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The Impact of Double-crested Cormorants on the Mississippi Delta Catfish Industry: A Bioenergetics Model

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Abstract.—A bioenergetics model was constructed and evaluated for estimating Double-crested Cormorant (*Phalacrocorax auritus*) energy expenditures, food demand and impact on the Channel Catfish (*Ictalurus punctatus*) industry in the Delta region of Mississippi. Large body mass (mean = 2.27 kg) and higher basal metabolism (115% to 128% of predicted) resulted in an average predicted food demand of 504 g/bird/day (range: 449 to 551) from November to March or 22% of body mass. Factoring in population sizes and proportional intake of catfish, Double-crested Cormorants may have eaten up to 20 million catfish per winter in 1989-90 and 1990-91 or approximately 4% of the estimated standing crop at a replacement cost of \$2 million (US\$) annually. More than 50% of catfish losses were projected to occur in February and March; negligible losses occurred in November.

Key words.—Aquaculture, bioenergetics, catfish, Channel Catfish, Double-crested Cormorant, foraging, *Ictalurus punctatus*, Mississippi, *Phalacrocorax auritus*, predation.

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Aquaculture farming has grown tremendously in the last 20 years in the southern states. This is particularly true of Channel Catfish (*Ictalurus punctatus*) farming in the Mississippi Delta. Following construction of the first catfish pond in 1965, the catfish industry grew rapidly (Wellborn 1987) and presently exceeds 40,000 ha (Brunson 1991). With the growth of this industry has come increasing complaints about predation by fish-eating birds on aquaculture stocks. For example, 87% of the Mississippi Delta catfish growers questioned about bird damage indicated they had a bird problem (Stickley and Andrews 1989). Although several species of birds including herons and egrets are involved in the damage problems, Double-crested Cormorants (*Phalacrocorax auritus*), based on their numbers and fishing abilities, are perceived to be the greatest threat to the catfish industry (Mississippi Cooperative Extension Service 1986). During the 1970s and early 1980s the North American interior populations of cormorants have grown at an annual rate of 25.5% in response to reductions in nest destruction, egg collecting and organochlorine contamina-

tion (Dolbeer 1990). Increasing numbers of this population are wintering in the Mississippi Delta and in 1988-89 U.S. Department of Agriculture - Animal Damage Control (USDA-ADC) estimated a minimum of 35,000 cormorants at 13 roost sites in this area of intensive catfish production (Stickley and Andrews 1989).

Although damage in the Mississippi Delta by cormorants has been estimated at \$3.3US million (Stickley and Andrews 1989), other lines of evidence were needed to validate this rough estimate. Direct damage assessment proved inadequate, because of the large geographic area covered by the catfish industry (approximately 16,000 km²) and the high variability reported in cormorant predation among ponds (Hodges 1989).

One approach to estimating crop loss in a large agricultural system is to mathematically model the energy flow between prey and predator (Weatherhead *et al.* 1982). This bioenergetic modelling approach has previously been applied to assess the impact of various cormorant species on marine and inland fisheries (Bayer 1989, Berry 1976, Cummings 1987, Winkler 1983). Preliminary

models and empirical observations have established a range of estimates for daily food demand of cormorants. Results of feeding studies have suggested that free-living *P. a. auritus* would consume from 20% to 25% of their body weight in fish daily (Wetmore 1927, Dunn 1975). Schramm *et al.* (1984) estimated the feeding rate of the smaller (mass = 1.5 to 1.8 kg) *P. a. floridanus* subspecies at 305 g of catfish/day. Another feeding study with this same subspecies indicated a mean daily food demand of 335 g/bird/day or 22.8% of body mass (Cummings 1987). Using allometric equations to predict existence metabolism and free living energy to be 1.5 times existence metabolism, Schramm *et al.* (1987) predicted that the *floridanus* subspecies would consume 247 g of fish/day.

The objective of the current study was to use bioenergetic modelling to refine past estimates of daily food demand of wintering Double-crested Cormorants and their impact on the Mississippi Delta catfish industry. This was accomplished using recent literature sources and site-specific data on wintering populations, food habits, daily activity budgets and digestion efficiencies.

MODEL CONSTRUCTION AND COMPONENTS

We constructed a 3-part model to estimate individual energy demands, population energy demands and catfish crop losses per month during two wintering periods: November to April 1989-90 and November to April 1990-91. We identified a number of parameters that were necessary to the model (Fig. 1). We calculated monthly averages for all of these, except for daily activity budgets and digestion efficiencies. A SAS computer program (SAS Institute 1987) was used to integrate data bases and perform calculations. We calculated the monthly Daily Energy Budget (DEB) with the following equation:

$$\text{DEB} = \text{BMR} + \text{thermoregulation} + \text{sum of energy costs for activity} \quad (1)$$

We partitioned the basal metabolic rate (BMR) into active (day) and inactive (night) phases (Aschoff and Pohl 1970). We used the following equation to predict the total energy required to support BMR:

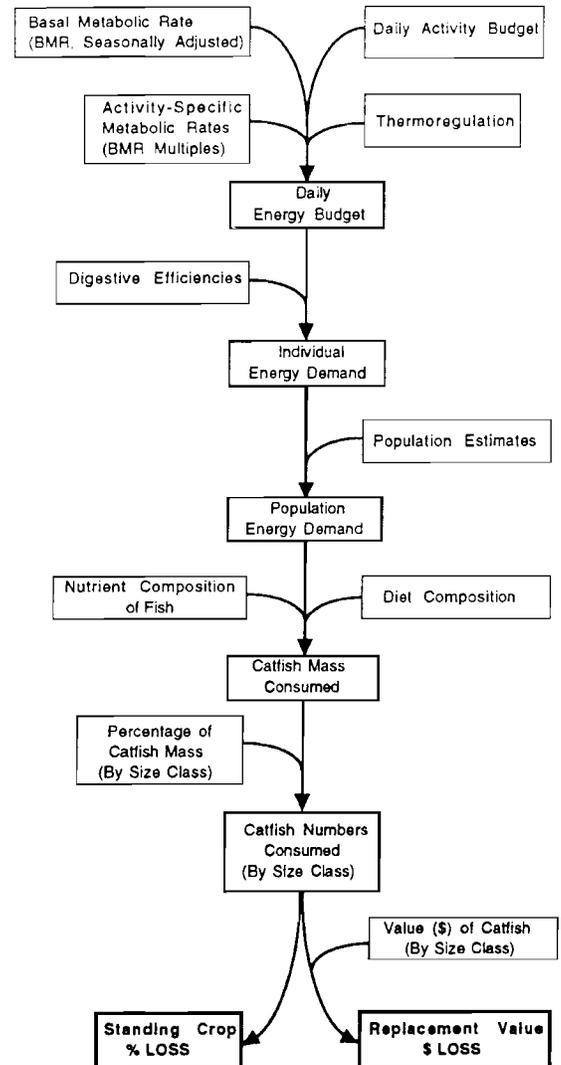


Figure 1. Flow chart of a bioenergetics model to project the daily energy budget and food demand of wintering Double-crested Cormorant populations and their impact on the catfish industry in the Delta region of Mississippi.

$$\text{BMR}_{\text{Tot}} = (\text{VO}_2) (\text{body mass}) (\text{hours in day}) (\text{energy in O}_2) \quad (2)$$

We calculated the average monthly volume of oxygen (VO_2) for cormorants with equations of Aschoff and Pohl (1970) based on mean monthly body mass of cormorants collected for food habits (Glahn *et al.* 1995) during 1989-90 and 1990-91 combined (Table 1). We increased the active phase VO_2 by 15% and the inactive phase VO_2 by 28% to align the values with empirical data on *P. a. floridanus* (Hennemann 1983; B. K. McNab, pers. comm.) Thus, daytime $\text{VO}_2 = 0.73 \text{ mL}$

Table 1. Monthly input parameters and calculated output of Basal Metabolic Rate (BMR) and energy expenditures for thermoregulation (THERMKJ) for individual Double-crested Cormorants wintering in the Mississippi Delta during the winters of 1989-90 and 1990-91.

| Year and month | Body mass ¹ (g) | Mean Temperatures | | Daylight (hours) | Night (hours) | BMR ² (kJ/day) | THERMKJ ³ (kJ/day) |
|-----------------|-------------------------------|-------------------|---------------|---------------------|------------------|------------------------------|----------------------------------|
| | | Day (°C) | Night (°C) | | | | |
| <u>1989-90:</u> | | | | | | | |
| November | 2,098 | 13.9 | 7.7 | 10.0 | 14.0 | 689 | 238 |
| December | 2,266 | 3.5 | -2.2 | 9.0 | 15.0 | 724 | 587 |
| January | 2,240 | 10.3 | 5.7 | 9.5 | 14.5 | 720 | 349 |
| February | 2,314 | 12.5 | 6.8 | 10.5 | 13.5 | 742 | 315 |
| March | 2,262 | 13.7 | 9.3 | 12.0 | 12.0 | 736 | 243 |
| April | 2,442 | 17.1 | 11.2 | 13.5 | 10.5 | 786 | 190 |
| <u>1990-91:</u> | | | | | | | |
| November | 2,098 | 14.5 | 7.9 | 10.0 | 14.0 | 689 | 229 |
| December | 2,266 | 10.0 | 4.3 | 9.0 | 15.0 | 724 | 386 |
| January | 2,240 | 6.2 | 2.2 | 9.5 | 14.5 | 720 | 463 |
| February | 2,314 | 10.1 | 5.0 | 10.5 | 13.5 | 742 | 381 |
| March | 2,262 | 14.4 | 8.4 | 12.0 | 12.0 | 736 | 247 |
| April | 2,442 | 19.9 | 15.4 | 13.5 | 10.5 | 786 | 76 |

¹Monthly means from both years of food habits study (Glahn *et al.* 1995).

²Based on an equation from Aschoff and Pohl (1970) and adjusted for a 115% increase during active phase (Daylight) and 128% increase during inactive phase (Night) (Hennemann 1983).

³Based on the equation from Hennemann (1983): THERMKJ = (1.34 - 0.0281 × Day temp) × (Body mass) × 0.01979 × Day hrs - Day BMR + (1.14 - 0.0290 × Day temp) × (Body mass) × 0.01979 × Night hrs - Night BMR.

O₂/g/h and nighttime VO₂ = 0.64 mL O₂/g/h. The mean number of hours in the day or night varied monthly (Table 1). The energy equivalent of oxygen was 0.01979 kJ/mL O₂ (Schmidt-Nielson 1983).

We calculated the additional energy beyond BMR that was required for thermoregulation during the day (DTHERMKJ) and night (NTHERMKJ) with variations on regressions obtained for smaller (1.33 kg) cormorants (Hennemann 1983). We assumed that the slope of the relationship and the lower critical temperatures for active and inactive phases would remain the same. However, we reasoned that as body mass increased and mass-specific BMR declined, the intercept would vary. We calculated the adjusted intercepts for each month and found that they varied <2.3%, and so we used the following average intercepts:

$$\begin{aligned} \text{DTHERMKJ} = & (1.34 - 0.0281 * ^\circ\text{C}) \\ & (\text{body mass}) (\text{energy in O}_2) \\ & (\text{hours in day}) - \text{BMR}_{\text{day}} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{NTHERMKJ} = & (1.14 - 0.0290 * ^\circ\text{C}) \\ & (\text{body mass}) (\text{energy in O}_2) \end{aligned}$$

$$(\text{hours in night}) - \text{BMR}_{\text{night}} \quad (4)$$

We substituted monthly means for temperature (°C) and length of day or night (Table 1). We corrected for previous inclusion of BMR in the regression equations by subtraction.

We included in the model five activities and their time budgets discerned from radio telemetry data of free-living Double-crested Cormorants wintering in the Mississippi Delta (King *et al.* 1995): flying, diving, swimming, resting during the day, and resting during the night (Table 2). We estimated the energetic costs of these activities in units of BMR multiples from published values for other species owing to the absence of suitable data for cormorants (Table 2). To translate DEB into Daily Energy Demand (DED) we divided DEB by the average metabolic energy coefficient (79%) of Double-crested Cormorants fed diets of catfish and Gizzard Shad (*Dorosoma cepedianum*) (Brugger 1993).

We multiplied the monthly estimates of DED for individuals by mean monthly population estimates of Double-crested Cormo-

Table 2. Energy expenditure expressed as a multiple of basal metabolic rate (BMR) and daily activity budgets of Double-crested Cormorants wintering in the Delta region of Mississippi. Sources of the BMR multiples are published in these citations on other species.

| Day or night | Activity | % of day or night ¹ | BMR multiple | Source |
|--------------|----------|--------------------------------|--------------|-----------------------------------|
| Day | Flight | 8.5 | 7 | Masman and Klaassen (1987) |
| Day | Dive | 3.5 | 7 | Birt-Friesen <i>et al.</i> (1989) |
| Day | Swim | 24.0 | 3.5 | Prange and Schmidt-Nielson (1970) |
| Day | Resting | 64.0 | 2 | Bernstein and Maxson (1985) |
| Night | Resting | 100 | 1.5 | Bernstein and Maxson (1985) |

¹Based on data from King *et al.* 1995.

rants wintering in the Mississippi Delta (Aderman and Hill 1995) to obtain an estimate of monthly population energy demands. Each monthly population, estimated at the beginning of each month, was averaged with that of the subsequent month to obtain the average population for that month.

To transform the monthly energy demand of the cormorant population into the monthly populations of fish consumed required the following information: (1) the percent biomass of the diet of major fish groups consumed; (2) the percent of the diet by size class and number of fish by weight in that size class; and (3) the energy (kJ) content in each fish group. The monthly cormorant diet for the winters of 1989-90 and 1990-91 and distribution of the diet by size class (Glahn *et al.* 1995) were used to satisfy the first two data requirements. Data from Brugger (1993) were used to satisfy the last requirement. Because diet varied between two general locations of roosting areas, diet was weighted proportionally to roosting populations in these areas. Percent of the diet by fish type (catfish, shad, bream, other) was multiplied by energy content of each fish type to determine the portion of the monthly population energy demand attributed to each fish type. The total biomass of each fish type consumed monthly was then calculated by dividing these energy demands by energy content per gram of fish by type. We then calculated catfish numbers consumed by multiplying the percentage of catfish consumed in each of 12 commercial size classes times the number per unit weight in that size class (Wellborn 1987) by the total monthly biomass of catfish consumed.

To assess the economic impact of Double-crested Cormorant predation, two economic parameters about the Mississippi Delta catfish industry were included in the model. These included the cost of replacement for catfish consumed by commercial size class and the "standing crop" of stocker size catfish (i.e., 10 to 20 cm length) that are the typical prey of cormorants (Glahn *et al.* 1995). The calculation of replacement cost assumed \$20US per thousand fish plus a variable cost of \$0.0049 to \$0.0069/cm times the size (5 through 28 cm) of 12 commercial size classes in 2.54 cm increments (J. E. Waldrop, pers. comm.). Larger fish (≥ 28 cm) were based on the number/kg times \$1.54/kg. Replacement cost was used because it provided a realistic commercial value of the fish at the time it was removed by cormorants without us needing to assume that the fish survived to harvest.

The "standing crop" of catfish in the size classes most often preyed upon by cormorants (10 to 23 cm) (Glahn *et al.* 1995) was difficult to identify. Agricultural statistics (USDA 1992) indicated that there were 157 million small stockers (15 to 23 cm size) and 599 million fingerling (<15 cm) in grower inventories as of January 1991. However, the number of fingerlings > 7 cm or exposed in ponds to cormorant predation was unknown. To calculate an estimate of the total "standing crop" vulnerable to cormorant predation, we used the total area of catfish ponds stocked in the Mississippi Delta (c. 32,000 ha) times the average stocking rate of 12,350 fish/ha (M. W. Brunson, pers. comm.) for all months except March and April. Because these latter months are the height of the stocking season (USDA 1992),

we increased the stocking rate of ponds by 50% or 18,525 catfish/ha (based on the proportional higher stocking rate for March and April; see USDA 1992). This resulted in "standing crops" of catfish vulnerable to predation of 395 million catfish from November through February and 592.5 million catfish in March and April.

BIOENERGETIC OUTPUT

Our adjustment to allometric equations suggested by Hennemann (1983) resulted in an estimated average BMR of 732.7 kJ/bird/day that ranged from 689 kJ/bird/day in November to 786 kJ/bird/day in April (Table 1). Monthly changes in BMR were due to monthly changes in average body mass of 2,270 g ranging from 2,098 in November to 2,442 g in April (Table 1).

The average daily energy budget (DEB) among months and years was 1926.7 kJ/bird/day and ranged from 1,716 kJ/bird/day in November 1989 to 2105 kJ/bird/day in December, 1989 (Table 3). The average DEB in 1989-90 of 1,938.5 kJ/bird/day was similar to 1,914.9 kJ/bird/day estimated in 1990-91, despite the unusually cold December in 1989. The ratios of DEB:BMR ranged from 2.5 to 2.9 among months (Table 3). Based on an 79% digestive efficiency and the average energy content of fish consumed at

4.84 kJ/g (Brugger 1993), the average daily fish consumption by individual cormorants was approximately 504 (± 25) g fresh fish/bird/day and varied with DEB among months (Table 3). Daily fish intake of these wintering birds averaged 22.2% of their body mass each month (Table 3).

IMPACT ON CATFISH PRODUCTION

Monthly Cormorant populations varied from approximately 7,000 to 27,000 birds and peaked in either February or March each year. Percent catfish in the diet also varied monthly from 0 to 97%. Diet showed a trend similar to populations with low catfish consumption in fall and peak catfish consumption in February, March and April. Owing to these two factors, the largest amount of catfish was consumed in February and March, and in both years more than half of the total catfish was consumed in these two months (Table 4). Over the years 1989-90 and 1990-91, consumption of catfish from November through April was estimated at 939 and 842 metric tons of catfish, respectively (Table 4). Size classes of catfish consumed were primarily in the range of 10 to 20 cm (Glahn *et al.* 1995). Based on percentages by weight of the size classes consumed and their numbers per unit weight, catfish biomass was equated to approximately 20

Table 3. Monthly estimates calculated from a bioenergetics model of individual energy demand (daily energy budget, [DEB]), food consumption, and ratios of DEB:BMR and fish intake: body mass of Double-crested Cormorants in the Mississippi Delta during the winters of 1989-90 and 1990-91.

| Year and month | DEB (kJ/bird-day) | DEB:BMR (ratio) | Fish consumption (g/bird-day) | Fish intake: body mass (%) |
|-----------------|----------------------|--------------------|----------------------------------|-------------------------------|
| <u>1989-90:</u> | | | | |
| November | 1,726 | 2.2 | 451 | 21.5 |
| December | 2,106 | 2.9 | 551 | 24.3 |
| January | 1,882 | 2.6 | 492 | 22.0 |
| February | 1,940 | 2.7 | 508 | 22.0 |
| March | 1,924 | 2.6 | 503 | 22.2 |
| April | 2,053 | 2.6 | 537 | 22.0 |
| <u>1990-91</u> | | | | |
| November | 1,716 | 2.5 | 448 | 21.3 |
| December | 1,904 | 2.6 | 498 | 21.9 |
| January | 1,996 | 2.8 | 521 | 23.3 |
| February | 2,006 | 2.7 | 525 | 22.7 |
| March | 1,927 | 2.6 | 504 | 22.3 |
| April | 1,940 | 2.5 | 507 | 20.8 |

Table 4. Monthly projected catfish losses due to Double-crested Cormorant predation in the Mississippi Delta during the winters of 1989-90 and 1990-91 in relation to changes in cormorant populations and diet.

| Year and month | Cormorant populations ¹ | % Diet catfish ² | Catfish consumed (tons) | No. catfish consumed (millions) | Percent consumed ³ | Replacement cost (\$ × 10 ³) |
|-----------------|------------------------------------|-----------------------------|-------------------------|---------------------------------|-------------------------------|--|
| <u>1989-90:</u> | | | | | | |
| November | 9,622 | 12.9 | 17.2 | 4 | 0.1 | 37.5 |
| December | 13,678 | 0 | 0 | 0 | 0 | 0 |
| January | 7,374 | 55.0 | 63.2 | 1.4 | 0.3 | 137.9 |
| February | 21,883 | 80.0 | 252.6 | 5.4 | 1.4 | 551.3 |
| March | 27,114 | 96.8 | 416.2 | 8.9 | 1.5 | 908.5 |
| April | 12,716 | 91.6 | 189.7 | 4.1 | 0.7 | 414.2 |
| Annual totals: | | | 938.9 | 20.2 | 4.0 | 2,049.4 |
| <u>1990-91:</u> | | | | | | |
| November | 9,834 | 1.0 | 1.4 | <0.1 | <0.1 | 3.0 |
| December | 17,547 | 45.8 | 125.2 | 2.7 | 0.6 | 273.4 |
| January | 22,087 | 55.4 | 199.5 | 4.3 | 1.1 | 435.3 |
| February | 23,914 | 58.5 | 212.8 | 4.6 | 1.2 | 464.4 |
| March | 20,732 | 77.4 | 254.1 | 5.4 | 1.0 | 554.6 |
| April | 6,912 | 45.5 | 48.6 | 1.0 | 0.1 | 106.2 |
| Annual totals: | | | 841.6 | 18.0 | 4.0 | 1,836.9 |

¹Based on adjusted mean population size (birds) from Aderman and Hill (1995).

²Based on weighted diet from Glahn *et al.* (1995).

³Based on estimated catfish "standing crops" of 395 million fish for the months November through February and 592.5 million fish for the months March and April.

and 18 million catfish consumed per year, respectively (Table 4). These catfish numbers corresponded to approximately 4% of the estimated catfish standing crop each year (Table 4). Based on catfish numbers consumed and the cost of replacement of these fish, annual losses to the catfish industry were predicted at \$2.0 million and \$1.8 million (US\$) during 1989-90 and 1990-91, respectively (Table 4).

DISCUSSION

Our estimate of BMR for *P. a. auritus* is based on empirical data on *P. a. floridanus* (Hennemann 1983) which suggests metabolic rates that are 115% during the active phase and 128% during the inactive phase of that predicted by allometric equations (Aschoff and Pohl 1970). Higher than predicted metabolic rates has also been reported for Blue-eyed Shags (*Phalacrocorax atriceps*) (Bernstein and Maxson 1985). Monthly changes in average body mass of birds was accounted for in the model by varying BMR with body mass among months. This build up of body fat from November

through April in preparation for migration is an important factor in increasing energy demand (Kendeigh *et al.* 1977). Our monthly DEB estimates varied with body mass and temperature and were in range of the estimate of 2,072 kJ/bird/day suggested for breeding *P. a. auritus* in Maine (Dunn 1975). Our ratios of DEB:BMR also varied with body weight and temperature and fell within the range of the 2 to 3 suggested by Guillet and Furness (1985). Although large differences in average body mass between subspecies of Double-crested Cormorants tends to confound comparisons of energy and food demand, our predicted average monthly fish intake (504 g) was only slightly in excess of the maximum daily food intake (420 to 503 g) reported in cage trials with smaller birds of unknown subspecies (Wetmore 1927, Brugger 1993). Our estimate of percent food intake relative to body mass was similar to the range of percent food intake (20 to 27%) previously reported for various subspecies of Double-crested Cormorants (Wetmore 1927, Dunn 1975, Schramm *et al.* 1984, Cummings 1987, Brugger 1993). As reviewed by Dunn

(1975) and Berry (1976) the same range of percent food intake by several species of cormorant has been reported worldwide. Considering that our predictions of Double-crested Cormorant energy requirements and food demand appeared to be within range of the existing literature, this portion of the model appears adequate until more definitive data from studies with doubly-labelled water (Nagy 1983) become available.

In addition to varying with monthly energy demands, monthly consumption of catfish from the model was largely influenced by average monthly populations (Aderman and Hill 1995) and the percent catfish in the diet (Glahn *et al.* 1995). After averaging population data from Aderman and Hill (1995) populations were the lowest in the fall, peaked in February and March and fell in April due to migration. Because all cormorant roosting-sites in the study area were not always located or counted, population estimates likely underestimated total populations (Aderman and Hill 1995). However, based on the small number of new roost sites located with telemetry (King *et al.* 1995), we do not expect this error to be large, probably less than 10%. More than half of the average annual consumption of 19 million catfish by cormorants was predicted to occur in February and March due to increasing cormorant populations and a shift in the diet towards more catfish during those months. Our average annual monetary loss figure of \$1.9 million (US\$) was 40% less than the annual loss of \$3.3 million estimated by Stickley and Andrews (1989). Although they assumed a cormorant would eat only 305 g of fish per day (Schramm *et al.* 1984), the previous study assumed a diet consisting of 100% catfish and cormorant populations of 35,000 birds throughout the winter months. With the same assumptions, our model would also have produced much higher losses. Considering the empirical data assembled to construct this model, we believe it provides the best present estimate of the impact of Double-crested Cormorant predation on the Mississippi Delta catfish industry during the winters of 1989-90 and 1990-91. These projected losses have only considered replace-

ment cost of fish removed by predation. Future research is needed to define the extent of losses due to cormorant predation at the time of catfish harvest.

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