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Impact of Great Blue Heron Predation at Trout-Rearing Facilities in the Northeastern United States

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Abstract.—Stomach content analysis and raceway exclusion trials were conducted to evaluate the impact of great blue herons *Ardea herodias* at each of five trout-rearing facilities in the northeastern United States. Forty-two great blue herons, collected from July through September 1995 at five facilities, averaged 1.6 trout/bird or about half of their daily food requirement of 300 g/bird, in a single feeding. With two crepuscular foraging periods per day, great blue herons probably ate about three trout/d. Great blue herons consumed trout averaging 21.6 cm in total length, which is consistent with published visual estimates. However, great blue herons consumed trout ranging from 12 cm to 38 cm, suggesting that most commercially produced trout would be vulnerable to heron predation. By comparing trout inventories between pairs of net-protected and unprotected pools, we measured trout losses due to great blue heron predation at the unprotected pool and extrapolated losses for each facility. Negligible trout losses at two sites were associated with either no great blue heron use of the unprotected pool or inventory shortages from the protected pool exceeding 2,800 fish. At the remaining three sites, trout losses ranged from 9.1% to 39.4%. The economic impact of these losses relative to great blue heron use patterns is discussed. Because large fish losses were documented from both bird predation and other causes, further controlled studies of this nature are recommended as a procedure for aquaculture managers to assess their losses to great blue herons and other avian predators.

The trout-rearing industry in the northeastern United States is centered in Pennsylvania and New York, and in 1995 was valued at more than US$5.7 million (USDA 1995). In the same year, producers identified predation as their number one constraint on production, with production losses due to predators reported at 46% and 11% in Pennsylvania and New York, respectively (USDA 1995). Although a number of predators eat trout in this region (Parkhurst et al. 1992; Glahn et al. 1999, this issue), 78% of producers interviewed in 1995 named the great blue heron *Ardea herodias* as the most important predator of concern, and great blue herons were observed at 90% of 30 facilities surveyed in the region (Glahn et al. 1999). However, the impact of heron predation on trout production in the northeastern United States has not been well documented. Some authors have used dietary information from predators to estimate the number of fish they consume relative to their daily food demand (Hoy et al. 1989; Stickley et al. 1995), but this information does not exist for great blue herons at northeastern trout-rearing facilities. Systematic bird observations have been widely used to estimate production losses caused by great blue herons and other avian species at aquaculture facilities (Parkhurst et al. 1992; Stickley et al. 1992; Stickley et al. 1995; Pitt and Conover 1996; Glahn et al. 1999), but they have several limitations. First, they do not account for indirect fish losses caused by great blue herons injuring fish but not consuming them or the extent that fish consumed would have died of other causes. Second, the size of the fish consumed, an important economic variable of production losses, may be difficult to accurately ascertain from observation alone. Third, and possibly most important, these techniques are typically difficult for aquaculture managers to use in assessing their own losses.

In this study, we conducted stomach content analyses and raceway exclusion trials to clarify the impact of great blue herons at selected trout-rearing

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facilities in New York and Pennsylvania. In part, this study was conducted concurrently with that of Glahn et al. (1999), but involved different methods and facilities.

Methods

Stomach content analysis.—Identifiable stomach contents of 42 great blue herons were analyzed to determine the occurrence of commercially available fish in the diet and the size of fish eaten. Birds were collected by shotgun at five trout-rearing facilities in eastern and central Pennsylvania during the primary predation period from July through September 1995. These facilities were identified during preliminary investigations by Glahn et al. (1999), but were not included in the second phase of their study. We collected herons in the morning or evening when the highest densities of these birds occurred. To minimize collection of birds with empty stomachs, we allowed the great blue herons to forage at the facility from 30 to 60 min before collecting them. The timing of collection corresponded with the departure of the first birds from the facility. Following collection, the stomach and esophagus were removed from the herons and their contents placed into a dissection pan. We then sorted these contents into commercially raised fish (primarily rainbow trout *Oncorhynchus mykiss* and brown trout *salmo trutta*), noncommercial fish, other animal matter, and vegetable matter. The percent volume of each food category was estimated. All undigested food items were then visually identified as to species or genus, and the total lengths of all fish were measured to the nearest centimeter. We used length-to-weight equations from Piper et al. (1982) to estimate the body mass of trout consumed by great blue herons. A one-way analysis of variance (ANOVA) was used to test for differences in lengths of trout consumed, among facilities and months.

Raceway exclusion trials.—To measure losses caused by great blue herons, three private facilities with earthen raceways in eastern Pennsylvania and two state facilities with concrete raceways in western New York were selected in the spring of 1996, based on a history of great blue heron predation at these facilities. At each facility, a pair of raceway pools was selected that contained similar numbers, species, and size-classes of trout. Each pool was stocked or inventoried in May or June. During this inventory, we examined a sample of fish and recorded the percent of fish that were scarred. At the time of stocking or initial inventory, one pool was protected from birds with 5-cm polypropylene netting (J. A. Cissel Manufacturing Co.), and the other was left unprotected. Netting systems varied with the type of raceway. At earthen raceways, a tent-shaped configuration was supported with three 2.4-m T-shaped lengths of 10-cm polyvinyl chloride (PVC) pipe positioned along the center of the raceway. A flanged steel base was fitted to the PVC pipe for support, and the netting was attached to the top of the raceway banks with tent stakes. At concrete raceways, we fastened the netting to panels constructed of 3.75-cm PVC pipe and laid these panels over the raceway. The estimated cost of materials to exclude birds from these pools ranged from $300 to $500 per pool.

We conducted initial observations at pools to ascertain that the exclusion systems actually excluded birds. We subsequently made bimonthly visits to these facilities from June to the end of September or early October when these pairs of raceway pools were inventoried. During each visit, we conducted four great blue heron population surveys at 3–5 h intervals throughout the day, beginning during the first hour after dawn and ending during the last hour before dusk. During these surveys, the number of herons using the unprotected pool was recorded along with the number of herons using the entire facility. Facility managers maintained records on fish they removed or found dead in each pool during the trial period. During fall inventories, facility personnel individually counted or estimated numbers in each pool based on total weight and counted samples of weighed fish. Each sample of fish was also examined for scars caused by herons and other fish-eating birds. We categorized scars into pinch marks caused by birds holding the fish in the bill and puncture wounds caused by birds spearing the fish.

To estimate the fish lost due to great blue heron predation, we first subtracted the number of fish removed by facility staff during the trial. We then determined the difference in beginning and ending inventories at the protected pools. This difference was assumed to represent the loss from other causes and was subtracted from the difference in beginning and ending inventories at the unprotected pool. To this figure, we added the number of fish estimated to have puncture wound scars from heron attacks that would probably have been lost from production. We used a moving average of great blue herons observed over time multiplied by the total daylight hours between surveys to calculate heron-hours of use of unprotected pool and of the entire facility (Glahn et al. 1999). Great blue heron

TABLE 1.—Mean number of trout per heron, mean trout lengths (±SE), and other identifiable prey in the stomach contents of great blue herons collected at five trout-rearing facilities in eastern and central Pennsylvania during the months of July, August, and September, 1995.

Facility	Number of: Herons examined	Trout/heron, mean (range)	Trout measured	Mean ± SE trout length (cm)	Other prey identified (number)
Green Walk	20	1.25 (1–3)	25	24.22 ± 1.35	Bullheaad (1)
Paradise Trout	11	1.54 (1–4)	17	18.06 ± 1.35	None
Cedar Springs	4	1.50 (1–2)	7	21.63 ± 1.28	None
Arrowhead Springs	4	3.00 (1–5)	12	21.27 ± 0.31	None
Green Spring	3	1.00 (1–1)	3	21.00 ± 0.58	Bluegill (1)

predation losses at each facility during the trial were estimated by multiplying the heron predation loss in the unprotected pool by the ratio of heron use at the entire facility to the heron use at the unprotected pool. We extrapolated the annual loss from this estimate by multiplying it by the ratio of the total estimated number of days (168) of heron predation (Glahn et al. 1999) to the number of days in the trial.

Results

Stomach Content Analysis

The 42 great blue herons collected at five trout-rearing facilities had almost identical stomach contents (Table 1). Approximately 96% of the fish identified in stomach samples ($N = 68$) were trout. The balance of the identifiable animal matter consisted of one bullhead *Ameiurus* sp., one bluegill *Lepomis macrochirus,* and one crayfish *Procambarus* sp. Great blue herons contained a mean of 1.6 trout (range = 1–5, SE = 0.159) within 1 h after arriving at hatcheries in the morning or evening. The mean total length of trout consumed was 21.6 cm (range = 12–38 cm; SE = 0.724), which differed among facilities ($P = 0.014$, $F = 3.43$, df = 4,58), but not months of collection ($P = 0.680$, $F = 0.39$, df = 3,60). Trout consumed at Green Walk Hatchery were larger ($P < 0.05$) than the fish consumed at Paradise Hatchery (Table 1). The largest trout consumed at Green Walk was 38 cm and was taken in September; three other trout consumed at this facility in September exceeded 30 cm.

Raceway Exclusion Trials

Stocking rates, fish species, and fish size varied among trial sites (Table 2) as did the trial duration (Table 3). Measured losses from primarily great blue heron predation at five facilities ranged from zero to 39.4% (Table 3). Losses that occurred were assumed to be caused primarily by great blue herons because only herons were observed to forage at the pools under study, despite other predators sometimes being present at these facilities. Negligible losses at the two state hatcheries in New York (Rome and Bath) were associated with either no great blue heron use of the unprotected pool or unexplained inventory shortages from other causes at the excluded pool that exceeded 2,800 fish (Table 3). Although no losses were projected from observational estimates at Bath New York State Hatchery, we estimated a 4% loss of 888 trout from the Rome New York State Hatchery. An inventory shortage of 5,060 brown trout *Salmo trutta* was recorded from a second unprotected pool at the Bath hatchery that great blue herons consistently used for foraging. However, lack of actual great blue heron counts and a similar control pool pre-

TABLE 2.—Species, size-classes at the start and end of the trial, and numbers of trout stocked and inventoried from raceways protected and unprotected from great blue heron predation at five trout-rearing facilities in Pennsylvania and New York, 1996.

Facility	Trout species	Trout size (cm) Start	End	Number stocked Protected	Unprotected	Number inventoried Protected	Unprotected
Paradise	Rainbow	25	29	3,000	5,000	1,005	1,809
Cherry Valley	Brown	21	29	6,000	6,000	3,563	3,106
Green Walk	Rainbow	21	32	2,200	2,200	1,943	1,766
Rome	Brown	11	19	22,000	22,000	19,126	19,800
Bath I	Rainbow	8	14	24,860	24,860	24,150	25,940
Bath II	Brown	8	14	None	51,150	None	46,070

TABLE 3.—Calculations of fish loss and economic impact due primarily to great blue heron predation at five trout-rearing facilities in New York and Pennsylvania during raceway exclusion trials in 1996.

Facility	Trial duration (d)	Differences in fish inventories: Protected pool		Differences in fish inventories: Unprotected pool		Fish losses/pool from predation			Estimate of great blue heron use (heron-hours)		Total facility loss[a]	
		Missing	Scarred	Missing	Scarred	Number	Percent	Dollars	Pool	Facility	Fish	Dollars
Paradise	124	735	0	2,672	32	1,969	39.4	4,922	605.2	5,967.8	26,303	65,759
Cherry Valley	98	2,437	0	2,819	71	453	12.7	1,200	1,222.6	6,565.6	3,897	10,322
Green Walk	96	257	0	434	0	177	9.1	531	842.6	7,249.0	2,665	7,992
Rome	132	2,874	0	2,200	0	0	0	0	403.8	4,476.8	None	None
Bath I	115	710	0	0	0	0	0	0	0	309.2	None	None

[a] Total facility loss was calculated as pool losses times the ratio of facility to pool heron use estimates divided by the percent of trial days in the estimated 168 days of expected heron predation at the facility.

cluded estimating the actual loss due to heron predation (Table 2). Losses under heavy great blue heron use at the three remaining hatcheries in eastern Pennsylvania ranged from 9.1% to 39.4% and involved fish numbers ranging from 177 to 1,969 per pool (Table 3). These fish were valued at between $531 and $4,922. Based on observational estimates, 1,854, 2,690 and 1,332 trout were removed by great blue herons from unprotected pools at Green Walk, Cherry Valley, and Paradise hatcheries, respectively. The estimated total facility losses at each of the three facilities over the estimated 168-d predation period ranged from 2,665 fish to 26,303 fish, with an estimated monetary value ranging from almost $8,000 to almost $66,000 (Table 3).

Discussion

Despite the wide variety of animal matter that great blue herons have been reported to consume (Palmer 1962), herons using trout-rearing facilities had a diet consisting almost exclusively of trout. The average size of trout that herons consumed is consistent with that previously reported from observational studies in the northeastern United States (Parkhurst et al. 1992; Glahn et al. 1999) and elsewhere (Pitt and Conover 1996). However, the largest size of trout that herons consumed in this study (38 cm) has not been previously reported in the literature and suggests that most commercially produced trout might be vulnerable to great blue heron predation.

Allowing great blue herons to forage before collection provided an estimate of 1.6 trout per feeding during primary foraging periods in the morning and the evening. Parkhurst (1989) indicated that each great blue heron probably consumed approximately 300 g of trout per day. This is consistent with calculations based on data from Bennett (1993). Bennett (1993) reported that adult herons on a maintenance diet of fish had a gross energy intake of 1,434 kJ/d. At the reported wet weight energy value of trout at 7.31 kJ/g (Bennett 1993), the maintenance diet of herons would be 196 g. Assuming that free-ranging great blue herons require 1.5 times their maintenance requirement (Schramm et al. 1987), herons foraging exclusively on trout need approximately 300 g of trout per day. Because the average weight of a 21.6-cm trout is approximately 112 g, each great blue heron could satisfy its daily food requirement by consuming approximately three trout. Assuming that the same herons foraged at the same facilities in a crepuscular pattern twice per day, they could obtain their total daily food requirement by consuming 1.6 average-size trout per feeding. However, in our stomach content analysis, 24% of the 42 herons had in excess of 300 g of trout in their stomachs, and thus exceeded their expected daily food requirement of trout in a single feeding.

The herons we collected foraged for approximately 45 min in the morning and 45 min in the evening, for a total foraging time of 1.5 h/day. Because we collected all birds as the first birds started to depart the facility, we assumed that most birds were almost done feeding. Glahn et al. (1999) estimated the consumption rate of great blue herons from observations at approximately two trout/h. Assuming that most of this foraging is confined to only 1.5 h/d, this would also calculate at three trout/d or the total daily food requirement of great blue herons. If this calculation is approximately correct, trout producers can roughly calculate the number of fish they are losing to herons by multiplying the average number of herons seen during morning and evening surveys by three trout/d for each great blue heron.

Our estimates of production losses varied greatly among sites. Although in one case, this was a result of negligible pool use by great blue herons, in two cases this was the result of large inventory reductions in the protected pool. At Cherry Valley, large losses in the protected pool, which was positioned near a stream, appeared to be caused by a river otter *Lutra canadensis*. An otter slide under the netting was noted at inventory. No such sign of otter activity was observed at the unprotected pool. Assuming otters removed a significant number of fish from the protected pool, but not the unprotected pool, the actual number of fish removed by herons from the unprotected pool was probably greater. The observational estimates indicate that herons removed 2,690 fish or 44.8% of the fish stocked, which is consistent with the inventory shortage of 2,819 fish from this pool. We cannot explain the more than 10% (>2,800 fish) inventory shortage in the protected pool at Rome hatchery, but it clearly was large enough to mask the small projected loss due to great blue heron use of the unprotected pool. At Green Walk, low measured losses compared with those predicted from observations may have been associated with the low stocking density and the positioning of this pool near a residence. Parkhurst (1989) reported that foraging efficiency of avian predators could probably be affected by human disturbance, and efficiency would logically decrease with lower prey density.

These data provide documentation of actual production losses caused by great blue herons at trout-rearing facilities in the northeastern United States. Large facility losses were associated with periodic morning and evening use by more than 20 great blue herons per site. However, these losses may be atypically high in light of average bird use of facilities in the Northeast (Glahn et al. 1999). More typical losses caused by one to six great blue herons using a facility might be extrapolated from the losses measured from each study pool because heron use of these pools was within this range.

In few cases have trout losses due to avian predation been directly measured. Following exclusion of birds from a state-operated trout-rearing facility in Pennsylvania, Hubley (1992) placed a yearly loss to black-crowned night herons *Nycticorax nycticorax* and great blue herons at more than 400,000 trout, worth approximately $0.5 million. Exclusion of great blue herons and black-crowned night herons from raceways at a large private hatchery in Pennsylvania with an overhead wire and chain link fence system in 1996 provided comparative data with the previous year. In 1996, August inventories of 9 in to 14 in rainbow trout at this facility were reported (Renee Swank, Limestone Springs Hatchery, personal communication) to increase by 258,120 fish compared with 1995, a 44.6% increase. At an average value of $1.78/fish, predation loss in 1995 was calculated at $459,453.

Great blue herons foraging at trout-rearing facilities are highly efficient predators on medium and large commercially produced trout and may readily subsist on a diet of trout alone. Although the number of trout eaten probably varies with sizes of fish consumed, great blue herons are probably consuming on average about three trout/d. Because most of this foraging occurs near dawn and dusk, many trout producers may not be aware of the extent of their problem. Observations during these periods can provide a preliminary means of assessing the extent of bird predation at a site.

Implications from our raceway exclusion trials confirm the extreme losses that can result from great blue heron predation. However, we also observed large losses from other causes. Thus, additional controlled studies are needed to verify losses from great blue herons and other avian predators on a site-by-site basis. Only with studies of this nature can trout producers evaluate the true economic impact inflicted by herons and other avian predators. Because of high potential losses, trout producers should take necessary preventive measures to protect their fish stocks. As evidenced by our trials, simple netting systems can provide a high degree of protection from great blue herons and presumably other avian predators. Although these systems may hinder routine maintenance of raceways, they appeared to be cost-effective in cases where great blue heron predation was a substantial problem.

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