EFFECT OF PISCIVOROUS BIRDS, PARTICULARLY CORMORANTS, ON RESERVOIR AND AQUACULTURAL FISHES IN OKLAHOMA

By

ROBERT LEE SIMMONDS, JR.

Bachelor of Science

Lake Superior State University

Sault Sainte Marie, Michigan

1992

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1995

EFFECT OF PISCIVOROUS BIRDS, PARTICULARLY CORMORANTS, ON RESERVOIR AND AQUACULTURAL FISHES IN OKLAHOMA

Thesis Approved:

Thesis Adviser

James H. Shaw

Thomas C. Collins
Dean of the Graduate College

ACKNOWLEDGMENTS

I wish to express my deepest appreciation to my major advisors, Drs. Alexander V. Zale and David M. Leslie, Jr. Both provided immeasurable support and encouragement, as well as providing valuable technical expertise. They also were extremely prompt and encouraging when reviewing drafts of the thesis. I would also like to thank Dr. James H. Shaw for serving on my committee and Dr. Anthony Echelle for serving as a substitute committee member at my defense.

I am grateful to Mark Braley, Jon Boren, Tony Lovelace, and Jeff Spencer for assisting with field work; Conrad Toepfer for assisting with statistical analyses; and my fellow graduate students for providing camaraderie.

I gratefully acknowledge the staff of the Oklahoma Cooperative Fish and Wildlife Research Unit for their support, especially Judy Gray who always willing to help, and the U. S. Fish and Wildlife Service for their financial support.

I would especially like to thank my wife Shelley and son Christopher for following me to Oklahoma and for accepting the field work and long hours associated with graduate work. Shelley spent several long nights helping to get the thesis finished. I also need to thank my parents for a lifetime of support.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

CHAPTER II

CHAPTER IV

LIST OF FIGURES

Figures Page

CHAPTER II

CHAPTER III

CHAPTER I

INTRODUCTION

This thesis is composed of 3 manuscripts written in formats suitable for submission to selected scientific journals. Each manuscript is complete without supporting materials. Chapter II, "Physical and biological determinants of double-crested cormorant density on Oklahoma reservoirs" is written in the format of *Colonial Waterbirds*. Chapter III, "Effect of double-crested cormorant predation on reservoir sport and forage fish populations in Oklahoma" is written in the format of the *Journal of Wildlife Management*. Chapter IV, "Double-crested cormorant depredation of channel catfish at aquaculture facilities in Oklahoma" is written in the format of the *Proceedings of the 12th Great Plains Wildlife Damage Control Workshop*.

CHAPTER II

PHYSICAL AND BIOLOGICAL DETERMINANTS OF DOUBLE-CRESTED CORMORANT DENSITY ON OKLAHOMA RESERVOIRS

Abstract.---We used regression modeling to identify reservoir characteristics that affected Double-crested Cormorant (*Phalacrocorax auritus*) density on reservoirs in Oklahoma. Surface area, $\log_{10}$(drainage basin area), and boat ramp density were significantly ($P < 0.001$) correlated with Double-crested Cormorant density in autumn (Sep-Dec). Percentage of forested shoreline and boat ramp density produced the best ($P < 0.001$) multiple regression model predicting Double-crested Cormorant density in autumn. Drainage basin area ($P < 0.01$), (Gizzard Shad catch-per-unit-effort)^2 ($P < 0.05$), and (surface area)^{½} ($P < 0.01$) were correlated with Double-crested Cormorant density in winter (Jan-Feb). The best multiple variable index of Double-crested Cormorant density in winter consisted of mean depth, percentage of forested shoreline, and boat ramp density ($P < 0.001$). Only boat ramp density ($P < 0.01$) was correlated with Double-crested Cormorant density in spring (Mar-May). Mean depth, percentage of forested shoreline, and boat ramp density was the best ($P < 0.001$) multiple index of Double-crested Cormorant density in spring. Disturbance, roosting, and foraging related factors affected Double-crested Cormorant density on reservoirs in all seasons. Drainage basin, a probable migration-related factor, affected Double-crested Cormorant density on reservoirs in autumn and winter.

Key Words.---Double-crested Cormorant, habitat, migration, Oklahoma, *Phalacrocorax auritus*, reservoir, wintering.

Dramatic increases in Double-crested Cormorant (*Phalacrocorax auritus*) populations have been reported in the Great Lakes Region and Canada (e.g., Koonz and Rakowski 1985, Price and Weseloh 1986, Craven and Lev 1987, Hobson *et al.* 1989). Populations are now at or near record levels in some parts of North America (Koonz and Rakowski 1985), and several new breeding colonies have been reported (e.g., Buckley and Buckley 1984, Findholt 1988). Cormorant increases have been attributed to increased protection, reduced environmental pesticide contamination, increased winter survival, and an increase in impounded waters (Ludwig 1984, Vermeer and Rankin 1984, Price and Weseloh 1986, Findholt 1988). Impounded waters may increase foraging opportunities and nesting habitat (Vermeer and Rankin 1984, Findholt 1988).

Double-crested Cormorants generally consume more rough and forage fishes than commercial and sport fishes (Lewis 1929, Mendall 1936, McLeod and Bondar 1953, Craven and Lev 1987, Hobson *et al.* 1989, Campo *et al.* 1993). Campo *et al.* (1993) identified 29 fish species in stomachs of 494 Double-crested Cormorants collected on Texas inland waters. Shad (*Dorosoma* spp.) and sunfishes (*Lepomis* spp.) accounted for 90% (by number) of the fishes < 125 mm in length. Largemouth Bass (*Micropterus salmoides*), White Bass (*Morone chrysops*), catfish (*Ictalurus* spp.), and crappie (*Pomoxis* spp.) accounted for only 3% of fish consumed by Double-crested Cormorants by number but 31.8% by weight.

Many anglers consider Double-crested Cormorants a threat to fishing opportunities; managers are currently monitoring Double-crested Cormorant numbers and evaluating the impact of Double-crested Cormorant predation on sport fish populations. It is conceivable that they may be faced with the need to control Double-crested Cormorants in some areas by manipulating reservoir features. With constant bird densities greater than those observed on most Oklahoma reservoirs, Double-crested Cormorants could impact sport fish populations (see Chapter III). We used regression modeling to identify variables that affected Double-crested Cormorant density on reservoirs in the southcentral Great Plains.

Our objectives were to: 1) evaluate Double-crested Cormorant density on eight Oklahoma reservoirs; 2) use regression modeling to identify factors that affect Double-crested Cormorant density on reservoirs; and 3) provide management recommendations regarding issues related to Double-crested Cormorants in Oklahoma. We hypothesized that Double-crested Cormorant density would be correlated positively with reservoir surface area, drainage basin area, water clarity, roost site availability, and forage abundance and negatively with mean depth and human disturbance.

STUDY AREA AND METHODS

The study was conducted on eight reservoirs located in northcentral and northeastern Oklahoma. Reservoirs were selected to cover variation in surface area, mean depth, and history of cormorant use (M. O'Melia, Oklahoma Department of Wildlife Conservation, personal communication). We assumed that these reservoirs also would vary with regard to drainage basin area, water clarity, percent of forested shoreline, fish abundance, and human use. Reservoir location was taken into account to permit surveying all reservoirs in a 5-day period. The reservoirs were authorized for many purposes including flood control; municipal, agricultural, and industrial water sources; hydropower; and recreation (Oklahoma Water Resources Board 1990). Reservoirs were located in both prairie and forest ecoregions of Oklahoma (Bailey 1980). Reservoirs were small to medium in size (308-8,053 ha) and were characterized by shallow (mean depth generally < 8 m) turbid water.

Counts of Double-crested Cormorants were conducted at all reservoirs from October through May 1992-93 and September through April 1993-94. Birds were counted weekly from October through December 1992 and biweekly thereafter. Travel routes were selected around each reservoir such that a maximum number of non-overlapping observation points could be used at each reservoir. Weekly reservoir order, daily reservoir order (when greater than one reservoir was surveyed in one day), and starting points were randomly determined before surveying commenced. Routes around each lake were traveled in a clockwise direction. Number of sites and percentage of reservoir observed varied due to reservoir size and accessibility (Table 1). Flooding, closing of campgrounds, and road conditions affected the number of sites surveyed at each reservoir. Swimming, roosting, and flying birds were counted from shore using 10x50 binoculars and a 15-60X spotting scope. Distance to birds was estimated in 3 categories: 0-500 m, 500-1,000 m, and 1,000-1,400 m. Distances were used to calculate area observed and bird density at each site.

Double-crested Cormorants were easily distinguished from other birds based on body shape and postures, feeding habits, and roosting habits.

Count data were used to calculate monthly estimates of Double-crested Cormorant density (cormorant-use-days/ha; Ottenbacher et al. 1994, except that estimate intervals were expanded beyond counts to include all days in each month surveyed). One cormorant-use-day was defined as use by one Double-crested Cormorant on one reservoir for one day. Counts were stratified into three seasons: autumn (Sep-Dec), winter (Jan-Feb), and spring (Mar-May). A monthly observation was defined as the total number of use-days/ha in a given month at a given reservoir, and monthly observations from both years were used in regression analyses by season. No reservoirs were sampled in September 1992 and the two sampled in May 1994 were ommitted; therefore, n = 56 monthly observations in autumn (i.e., three observations at each of eight reservoirs in 1992 and four observations at each reservoir in 1993), n = 32 in winter, and n = 40 in spring (i.e., three observations at each reservoir of eight reservoirs in 1993 and two at each in 1994).

Physical and biological characteristics of the eight reservoirs were measured (Table 2). Reservoir surface area, mean depth, drainage basin, and number of boat ramps were obtained from the Oklahoma Water Resources Board (1990) and Martin and Hanson (1966). Boat ramp density was used as an index of human-related disturbance and was calculated by dividing the number of ramps on a reservoir by the reservoir surface area. Water clarity was obtained with a secchi disk at all accessible sites (some sites were located on bridges or dams, and measurements were not feasible); mean monthly secchi disk measurements were calculated. Forage abundance was estimated using catch-per-unit-effort (CPUE) of Gizzard Shad (*Dorosoma cepedianum*) $\leq$ 300 mm total length (TL); CPUE estimates were based on spring electrofishing and autumn gill netting data provided by the Oklahoma Department of Wildlife Conservation. About 90% (by weight) of Gizzard Shad consumed by Double-crested Cormorants in Texas during 1986-87 were $\leq$ 300 mm TL (J. C. Barron, Texas Parks Wildl. Dept., personal communication). CPUE estimates were the only data available for all reservoirs, but not all reservoirs were sampled annually. Therefore, we used spring electrofishing data from 1987-92 and autumn gill netting data from 1986-94 to obtain estimates for each reservoir (CPUE estimates were averaged when more than one was available from 1992-94). As an index of roost site availability, the percentage of forested shoreline was calculated for each reservoir from Soil Conservation Service digital databases at the Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

Simple and multivariate regression analyses were used to identify variables that affected Double-crested Cormorant abundance on reservoirs. An inverse transformation, 1/[(monthly cormorant-use-days/ha) + 1], was used to improve normality and reduce skewness of the dependent variable. The SAS regression procedure (SAS Institute 1985) was used to examine simple linear relationships between the dependent variable and eight independent variables (Table 2). Scatter plots and residual plots were used to diagnose increasing error variance and curvilinear trends. Appropriate transformations were performed on independent variables as needed. The SAS stepwise multiple regression procedure, maxR option, was used to identify the 'best' models (SAS Institute 1985). Final models were selected based on changes in the coefficient of multiple determination (R^2) and the adjusted R^2 as the number of variables in the model increased (Neter et al. 1990). As a general rule, an additional variable was added if it resulted in increases of > 0.05 in the R^2 and > 0.025 in the adjusted R^2. Partial plots also were used to evaluate the aptness of preliminary models. Models were checked for multicollinearity of independent variables and were rejected if variance inflation factors were > 10 (Neter et al. 1990). Outlying observations were diagnosed with the hat matrix and studentized deleted residuals, and the influence of outlying observations was diagnosed with Cook's distance measure *D* (Neter et al. 1990). Three influential outlying observations were identified but were not removed because no measurement error or other reason for deletion was determined.

RESULTS

Double-crested Cormorant Density

The greatest Double-crested Cormorant density, 142 total cormorant-use-days/ha, occurred at Webber's Falls reservoir in autumn 1992 (Table 3). Density at Webber's Falls reservoir in autumn 1992 exceeded densities during that period at all other reservoirs combined. Double-crested Cormorants were observed on all reservoirs but were absent during at least one season on five of eight reservoirs. Confidence intervals of bird density estimates were relatively large, despite stratifying counts by season. Most birds counted were migratory, and bird numbers fluctuated as birds migrated to or from wintering or breeding grounds. The mean of total seasonal densities (pooling all seasons and all reservoirs; Table 3) was greater in 1992-93 (19.77 ± 33.69 cormorant-use-days/ha; $\bar{x} \pm$ SD) than in 1993-94 (5.03 ± 9.43 cormorant-use-days/ha) (t = 2.063, $P = 0.049$). Bird density was generally greatest in autumn, followed in decreasing order by spring and winter. Webber's Falls was an exception in 1992-93 with greater bird numbers in winter than spring.

Regression Models

In autumn, variables $\log_{10}$(BASIN), RAMPS, and SIZE were correlated significantly ($P < 0.05$, $r^2 > 0.2$) with inverse monthly cormorant-use-days/ha (Table 4). BASIN, $(\text{CPUESE})^2$, and $(\text{SIZE})^{1/2}$ produced significant simple regression models with Double-crested Cormorant density in winter. In spring, only RAMPS was correlated with Double-crested Cormorant density. Other variables produced models with $P < 0.05$, but they accounted for <20% of the variability in Double-crested Cormorant density.

The best multiple regression model for predicting Double-crested Cormorant density on reservoirs in autumn contained two variables, RAMPS and FOREST (Table 4). In winter and spring, FOREST, RAMPS, and MDEPTH produced the best multiple regression model predicting Double-crested Cormorant density.

DISCUSSION

Double-crested Cormorant Density

Density of Double-crested Cormorants was greater in 1992-93 than in 1993-94, primarily because of high bird numbers in late autumn 1992-93 and throughout the winter at some reservoirs. This may have been due to climatic differences between years. Mean monthly temperatures were similar between field seasons; however, mean low temperatures differed. During 1992-93 surveys, mean low temperature dropped to -6°C in December and reached a mean low of -11°C in January (National Climate Center 1992-94). During 1993-94 surveys, mean low temperature dropped to -9°C in December and reached a low of -13°C in January. Some reservoirs were almost completely ice covered in January of the 1993-94 field season. Colder temperatures in 1993-94 likely caused birds to migrate farther south rather than wintering on northeastern Oklahoma reservoirs.

Autumn

The variable SIZE explained over 40% of the variability in autumn Double-crested Cormorant density. SIZE was correlated positively with Double-crested Cormorant density (negatively correlated with the inverse of Double-crested Cormorant density). Many Double-crested Cormorants were observed in large flocks; flocks > 500 birds were observed on four of the eight reservoirs surveyed, and 14 flocks > 1,000 birds were observed. Larger reservoirs may provide more forage for large numbers of Double-crested Cormorants, and they are more visible and more likely to be encountered than smaller reservoirs.

Double-crested Cormorant density at aquaculture facilities in Oklahoma also was correlated positively with surface area of water at facilities <10 ha (see Chapter IV). Wintering piscivorous waterfowl abundance on Swiss lakes was correlated positively with surface area (Suter 1994). Piscivore foraging was concentrated in the pelagic zone, and lakes with large surface areas generally had larger pelagic zones than small lakes.

Double-crested Cormorant density was correlated positively with BASIN. Autumn migration of Double-crested Cormorants in Oklahoma occurred over a period of several months (Fig. 1). Birds apparently travel at a slower rate than in spring migration and may be more apt to follow waterways. Reservoirs with larger drainage basins have larger areas flowing into them, and if Double-crested Cormorants are following waterways, more birds are likely to 'flow' into these reservoirs.

Double-crested Cormorant density was affected negatively by RAMPS. Greater boat traffic would result in a greater number of encounters between boaters and Double-crested Cormorants. Double-crested Cormorants do appear to be somewhat tolerant of boating activity (personal observation), and they frequently habituate to activities designed to discourage bird use at aquaculture facilities (e.g., Stickley *et al.* 1995). However, some boaters were observed actively harassing Double-crested Cormorants; thus if more boats are present, more active harassment is likely. Sufficient chance encounters and harassment may reduce the number of Double-crested Cormorants using a reservoir.

RAMPS and FOREST produced the best multiple regression model describing Double-crested Cormorant density on reservoirs in autumn. Double-crested Cormorant density was affected negatively by boat ramp density and positively by the amount of forested shoreline. Double-crested Cormorants spend much of the mid-day hours roosting on dead trees and stumps, live trees, buoys, pilings, or any other objects that are near the water and offer an unobstructed view (Bartholomew 1943). Double-crested Cormorants also move to an evening roost where thousands may congregate (Mendall 1936, Bartholomew 1943). We observed Double-crested Cormorants roosting on logs, snags, trees, rocks, buoys, and docks. Although large flocks of birds were observed roosting in groups of snags, Double-crested Cormorants never outnumbered available roost sites, even on reservoirs with small amounts of forested shoreline. However, Double-crested Cormorants likely selected preferred roost sites in undisturbed areas. Reservoirs with large areas of forested shoreline may have provided a greater number of these preferred areas than reservoirs with small areas of forested shoreline.

Winter

Winter Double-crested Cormorant density increased with both SIZE and BASIN, which paralleled autumn observations. Some reservoirs that received high Double-crested Cormorant density in autumn also maintained wintering bird populations; thus, they may have been attracted to a reservoir in autumn and remained on these reservoirs during winter.

Double-crested Cormorant density also increased with CPUESE. Forage abundance was likely most important in winter, when birds remained in an area for several months. Reservoirs that contained greater numbers of forage fishes would be able to support greater numbers of wintering Double-crested Cormorants. On Swiss lakes, coarse fish yield was correlated positively with and explained 40-60% of the variation in overwintering piscivorous bird abundance (Suter 1995). Suter (1995) concluded that food or foraging-related characteristics affected abundance of overwintering waterfowl. Weseloh and Ewins (1994) identified forage fish abundance as one of three primary factors explaining recent Double-crested Cormorant population increases in the Great Lakes. Increases in Double-crested Cormorant numbers on Little Galloo Island, Lake Ontario, were correlated positively with indices of sexually mature alewife three years previous to bird surveys (Weseloh and Ewins 1994). Double-crested Cormorants also are known to congregate and cause severe depredations at aquaculture facilities where fish abundance is high (Scanlon et al. 1978, Schramm et al. 1984, Craven and Lev 1987, Parkhurst et al. 1987, Stickley et al. 1992).

Forage abundance (CPUESE or CPUEFG) occurred in only one of 10 regression models generated (Table 4). However, forage abundance may have been identified as a more important factor if a better index of forage abundance was available. Data used for indices of forage abundance were not collected annually; therefore, we had to include data from 1986-1994 to obtain estimates for all reservoirs. However, Gizzard Shad recruitment and abundance are highly variable and depend on the condition of adults at the time of spawning (Stock 1971, Kampa 1984). Therefore, our estimates may not have adequately depicted fish abundance from 1992-94 and may have obscured the effect of fish abundance on Double-crested Cormorant density.

The best model for Double-crested Cormorant density in winter consisted of three variables: FOREST, RAMPS, and MDEPTH. RAMPS and MDEPTH were correlated negatively and FOREST was correlated positively with Double-crested Cormorant density. Shallow reservoirs likely provide better foraging opportunities than deep reservoirs, and foraging opportunities would be particularly important for wintering birds. Preferred Double-crested Cormorant feeding areas are near shore in shallow water over flat sandy or rocky substrates (Lewis 1929, Palmer 1962, Ainley *et al.* 1981, Hatch 1983, Craven and Lev 1987) and range in depth from 2 to 18 m but are generally < 9 m (Lewis 1929, Mendall 1936, Palmer 1962, Craven and Lev 1987, Campo *et al.* 1993, Custer and Bunck 1992). Foraging frequency of both Reed Cormorants (*P. africanus*) and White-breasted Cormorants (*P. carbo*) in South Africa were greater than expected in shallow water (Monadjem *et al.* 1995).

Spring

RAMPS was the only variable correlated with Double-crested Cormorant density in spring and was correlated negatively. Spring migration was more abrupt than autumn migration (Fig. 1), and thus double-crested cormorants spent less time on individual reservoirs in spring than in autumn or winter. Forage and roosting-related factors may have been less important than during other periods.

RAMPS, FOREST, and MDEPTH produced the best multiple regression model in spring. Although only RAMPS produced a significant simple regression, this combination produced the best multiple regression model, as it did in winter. The combination takes into account disturbance, roosting, and feeding factors.

CONCLUSIONS

Double-crested Cormorant density on Oklahoma reservoirs was highly variable among reservoirs and also between years on individual reservoirs. Reservoirs were used primarily during autumn and spring migration; however, wintering Double-crested Cormorant populations did occur on some reservoirs. Double-crested Cormorant density was correlated with several variables, but in every season the 'best' multiple regression model was comprised partially or entirely of boat ramp density and the percentage of forested shoreline. These factors were related to human disturbance and roost availability. Managers may be able to manipulate such variables to reduce Double-crested Cormorant density on reservoirs, but the relatively low amount of variability in Double-crested Cormorant density accounted for in our regression models (Table 4) should alert them that other important but unmeasured variables affected reservoir selection. Prior to large-scale manipulations, controlled experiments should be conducted to more precisely identify the effect of these and other variables on Double-crested Cormorant density.

ACKNOWLEDGMENTS

We thank J. Boren, M. Braley, A. Lovelace, and J. Spencer for assisting with piscivorous bird counts. Thanks also to K. K. Cunningham, Oklahoma

Department of Wildlife Conservation; M. Gregory, Oklahoma State University; and J. C. Barron, Texas Parks and Wildlife Department for providing supportive data and technical support. J. H. Shaw and A. A. Echelle reviewed the manuscript, and R.W. Pitman served as U. S. Fish and Wildlife Service (USFWS) Project Leader. This project was funded by Region 2 Fishery Resources, USFWS, with additional support from the Oklahoma Cooperative Fish and Wildlife Research Unit (National Biological Service, Oklahoma State University, Oklahoma Department Wildlife Conservation, and Wildlife Management Institute, cooperating).

LITERATURE CITED

Ainley, D. G., D. W. Anderson, and P. R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. Condor 83:120-131.

Bartholomew, G. A., Jr. 1943. The daily movements of cormorants on San Francisco Bay. Condor 45:3-18.

Bailey, R. G. 1980. Description of the ecoregions of the United States. United States Department of Agriculture, Misc. Pub. No. 1391. 77pp.

Buckley, P. A., and F. G. Buckley. 1984. Expanding Double-crested Cormorant and Laughing Gull populations on Long Island, NY. Kingbird 34:146-155.

Campo, J. J., B. Thompson, J. C. Barron, P. P. Durocher, and S. J. Gutreuter. 1993. Diet of Double-crested Cormorants wintering in Texas. Journal of Field Ornithology 64:135-144.

Craven, S. R., and E. Lev. 1987. Double-crested Cormorants in the Apostle Islands, Wisconsin, USA: population trends, food habits, and fishery depredations. Colonial Waterbirds 10:64-71.

Custer, T. W., and C. Bunck. 1992. Feeding flights of breeding Double-crested Cormorants at two Wisconsin colonies. Journal of Field Ornithology 63:203-211.

Findholt, S. L. 1988. Status, distribution and habitat affinities of Double-crested Cormorant nesting colonies in Wyoming. Colonial Waterbirds 11:245-251.

Hatch, J. J. 1983. Diet of an expanding population of Double-crested Cormorants. Colonial Waterbirds 6:71. (abstract).

Hobson, K. A,, R. W. Knapton, and W. Lysack. 1989. Population, diet and reproductive success of Double-crested Cormorants breeding on Lake Winnipegosis, Manitoba, in 1987. Colonial Waterbirds 12:191-197.

Kampa, J. M. 1984. Density-dependent regulation of gizzard shad populations in experimental ponds. Unpublished M.S. Thesis, University of Missouri-Columbia. 71pp.

Koonz, W. H., and P. W. Rakowski. 1985. Status of colonial waterbirds nesting in southern Manitoba. Canadian Field-Naturalist 99:19-29.

Lewis, H. F. 1929. The natural history of the Double-crested Cormorant (*Phalacrocorax auritus auritus* (Lesson)). Ottawa, Canada: Ru-Mi-Lou Books. 94pp.

Ludwig, J. P. 1984. Decline, resurgence and population dynamics of Michigan and Great Lakes Double-crested Cormorants. Jack Pine Warbler 62:92-102.

Martin, R. O. R., and R. L. Hanson. 1966. Reservoirs in the United States.

Geological Survey Water-Supply Paper 1838, U.S. Government Printing Office, Washington, D.C., USA. 115pp.

McLeod, J. A., and G. F. Bondar. 1953. A brief study of the Double-crested Cormorant on Lake Winnipegosis. Canadian Field-Naturalist 67:1-11.

Mendall, H. L. 1936. The home-life and economic status of the Double-crested Cormorant (*Phalacrocorax auritus auritus*). Orono, Maine, USA: Univ. Maine Studies, Second Series, no. 38. 159pp.

Monadjem, A., R. N. Owen-Smith, and A. C. Kemp. 1995. The influence of water depth on foraging location of two species of kingfisher and two species of cormorant on the Sabie River within the Druger National Park. African Journal of Ecology 33:81-83.

National Climate Center. 1992-94. Climatological data, Oklahoma. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climate Center 101:(10-12), 102:(1-5, 9-12), 103:(1-4).

Neter, J., W. Wasserman, and M. H. Kutner. 1990. Applied linear statistical models. Homewood, Illinois, USA: Richard D. Irwin, Incorporated. 1181pp.

Oklahoma Water Resource Board. 1990. Oklahoma's water atlas. Norman, Oklahoma, USA: Univ. of Oklahoma Printing Services. 360pp.

Ottenbacher, M. J., D. K. Hepworth, and L. N. Berg. 1994. Observations on Double-crested Cormorants (*Phalacrocorax auritus*) at sportfishing waters in southwestern Utah. Great Basin Naturalist 54:272-286.

Palmer, R. S., (ed.). 1962. Handbook of North American Birds, Vol. 1, Loons through Flamingos. New Haven, Connecticut, USA: Yale University Press. 567pp.

Parkhurst, J. A., R. P. Brooks, and D. E. Arnold. 1987. A survey of wildlife depredation and control techniques at fish-rearing facilities. Wildlife Society Bulletin 15:386-394.

Price, I. M., and D. V. Weseloh. 1986. Increased numbers and productivity of Double-crested Cormorants, *Phalacrocorax auritus*, on Lake Ontario. Canadian Field-Naturalist 100:474-482.

SAS Institute Incorporated. 1985. SAS user's guide: Statistics, Version 5 Edition. Cary, North Carolina, USA: SAS Institute Incorporated. 956pp.

Scanlon, P. F., L. A. Helfrich, and R. E. Stultz. 1978. Extent and severity of avian predation at federal fish hatcheries in the U.S. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 32:470-473.

Schramm, H. L., Jr., B. French, and M. Ednoff. 1984. Depredation of Channel Catfish by Florida Double-crested Cormorants. Progressive Fish-Culturist 46:41-43.

Stock, J. N. 1971. A study of some effects of population density on Gizzard Shad and Bluegill growth and recruitment in ponds. Unpublished M.S. Thesis, University of Missouri-Columbia. 107pp.

Stickley, A. R., Jr., D. F. Mott, and J. O. King. 1995. Short-term effects of an inflatable effigy on cormorants at catfish farms. Wildlife Society Bulletin 23:73-77.

_____, G. L. Warrick, and J. F. Glahn. 1992. Impact of Double-crested Cormorant depredations on Channel Catfish farms. Journal of the World Aquaculture Society 23:192-198.

Suter, W. 1994. Overwintering waterfowl on Swiss lakes: how are abundance and species richness influenced by trophic status and lake morphology? Hydrobiologia 279/280: 1-14.

Vermeer, K. and L. Rankin. 1984. Population trends in nesting Double-crested and Pelagic Cormorants in Canada. Murrelet 65:1-9.

Weseloh, D. V. C., P. J. Ewins. 1994. Characteristics of a rapidly increasing colony of Double-crested Cormorants (*Phalacrocorax auritus*) in Lake Ontario: Population size, reproductive parameters and band recoveries. Journal of Great Lakes Research 20:443-456.

Table 1. Number of sites, area observed, and percent of reservoir observed on Oklahoma reservoirs surveyed for piscivorous birds, October 1992 through May 1994.

Reservoir	Sites[a]	Area (ha)	Percent
Bluestem	2	142	46.1
Carl Blackwell	6 - 10	199 - 583	14.6 - 42.7
Fort Gibson	8 - 38	406 - 4,002	5.0 - 49.7
Heyburn	3	156 - 159	43.8 - 44.7
Kaw	7 - 20	838 - 2,507	12.2 - 36.4
Sooner	2 - 14	226 - 686	10.3 - 31.4
Tenkiller Ferry	15 - 33	1,389 - 2,967	26.6 - 56.8
Webber's Falls	9 - 11	1,237 - 1,339	26.4 - 25.7

[a] Flooding, closing of campgrounds, and road conditions affected the number of sites surveyed.

Table 2. Summary statistics of variables evaluated as affecting Double-crested Cormorant use of Oklahoma reservoirs, 1992-94.

Variable	Acronym	*n*	$\bar{x}$	SD	Range
Surface area (ha)	SIZE	128	3,634.8	2,803.4	308.0 - 8,053.0
Mean depth (m)	MDEPTH	128	7.0	3.7	2.6 - 15.5
Drainage basin (km^2)	BASIN	128	51,328.0	85,353.0	74.0 - 252,286.0
Water clarity (cm)[a]	SECCHI	128	59.2	44.9	2.0 - 259.0
Forested shoreline (%)	FOREST	128	32.0	24.2	0.7 - 68.3
Boat ramp density (ramps/ha)	RAMPS	128	0.38	0.3	0.1 - 1.1
CPUE spring electrofishing (fish/hr)[b]	CPUESE	128	62.8	39.2	1.4 - 123.0
CPUE autumn gill netting (fish/net-hr)[c]	CPUEFG	128	0.47	0.4	0.0 - 1.2

[a] Secchi disk was used to measure water clarity.

[b] Catch-per-unit-effort of Gizzard Shad ≤ 300mm collected during Oklahoma Department of Wildlife Conservation (ODWC) spring electrofishing.

[c] Catch-per-unit-effort of Gizzard Shad ≤ 300mm collected during ODWC autumn gill netting.

Table 3. Total number of Double-crested Cormorant-use-days/ha (± 95% CI) by season on eight reservoirs in Oklahoma, 1992-94.

	Total Cormorant Use-Days/ha					
	1992-93			1993-94		
Reservoir	Oct - Dec	Jan - Feb	Mar - May	Sep - Dec	Jan - Feb	Mar - Apr
Bluestem	0.97 ± 1.05	0.00 ± 0.00	1.90 ± 3.27	0.11 ± 0.21	0.00 ± 0.00	0.13 ± 0.26[a]
Carl Blackwell	2.05 ± 1.14	0.00 ± 0.00	2.77 ± 2.09	1.81 ± 2.60	0.00 ± 0.00	2.04 ± 3.10
Fort Gibson	43.46 ±14.27	35.77 ±13.21	51.75 ±31.48	37.86 ±19.41	0.20 ± 0.14	29.21 ±24.71
Heyburn	0.77 ± 0.56	0.00 ± 0.00	0.59 ± 0.97	0.00 ± 0.00	0.00 ± 0.00	0.69 ± 0.59
Kaw	55.22 ±59.72	0.03 ± 0.05	1.68 ± 1.89	4.60 ± 0.00	0.00 ± 0.00	0.36 ± 0.48[a]
Sooner	5.03 ± 3.27	0.28 ± 0.22	9.71 ± 7.86	11.93 ±16.30	0.00 ± 0.00	5.75 ± 3.33
Tenkiller Ferry	10.08 ± 5.72	0.30 ± 0.37	8.89 ± 9.29	8.45 ± 7.50	1.02 ± 1.29	2.75 ± 2.15
Webber's Falls	142.13 ±90.88	72.35 ±85.66	28.84 ±24.50	7.33 ± 8.44	1.45 ± 2.32	5.03 ± 6.32

[a] Mar - May

Table 4. Simple and multiple regression equations for predicting the inverse of migratory and wintering Double-crested Cormorant density, Y = 1/[(cormorant-use-days/ha) + 1], on Oklahoma reservoirs, 1992-94.

Season[a]	Equation[b]	n[c]	r^2	Adj-R^2	P
Autumn					
	$Y = 0.0.973 - 0.128 \log_{10}(\mathrm{BASIN})$	56	0.251	n/a[d]	0.0001
	$Y = 0.352 + 0.494$ RAMPS	56	0.225	n/a	0.0002
	$Y = 0.818 - 0.0000773$ SIZE	56	0.403	n/a	0.0001
	$Y = 0.49 - 0.0079$ FOREST $+ 0.799$ RAMPS	56	n/a	0.433	0.0001
Winter					
	$Y = 0.912 - 0.00000188$ BASIN	32	0.251	n/a	0.0035
	$Y = 0.99 - 0.0000317\ (\mathrm{CPUESE})^2$	32	0.218	n/a	0.0466
	$Y = 1.125 - 0.0057\ (\mathrm{SIZE})^{1/2}$	32	0.22	n/a	0.0085
	$Y = 0.557 + 0.0425$ MDEPTH $- 0.0114$ FOREST $+ 0.872$ RAMPS	32	n/a	0.474	0.0001

Table 4. Continued.

Season[a]	Equation[b]	n[c]	r^2	Adj-R^2	P
Spring					
	Y = 0.361 + 0.479 RAMPS	40	0.237	n/a	0.0015
	Y = 0.289 - 0.00673 FOREST + 0.819 RAMPS + 0.0228 MDEPTH	40	n/a	0.335	0.0005

[a] Seasons: autumn = Sep-Dec; winter = Jan-Feb; spring = Mar-May.

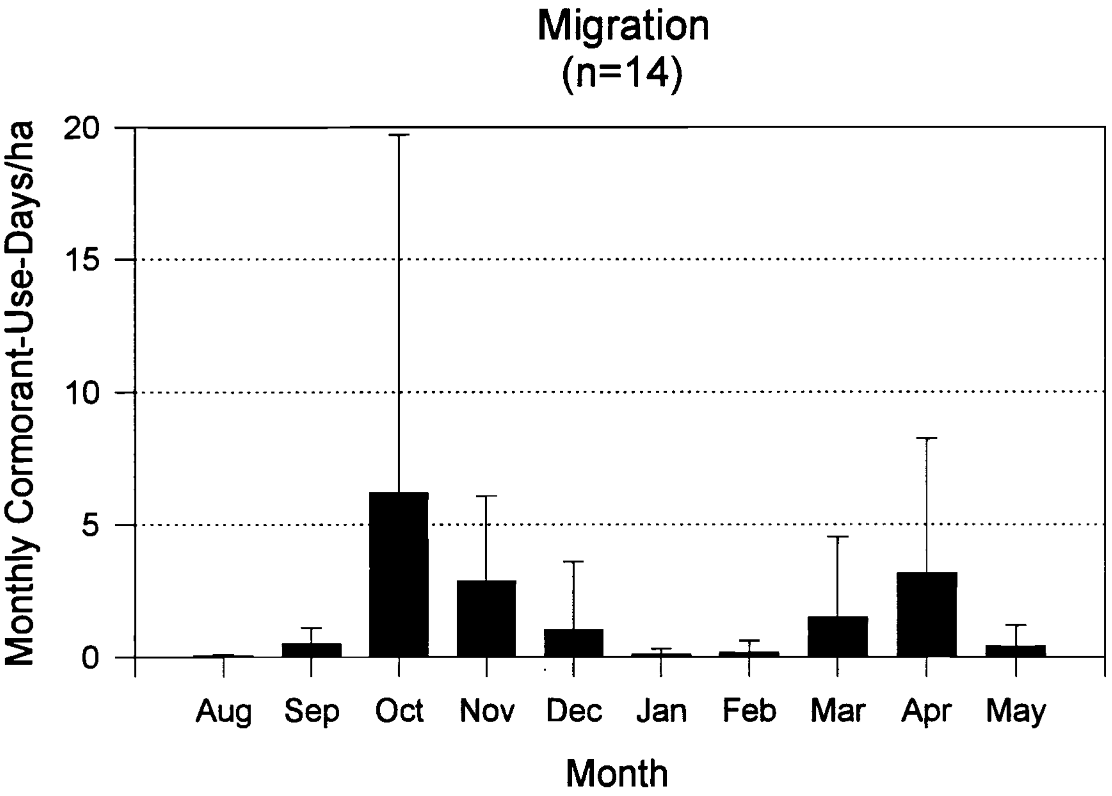
[b] Independent variables: BASIN = drainage basin (km^2), CPUESE = catch-per-unit-effort of Gizzard Shad $\leq$ 300 mm collected during spring electrofishing, FOREST = percentage forested shoreline (%), MDEPTH = mean depth (m), RAMPS = boat ramp density (ramps/ha), SIZE = surface area (ha).

[c] n = number of monthly observations in a season (e.g., three observations at each of eight reservoirs in autumn 1992 and four observations at each reservoir in autumn 1993).

[d] n/a = not applicable.

FIGURE LEGEND

Fig. 1. Mean monthly double-crested cormorant density (cormorant-use-days/ha; error bars = SD) at eight Oklahoma reservoirs in 1992-94. Eight reservoirs were surveyed for two years for a total of 16 reservoir observations; 14 indicated migration use only and two indicated migration and wintering use. Note different scales on the two graphs.


Migration
(n=14)
Monthly Cormorant-Use-Days/ha
20
15
10
5
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Month

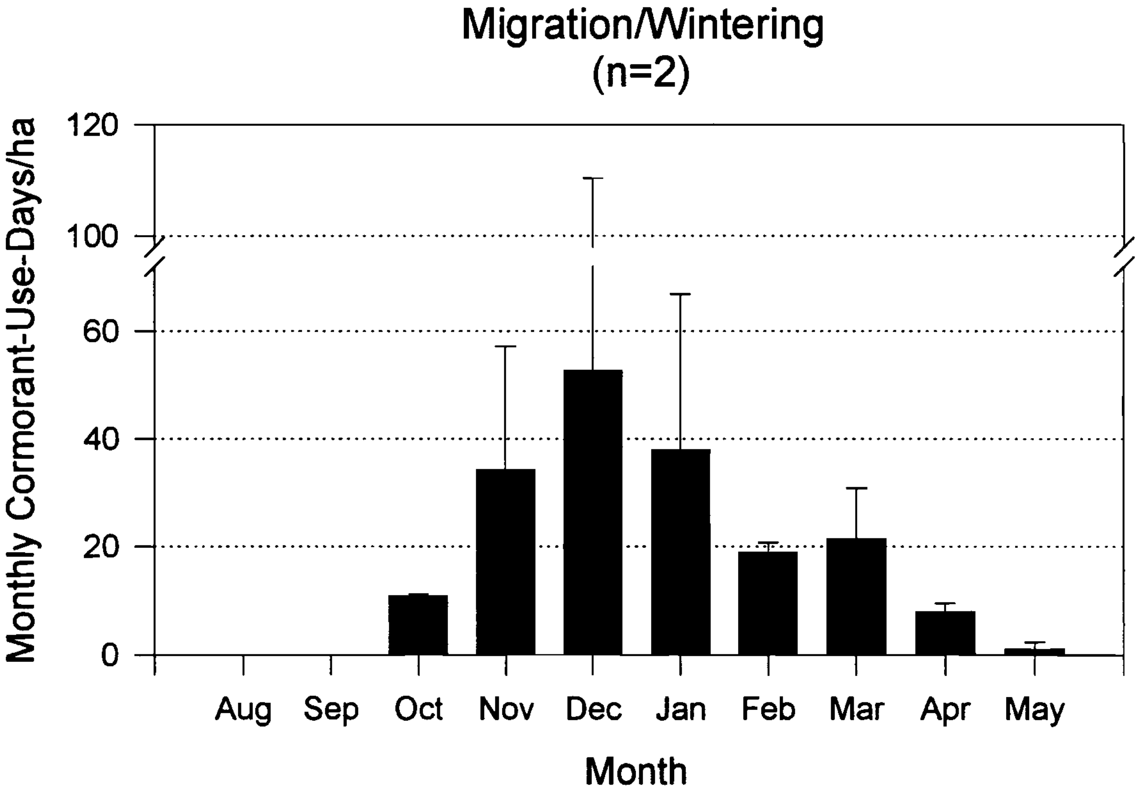

Migration/Wintering
(n=2)
Monthly Cormorant-Use-Days/ha
120
100
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Month

Fig. 1

CHAPTER III

EFFECT OF DOUBLE-CRESTED CORMORANT PREDATION ON RESERVOIR SPORT AND FORAGE FISH POPULATIONS IN OKLAHOMA

Abstract: Double-crested cormorant (*Phalacrocorax auritus*) populations have increased rapidly in recent years, as have concerns among anglers regarding potential losses of reservoir fishes. We adapted the Ricker equilibrium-yield model to evaluate effects of double-crested cormorant predation on standing crop and yield of reservoir sport and forage fishes. Double-crested cormorant densities were highly variable among reservoirs and between years, but densities at most reservoirs (14 of 16 reservoir observations [8 reservoirs x 2 years]) were low, with a mean monthly rate of 2.5 ± 4.2 (SD) cormorant-use-days/ha during migration (Sep-Dec and Mar-May). At this level of predation in perpetuity, yields were reduced by 3.1 and 18.8% for channel catfish (*Ictalurus punctatus*), 4.4 and 22.1% for largemouth bass (*Micropterus salmoides*), and 1.8 and 5.3% for white crappie (*Pomoxis annularis*), given density-dependent and density-independent fish growth, respectively. Gizzard shad (*Dorosoma cepedianum*) standing crop was reduced by 1.5 and 5.6% given density-dependent and density-independent fish growth, respectively. Densities during the remaining 2 reservoir observations were high, with a mean monthly level of 23.4 ± 14.2 (SD) cormorant-use-days/ha during migration/winter (Sep-May). If this level of predation persisted in perpetuity (i.e., all variables were in equilibrium), fish populations could be reduced substantially. However, high predation rates did not persist at either reservoir; each had high double-crested cormorant density in only 1 of the census years and substantially lower density the following year. Because of potential impacts to sport fisheries in some reservoirs, monitoring double-crested cormorants is recommended to determine long-term density and reservoir use patterns.

Key words: Double-crested cormorant, equilibrium-yield model, forage fish, Oklahoma, *Phalacrocorax auritus*, predation, reservoir, sport fish.

Double-crested cormorant populations have increased dramatically during the past 20 years (Ludwig 1984, Price and Weseloh 1986, Craven and Lev 1987, Hobson *et al.* 1989), due to increased government protection and a reduction in environmental pesticide contamination (Ludwig 1984, Vermeer and Rankin 1984, Price and Weseloh 1986). Double-crested cormorant populations are at or near record levels in parts of North America (Koonz and Rakowski 1985), and new breeding colonies have been reported (e.g., Buckley and Buckley 1984). Double-crested cormorants were the most seasonally abundant piscivorous bird on Oklahoma reservoirs in 1992-94 (Appendix A).

Double-crested cormorants are almost exclusively piscivorous and tend to consume the most abundant fishes present (Lewis 1929, Craven and Lev 1987, Campo *et al.* 1988, Hobson *et al.* 1989). Therefore, they tend to consume more rough and forage fishes than commercial or sport fishes (Lewis 1929, Craven and Lev 1987, Campo *et al.* 1988, Hobson *et al.* 1989). However, sport fishes can be common in their diets when feeding in reservoirs with high sport fish densities (Campo et al. 1993).

Water quality, angling pressure, reservoir age, water level fluctuations, predation, and other factors affect the quality of fishing in a reservoir. Predation by piscivorous birds is perhaps one of the most obvious to anglers. Anglers throughout North America have expressed concern regarding the effect of double-crested cormorant predation on fish populations. In response to complaints from anglers, the Oklahoma Senate recently passed Senate Bill 362 declaring the double-crested cormorant a nuisance species. To address concerns, some researchers have calculated the biomass of fish consumed by double-crested cormorants (e.g., Ottenbacher et al. 1994), but their effects on standing crop and yield of sport and forage fishes have not been evaluated.

Our objective was to model effects of double-crested cormorant predation on fish standing crop and yield in a typical southcentral Great Plains reservoir. We used data from observations of double-crested cormorants in Oklahoma and Texas and data on Oklahoma fish stocks to simulate effects of double-crested cormorant predation on reservoir populations of channel catfish, largemouth bass, white crappie, and gizzard shad. We hypothesized that current rates of double-crested cormorant predation would not tangibly reduce standing crops or yields of reservoir sport and forage fishes.

We wish to acknowledge K. K. Cunningham of the Fisheries Research Lab, Oklahoma Department of Wildlife Conservation (ODWC), for providing catch-per-unit-effort data and J. C. Barron of the Texas Parks and Wildlife Department for providing data on the diets of double-crested cormorants. A. A. Echelle and J. H. Shaw reviewed the manuscript, and R.W. Pitman served as

U.S. Fish and Wildlife Service (USFWS) Project Leader. This project was funded by Region 2 Fishery Resources, USFWS, with additional support from the Oklahoma Cooperative Fish and Wildlife Research Unit (National Biological Service, Oklahoma State University, ODWC, and Wildlife Management Institute, cooperating).

METHODS

Model Description

We used an adaptation of the Ricker equilibrium-yield model (Ricker 1975) to evaluate effects of double-crested cormorant predation on standing crop and yield of reservoir fishes. Standing crop was defined as the amount of fish in a reservoir (kg/ha) and fish yield as the annual harvest of fish by anglers (kg/ha/yr). The Ricker (1975) equilibrium-yield model was developed as a tool for determining conditions needed to maximize fish yield. Equilibrium-yield models have been used extensively to determine effects of harvest regulations on fish yield (e.g., Chadwick 1969, Sakagawa and Pycha 1971, Goodyear 1984, Colvin 1991b). We used the model because of its simplicity and ability to meet our objective.

We initially executed the Ricker equilibrium-yield model without double-crested cormorant predation, modeling fish species individually. Each year in the lifespan of each fish species was divided into monthly intervals, except June through August, which was considered 1 interval because double-crested cormorant predation was absent. We began modeling fish in September of their hatch year, corresponding to the arrival of double-crested cormorants. Parameters associated with the model remained constant throughout each interval. Fish length at the beginning of each interval was determined by dividing the annual amount of growth among intervals that occurred during the growing season (e.g., if 2-year-old channel catfish grew 70 mm and the growing season was 7 months, then fish size increased 10 mm/month during the growing season). Length-weight relationships were used to convert fish lengths to weights. The natural log of each weight was calculated, and the difference between $\log_e$(weight) of successive intervals was used as the instantaneous rate of growth (G). Instantaneous rates of natural and angling mortality were calculated from annual rates as described by Ricker (1975). The instantaneous rate of natural mortality (M) was partitioned equally among months. The instantaneous rate of angling mortality (F) was applied only to fish greater than of equal to the minimum size harvested by anglers (M. Ambler, ODWC, pers. comm.) and was partitioned among intervals based on estimates of seasonal angling pressure (Glass 1982, Angyal et al. 1987, Zale and Stubs 1991).

For each interval, rates of mortality were subtracted from the rate of growth and used to calculate a weight change factor (e^{G-M-F}). The weight change factor was used to adjust weight of the fish stock at the beginning of each interval. Stock weight was the weight of fish at each interval. The model was designed to calculate yield-per-recruit, in which an arbitrary starting stock is typically used. However, rather than determine the yield-per-recruit, we determined the yield given the standing crop of fish in a typical Oklahoma reservoir. We initially selected an arbitrary starting stock. The standing crop was then calculated by summing weights of fish stocks in October for each year class of fish. The starting stock was adjusted until the total standing crop was appropriate for the fish species modeled. Yield was calculated by multiplying the average stock by the instantaneous rate of angling mortality at each interval. Total yield was the sum of the yield at each interval.

Data were not available to calculate an instantaneous rate of double-crested cormorant-induced fish mortality; rates must be calculated concurrent to calculation of natural and angling mortality rates to determine the fraction of natural mortality attributable to double-crested cormorant predation. Therefore, the amount of fish consumed by double-crested cormorants was subtracted from the fish stock at appropriate age intervals. Ages were selected based on species-specific sizes of fish consumed by double-crested cormorants in reservoirs in Texas (J. C. Barron, Texas Parks Wildl. Dep., pers. comm.).

Double-crested cormorant abundance was entered into the model as monthly cormorant-use-days/ha; 1 cormorant-use-day/ha was defined as use by 1 double-crested cormorant/ha on 1 reservoir for 1 day. We assumed a daily intake of 400 g of fish per cormorant-use-day (Schramm et al. 1987, Brugger 1993, Ottenbacher et al. 1994, Glahn and Brugger *in press*). Double-crested cormorant predation was partitioned among fish species based on the species composition of the diets of double-crested cormorants in reservoirs in Texas (Campo et al. 1993). The amount of each fish species consumed per cormorant-use-day (x) was determined by:

$$x = a * b, \qquad (1)$$

where a was the total fish consumption in kilograms per cormorant-use-day and b was the percentage of the fish species in the diets of the double-crested cormorant.

The amount of each fish species consumed during a model interval (y) was calculated by:

$$y = x * cf, \qquad (2)$$

where x was defined as in Eq. (1) and cf was a correction factor that partitioned predation by double-crested cormorants among fish sizes based on sizes consumed by double-crested cormorants in Texas. The y value for each model interval was subtracted from the fish stock after the stock was multiplied by the weight change factor to calculate the new standing stock.

Counts of piscivorous birds were conducted at 8 reservoirs in Oklahoma during 2 field seasons for a total of 16 reservoir observations (for detailed methods, see Chapter II). Double-crested cormorants were most abundant during autumn (Sep-Dec) and spring (Mar-May) migrations in 14 of 16 observations and abundant throughout migration and wintering periods (Oct-May) in the remaining 2 observations (Fig. 1). Mean monthly cormorant-use-days/ha was calculated for migration and wintering months. Three modeling scenarios were developed based on those observations. In the migration scenario, double-crested cormorant predation was applied only during autumn and spring migrations (Sep-Dec and Mar-May). In the wintering scenario, predation was applied only during winter (Jan-Feb); the wintering scenario was not observed in Oklahoma but may occur in other areas. In the migration/wintering scenario, double-crested cormorant predation was applied from September through May. In our initial modeling, we set double-crested cormorant densities at 0, 5, 10, and 15 cormorant-use-days/ha/month corresponding to zero, low, moderate, and high densities. Mean monthly densities for 15 of 16 observations at Oklahoma reservoirs were <15 cormorant-use-days/ha/month (Appendix B). We also set densities equal to means at reservoirs used in migration only and in migration/wintering; annual fish consumption (kg/ha) at those levels was determined for each species.

Density-dependent growth has been observed in many fish populations (e.g., black crappie [*Pomoxis nigromaculatus*], Schramm et al. 1985; channel catfish, Tiemier 1957; gizzard shad, Buynak et al. 1992), and as double-crested cormorant predation increases, fish densities likely decrease. Therefore, instantaneous rate of growth of fish was manually increased in 10% increments at all levels of monthly cormorant-use-days. We used production rate (amount of fish biomass generated per unit area per unit time) to determine growth rate increases. We assumed that production was environmentally limited and that a given fish population was maximizing productivity before double-crested cormorant predation. Annual production was not allowed to exceed pre-double-crested cormorant levels after predation was applied and the instantaneous rate of growth was increased. The following measure of annual production/ha (*P*) was used:

$$P = \sum_{i=1}^{N} G_i * as_i \qquad (3)$$

where N was the total number of intervals, G_i was the instantaneous rate of growth of the ith interval, and as_i was the average weight of the stock during the ith interval. Instantaneous rates of growth for intervals that contained sizes of fish consumed by double-crested cormorants were increased in proportion to the amount of fish consumed during the interval. When predation was restricted to winter months when no growth occurred, instantaneous rate of growth of the nearest interval with growing fish was increased in proportion to the amount of fish consumed during the corresponding winter interval. The instantaneous rate of growth was increased until the annual production rate without double-crested predation was reached or until the rate of individual growth was increased by 50%. To be conservative, increases to growth were restricted to 50% based on our calculations from data in Mense (1976); mean length of the fastest growing fish ≤3 years of age were 80, 58, 49, and 72% greater than the statewide average (used in models) for channel catfish, gizzard shad, largemouth bass, and white crappie, respectively.

Parameter Estimation

Growth Rate.--Instantaneous rates of growth, G, for each species modeled were calculated from statewide Oklahoma average age and growth data (Mense 1976). Fish lengths were converted to weight using statewide average length-weight relationships (Mense 1976). Annual growth was assumed to occur at a constant rate over a 210-day growing season that extended from 1 May to 30 November (Jenkins 1976).

Natural Mortality.--Instantaneous rates of natural mortality, *M*, were calculated from annual rates of natural mortality (Ricker 1975). The rate of natural mortality incorporated all types of mortality except angling mortality and double-crested cormorant depredation. To minimize the amount of double-crested cormorant-related mortality included in rates of natural mortality, rates of natural mortality estimated prior to 1980 or prior to increased double-crested cormorant abundance were used whenever possible. A 30% annual rate of natural mortality was used for channel catfish (Ricker 1975, McCammon and LaFaunce 1961, Mayhew 1972), 32% for largemouth bass (Carlander 1977, summarized by Orth 1977), 45% for white crappie (Angyal et al. 1987, Colvin 1991a, Reed and Davies 1991, Zale and Stubbs 1991), and 55% for gizzard shad (Jester and Jensen 1972; our calculations from ODWC unpubl. data; Michaletz 1988; V. DiCenzo, Auburn Univ, pers. comm.). We assumed that natural mortality occurred at a constant rate throughout the year and was the same for all age classes of fish modeled (Ricker 1975).

Angling Mortality.--Instantaneous rates of angling mortality, *F*, were calculated from annual rates of angling mortality (Ricker 1975); no angling mortality was applied to gizzard shad. A 25% annual rate of angling mortality was used for channel catfish (Ricker 1975, McCammon and LaFaunce 1961, Mayhew 1972), 35% for largemouth bass (Carlander 1977, summarized by Orth 1977), and 36% for white crappie (Angyal et al. 1987, Colvin 1991a, Reed and Davies 1991, Zale and Stubbs 1991). The annual rate of angling mortality was varied among sizes of fish for each species because large fish are more likely to be kept by anglers than small fish. Angling mortality was first applied to channel catfish 254 - 304 mm in length, largemouth bass 242 - 308 mm in length, and white crappie 148 - 201 mm in length, at 25% of the rates given above; fish in these size ranges were kept by about 25% of fishermen (M. Ambler, ODWC, pers. comm.). Larger fish were subjected to the full rates of angling mortality. Angling mortality was partitioned by season based on creel survey results (Glass 1982, Angyal et al. 1987, Zale and Stubs 1991). The rate of angling mortality for channel catfish was partitioned as 25% spring (Mar-May), 60% summer (Jun-Aug), 15% autumn (Sep-Nov), and 0% winter (Dec-Feb); largemouth bass angling mortality was partitioned as 50% spring, 25% summer, 20% autumn, and 5% winter; and white crappie angling mortality was partitioned as 60% spring, 20% summer, 10% autumn, and 10% winter.

Standing Crop.--Estimates of standing crop used in models were based on those in Oklahoma and other midwestern states. Total standing crop was about 314 kg/ha (Jenkins 1955, Johnson 1974, Miller and Barclay 1974, Jenkins 1976). We assumed standing crops of 17 kg/ha (5.4% of total) for channel catfish (ODWC unpubl. data, Johnson 1974, Jenkins 1976, Willis and Jones 1986), 21 kg/ha (6.7%) for largemouth bass (ODWC unpubl. data, Carlander 1955, Jenkins 1955, Johnson 1974, Bryant and Houser 1971, Miller and Barclay

1974, Jenkins 1976, Willis and Jones 1986), 18 kg/ha (5.7%) for white crappie (ODWC unpubl. data, Johnson 1974, Miller and Barclay 1974, Jenkins 1976, Willis and Jones 1986, Angyal et al. 1987), and 183 kg/ha (58.3%) for gizzard shad (ODWC unpubl. data, Jenkins 1976, summarized by Kampa 1984).

Double-crested Cormorant Predation.--Percentages of fish in the diets of double-crested cormorants were calculated from Campo et al. (1993). Blue tilapia (*Tilapia aurea*) was a major prey species of double-crested cormorants in Texas (18.2% by weight), but they are uncommon in Oklahoma. Therefore, we recalculated the percentage of prey species consumed using the total weight of prey without blue tilapia. We assumed that channel catfish comprised 5.9% (by weight) of the diets of double-crested cormorants, largemouth bass 10.5%, crappie 6.8%, and shad 31.9%. Because black crappie and threadfin shad (*D. petenence*) are less abundant in Oklahoma than in Texas (K. Cunningham ODWC pers. comm.), we considered all crappie and shad in the diets of double-crested cormorants to be white crappie and gizzard shad, respectively.

Assumptions and Limitations

An underlying assumption of the Ricker model is that all conditions associated with the model are in equilibrium. It assumes constant steady-state conditions (i.e., recruitment, growth rate, natural mortality rate, angling mortality rate, double-crested cormorant predation rate, and standing crop) *in perpetuity* and provides estimates of angler yield and standing crop under static conditions. We varied double-crested cormorant densities and therefore, predation rates, to determine this effect on equilibrium yields and standing stocks. Growth rates also were varied to allow for various levels of density-dependent fish growth. Although predation and growth rates were varied among simulations, conditions during individual simulations remained constant in perpetuity. We also assumed that all forms of mortality were additive and that decreased fish abundance, resulting from double-crested cormorant predation, caused increased individual fish growth rates but not increased population production rates.

Because we modeled steady-state conditions, we were unable to directly account for annual variation in double-crested cormorant density. However, density estimates based on long-term abundances could be used to address this limitation. The diet of double-crested cormorants also remained constant in perpetuity, regardless of fish density; therefore, double-crested cormorants consumed the same weight of a given fish species whether the standing crop of the fish was 20 kg/ha or 2 kg/ha. The percentage of a given fish in their diet would be expected to decrease as the standing crop of the fish decreased. This limitation would cause our modeled fish populations to decrease more rapidly than would be expected in nature (i.e., some reductions in yield were mathematically possible but biologically unrealistic).

RESULTS

Increases to double-crested cormorant density and instantaneous rates of growth were the primary factors that affected fish standing crop and yield in our simulations (Figs. 2-5). Effects of cormorant-use-days/ha on standing crop and yield were greatest under the migration/wintering scenario, because double-crested cormorant predation was applied for the longest period of time (Sep-May). Results of our model simulations are presented in 2 ways for each fish species. First, we present effects of double-crested cormorant predation with no changes to instantaneous growth rate as predation increased; in other words, we assumed only density-independent growth, which was fixed for each fish species by size class, as described above. Second, we present effects of double-crested cormorant predation with the density-dependent increases to instantaneous growth rates of fish that were necessary to return fish production (kg/yr) to the level prior to double-crested cormorant predation. Standing crops and yields did not return completely to pre-double-crested cormorant levels because although the amount of fish produced returned to pre-predation levels, some of these fish were consumed by double-crested cormorants. In most cases, the increases to instantaneous growth rates that were necessary to achieve maximum compensation for double-crested cormorant predation were ≤40%. It is important to remember that all simulations assume *steady-state conditions in perpetuity*.

Channel Catfish

No Change to Instantaneous Growth Rate.--Channel catfish yield was 3.2 kg/ha without double-crested cormorant predation (Fig. 2). In the migration scenario, low (5 cormorant-use-days/ha/month) bird density reduced channel catfish yield by 37.5%. At high (15 cormorant-use-days/ha/month) double-crested cormorant density during migration and no density-dependent changes to instantaneous growth rates, it was mathematically possible to reduce channel catfish yield to 0 kg/ha. In the wintering scenario, low and high bird densities reduced channel catfish yield by 9.4 and 34.4%, respectively. In the migration/wintering scenario, low and high bird densities reduced channel catfish yield by 46.9 and 100%, respectively.

Change to Instantaneous Growth Rate.--In the migration scenario, low and high bird densities reduced channel catfish yield by 9.4 and 31.3%, given increases to instantaneous growth rates of 11.3 and 37.4%, respectively (such increases were required to return channel catfish production to pre-double-crested cormorant levels) (Fig. 2). In the wintering scenario, low and high bird densities reduced channel catfish yield by 3.1 and 18.8%, given increases to instantaneous growth rates of 24.0 and 50.0%, respectively. In the migration/wintering scenario, low and high bird densities reduced channel catfish yield by 12.5 and 40.6%, given increases to instantaneous growth rates of 13.3 and 44.1%, respectively. Changes to standing crops paralleled changes to yield (Fig. 2).

Largemouth Bass

No Change to Instantaneous Growth Rate.--Largemouth bass yield was 6.8 kg/ha without double-crested cormorant predation (Fig. 3). In the migration scenario, low and high bird densities reduced largemouth bass yield by 45.6 and 100%, respectively. In the wintering scenario, low and high bird densities reduced largemouth bass yield by 11.8 and 36.8%, respectively. In the migration/wintering scenario, low and high bird densities reduced largemouth bass yield by 57.4 and 100%, respectively.

Change to Instantaneous Growth Rate.--In the migration scenario, low and high bird densities reduced largemouth bass yield by 7.4 and 22.1%, given increases to instantaneous growth rates of 13.5 and 48.4%, respectively (Fig. 3). In the wintering scenario, low and high bird densities reduced largemouth bass yield by 1.5 and 5.9%, given increases to instantaneous growth rates of 8.4 and 26.9%, respectively. In the migration/wintering scenario, low and high bird densities reduced largemouth bass yield by 8.8 and 27.9%, given increases to instantaneous growth rates of 12.6 and 48.5%, respectively. Changes to standing crops paralleled changes to yield (Fig. 3).

White Crappie

No Change to Instantaneous Growth Rate.--White crappie yield was 5.7 kg/ha without double-crested cormorant predation (Fig. 4). In the migration scenario, low and high bird densities reduced white crappie yield by 10.5 and 35.1%, respectively. In the wintering scenario, low and high bird densities reduced white crappie yield by 1.8 and 7.0%, respectively. In the migration/wintering scenario, low and high bird densities reduced white crappie yield by 14.0 and 42.1%, respectively.

Change to Instantaneous Growth Rate.--In the migration scenario, low and high bird densities reduced white crappie yield by 5.3 and 15.8%, given increases to instantaneous growth rates of 4.0 and 12.8%, respectively (Fig. 4). In the wintering scenario, low and high bird densities reduced white crappie yield by 1.8 and 5.3%, given increases to instantaneous growth rates of 2.5 and 7.7%, respectively. In the migration/wintering scenario, low and high bird densities reduced white crappie yield by 7.0 and 21.1%, given increases to instantaneous growth rates of 3.8 and 12.2%, respectively. Changes to standing crops paralleled changes to yield (Fig. 4).

Gizzard Shad

No Change to Instantaneous Growth Rate.--Gizzard shad standing crop was 183.0 kg/ha without double-crested cormorant predation (Fig. 5). In the migration scenario, low and high bird densities reduced gizzard shad standing crop by 11.3 and 33.9%, respectively. In the wintering scenario, low and high bird densities reduced gizzard shad standing crop by 3.0 and 9.0%, respectively. In the migration/wintering scenario, low and high bird densities reduced gizzard shad standing crop by 14.3 and 42.8%, respectively.

Change to Instantaneous Growth Rate.--In the migration scenario, low and high bird densities reduced gizzard shad standing crop by 3.1 and 8.7%, given increases to instantaneous growth rates of 3.6 and 11.3%, respectively (Fig. 5). In the wintering scenario, low and high bird densities reduced gizzard shad standing crop by 0.9 and 2.6%, given increases to instantaneous growth rates of 2.8 and 8.7%, respectively. In the migration/wintering scenario, low and high bird densities reduced gizzard shad standing crop by 3.8 and 11.3%, given increases to instantaneous growth rates of 3.5 and 10.9%, respectively.

Specific Reservoir Effects

Double-crested cormorant density varied among Oklahoma reservoirs (Appendix B). Double-crested cormorant densities during 14 of 16 reservoir observations were greatest during autumn and spring migration with a mean monthly rate of 2.5 ± 4.2 (SD) cormorant-use-days/ha during migration (Sep-Dec and Mar-May). In a migration scenario with a bird density of 2.5 cormorant-use-days/ha/month, yields were reduced by 3.1 and 18.8% for channel catfish, 4.4 and 22.1% for largemouth bass, and 1.8 and 5.3% for white crappie with and without changes to instantaneous growth rates, respectively (Figs. 2-4). Gizzard shad standing crop was reduced by 1.5 and 5.6% with and without changes to instantaneous growth rates, respectively (Fig. 5). Annual rates of fish consumption were 0.53 kg/ha for channel catfish, 0.74 kg/ha for largemouth bass, 0.48 kg/ha for white crappie, and 2.23 kg/ha for gizzard shad.

Densities during 2 (both in 1992-93) of 16 observations were high during the migration/wintering period; the overall mean monthly rate from both observations combined was 23.4 ± 14.2 (SD) cormorant-use-days/ha (Oct-May). In a migration/wintering scenario with a bird density of 23.4 cormorant-use-days/ha/month from September through May in perpetuity (recall that such high densities were observed in only 1 of our 2 census years), channel catfish and largemouth bass yields each could be reduced by 100% (no fish reached harvestable size). Standing crops could be reduced by 86.5% and 97.1%, respectively. These reductions were mathematically possible but were primarily a result of our model's inability to decrease the percentage of a given fish species in the diet of double-crested cormorants as its density decreased. White crappie yields were reduced by 33.3 and 61.4% and gizzard shad standing crop by 17.5 and 66.8 with and without changes to instantaneous growth rates, respectively. Annual fish consumption was 6.32 kg/ha for channel catfish, 8.85 kg/ha for largemouth bass, 5.73 for white crappie, and 26.87 kg/ha for gizzard shad.

DISCUSSION

Channel catfish and largemouth bass yields were affected most by simulated double-crested cormorant predation primarily because both fish were long-lived; therefore, the standing crops were divided among many age classes, which resulted in relatively low standing crops of the small fish that were consumed most often by double-crested cormorants. Largemouth bass also were affected more than other sport fish in some situations because they were the most abundant sport fish in the diets of double-crested cormorants (although gizzard shad were a greater percentage of double-crested cormorant diets, they had a substantially greater standing crop). Largemouth bass $\leq$1 year of age were predated more heavily than other young-of-year (YOY) fishes, which impacted largemouth bass when standing stock was at its lowest value.

White crappie yield was less affected by double-crested cormorant predation than other sport fish primarily because white crappie were short-lived and thus a greater percentage of the standing crop was in young age classes that were more able to withstand heavy predation. White crappie also were a relatively small percentage of the diets of double-crested cormorants (6.8%).

In our model, double-crested cormorants consumed a greater biomass of gizzard shad than any other prey species, but gizzard shad abundance was reduced by the smallest percentage of any prey species. Gizzard shad standing crop was almost 10 times greater than any other prey species and therefore was able to withstand extensive double-crested cormorant predation.

Increased instantaneous growth rates of fish as standing crop decreased compensated for much of the loss from double-crested cormorant predation in our simulations. We believe that such effects occur in wild fish populations and can be justified by considerable empirical evidence in the literature. Tiemier (1957) reported density-dependent growth of channel catfish in ponds. Muoneke et al. (1992) recommended reduction of white crappie abundance to improve growth. Black crappie growth was significantly greater following removal of fish by commercial fishermen (Schramm et al. 1985). Mean black crappie length "increased appreciably" following mechanical removal of fish (Hanson et al. 1983). Length of YOY gizzard shad and adult growth were inversely related to stocking density in ponds (Stock 1971, Kampa 1984, Buynak et al. 1992). Density-dependent growth also has been demonstrated for populations of Arctic char (*Salvelinus alpinus*) (Amundsen et al 1993), black crappie (Miller et al. 1990), bluegill sunfish (*Lepomis macrochirus*) (Murnyak et al. 1984), brook trout (*Salvelinus fontinalis*) (Greene 1955, Reimers 1979, Donald and Alger 1989), lake herring (*Coregonus artedii*) (Bowen et al. 1991), northern pike (*Esox lucius*) (Diana 1987), perch (*Perca fluviatilis*) (Rask 1992), roach (*Rutilus rutilus*) (Burrough and Kennedy 1979), rock bass (*Ambloplites rupestris*) (Beckman 1941, 1943), and sockeye salmon (*Oncorhynchus nerka*) (Goodlad et at. 1974).

Growth rates in our models generally had to be increased <40% to increase fish production to pre-double-crested cormorant levels, but they could have been realistically increased as much as 49-80% based on the difference between the average (used in our models) and fastest growing fish in Oklahoma (Mense 1976). Therefore, our increases to instantaneous growth rates were conservative and may have overemphasized the impact of double-crested cormorant predation. Without increased growth rates and with high double-crested cormorant numbers in perpetuity, yields of channel catfish and largemouth bass theoretically could be reduced to zero (i.e., no fish reached harvestable size). This assumed that conditions were in equilibrium in perpetuity and percentages of a fish species in diets of double-crested cormorants remained constant regardless of fish abundance. However, if the standing crop of a given fish decreased, its prevalence in the diets of double-crested cormorants likely would decrease. As abundances of all fish species were reduced, double-crested cormorant density on a reservoir also would be expected to diminish. Eventually, a fish population would stabilize at a lower density, rather than being eliminated. Alternatively, fish populations may be cyclic, decreasing in years of high double-crested cormorant density and rebuilding in subsequent years.

Double-crested cormorant density at Oklahoma reservoirs from 1992-94 varied among reservoirs and between years (Appendix B). Current double-crested cormorant predation at most reservoirs (14 of 16 reservoir observations) could reduce fish yields by <5%. However, predation at other reservoirs (2 of 16 observations) could reduce fish yield *if* it persisted indefinitely. Modeled losses were based on the assumption that *all* conditions were in *static* *equilibrium*. Therefore, double-crested cormorant density would have to remain at 23.4 cormorant-use-days/ha/month from September through May every year in perpetuity to achieve the modeled reductions in fish yield. This did not occur at either reservoir (Fort Gibson and Webber's Falls) that received high double-crested cormorant use during migration/wintering. Each reservoir had a high double-crested cormorant density in migration/wintering during only 1 of our 2 census years. Double-crested cormorant densities in the following year were substantially lower than the preceding year (Appendix B), and densities were greatest during migration rather than during migration/wintering.

Double-crested cormorant densities on Oklahoma reservoirs were highly variable, and some reservoirs appeared to be 'hot spots' for double-crested cormorant activity in 1 of our 2 census years. Because our model simulated equilibrium situations, double-crested cormorant density in the model also were set at a fixed level. Overestimation of long-term double-crested cormorant density may have resulted if counts were conducted only during years of exceptionally high bird density, and underestimation may have occurred if these counts failed to include years of high densities. Because counts were conducted for only 2 years, we were unable to determine the frequency and location of 'hot spots.'

Total cormorant-use-days/ha from about September through May on individual Oklahoma reservoirs (0.2-243.3) were substantially greater than densities at Utah reservoirs (0-34 bird-days/ha) from about March through November (Ottenbacher et al. 1994). However, annual rates of trout consumption in Utah ranged from 0-9.9 kg/ha and were comparable to modeled consumption rates of individual sport fish species in Oklahoma (0.5-8.9 kg/ha). Rates of trout consumption were high relative to densities of double-crested cormorants because trout comprised 80-100% of the diets of double-crested cormorants in 14 of 22 reservoir observations (Ottenbacher et al. 1994). Following Campo et al. (1993), we assumed that individual sport fishes comprised only 5.9-10.5% of double-crested cormorant diets in Oklahoma.

Effects of double-crested cormorant predation on fish populations could be detrimental, beneficial, or neutral if effects negate each other. Removal of fish by double-crested cormorants could reduce survival, standing crop, and yield of a particular fish population. By consuming small sizes of fish, double-crested cormorants could reduce the amount of forage available to large sport fish. On the other hand, removal of fish may be beneficial to the species consumed and other fish species. Fish removal can decrease competition and thereby increase rate of growth of the remaining fish, potentially alleviating stunting problems that can occur in fish populations (e.g., Beckman 1941, 1943;

Greene 1955; Burrough and Kennedy 1979; Hanson et al. 1983; Donald and Alger 1989).

Gizzard shad can be beneficial or detrimental to reservoir sport fish populations. Gizzard shad can provide forage for large sport fish, but they can also compete for zooplankton with juvenile sport fish (Kirk and Davies 1987, Guest et al. 1990, Dettmers and Stein 1992) and are of no angling value. Gizzard shad tend to overpopulate, and removal of these excess fish has been accomplished by chemical treatments or by the introduction of predatory fish (reviewed by Noble 1981 and by Devries and Stein 1990). Double-crested cormorant predation conceivably could function as a biological control of gizzard shad populations under the appropriate conditions. According to Kampa (1984), lower gizzard shad densities can result in an increased rate of growth, better adult shad condition, increased reproductive potential, and large crops of YOY fish. In time, greater densities of YOY fish may lead to stunted fish growth thereby increasing the amount of time that fish are available as forage (Kampa 1984).

Reported effects of double-crested cormorant predation on fish populations in North America vary widely both among and within states and Canadian provinces. Double-crested cormorants tend to consume whatever fishes are most abundant and generally consume rough and forage fishes rather than commercial or sport fishes. Double-crested cormorants generally have negligible impacts on sport fish populations (e.g., Craven and Lev 1987, Hobson *et al.* 1989); however, potential reductions in sport fish populations have been reported in Canada (Baillie 1947, Ayles et al 1976, Christie et al 1987), North Dakota (Myers and Peterka 1976), Texas (Campo et al 1993), and Utah (Ottenbacher et al. 1994). The extent of sport fish losses in Texas was a function of sport fish abundance (Campo et al. 1993), and substantial sport fish losses occurred in reservoirs that contained predominantly sport fish species. Double-crested cormorants also consumed harvestable size sport fish in some reservoirs in Texas.

MANAGEMENT IMPLICATIONS

Our modeling suggests that current levels of double-crested cormorants, averaged across the 8 reservoirs that we sampled, have a negligible effect on sport and forage fish populations in Oklahoma. Catfish and largemouth bass could be affected to a greater extent than white crappie. If large numbers of double-crested cormorants (e.g., 23 cormorants/ha/day as was observed during 1 winter only at Fort Gibson and Webber's Falls) used the same reservoir every year in perpetuity, significant reductions of catfish and largemouth bass yields would be mathematically possible. Importantly, we did not observe repeated use of reservoirs by such densities of double-crested cormorants year-after-year and therefore consider such a scenario to be unlikely biologically.

Predation by double-crested cormorants theoretically could reduce sport fish yield in some situations, and future monitoring of double-crested cormorant density on reservoirs that receive heavy use year-after-year is warranted. Potential problems may be most likely to occur on reservoirs with large sport fish populations because double-crested cormorants tend to consume whatever fishes are most abundant (Lewis 1929, Craven and Lev 1987, Campo *et al.* 1988, Hobson *et al.* 1989). Such losses may be avoided with high angler and recreational pressure on such reservoirs; double-crested cormorant density was correlated negatively with human disturbance on Oklahoma reservoirs (see Chapter II). Because of potential impact to sport fisheries, more study and complex modeling are recommended. Intensive study on a reservoir inhabited by abundant sport fish and double-crested cormorant populations may be the most useful. These data would improve future modeling attempts and facilitate adaptation of models to specific reservoirs. Future models should address variability in double-crested cormorant occurrence and relationships between fish abundance and double-crested cormorant foraging habits.

LITERATURE CITED

Amundsen, P.-A. Klemetsen, and P. E. Grotnes. 1993. Rehabilitation of a stunted population of Arctic char by intensive fishing. N. Am. J. Fish. Manage. 13:482-491.

Angyal, R., R. Glass, and O. E. Maughan. 1987. The characteristics of the white crappie population of Sooner Lake, Oklahoma. Proc. Okla. Acad. Sci. 67:1-10.

Ayles, G. B., J. G. I. Lark, J. Barica, and H. Kling. 1976. Seasonal mortality of rainbow trout (*Salmo gairdneri*) planted in small eutrophic lakes of central Canada. J. Fish. Res. Board Can. 33:647-655.

Baillie, J. L., Jr. 1947. The double-crested cormorant nesting in Ontario. Can. Field-Nat. 61(4):119-126.

Beckman, W. C. 1941. Increased growth rate of rock bass, *Ambloplites rupestris* (Rafinesque), following reduction in the density of the population. Trans. Am. Fish. Soc. 70:143-148.

_____. 1943. Further studies on the increased growth rate of rock bass, *Ambloplites rupestris* (Rafinesque), following reduction in the density of the population. Trans. Am. Fish. Soc. 72:72-78.

Bowen, S. H., D. J. D'Angelo, S. H. Arnold, M. J. Keniry, and R. J. Albrecht. 1991. Density-dependent maturation, growth, and female dominance in Lake Superior lake herring (*Coregonus artedii*). Can. J. Fish. Aquat. Sci. 48:569-576.

Brugger, K. E. 1993. Digestibility of three fish species by double-crested cormorants. Condor 95:25-32.

Bryant, H. E., and A. Houser. 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals Reservoirs. Pages 349-357 *in* G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc., Washington, D.C.

Buckley, P. A., and F. G. Buckley. 1984. Expanding double-crested cormorant and laughing gull populations on Long Island, NY. Kingbird 34:146-155.

Burrough, R. J., and C. R. Kennedy. 1979. The occurrence and natural alleviations of stunting in a population of roach, *Rutilus rutilus* (L.). J. Fish Biol. 15:93-109.

Buynak, G. L., R. S. Hale, and B. Mitchell. 1992. Differential growth of young-of-year gizzard shad in several Kentucky reservoirs. N. Am. J. Fish. Manage. 12:656-662.

Campo, J. J., B. Thompson, J. C. Barron, P. P. Durocher, and S. J. Gutreuter. 1993. Diet of double-crested cormorants wintering in Texas. J. Field Ornith. 64:135-144.

Carlander, K. D. 1955. The standing crop of fish in lakes. J. Fish. Res. Board Can. 12:543-570.

_____. 1977. Handbook of freshwater fishery biology, volume 2. Iowa State Univ. Press, Ames. 431pp.

Chadwick, H. K. 1969. An evaluation of striped bass angling regulations based on an equilibrium yield model. Calif. Fish and Game 55:42-49.

Christie, W. J., K. A. Scott, P. G. Sly, and R. H. Strus. 1987. Recent changes in the aquatic food web of eastern Lake Ontario. Can. J. Fish. Aquat. Sci. 44:37-52.

Colvin, M. A. 1991a. Population characteristics and angler harvest of white crappies in four large Missouri reservoirs. N. Am. J. Fish. Manage. 11:572-584.

_____. 1991b. Evaluation of minimum-size limits and reduced daily limits on the crappie populations and fisheries in five large Missouri reservoirs. N. Am. J. Fish. Manage. 11:585-597.

Craven, S. R., and E. Lev. 1987. Double-crested cormorants in the Apostle Islands, Wisconsin, USA: population trends, food habits, and fishery depredations. Colonial Waterbirds 10:64-71.

Dettmers, J. M., and R. A. Stein. 1992. Food consumption by larval gizzard shad: zooplankton effects and implications for reservoir communities. Trans. Am. Fish. Soc. 121:494-507.

DeVries, D. R., and R. A. Stein. 1990. Manipulating shad to enhance sport fisheries in North America: an assessment. N. Am. J. Fish. Manage. 10:209-223.

Diana, J. S. 1987. Simulation of mechanisms causing stunting in northern pike populations. Trans. Am. Fish. Soc. 116:612-617.

Donald, B. D., and D. J. Alger. 1989. Evaluation of exploitation as a means of improving growth in a stunted population of brook trout. N. Am. J. Fish. Manage. 9:177-183.

Glahn, J. F., and K. E. Brugger. 1995. The impact of double-crested cormorants on the Mississippi Delta catfish industry: a bioenergetics model. *In press in* D. N. Nettleship and D. C. Dubby, eds. The double-crested cormorant: biology, conservation and management. Colonial Waterbirds Spec. Pub. 17.

Glass, R. D. 1982. Exploitation of white crappie and associated species in Sooner Lake, Oklahoma. M.S. Thesis, Okla. State Univ, Stillwater. 61pp.

Goodlad, J. C., T. W. Gjernes, and E. L. Brannon. 1974. Factors affecting sockeye salmon (*Oncorhynchus nerka*) growth in four lakes of the Fraser River system. J. Fish. Res. Board Can. 31:871-892.

Goodyear, C. P. 1984. Analysis of potential yield per recruit for striped bass produced in Chesapeake Bay. N. Am. J. Fish. Manage. 4:488-496.

Greene, A. F. C. 1955. Will stunted brook trout grow? Prog. Fish-Cult. 17:91.

Guest, W. C., R. W. Drenner, S. T. Threlkeld, F. D. Martin, and J. D. Smith. 1990. Effects of gizzard shad and threadfin shad on zooplankton and young-of-year white crappie production. Trans. Am. Fish. Soc. 119:529-536.

Hanson, D. A., B. J. Belonger, and D. L. Schoenike. 1983. Evaluation of a mechanical population reduction of black crappie and black bullheads in a small Wisconsin Lake. N. Am. J. Fish. Manage. 3:41-47.

Hobson, K. A,, R. W. Knapton, and W. Lysack. 1989. Population, diet and reproductive success of double-crested cormorants breeding on Lake Winnipegosis, Manitoba, in 1987. Colonial Waterbirds 12:191-197.

Jenkins, R. M. 1955. The effect of gizzard shad on the fish population of a small Oklahoma lake. Trans. Am. Fish. Soc. 85:58-74.

_____. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. Ann. Okla. Acad. Sci. 5:11-20.

Jester, D. B., and B. L. Jensen. 1972. Life history and ecology of the gizzard shad, *Dorosoma cepedianum* (Le Sueur), with reference to Elephant Butte Lake. New Mexico State Univ. Agric. Exp. Stn. Res. Rep. 218, Las Cruces. 56pp.

Johnson, J. N. 1974. Effects of water level fluctuations on growth, relative abundance and standing crop of fishes in Lake Carl Blackwell, Oklahoma. M.S. Thesis, Okla. State Univ., Stillwater. 72pp.

Kampa, J. M. 1984. Density-dependent regulation of gizzard shad populations in experimental ponds. M.S. Thesis, Univ. Missouri, Columbia. 71pp.

Kirk, J. P., and W. D. Davies. 1987. Competitive influences of gizzard shad on largemouth bass and bluegill in small impoundments. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 39:116-124.

Koonz, W. H., and P. W. Rakowski. 1985. Status of colonial waterbirds nesting in southern Manitoba. Can. Field-Nat. 99:19-29.

Lewis, H. F. 1929. The natural history of the Double-crested Cormorant (*Phalacrocorax auritus auritus* (Lesson)). Ru-Mi-Lou Books, Ottawa, Canada. 94pp.

Ludwig, J. P. 1984. Decline, resurgence and population dynamics of Michigan and Great Lakes double-crested cormorants. Jack Pine Warbler 62:92-102.

Mayhew, J. 1972. Some biological characteristics of a channel catfish population in the lower Des Moines River with an evaluation of potential commercial harvest. Iowa Conserv. Comm. Fish. Res. Tech. Series 72-2.

McCammon, G. W., and D. A. Lafaunce. 1961. Mortality rates and movement in the channel catfish population of the Sacramento Valley. Calif. Fish and Game 47:5-26.

Mense, J. B. 1976. Growth and length-weight relationships of twenty-one reservoir fishes in Oklahoma. Okla. Fish. Res. Lab., Bull. 13. 153pp.

Michaletz, P. 1988. A review of the ecology and management of gizzard and threadfin shad. Missouri Dep. Conserv., Fed. Aid Proj. F-1-R-37-I-28-1

Final Rep., Jefferson City. 38pp.

Miller, S. W., and J. S. Barclay. 1974. Predation in warm water reservoirs by wintering common mergansers. Proc. Southeast. Assoc. Game and Fish Comm. 28:243-252.

Miller, S. J., D. D. Fox, L. A. Bull, and T. D. McCall. 1990. Population dynamics of black crappie in Lake Okeechobee, Florida, following suspension of commercial harvest. N. Am. J. Fish. Manage. 10:98-105.

Muoneke, M. I., C. C. Henry, and O. E. Maughan. 1992. Population structure and food habits of white crappie *Pomoxis annularis* Rafinesque in a turbid Oklahoma reservoir. J. Fish Biol. 41:647-654.

Murnyak, D. F., M. O. Murnyak, and L. J. Wolgast. 1984. Growth of stunted and nonstunted bluegill sunfish in ponds. Prog. Fish-Cult. 46:133-138.

Myers, G. L., and J. J. Peterka. 1976. Survival and growth of rainbow trout (*Salmo gairdneri*) in four prairie lakes, North Dakota. J. Fish. Res. Board Can. 33:1192-1195.

Noble, R. L. 1981. Management of forage fishes in impoundments of the southern United States. Trans. Am. Fish. Soc. 110:738-750.

Orth, D. J. 1977. Development of a computer simulation model of largemouth bass population dynamics. M.S. Thesis, Okla. State Univ., Stillwater. 134pp.

Ottenbacher, M. J., D. K. Hepworth, and L. N. Berg. 1994. Observations on double-crested cormorants (*Phalacrocorax auritus*) at sportfishing waters in southwestern Utah. Great Basin Nat. 54:272-286.

Price, I. M., and D. V. Weseloh. 1986. Increased numbers and productivity of double-crested cormorants, *Phalacrocorax auritus*, on Lake Ontario. Can. Field-Nat. 100:474-482.

Rask, M. 1992. Changes in the density, population structure, growth and reproduction of perch, *Perca fluviatilis* L. in two acidic forest lakes in southern Finland. Envir. Poll. 78:121-125.

Reed, J. R., and W. D. Davies. 1991. Population dynamics of black crappies and white crappies in Weiss Reservoir, Alabama: implications for the implementation of harvest restrictions. N. Am. J. Fish. Manage. 11:598-603.

Reimers, N. 1979. A history of a stunted brook trout population in an alpine lake: a life span of 24 years. Calif. Fish and Game 65:195-215.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull., 191:382pp.

Sakagawa, G. T., and R. L. Pycha. 1971. Population biology of lake trout (*Salvelinus namaycush*) of Lake Superior before 1950. J. Fish. Res. Board Can. 28:65-71.

Schramm, H. L., Jr., M. W. Collopy, and E. A. Okrah. 1987. Potential problems of bird predation for fish culture in Florida. Prog. Fish-Cult. 49:44-48.

_____, Jr., J. V. Shireman, D. E. Hammond, D. M. Powell. 1985. Effect of commercial harvest of sport fish on the black crappie population in Lake Okeechobee, Florida. N. Am. J. Fish. Manage. 5:217-226.

Stock, J. N. 1971. A study of some effects of population density on gizzard shad and bluegill growth and recruitment in ponds. M.S. Thesis, Univ. Missouri, Columbia. 107pp.

Tiemier, O. W. 1957. Notes on stunting and recovery of the channel catfish. Trans. Kansas Acad. Sci. 60:294-296.

Vermeer, K. and L. Rankin. 1984. Population trends in nesting double-crested and pelagic cormorants in Canada. Murrelet 65:1-9.

Willis, D. W. and L. D. Jones. 1986. Fish standing crops in wooded and nonwooded coves of Kansas reservoirs. N. Am. J. Fish. Manage. 6:105-108.

Zale, A. V., and K. C. Stubbs. 1991. Development of a white crappie fishery in a stage-fill impoundment in Oklahoma. Okla. Dep. Wildl. Conserv., Fed. Aid Proj. F-41-R-13 Final Rep., Oklahoma City. 35pp.

LIST OF FIGURES

Fig. 1. Mean monthly double-crested cormorant density (cormorant-use-days/ha; error bars=SD) at 8 Oklahoma reservoirs in 1992-94. Eight reservoirs were surveyed for 2 years for a total of 16 reservoir observations; 14 indicated migration use only and 2 indicated migration and wintering use. Note different scales on the 2 graphs.

Fig. 2. Standing crop (kg/ha) and annual yield (kg/ha) of channel catfish modeled with a modified Ricker equilibrium-yield model, given variable double-crested cormorant densities and increases in the instantaneous rates of growth of fish, during migration (Sep-Dec and Mar-May), wintering (Jan-Feb), and migration/wintering (Sep-May) periods. The terminal point on those lines illustrating double-crested cormorant predation represents the percent increase in instantaneous growth rate on the x-axis necessary to return yield and standing crop to pre-double-crested cormorant production levels.

Fig. 3. Standing crop (kg/ha) and annual yield (kg/ha) of largemouth bass modeled with a modified Ricker equilibrium-yield model, given variable double-crested cormorant densities and increases in the instantaneous rates of growth of fish, during migration (Sep-Dec and Mar-May), wintering (Jan-Feb), and migration/wintering (Sep-May) periods. The terminal point on those lines illustrating double-crested cormorant predation represents the percent increase in instantaneous growth rate on the x-axis necessary to return yield and standing

crop to pre-double-crested cormorant production levels.

Fig. 4. Standing crop (kg/ha) and annual yield (kg/ha) of white crappie modeled with a modified Ricker equilibrium-yield model, given variable double-crested cormorant densities and increases in the instantaneous rates of growth of fish, during migration (Sep-Dec and Mar-May), wintering (Jan-Feb), and migration/wintering (Sep-May) periods. The terminal point on those lines illustrating double-crested cormorant predation represents the percent increase in instantaneous growth rate on the x-axis necessary to return yield and standing crop to pre-double-crested cormorant production levels.

Fig. 5. Standing crop (kg/ha) of gizzard shad modeled with a modified Ricker equilibrium-yield model, given variable double-crested cormorant densities and increases in the instantaneous rates of growth of fish, during migration (Sep-Dec and Mar-May), wintering (Jan-Feb), and migration/wintering (Sep-May) periods. The terminal point on those lines illustrating double-crested cormorant predation represents the percent increase in instantaneous growth rate on the x-axis necessary to return standing crop to pre-double-crested cormorant production levels.

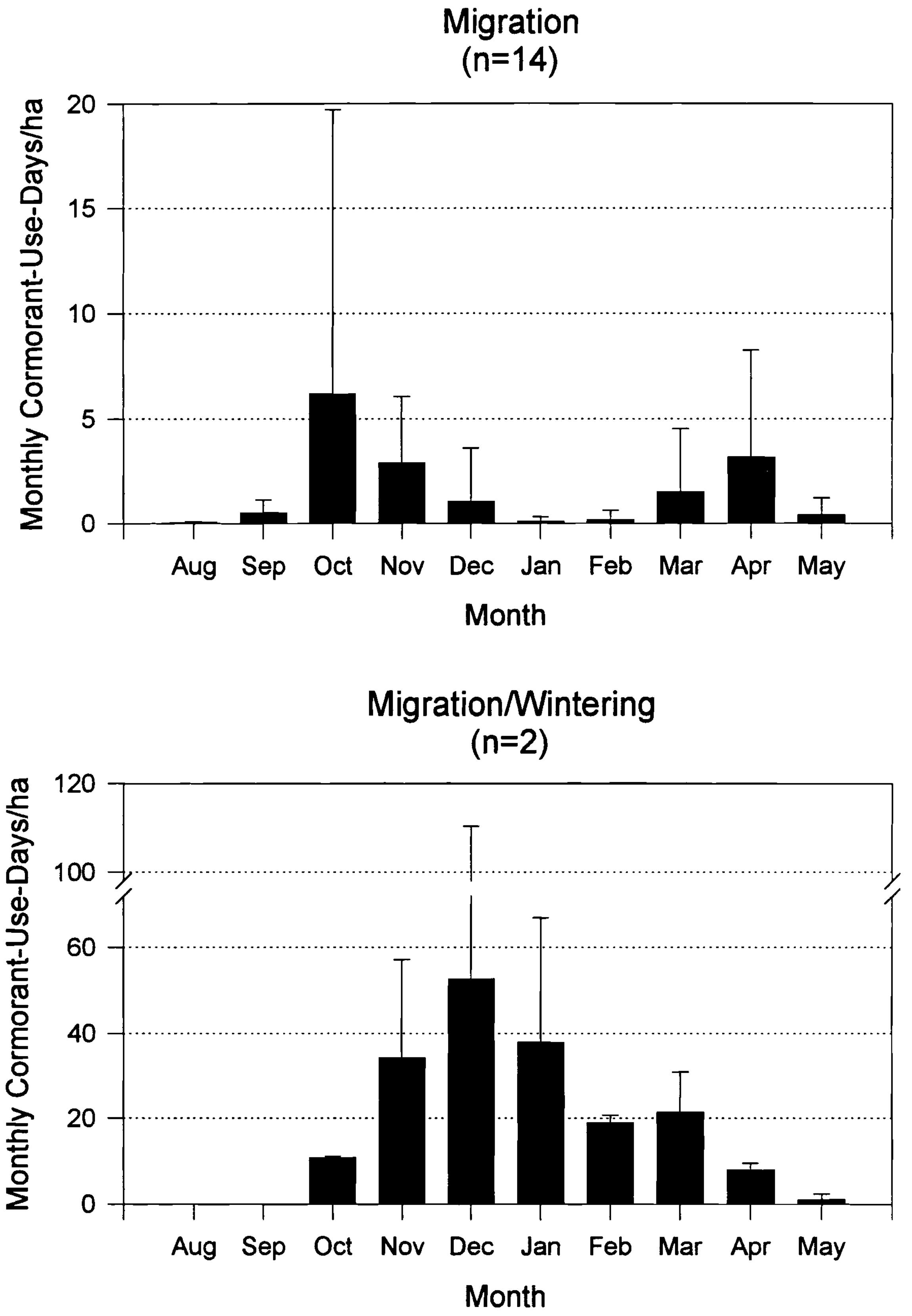

Migration
(n=14)
Monthly Cormorant-Use-Days/ha
20
15
10
5
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Month
Migration/Wintering
(n=2)
Monthly Cormorant-Use-Days/ha
120
100
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Month

Fig. 1

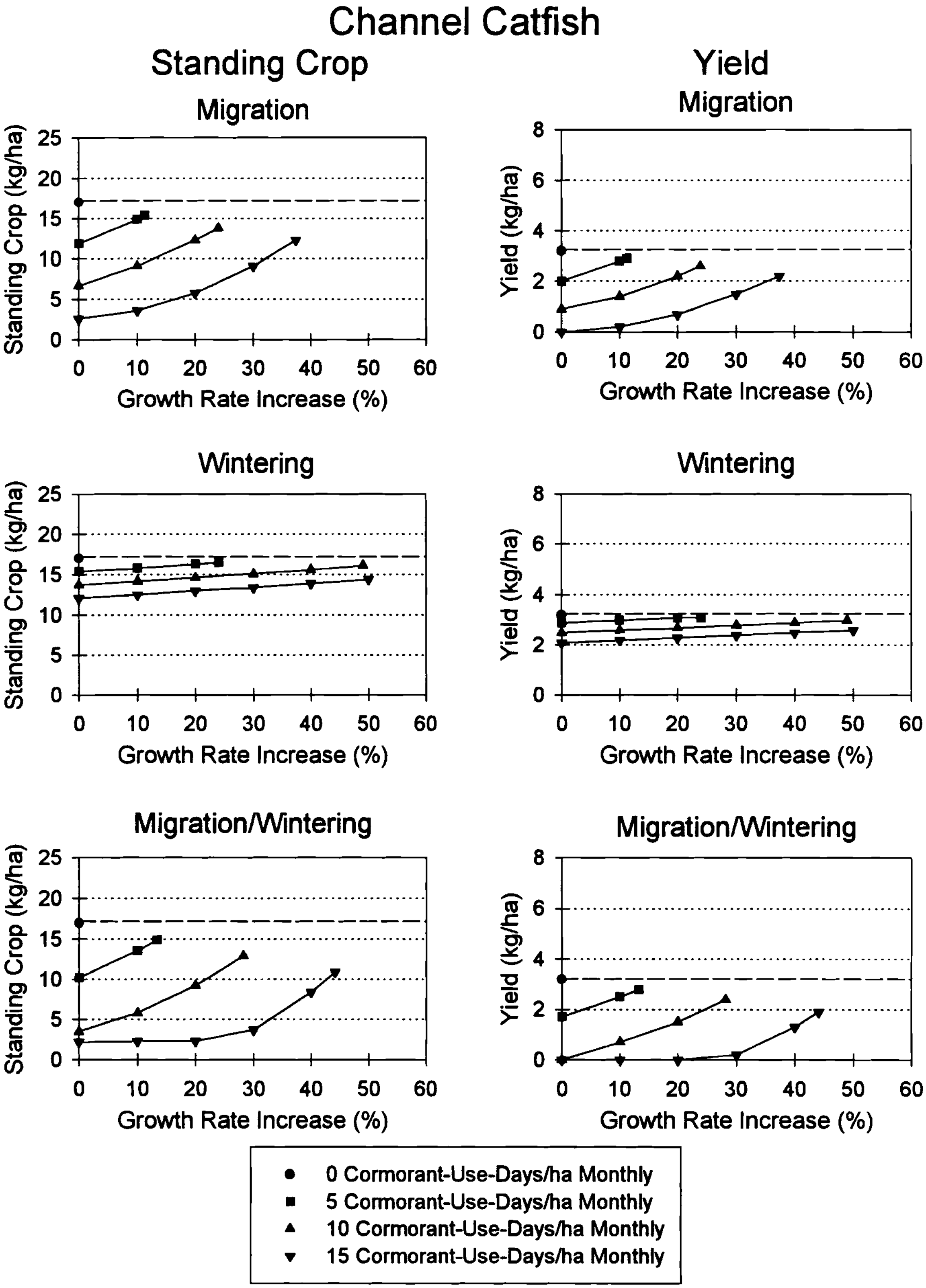

Channel Catfish
Standing Crop
Yield
Migration
Standing Crop (kg/ha)
25
20
15
10
5
0
0
10
20
30
40
50
60
Growth Rate Increase (%)
Migration
Yield (kg/ha)
8
6
4
2
0
0
10
20
30
40
50
60
Growth Rate Increase (%)
Wintering
Standing Crop (kg/ha)
Growth Rate Increase (%)
Wintering
Yield (kg/ha)
Growth Rate Increase (%)
Migration/Wintering
Standing Crop (kg/ha)
Growth Rate Increase (%)
Migration/Wintering
Yield (kg/ha)
Growth Rate Increase (%)
● 0 Cormorant-Use-Days/ha Monthly
■ 5 Cormorant-Use-Days/ha Monthly
▲ 10 Cormorant-Use-Days/ha Monthly
▼ 15 Cormorant-Use-Days/ha Monthly

Fig. 2

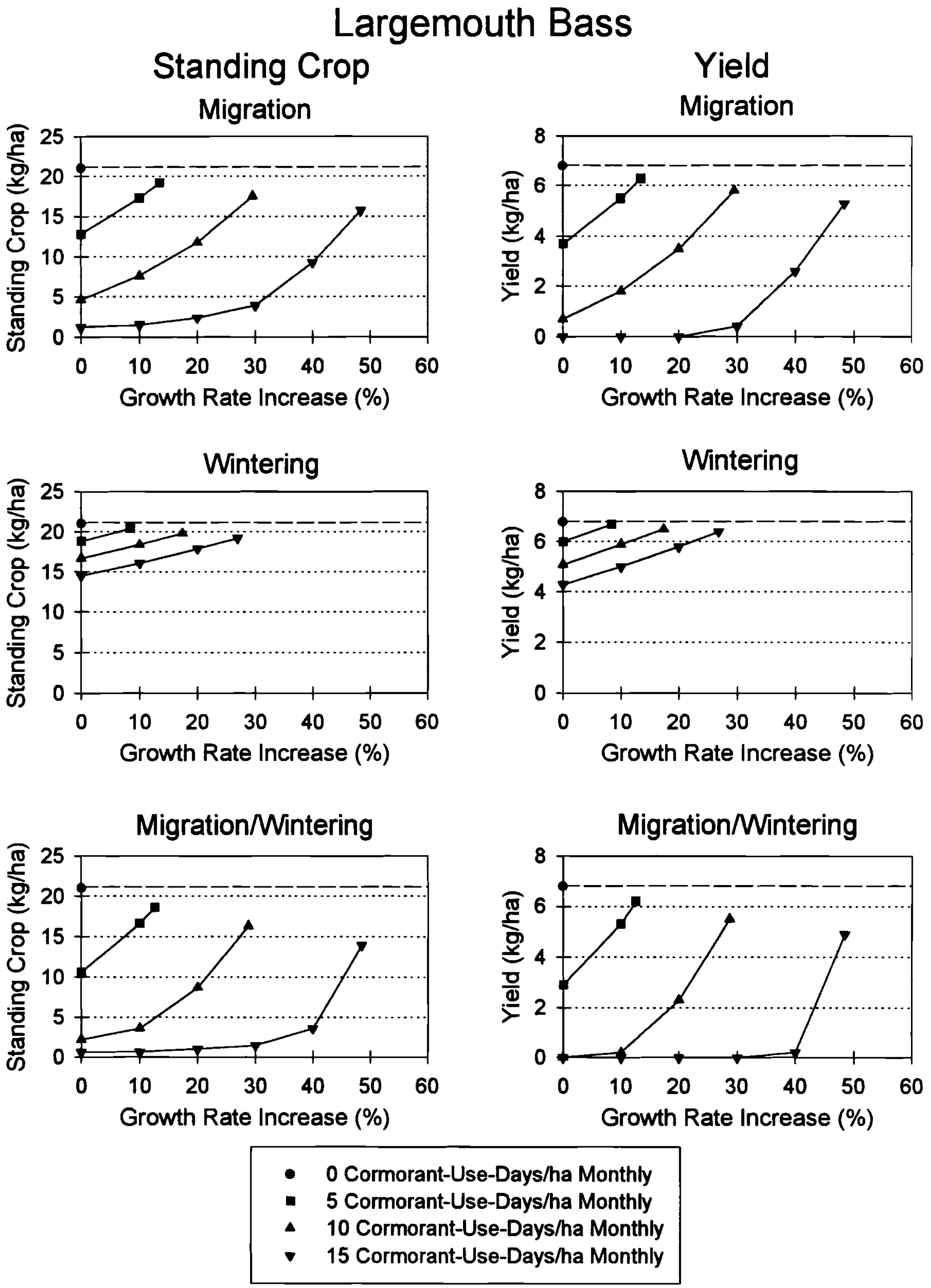

Largemouth Bass
Standing Crop
Yield
Migration
Wintering
Migration/Wintering
Standing Crop (kg/ha)
Yield (kg/ha)
Growth Rate Increase (%)
0
5
10
15
20
25
0
2
4
6
8
0
10
20
30
40
50
60
● 0 Cormorant-Use-Days/ha Monthly
■ 5 Cormorant-Use-Days/ha Monthly
▲ 10 Cormorant-Use-Days/ha Monthly
▼ 15 Cormorant-Use-Days/ha Monthly

Fig. 3

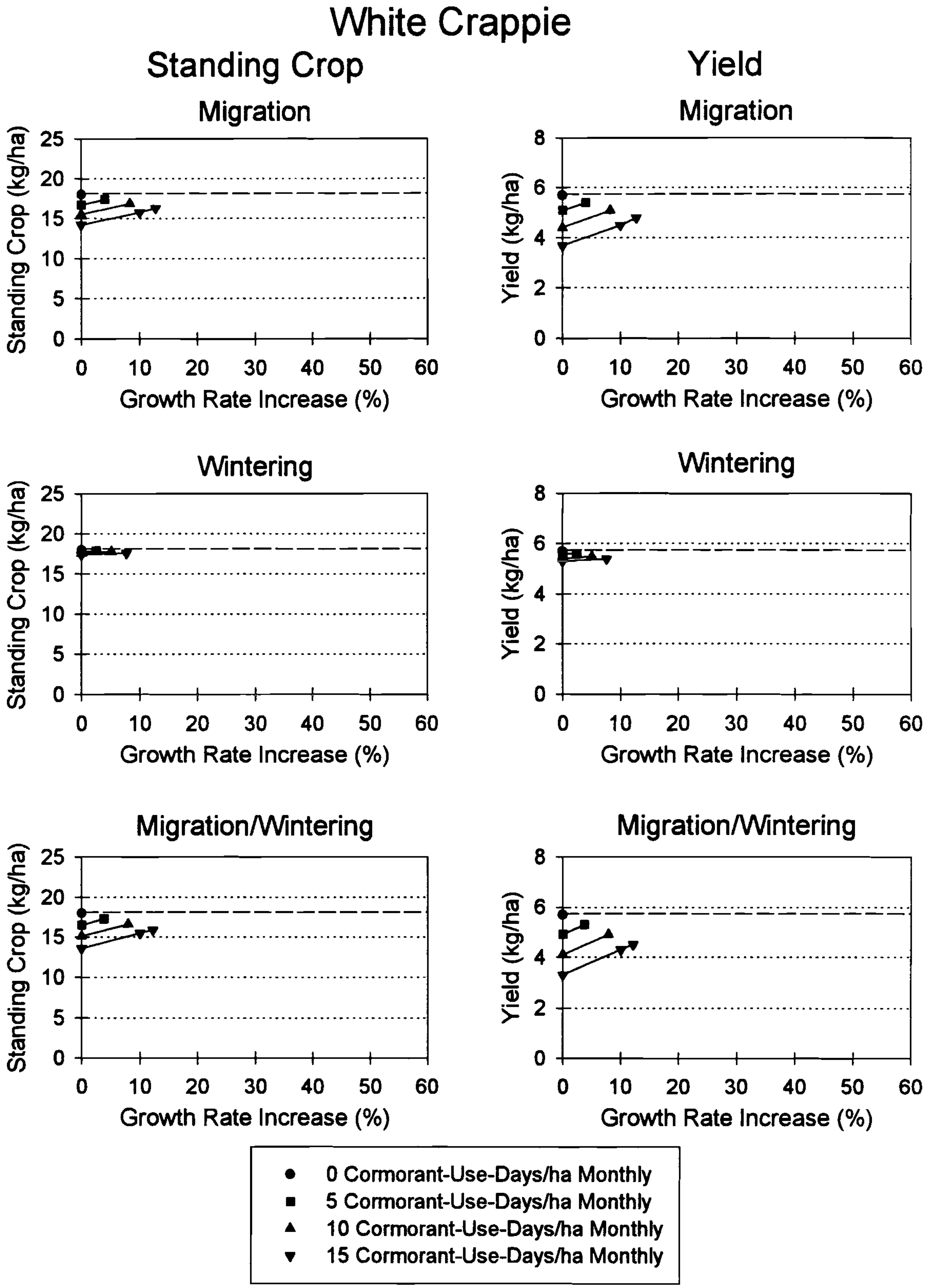

White Crappie
Standing Crop
Yield
Migration
Wintering
Migration/Wintering
Standing Crop (kg/ha)
Yield (kg/ha)
Growth Rate Increase (%)
0
5
10
15
20
25
2
4
6
8
30
40
50
60
● 0 Cormorant-Use-Days/ha Monthly
■ 5 Cormorant-Use-Days/ha Monthly
▲ 10 Cormorant-Use-Days/ha Monthly
▼ 15 Cormorant-Use-Days/ha Monthly

Fig. 4

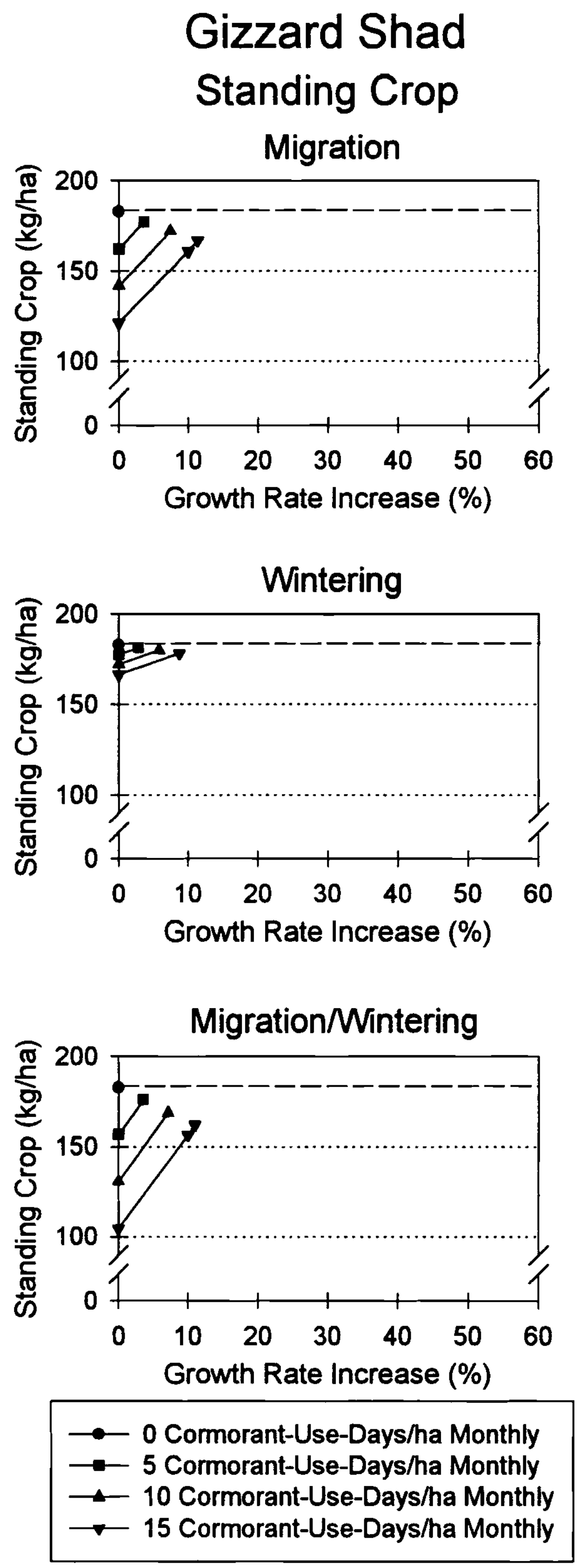

Gizzard Shad
Standing Crop
Migration
Standing Crop (kg/ha)
200
150
100
0
0
10
20
30
40
50
60
Growth Rate Increase (%)
Wintering
Standing Crop (kg/ha)
200
150
100
0
0
10
20
30
40
50
60
Growth Rate Increase (%)
Migration/Wintering
Standing Crop (kg/ha)
200
150
100
0
0
10
20
30
40
50
60
Growth Rate Increase (%)
0 Cormorant-Use-Days/ha Monthly
5 Cormorant-Use-Days/ha Monthly
10 Cormorant-Use-Days/ha Monthly
15 Cormorant-Use-Days/ha Monthly

Fig. 5

CHAPTER IV

DOUBLE-CRESTED CORMORANT DEPREDATION OF CATFISH AT AQUACULTURE FACILITIES IN OKLAHOMA

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 density. 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 ± 8,729 kg (¯ ± SE) of catfish, valued at $13,672-$36,195 (depending on size of fish consumed), which was equivalent to about 3-7% of the value of Oklahoma catfish sales in 1993.

Key Words: aquaculture, catfish, depredation, double-crested cormorant, *Ictalurus*, Oklahoma, *Phalacrocorax auritus*, predator control.

Oklahoma has about 324 ha of surface water in catfish 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 (see Chapter II) 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; (3) and make management recommendations regarding cormorant depredation and control.

We sincerely thank the facility operators who participated: L. Andrews, C.C. Bott, J.N. Dooley, M. Fram, W. Harden, T.D. Inslee and Sons, M.G. Lucky, M. McBride, J.N. Payton, and D. Wingo. Thanks are also extended to M. Beem and C. Kleinholz for technical support and assistance with farmers. A. A. Echelle and J. H. Shaw reviewed the manuscript and R.W. Pitman served as U. S. Fish and Wildlife Service (USFWS) Project Leader. This project was funded by Region 2 Fishery Resources, USFWS, with additional support from the Oklahoma Cooperative Fish and Wildlife Research Unit (National Biological

Service, Oklahoma State University, Oklahoma Department Wildlife Conservation, and Wildlife Management Institute, cooperating).

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. Each farmer was 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 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 dropped 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 densities at each facility were classified as having cormorant densities (mean birds/ha/day) ranging from zero (0), rare (0-0.1), low (0.1-0.3), moderate (0.6-1.0), to high (>1.0) and were assigned a corresponding rank of 1-5, respectively. Spearman's rank correlation (SAS Institute 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 USGS topographic maps; our observations of cormorant use of reservoirs and rivers in Oklahoma (see Chapter II) suggest 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 formula:

$$LOSS_n = \bar{x}_n * 0.4\ kg * 244\ days * {}^{9}\ 4\ ha$$

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 both 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 (Table 1). Facility size ranged from 0.7-20.8 ha of surface water (Table 1). 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 statewide catfish loss based on each of the 10 facilities surveyed ranged from 0-117,635 kg (Table 1). Mean estimated catfish loss in 1993 in Oklahoma was 18,240 kg ± 35,881 kg (¯ ± 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 ± 8,729 kg ($^{-}$ ± SE).

Statewide 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 non-target 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 the 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 (see Chapter II); larger facilities may attract migrating cormorants because 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). Forested areas also provide concealment for predators, especially humans, and this was likely the primary reason for the negative correlation.

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 (see Chapter II).

Loss of catfish in Oklahoma varied greatly among aquaculture facilities (18,240 ± 35,881 kg) with some localized high levels of cormorant depredation. Estimated loss at Facility 7 (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 7 reduced the magnitude and variability of the statewide estimate to 7,196 ± 8,729 kg.

Estimated loss of income due to cormorant depredation depended on the price/kg of catfish consumed. Cormorants primarily consume fish ≤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)-$36195 (fingerling/fry size) which was equivalent to 2.8-7.3% of total Oklahoma catfish sales in 1993. Stickley and Andrews (1989) estimated catfish loss 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 may change if cormorant density increases or in mild winters when more cormorants appear to 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 provide concealment for predators. 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 1995). 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 targeted and similar non-target species (Stickley [1990] contains illustrations of piscivorous avian predators and similar species, as well as a 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.

LITERATURE CITED

Agricultural Statistics Board. 1994. Oklahoma catfish: vol. 6. Okla. Agric. Stats. Serv., Okla. Dep. Agric., USDA, Okla. City, OK.

Barlow, C.G., and K. Bock. 1984. Predation of fish in farm dams by cormorants, *Phalacrocorax* spp. Aust. Wildl. Res. 11:559-566.

Brugger, K.E. 1993. Digestibility of three fish species by double-crested cormorants. Condor 95:25-32.

Campo, J.J., B.C. Thompson, J.C. Barron, R.C. Telfair II, P. Durocher, and S. Gutreuter. 1993. Diet of double-crested cormorants wintering in Texas. J. Field Ornith. 64:135-144.

Craven, S.R., and E. Lev. 1987. Double-crested cormorants in the Apostle Islands, Wisconsin, USA: population trends, food habits, and fishery depredations. Col. Waterbirds 10:64-71.

Dubovsky, J.A. 1987. Wintering waterfowl abundance and habitat associations with catfish ponds in the Alluvial Valley Region of Mississippi. M.S. Thesis, Mississippi State Univ., Mississippi State. 101pp.

Glahn, J.F., and K.E. Brugger. 1995. The impact of double-crested cormorants on the Mississippi Delta catfish industry: a bioenergetics model. In press *in* D. N. Nettleship, and D. C. Duffy, eds. The double-crested cormorant: biology, conservation, and management. Col. Waterbirds Spec. Publ. No. 17.

Hobson, K.A., R.W. Knapton, and W. Lysack. 1989. Population, diet and reproductive success of double-crested cormorants breeding on Lake Winnipegosis, Manitoba, in 1987. Col. Waterbirds 12:191-197.

Klimkowski, M.A. 1993. Management methods of commercial catfish farmers in Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater. 120pp.

Lagler, K.F. 1939. The control of fish predators at hatcheries and rearing stations. J. Wildl. Manage. 3:169-179.

Lewis, H.F. 1929. The natural history of the double-crested cormorant (*Phalacrocorax auritus auritus* (Lesson)). Ru-Mi-Lou Books, Ottawa, Canada. 94pp.

Moerbeek, D.J., W.H. van Dobben, E.R. Osieck, G.C. Boere, and C.M. Bungenberg de Jong. 1987. Cormorant damage prevention at a fish farm in the Netherlands. Biol. Conserv. 39:23-38.

Morrison, K. 1975. War on birds. Defenders of Wildlife 50:17-19.

Mott, D.F., and Boyd, F.L. 1995. Preventing cormorant depredations at aquaculture facilities in the southeastern United States. In press *in* D. N. Nettleship, and D. C. Duffy, eds. The double-crested cormorant: biology, conservation, and management. Col. Waterbirds Spec. Publ. No. 17.

Munro, J.A. 1927. Observations on the double-crested cormorant (*Phalacrocorax auritus*) on Lake Manitoba. Can. Field-Nat. . 41:102-108.

Naggiar, M. 1974. Man vs. birds. Flor. Wildl. 27(12):2-5.

Oklahoma Department of Agriculture. Undated. Oklahoma channel catfish directory. Okla. Dep. Agric., Market Develop. Services, Okla. City. 35pp.

Parkhurst, J.A., R.P. Brooks, and D.E. Arnold. 1987. A survey of wildlife depredation and control techniques at fish-rearing facilities. Wildl. Soc. Bull. 15:386-394.

Pough, R.H. 1940. Blue herons can't read. Bird-Lore. 42:507-516.

SAS Institute Inc. 1985. SAS user's guide: Statistics, Version 5 ed. SAS Inst., Inc., Cary, North Carolina. 956pp.

Scanlon, P.F., L.A. Helfrich, and R.E. Stultz. 1978. Extent and severity of avian predation at federal fish hatcheries in the United States. Proc. Ann. Conf. Southeast. Assoc. Fish Wildl. Agencies 32:470-473.

Schramm, H.L., Jr., M.W. Collopy, E.A. Okrah. 1987. Potential problems of bird predation for fish culture in Florida. Prog. Fish Cult. 49:44-49.

_____, B. French, and M. Ednoff. 1984. Depredation of channel catfish by Florida double-crested cormorants. Prog. Fish Cult. 46:41-43.

Stickley, A.R. 1990. Avian predators on Southern aquaculture. U.S. Dep. Agric., South. Reg. Aquacult. Cent., Publ. No. 400. 8pp.

_____, and K.J. Andrews. 1989. Survey of Mississippi catfish farmers on means, effort, and costs to repel fish-eating birds from ponds. Proc. East. Wildl. Damage Control Conf. 4:105-108.

_____, G.L. Warrick, and J.F. Glahn. 1992. Impact of double-crested cormorant depredations on channel catfish farms. J. World Aquacult. Soc. 23:192-198.

Williams, T. 1992. Killer fish farms. Audubon 1992(2):14-22.

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 statewide catfish loss (kg) at selected aquaculture facilities in Oklahoma, October-May, 1992-94.

	Cormorant Density			Percentage	Distance to	
Facility	(1992-93)	(1993-94)	Surface Area	Forested Shoreline	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)	1.13 (5)	4.9	5	27	13,882
4	0.002 (2)	0 (1)	5.3	25	10	32
5	0 (1)	0 (1)	0.7	100	20	0
6	0.783 (4)	0.13 (3)	20.8	50	39	20,144
7	3.6 (5)	0.853 (4)	9.6	25	30	117,635
8	0.149 (3)	0.184 (3)	6.8	75	7	5,218

Table 1. Continued.

	Cormorant Density			Percentage	Distance to	
Facility	(1992-93)	(1993-94)	Surface Area	Forested Shoreline	Reservoir/ River[a]	Catfish Loss[b]
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 (1)	0 (1)	3.5	100	1	0

[a] Reservoirs > 2000 ha and rivers >500 km in length

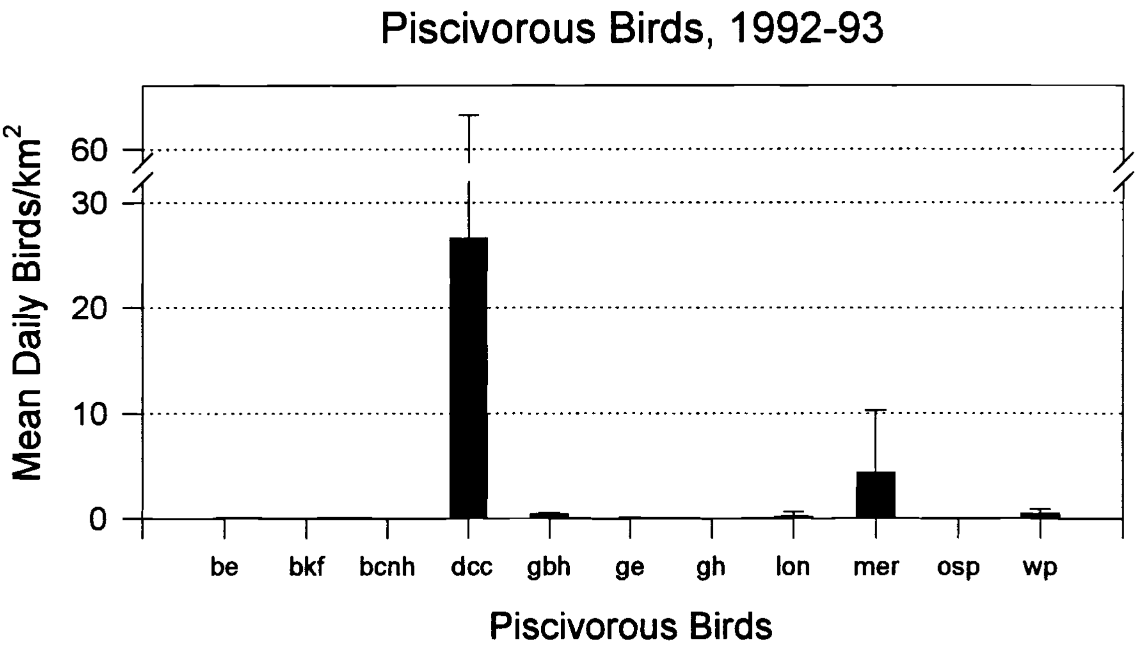
[b] 1993 statewide estimates based on losses at each facility

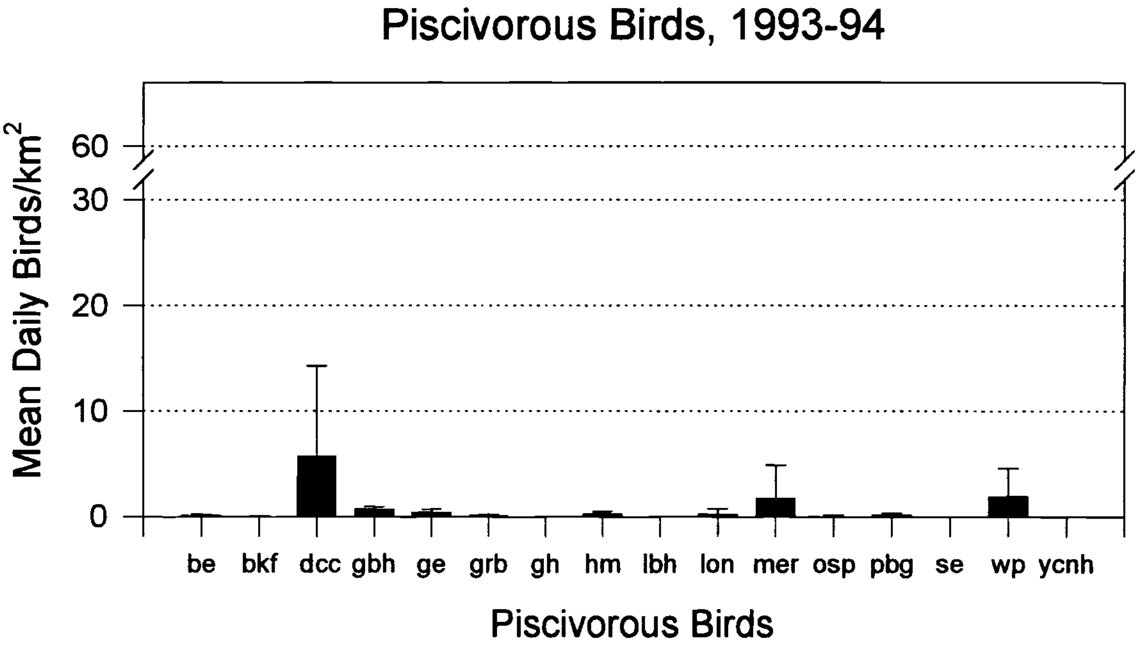
[c] Facility lost to bankruptcy after 1992/93 field season

[d] Cormorant density rank (rank of 1=0 birds/ha/day, 2=0-0.1, 3=0.1-0.3, 4=0.3-1.0, 5=>1.0)

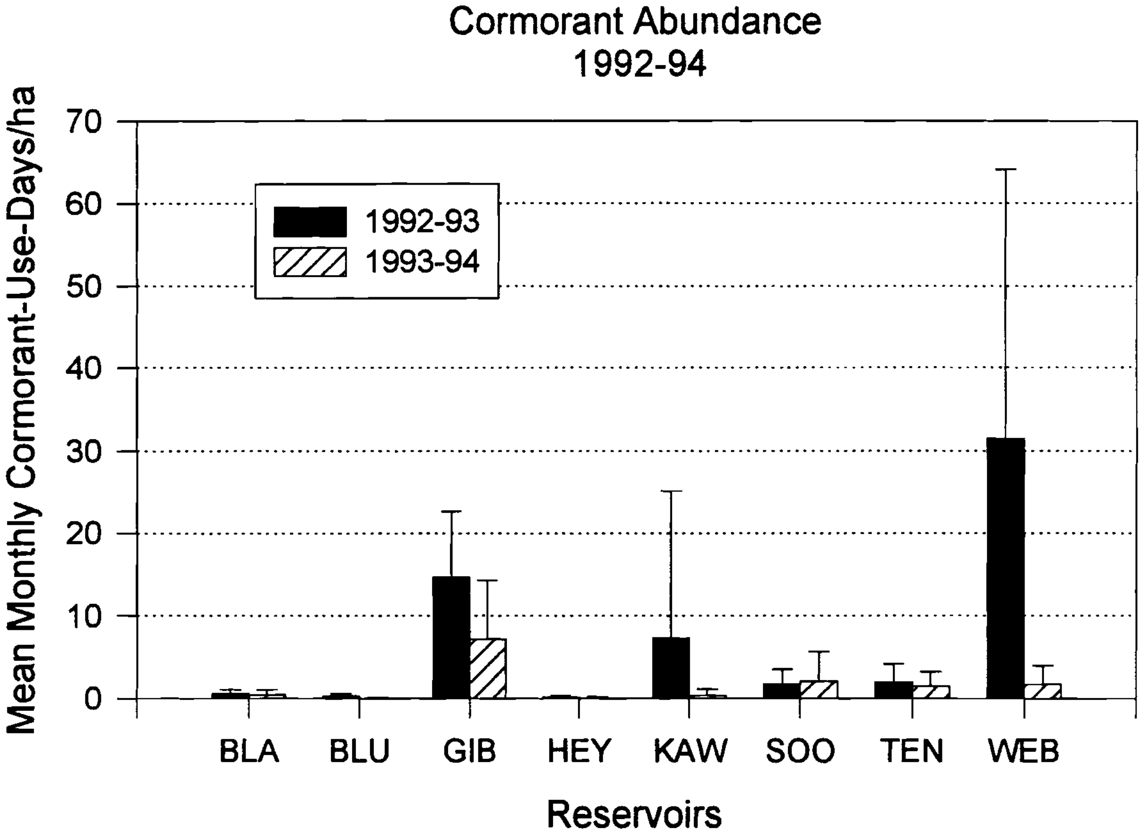
[e] 1992/93 estimate based on counts from December-May

APPENDIXES





Appendix A. Mean daily piscivorous bird densities (birds/km^2; error bars=SD) at 8 Oklahoma reservoirs, 1992-94. Be=bald eagle, bkf=belted kingfisher, bcnh=black-crowned night heron, dcc=double-crested cormorant, gbh=great blue heron, ge=great egret, grb=grebe, gh=green heron, hm=hooded merganser, lbh=little blue heron, lon=loon, mer=merganser, osp=osprey, pbg=pied-billed grebe, se=snowy egret, wp=white pelican, ycnh=yellow-crown night herons. (See Appendix C for scientific names).



Appendix B. Mean monthly double-crested cormorant density (cormorant-use-days/ha; error bars=SD) at 8 Oklahoma reservoirs from about September through May 1992-94. LCB = Lake Carl Blackwell, BLU = Bluestem, GIB = Fort Gibson, HEY = Heyburn, KAW = Kaw, SOO = Sooner, TEN = Tenkiller Ferry, WEB = Webber's Falls.

Appendix C. Mean daily number of birds/km^2 encountered in piscivorous bird surveys of Oklahoma reservoirs, October 1992 through May 1993. Lake abbreviations are: LCB = Lake Carl Blackwell, BLU = Bluestem, GIB = Fort Gibson, HEY = Heyburn, KAW = Kaw, SOO = Sooner, TEN = Tenkiller Ferry, WEB = Webber's Falls.

Common name (Scientific name)	BLU	LCB	GIB	HEY	KAW	SOO	TEN	WEB
Bald Eagle (*Haliaeetus leucocephalus*)	0	0.071	0.027	0	0.041	0.019	0.017	0.012
Belted Kingfisher (*Megaceryle alcyon*)	0	0	0.002	0	0	0.015	0.007	0.008
Black-Crowned Night Heron (*Nycticorax nycticorax*)	0	0	0	0	0.004	0	0	0
Double-crested Cormorant (*Phalacrocorax auritus*)	2.065	1.15	52.901	0.612	30.573	6.213	8.477	111.177
Great Blue Heron (*Ardea herodias*)	0.297	0.318	0.694	0.369	0.357	0.188	0.397	0.613
Great Egret (*Casmerodius albus*)	0.017	0	0.027	0.032	0.151	0	0.048	0.095

Appendix C. Continued.

Common name (Scientific name)	BLU	LCB	GIB	HEY	KAW	SOO	TEN	WEB
Green Heron (*Butorides striatus*)	0.009	0	0.002	0	0	0.007	0.002	0.004
Loons (*Gavia* spp.)	0	0	0	0	0.002	0.084	1.402	0
Mergansers (*Mergus* spp. and *Lophodytes cucullatus*)	15.069	8.716	0.707	0	9.866	0.417	0.142	0.072
Osprey (*Pandion haliaetus*)	0	0	0	0	0.005	0.071	0.033	0
White Pelican (*Pelecanus erythrorhynchos*)	0	0	0.532	0.032	0.487	0.578	0.823	1.321

Appendix D. Mean daily number of birds/km^2 encountered in piscivorous bird surveys of Oklahoma reservoirs, August 1993 through April 1994. Lake abbreviations are: LCB = Lake Carl Blackwell, BLU = Bluestem, GIB = Fort Gibson, HEY = Heyburn, KAW = Kaw, SOO = Sooner, TEN = Tenkiller Ferry, WEB = Webber's Falls.

Common name (Scientific name)	BLU	LCB	GIB	HEY	KAW	SOO	TEN	WEB
Bald Eagle (*Haliaeetus leucocephalus*)	0.051	0.334	0.043	0	0.058	0.047	0.062	0.028
Belted Kingfisher (*Megaceryle alcyon*)	0.009	0	0.026	0	0.002	0.023	0.043	0.016
Double-crested Cormorant (*Phalacrocorax auritus*)	1.427	0.074	25.979	0.237	1.719	6.692	4.743	5.301
Great Blue Heron (*Ardea herodias*)	0.473	0.78	1.083	0.609	0.323	0.598	0.901	0.824
Great Egret (*Casmerodius albus*)	0.054	0.26	0.933	0.541	0.142	0.172	0.258	0.574
Grebes (*Podiceps* spp.)	0.01	0	0.264	0.034	0	0.3	0.219	0

Appendix D. Continued.

Common name (Scientific name)	BLU	LCB	GIB	HEY	KAW	SOO	TEN	WEB
Green Heron (*Butorides striatus*)	0	0	0	0	0	0	0	0.004
Hooded Merganser (*Lophodytes cucullatus*)	0.63	0	0.04	0.44	0.079	0.701	0	0.019
Little Blue Heron (*Florida caerulea*)	0	0	0.009	0.034	0	0	0.045	0.055
Loons (*Gavia* spp.)	0	0.074	0.002	0	0	0.102	1.532	0
Mergansers (*Mergus* spp. and *Lophodytes cucullatus*)	0.892	2.229	0.812	0	9.451	0.491	0.093	0.154
Osprey (*Pandion haliaetus*)	0	0	0.023	0	0.008	0.237	0.031	0
Pied-Billed Grebe (*Podilymbus podiceps*)	0.057	0.111	0.129	0.067	0.046	0.524	0.238	0.037

Appendix D. Continued.

Common name (Scientific name)	BLU	LCB	GIB	HEY	KAW	SOO	TEN	WEB
Snowy Egret (*Egretta thula*)	0	0	0.004	0	0.002	0.016	0.05	0
White Pelican (*Pelecanus erythrorhynchos*)	0	0	3.178	7.442	0.733	0	0.619	3.762
Yellow-Crowned Night Heron (*Nyctanassa violacea*)	0	0	0	0	0	0	0	0.005

VITA

Robert L. Simmonds, Jr.

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF PISCIVOROUS BIRDS, PARTICULARLY CORMORANTS, ON RESERVOIR AND AQUACULTURAL FISHES IN OKLAHOMA

Major Field: Wildlife and Fisheries Ecology

Biographical:

Education: Received Bachelor of Science Degree in Fisheries and Wildlife Management from Lake Superior State University, Sault Sainte Marie, Michigan in May 1993. Completed requirements for the Master of Science degree with a major in Wildlife and Fisheries Ecology at Oklahoma State University, Stillwater, Oklahoma in December 1995.

Experience: Wildlife Volunteer, U.S. Fish and Wildlife Service, Shiawassee National Wildlife Refuge, May-August 1990; Research Technician, Lake Superior State University, School of Science and Natural Resources, May-August 1991; Hatchery Technician, Lake Superior State University, Aquatics Research Laboratory, August-December 1991; Fishery Volunteer, Oklahoma Cooperative Fish and Wildlife Research Unit, August 1994-April 1995; Graduate Teaching Assistant, Oklahoma State University, Department of Zoology, August-December 1994; Graduate Research Assistant, Oklahoma Cooperative Fish and Wildlife Research Unit, July 1992-August 1994 and January-June 1995.

Professional Memberships: American Fisheries Society, Colonial Waterbirds Society, The Wildlife Society, Wilson Ornithological Society.