2021

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Clements, Stephen A.; Dorr, Brian S.; Davis, Brian; Roy, Luke A.; Engle, Carole R.; Hanson-Dorr, Katie C.; and Kelly, Anita M., "Distribution and abundance of scaup using baitfish and sportfish farms in eastern Arkansas" (2021). *USDA National Wildlife Research Center - Staff Publications*. 2448.
https://digitalcommons.unl.edu/icwdm_usdanwrc/2448

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Received: 9 April 2020 | Revised: 3 September 2020 | Accepted: 29 October 2020

DOI: 10.1111/jwas.12752

APPLIED STUDIES

Journal of the World Aquaculture Society | WORLD AQUACULTURE Society | WILEY

Distribution and abundance of scaup using baitfish and sportfish farms in eastern Arkansas

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Funding information
Southern Regional Aquaculture Center, Grant/Award Number: 2016-38500-25752

Abstract

Arkansas' bait- and sportfish facilities are commonly used by various piscivorous bird species, including lesser scaup (*Aythya affinis*) and greater scaup (*A. marila*) that consume substantial quantities of fish. To mediate this predation, farmers implement extensive bird harassment programs that create additional costs to fish loss, thus research investigating the distribution and abundance of scaup is needed to help farmers allocate their bird harassment efforts more efficiently. In winters 2016–2017 and 2017–2018 we conducted 1,368 pond surveys to investigate pond use by scaup on farms during birds' regular wintering period (i.e., November–March). We used intrinsic and extrinsic pond-level and farm-level characteristics as explanatory variables in generalized linear models to reveal characteristics associated with increased scaup use. Inter-annual differences in scaup use were also considered in each model. Our pond-level model showed that scaup occurred more frequently on larger golden shiner (*Notemigonus crysoleucas*) and fathead minnow (*Pimephales promelas*) ponds stocked at greater densities, particularly during our second study winter. Our farm-level model suggested that farms further from major rivers and with an average pond size of approximately eight hectares had the greatest probability of scaup use. Producers can apply findings from our models to implement bird harassment efforts in times and locations where scaup predation is more likely to occur.

KEYWORDS

aquaculture, Arkansas, *Aythya* spp., scaup, wildlife damage management

1 | INTRODUCTION

Aquaculture industries commercially producing fish are frequently used by piscivorous birds, resulting in frustrating scenarios of human-wildlife conflict (Littauer, Glahn, Reinhold, & Brunson, 1997). It is important to understand the dynamics of these challenges to help producers maintain profitable aquaculture enterprises (Engle, Stone, & Park, 2000; King, 2005). Through farm sales, the Arkansas aquaculture industry produces approximately 63% of the total baitfish and 31% of the total sportfish sold in the United States, worth an estimated $26 million in revenue for the state (USDA, 2014). The primary species produced include golden shiners (*Notemigonus crysoleucas*), fathead minnows (*Pimephales promelas*), and goldfish (*Carassius auratus*). Like many other aquaculture industries, Arkansas farms are faced with human-wildlife conflicts that naturally arise as producers work to sustain economic profits, while wildlife exploit food-rich resources.

Some of the common fish-eating birds compromising Arkansas bait- and sportfish farms include great blue herons (*Ardea herodias*), little blue herons (*Egretta caerulea*), great egrets (*A. alba*), snowy egrets (*E. thula*), and double-crested cormorants (*Phalacrocorax auritus*). In addition, lesser scaup (*Aythya affinis*) and greater scaup (*A. marila*), hereafter scaup, have gained attention from farmers as potentially significant predators of Arkansas' commercially grown baitfish and sportfish (Hoy, Jones, & Bivings, 1989; Philipp & Hoy, 1997; Werner, Harrel, & Wooten, 2005). Scaup are not typically recognized as fish-eating birds, as invertebrates typically comprise much of their diet in natural systems (Afton, Hier, & Paulus, 1991; Hoppe, Smith, & Wester, 1986). However, in some instances scaup have been observed exploiting high densities of small fish stocked in Arkansas bait- and sportfish ponds (Clements et al., 2020; Philipp & Hoy, 1997; Wooten & Werner, 2004). The apparent recent increase in the use of ponds by scaup has increased employee man-hours and other resources devoted to harassing birds.

The aquaculture industry employs several methods to control avian predation of fish, and cormorants, pelicans, herons, egrets, sea ducks, and other species are often a focus (Dorr & Taylor, 2003; Glahn, Tobin, & Blackwell, 2000; Gorenzel, Conte, & Salmon, 1994; Hoy et al., 1989; King, 2005; Reinhold & Sloan, 1999; Richman, Varennes, Bonadelli, & Guillemette, 2013). Three primary categories of predatory bird control are used at aquaculture facilities, including: (1) exclusion, (2) nonlethal harassment (frightening), and (3) lethal control (Gorenzel et al., 1994; Reinhold & Sloan, 1999). These control methods have been successful to some degree, but are not a panacea against avian depredation. Exclusion devices are likely the most effective, but are typically too expensive for large farms (Glahn et al., 2000). Perhaps the most efficient method to deter birds is a harassment program, used in combination with limited lethal harvest of persistent birds that if not dispersed or removed, often attract other birds (Hoy et al., 1989).

Herein, we investigated the distribution and abundance of scaup on baitfish and sportfish ponds to better understand how scaup use aquaculture ponds. We used presence/absence and count data collected from pond surveys that were also used to estimate overall consumption of fish (Clements, 2019). The overarching goal of this work was to reveal potential strategies for improving current harassment programs. We hypothesized that there are particular pond and farm characteristics or fish assemblages associated with both a greater probability of scaup use and greater abundances of scaup. Clements et al. (2020) found that chironomids are an important food source for scaup in the surveyed aquaculture ponds. Thus, we hypothesized that chironomid density in ponds would also be a characteristic influencing scaup use of ponds. Understanding the characteristics associated with increased scaup use will help farmers more efficiently allocate their bird harassment efforts to areas and times when scaup are most likely to substantially negatively impact their crop.

2 | MATERIALS AND METHODS

2.1 | Study area

We conducted this study in Lonoke and Prairie Counties, Arkansas, the two counties that contained 72% of all baitfish and sportfish farms in Arkansas. Of the 26 unique farms within these two counties, 15 farms were randomly selected for surveys (nine in Lonoke; six in Prairie).

Farms varied considerably in production area, distribution across the landscape, and fish species grown. Total production area on farms ranged from 35.9 to 1106.2 ha ($\bar{x}$ = 313.7 ha; median = 325.4 ha) and consisted of 13–292 ponds ($\bar{x}$ = 87 ponds; median = 65). To more proportionately distribute our pond surveys over the entire study area and across the various fish species produced, 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). Pond group production area ranged from 26.6 to 353.4 ha ($\bar{x}$ = 123.8 ha; median = 94.0 ha) and contained of 6–127 ponds ($\bar{x}$ = 34 ponds; median = 27).

We digitized all ponds within our pond groups in ArcMap using high-resolution imagery produced by the National Agriculture Imagery Program (NAIP), and 30-m resolution LandSat-8 imagery obtained from the U.S. Geological Survey (USGS) Earth Explorer. Pond size was highly variable, ranging from 0.1 to 30.4 ha ($\bar{x}$ = 3.6 ha; median = 2.6 ha). Approximately 80% (n = 952) of the total ponds in our survey area contained golden shiners, fathead minnows, goldfish, or sunfish.

2.2 | Pond survey design

To assess the distribution and abundance of scaup using baitfish and sportfish farms, we conducted bimonthly ground surveys from November through March 2016–2017 and 2017–2018, coinciding with scaup migration in this part of the Mississippi Alluvial Valley (MAV, Baldassarre, 2014). For survey purposes, all pond groups were separated into two survey routes, each containing 19 pond groups. Each day of surveys (11 survey-days in 2016–2017; 9 survey-days 2017–2018), each route was simultaneously surveyed by separate teams of researchers in order to complete surveys in a single day and avoid double-counting of birds. 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, a third starting location was added to further reduce any effects of time of day. For both winters, one of the available starting locations was randomly selected for the first survey-day, then systematically rotated for each of the following survey-days.

Within each route, we randomly selected two ponds from each of the 38 pond groups to conduct bird surveys, with some exceptions (<10 pond surveys) because of temporary access issues or time delays. Given the large size of our study area, surveying more than 2 ponds/pond group was not possible to complete in 1 day. In 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 min, depending on pond size and 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).

After completing daily surveys, information from growers was collected on the species, size, and density of fish stocked in each of the surveyed ponds. Fish density was defined as the amount of fish at the time of the survey, not the amount of fish stocked, as harvesting could occur throughout the year based on producer harvest schedules. We placed the estimated density in to one of seven density categories (Table 1). Additionally, we obtained pond sizes by digitizing farms included in our surveys in ArcMap using high-resolution imagery captured by the National Agriculture Imagery Program (NAIP) and obtained from the USDA Geospatial Gateway. We provide the variables of interest in Tables 1 and 2.

In addition to predictors at the pond scale, we also evaluated larger scale factors (e.g., amount of surrounding aquaculture or natural habitat) that could influence pond use by scaup. We predicted that scaup use would increase on areas surrounded by larger amounts of aquaculture and other bodies of water. We evaluated this with ArcMap by calculating the total area of aquaculture and other water bodies within 1, 2, and 3 km buffers around the center points of our 38 pond groups to determine influence of water density on scaup distribution. We compared 1, 2, and 3 km buffers, as areas with a radius > 3 km resulted in substantial overlap among pond groups, and areas with a radius < 1 km typically only contained aquaculture ponds from that pond group alone, which did not address the proposed question. We found that a 1-km buffer increased variability between pond groups and thus we used results from that spatial scale in our modeling. When calculating the total area of other water bodies, we included all water bodies with a surface area >0.59 ha, as this was the smallest sized aquaculture pond that we observed being used by scaup. Two major rivers, the White and Arkansas, border our survey area on the east and west, respectively. To investigate whether rivers influenced scaup distribution on aquaculture ponds lying between the rivers, we measured the nearest distance from each pond group to the two rivers. When assessing these pond group level characteristics, we also examined the effect of average pond sizes within our pond groups. Variables considered in the pond group model are provided (Table 3).

TABLE 1 Categorical variables considered in distribution and abundance models used to evaluate scaup use of commercial bait- and sportfish ponds in Arkansas during winters 2016–2017 and 2017–2018

Variable	# Categories	Categories
Year[a]	2	1;2
Fish species[b]	5	GOSH; FATH; GLDF; SUNF; OTHER
Fish density	7	<20,000; 20,000-49,999; 50,000-99,999; 100,000-149,999; 150,000-199,999; 200,000-399,999; ≥400,000 fish/acre

[a]1-2016-2017; 2-2017-2018.
[b]Golden shiner (GOSH); fathead minnow (FATH); goldfish (GLDF); sunfish (SUNF); other sportfish (OTHER).

TABLE 2 Continuous variables considered in distribution and abundance models used to evaluate scaup use of commercial bait- and sportfish ponds in Arkansas during winters 2016–2017 and 2017–2018

Variable	Units	Range
Day[a]	day	1–152
Fish size	mm	19.1–872.4
Pond size[b]	ha	0.1–25.1 (0.1–30.4)
Dist. to activity center	km	0.02–7.4

[a]Day 1 = Nov. 1st.
[b]Range of pond sizes from data set used for distribution model (range from less restricted dataset used for abundance model).

TABLE 3 Variables considered in pond group model used to evaluate scaup use of commercial bait- and sportfish pond groups in Arkansas during winters 2016–2017 and 2017–2018

Variable	Data type	Units	Range
Year[a]	Categorical		1; 2
Average pond size	Continuous	ha	0.7–13.7
Aquaculture area[b,c]	Continuous	ha	25.9–265.5
Other water area[b,d]	Continuous	ha	0.0–17.0
All water area[b,e]	Continuous	ha	29.0–265.5
Distance to river[f]	Continuous	km	1.6–29.0

[a]1: winter 2016–2017; 2: winter 2017–2018.
[b]Area within a 1 km radius buffer.
[c]Area of all aquaculture ponds within buffer.
[d]Area of all other water (>0.59 ha) within buffer.
[e]Aquaculture and other water area combined.
[f]Arkansas or White River.

2.3 | Sediment sampling

Scaup collected during the 2016–2017 winter and used for diet analysis in Clements et al. (2020) revealed that chironomids were being consumed in abundance from baitfish and sportfish ponds. This led us to hypothesize that chironomid densities in ponds influenced pond selection by scaup. Thus, we collected sediment samples in November, January, and March of winter 2017–2018. We collected sediment samples from golden shiner, goldfish, and sunfish ponds that contained low, medium, and high densities of fish relative to typical stocking practices of each species. Twenty-seven ponds were sampled each of the three sampling months, apart from one pond that was drained before the March sampling period. We extracted soil samples with a 10.1 cm diameter core sampler. Each sampled pond was designated a north, south, east, and west bank, where one sediment sample was collected 1 m from a random point on each bank to a depth of approximately 10 cm in to sediment (Manley, Kaminski, Reinecke, & Gerard, 2004), totaling four samples per pond, or 108 total samples each survey period. We placed samples in labeled Ziploc bags, and iced them in coolers until returning them to Mississippi State for immediate processing.

Procedures and intensity of sediment sampling was developed to provide preliminary baseline estimates of trends in invertebrate abundance across pond types and times of the year. This was in part because we did not have comprehensive diet data until the end of year 1 so we could only sample in year 2 and logistically we could not sample a large number of ponds and pond area and still complete other research needs. We selected to sample the perimeter of ponds (1 m from the pond bank) for three reasons: (1) because many scaup were observed foraging close to pond margins, which is also where invertebrate densities tend to be highest (Feaga, 2014), (2) because of the collection method used (shotguns) scaup were collected feeding within 30 m of the pond margin and we wanted to sample in the same region of the pond where diet samples were obtained and (3) sampling further than 1 m from the shore in many cases would require the use of a boat.

Sample Processing—Each sample was rinsed through (0.6 and 2 mm) nested sieves to remove as much sediment as possible for macroinvertebrate identification. Macroinvertebrates classified as Chironomidae were enumerated and stored in one vial and all other macroinvertebrates were stored separately. Once all macroinvertebrates were removed from the sample, contents from each of the two sample vials were dried at 60°C for 24 hr (Foth, Straub, Kaminski, Davis, & Leininger, 2014) and weighed to the nearest mg. Weights were used to calculate the total biomass (kg [dry]/ha) and averaged to calculate total biomass per pond.

2.4 | Statistical analysis

Scaup Distribution and Abundance—To analyze scaup distribution and abundance relative to pond characteristics, we created a hurdle model using two generalized linear mixed models. Hurdle models are useful when data contain many zeros. We first modeled the occurrence of zero and non-zeros in the data, then modeled values greater than zero separately (Dalrymple, Hudon, & Ford, 2003). The first half of our model, investigated where birds were located (i.e., distribution), followed a binomial distribution using presence/absence of scaup on ponds. We used backward stepwise selection to choose the best fitting model by beginning with a full model and removing variables with the largest *p* values until all variables were significant (Bursac, Gauss, Williams, & Hosmer, 2008). We assessed collinearity among variables in our full models using generalized variance inflation factors (GVIFs). With categorical variables present in our models, we used $GVIF^{(1/[2*df])}$ values to compare across dimensions with a threshold of $GVIF^{(1/[2*df])} > 10^{(1/[2*df])}$ to decide if variables should be removed (Fox & Weisberg, 2011; Minchin et al., 2019). Likelihood ratio tests were used to compare models including and excluding categorical variables to determine if they significantly improved the model (Bolker, 2008). The second part of the model consisted of actual scaup counts (i.e., abundance), which followed a negative binomial distribution. Again, we used backward stepwise selection to find the best supported model. Our pond groups were treated as a random variable in both models to account for the differences in pond group use. Nonlinear terms were considered while examining plots of the residuals versus independent variables for both models. We could not collect information for all variables (i.e., fish size and density at the time of survey) for each surveyed pond which limited our initial dataset. We began our analysis with a restricted dataset, but once a limiting variable was removed as an insignificant predictor, additional surveys only missing that variable were returned to the data set. The top model selected was used to further investigate and summarize trends for the selected variables.

To analyze scaup distribution at the pond group level, we used a generalized linear model following a binomial distribution. The dependent variable was defined as the proportion of survey periods in which scaup were observed on at least one of our two randomly selected ponds on that pond group. We used backward stepwise selection to choose the best-fitting model predicting the probability of finding scaup on a pond group.

Sediment Samples—Our initial sampling design was developed to allow for a repeated measures ANOVA. However, because farmers drained ponds in late winter and early spring, we could not sample all ponds during the final sampling period. To retain as much data as possible in an already limited dataset, we used a linear mixed model with pond as a random effect and an AR (1) autocorrelation structure. General linear mixed models are a good substitute for repeated measures ANOVA as mixed models can fit missing data (Krueger & Tian, 2004). Total invertebrate and chironomid biomass (kg [dry]/ha) was transformed using Tukey's Ladder of Power transformation, and used as the dependent variable. All reported density values were back-transformed from our transformed dataset. Fish category (golden shiner, goldfish, and sportfish) and fish density (high, medium, low) were considered as independent variables along with survey period (November, January, and March) as the "repeated measure." In all models, for instances when we detected significant differences within categorical variables, we conducted post hoc tests using the *emmeans* package in RStudio (Lenth, 2018). This method compares all pairs of means using a Tukey's Test, and we assessed it with α of .05.

3 | RESULTS

3.1 | Scaup distribution and abundance

A total of 1,368 individual pond surveys were used in our analysis (767 in winter 2016–2017; 601 in winter 2017–2018). In all full models, we detected no collinearity among variables ($GVIF^{(1/[2*df])} > 10^{(1/[2*df])}$), so no variables were removed from analysis. For scaup distribution, the model that best explained the probability of scaup on ponds contained all variables except fish size and distance to activity center (Table 4). That model explained 45% of the total variation in scaup distribution. During year 2, there was a significantly greater overall chance of finding birds on ponds than in year 1 ($p < .001$). Among fish types, scaup were found on goldfish and "other" sportfish ponds significantly less frequently than on ponds containing golden shiners ($p = .002$; .012 respectively) or fathead minnow

TABLE 4 Beta (β) coefficient means, standard error (SE), and 95% confidence interval (CI) for top hurdle model fixed effects estimating the distribution and abundance of scaup on Arkansas baitfish and sportfish aquaculture facilities in winters 2016–2017 and 2017–2018

Model parameter	β estimate	SE	95% LCI	95% UCI
Distribution (n = 987)				
Intercept*	−1.406	0.531	−2.447	−0.365
Pond size*	0.422	0.123	0.181	0.663
Day*	0.334	0.112	0.115	0.553
Day^{2}*	−0.821	0.124	−1.064	−0.579
Year (ref. year 1)				
Year 2*	1.788	0.232	1.333	2.243
Fish density (ref. 1)				
Density 2	−0.718	0.455	−1.610	0.175
Density 3	−0.435	0.420	−1.259	0.388
Density 4	−0.204	0.439	−1.065	0.657
Density 5	0.006	0.443	−0.863	0.875
Density 6	0.249	0.484	−0.699	1.197
Density 7*	1.090	0.547	0.019	2.161
Fish species[a] (ref. FATH)				
GOSH	−0.085	0.419	−0.906	0.737
GLDF	−3.759	1.016	−5.751	−1.767
SUNF*	−1.207	0.559	−2.301	−0.112
Other*	−2.109	0.644	−3.371	−0.846
Abundance (n = 269)				
Intercept*	2.687	0.162	2.369	3.004
Pond size*	0.241	0.087	0.072	0.411
Day*	−0.181	0.069	−0.315	−0.046
Year (ref. year 1)				
Year*	0.305	0.153	0.005	0.606

[a]Golden shiner (GOSH); fathead minnow (FATH); goldfish (GLDF); sunfish (SUNF); other sportfish (OTHER).

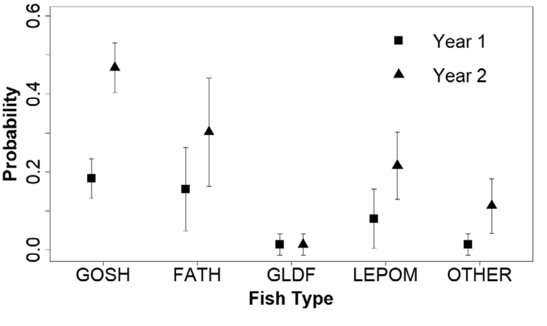

FIGURE 1 Probability of pond use by scaup (±95% confidence interval) on golden shiner (GOSH), fathead minnow (FATH), goldfish (GLDF), *Lepomis* spp. (LEPOM; sunfish), and other sportfish (OTHER) ponds in Arkansas during winters 2016–2017 (year 1, n = 463) and 2017–2018 (year 2, n = 524)

(p = .002, .009 respectively; Figure 1). Fish density significantly improved our model ($x^2[6]$ = 13.96, p = .030) and indicated that overall probability of scaup use increased with stocking density, particularly during year 2 (Figure 2). Our “day” variable was best represented with a squared term (p < .001; Figure 3), indicating a peak in the probability of

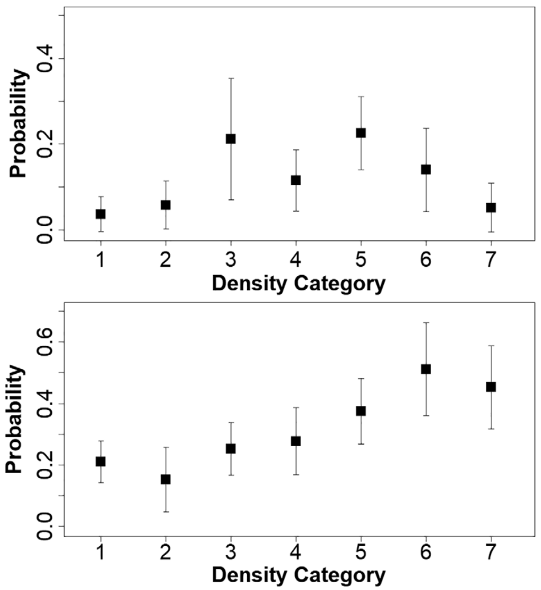

FIGURE 2 Probability of pond use by scaup (±95% confidence interval) on Arkansas baitfish and sportfish ponds in winters (a) 2016–2017 (n = 463) and (b) 2017–2018 (n = 524), containing different levels of fish density. (categories: 1: <20,000; 2:20,000–49,999; 3: 50,000–99,999; 4: 100,000–149,999; 5: 150,000–199,999; 6: 200,000–399,999; 7: ≥400,000 fish/acre)

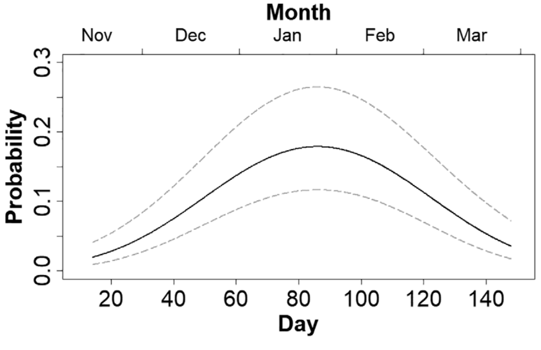

FIGURE 3 Probability of pond use by scaup (±95% confidence interval) on baitfish and sportfish pond in Arkansas throughout their wintering season and migration during winters, 2016–2018 (n = 987) (day 1 = Nov. 1st)

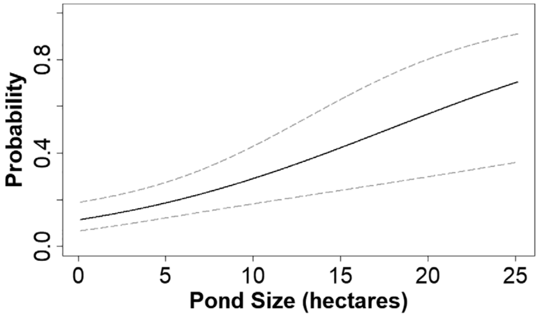

FIGURE 4 Probability of pond use by scaup (±95% confidence interval) on baitfish and sportfish ponds in Arkansas in relation to pond size during winters, 2016–2018 (n = 987)

finding scaup on a pond in late January, and that the overall probability of scaup use increased with pond size (p < .001; Figure 4).

On ponds containing scaup, flock size ranged from 1 to 225 birds, with a median of 11. Our top abundance model included day, year, and pond size as significant predictors of flock size (Table 4). There appears to be substantial variation in scaup abundance within days and pond sizes, as our model only explained 6% of the overall variation

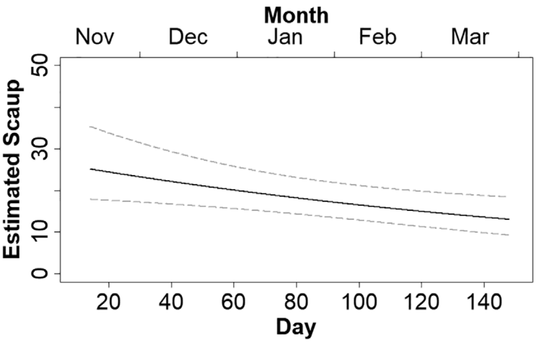

FIGURE 5 Relationship between scaup abundance (±95% confidence interval) and day of wintering season on baitfish and sportfish ponds in Arkansas during winters, 2016–2017 (n = 92) and 2017–2018 (n = 177; day 1 = Nov. 1st)

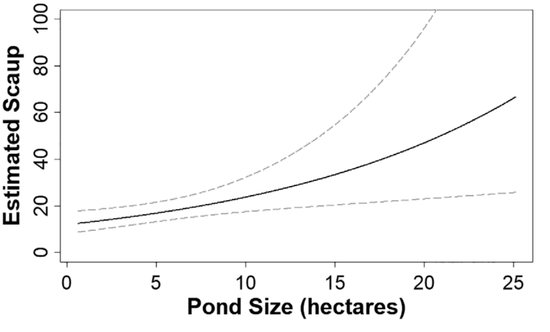

FIGURE 6 Relationship between scaup abundance (±95% confidence interval) and pond size (ha) of baitfish and sportfish ponds in Arkansas during winters, 2016–2017 (n = 92) and 2017–2018 (n = 177)

TABLE 5 Beta (β) coefficient means, standard error (SE), and 95% confidence interval (CI) for top pond group model parameters estimating the probability of observing scaup on a bait- and sportfish pond group in Arkansas during winters 2016–2017 (n = 402) and 2017–2018 (n = 305)

Model parameter	β estimate	SE	95% LCI	95% UCI
Intercept*	−5.532	0.690	−6.956	−4.241
Distance to river*	0.038	0.015	0.008	0.069
Average pond size*	1.152	0.187	0.810	1.555
Average pond size^{2}*	−0.076	0.015	−0.110	−0.049
Year (ref. year 1)				
Year 2*	1.279	0.262	0.774	1.801

in scaup abundance. The model showed that scaup abundance on ponds decreased through winter (p = .008; Figure 5), but increased with pond size (p = .005; Figure 6). Mean flock size was greatest during the second winter ($\bar{x}$ = 25.6, SE = 2.98) compared to the first ($\bar{x}$ = 18.7, SE = 3.57, p = .047).

Our pond group scale distribution model indicated that year, average pond size, and distance to the nearest river predicted scaup use on a pond group (Table 5) and explained 32% of the overall variation. As our initial distribution model suggested, the probability of observing scaup was significantly greater in our second survey winter (p < .001). Average pond size on a pond group was best represented by a squared term (p < .001; Figure 7) suggesting some decline in scaup use after average pond size reached some "optimal" pond size. Finally, our model suggested a gradual increase in pond group use by scaup as their distance from either the Arkansas or White River increased (p = .042; Figure 8).

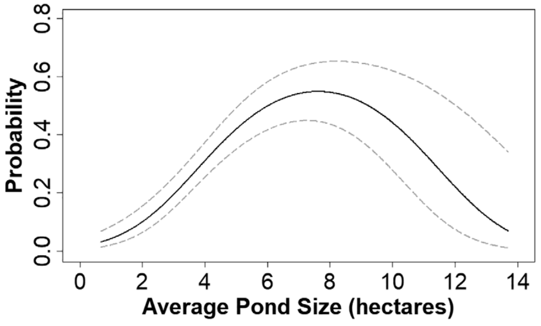

FIGURE 7 Probability of pond group use by scaup (±95% confidence interval) on baitfish and sportfish pond groups in Arkansas in relation to average pond size (ha) during winters, 2016–2017 (n = 402) and 2017–2018 (n = 305)

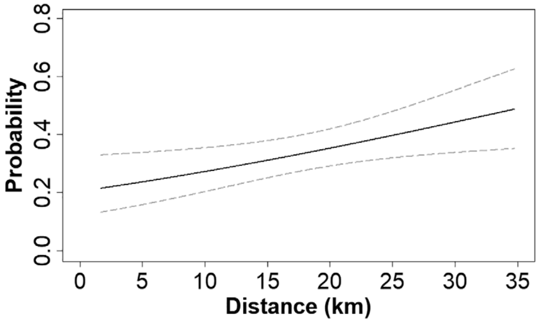

FIGURE 8 Probability of pond group use by scaup (±95% confidence interval) on baitfish and sportfish pond groups in Arkansas in relation their nearest distance (km) to the Arkansas or White rivers during winters, 2016–2017 (n = 402) and 2017–2018 (n = 305)

TABLE 6 Back-transformed mean ($\bar{x}$) and lower and upper limits of a 95% confidence interval (CI) for total macroinvertebrate biomass (kg [dry]/ha) from sediment samples collected in Arkansas golden shiner, goldfish, and sunfish ponds across survey periods, winter 2017–2018 (n = 80)

	Golden shiner			Goldfish			Sunfish		
Survey period	$\bar{x}$	LCI	UCI	$\bar{x}$	LCI	UCI	$\bar{x}$	LCI	UCI
November	72.1	46.4	111	20.4	11.5	35.3	31.1	19.6	48.5
January	68.3	39.6	115	38.8	22.2	66.2	34.3	23.7	49.2
March	34.0	16.6	91.3	39.5	18.7	80.2	16.5	9.4	28.4

3.2 | Sediment samples

We collected a total of 320 sediment samples from 27 ponds over winter 2017–2018. Total macroinvertebrate biomass in our sample ponds was an estimated 36.6 kg/ha (CI = 27.5–48.4). Among fish category, fish density, and survey period, survey period was the only significant predictor in our mixed effects model (χ^2[2] = 6.80, p = .033), as was its interaction with fish category (χ^2[4] = 9.65, p = .047, Table 6). Macroinvertebrate biomass peaked in January ($\bar{x}$ = 45.1, 95% CI = 33.4–60.5), but January only departed from the lowest biomass estimate in March ($\bar{x}$ = 29.5, 95% CI = 19.1–45.0; t_{35} = 2.48, p = .047). Our November estimate ($\bar{x}$ = 36.1, 95% CI = 25.7–50.3) did not differ from January (t_{35} = 1.47, p = .320) or March (t_{35} = 0.88, p = .658).

For chironomid biomass (kg/ha), fish category was a significant predictor (χ^2[2] = 11.40, p = .003), as were the interactions of fish category with fish density (χ^2[4] = 10.20, p = .037) and fish category with survey period (χ^2[4] = 10.36, p = .035). Overall mean chironomid biomass in winter 2017–2018 was 1.75 kg/ha (CI = 0.76–3.40). However, the estimated chironomid biomass was significantly less in golden shiner ponds ($\bar{x}$ = 0.23, 95% CI = 0.02–0.90) than in goldfish ($\bar{x}$ = 3.54, 95% CI = 0.78–10.0; t_{18} = 3.04, p = .018) or sunfish ponds ($\bar{x}$ = 3.36, 95%

TABLE 7 Back-transformed mean (x̄) and lower and upper limits of a 95% confidence interval (CI) for chironomid biomass (kg [dry]/ha) from sediment samples (n = 80) collected in Arkansas golden shiner, goldfish, and sunfish ponds across survey periods, winter 2017–2018

	Golden shiner			Goldfish			Sunfish		
	$\bar{x}$	LCI	UCI	$\bar{x}$	LCI	UCI	$\bar{x}$	LCI	UCI
Survey period									
November	0.51	0.06	1.90	1.37	0.15	5.14	5.49	1.62	13.4
January	0.23	0.01	1.11	6.15	1.05	19.4	3.93	1.34	8.85
March	0.09	0.00	1.04	4.41	1.11	11.7	1.55	0.33	4.38
Fish density									
High	0.00	0.00	0.07	13.8	6.99	24.3	2.18	0.68	5.17
Medium	0.50	0.05	1.94	0.73	0.06	3.06	2.79	0.61	7.89
Low	1.00	0.15	3.28	2.26	0.29	7.96	4.88	1.56	11.4

CI = 1.71–5.89; t_{18} = 2.79. p = .031). We provide estimated chironomid densities within fish categories across time and fish density (Table 7).

4 | DISCUSSION

4.1 | Scaup distribution and abundance

As hypothesized, both intrinsic and extrinsic characteristics of ponds influenced scaup use. The hurdle model suggested that predicting scaup abundance is more tenuous than that of their distribution. Because scaup may form large flocks on water, it is possible that bird abundances on individual ponds was mostly influenced by the number of scaup in the area, and not necessarily the pond characteristics themselves. Examining the individual ponds on which flocks were distributed was the most useful measure for developing management implications. Our distribution model indicated that scaup use changed substantially both within and between winters. We also discovered that scaup were most likely to use golden shiner, fathead minnow, and sunfish ponds and were typically found on large ponds containing high densities of fish.

We found differences between years in the probability of observing scaup and their overall abundances on ponds which may reflect differences in weather. Mean daily temperatures during winters 2016–2017 and 2017–2018 were 9.8 and 7.9°C, respectively (National Oceanic and Atmospheric Administration, 2018). The relatively colder temperatures in 2017–2018 likely positively influenced scaup abundances during the winter. In contrast, we postulate that large numbers of scaup remained north of Arkansas, or perhaps elsewhere, on ice free water during much of the milder 2016–2017 winter. Considering scaup distribute themselves across a large portion of North America during winter, it is challenging to isolate specific regions where the majority are at any given time, but some state-specific mid-winter waterfowl surveys can provide supporting evidence to our postulate. For example, surveys from northern states such as Michigan, Ohio, and Illinois resulted in at least 8 times more scaup counted in January of 2017 than January of 2018, while surveys in southern states such as Tennessee, Arkansas, and Louisiana counted no more than half as many scaup in January of 2017 as counted in January of 2018 (Fronscak, 2017, 2018). These examples suggest large numbers of scaup stayed in the northern part of their range in milder winter 2016–2017 relative to 2017–2018. In addition to annual differences in overall scaup abundances, increasing scaup use with increased fish density was more apparent in our second winter (i.e., see Figure 2), when a much greater proportion of scaup consumed fish (Clements et al., 2020).

In our pond group scale model, we included the minimum distance to either the Arkansas or White Rivers as a potential predictor of scaup distribution. This approach seemed warranted because some producers believed scaup travel back and forth from the rivers as they were being harassed, ultimately using the rivers as temporary refuge or roosting habitat. For rivers to be a significant predictor, we hypothesized a positive relationship between proximity of a pond group to one of the rivers, and the probability of observing scaup on them. However, we actually observed scaup less frequently on pond groups nearer rivers. Although scaup may use rivers for refuge and roosting habitat, the observed pattern suggests that birds did not select pond groups because of their close proximity to rivers. Contrary to our results, Dubovsky and Kaminski (1992) found that scaup abundance on clusters of catfish aquaculture ponds in the MAV was inversely related to their distance to the Mississippi River. Given that the Mississippi River is a major migration corridor for waterfowl, it is likely that it has a stronger influence on scaup distribution that the Arkansas or White Rivers. Dubovsky and Kaminski (1992) also found that scaup abundance was positively correlated with the amount of catfish ponds within a 1.6 km band around their clusters. A similar variable that we measured was not significant in our pond group model. We presume that the close proximity of our pond groups, within only two counties of Arkansas, resulted in scaup easily finding and subsequently being detected consistently across all pond groups.

We also found that the probability of scaup use declined on pond groups when average pond size began exceeding approximately 8 ha, despite our pond scale model indicating that the probability of scaup use increased with pond size. We rationalized that farms with relatively small and large average pond sizes were less attractive to scaup than those with an average pond size near 8 ha, despite scaup being likely to use the largest ponds on the pond group. It is important to note that the average size of goldfish ponds surveyed ($\bar{x}$ = 1.20 ha, SD = 1.06) is approximately 74% smaller than the average of all other ponds ($\bar{x}$ = 4.61 ha, SD = 3.90), which would likely explain why scaup were rarely observed on randomly selected goldfish ponds in either winter. Through general observation, surveyors did observe more scaup on goldfish ponds in the second winter and were able to collect birds foraging on goldfish during that winter (Clements et al., 2020), suggesting that at particular times, scaup may disregard the general avoidance of small ponds if feeding in them provides a greater benefit.

4.2 | Sediment samples

Our overall macroinvertebrate biomass estimates were comparable to biomass estimates existing in Mississippi's production catfish ponds (i.e., 53.16 kg/ha; Feaga, 2014) and to values in other wetland systems such as naturally flooded forests in the MAV (Foth et al., 2014; Wehrle, Kaminski, Leopold, & Smith, 1995), and Midwestern impoundments (Michaletz, Doisy, & Rabeni, 2005). Our findings from diet analysis suggest that Chironomidae is the most important invertebrate family for scaup using our survey area (Clements et al., 2020). Thus, we hypothesized that chironomid biomass in ponds may be a driver in scaup use of ponds. Considering that we found scaup more often on golden shiner than goldfish ponds, we predicted that shiner ponds would have the greatest densities of chironomids. However, our mixed effects model indicated that golden shiner ponds actually contained the lowest densities of chironomids.

Invertebrate densities in ponds could be influenced by several factors including bottom substrate (Ali & Mulla, 1976), dissolved oxygen, water temperature (Dinsmore, Scrimgeour, & Prepas, 1999), chlorophyll concentration (Michaletz et al., 2005), or fish species grown in ponds (Michaletz et al., 2005; Zimmer, Hanson, Butler, & Duff, 2001). Moreover, invertebrate species composition and the area that we sampled within the water body also could influence the observed patterns (Michaletz et al., 2005). It is also possible our pond perimeter samples overestimate chironomid density as invertebrate densities may not have been consistent across the entire pond (Feaga, 2014), and the small sample size of (320 sediment samples from 27 ponds) relative to total study area may not accurately capture trends in chironomid abundance and scaup use among ponds and years. Additional research focused on what factors influence invertebrate biomass and bird use on ponds on baitfish aquaculture would be informative. Given the above, we observed differences in Chironomidae and total macroinvertebrate biomass among fish types in ponds and time of year. Presumably, if scaup were strongly influenced by chironomid and other invertebrate density this would have been detected as well.

5 | CONCLUSION

The results of our models reveal several management strategies that could help farmers decrease fish loss to scaup. For example, although farmers cannot control the weather, our models suggest that farmers could potentially save money and time by reducing harassment intensity of scaup during warmer winters when fewer scaup are present and are likely not consuming substantial quantities of fish (Clements et al., 2020). Resources saved during these “low risk” years could allow for more intense and effective harassment when scaup are expected to have a greater impact on their crop. Ignoring scaup when their densities are not problematic for fish could also make their harassment efforts more effective during periods of increased predation, as birds would not already be acclimated to harassment techniques. As noted in Clements et al. (2020), scaup exhibited a change in foraging behavior (i.e., aggressive diving in dense flocks, near the pond's edge) in many instances when scaup were consuming fish and would warrant extensive harassment efforts from producers. Understandably, even when scaup are not present or observed consuming fish, high levels of activity in other fish-eating bird species may still warrant bird harassment, but a greater focus could be placed on species other than scaup. Future analysis of pond use by other fish-eating bird species counted during the surveys in this study and combined with previous unpublished surveys could reveal potential patterns in bird use across species, further improving the ability of fish producers to manage their farms in a way that minimizes impacts from fish-eating birds.

Additionally, farmers could take advantage of scaup tendencies to use larger ponds by stocking their most vulnerable fish in their smallest ponds and keep larger (>9 cm) fish in the larger ponds. The largest golden shiner recorded from scaup collections on baitfish ponds in Arkansas was 9 cm (Clements, 2019). Moreover, it would be easier for farmers to harass birds on smaller ponds as farmers can approach birds from any side of the pond. Through observations made by surveyors, in the relatively rare instances when scaup used smaller ponds (e.g., goldfish), it seemed more likely that scaup were consuming fish. If fish cannot be grown in smaller ponds, we recommend that farmers focus harassment efforts on ponds stocked at the highest densities of fish, as scaup increased their use of ponds containing relatively higher densities of fish. When multiple species of fish are produced on the same farm, ponds containing fathead minnows and golden shiners should receive the greatest harassment priority because of their affinity by scaup.

ACKNOWLEDGMENTS

Funding was provided in part by the Southern Regional Aquaculture Center through Grant number 2016-38500-25752 from the U.S. Department of Agriculture National Institute of Food and Agriculture. We are thankful for the USDA/APHIS/WS National Wildlife Research Center-Mississippi Field Station for providing staff, vehicles, and a host of other supplies that made the completion of this study possible and the UDSA/APHIS Wildlife Services in Arkansas for their assistance in bird collections and facilitating contact with producers. We thank the Forest and Wildlife Research center (FWRC) at Mississippi State University for support. We especially thank the baitfish and sportfish producers of Arkansas that allowed us access to their facilities and generously provided us with the information needed to complete analysis. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

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How to cite this article: Clements SA, Dorr BS, Davis JB, et al. Distribution and abundance of scaup using baitfish and sportfish farms in eastern Arkansas. *J World Aquac Soc*. 2021;52:347–361. https://doi.org/10.1111/jwas.12752