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Abstract: Aquaculture in North America varies geographically with respect to species cultured, annual production, size, complexity, and spatial arrangement of facilities. Species assemblages of predacious birds using aquaculture facilities also vary with many of these industry characteristics. Wading birds are highly adaptable, relatively ubiquitous throughout the aquaculture industry, and often associated with fish depredation problems at aquaculture facilities. Suitability of information regarding the impacts of wading birds to aquaculture varies dramatically by depredating species and industry sector. Great blue herons (*Ardea herodias*) cause considerable depredation losses on trout aquaculture in the Northeast, and current research suggests that little blue herons (*Egretta caerulea*) negatively impact baitfish aquaculture. Early research provided similar findings with great blue heron depredations on catfish aquaculture. Recent research however, initiated a paradigm shift in management by demonstrating that some wading birds like the great blue heron and great egret (*Casmerodius albus*) largely eat diseased catfish and consumption of healthy catfish can be limited by specific management efforts. However, information is lacking on other wading bird species and their impacts to cultured species such as baitfish and crawfish. Issues regarding wading bird depredations are dynamic and evolve with changing demographics of both the aquaculture industry and wading bird populations. Emerging issues include great blue herons as possible vectors for whirling disease in Northeastern trout aquaculture and predation on catfish by wood storks (*Mycteria americana)*. As local, regional, and continental populations of wading birds continue to change in number and geographic distribution, it is imperative that research identify where and how aquaculture production losses occur and guide science-based management plans to abate production loss. We discuss current population status and trends for selected wading birds and their potential impacts and management on major aquaculture industries in the United States.

Key words: aquaculture, damage management, depredation, egrets, herons, ibis, storks

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INTRODUCTION

Aquaculture in North America varies geographically with respect to species cultured, annual production, size, complexity, and spatial arrangement of facilities. Species assemblages of predacious birds using aquaculture facilities also vary with many of these industry characteristics. These avian predators are attracted to aquaculture facilities in the United States primarily because ponds and open raceways provide a constant and readily accessible food supply for these animals (Parkhurst et al. 1992). Wading birds in general are a primary class of fish-eating bird associated with fish depredation problems at aquaculture facilities. These birds are highly adaptable and relatively ubiquitous throughout the aquaculture industry. However, the mere presence of these predators around aquaculture facilities does not necessarily mean that significant depredation problems are occurring. Available information regarding the impacts of wading birds to aquaculture varies dramatically by depredating species and industry sector. Although all these species consume cultured fish, their biology, distribution, and dietary preferences dictate the extent of depredation problems they cause and the approaches needed to alleviate their depredations. With the exception of total bird exclusion from ponds, there is no single solution to resolve all bird depredation problems. In most cases, an integrated management approach to alleviating bird depredations must be considered.

As both the aquaculture industry and local, regional, and continental populations of wading birds continue to change in size and geographic distribution, it is imperative that research identify where and how aquaculture production losses occur and guide science-based management plans to abate production loss. We discuss current status and trends for selected wading birds and aquaculture industries and give an overview of potential impacts and management on selected aquaculture industries in the United States.

North American Aquaculture

For the purposes of this paper, we describe North American aquaculture as the commercial production of cultured species by private individuals or entities for private consumer purchase. As such, we do not address issues associated with the production of fish species for stocking and maintenance of public waters, which is primarily a function of state and federal hatchery systems.

Commercial U.S. aquacultural production is composed of the production of food fish (primarily catfish, trout, and salmon), ornamental fish, baitfish, mollusks, crustaceans, aquatic plants and algae, and even some reptiles such as alligators and turtles (USDA-ERS 2000). These organisms are grown in a wide variety of climates with either fresh or saltwater and utilize a variety of production systems (USDA-ERS 2000). Between 1980 and 1998, the value of all U.S. aquaculture production rose over 400 percent, with farm-level sales reaching approximately $978 million (NASS 1998). Although there are a wide variety of species and culture methods, we focus on the most economically prominent aquaculture industries experiencing wading bird depredation. These include catfish, trout, crawfish, baitfish, and ornamental fish aquaculture. Combined, these aquaculture products accounted for U.S. $629.5 million (65%) of total aquaculture sales in the U.S. in 1998 (NASS 1998).

Wading Birds

Wading birds make up a relatively small and specialized group of birds in North America (AOU 2002), comprising 20 species and 13 genera in four families. Most species prey on fish, crustaceans and invertebrates (Gough et al. 1998) and have the potential to impact various types of aquaculture. As a group, wading birds include some of the most prevalent species cited as problems in aquaculture (Wywialowski 1999). Depending on the source, 12 species of wading birds are reported as causing damage to aquaculture in North America (Stickley 1990, Gorenzel et al. 1994). These problems have been associated with depredations on catfish

(Glahn et al. 1999b), trout (Parkhurst et al. 1992; Pitt and Conover 1996; Glahn et al. 1999a), bait fish (Hoy and Bivings 1989), and ornamental fish (Avery et al. 1999). The wading birds most often associated with aquaculture depredations include the herons, egrets, white Ibis (*Eudocimus albus*), and more recently the woodstork (*Mycteria americana*). Current populations of all but one depredating species are stable or increasing in North America (Sauer et al. 2002). The one species showing a declining population trend is the little blue heron (*Egretta caerula*).

Wading Birds And Catfish Aquaculture

Catfish typically are grown in open freshwater ponds, with the total area of catfish aquaculture in the U.S. encompassing about 76,000 water hectares, of which approximately 45,000 ha are in the delta region of Mississippi (NASS 2003). Currently the average farm size in the delta region of Mississippi is about 127 ha, with individual ponds averaging about 6 ha (Glahn et al. 2000). The farm-level dollar value of the catfish industry exceeds all other aquaculture products in the U.S. However, the per-unit-value of food-size fish is relatively low, being in the range of U.S. $1.25-1.65/kg (USDA-ERS 2003). These factors related to size of the industry, size of farms, individual ponds, and the per unit value of fish, tend to limit the available options for dealing with wading bird issues.

Because of its economic importance, the catfish aquaculture industry has received the most attention with respect to management and control of wading bird depredation. The two wading bird species implicated most often in depredations on catfish are the great blue heron (*Ardea herodius*) and the great egret (A*rdea alba*) (Hodges 1989; Ross 1994; Glahn et al. 1999b). Snowy egrets (*Egretta thula*), little blue herons, black-crowned night herons (*Nycticorax nycticorax*), and cattle egrets (*Bubulcus ibis*) have been observed at catfish farms, but there is little evidence to suggest they cause significant losses (Stickley 1990, Glahn et al. 1999b).

Recent research on the similarity in diet and foraging behavior of both herons and egrets raised questions regarding the extent and impact of their depredations at catfish farms. Most of the catfish consumed by herons and egrets were taken in the spring or fall, when catfish diseases were prevalent (Stickley et al. 1995; Glahn et al. 1999b). Studies of captive herons suggested they were inefficient at capturing healthy catfish and subsist mainly on diseased catfish and non-commercial fish (sunfish and shad) in ponds (Glahn et al. 2000). This is consistent with a recent study by Glahn et al. (2002) indicating that 85% of live catfish captured by great-blue herons congregating at commercial catfish ponds in the fall and winter were diseased and 76% were terminally ill. An exception occurred during fish feeding when most (75%) of the live catfish consumed by great-blue herons were healthy. However, fish feeding is a limited event occurring from about April to October and generally lasting about 20-30 minutes per pond (Glahn et al. 2002) . Thus, the total amount of healthy catfish removed is limited by the seasonal and daily duration of feeding (Glahn et al. 2002). These characteristics of targeting sick fish and congregating at diseased ponds and fingerling ponds limit average losses of healthy fish to less than 1% of total fish stocked (Glahn et al. 2002).

Although the economic impact of great egrets has not been extensively studied, it is likely less than that caused by herons because of several factors. Great egrets, based on energetic demands, required about half the dietary intake of great blue herons (Schramm et al. 1987). Great egrets also appear to prefer smaller fingerlings, which are typically stocked at much higher densities and are less costly, thereby reducing overall impacts (Werner et al. 2001). Based on observations on catfish ponds, great egret diet was only 8% live catfish, with the remainder being wild fish and dead catfish (Glahn et al. 1999b). Like herons, egrets consumed diseased fish that were likely to die anyway (Hodges 1989; Glahn et al. 1999b). Thus, their economic impact is probably negligible.

Wood storks have become more of a concern with respect to catfish aquaculture in recent years, particularly in east Mississippi and Alabama, where post-breeding dispersal has brought these birds into greater contact with catfish aquaculture. Current research suggests that although wood storks readily eat catfish, they will not forage in ponds at typical catfish industry depths of $\geq$ 1 m. Like herons, wood storks are probably focusing on dead and dying fish (Taylor, USDA/ Wildlife Services/ National Wildlife Research Center unpublished). However, in ponds with water depths $\leq$ 30 cm in depth, or where factors such as low dissolved oxygen or fish feeding make fish available for predation, wood storks may have an impact (Taylor, USDA/ Wildlife Services/ National Wildlife Research Center unpublished).

Under the Endangered Species Act, it is illegal to "take", harass or otherwise disturb wood storks. Additionally, because woodstorks are listed as an endangered species in some areas of the U.S., their presence can affect control efforts for other depredating species with which they may be associated. This legal status limits the options for deterring these birds from utilizing aquaculture. Current research is underway at the NWRC, Mississippi Field Station, to identify movements of wood storks in relation to aquaculture and the extent of utilization of catfish ponds by wood storks.

Because herons and egrets prey on large numbers of diseased and dead catfish, these birds could transmit disease organisms from one pond to another. One of the most prevalent and destructive bacterial diseases to catfish is *Edwardsiella ictaluri* (ESC). Waterstrat et al. (1999) were unable to culture viable bacteria from fecal samples of herons repeatedly fed catfish fingerlings that had been injected with high concentrations of ESC. Waterstrat et al. (1999), found the high body temperatures (41° C) of herons effectively suppressed the growth of the ESC organism, limiting their role in disease transmission among ponds. Because most wading birds have similar body temperatures, it is unlikely related species transmit ESC. However, further research is needed to clarify the role of wading birds as vectors for other diseases such as proliferative gill disease.

Management recommendations regarding wading birds and catfish aquaculture focus on maximizing the effectiveness of control efforts with respect to the biology and behavior of the birds (Glahn et al. 1999b, Glahn et al. 2002). Maintaining water depths greater than 1 m limit the area available for foraging. Alternating feeding schedules or patterns and temporarily feeding sinking rather than floating feed may reduce predation during these periods (Glahn et al. 2002). Producers should focus their control and dispersal (pyrotechnics, lethal shooting) efforts on wading birds that are feeding on catfish brought to the surface during fish feeding, thereby, minimizing their control efforts and costs, and maximizing the protection of healthy fish. Additional research can refine methods used and their effectiveness in limiting depredations and ultimately benefit the bottom line for producers.

Wading Birds And Trout Aquaculture

Major areas of trout production are geographically widespread. However, Idaho accounted for 47% ($72.5 million U.S.) of total sales of $154.3 million in 1997 (NASS 1998). Also in the western U.S., California, Colorado, Oregon and Utah accounted for 16% of total sales ($11.5 million). In the eastern U.S., Pennsylvania, New York, West Virginia, Maine, North Carolina and Virginia accounted for 24% ($17.0 million). However, Pennsylvania and North Carolina alone accounted for 68% ($11.6 million) of this regional total (NASS 1998).

Trout are produced primarily in concrete or earthen raceways, or small pay-to-fish ponds (Glahn 1997). Trout aquaculture facilities vary in size from a single 0.04-ha pond to as much as 40-ha of ponds. Facilities typically comprise several hectares of concrete or earthen raceways (Glahn 1997). Per-unit-values of trout are high relative to other cultured species such as catfish, with nationwide averages ranging from $2.33/ kg for foodfish and $5.04/kg for stocker size fish (NASS 1998). Thus, per fish losses are greater, affecting both economic impacts to individual producers and the extent of methods available to producers.

Nationwide, commercial trout producers estimated losses of 7.8% in 2002 due to predation (NASS 2003a). This equates to approximately $5.4 million in losses to the industry. However, predation losses vary greatly among facilities depending on culture method and spatial complexity. Great blue herons are the species most often implicated in losses on trout aquaculture (Glahn et al. 1999c) but the green-backed herons (*Butroides striatus*), and black-crowned night herons also cause damage (Glahn 1997). Glahn et al. (1999c) estimated average losses due to great blue herons were $16,815 (range: $0-$65,759) for five Pennsylvania farms over a 168-d period. Glahn et al. (1999c) also reported two producers who estimated annual losses of $500,000 and $459,453 due to predation by great blue herons and black-crowned night herons. These producer estimates were based on increases in production after installation of bird exclusion systems.

Great blue herons are capable of transmitting viable *Myxosoma cerebralis* (whirling disease) spores in their feces (Meyers et al. 1970). Taylor and Lott (1978) demonstrated that rainbow trout could be infected with whirling disease spores that had passed through the gut of a black-crowned night heron. Currently, there is little information regarding these birds as vectors for whirling disease or other diseases and how it may impact the trout aquaculture industry.

The diversity of trout aquaculture and the species that cause depredation problems have led to a diversity of methods for dealing with them. With the exception of complete exclusion, several integrated approaches are needed to alleviate these problems. Glahn (1997) describes methods for assessment of losses prior to implementing control measures to ensure efforts are cost effective. Barrier systems usually are the most effective method (Glahn 1997). Exclusion sometimes is practical method if losses can justify the expense and the facility can feasibly incorporate exclusion in its operations. A possible added benefit of complete exclusion is the reduction in disease transmission by depredating birds. However, the extent to which this may be a benefit is unknown. Less expensive partial exclusion systems (i.e. overhead wires) can also be used, but these systems are generally less effective for the smaller wading bird species (Glahn 1997). For a compete review of management techniques and recommendations see Glahn (1997).

Glahn et al. (1999c) evaluated bird depredation losses to 5 farms in Pennsylvania. Due to the small sample size and geographic location, these results may not be reflective of industry losses as a whole. Further evaluation of losses due to wildlife in various regions and facility characteristics would facilitate development of cost effective methods for reducing damage. Future management and research effort should focus on refining loss estimates due to wading birds by region and facility and evaluating wading birds as possible vectors for disease.

Wading Birds And Ornamental Fish Aquaculture

The total value of ornamental aquaculture sales in the U.S. was $70 million in 1997 (NASS 1998). Eight-two percent of these sales ($56 million) originated from the state of Florida. Tropical fish in Florida typically are grown in small (0.024-ha), outdoor ponds on farms averaging about 5 ha (Avery et al. 1999). Prices for the different species of tropical fish vary widely, but generally are much higher on a per-unit basis than other types of cultured fish (Avery et al. 1999).

Seven species of wading birds have been implicated in ornamental aquaculture losses. The species most often implicated are the snowy egrets (*Egretta thula*), green-backed herons, tricolored herons (*E. tricolor*) and little blue herons (Avery et al. 1999). The typically small size, high stocking densities, and bright colors make these fish relatively easy targets for these wading bird species.

Avery et al. (1999) estimated average losses of $1,360 per pond due to wading birds at four farms for 15 species of ornamental fish. This compared with average losses of $589/pond on ponds with complete exclusion devices (netting), providing a $771/pond net benefit. Avery et al. (1999) concluded that exclusion appeared to be the best single method for reducing the effects of bird depredation on ornamental aquaculture.

Avery et al. (1999) identified several research needs concerning bird depredation on ornamental aquaculture. These needs include determining the food habits of various depredating species, refining quantification of depredation impacts and economic loss estimates, refining control methods, and conducting cost-benefit analyses of these methods. Additionally, the role of birds as possible vectors for disease is a concern. Disease transmission may be particularly important as some non-native cultured species may have limited defenses to existing native pathogens.

Wading Birds And Baitfish Aquaculture

Baitfish are produced, at least at a small scale, in almost every state in the U.S., with a total value of $37.5 million in 1997 (NASS 1998). However, only 14 states had reportable levels of sales and 61% ($23 million) of those sales originate from Arkansas. Arkansas baitfish facilities and ponds are large relative to trout and ornamental fish culture. Engle and Stone (1996) suggested a representative Arkansas farm is about 65 ha of water surface, with individual ponds being about 4 ha in size. Engle and Stone (1996) estimated that a farm of this size would produce about $198,000 in gross receipts at $6.06/kg unit price.

Golden shiner (*Notemigonus crysoleucas)*, fathead minnow (*Pimephales promelas*), and goldfish (*Carassius auratus)*, account for 90% of all baitfish sales in the U.S. (Stone and Thomforde 2001). These species are generally small, brightly colored, and lack defensive spines. As with ornamental fish culture, these factors increase baitfish availability to a greater number of wading bird species. Werner et al. (unpublished) found that 67% of producers consider wading birds to be the most important negative impact to production of baitfish. Gunderson and Tucker (2000) suggested that depredations caused by birds must be addressed as a limiting factor on expansion of the baitfish industry.

The primary depredating species found on baitfish farms in Arkansas, include the little blue heron, snowy egret, great egret, and great blue heron (Hoy 1994). Werner et al. (unpublished) found the most abundant species in their study was the little blue heron. Producers reported per farm, between 50 and 200 great blue herons from July-March and between 100-3,000 little blue herons and great egrets from June-October (Werner et al. unpublished).

The primary techniques used to deter birds from these facilities are the "harassment patrol", in which an individual pursues the birds with pyrotechnics, shotguns and stationary frightening devices such as propane cannons. Werner et al. (unpublished) reported that small baitfish farms (< 202 ha) annually spent $12,180 on bird harassment, and large farms (>202 ha, averaged $50,750. Losses due to bird depredation were estimated to exceed harassment costs for all farm sizes at bird abundance levels of 50% of the average reported by producers, and at a baitfish pond side sale value of $6.62/kg (Werner et al. unpublished). Werner et al. (unpublished) suggested that wading birds have a significant economic impact on baitfish aquaculture. However, the study was done on a limited number of farms, assumed all fish depredated would survive to sale, and there was no compensatory growth or mortality of remaining fish. Therefore, economic loss estimates should be considered with caution as industry-wide estimates may be higher or lower.

Werner et al. (unpublished) suggested that pre-breeding dispersal of nesting colonies near aquaculture facilities might be a more economical measure for reducing wading bird depredations than harassment patrols on baitfish farms. However, until loss estimates are refined and cumulative effects of depredating species are included, it is difficult to make effective assessments of the cost effectiveness of different control measures. Given these caveats, existing studies have demonstrated the potential for significant impacts to baitfish aquaculture production. Further research is needed to evaluate and verify these impacts.

Further refinement of loss estimates due to wading birds on baitfish aquaculture should include accurate identification of bird species, numbers of birds utilizing baitfish ponds, food habits of depredating birds, compensatory growth and mortality, alternative control methods, and cost-benefit analyses of these methods. Additionally, as with other types of aquaculture, little is known regarding the role of wading birds as potential vectors of disease to baitfish.

Wading Birds And Crawfish Aquaculture

The crawfish industry is the largest, commercially viable, crustacean aquaculture industry in North America (McClain and Romaire 1999). Louisiana leads the nation in production of crawfish with over 34,250 ha of flooded land in production (LCES 2002). Over 13 million kg of crawfish with a farm value of $37 million were produced in the state in 2001 (LCES 2002). The per-unit-value of crawfish at the farm level is approximately $2.8 kg.

Crawfish farms are diverse in shape and size. Typical ponds are 5-10 ha, with most facilities being 50 ha or less (Avery and Lorio 1999). Ponds often are rotated with other crops such as rice and soybeans and can have complex flooding and draining production regimes. Ponds typically are flooded to a depth of about 46-56 cm. Crawfish ponds also typically have 3-5 age classes and size classes present at any one time. The combination of a desirable crustacean food resource, high density of the food resource, shallow water depths, and location in a geographic area conducive to large numbers of wading birds increases the susceptibility of crawfish farms to depredation by wading birds.

Fifteen species of wading birds have been identified as depredating crawfish aquaculture (Fleury and Sherry 1995). However, four species are considered the primary depredating species: white ibis, great egret, yellow crowned night heron (*Nyctanassa violacea*), and great blue heron (Fleury and Sherry 1995). Currently there is little or no information as to the extent of losses due to wading birds on crawfish aquaculture. However, based on Christmas bird counts and breeding bird survey data (Sauer et al. 2002), there is a strong correlation between increases in some species (white ibis, white faced ibis, *Plegadis chihi*) in Louisiana and increases in crawfish aquaculture acreage (Fleury and Sherry 1995, Avery and Lorio 1999).

Although basic damage abatement strategies for other aquaculture products may be effective on crawfish aquaculture, without loss estimates effectiveness is difficult to evaluate. The current status of knowledge regarding wading bird damage to crawfish aquaculture is at descriptive level with little empirical evidence of extent of depredation and loss. Establishment of the depredating species, their numbers, food habits, foraging strategies, bioenergetics, and loss at harvest, are required before cost effective strategies can be developed.

SUMMARY

Losses due to wading birds on catfish aquaculture are minimal or preventable due to their targeting of primarily sick fish and smaller size classes of catfish. Specific management recommendations focus on dispersing birds while healthy fish are being fed or otherwise brought to the pond surface. Impacts to trout aquaculture in the East are well documented. However, further refinement of losses estimates and damage abatement methods in the eastern U.S. and elsewhere are needed. Impacts to ornamental fish due to wading bird depredations in many cases can be limited with total or partial exclusion systems. Conversely, information regarding wading bird depredations to baitfish culture is limited but strongly suggests that wading birds can have a significant impact on baitfish production. Further research is needed to define these losses and develop management strategies. Wading bird damage to crawfish aquaculture is in the initial stages of evaluation. Currently, there is little evidence to make a judgment as to extent of losses or cost effectiveness of methods for limiting those losses. All the aquaculture products discussed in this paper have the potential to be negatively affected by diseases vectored by wading birds. Disease vectoring by birds is an emerging area of research interest applicable across cultured fish and crustaceans and wading birds species and regions.

As with any wildlife damage issue, there are exceptions to the general descriptions provided here. As the demographics of both the aquaculture industry and wading bird populations change, and as new products emerge or are developed (e.g. shrimp, tilapia,), new depredation issues will inevitably occur. Given this caveat, each situation should be evaluated on a case-by-case basis by trained biologists to determine the level of impacts and possible abatement methods.

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