cormorant-days/ha) and gross catfish production (kg/ha) at research ponds stocked with 18,500 fish/ha (Hanson and Li unpublished data). Cormorant-days/ha were calculated from observed mortalities assuming that cormorants remove 7 catfish/bird/day.

$$y = -0.00005x^2 - 2.58970x + 9214.57630$$
$$r^2 = 0.51, P = 0.002$$

Fig. 2. The relationship between simulated cormorant predation (cormorant-days/ha) and gross catfish production (kg/ha) at research ponds stocked with 25,000 fish/ha (Hanson and Li unpublished data). Cormorant-days/ha were calculated from observed mortalities assuming that cormorants remove 7 catfish/bird/day.

data) from nutrition studies where a range of recorded fingerling mortalities occurred. During these studies, catfish were stocked in a series of 0.04-ha ponds at either 18,500 fish/ha or 25,000 fish/ha and inventoried at the end of the growing season. To adapt these data, we assumed that cormorants were responsible for all observed fingerling mortalities recorded. However, observed mortality reflects only a variable percentage of the total fish unaccounted for at inventory (Tucker et al. 1992). Mortalities unaccounted for occur from some dead catfish sinking to the bottom of the pond or from some being scavenged by predators. Assuming that cormorants foraging at these ponds consumed 7 catfish fingerlings/bird/day (Glahn, unpublished data), we derived the number of cormorant-days/ha that these catfish mortalities might represent. We then regressed these data against catfish production (kg/ha) reported for these ponds in polynomial models that best fit the data (Figs.1 and 2).

The gentle slope of the relationship between simulated cormorant predation and gross catfish production suggests that cormorant predation must reach a certain threshold before there are any significant effects on production (Figs. 1 and 2). Factors contributing to this are varying degrees of unaccounted for fish mortality (Tucker et. al. 1992) and compensatory growth of surviving fish (Glahn, unpublished data). In fact at these stocking rates, production does not appear to be substantially reduced until predation exceeded 500 cormorant-days/ha. This is not surprising since at higher stocking rates there would be a smaller percent loss of fish at comparable levels of predation. Based on differences in model predictions between zero and 500 cormorant-days/ha, gross production yields were

reduced by 11% and 14% at stocking rates of 18,500 fish/ha and 25,000 fish/ha, respectively. Although further data are needed to refine these models, the present data suggests that cormorant predation would continue to affect production at higher stocking rates, but either to a lesser degree or not until predation reached a higher threshold of cormorant activity. Considering the growth of cormorant populations in catfish production areas, this level of cormorant activity might well be exceeded, but further research is needed to document present cormorant activity patterns on catfish ponds. Thus, higher stocking rates alone may not be enough to mitigate the effects of cormorant predation on catfish production. Moreover, higher stocking rates increase production costs and the risk of fish mortality from disease and water quality problems (Tucker et al. 1992, Engle and Kouka 1996). However, efforts to manage cormorant populations on ponds below thresholds of predation at these stocking rates may mitigate production losses due to predation.

ACKNOWLEDGMENTS

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