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Abstract.—Few studies have investigated the use of aquaculture-produced foods by piscivorous birds. American White Pelicans (*Pelecanus erythrorhynchos*) were collected from four locations (two aquaculture, one riverine and one coastal) in the southeastern United States during winter and spring 1998-1999 to assess the contribution (biomass, frequency of occurrence) of aquaculture-produced foods and their effect on body condition. Pelican diets reflected opportunistic foraging across locations. Diet near catfish ponds consisted mostly of Channel Catfish (*Ictalurus punctatus*). Diets along the Mississippi River had similarly high biomass of catfish, but otolith counts suggested lower use of catfish. Diets near crawfish (*Procambarus* spp.) ponds included shad (*Dorsomis* spp.), crawfish and sunfish (*Lepomis* spp.); whereas diets from coastal Louisiana were predominantly salt water fish. Pelican body condition, as indexed by percent omental fat, was similar between seasons but higher at catfish ponds. Foraging at crawfish ponds did not improve body condition over foraging in natural conditions. The superabundant, large and vulnerable food source (i.e. catfish in aquaculture ponds) likely resulted in reduced energy expenditures by pelicans, which would improve body condition. Higher fat reserves could facilitate spring migration and reproductive success. American White Pelican use of catfish at aquaculture facilities is predicted to continue and likely increase. *Received 22 July 2009, accepted 8 October 2009.*

Key words.—American White Pelican, aquaculture, body condition, Channel Catfish, diet, *Ictalurus, Pelecanus erythrorhynchos*, southeastern United States.

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Wildlife use of superabundant food occurs when the food in question is much more abundant than the requirements of the consumers, even if the food comprises most of the diet of the species involved (Lack 1946). Wildlife use of some agricultural commodities have been widely documented and publicized. For example, white-tailed deer (*Odocoileus virginianus*) and blackbirds commonly depredate agricultural crops (Conover 1994; Linz *et al.* 2003). These superabundant food sources are often credited with enhancing survival and reproductive fitness (Glahn *et al.* 2000). Until recently, the potential benefit to wildlife foraging on commercial aquaculture has received little attention.

Commercial aquaculture production in the southeastern United States has grown dramatically during the past 25 years. For example, the number of hectares of commercial catfish (*Ictalurus punctatus*) production in the southeastern United States (Alabama, Arkansas, Louisiana and Mississippi) increased from 28,000 ha to 61,000 ha from 1987 to 2007 (USDA 2008). Concurrent to this increase in production area has been an increase in the numbers of piscivorous birds foraging at aquaculture facilities (Stickley and Andrews 1989; Fleury 1993; King and Werner 2001; Glahn and King 2004). Double-crested Cormorants (*Phalacrocorax auritus*) have been regarded as the major depredating species in the southeastern United States, particularly at commercial catfish ponds (Wywialowski 1999; Glahn and King 2004).

Similar to Double-crested Cormorants, use of aquaculture facilities by American

White Pelicans (*Pelecanus erythrorhynchos*) has increased during the last 20 years (King 1997; King 2005). Pelican foraging at commercial ponds was first reported during the 1990s (King 1997). More recently, flocks of >2000 pelicans have been observed foraging on commercial catfish ponds, as well as at commercial crawfish (*Procambarus* spp.) ponds in southern Louisiana (King 1997; King and Michot 2002; King 2005). American White Pelicans also come in conflict with southeastern aquaculture by using this superabundant and readily available food source (King 1997; King 2005).

Cormorant exploitation of aquaculture may lead to increased survival and enhanced productivity (Weseloh and Ewins 1994; Duffy 1995). Glahn *et al.* (2000) found that wintering Double-crested Cormorants collected in the intensive aquaculture region of Mississippi and foraging on catfish had significantly higher levels of fat than cormorants collected in eastern Alabama (a non-aquaculture region). The improved body condition led Glahn *et al.* (2000) to suggest that cormorants exploiting catfish aquaculture increased their survival and contributed to cormorant population increases. We hypothesize that the same might be true for American White Pelicans.

The goal of this research was to provide insight on the effects of catfish exploitation at aquaculture facilities on the body condition of American White Pelicans. The study objectives were to: 1) estimate if pelican diet reflects use of nearby foraging resources, including aquaculture facilities and 2) determine if use of superabundant food resources at aquaculture facilities improved pelican body condition, as indexed by body fat.

METHODS

Study Area

American White Pelicans were collected from loafing sites (King 1997; King and Werner 2001; King and Michot 2002; King 2005) during winter (December 1998, January-February 1999) and spring (March 1999 and April 1998, 1999) at four geographic regions in Mississippi and Louisiana (Fig. 1). King and Werner (2001) found that in intensive aquaculture areas, pelicans typically forage near their loafing sites. The Mississippi aquaculture pond location included two collection sites

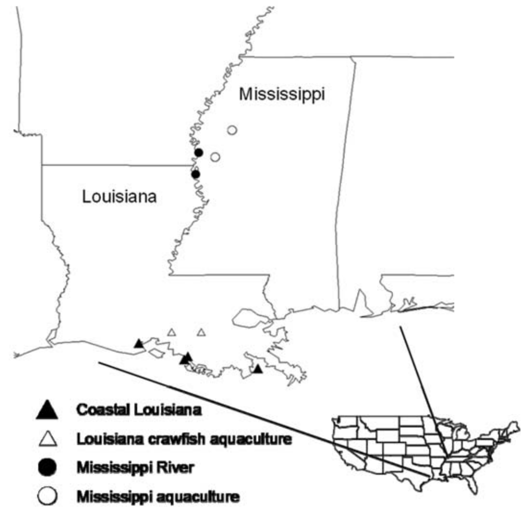

Figure 1. Location of study areas for estimating American White Pelican diet from the southeastern United States, December-April 1998-1999.

<1.6 km from catfish aquaculture facilities in LeFlore and Washington Counties, Mississippi. The Mississippi River location included two sites; a mud flat in the Mississippi River and an oxbow lake inside the Mississippi River levee in Issaquena and Washington counties, Mississippi. The Mississippi River collection location was ≥30 km from the nearest catfish aquaculture facility. The Louisiana crawfish location consisted of two collection sites <3 km from crawfish aquaculture facilities in Assumption and St. Mary Parishes, Louisiana. The Coastal Louisiana location included three sites within marsh habitat in Jefferson, St. Mary and Vermillion Parishes, Louisiana. Coastal Louisiana collection sites were >40 km from the nearest crawfish aquaculture ponds.

Catfish aquaculture ponds in Mississippi average 6 ha in size and are about 1.5 m deep. Recommended catfish fingerling stocking rates are about 20,000 fish/ha but may vary widely depending on the culture method employed (Tucker *et al.* 2004). In Mississippi, the most common culture method involves multiple age classes of fish being grown in a single pond (Tucker *et al.* 2004). The method provides a continuum of fish sizes, ranging from recently stocked fingerlings (16 g and 13 cm) to food size fish (>1.5 kg and 50 cm), and provides harvestable fish on a near constant basis (Tucker *et al.* 2004). Shad (*Dorsomis* spp.) and sunfish (*Lepomis* spp.) are endemic to most freshwater areas in the southeastern United States and these fishes are often found in commercial aquaculture ponds due to flooding overflow into fish ponds or transported by wildlife (J. Avery, National Warmwater Aquaculture Center, personal communication).

Field and Laboratory Methods

American White Pelicans were collected from loafing areas using shotguns or center-fire rifles. The age of each bird was determined using external plumage characteristics and other morphological features (Johnsgard 1993; Knopf and Evans 2004); sex was determined by examination of reproductive organs. The esophagus, stomach and lower gastro-intestinal tract was removed as soon as possible from each bird, stored on ice in a labeled plastic bag, and transported to the National Wildlife Research Center Mississippi Field Station, Starkville, Mississippi. All procedures involving American White Pelicans were conducted under an IACUC-approved United States Department of Agriculture, Wildlife Services, National Wildlife Research Center study protocol (QA-577), a Louisiana Department of Wildlife and Fisheries Scientific Collecting Permit, a Mississippi Department of Wildlife, Fisheries and Parks Administrative Scientific Collecting Permit and a United States Department of Interior Scientific Collecting Permit.

Stomach contents were removed and all prey items were identified, measured and weighed to the nearest gram following procedures in Glahn *et al.* (1995; 1998; 2000). Teleost otoliths were retained for prey identification and to increase species composition (Harrel and Stringer 1996; Derby and Lovvorn 1997; Glahn *et al.*1998). Otoliths were used to identify fish prey items to family and genus using methods described in Glahn *et al.* (1998). No attempt was made to determine fish length or age using otoliths due to possible erosion of otoliths (Johnstone *et al.* 1990). Omental fat was scraped from the stomach exterior, placed in a plastic weighing dish, and weighed to the nearest gram (Glahn *et al.* 2000).

Statistical Analyses

The biomass of each whole fish and crawfish found in pelican gastro-intestinal tracts was estimated based on length-to-weight equations (Kohler and Hubert 1993; Glahn *et al.* 1995; Murphy and Willis 1996). These food items were grouped into five categories of dominant prey types (catfish, shad, crawfish, sunfish and other fish). Data were too sparse to consider both spatial and temporal comparisons or among age and gender of birds. To compare prey size the mean length of the most frequently occurring prey (i.e. catfish) was compared with the mean length of all other prey species combined using a *t*-test.

Fish otoliths from the stomachs of fish-eating birds can provide useful dietary information (Glahn *et al.* 1998), therefore the percent by number of otoliths found in pelicans across the four collection locations were grouped into the following categories and compared: catfish, shad, sunfish and other fish (including a wide variety of primarily salt water fish families and genera). Omental fat was expressed as a percentage of total body weight. A general linear model analysis of variance (PROC GLM; SAS 1989) with least significant difference multiple range test was used to compare mean percent omental fat between seasons (winter, spring) and across the four geographic locations. Limited sample sizes precluded analyses by sex or age class. Statistical tests were considered to be significant at $P \leq 0.05$ and reported means are ±SD.

RESULTS

A total of 187 American White Pelicans were collected, 86 during winter and 101 during spring. Fifty-seven pelicans were collected from Mississippi catfish ponds (20 in winter, 37 in spring), 49 pelicans from the Mississippi River (20 in winter, 29 in spring), 42 pelicans from Louisiana crawfish ponds (24 in winter, 18 in spring), and 39 birds from coastal Louisiana (22 in winter, 17 in spring).

Catfish represented >99% of whole fish biomass consumed by pelicans in all areas of Mississippi, with comparable biomass between pelicans from catfish ponds and the Mississippi River (Table 1). Maximum estimated catfish biomass collected from a single pelican was 3.1 kg. Shad represented the greatest percentage of prey biomass (32.8%) in pelicans from Louisiana crawfish ponds, followed by crawfish and sunfish. Coastal Louisiana pelicans consumed primarily saltwater fish. Estimated mean length of catfish consumed by pelicans (267 ± 113 mm, N = 81) was 4.5 times greater ($t = 15.82$, 92 df, $P < 0.001$) than the estimated mean length of other fish consumed (60 ± 43 mm, N = 160) by pelicans.

Based on otoliths, pelicans at Mississippi catfish ponds consumed at least three times more catfish than did pelicans at other locations (Table 2). The difference in the number of shad represented in whole prey and otoliths may be due to shad being generally

Table 1. Percent biomass of prey items in gastrointestinal tracts of American White Pelicans from the southeastern United States, December-April 1998-1999. (N = number of whole prey).

		Prey item				
Location	N	Catfish	Shad	Crawfish	Sunfish	Other
Mississippi catfish ponds	28	99.6	0.4	0.0	0.0	0.0
Mississippi River	15	99.2	0.8	0.0	0.0	0.0
Louisiana crawfish ponds	16	6.8	32.8	23.7	20.2	16.6
Coastal Louisiana	10	1.0	0.0	0.0	0.0	99.0

Table 2. Percent of teleost otoliths in gastrointestinal tracts of American White Pelicans from the southeastern United States, December-April 1998-1999. (N = number of otoliths).

	Prey item (%)				
Location	N	Catfish	Shad	Sunfish	Other
Mississippi catfish ponds	153	87.6	8.5	2.0	2.0
Mississippi River	222	29.7	58.6	6.3	5.4
Louisiana crawfish ponds	1,241	0.5	63.3	27.6	8.7
Coastal Louisiana	243	1.2	7.4	12.8	78.6

smaller and easier to digest than catfish. Shad represented the majority of fish consumed by pelicans along the Mississippi River and at Louisiana crawfish ponds. As with whole prey examined, otoliths collected from coastal Louisiana pelicans were primarily from saltwater fishes.

Mean percent omental fat in pelicans varied across study locations ($F = 18.85$; 3,183 df; $P < 0.001$), with overall highest ($P < 0.05$) fat levels occurring in pelicans collected from catfish ponds in Mississippi (Table 3). Mean percent omental fat in pelicans collected from the Mississippi River and coastal Louisiana was similar ($P > 0.05$) and both were greater than the mean percent omental fat in pelicans from Louisiana aquaculture facilities ($P < 0.05$).

For all locations combined, percent omental fat was similar ($F = 2.93$; 1,185 df; $P = 0.089$) between winter and spring. There was an interaction, however, between season and collection location ($F = 36.01$; 3,183 df; $P < 0.001$), with omental fat increasing from winter to spring in pelicans collected only at Mississippi catfish ponds.

DISCUSSION

American White Pelicans are generally described as opportunistic shallow water foragers that use a variety of aquatic habitats (Johnsgard 1993; King and Werner 2001; King and Michot 2002; Knopf and Evans 2004). Our study documents the widespread use of both catfish and crawfish aquaculture facilities by pelicans. Previous studies have shown that American White Pelicans use southeastern catfish ponds while staging for spring migration (King and Werner 2001; King and Grewe 2001; King and Michot 2002). Pelicans are more prevalent on catfish ponds during spring and are tenacious foragers, making them hard to disperse from ponds and nearby loafing sites (King and Michot 2002; King 2005). The sizes of catfish found in pelican stomachs were comparable to the sizes of fish typically found in catfish aquaculture ponds. Further, the majority of channel catfish consumed by pelicans collected at aquaculture and river sites in Mississippi were commercially raised because undigested portions of corn kernels were found in the pelican stomachs. Commercial catfish feeds often utilize corn as an energy supplement (Robinson *et al.* 2004).

Pelicans loafing along the Mississippi River also foraged on catfish, potentially from natural water bodies and/or from aquaculture ponds. Pelicans do forage in natural areas (King and Werner 2001; King and Mi-

Table 3. Mean (SD) percent omental fat in American White Pelicans from the southeastern United States during winter (Dec-Feb) and spring, (Mar-Apr), 1998-1999. Means within a row with different letters are significantly different ($P < 0.05$).

	Winter			Spring		
Location	N	$\bar{x}$	SD	N	$\bar{x}$	SD
Mississippi catfish ponds	20	0.81^{a}	0.35	37	3.15^{b}	1.44
Mississippi River	20	2.58^{a}	1.14	29	1.05^{a}	0.49
Louisiana crawfish ponds	24	1.07^{a}	0.81	18	0.45^{a}	0.25
Coastal Louisiana	22	1.31^{a}	1.03	17	1.86^{a}	1.22

chot 2002), coming in contact with shad and other endemic prey species. This study documented that coastal Louisiana birds foraged almost exclusively on naturally-occurring brackish and saltwater species.

Pelicans foraging on catfish during spring (presumably from catfish ponds) were in better physical condition than birds not exploiting catfish aquaculture. Typical catfish aquaculture ponds appear to provide a near-perfect foraging environment for American White Pelicans (King 2005), as the relatively small and shallow ponds assure that the fish are confined and vulnerable to foraging pelicans. In addition, stocking densities of catfish at aquaculture facilities far exceed fish densities observed in natural water bodies. Consequently, pelicans foraging in catfish ponds spend less time per day foraging than birds foraging in natural areas (King and Werner 2001). Thus, pelicans foraging on superabundant commercial catfish can meet their energetic demands with less effort, leading to higher body fat content and better overall body condition. Pelicans are capable of traveling long distances to reach foraging sites (Knopf and Evans 2004). Although pelicans loafing along the Mississippi River exploited commercial catfish, the increased energy expended by flying ≥30 km to reach the ponds may have resulted in lower mean percent levels of omental fat.

Percent body fat of American White Pelicans foraging in commercial crawfish ponds was lower than for pelicans foraging elsewhere. Although crawfish in commercial aquaculture ponds were abundant, they were likely more difficult to capture in adequate quantities and were undoubtedly less digestible than fish due to their exoskeleton. Therefore, pelicans exploiting crawfish ponds did not benefit from enhanced body condition as pelicans exploiting catfish ponds.

These data show that pelicans foraging at catfish aquaculture facilities, particularly during spring, are in better physical condition (as indexed by percent body fat) than pelicans that forage at alternate locations. Increased body fat has been positively associated with migratory and reproductive success in birds (Ankney and MacInnes 1978; Moore *et al.* 1995); consequently pelicans foraging at catfish aquaculture are likely in better condition for spring migration to breeding grounds. Increased condition could also improve reproductive performance and survival (Rogers 1987; Rowe *et al.* 1994), resulting in potential population increases for this species. A similar avian response to foraging at catfish aquaculture facilities has been reported for Double-crested Cormorants (Hatch and Weseloh 1999; Glahn *et al.* 2000).

Management Implications

These data, combined with previous research, suggest American White Pelican exploitation of the superabundant food provided by catfish aquaculture will likely continue and possibly increase. Exploitation of catfish aquaculture has been credited with causing a shift in the winter range of Double-crested Cormorants (Weseloh and Ewins 1994). Similarly, King and Grewe (2001) described an apparent shift in American White Pelican wintering ranges associated with increased catfish aquaculture. Improved body condition resulting from exploitation of catfish aquaculture may result in higher survival and improved reproductive performance of American White Pelicans. The use of catfish aquaculture by pelicans will likely continue and as more pelicans learn to exploit catfish aquaculture, conflicts with producers will likely increase. Management strategies to reduce pelican predation should focus on deterring pelican foraging at catfish aquaculture facilities, especially during spring.

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