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Abstract: Oklahoma has about 324 ha of surface water in catfish (*Ictalurus* spp.) production. The state also supports a large number of migrating and wintering piscivorous birds, particularly double-crested cormorants (*Phalacrocorax auritus*). To address concerns of aquaculture facility operators regarding loss of fish to cormorants, we asked 11 operators to conduct regular counts of piscivorous birds at each facility. These data were used to determine factors affecting cormorant density at facilities and to estimate amount of catfish lost to cormorant depredation. Cormorant density (birds/ha/day) was positively correlated with surface area of water in production at facilities <10 ha (r = 0.621, P = 0.004) and negatively correlated with percentage of forested shoreline at each facility (r = -0.518, P = 0.016). Distance to nearest major reservoir or river was not significantly correlated with cormorant densities. To estimate depredation, we assumed a daily intake of 0.4 kg of fish per cormorant and used the average number of birds counted at participating facilities. Cormorants consumed an estimated 7,196 $\pm$ 8,729 kg ($\bar{x}$ $\pm$ SE) of catfish, valued at $13,672-$36,195 (depending on size of fish consumed), or about 3-7% of Oklahoma catfish sales in 1993.

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Oklahoma has about 324 ha of surface water in catfish (*Ictalurus* sp.) production (Agricultural Statistics Board 1994), and according to a 1992 survey of Oklahoma catfish producers, bird depredation was the most serious problem faced (Klimkowski 1993). Problems with double-crested cormorants (*Phalacrocorax auritus*) were reported by 87% of 281 catfish farmers surveyed in Mississippi (Stickley and Andrews 1989). Double-crested cormorants cause concern because of their piscivorous food habits (e.g., Munro 1927, Lewis 1929, Campo et al. 1993) and recent population increases (e.g., Craven and Lev 1987, Hobson et al. 1989). Cormorants are common in Oklahoma from October-May (Okla. State Univ., unpubl. data) and can cause substantial loss of catfish in areas where fish are concentrated, such as aquaculture facilities (Scanlon et al. 1978, Schramm et al. 1984, Craven and Lev 1987, Parkhurst et al. 1987, Stickley et al. 1992). Our objectives were to: (1) determine the factors affecting cormorant density at aquaculture facilities, (2) evaluate the impact of cormorant depredation at aquaculture facilities in Oklahoma, and (3) make management recommendations regarding cormorant depredation and control.

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METHODS

We requested assistance with the project from the 157 catfish farmers listed in the Oklahoma Channel Catfish Directory (Oklahoma Department of Agriculture, undated) by mail and in some cases by telephone; 11 facilities agreed to participate. During an on-site consultation, we provided each farmer with bird identification information, determined facility size, and estimated the percentage of shoreline forested within 50 m of the ponds. Farmers were later provided with data sheets tailored to their bird identification skills. We initially requested daily counts of piscivorous birds but later reduced counts to weekly intervals to increase cooperation and uniformity of data collection. Data were collected from October-May, 1992-93

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and 1993-94. Informal discussions of cormorant depredation and control methods occurred throughout the study.

Operator estimates were used to calculate mean number of cormorants/day at each facility during each field season. Means were divided by surface area of water in fish production at respective facilities resulting in estimates of mean birds/ha/day from October-May for the 1992-93 and 1993-94 field seasons. One farmer failed to collect data and was deleted from the project during the 1992-93 field season, 1 facility was added in December 1992, and 1 facility was lost to bankruptcy after the first field season. This resulted in 11 facilities for the 1992-93 field season and 10 facilities for the 1993-94 field season. Because of variation in data collection methods, operator estimates of cormorant abundances at each facility were classified as having cormorant densities (mean no. birds/ha/day) of zero (0), rare (0-0.1), low (0.1-0.3), moderate (0.6-1.0), or high (>1.0) and were assigned a corresponding rank of 1-5, respectively. Spearman's rank correlation (SAS Inst. 1988) was used to investigate possible correlations between daily bird density and factors that may affect bird density at a facility (i.e., ha of surface water in production, percentage of forested shoreline, and distance to nearest reservoir or river). Distance from each facility to nearest reservoir >2,000 ha or river >500 km in length was measured from U.S. Geological Survey topographic maps; our observations of cormorant use of reservoirs and rivers in Oklahoma (Okla. State Univ., unpubl. data) indicate that cormorant density is greatest on reservoirs >2,000 ha and rivers >500 km in length.

Estimates of fish lost to cormorant depredation at the 10 facilities studied during 1993 were used to estimate statewide loss for 1993. We assumed a consumption rate of 0.4 kg of catfish/bird/day (Schramm et al. 1987, Brugger 1993, Glahn and Brugger 1995) for 244 days (Jan-May and Oct-Dec) in 1993 and a statewide total of 324 surface ha of water in catfish production. To calculate an estimate of statewide catfish loss that included standard error, we first calculated 10 estimates of statewide loss based on each facility with the following equation:

$$\text{LOSS} = \bar{x}_n * 0.4\text{kg} * 244 \text{ days} * 324 \text{ ha}$$

where LOSS_n = kg of catfish lost statewide to cormorant depredation based on loss at facility n and $\bar{x}_n$ = mean daily cormorant density (birds/ha/day) at facility n during 1993. Mean and standard error were calculated from the 10 statewide loss estimates. Mean loss (kg) was used to calculate the value of fish lost. Because cormorants consume various sizes of fish, the number of kilograms of fish lost was multiplied by the price/kg of fingerling/fry size ($5.03) and food size ($1.90) catfish (Agricultural Statistics Board 1994).

RESULTS

Many farmers reported monthly, rather than weekly, estimates of cormorant density or estimated weekly density at the end of each month. Mean densities ranged from 0-3.6 birds/ha/day, facility size ranged from 0.7-20.8 ha of surface water, percentage of forested shoreline ranged from 5-100%, and distance to nearest major reservoir or river ranged from 1-39 km (Table 1).

Spearman's rank correlations were performed on observations from both field seasons combined (n = 21). When all observations were included, bird density was not correlated with surface area of water in production (r = 0.407, P = 0.067). However, bird density was significantly correlated with surface area of water in production when 2 outlying observations from the largest facility were removed (r = 0.621, P = 0.004). Bird density was negatively correlated with percentage of forested shoreline (r = -0.518, P = 0.016). No correlation with distance to nearest major reservoir or river existed (r = 0.226, P = 0.325).

Estimates of catfish loss based on each of the 10 facilities surveyed ranged from 0-117,635 kg (Table 1). Mean estimated catfish loss per facility in 1993 in Oklahoma was 18,240 kg $\pm$ 35,881 kg ($\bar{x}$ $\pm$ SE). Facility 7 reported exceptionally high cormorant densities during April and May. The farmer estimated birds once a month for the entire month and may have overestimated cormorant density. Statewide loss estimated without this facility was 7,196 $\pm$ 8,729 kg ($\bar{x}$ $\pm$ SE).

Individual facility loss ranged from $34,656 (food size)-$91,746 (fingerling/fry size) using the 18,240 kg loss estimate and from $13,672 (food size)-$36,195 (fingerling/fry size) based on the 7,196 kg loss estimate. Total catfish sales in Oklahoma were about $494,000 in 1993, and loss to cormorants accounted for 7-18.6% and 2.8-7.3% of total sales using the 18,240 kg and 7,196 kg loss estimates, respectively.

Most farmers in our study that were concerned with bird depredation used shooting to kill as their primary control method, but only one considered shooting effective. Most considered shooting an expensive, temporary solution because birds often moved to other ponds or returned shortly after shooting ceased. Based on farmers' descriptions, some farmers were unable to accurately identify bird predators and killed nontarget birds [e.g., American anhinga (*Anhinga anhinga*), cattle egret (*Bubulcus ibis*), and little blue heron (*Florida caerulea*)]. Cracker shells were used successfully against pelicans at one of our facilities, but a propane cannon was considered ineffective at another. Twine suspended 30 cm above ponds at 9 m intervals was effective at one facility, but the operator reported problems with lines sagging. Some birds were able to fly under lines near levees where lines were raised to compensate for sagging. Our farmers reported greatest effectiveness using a combination of techniques.

DISCUSSION

Surface area of water in fish production explained over 60% of the variability in cormorant density when observations from the largest facility (facility 6) were removed. Facility 6 was removed because of its large size in relation to remaining facilities (Table 1). Cormorant density was positively correlated with surface area of water in production at facilities <10 ha in size, but cormorants appeared to reach their maximum density at facilities of this size. Most cormorants in Oklahoma migrate and travel in large flocks (Okla. State Univ., unpubl. data); larger facilities may attract migrating cormorants be-

Table 1. Mean density (birds/ha/day) of double-crested cormorants (and corresponding rank), surface area of water in fish production (ha), percentage of forested shoreline, distance to nearest major reservoir or river (km), and estimated catfish loss (kg) at selected aquaculture facilities in Oklahoma, October-May, 1992-94.

Facility	Cormorant density (1992-93)	Cormorant density (1993-94)	Surface area	Percent forested shoreline	Distance to reservoir/ river[a]	Catfish loss[b]
1[c]	0.385 (4[d])	— (-)	2.6	5	1	—
2[e]	0.004 (2)	0.004 (2)	2.8	100	32	95
3	1.274 (5)	1.130 (5)	4.9	5	27	13,882
4	0.002 (2)	0.000 (1)	5.3	25	10	32
5	0.000 (1)	0.000 (1)	0.7	100	20	0
6	0.783 (4)	0.130 (3)	20.8	50	39	20,144
7	3.600 (5)	0.853 (4)	9.6	25	30	117,635
8	0.149 (3)	0.184 (3)	6.8	75	7	5,218
9	0.753 (4)	2.412 (5)	8.6	100	3	20,681
10	0.206 (3)	0.143 (3)	2.5	50	16	4,712
11	0.000 (1)	0.000 (1)	3.5	100	1	0

[a] Reservoirs >2000 ha and rivers >500 km in length.
[b] 1993 statewide estimates based on losses at each facility.
[c] *Facility lost to bankruptcy after 1992/93 field season.*
[d] Cormorant density rank (1 = 0 birds/ha/day; 2 = 0-0.1; 3 = 0.1-0.3; 4 = 0.3-1.0; 5 = >1.0).
[e] 1992/93 estimate based on counts from December-May.

cause they are more visible and can potentially provide more forage than smaller facilities. Waterfowl abundance was positively correlated with water area at catfish production facilities in Mississippi (Dubovsky 1987).

Cormorant density was negatively correlated with percentage of forested area around the facilities. Facilities surrounded by trees may be more difficult to locate by low flying cormorants. Also, cormorants require a "running" start to take flight, and trees surrounding ponds or facilities may hinder their ability to take flight similar to the effect of over-hanging wires (e.g., Moerbeek et al. 1987).

Distance to the nearest major reservoir or river was not related to cormorant density, in contrast to Dubovsky (1987) who established a negative correlation between waterfowl abundance in Mississippi and distance to the Mississippi River. We hypothesized that cormorants would be more likely to encounter facilities near large reservoirs or rivers because many Oklahoma reservoirs are frequently used by double-crested cormorants (Okla. State Univ., unpubl. data).

Loss of catfish in Oklahoma varied greatly among aquaculture facilities (18,240 $\pm$ 35,881 kg) with some localized high levels of cormorant depredation. Estimated loss at facility 5 (117,635 kg) was over 5 times greater than loss at any other facility, accounted for most of the variability in statewide loss, and was primarily due to counts of 150 and 116 cormorants/day during April and May, respectively. These numbers greatly exceeded monthly counts for all other months and all other facilities and may have been the result of overestimation by the farmer due to frustration with cormorant depredation and/or a result of estimating birds monthly rather than weekly as requested. Omitting facility 5 reduced the magnitude and variability of the statewide estimate to 7,196 $\pm$ 8,729 kg.

Estimated loss of income due to cormorant depredation depended on the price/kg of catfish consumed. Cormorants primarily consume fish $\leq$125 mm in length but may consume fish up to 415 mm (Campo et al. 1993) and thus may consume catfish ranging from fingerling/fry size ($5.03/kg) to food size ($1.90/kg). Using a statewide catfish loss estimate of 7,196 kg, we calculated a monetary loss of $13,672 (food size)-$36,195 (fingerling/fry size) or 2.8-7.3% of total Oklahoma catfish sales in 1993. Stickley and Andrews (1989) estimated catfish losses to cormorant depredation of about 3% of statewide sales in Mississippi. Our loss estimate may be conservative because: (1) it does not include birds that may be present from June-September, (2) cormorants may consume >0.4 kg of fish/bird/day when fish are highly concentrated in farm ponds, and (3) fish damaged or lost to disease after sustaining a cormorant-related injury were not accounted for. Our estimate may be liberal if our consumption rate of 0.4 kg/bird/day overestimated actual intake because aggressive harassment tactics at particular facilities sufficiently restricted cormorant feeding.

MANAGEMENT IMPLICATIONS

Cormorant depredation of catfish can be a substantial problem for individual Oklahoma catfish farmers, but it does not appear to be uniform across the state. This situation may change if the cormorant population continues to increase or in mild winters when more cormorants may reside in Oklahoma. Cormorant density at aquaculture facilities is negatively correlated with percentage of forested shoreline and appears to be positively correlated with surface area of water in production. Smaller facilities constructed in forested areas may reduce the cormorant's ability to locate them and may obstruct landing and take-off opportunities. Successful methods of reducing avian depredation at aquaculture facilities include installing screens or suspended lines over ponds, maintaining a high rate of human activity near ponds, stocking fish at lower densities and later in the spring, and stocking buffer species (Lagler 1939, Naggiar 1974, Barlow and Bock 1984, Moerbeek et al. 1987, Parkhurst et al. 1987, Mott and Boyd 1994). Cormorant control methods used by Oklahoma catfish farmers were generally unsuccessful. Shooting and suspending twine across ponds were considered somewhat effective by some farmers. However, shooting and other forms of lethal control are controversial and often counter-productive (e.g., Pough 1940, Morrison 1975, Williams 1992). Farmers receiving depredation permits should be required to demonstrate the ability to distinguish between target and similar non-target species (Stickley [1990] contains illustrations of piscivorous avian predators and similar species, as well as brief descriptions, including diet information).

Better estimates of cormorant densities at aquaculture facilities are needed. Weekly or bi-weekly telephone interviews with catfish farmers may be required to retrieve data efficiently. An accurate assessment of cormorant-related catfish loss (including injuries to fish) in relation to other causes of loss should be determined.

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