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THE WILDLIFE SOCIETY

Research Article

Scaup Depredation on Arkansas Baitfish and Sportfish Aquaculture

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ABSTRACT Lesser scaup (*Aythya affinis*) and greater scaup (*A. marila*), hereafter scaup, consume a variety of aquatic invertebrates, plants, and occasionally small fish. Scaup have foraged on commercial aquaculture farms in the southern United States for decades. However, the types, abundance, and rate of fish exploitation by scaup on baitfish and sportfish farms are not well documented. Thus, information is needed to understand how fish and other foods influence scaup use of aquatic resources, and any potential economic effects of depredation of fish. From November–March in winters 2016–2017 and 2017–2018, we conducted 1,458 pond surveys to estimate the abundance and distribution of scaup on Arkansas baitfish and sportfish farms that commercially produce species such as golden shiners (*Notemigonus crysoleucas*), fathead minnows (*Pimephales promelas*), goldfish (*Carassius auratus*), and sunfish (*Lepomis* spp.). We also collected and processed 531 foraging scaup and quantified the proportion of scaup consuming fish and the proportion of their diet obtained from fish. Fish consumption was highly variable between years. In our survey area, we estimated total fish consumption at 1,400 kg and 60,500 kg for winters 2016–2017 and 2017–2018, respectively. Sunfish ponds experienced the maximum loss (18,000 fish/ha) during winter 2017–2018, while goldfish ponds experienced a loss of just 2,600 fish/ha during the same winter. The estimates of baitfish and sportfish loss to scaup revealed potential management strategies for minimizing fish loss and can inform economic analysis of the financial impact of scaup on producers. © 2021 The Wildlife Society.

KEY WORDS aquaculture, Arkansas, *Aythya* spp., baitfish, scaup, sportfish, wildlife damage management.

Scaup are diving ducks that typically use rivers, lakes, bays, and other more semi- or permanently-flooded aquatic habitats (Baldassarre 2014, Anteau et al. 2020). Scaup diets consist of a diversity of both plant and animal organisms depending on location within their range and time of year (Bartonek and Hickey 1969, Dirschl 1969, Ross et al. 2005, Badzinski and Petrie 2006, Anteau and Afton 2008). Diets of scaup collected at southern latitudes of the United States tend to be composed primarily of animal organisms from classes Bivalvia, Gastropoda, and Insecta (Hoppe et al. 1986, Afton et al. 1991, Wooten and Werner 2004, Stroud et al. 2019).

Although not commonly regarded as a fish-eating bird, scaup may consume substantial quantities of fish (Rogers and Korschgen 1966, Philipp and Hoy 1997, Wooten and Werner 2004). Rogers and Korschgen (1966) collected 37 scaup from two locations in Lousiana and found that collectively 46% ($n = 17$) of the scaup contained fish fragments or sheepshead minnows (*Cyprinodon variegatus*), which represented 42% of their diet by volume. Other examples of fish consumption by scaup occurred on ponds used for commercial baitfish production in Arkansas

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(Philipp and Hoy 1997, Wooten and Werner 2004) that presumably have much higher densities of fish than natural wetland and lake habitats where scaup have often been collected for diet analysis (Afton et al. 1991, Stroud et al. 2019). Afton et al. (1991) collected scaup from Rockefeller Wildlife Refuge and found that fish represented <0.05% of lesser scaup diets during midwinter migration in southwestern Louisiana. Given previous work, it seems the role of fish in the diets of scaup are equivocal, particularly when comparing scaup foraging dynamics between aquaculture facilities and otherwise natural wetlands or lakes used by migrating and wintering birds.

Compared to natural habitats, aquaculture facilities provide a novel resource for foraging and roosting for scaup and other waterbirds, which presents questions, opportunities, and potential concerns. For example, are aquaculture facilities providing some of the typical invertebrate foods that the birds may encounter in other habitats? Or are energy-rich fish species being targeted because of ease of accessibility in the enclosed aquaculture ponds? If scaup are targeting fish, what are the economic ramifications to the producers?

Aquaculture in the United States is a $1.3 billion industry with >3,000 individual farms existing in 48 states (United States Department of Agriculture [USDA] 2014). The baitfish industry contributes $30 million in farm-gate sales (i.e., wholesale) throughout the United States, with nearly 63% of those sales derived from Arkansas (USDA 2014). Arkansas also produces 31% of the U.S. sportfish industry's farm-gate sales, or an additional $7.3 million in revenue (USDA 2014). Golden shiners (*Notemigonus crysoleucas*), fathead minnows (*Pimephales promelas*), channel catfish (*Ictalurus punctatus*), and goldfish (*Carassius auratus*) are the primary fish products originating from Arkansas.

In Arkansas, the commercial baitfish industry produces densities of fish that attract waterbirds within a highly-modified landscape where foraging opportunities for these birds have been greatly reduced (Elliott and McKnight 2000, Werner et al. 2005). In addition to direct predation, birds can also negatively influence baitfish aquaculture by consuming enough baitfish per pond to reduce overall densities; reductions in fish density ultimately cause baitfish to grow larger than the desired saleable size class. If fish grow beyond that size threshold, their market values substantially decrease (Engle et al. 2000). To reduce direct and indirect losses caused by scaup and other fish-eating birds, farmers use both non-lethal harassment (frightening) and some lethal control measures to deter birds from using ponds (Hoy et al. 1989).

The prevalence of fish in scaup diets may partially depend on foraging location and local abundances of food available to these birds. Recent observations by Arkansas fish producers and previous on-farm studies suggest that fish consumption by scaup at baitfish facilities could be much greater than that perceived decades ago (Philipp and Hoy 1997, Wooten and Werner 2004, Roy et al. 2015, 2016). Producers have observed direct consumption of fish by scaup, as have duck hunters that harvested scaup when leasing ponds on fish farms during hunting season (Roy et al. 2015, 2016). Highly visible ponds stocked densely with small fish may provide an easily accessible and profitable foraging environment, but one that has been previously dismissed given the traditional paradigm of fish being unimportant to scaup in more natural habitats.

In addition to needing a better understanding of how or why scaup exploit bait- and sport-fish facilities, there are potential economic implications. The baitfish industry currently faces challenges related to increasing costs of water, land, and competition from products that reduce the need for live bait (i.e., artificial lures). These factors make the maximization of merchantable fish product more paramount (Engle et al. 2000). Given all of the uncertainties, research that determines the role of scaup in foraging on baitfish and sportfish ponds is needed. Toward that end, the overarching goal of our study was to investigate foraging behavior and quantify the amount of bait- and sportfish consumed annually by wintering scaup on Arkansas baitfish aquaculture. Our two major objectives included: 1) Estimate scaup abundance and distribution across pond production types existing at those facilities, and 2) estimate the quantity of fish or other foods consumed by individual scaup using aquaculture facilities during two winters. We hypothesized that predation of baitfish and sportfish by scaup would occur annually in Arkansas. We predicted that fish loss would increase through mid-winter as scaup abundance increased within the survey area, eventually peaking in late-winter (i.e., Feb), just prior to spring migration.

STUDY AREA

Our study was conducted in Lonoke and Prairie Counties, Arkansas, an area which contained 72% of all baitfish and sportfish farms in the state. A total of 26 unique farms existed within the 2 counties, of which we randomly selected 15 to survey (9 in Lonoke; 6 in Prairie). The selected farms varied considerably in production area, distribution across the landscape, and fish species grown. Total production area on farms ranged from 35.9–1,106.2 ha ($\bar{x} = 313.7$ ha) and consisted of 13–292 ponds ($\bar{x} = 87$ ponds). To minimize over-or under-sampling of specific farms, we divided the 15 farms into 38 pond groups (i.e., groups of ponds under the same ownership that were separated from other pond groups by geographical features such as roadways or tree lines; Fig. 1). Pond group production area ranged from 26.6–353.4 ha ($\bar{x} = 123.8$ ha) and consisted of 6–127 ponds ($\bar{x} = 34$ ponds). Eighteen percent ($n = 7$) of pond groups produced just one species of fish, whereas the remainder grew multiple species. Creating pond groups allowed us to better proportionately allocate our pond sampling over the entire study area and across the various fish species produced.

We digitized all ponds within our pond groups in a geographic information system (ArcGis 10.4, Esri, Redlands, CA, USA) using high-resolution imagery produced by the National Agriculture Imagery Program (NAIP) and obtained from the USDA, Geospatial

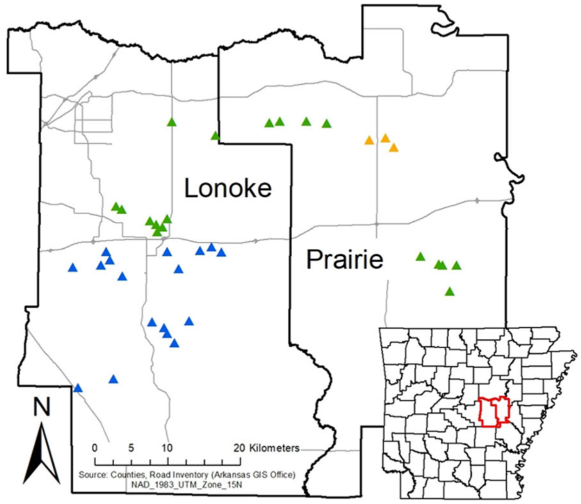

Figure 1. Locations of 38 pond groups used to estimate total fish loss from scaup in eastern Arkansas, USA, winters 2016–2017 and 2017–2018. Pond groups were created from 15 individual baitfish and sportfish farms located in Lonoke and Prairie counties, Arkansas. Gold triangles represent the 3 pond groups (one farm) dropped between winters. Blue and green triangles distinguish the 2 survey routes completed each survey period.

Gateway (https://datagateway.nrcs.usda.gov, accessed 6 Sept 2016), along with 30-meter resolution LandSat-8 imagery obtained from the U.S. Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/, accessed 6 Sept 2016). Pond size was highly variable, ranging from 0.1 to 30.4 ha ($\bar{x} = 3.6$ ha). Approximately 80% (n = 952) of the total ponds in our survey area contained golden shiners, fathead minnows, goldfish, or sunfish (*Lepomis* spp.). Less than 5% of those ponds contained multiple species of fish; those that did typically contained a combination of sunfish and large grass carp (*Ctenopharyngodon idella*).

METHODS

Survey Procedures

To assess the distribution and abundance of scaup using baitfish and sportfish farms, we conducted bimonthly ground surveys from November through March of 2016–2017 and 2017–2018, coinciding with scaup migration in this part of the Mississippi Alluvial Valley (Baldassarre 2014). For survey purposes, we separated all pond groups into 2 survey routes, each containing 19 pond groups. We removed one farm, comprising 3 pond groups, during the second winter due to access limitations. Consequently, in the second year, the 2 routes were reduced to 17 and 18 pond groups each, and the surveys ($n = 66$) from the removed pond groups were not used when estimating scaup abundance to ensure total area was comparable between years. During each sampling period, each route was simultaneously surveyed by a separate team of researchers. We defined a sampling period as a single day of pond surveys followed by multiple days of scaup collections, never exceeding 5 total days ($n = 11$ and 9 sampling periods in 2016–2017 and 2017–2018, respectively). Each survey team alternated between two different starting locations for each survey-day to reduce surveying individual pond groups at the same time of day during each survey. During the second winter, logistical changes (i.e., the removal of three pond groups from surveys) allowed for a third starting location to be added to further reduce any effects of time of day. For both winters, we randomly selected one of the available starting locations for the first survey-day, then systematically rotated for each of the following sampling periods.

Within each route, we randomly selected 2 ponds from each of the 38 pond groups to conduct bird surveys, with some exceptions (<10 pond surveys) due to temporary access issues or time delays (e.g., weather or farm activities). Given the large size of our study area, surveying more than 76 randomly selected ponds across all 38 pond groups would not be possible to complete in one day's time. In the rare instances that all surveys were not completed, we used all surveys that were completed for subsequent analysis. We surveyed each selected pond for 5–15 minutes, depending on the size of the pond and the number of birds present. We used binoculars and spotting scopes from distances that minimally disturbed birds but permitted an unobstructed view of most of the pond surface (50–300 m from pond's edge). We recorded the fish species stocked (i.e., production type) in each of the surveyed ponds to evaluate scaup distribution across production types.

Scaup Collection Criteria

During each survey-day, we also counted all scaup opportunistically observed while traveling within each of the 38 pond groups, regardless of the occupied pond being one that was randomly selected as a survey pond. The counts were used to decide from which pond groups to subsequently collect birds. Our goal was to collect 30 scaup from a minimum of 3 pond groups each sampling period. In one case, however, all scaup were collected from just 2 pond groups. We used 150 individual scaup as the minimum number of birds within a pond group to consider it for a collection. If 4 or more pond groups had >150 scaup counted, 3 pond groups were randomly selected for collection. When 3 pond groups or less had 150 birds, we first attempted scaup collections from pond groups that met the minimum criteria, and then opportunistically collected scaup from accessible pond groups where present. Ultimately, the 150-bird constraint was used to focus collections where we believed collection goals could realistically be met, while maintaining the randomization of our collections to ensure representative samples were obtained.

Targeted scaup collections.—In some instances, we collected birds outside of the aforementioned procedures, either before the survey-day was completed or on pond groups where relatively few scaup were present, but on production types (i.e., the species of fish grown in a pond) where samples were limited. The targeted collections were typically performed to either add to low overall collection numbers, because of lack of birds using ponds, or to obtain additional samples from under-represented production types (e.g., goldfish ponds). Targeted collections represented 14% of all birds collected during the study.

Pond selection for bird harvest.—For all collections, we selected individual ponds within pond groups for collections by behavior of the birds (foraging) as well as logistical constraints (e.g., presence of hunters, pond harvesting, accessibility). Collection of foraging scaup was solely conducted to acquire adequate diet samples. Scaup were typically observed conducting all daily activities (e.g., loafing and foraging) on the same ponds; therefore, we assumed that all scaup counted were on ponds in which they foraged.

Scaup Collections

Before collecting scaup, birds were observed foraging for approximately 10 minutes to ensure they contained quantifiable prey items (Swanson and Bartonek 1970, Callicutt et al. 2011). Each researcher was equipped with a 12-gauge shotgun or .22 caliber rimfire rifle, and either stalked birds on foot or shot from a temporary blind. Scaup collection methods were approved by the USDA APHIS Wildlife Services and the National Wildlife Research Center's Institutional Animal Care and Use Committee and attending veterinarian (Quality Assurance Protocol 2599). All collections were conducted under Arkansas Game and Fish Commission scientific collection permits #012620161 and #011720175, and the U.S. Fish and Wildlife Service Migratory Bird Permit #MB019065-3. We injected up to 60 mL of cold phosphate buffered saline (PBS) into the upper gastric tract of each bird immediately after collection and attached a zip tie around their neck to retain the fluid and slow the digestive process. We labeled each bird with a Tyvek® tag indicating the location and date of harvest. We then bagged and maintained birds on ice until they were transported to the Mississippi State Field Station necropsy lab. All birds were necropsied within 72 hours of being collected.

During necropsies, we removed the gastrointestinal tract (GI tract), including the gizzard, proventriculus, and esophagus, from each bird and froze each separately until they could be later dissected. During summers of 2017 and 2018, we thawed each GI tract and further dissected them to remove all food items. The esophagi and proventriculi were treated separately from the gizzards. Gizzards were checked for presence or absence of fish parts, but because of bias associated with recognizable food items in birds' gizzards, we did not use the contents in the overall diet proportions for each bird (Swanson and Bartonek 1970). We sorted and recorded food items found in the esophagi and proventriculus as fish, invertebrate, or seeds, dried the contents for 22–24 hours at 60°C (Afton et al. 1991, Foth et al. 2014), and weighed the samples to the nearest mg (Hoppe et al. 1986) to estimate the dry-weight proportion of each item in the bird's total diet. Fish and invertebrates were identified to the lowest taxonomic group possible.

Statistical Analysis

Abundance and Distribution.—We restricted our estimates of bird abundance and distribution to 4 production types (i.e., ponds containing either golden shiners, fathead minnows, goldfish, or sunfish) as these are the only species we have evidence of scaup consuming, based on previous studies (Philipp and Hoy 1997, Wooten and Werner 2004, Roy et al. 2015, 2016) and our own observations. To estimate the total number of scaup using all 4 production types during each sampling period, we calculated the total number of birds using each type first, then summed to derive a total estimate of scaup present each survey day. We estimated the total number of scaup using each production type by multiplying the average number of scaup/pond (calculated from surveyed ponds during that sampling period) by the total number of ponds available of that type. To evaluate the potential of production type preferences, we compared the total monthly proportion of birds found on each type to the expected proportion of birds found on each type (i.e., equivalent to the proportion of the total ponds available) using a non-parametric Wilcoxon signed rank test ($\alpha = 0.05$).

We were able to obtain information about the species of fish present in each pond for >50% of pond groups. For larger pond groups where fish species were only known for surveyed ponds, we estimated the number of ponds in each production type by extrapolating the proportions of each type in our random pond surveys to the total ponds in the pond group. During winter, some ponds were drained either because all fish were harvested or for preparation of nursery ponds during the subsequent spring. We removed these dry ponds from the analysis when calculating total scaup estimates. Because it was not logistically possible for us to survey each pond group in its entirety each survey day, the total number of dry ponds was not known. We estimated the number of dry ponds for each survey day by enumerating the number of dry ponds within our survey area using available 30-meter resolution LandSat-8 imagery obtained from the USGS Earth Explorer (https://earthexplorer.usgs.gov/, accessed 10 Sept 2018) during the two winters. We created a linear regression equation using day of the winter season as the independent variable and proportion of dry ponds as the dependent variable (Fig. 2). We pooled data from both winters due to limited days of LandSat-8 imagery that lacked excess cloud cover blocking ponds. However, we did not expect changes in production practices between winters. We then distributed the number of dry ponds

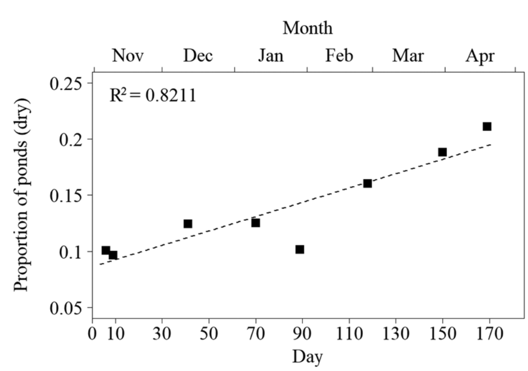

Figure 2. Proportions of total baitfish and sportfish ponds that were dry during winter. Estimated from LandSat-8 imagery, US Geological Survey (USGS) Earth Explorer during winters 2016–2017 and 2017–2018 on 14 baitfish and sportfish farms in Lonoke and Prairie Counties, Arkansas, USA.

estimated from the regression equation by production type based on total proportion of the surveyed area.

We modeled the estimated scaup totals for each survey-day using polynomial regression. We defined the wintering season as 151 days (1 Nov–31 Mar), therefore day 0 (31 Oct) and day 152 (1 Apr) were assumed to have zero scaup (Dorr et al. 2012). When selecting polynomial models to depict scaup use of our survey area each winter, we wanted to minimize the sum of squares of the residuals (SSR) and increase R-squared, while not including unnecessary parameters in our models. We examined models of orders 2–9 by comparing each to the preceding order using a partial F-test ($\alpha = 0.05$) to evaluate the significance of adding the additional parameter (Lindsey and Sheather 2010). We selected the model in which there was no further significant reduction in the SSR according to the partial F-tests. Linear (first order) models were not considered because ecologically it is understood that a migratory population would not grow or decline linearly in an area within a year's time, as birds will arrive and eventually leave the area.

Using individual models for each year, we added the estimated number of scaup present for each of the 151 days in the winter season to produce the total number of scaup-use days (SUDs; Dorr et al. 2012). We used the same approach to calculate SUDs under the upper and lower 95% confidence limits of the models, to calculate a high and low estimate for each year in the study area. We then divided the total number of SUDs among the 4 production types based on the proportion of birds using each. We also assessed the monthly proportion of ponds being used by scaup, as SUDs were not distributed evenly across all ponds. We compared the monthly proportions of ponds used by scaup that we observed, by running logistic regression and investigating differences in proportions using the emmeans package (Lenth 2018) in program R (R Core Team 2018), which compares all pairs using a Tukey's test (α of 0.05).

Scaup Diets.—By pooling scaup that were collected from all of the ponds, we used presence or absence data of fish parts in the GI tract to estimate the mean proportion of birds consuming fish during each month. We weighted proportions by the square root of the number of birds collected from each pond and scaled the proportions to maintain our sample size. We compared ($\alpha = 0.05$) monthly proportions of scaup consuming fish using logistic regression and conducted post hoc Tukey's tests (α of 0.05) using the package emmeans (Lenth 2018) in program R (R Core Team 2018). For clarity of post hoc analyses results, significant differences are reported in figures. This procedure allowed us to estimate the number of SUDs on each fish category type associated with only those scaup consuming fish (i.e., Fish-Consumption Days, FCDs). To calculate the amount of fish consumed during those FCDs, we estimated the aggregate percent of fish in the diet of scaup for each month using just the birds that contained fish and had ≥5 mg of dried food material in their GI tract. We used an asymptotic Wilcoxon-Mann-Whitney test to compare ($\alpha = 0.05$) the proportion of fish in the diet of just the birds containing goldfish, golden shiners, and sunfish to consider pooling species. In other words, when scaup did consume fish, we wanted to know if there were differences in the proportion of fish found in their diet with respect to the fish species consumed.

We estimated the quantity (kg) of fish consumed/scaup/day by calculating the proportion of their daily energy expenditure (DEE) of 811 kJ/bird/day (Lovvorn et al. 2013) that would be comprised of fish during each month of a winter. Proportion calculations assumed true metabolizable energy (TME; Sibbald 1976, Miller and Reinecke 1984) values of 3.66, 0.70, and 1.13 kcal/g for fish, invertebrates, and seeds, respectively, based on average TME values for common food items in scaup that have been calculated in previous studies from other captive waterfowl species (Table 1). We used the aggregate proportion of each food type in scaup diets by month for this analysis. We calculated the average sizes of fish being consumed by scaup from direct measurements and length-weight regressions (Anderson and Neumann 1996, Stone et al. 2003, N. Stone and R. T. Lochmann, University of Arkansas at Pine Bluff,

Table 1. Published true metabolizable energy (TME, kcal/g) values of common prey types found in scaup collected from baitfish and sportfish ponds in Lonoke and Prairie Counties, Arkansas, USA, winters 2016–2017 and 2017–2018.

Prey Type	TME[a]	Species[b]	Source
Fish			
Fundulus spp.	3.66	ABDU	Coluccy et al. 2015
Seeds[c]			
Polygonum spp.	1.52	MALL	Checkett et al. 2002
	1.08	MALL	Hoffman and Bookhout 1985
	1.25	NOPI	Hoffman and Bookhout 1985
	1.30	BWTE	Sherfy et al. 2001
	1.29		
Potomogeton spp.	1.42	MALL	Ballard et al. 2004
	0.82	NA	Brasher et al. 2007
	0.64	NA	Muztar et al. 1977
	0.96		
Invertebrates[d]			
Gastropoda	0.39	ABDU	Jorde and Owen 1988
	0.60	NOPI	Ballard et al. 2004
	−0.09	BWTE	Sherfy 1999
	0.30		
Malacostraca[e]	2.21	ABDU	Jorde and Owen 1988
	2.02	ABDU	Coluccy et al. 2015
	2.36	NOPI	Ballard et al. 2004
	0.33	BWTE	Sherfy 1999
	1.73		
Diptera	0.27	BWTE	Sherfy 1999
Hemiptera	0.48	BWTE	Sherfy 1999

[a] Bolded numbers represent mean values for each prey type. Boxed numbers were then averaged to have one value for each prey category. (i.e., Fish = 3.66; Seeds = 1.13; Invertebrates = 0.70).

[b] ABDU = American black duck, BWTE = blue-winged teal, MALL = mallard, NOPI = northern pintail.

[c] *Polygonum* spp. and *Potomogeton* spp. comprised >60% of the total seeds found in collected scaup during both years.

[d] Gastropoda, Malacostaca, Diptera, and Hemiptera made up >90% of the total invertebrates found in collected scaup during both years.

[e] Malacostraca includes all *Gammarus* spp. except for one grass shrimp value from Coluccy et al. 2015.

unpublished data). By combining this information with our abundance estimates of scaup using farms during winter, and the proportion of those scaup consuming baitfish or sportfish, we could estimate the total amount of fish consumed by scaup through time during both winters.

Scaup Depredation of Fish.—We used the following equation to calculate the total amount of fish consumed annually:

$$\textit{Total fish consumed}\,(\text{kg/year}) = \textit{fish consumed}\,(\text{kg/bird/day}) \times \textit{total fish-consumption days}\,(\text{No./year})$$

To calculate biomass of fish consumed in kg-loss/ha, we divided the total loss by the total area in production for each fish species, which we estimated by multiplying the total number of ponds by the average pond size for that fish species. We calculated the number of fish-consumed/ha (i.e., fish/ha) for each species by estimating the proportion of fish being consumed in each of 5 individual fish weight categories (0–0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0, ≥2.0 g) using all measurable fish of that species found in scaup, then calculated the proportion of fish in each category that contributed to the total biomass/ha lost and divided that portion of the total biomass by the mean fish size in that category. The total amount of fish in all 5 categories were then summed together. We used golden shiner data to estimate fish/ha for fathead minnows because no measurable fathead minnows were found in scaup, and golden shiners would be the closest representative size.

RESULTS

Abundance and Distribution

We conducted 1,458 individual pond surveys from November through March 2016–2017 ($n = 830$ surveys) and 2017–2018 ($n = 628$ surveys). We removed 66 surveys from the 3 pond groups dropped between winters and 277 surveys conducted on empty ponds or ponds not containing one of the 4 targeted production types. We used the remaining 1,115 individual pond surveys completed on 549 unique golden shiners, fathead minnows, goldfish, or sunfish ponds (~46% of total unique ponds) for analyses.

During winter 2016–2017 (year 1) we counted 1,684 scaup on randomly-selected ponds of the 4 pond production types. In contrast, we counted 4,338 scaup during winter 2017-2018 (year 2). Based on the minimized SSR partial F-test, we fitted seventh- ($y = 0.000000005x^7 - 0.0000029x^6 + 0.0006220x^5 - 0.06521x^4 + 3.5080x^3 - 89.3004x^2 + 839.1159x - 9.3207$) and fifth-order ($y = -0.0000089x^5 + 0.002927x^4 - 0.2986x^3 + 7.5158x^2 + 244.6128x - 146.8086$) polynomial models to the extrapolated estimates of scaup in the survey area for years 1 and 2, respectively (Fig. 3; Table 2). We estimated a total of 292,000 SUDs (95% CI = 33,000–692,000) in year 1, and 875,000 SUDs (95% CI = 421,000–1,356,000) in year 2. Most (68% and 69%) of the total SUDs were associated with golden shiner ponds in year 1 and year 2, respectively. The SUDs were not distributed evenly across all ponds in the survey area because at any given time some ponds were not being used. December of year 2 was associated with the greatest proportion of ponds used, although this value did not differ from January ($P = 0.748$) and February ($P = 0.518$) of that year (Fig. 4). The lowest proportion of ponds being used was observed during November of year 1, which differed from January ($P = 0.003$), February ($P = 0.009$), and March ($P = 0.021$), but did not differ from December ($P = 0.075$) of that year (Fig. 4). In both winters, scaup were consistently found on golden shiner ponds in greater proportion than their availability (year 1, $V = 58$, $P = 0.029$; year 2, $V = 45$, $P = 0.004$), while scaup consistently used goldfish ponds less frequently than their availability (year 1, $V = 0$, $P = 0.002$; year 2, $V = 0$, $P = 0.005$) in our survey area (Fig. 5).

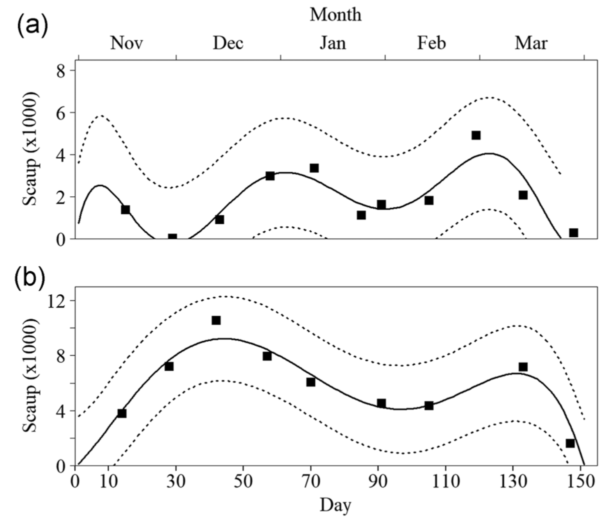

Figure 3. Polynomial curves representing total numbers of scaup estimated from ground surveys on 14 baitfish and sportfish farms in Lonoke and Prairie Counties, Arkansas, USA, during winters a) 2016–2017 and b) 2017–2018 (See results for regression equations). These polynomial models with 95% confidence intervals were used to calculate high and low estimates of Scaup-use days, which are represented by the area under each curve. We defined the wintering season as 151 days (1 November–31 March), therefore day 0 (31 October) and day 152 (1 April) were assumed to have zero scaup.

Scaup Diets

We collected and processed a total of 531 scaup (512 lesser and 19 greater) for diet analysis. In year 1, 5 of 269 scaup collected contained some evidence of fish, 4 of which only contained fish fragments in the gizzard; thus, could not be used for diet analysis. Moreover, that year, 85% ($n = 177$) of scaup collected with prey items above the gizzard contained Chironomidae (chironomids). However, in year 2, 29% ($n = 77$) of the 262 birds collected contained evidence of fish, and 92% ($n = 71$) of those birds contained fish parts above the gizzard that could be used for estimating overall diet proportions. In year 2, the proportion of scaup consuming fish (Fig. 6) was greatest in February, which was significantly different from November ($P = 0.002$), December ($P = 0.048$), and March ($P = 0.002$), but not January ($P = 0.997$). To calculate the proportion of scaup diet derived from fish, we pooled scaup collected from all production types because no statistical differences occurred between scaup collected from golden shiner and goldfish ponds ($W = 186.5$, $P = 0.235$),

Table 2. Adjusted R^2 and partial F-test statistics of polynomial models (orders 2–9) representing trends of scaup abundance on 14 baitfish and sportfish farms, winters of 2016–2017 and 2017–2018, Lonoke and Prairie Counties, Arkansas, USA.

Polynomial Order	2016–2017			2017–2018		
	Adjusted R^2	F^a	P^b	Adjusted R^2	F^a	P^b
2	0.23			0.45		
3	0.26	1.46	0.26	0.51	1.97	0.20
4	0.24	1.08	0.38	0.73	6.45	0.04*
5	0.21	0.68	0.44	0.91	13.10	0.02*
6	0.08	0.03	0.86	0.93	2.32	0.20
7	0.69	12.97	0.02*	0.92	0.66	0.48
8	0.63	0.09	0.78	0.89	0.10	0.78
9	0.79	3.97	0.14	0.98	10.79	0.19

[a] F statistic from partial F-test comparing the respective polynomial model to the previous order.
[b] P indicates the probability that the sum of squares of the residuals differs from the previous lower order (*represents significant values).

golden shiner and sunfish ponds ($W = 305.5$, $P = 0.999$), or goldfish and sunfish ponds ($W = 155.0$, $P = 0.262$) relative to the proportion of fish in scaup diets. The proportion of scaups' diet derived from fish in year 2 for the 68 birds that contained evidence of fish above the gizzard and contained ≥5 mg of dried diet ranged from 0.01 (SE = 0.01) in November to 0.79 (SE = 0.11) in December (Fig. 6). Mean lengths of fish consumed were 44.4, 39.5, and 48.3 mm for golden shiner, goldfish, and sunfish, respectively (Table 3). Of 54 scaup collected with fish identifiable to at least family (38 with fish identifiable to species), just one contained a fish that was inconsistent with the fish species grown in the pond from which it was collected.

Scaup Depredation of Fish

We based conversions of dry fish mass to wet mass from a subsample of golden shiner, goldfish, sunfish, and unidentified Cyprinidae samples ($n = 16$, 1, 5, and 6, respectively) that contained whole fish; percentage dry mass was estimated as 17.9% (SE = 0.06) of wet mass. We estimated peak fish consumption at 281.7 g/bird/day in December of year 2. However, January of year 2 was estimated to have the maximum amount of total fish loss due to the elevated proportion of birds consuming fish (Table 4). Although some scaup in year 1 contained evidence of fish, lack of intact fish in the esophagus and proventriculus prevented us from calculating mass and therefore proportion of fish in the diet specific to year 1 (Table 5). We therefore assumed that the few scaup consuming fish in year 1 would have done so in similar proportion to scaup in year 2 to calculate total fish loss in year 1. We estimated total fish loss in the survey area at 1,400 and 60,500 kg for years 1 and 2, respectively (Tables 4 and 5). Standardized estimates for fish biomass lost indicated that maximum loss was experienced in fathead minnow ponds in year 1 and sunfish ponds in year 2 (Table 6). Based on sizes of fish that scaup consumed, maximum individual fish loss was also fathead minnows in year 1 and sunfish in year 2 (Table 6).

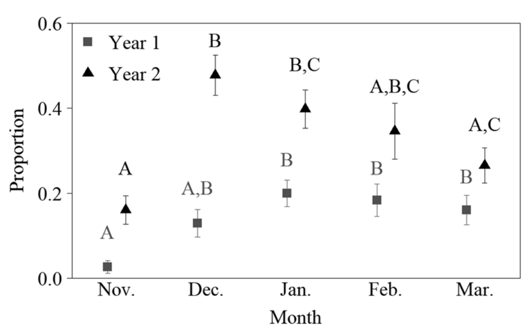

Figure 4. Monthly proportion of individual pond surveys with scaup present during winters 2016–2017 and 2017–2018 on Arkansas, USA baitfish and sportfish ponds containing golden shiner, fathead minnow, goldfish, or sunfish. Letters depict Tukey's test results for determining significant differences within winters.

DISCUSSION

Our results demonstrate that scaup can consume substantial amounts of baitfish but there was considerable inter-annual variability in depredation of fish by scaup. We believe that this variability may be a result of the disparate winter weather patterns between surveyed years. The mean minimum daily temperature of winter 2016–2017 was 4.1°C (SE = 0.5) with 9 days of a mean daily temperature below 0°C, while the mean minimum daily temperature of 2017–2018 was 2.4°C (SE = 0.5) with 19 days of a mean daily temperature below 0°C (National Oceanic and Atmospheric Administration 2018). Winter severity can influence fall and winter migrations of waterfowl (Švažas et al. 2001, Schummer et al. 2010), which suggests that the relatively warm temperatures in 2016–2017 (year 1) may have influenced the 67% lower estimate of SUDs observed in that year, as scaup may have wintered north of Arkansas.

Variability in temperatures between years may have also influenced the levels of fish consumption by scaup, i.e., more fish were consumed by scaup concomitant with colder winter temperatures (Clements et al. 2020). Similar behaviors were observed in mallards (*Anas platyrhynchos*) wintering in North Dakota below the Garrison Dam where rainbow smelt (*Osmerus mordax*) were found in greater proportion in mallards collected during colder than in relatively warmer winters (Olsen et al. 2011). Unlike scaup, winter snowfall amounts during the Olsen et al. (2011) study may have shifted diets, as increased snowfall would

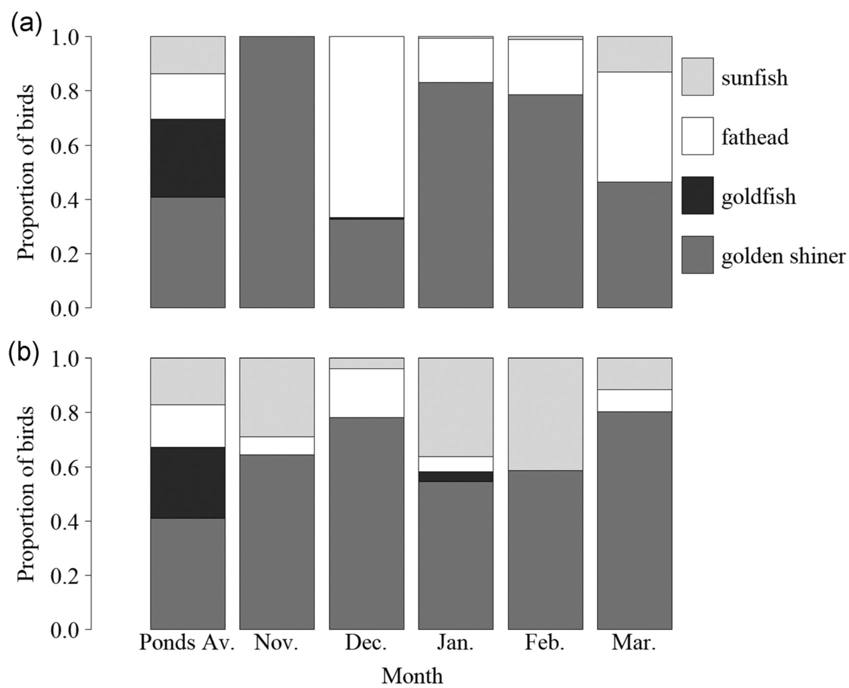

Figure 5. Monthly proportion of total baitfish and sportfish ponds of each category (far left column) available during winters a) 2016–2017 and b) 2017–2018 and the proportion of the total numbers of scaup estimated on ground surveys of each production type for each month during a respective winter, Lonoke County, Arkansas, USA.

have decreased opportunity for mallards to feed in dry grain fields.

Future research is needed to test our current hypothesis that winter temperatures influence fish consumption by scaup, potentially through the use of captive scaup foraging through winter in ponds with known densities of fish and other available prey. What our study did reveal, is that in some years scaup likely do not play a significant role in fish predation on fish farms, indicating an overall lower level of depredation than revealed by previous studies conducted over a single winter. Relative to previous literature, the proportion of birds with evidence of fish in year 2 was comparable to that found by Wooten and Werner (2004), and Philipp and Hoy (1997). Our results, however, provide more precise estimates of fish loss to scaup because we derived robust scaup abundance estimates that were paired with fish consumption for each month during 2 consecutive winters. The 2 previous studies used apparent scaup abundance values and only one fish consumption value across a single winter.

Our estimate of fish consumption by scaup also improved the scaup energy budget methods used by Wooten and Werner (2004). For instance, Wooten and Werner (2004) estimated the proportion of a scaup's daily kcal energy intake replenished by fish based on the proportion of fish in the bird's diet. In contrast, Philipp and Hoy (1997) based consumption rates of fish by scaup solely on abundance and lengths of measurable fish detected. Previous researchers estimated the total energy intake of scaup each day (Sugden and Harris 1972, De Leeuw 1999, Lovvorn et al. 2013). However, we used the Lovvorn et al. (2013) DEE value of 811 kJ/bird/day because it incorporated the energy demands of surface activities, aerial flight, and diving of wild scaup, compared to data previously available from other published studies, mostly derived from captive scaup.

When calculating the proportion of fish in scaup diets, all fish species were treated as equivalent, because statistically no differences were found in the proportion of fish in the diets of scaup collected from golden shiner, goldfish, and sunfish ponds. Four scaup that contained fish were collected from fathead minnow ponds; those 4 scaup had a lesser proportion of fish in their diet than those collected from golden shiner, goldfish, and sunfish ponds, and none had identifiable fathead minnows. It is likely that the unidentified fish were fathead minnows, as they were detected in scaup in a previous study (Philipp and Hoy 1997) and from preliminary collections in 2014 (Roy et al. 2015). We attribute the lack of concrete evidence of fathead minnow consumption and similar quantities of consumption in our study to a relatively small number of scaup collected from fathead minnow ponds, particularly during months with elevated fish consumption in year 2. During that winter we collected just 22 scaup from fathead minnow ponds.

Published TME values for invertebrates and seeds were accessible for just a few waterfowl species and to our knowledge there are no TME values obtained from foraging trials with scaup. Despite these potential limitations and data gaps, it is reasonable to assume that averaged available TME values of common prey items found in scaup were representative of energy gained by scaup. The heightened TME value obtained for fish (Coluccy et al. 2015) compared to seeds and invertebrates emphasizes the potential

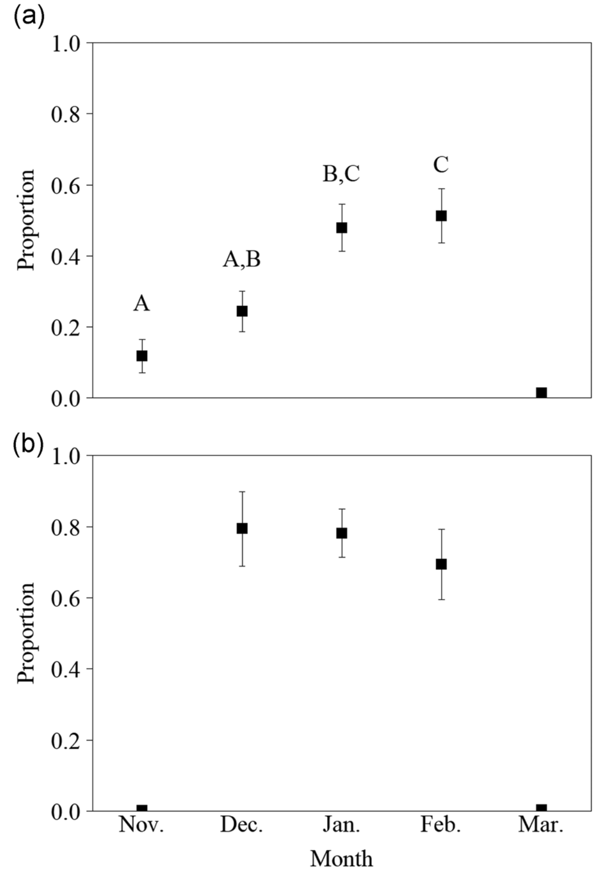

Figure 6. Monthly a) mean (±SE) proportion of scaup collected from baitfish and sportfish ponds in winter 2017–2018 that contained evidence of fish in the gizzard, esophagus, or proventriculus, weighted by the square root of number of scaup collected from each pond. Letters depict Tukey's test results for determining significant differences. and b) aggregate proportion by weight (±SE) of fish in the diet of all scaup containing fish parts above the gizzard and ≥5 mg of dried prey items (n = 68) collected from baitfish and sportfish ponds, winter 2017–2018, Lonoke and Prairie counties, Arkansas, USA.

Table 3. Lengths, weights, and quantities of golden shiners (*Notemigonus crysoleucas*), goldfish (*Carassius auratus*), and sunfish (*Lepomis* spp.) consumed by scaup collected from aquaculture ponds, Lonoke and Prairie Counties in Arkansas, USA, winter 2017–2018.

	Golden shiners	Goldfish	Sunfish
No. measurable fish[a]	283.0	18.0	38.0
Mean length (mm)	44.4	39.5	48.3
Max. length (mm)	90.3	65.0	59.2
Mean weight (g)	0.9	1.1	1.4
Max. weight (g)	7.2	4.7	2.6
Mean no. fish above gizzard[b]	20.7	4.8	5.1
Max. no. fish above gizzard[b]	112.0	10.0	13.0

[a] Total length (mm) and weights (g) were obtained for all fish when possible, but for degraded fish, standard length or anal fin length were collected and converted to total length and weights using regressions we created from fish sampled from farms or from Anderson and Neumann (1996), Stone et al. (2003), and N. Stone and R. T. Lochmann, University of Arkansas Pine Bluff, unpublished data.

[b] Number of fish above the gizzard only includes fish identifiable to species and did not include additional fish parts.

importance of fish in the daily winter diet of scaup using our study farms. The high energetic value of fish may be particularly important given that fish were consumed when environmental conditions were more energetically demanding. However, we recognize the possibility that the large TME value for fish inflated the importance of fish in scaup diets. If we ignored the differences in TME values between prey types and assumed seeds and invertebrates to be equally as important as fish, there would be a substantial decrease in fish loss from our reported estimates. For example, in year 2 there would have been a 21%, or 12,560 kg, decrease in the estimated amount of fish loss caused by scaup in the study area. Given the potentially variable and uncertain estimates of TME of some foods, research is needed to produce TME values for various prey types, including fish, specific to scaup foraging dynamics. Additional research on TME values specific to scaup prey would yield a more precise estimate of fish consumption by scaup. Updated prey TME values may help reveal the importance of fish in scaup diets, particularly when abundance or availability of other prey types (e.g., chironomids) may be limiting.

Similar to previous research, (Hoppe et al. 1986, Afton et al. 1991), our study confirmed that chironomids are important prey for scaup. Chironomids are relatively lipid dense (Krapu and Swanson 1975, Habashy 2005, Fard et al. 2014), and these fat-rich nutrients are important for birds during spring migration and egg laying (Ryder 1970, Afton and Ankney 1991, Anteau and Afton 2008), although lipid reserves in Insecta do not peak until summer (Gardner et al. 1985, Meier et al. 2000). In contrast to some insects, fish may accumulate lipid reserves during fall as a mechanism to sustain them through winter (Booth and Keast 1986, Dal Bosco et al. 2012) potentially providing greater lipid concentrations than insects into late winter (Delahunty and De Vlaming 1980). The common fish species consumed by scaup in our study represent a comparable lipid concentration to that of chironomids (Lochmann et al. 2011, Lochmann et al. 2014, Dinken 2018). Ultimately, the relatively high energy concentration in fish may provide staple forage in two ways: 1) by allowing scaup to shift foraging strategies and elevate fish consumption in colder winters, or colder periods within a winter, and 2) by providing a nutrient staple during periods of low chironomid or other food abundance or availability.

In addition to potential nutrient tradeoffs in forage types for scaup, shifting to fish consumption may be induced by behavioral mechanisms. For instance, the fish species in our study ponds will become less mobile during colder temperatures (Guderley and Blier 1988, Bennett 1990), likely improving their capture by depredating birds (Hurst 2007). We recognize that scaup may be targeting larger, energy-dense fish prey in colder periods because scaup themselves need greater nutrient intake, concomitantly with fish becoming sluggish and more easily caught in colder periods. Although we cannot fully reconcile these nutrition and behavioral mechanisms from this study, it appears that

Table 4. Estimated scaup-use days (SUDs[a]), proportion of scaup consuming fish (pSCF[b]), fish consumption (FC[c]), and total fish loss per month (FL[d]) on 14 baitfish and sportfish farms in Lonoke and Prairie Counties, Arkansas, USA, winter 2017–2018.

Month	SUDs (10^3)	$SUDs_{Low}$ (10^3)	$SUDs_{High}$ (10^3)	pSCF(SE)	FC (g $bird^{-1}day^{-1}$)	FC_{Low} (g $bird^{-1}day^{-1}$)	FC_{High} (g $bird^{-1}day^{-1}$)	tFL (10^3 kg)	tFL_{Low} (10^3 kg)	tFL_{High} (10^3 kg)
Nov.	130	52	227	0.118 (0.047)	1.00	0.60	1.40	0.02	<0.01	0.05
Dec.	273	178	368	0.244 (0.056)	281.73	272.00	289.66	18.73	9.05	31.98
Jan.	178	83	273	0.479 (0.066)	275.52	267.49	282.64	23.51	9.14	42.14
Feb.	131	41	222	0.513 (0.076)	270.59	258.57	280.37	18.25	4.68	36.59
Mar.	163	68	266	0.014 (0.016)	3.39	3.39	3.39	0.01	<0.01	0.03
Total	875	421	1,356					60.51	22.88	110.8

[a] Scaup-use days were calculated by integrating the area under the curve of the associated polynomial model. Low and High SUDs were calculated by integrating the area under the curve of a 95% confidence interval around the polynomial model.
[b] The proportion of scaup consuming fish in each month was derived from a mean and SE of the proportion of birds consuming fish within each pond, weighted by the $\sqrt{n}$ *scaup* collected from each pond and scaled to the original sample size.
[c] Daily fish consumption for each bird was calculated by estimating the proportion of a scaup's daily energy expenditure replenished by consuming fish and converting that value to wet grams of fish. High and low values were calculated based on ±1 SE of the aggregate proportion of fish in the scaup diet.
[d] Fish loss was estimated by multiplying SUDs, pSCF, and FC. High and low values were calculated by multiplying all 3 high and low values of SUDs, pSCF, and FC, respectively. Calculations based on values in the table may not be exact with number rounding.

scaup variably influence fish losses in our study area based on environmental conditions (e.g., winter temperature).

MANAGEMENT IMPLICATIONS

Our study suggested that in warmer winters (~9 days of a mean daily temperature below 0°C) or during warm periods of spring migration, scaup are less detrimental to fish in commercial aquaculture ponds. Therefore, producers may conserve money (e.g., employee salaries, fuel and repair for vehicles, and ammunition) during low-risk periods (warmer winters), making available greater fiscal resources when scaup are a greater threat, such as in colder winters. Also, strategically targeting harassment of scaup may pay dividends relative to scaup behavior. That is, choosing not to harass scaup when they are less of a threat to fish, such as in warmer winters, could help avoid any pre-conditioning of the birds to harassment techniques. Theoretically, harassment would be more effective when it is most needed, such as during periods of increased fish consumption.

Recently, producers were allowed 25 scaup on their annual depredation permits, but this take was only legal outside of Arkansas' regular 60-day waterfowl hunting season (Micheal Kearby, USDA Wildlife Services, personal communication). Despite the additional costs and burdens hunter access invokes on farmers, every producer that participated in our study allowed some degree of waterfowl hunting on their farms to mitigate the impact of scaup on fish depredation.

Depredation of fish by scaup however, is not restricted to waterfowl hunting season. For instance, approximately 40% of the estimated fish consumption occurred outside of Arkansas' waterfowl hunting season during winter 2017–2018. Annually, about 14 permit holders in Arkansas request a combined total of approximately 350 scaup on depredation permits (Micheal Kearby, USDA Wildlife Services, personal communication), which is equivalent to <1% of the estimated annual scaup harvest by hunters across the Mississippi Flyway (Raftovich et al. 2018, Raftovich et al. 2019). With much of the depredation of fish by scaup occurring at times when hunters cannot be used as a management tool, we recommend continued issuance of depredation permits so that farmers can continue some level of

Table 5. Estimated scaup-use days (SUDs[a]), proportion of scaup consuming fish (pSCF[b]), fish consumption (FC[c]), and total fish loss per month (FL[d]) on 14 baitfish and sportfish farms in Lonoke and Prairie Counties, Arkansas, USA, winter 2016–2017.

Month	SUDs (10^3)	$SUDs_{Low}$ (10^3)	$SUDs_{High}$ (10^3)	pSCF(SE)	FC (g $bird^{-1}day^{-1}$)	FC_{Low} (g $bird^{-1}day^{-1}$)	FC_{High} (g $bird^{-1}day^{-1}$)	tFL (10^3 kg)	tFL_{Low} (10^3 kg)	tFL_{High} (10^3 kg)
Nov.	35	0	121	0	NA	NA	NA	0	0	0
Dec.	50	3	131	0.082 (0.042)	281.7	272.0	289.7	1.17	0.04	4.73
Jan.	71	5	149	0	NA	NA	NA	0	0	0
Feb.	72	10	143	0.014 (0.014)	270.6	258.6	280.4	0.27	<0.01	1.12
Mar.	64	14	148	0.013 (0.013)	3.4	3.4	3.4	<0.01	<0.01	0.01
Total	292	33	692					1.44	0.04	5.86

[a] Scaup-use days were calculated by integrating the area under the curve of the associated polynomial model. Low and High SUDs were calculated by integrating the area under the curve of a 95% confidence interval around the polynomial model.
[b] The proportion of scaup consuming fish in each month was derived from a mean and SE of the proportion of birds consuming fish within each pond, weighted by the $\sqrt{n}$ *birds* collected from each pond and scaled to the original sample size.
[c] Daily fish consumption for each bird was calculated by estimating the proportion of a scaup's daily energy expenditure replenished by consuming fish and converting that value to wet grams of fish. High and low values were calculated based on ±1 SE of the aggregate proportion of fish in the scaup diet. Values were obtained from winter 2017–2018; fish consumption by scaup was too sparse in winter 2016–2017 for analysis.
[d] Fish loss was estimated by multiplying SUDs, pSCF, and FC. High and low values were calculated by multiplying all 3 high and low values of SUDs, pSCF, and FC, respectively. Calculations based on values in the table may not be exact with number rounding.

Table 6. Proportion of scaup-use days (pSUDs[a]), total fish loss (tFL[a]) and fish loss (FL[c]) per hectare based on the mean pond size (ha) associated with each production type, Lonoke and Prairie Counties, Arkansas, USA, winters 2016–2017 and 2017–2018.

Fish Species	pSUD	tFL (10^3 kg)	tFL_{Low} (10^3 kg)	tFL_{High} (10^3 kg)	Mean Pond Size (SD)	FL (kg/ha)	FL_{Low} (kg/ha)	FL_{High} (kg/ha)	FL (fish/ha)	FL_{Low} (fish/ha)	FL_{High} (fish/ha)
2016–2017											
golden shiner	67.3%	0.59	0.01	2.43	5.93 (4.09)	0.29	<0.01	1.18	320	<10	1,290
fathead minnow	29.3%	0.84	0.02	3.39	3.08 (2.12)	1.90	0.06	7.70	2,080	60	8,440
goldfish	0.1%	<0.01	<0.01	0.03	1.20 (1.05)	0.03	<0.01	0.12	30	<10	110
sunfish	3.2%	<0.01	<0.01	0.01	5.40 (4.32)	<0.01	<0.01	0.02	<10	<10	10
2017–2018											
golden shiner	68.7%	38.13	14.79	69.40	6.50 (4.13)	16.22	6.29	29.52	17,800	6,890	32,300
fathead minnow	9.3%	4.67	2.14	8.09	3.11 (2.09)	10.73	4.91	18.59	11,800	5,380	20,400
goldfish	0.8%	0.88	0.30	1.58	1.35 (1.23)	2.81	1.09	5.03	2,570	900	4,590
sunfish	21.3%	16.83	5.61	31.73	4.30 (3.63)	25.76	8.59	48.56	18,000	6,000	33,000

[a] Proportion of total estimated SUDs associated with the respective production type.
[b] Total fish loss was estimated by multiplying SUDs associated with the respective fish species, proportion of scaup consuming fish (pSCF), and daily fish consumption (FC). High and low values were calculated by multiplying all 3 high and low values of SUDs, pSCF, and FC.
[c] Standardized fish losses were calculated by dividing the total loss by the total area in production for each fish species to obtain kg/ha consumed and then converted to fish/ha loss based one sizes of fish found in collected scaup.

lethal harassment outside of the waterfowl hunting seasons. The lethal harvest of persistent birds, combined with non-lethal harassment, is the most effective way to control scaup use of ponds (Philipp and Hoy 1997).

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LITERATURE CITED

Afton, A. D., and C. D. Ankney. 1991. Nutrient-reserve dynamics of breeding Lesser Scaup: A test of competing hypotheses. Condor 93:89–97.

Afton, A. D., R. H. Hier, and S. L. Paulus. 1991. Lesser Scaup diets during migration and winter in the Mississippi flyway. Canadian Journal of Zoology 69:328–333.

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, Second edition. American Fisheries Society, Bethesda, Maryland, USA.

Anteau, M. J., and A. D. Afton. 2008. Diets of lesser scaup during spring migration throughout the upper-Midwest are consistent with the spring condition hypothesis. Waterbirds 31:97–106.

Anteau, M. J., J. DeVink, D. N. Koons, J. E. Austin, C. M. Custer, and A. D. Afton 2020. Lesser Scaup (*Aythya affinis*), version 1 *in* Birds of the World, A. F. Poole, editor. Cornell Lab of Ornithology, Ithaca, NY, USA.

Badzinski, S. S., and S. A. Petrie. 2006. Diets of lesser and greater scaup during autumn and spring on the lower great lakes. Wildlife Society Bulletin 34:664–674.

Baldassarre, G. A. 2014. Ducks, geese, and swans of North America. Johns Hopkins University Press, Baltimore, Maryland, USA.

Ballard, B. M., J. E. Thompson, M. J. Petrie, M. Checkett, and D. G. Hewitt. 2004. Diet and nutrition of Northern Pintails wintering along the southern coast of Texas. Journal of Wildlife Management 68:371–382.

Bartonek, J. C., and J. J. Hickey. 1969. Food habits of canvasbacks, redheads, and lesser scaup in Manitoba. The Condor 71:280–290.

Bennett, A. F. 1990. Thermal dependence of locomotor capacity. American Journal of Physiology 259:R253–R258.

Booth, D. J., and J. A. Keast. 1986. Growth energy partitioning by juvenile bluegill sunfish, *Lepomis macrochirus* Rafinesque. Journal of Fish Biology 28:37–45.

Brasher, M. G., J. D. Steckel, and R. J. Gates. 2007. Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71:2532–2541.

Callicutt, J. T., H. M. Hagy, and M. L. Schummer. 2011. The food preference paradigm: a review of autumn-winter food use by North American dabbling ducks (1900–2009). Journal of Fish and Wildlife Management 2:29–40.

Checkett, J. M., R. D. Drobney, M. J. Petrie, and D. A. Graber. 2002. True metabolizable energy of moist-soil seeds. Wildlife Society Bulletin 30:1113–1119.

Clements, S. A., B. S. Dorr, J. B. Davis, L. A. Roy, C. R. Engle, K. C. Hanson-Dorr, and A. M. Kelly. 2020. Diets of scaup occupying baitfish and sportfish farms in eastern Arkansas. Food Webs 23:e00141.

Coluccy, J. M., M. V. Castelli, P. M. Castelli, J. W. Simpson, S. R. McWilliams, and L. Armstrong. 2015. True metabolizable energy of American Black Duck foods. Journal of Wildlife Management 79:344–348.

Dal Bosco, A., C. Mugnai, E. Mourvaki, and C. Castellini. 2012. Seasonal changes in the fillet fatty acid profile and nutritional characteristics of wild Trasimeno Lake goldfish (*Carassius auratus* L.). Food Chemistry 132:830–834.

Delahunty, G., and V. L. De Vlaming. 1980. Seasonal relationships of ovary weight, liver weight and fat stores with body weight in the goldfish, *Carassius auratus* (L.). Journal of Fish Biology 16:5–13.

De Leeuw, J. J. 1999. Food intake rates and habitat segregation of Tufted Duck *Aythya fuligula* and Scaup *Aythya marila* exploiting Zebra Mussels *Dreissena polymorpha*. Ardea 87:15–31.

Dinken, C. P. 2018. The effects of diet, population, and water temperature on the stress response of angled Largemouth Bass *Micropterus salmoides*. M.Sc. thesis, Mississippi State University, Mississippi State, USA.

Dirschl, H. J. 1969. Foods of lesser scaup and blue-winged teal in the Saskatchewan River delta. Journal of Wildlife Management 33:77–87.

Dorr, B. S., L. W. Burger, S. C. Barras, and K. C. Godwin. 2012. Economic impact of Double-Crested Cormorant, *Phalacrocorax auritus,* depredation on Channel Catfish, *Ictalurus punctatus,* aquaculture in Mississippi, USA. Journal of the World Aquaculture Society 43:502–513.
Elliott, L. and K. McKnight. 2000. U.S. shorebird conservation plan: lower Mississippi/Western Gulf Coast Planning Region. Manomet, Massachusetts. <http://www.shorebirdplan.org/wp-content/uploads/2013/01/MAVWGC1.pdf>. Accessed 19 May 2020.
Engle, C. R., N. Stone, and E. Park. 2000. An analysis of production and financial performance of baitfish production. Journal of Applied Aquaculture 10:1–15.
Fard, M. S., F. Pasmans, C. Adriaensen, G. D. Laing, G. P. J. Janssens, and A. Martel. 2014. Chironomidae bloodworms larvae as aquatic amphibian food. Zoo Biology 33:221–227.
Foth, J. R., J. N. Straub, R. M. Kaminski, J. B. Davis, and T. D. Leininger. 2014. Aquatic invertebrate abundance and biomass in Arkansas, Mississippi, and Missouri bottomland hardwood forests during winter. Journal of Fish and Wildlife Management 5:243–251.
Gardner, W. S., T. F. Nalepa, W. A. Frez, E. A. Cichocki, and P. F. Landrum. 1985. Seasonal patterns in lipid content of Lake Michigan macroinvertebrates. Canadian Journal of Fisheries and Aquatic Sciences 42:1827–1832.
Guderley, H., and P. Blier. 1988. Thermal acclimation in fish: conservative and labile properties of swimming muscle. Canadian Journal of Zoology 66:1105–1115.
Habashy, M. M. 2005. Culture of chironomid larvae (insect- diptera-chironomidae) under different feeding systems. Egyptian Journal of Aquatic Research 31:403–418.
Hoffman, R. D., and T. A. Bookhout. 1985. Metabolizable energy of seeds consumed by ducks in Lake Erie marshes. Transactions of North American Wildlife and Natural Resources Conference 50:557–565.
Hoppe, R. T., L. M. Smith, and D. B. Wester. 1986. Foods of wintering diving ducks in South Carolina. Journal of Field Ornithology 57:126–134.
Hoy, M. D., J. W. Jones, and A. E. Bivings. 1989. Economic impact and control of wading birds at Arkansas minnow ponds. Pages 109–112 *in* S. R. Craven, editor. Proceedings of the Fourth Eastern Wildlife Damage Control Conference, Madison, Wisconsin, USA.
Hurst, T. P. 2007. Causes and consequences of winter mortality in fishes. Journal of Fish Biology 71:315–345.
Jorde, D. G., and R. B. Owen, Jr. 1988. Efficiency of nutrient use by American Black Ducks wintering in Maine. Journal of Wildlife Management 52:209–214.
Krapu, G. L., and G. A. Swanson. 1975. Some nutritional aspects of reproduction in prairie nesting pintails. Journal of Wildlife Management 39:156–162.
Lenth, R. 2018. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.3.1. <https://CRAN.R-project.org/package=emmeans>. Accessed 27 Dec 2018.
Lindsey, C., and S. Sheather. 2010. Variable selection in linear regression. The Stata Journal 10:650–669.
Lochmann, R. T., H. Phillips, D. Weldon, N. Stone, and C. Engle. 2014. Effects of dietary protein and fish density on performance and production economics of Golden Shiners in pools. North American Journal of Aquaculture 76:130–137.
Lochmann, R. T., T. D. Sink, and H. Phillips. 2011. Effects of dietary lipids concentration and a dairy-yeast prebiotic on growth, body composition, and survival of stressed Goldfish challenged with *Flavobacterium columnare*. North American Journal of Aquaculture 73:239–247.
Lovvorn, J. R., S. E. W. De La Cruz, J. Y. Takekawa, L. E. Shaskey, and S. E. Richman. 2013. Niche overlap, threshold food densities, and limits to prey depletion for a diving duck assemblage in an estuarine bay. Marine Ecology Progress Series 476:251–268.
Meier, G. M., E. I. Meyer, and S. Meyns. 2000. Lipid content of stream macroinvertebrates. Archiv für Hydrobiologie 147:447–463.
Miller, M. R., and K. J. Reinecke. 1984. Proper expression of metabolizable energy in avian energetics. Condor 86:396–400.
Muztar, A. J., S. J. Slinger, and J. H. Burton. 1977. Metabolizable energy content of freshwater plants in chickens and ducks. Poultry Science 56:1893–1899.
National Oceanic and Atmospheric Administration. 2018. National Centers for Environmental Information, Climate Data Online. <https://www.ncdc.noaa.gov/cdo-web/>. Accessed 13 Nov 2018.
Olsen R. E., R. R. Cox, Jr., A. D. Afton, and C. D. Ankney. 2011. Diet and gut morphology of male Mallards during winter in North Dakota. Waterbirds 34:59–69.
Philipp, M. C., and M. D. Hoy. 1997. Lesser Scaup depredation and economic impact at baitfish facilities in Arkansas. Pages 156–161 *in* C. D. Lee and S. E. Hygnstrom, editors. Thirteenth Great Plains Wildlife Damage Control Workshop Proceedings. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, Kansas, USA.
R Core Team. 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org. Accessed 5 April 2018.
Raftovich, R. V., S. C. Chandler, and K. K. Fleming. 2018. Migratory bird hunting activity and harvest during the 2016–17 and 2017–18 hunting seasons. U.S. Fish and Wildlife Service, Laurel, Maryland, USA.
Raftovich, R. V., K. K. Fleming, S. C. Chandler, and C. M. Cain. 2019. Migratory bird hunting activity and harvest during the 2017–18 and 2018–19 hunting seasons. U.S. Fish and Wildlife Service, Laurel, Maryland, USA.
Rogers, J. P., and L. J. Korschgen. 1966. Foods of lesser scaups on breeding, migration, and wintering areas. Journal of Wildlife Management 30:258–264.
Ross, K. R., S. A. Petrie, S. S. Badzinski, and A. Mullie. 2005. Autumn diet of greater scaup, lesser scaup, and long-tailed ducks on eastern Lake Ontario prior to zebra mussel invasion. Wildlife Society Bulletin 33:81–91.
Roy, L. A., M. Kearby, A. M. Kelly, and M. Hoy. 2015. Predation by lesser scaup on baitfish at commercial farms during winter of 2014. Arkansas Aquafarming 32:3.
Roy L. A., M. Kearby, A. M. Kelly, M. A. Smith, H. Park, and M. Hoy. 2016. Lesser scaup predation on Arkansas sportfish farms. Arkansas Aquafarming 33:3.
Ryder, J. P. 1970. A possible factor in the evolution of clutch size in Ross's Goose. Wilson Bulletin 82:5–13.
Schummer, M. L., R. M. Kaminski, A. H. Raedeke, and D. A. Graber. 2010. Weather-related indices of autumn-winter dabbling duck abundance in middle North America. Journal of Wildlife Management 74: 94–101.
Sherfy, M. H. 1999. Nutritional value and management of waterfowl and shorebird foods in the Atlantic coastal moist-soil impoundments. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, USA.
Sherfy, M. H., R. L. Kirkpatrick, and K. E. Webb Jr. 2001. Nutritional consequences of gastrolith ingestion in blue-winged teal: A test of the hard-seed-for-grit hypothesis. Journal of Wildlife Management 65:406–414.
Sibbald, I. R. 1976. A bioassay for true metabolizable energy in feedingstuffs. Poultry Science 55:303–308.
Stone, N., E. McNulty, and E. Park. 2003. The effect of stocking and feeding rates on growth and production of feeder Goldfish in pools. North American Journal of Aquaculture 65:82–90.
Stroud, C. N., C. E. Caputo, M. A. Poirrier, and K. M. Ringelman. 2019. Diet of lesser scaup wintering on Lake Pontchartrain, Louisiana. Journal of Fish and Wildlife Management 10:567–574.
Sugden, L. G., and L. E. Harris. 1972. Energy requirements and growth of captive Lesser Scaup. Poultry Science 51:625–633.
Švažas, S., R. Patapavičius, and M. Dagys. 2001. Recent changes in distribution of wintering populations of waterfowl established on the basis of Lithuanian ringing recoveries. Acta Zoologica Lituanica 11:235–242.
Swanson, G. A., and J. C. Bartonek. 1970. Bias associated with food analysis in gizzards of blue-winged teal. Journal of Wildlife Management 34:739–746.
U.S. Department of Agriculture [USDA]. 2014. 2012 Census of Agriculture: Census of Aquaculture (2013). Washington, D.C., USA.
Werner, S. J., J. B. Harrel, and D. E. Wooten. 2005. Foraging behavior and monetary impact of wading birds at Arkansas baitfish farms. Journal of the World Aquaculture Society 36:354–362.
Wooten, D. E., and S. J. Werner. 2004. Food habits of lesser scaup *Aythya affinis* occupying baitfish aquaculture facilities in Arkansas. Journal of the World Aquaculture Society 35:70–77.

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